EFFECTS OF MECHANICAL HARVEST AND SITE PREPARATION ON STORMFLOW WATER YIELDS AND SEDIMENT YIELDS FROM FOREST WATERSHEDS IN OUACHITA MOUNTAINS OF OKLAHOMA

By

JIANN-SHYNG HEH

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National Taiwan University

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Thesis Approved:

Edwin L. Miller
Thesis Adviser

Thomas B. Lynch

R. Jewell Crabtree

Norman N. Durham
Dean of the Graduate College

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GLOSSARY

Interception (Ic): is the vaporization of water intercepted during precipitation (rain or snow) from living or dead plant surfaces, including leaves, twigs, stems, down trees, forest litter and humus layers.

Transpiration (T): is the vaporization of water from the living cells of plant tissues (excludes intercept loss).

Evapotranspiration (ET): is any process by which liquid water in plant, soil or pond becomes a vapor.

Stormflow: is the sum of surface and subfurface stormflow and is the term most often used by hydrologists in describing the flood-producing characteristics of watersheds.

Streamflow: is the flow of water past any point in a natural channel above the bottoms and sides of the channel.

Water yield: is a drainage basin's total yield of liquid water during some period of time.

Baseflow: is normally thought to be the sole component of streamflow between storm or snowmelt periods, and thus baseflow is presumably the oldest water to be yielded by the basin.

Overland flow: is that part of streamflow derived from net precipitation which fails to infiltrate the mineral soil surface and runs over the surface of the soil to the nearest stream channel without infiltrate at any point.

Channel precipitation: is that part of streamflow derived from net precipitation falling directly into the flowing stream.

Peakflow rate: is the highest flow discharge rate for the entirely period of an individual storm event.

Total suspended solids (TSS): is the product of erosion and includes the solid particulate matter, both organic and inorganic, which moves in suspension with streamflow. Determined by filtration, TSS is normally expressed in terms of concentration ie. parts per million (ppm) or milligrams per liter (mg/l).

CHAPTER I

INTRODUCTION

Undisturbed forested watersheds are generally recognized as a source of high-quality water. Many forested watersheds are managed specifically for municipal water supply. Forest cover not only exerts a beneficial regulating influence on streamflow regimen but forest cover also maintains high water quality through protection against erosion, overland flow, sedimentation, and leaching of nutrients (Sopper, 1975). Watershed studies have shown that one of the primary factors affecting runoff and sediment transportation from managed forest land is the method of harvesting and site preparation.

The Ouachita Mountains run through southeast Oklahoma to west central Arkansas and cover about 11,700 square miles. Average rainfall is approximately fifty inches per year, snow contributes only a small part of annual precipitation. More than 80% of the Ouachita Mountain area is under forest vegetation. Major forest cover types in this area are shortleaf pine, loblolly pine, and mixed pine and hardwood. Shales, slates, quartzites, and sandstones are the primary geologic formations and are the parent materials for the mountain soils. Mountain soils range from very shallow and rocky profiles overlying resistant sandstones to deep colluvial and alluvial soils at the toe slopes and in flood plains and have moderately deep and loamy surface horizons.

Commercial forest production is an important land use in the Ouachita Mountains, and clearcutting is the most frequently used method for forest harvesting. Because of their special concern for productivity of the land and water quality, a private corporation, Weyerhaeuser Company, has established several experimental forest studies in the Ouachita Mountains. The purposes of these experimental studies are to test the influences of silvicultural activities, the impacts of forest road construction, timbering (harvesting) activities, and other forest operations. The Oklahoma Small Watershed Study, described in this report, is one of those experiments.

The objectives of this study are to condense the results of the Oklahoma Small Watershed study in terms that are understandable and useful to federal and state government officials, foresters, and to the public, all of whom are concerned with the relationship between water quality and silvicultural activities. Specific emaphases will be:

1) to ~~evaluate~~ investigate the stormflow response to harvesting and site preparation.

2) to determine if peakflows have responded to harvesting and site preparation.

3) to ~~evaluate~~ investigate sediment yields following harvesting and site preparation in comparison to control levels.

4) to evaluate if revegetation decreases any increase in stormflow, runoff, and sediment yield in the years following harvesting and site preparation.

CHAPTER II

LITERATURE REVIEW

Undisturbed forested watersheds are generally recognized as a source of high-quality water. The forest cover not only maintains high water quality through protection against erosion, overland flow, sedimentation, and leaching of nutrients, it also exerts a beneficial regulating influence on the streamflow regimen (Sopper, 1975). The theory that forests are more comsumptive of water and reduce total streamflow or water yield in comparison to other vegetation types is based on the principle that forests have higher interception (Ic) and transpiration (T) losses, so that net evapotranspiration (ET) is increased and stormflow is thereby reduced (Trimble, Weirich and Hoag, 1987). In principle, once forest cover has been removed, water yield as streamflow should increase significantly.

Forests with a heavy ground cover of organic litter are the most effective system for protecting soils from erosion by water. When forest vegetation has been removed and ground cover disturbed or removed, the soil is exposed to the environment. Without vegetative protection, surface soils can hardly resist the erosive power of the environment. A number of studies, designed to evaluate the soil and water impact of various combinations of silvicultural activities have been reported.

1) Stormflow water yields:

The principles of how watersheds respond to forest cutting are generally well established, although experimental findings do not always agree with earlier beliefs (USDA, 1977). Water yield from forest land is regulated by the types of vegetation, soil, topography, and climate. Forest management activities can significantly influence the timing and quantity of water yields. Clearcutting generally increases stream flow significantly from small watersheds until revegetation occurs (Hibbert, 1967). Many studies show that stormflow water yields after clearcutting will increase significantly in comparison to controlled (uncut) watersheds or the pre-cut period. Stormflow water yields will decrease to pre-treatment levels after revegetation has occured on most sites (Hibbert, 1967; Hornbeck, 1975; Patric, 1980). Intense storms on soils with high antecedent moisture content normally generate the majority of stormflow (Blackburn, Wood and DeHaven, 1986; USDA, 1977).

Cutting of trees reduces the transpirational draft on stored and slowly seeping water, and, usually increases amounts of water moving into streamflow or ground water. Within a given climatic region, increased water yield is somewhat propotional to the percentage of clearcut area (Hibbert, 1967). In the Appalachian Highlands, Douglass and

Swank (1972) found an increase in streamflow if more than 12 percent of forest cover was removed. With 90 percent of forest cover removed, an increase of 10 inches was reported for the first year after forest harvest. On the Fernow Experimental Forest in West Virginia, Reinhart and Eschner (1962) found that stream discharge was increased in proportion to the amount of timber cut. In their study, the annual discharge increased up to 5 area-inches the first year following clearcut harvest from the stands of mixed Appalachian hardwood species, including red oaks, sugar maple and yellow poplar. Aubertin and Patric (1974), also on the Fernow Experimental Forest, found clearcutting activities with forest road construction increased streamflow 8 area-inches during the first year after cutting.

Water yield as stormflow on three small watersheds in north-central Florida increased following forest removal especially for intermediate-size storms (Swindel et al, 1983). A clearcut and highly disturbed watershed produced the greatest amount of water flow, while the controlled, or uncut, watershed produced the least. In Minesota, clearcutting of upland hardwoods or conifers increased annual streamflow from 3.5 to 8 area-inches per year, depending on the amount of disturbance (Verry, 1986). Patric (1980) reported that water yield increased by 9.9 area-inches during the first year after clearcutting in West Virginia. In New Hampshire, annual streamflow increased from 9.1 to 13.8 area-inches after clearcutting a hardwood watershed without the removal of the timber from the area (Hornbeck, 1975). Patric and Reinhart (1971) reported that with complete devegetation, the maximum expected water yield increase, under local conditions of climate and soil, was about 12 area-inches on the Fernow Experimental Station, West Virginia.

Increases in water yield typically show a decline soon after forest harvest treatments, and the rate of decline is positively correlated to the rapidity of revegetation (Spurr and Barnes, 1982). Hibbert (1967), after reviewing thirty-nine studies, found streamflow increased from 1.4 to 18 area-inches the first year following deforestation on the catchments in these studies, then the increases declined the following years. He concluded that streamflow response is proportional to the reduction in forest cover. As the forest regrows following treatment, the increases in streamflow declined. The rate of decline varied widely and most were unpredictable between catchments, but appeared to be related to the rate of forest recovery.

In the Hubbard Brook, New Hampshire study (Hornbeck, 1975), in which a hardwood forest watershed was clearcut without the removal of logs in 1965, a herbicide was applied annually for the next three years. Revegetation was allowed starting on the fourth year after clearcutting. In the first three years of the post-treatment period, streamflow increased 9.5 to 14 area-inches (or 26 to 41 percent). Once revegetation started, the flow increases rapidly diminished. By the fourth year of regrowth, the seventh year after harvest, annual streamflow was nearly the same as that from undisturbed forests (Hornbeck, 1975). At the Coweeta Hydrologic Laboratory in North Carolina, a mixed-hardwood forest was initially clearcut in 1939, and the streamflow following cutting increased 17.29 area-inches the first year and 13.26 area-inches the second year over streamflow measured from a natural forest covered (controlled) watershed (Hoover, 1944). After twenty-three years, the streamflow from the clearcut watershed was still slightly above pretreatment levels at the same site, despite reforestation (Swank and Helvey, 1970).

On the Fernow Experimental Forest, Aubertin and Patric (1974) found clearcutting had increased streamflow 8 area-inches the first year following cutting, but rapid revegetation had reduced the increase in streamflow to 2.5 area-inches by the second year. Douglass and Swank (1972) concluded that water yield increases declined rapidly with revegetation of the forest and seldom extended beyond the fifth year. The rate of water yield decline is positively correlated to the rapidity of revegetation (Swindel et al, 1983). In the southeastern U.S., a broad study of 10 large river basins showed that reforestation reduced water yields in the river basins 1.2 to 4 area-inches between 1919 and 1967 (Trimble and Weirich, 1987; Trimble, Weirich and Hoag, 1987). These reductions in water yield constituted a 4 to

21 percent decrease in annual stream discharges and were statistically significant for a majority of the basins. In summarizing a number of studies in forests of the eastern U.S., Patric (1980) found tree regrowth returned stormflow nearly to precutting levels within five years. Stormflow decline following cutting was related to vegetation regrowth, but the relationship was not a consistent function of simple stand measurement (Swift and Swank, 1981).

Rogerson (1985) reported on the hydrologic responses to silvicultural practices in Ouachita Mountains. He found that stormflow water yields were significantly increased by forest harvest. In Rogerson's study, a clearcut watershed produced 10.2 area-inches (or 193 percent) more runoff than would have been expected without clearcutting the first year after treatment. Stormflow water yields from clearcut and mechanically prepared watersheds in the Ouachita Mountains were significantly higher than from uncut watersheds the second year but not the first, third, or fourth year after treatment (Miller, 1984). Contour ripping at the time of site preparation may have affected the reported stormflow response.

2). Peakflow discharge:

The prospect of great flood peaks after timber harvest, especially after clearcutting, has provoked concern. During the growing season, however, transpiration from forest cover removes water from storage during rainless periods creating a moisture deficit that is also a storage opportunity. Once the storage deficit is fully satisfied, there are no large differences between uncut and clearcut lands since their further storage possibilities are now equal. Thus, small watershed studies show widely variable effects of cutting on peakflows during the growing season, depending on soil moisture content at the beginning of a storm (Hewlett and Helvey, 1970, USDA, 1977).

Due to the characteristics of the west coast region of the United States: high rainfall, deep snowpacks, steep slopes and deep soils, the hydrological responses of forested lands are quite different than those of the eastern United States. In the west coastal range of the U.S., highest flows come during the winter months, a result of heavy rainfall on wet soils. Both the magnitude and frequency of floods appear to be increased as timber cutting extends through the redwood region (Lee, Kapple and Dawdy, 1975). Snowpack plays a very significant role in the west coast region on floodflow contribution. Reforestation is an effective tool in the regulation of flood conditions. A planted forest appeared to be more effective in reducing peakflows than a cut-over forest, probably due to the establishment of improved forest floor and soil conditions in California (Anderson, Hoover and Reinhart, 1976).

In the southern and eastern United States the effects of harvest on flood flows appears to differ from those in the western United States. The snowpack in these regions does not play as important a role as in the west coast region. Winter is the principal season of high precipitation on wet soils so winter months and hurricane months are the periods of highest flow on the eastern coastal plain of the U.S. (Anderson, Hoover and Reinhart, 1976). The occurrence of high flows in early spring rather than in winter is a distinguishing characteriistic of the northeastern region (Miller, Geraghty and Collins, 1962). The impact of clearcutting on the stormflow hydrograph will generally be a decrease in time to peakflow, and an increased volume of runoff. But, peakflows from cleared areas may be either larger or smaller than from uncut forests (USDA, 1977).

The differences between treated and uncut forests are created by the environmental conditions, not by the cutting. After a study of multi-resource effects of harvest, site preparation, and planting in the pine flatwoods, Swindel et al. (1983) reported that the average peakflow discharge seemed to increase after clearcutting had been applied but the increase was not as significant as the stormflow water yield increase. Peakflow rate was not detectably altered by minimum treatments imposed on watersheds, however, when maximum site disturbing treatments had been applied, the peakflow rates increased significantly and then slowly declined. Swindel et al. (1983) concluded that on clearcut areas, annual peakflows increases may persist for 15 years.

Regression analysis showed no significant differences in instananeous peakflows during the dormant season after deforestation in West Virginia (Patric and Reinhart, 1971). However, at the same site, instantaneous peakflows during the growing season on deforested watershed were four times greater than those on the undisturbed watershed. Hoover (1944) reported maximum peak-discharge during storm periods had not been significantly changed by clearcutting in North Carolina. More recently at Coweeta, after a 108 acres of mature hardwood forest on a high-elevation watershed was clearcut, peakflows increased only by an average of 9 percent (Hewlett and Helvey, 1970). Permanent changes from forest to agricultural and urban land use on two-thirds or more of a large watershed significantly increased the size of flood peaks of storms in the 2 to 30 year return interval in Minnesota (Verry, 1986).

In the first phase of the Oklahoma Small Watershed study in the Ouachita Mountains, a comparison of the eight largest peakflows which occured in the four years following clearcut treatments, revealed no significant effect on peakflow rate between clearcut and uncut treatments (Miller, 1984). Large peakflow events occured primarily during periods of high soil moisture.

Increases in interception, infiltration and opportunities for soil water storage which occur with plantation growth can reduce peak discharges. The reductions vary with the type of cover before reforestation, and the proportion of the area planted. The effect of forest establishment on peakflows are different for the various seasons of the year (Anderson, Hoover and Reinhart, 1976).

3). Sediment Yields:

Manipulation of forest cover is not only important in it's effect on water yields or changing peak discharges that may affect floods, but in regulating the timing of water flow and increasing or decreasing erosion on affected slopes (Spurr and Barnes, 1982). Surface erosion and mass soil movement pose a major water quality management problem today. Sediment is often regarded as the primary pollutant from silvicultural activities (USDA, 1977). Harvesting activities on forest lands may not only increase water yields, but may also increase sediment concentrations in streamflow, and consequently increase sediment yields. Therefore, a most undesirable circumstance is the occurrence of heavy rains following forest harvest and before revegetation stabilizes the soil (Spurr and Barnes, 1980).

The process of soil erosion involves three phases: (1). detachment of soil particles; (2). transportation of soil particles; and (3). deposition (Anderson, Hoover and Reinhart, 1976; Hewlett, 1982). Factors affecting the erosion process include: soil characteristics, such as soil texture, minerology, aggregate stability, organic matter, percolation and infiltration rates, topography, rainfall intensity, and the most important, vegetative cover (Brady, 1974; Pritchett and Fisher, 1987). Forest cover strongly influences the rate of soil erosion and the influx of erosional products into streams (Anderson, Hoover and Reinhart, 1976). The forest environment is generally stable with minimal soil loss by erosion unless it is severely disturbed.

A review of literature on sediment production from undisturbed forests in the southern U.S. revealed a range of sediment yields from trace levels to 0.32 tons per acre per year (Yoho, 1980). Sediment losses from well covered pine-hardwood mixed catchments in the Ozark Plateau of southern Missouri and northern Arkansas averaged only 19.7 pounds per acre per year during 1966-1974 (Rogerson, 1976). In northern Mississippi, soil losses of 200 pounds per acre per year were reported for recently undisturbed hardwood watersheds (Ursic, 1970), and Dils (1953) reported 154 pounds per acre from a watershed which supported hardwoods and 1 ton per acre from a farmed watershed.

Statistical analyses were made on 812 forest soil erosion measurements and estimates of sediment yield in forest streams in the continental U.S. (Patric, Evans and Helvey, 1984). More than 100 of those reports showed that streams draining forested land along the Pacific Coast yield far more sediment per unit area of watershed than do streams of forested regions elsewhere in the nation. In the remaining 700 reports, no significant differences (p=0.05) were found among sediment yields in streams draining predominantly forested land of the eastern United States and of western regions other than the Pacific Coast. About one third of the eastern and western erosion observations had sediment yields not exceeding 0.02 ton per acre per year, and three fourths of the total had sediment yields that did not exceed 0.25 ton per acre per year. One forth fell between 0.25 and 1.00 ton, and only a few of the soil erosion measurements exceeded 1.00 ton per acre annually. The authors indicated non-forest land use within some of the watersheds might account for many of the higher sediment yields.

Many investigations provide evidence that harvest and harvest-related operations have the potential to degrade water quality (USDA, 1977). However, the effects of logging operations are often difficult to separate from post-logging activities, especially site preparation or other forestry related activities. Fredriksen (1970) reported that on a watershed clearcut over a 3-year period with a sky-line system, therefore without forest road construction, sediment concentrations were modestly affected during the logging. Clearcutting alone was much less damaging than clearcutting in combination with forest roads (Fredriksen, 1972).

Impacts of harvesting and planting which may promote erosion include, the reduction of transpiration, vegetative cover removal, soil disturbance, soil compaction, and channel disturbance (Yoho, 1980). In the southeast U.S., major causes of sediment losses due to forest operations varied from basin to basin. In some cases, mechanical site preparation was identified as the most important factor

(Dissmeyer, 1976), while Dickerson (1974) found tree-length skidding with rubber-tired skidders caused minor increases in sediment yields on hilly terrain in north Mississippi.

Logging and site preparation increase the potential for sediment production by disturbing the soil and the protective forest floor. Disturbing the protective vegetation may bare the mineral soil to raindrop impact which breaks soil aggregates into smaller particles. These smaller particles are more easily detached and may leave the site in runoff water, thus infiltration is reduced and the possibility of surface runoff is increased (Edwards and Larson, 1964). Removal of vegetation and litter also reduces resistance to overland flow and increases flow velocity, which in turn increases the carrying power of runoff (Douglass, 1975). However, under reasonable conditions of timber harvest layout, where logging on clay soils during wet conditions is avoided and riparian areas are logged carefully, clearcutting on upland sites does not have to adversely affect water quality (Verry, 1972).

In the Athens Plateau area of southwestern Arkansas, the effects of mechanical and chemical site preparation following forest harvest were compared to an unharvested control treatment. Nine small experimental watersheds, with 50 percent shortleaf and loblolly pine and 50 percent mixed oak, hickory and gum were utilized in the study. Beasley, Granillo and Zillmer (1986) found that the mean annual sediment losses on the mechanically site prepared watersheds during the first post-treatment year were significantly higher than those from either chemically site prepared watersheds or controlled (uncut) watersheds. After the second year, the treatment effect was not statistically significant for either treatment, but erosion levels had not returned to pre-treatment levels.

Sediment losses due to clearcut and partial forest harvest treatments were measured on a small watershed study in the Ouachita Mountains (Rogerson, 1985). Site preparation on the clearcut watershed was chemical and caused no soil disturbance. Sediment yields increased only during the year of and the first year following the clearcut treatment (Rogerson, 1985). Sediment yields then quickly decreased to normal levels in following years. At the Hubbard Brook Experimental Forest, felling the trees and treating the area with herbicide to prevent forest regrowth increased sedimentation four times normal levels during the next two years (Pierce et al., 1970).

The effect of broadcast burning on soil movement varies from study to study and is related to the amount of exposed mineral soil and reduction in biomass on the site. Following a clearcut experiment in the Sumter National Forest in the southern Appalachian Mountains of South Carolina, VanLear and Danielovich (1988) reported that burning had no significant effect on erosion. They also found, compared to other studies, amounts of sediment collected from the clearcut but unburned plots, was relatively high compared to the sediment yield from an undisturbed watershed. They found that logging activities caused most of the soil movement and was more important than the impact on erosion caused by burning.

Once revegetation is started on clearcut watersheds, small plants with a diversity of heights and growth form provide two forms of soil protection. First, by reducing the impact of raindrops, the plants protect the soil against splash erosion, which is a significant factor in the detachment of soil particles from erosion-resistant aggregates. Second, plants and organic residues on the surface promote infiltration and impede the velocity of overland flow, thereby reducing its energy for detaching and transporting soil particles (Beasley and Gramillo, 1985).

Forest regeneration and subsequent growth increase interception and transpiration. Whether regeneration increases infiltration capacity depends on the soil's intial infiltration capacity. Consequently, water yield, peakflow, erosion and sedimentation will gradually be reduced as trees grow in height and density (Anderson, Hoover and Reinhart, 1976). Rapid revegetation quickly stabilizes most harvested and site prepared sites and increases evapotranspiration. Usually the additional yields of stormflow and sediment transportation from heavily cut areas appear to fall systematically and rapidly and return to normal or pre-cut levels within a few years as the revegetion occurs, although small effects may persist for several years. In summerizing a number of studies in the eastern United States, Patric (1980) reported tree regrowth returned sediment yields nearly to precutting level within five years after revegetation started. The effects of revegetation on soil erosion have been showed in a series of studies by Miller (1984) and Miller, Beasley and Lawson (1985). In an experiment in north Mississippi, planting pine decreased sediment concentrations to base rates in less than five years (Ursic, 1986).

Successful transition to the improved forest depends upon intensive site preparation to (1). dispose of debris, (2). reduce or eliminate competition, (3). prepare the mineral soil and; (4). provide a favorable microenvironment for establishment and early growth of the new forest stand (Parker, 1972). Parker noted that the practice of mechanical scarification in site preparation may have either a positive or negative effect on surface erosion. Although the purpose of site preperation is to create better forest regeneration, it also creates the opportunities for the erosion processes.

Harvesting and site preparation caused temporary increases in stormflow and peak discharge rates, and also significantly greater sediment concentrations and yields from sites in east Texas (Blackburn, Wood, and DeHaven, 1986). While site preparation may aid regeneration, the degree to which it is applied can greatly affect the potential for surface erosion. For instance, increases in sediment production were measured in western Oregon following a severe broadcast burn (Sidle, 1980), a pratice which generally is not of concern in the area.

Ripping or subsoil chiseling is a practice usually applied on soils with coarse surface and clayey subsoils prior to replanting. The advantages of ripping are: 1). to make planting easier; 2). planted trees have roots deeper in clay subsoils which increases survival; and 3). the ripping gives some local mechanical weed control near the seedling. Deep ripping of the soil normally is accomplished by pulling a one- or two-tonged ripper behind a crawler tractor. Although infiltration capacities are initially increased in the ripped areas, additional compacted areas may be produced by the heavy equipment tracks (Sidle, 1980).

Ripping usually produces a planting condition which encourages rapid root growth into the subsoil where the moisture supply generally is more favorable than in surface horizons. Ripping also increases the amount of water which enters subsoil storage. In this area, the soils have rocky or coarse textureed surface horzions and clayey subsoils. The surface horizons have low water holding capacities, however, the clayey subsoils have high water holding capacities. Without ripping, the root systems of first-year pine seedlings normally will grow only in the relatively droughty surface horizons. Ripping opens a channel through the surface horizons, and into the clayey subsoils which fills with material from the surface horizons. The fill material is an excellent rooting medium for seedlings planted in the rip channel. Seedling access to moisture is improved because the root system is planted closer to the subsoil and its store of water. Rips parallel to the contour can capture water that might normally be lost as surface runoff. The subsoil channel created by ripping not only physically directs water into the subsoil, it also greatly increases the area through which water can enter the subsoil. Ripping disrupts old root channels thereby reducing the loss of water normally piped through these channels into the parent materials. In a region where soil water is often the principal factor limiting seedling survival and growth, this increased storage and concentration of water can mean the difference between plantation success or failure. Ripping further indirectly increases the available soil moisture because soil tillage in the vicinity of the rip channel often reduces the populations of competing plants during the first year after ripping. Competition for nutrients is also reduced. Reduced competition alone is largely responsible for first-year plantation survival and growth improvments on deep coarse textured soils with intense weed competition (Dewit and Steinbrenner, 1981).

There are few studies that have reported the impacts of contour ripping on forest land, but contour cultivation studies on cropland or rangeland can be used to indicate possible effects. Ripping (to a depth of from 12 to 36 inches) is used to break or shatter compacted soil profile layers that may inhibit root development and/or moisture penetration (Branson et al, 1981), which would create more capacity for overland flow. In New Mexico, ripping (28 to 36 inches deep, 7 feet apart) reduced surface runoff 96 percent and erosion 85 percent in the first year after treatment on shale-derived soils (Dortignac and Hickey, 1963; Hickey and Dortignac, 1964), compared to the uncovered un-ripped areas. Contour cultivation is effective only in controlling erosion by surface flow. It is a part of the water disposal system generally, and it can be an effective way to conserve moisture during seasons of low rainfall. Ripping also shortens downhill slopes over which surface flow is free to move (Stallings, 1957).

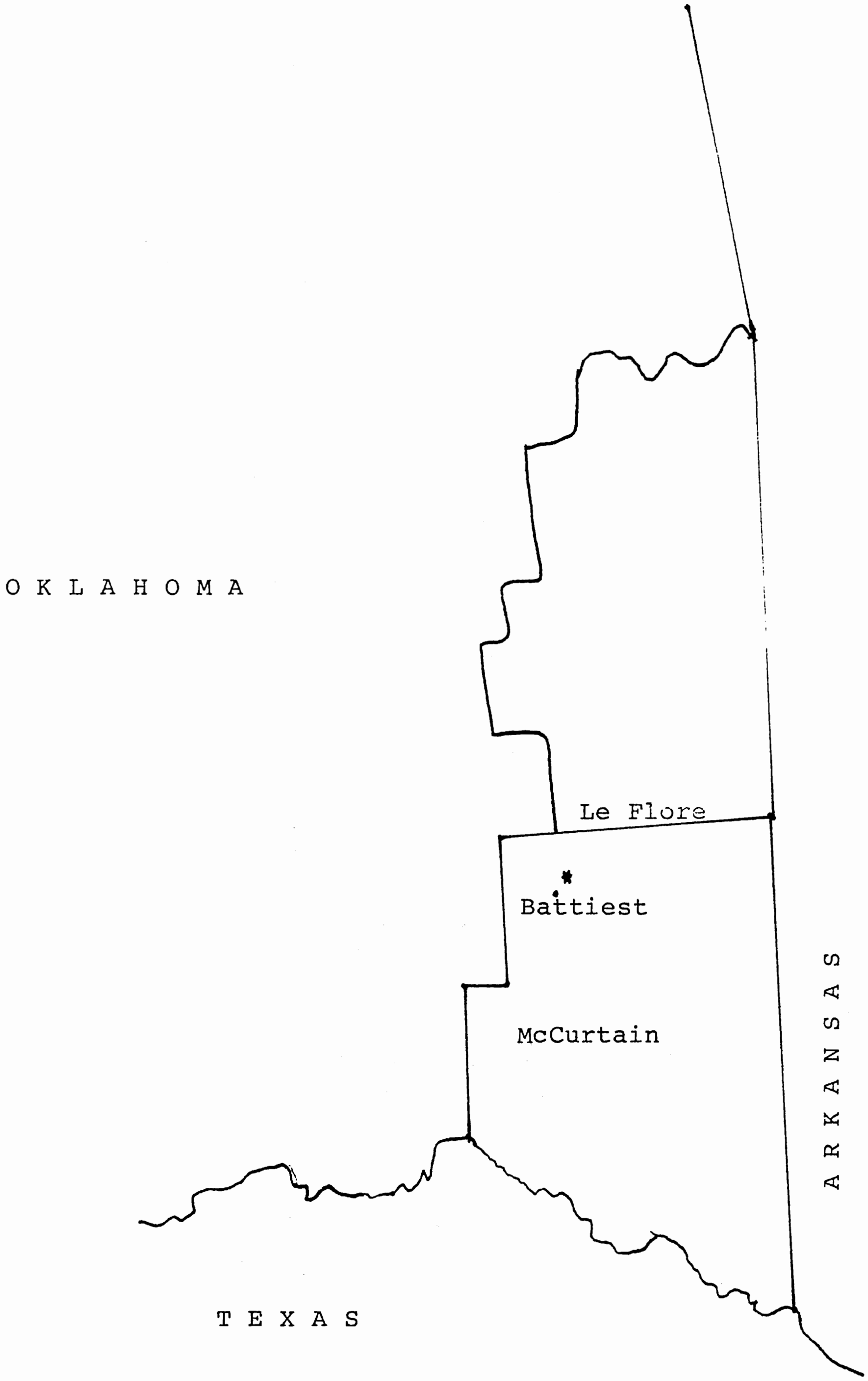
CHAPTER III

EXPERIMENTAL DESIGN

1).Study Area:

The experimental site is located in McCurtain County, about five miles northeast of Battiest, Oklahoma (Figure 1) on the western edge of the Ouachita Mountain region. The Ouachita Mountains run through southeast Oklahoma to west central Arkansas and cover about 11,700 square miles. More than 80% of the Ouachita Mountain area is under forest vegetation. Major forest cover types in this area are shortleaf pine, loblolly pine, and mixed pine and hardwood. Shales, slates, quartzites, and sandstones are the primary geologic formations and are the parent materials for the mountain soils. Mountain soils range from very shallow and rocky profiles overlying resistant sandstones to deep colluvial and alluvial soils at the toe slopes and in flood plains which have moderately deep and loamy surface horizons (Dewit and Steinbrenner, 1981).

Precipitation in the Ouachita Mountains averages about 50 inches annually. Average monthly rainfalls range from 3 inches in January to 9 inches in May. Summer and autumn droughts are common in the area. Snow only accounts for a small potion of the total precipitation. Annual pan evaporation averages about 70 inches (National Oceanic and Atmospheric Administration, 1968). Annual precipitation in



Note: * Experimental site

Figure 1. Experimental site, five miles northeast of Battiest, McCurtain County, Oklahoma.

McCurtain County is 54 inches, and monthly rainfall averages range from 3.5 inches in January to 6.3 inches in May (USDA Soil Conservation Service, 1974). Annual evapotranspiration (ET) averages 30 inches (Pettyjohn, White and Dunn, 1983), so there is generally a high soil moisture deficit during the summer season. Spring contributes the most rainfall with 31 percent of the annual amount and autumn has the lowest with only 13 percent (USDA Soil Conservation Service, 1974).

Soils in the study area are in the Goldston-Carnasaw-Sacul soil association. Goldston soils occupy about 35% of the area while Carnasaw and Sacul soils occupy 30 and 18% of the area respectively. These are loamy soils that contain shale and sandstone fragments and have a clayey subsoils. The slopes are moderately steep (12 to 20%) and the area is generally well drained. Because of steep slopes, rockiness of the soils, high precipitation and other favorable climatic factors, the soils in this area are well suited for growing trees. The principal concerns for management are the amounts of shale and sandstone fragments on the surface of Goldston soils and preventing erosion on Carnasaw and Sacul soils (USDA Soil Conservation Service, 1974).

2).Experimental Review:

The experiment was established on Weyerhaeuser Company lands in 1976 to examine the effects of forest harvest and site preparation on soil erosion and stormflow. Two phases were planned and the first phase has been completed and reported by Miller (1984). The second phase is the focus of research examined in this thesis.

In the first phase of this experiment, six small, 4 to 10 acre, natural headwater watersheds of similar geology soils, slope, aspect and vegetative cover were utilized. All were within 1.5 miles of one other which helped insure similar climatic conditions on all the watersheds. A completly randomized block design was utilized to test two treatments, clearcut harvest with mechanical site preparation including contour ripping and undisturbed forest cover (control treatment). The watersheds were gauged in 1978 and silvicultural treatments applied in 1979. Data were collected from 1978 to 1982 which provided four years of post-harvest water yield and water quality measurements.

In the second phase of the experiment, the three forested control watersheds from the first phase were utilized in a calibrated watershed study. Water yield and water quality data from 1978 through 1982 on the control watersheds serve as a data base for calibration. The remaining sections in the experimental design section describe the details of the second phase of the study.

3).Watershed Treatment:

Two harvest and site preparation treatments were applied to two of the watersheds (watersheds 4 and 5), while the third watershed (watershed 6) was maintained as a control (no silvicultural activities). All treatments were operational in nature and were not scaled down or modified for this experiment. The two silvicultural treatments applied were basically the same; clearcutting from March to April 1983 followed by tree crushing the residual vegetation and broadcast burning in July, 1983. There was only one exception: contour ripping was conducted on watershed 4 in August of 1983, but not on watershed 5. Due to a change in personnel, the study was terminated in October of 1985, but resumed in June of 1986.

Deep subsoiling or soil ripping to improve plantability and increase seedling survival and growth is becoming a common site preparation practice in the mid-south and on Weyerhaeuser lands in the Ouachita Mountains. Contour ripping with Caterpillar D-8 crawler tractor followed the broadcast burning on watershed 4. Rip furrows were on the contour and averaged 10 feet apart and 18 inches deep. Rip furrows did not extend through ephemeral stream channels. However, tractors ripped up to the channel and crossed stream channels as necessary, with chisels raised. In some cases, tractors turning near the stream channels caused soil disturbance on banks near the streams.

The two harvested and site prepared watersheds were planted by hand with loblolly pine seedings, on a 10 by 10 foot spacing, after soil fines had settled in rip furrows. No artificial revegetation other than hand planting of pine seedings on the watersheds was provided. Herbicide, 5.7% Pronone at 0.86 pounds per acre, was applied on watershed 4 on May 18, 1983 to reduce the growing competetion from plants other than loblolly pine seedings.

4).Instrumentation and Runoff Sampling:

Stormflow was measured in calibrated 3-foot H-type flumes. Approach Sections were 8.5 feet long and constructed of concrete. Approach cutoff walls were extended well into clayey B horizons. Traps were provided above the approach sections for gravel and stone-size bed load materials from ephemeral channels.

Two water and sediment sampling systems were used. ISCO (Instrument Specialties Company) model 1680 pumping samplers with 28-sample capability were installed with fixed level intakes 3-feet upstream from flume inlets. Floats with mercury switches were used to activate the pumps during runoff events, and discrete or individual samples were time sequenced.

Coshocton wheel samplers were installed below each flume to sample coarse sediment and provide a backup sampling system for the ISCO samplers. Coshocton samplers were set to initiate composite sampling at low flows. For small storms that did not generate stages high enough to activate the ISCO samplers, Coshocton samples were used to characterize water quality.

One-liter dip samples were collected manually on seclected watersheds for a limited number of storms. These dip samples were taken to check the ability of the automatic samplers to take representative samples. Sample collection and delivery to the lab was normally completed within 24 hours of runoff events.

Rainfall was measured with four tipping-bucket recording gages distributed over the study area. Standard 4-inch collection gages also were used as backup and to check recording equipment operation. Little variation in amounts of storm precipitation was observed among watersheds.

5).Flow and Sediment Analysis:

Stormflow was defined to include all flow starting with the rise from a particular rain storm. Since the watersheds utilized in this study are small natural headwater catchments, stormflows responed quickly to precipitation. There was rarely any flow before any precipitation had occured, and flow from the watersheds usually stopped within a few hours after precipitation had stopped. Therefore, little baseflow was recorded and did not significantly affect the result of this study. Any event which resulted in a hydrograph on record was recorded as an individual stormflow event. On a few occasions a small amount of flow was still occuring on a watershed from a previous storm. Any two consecutive flows were separated at the lowest flow rate between the two peaks, when flow did not cease between the peaks on the hydrograph. Two storm peaks would be considered as a single individual event if two peakflows occured within six hours of one another and the flow rate did not cease between the peaks.

Hydrographs were digitized, and runoff volumes corresponding to respective water samples were determined. Total suspended solids (TSS) concentrations of individual samples were multiplied by respective runoff volumes and summed to get total suspended sediment yield per storm. Sediment deposited in the flume approach sections was collected, weighed, and added to the suspended sediment to get the total sediment yield per storm. Sediment yields for all storms were added to obtain annual total sediment yield for each watershed.

6).Data Analysis:

To do a reliable analysis, a certain period of pre-treatment is necessary to establish the relationship between treated and control level outputs. During the study, measurable stormflow water yields were recorded for all years. The data sets which had been summarized on the control watersheds from 1978 to 1982 were used to establish the pre-treatment calibration. Using regression methods, the stormflows, and sediment yields from the clearcut and ripped watershed (treatment 1) and uncut watershed (or control forest, treatment 3) were compared for both pre- and post-treatment periods, year by year and overall. Similar comparison were made between clearcut without ripping watershed (treatment 2) and uncut watershed (treatment 3). Statistical comparison of the pre- and post-period regression equations were utilized to indicate if differences in stormflow or sediment yield occured between pre- and post-treatment periods.

Established statistical methods were used to test the effects of treatments (Sokal and Rohlf, 1973; Steel and Torrie, 1980). Ursic and Popham (1967) described the logic of using calibration regression in testing the impacts of watershed treatments:

> The calibration regression is compared by covariance analysis to the regression developed from post-treatment values. The null hypothesis is that the two regressions represent the same population. If this hypothesis is rejected, the conclusion is that the relationship between X and Y has changed that and the two equations describe the relationship before and after treatment.
>
> If the relationship has changed, covariance analysis can be extended to determine if the change is some function of X, or if it is best expressed as a constant for all value of X. The first step is to test for differences in slope. If the slopes differ, the magnitude of change varies with X. If the slopes do not differ, the test for difference in levels can be made. If levels differ, the differences represents the average change for any value of X. Since the hypothesis of equal slopes cannot be tested without some probability of error, the critical value for testing the hypothesis of equal levels cannot be precisely determined.

In the case of stormflow yields, two sets of hypotheses were examined as follows. First (Figure 2):

Ho: Slope of post-treatment = slope of pre-treatment

Ha: Slope of post-treatment ≠ slope of pre-treatment

If no differences were indicated in slopes between pre- and post-treatment stormflow regression, the second set of hypothesis was tested (Figure 3):

Ursic, S. J. and T. W. Popham, 1967, Using Ronoff Events to Calibrate Small Forested Catchment., Proceeding, in International Union of Forestry Research Organizations Congress, p. 319-324.

Ho: Adjusted mean Y of post-treatment $\leq$ adjusted mean Y of pre-treatment.

Ha: Adjusted mean Y of post-treatment > adjusted mean Y of pre-treatment.

In this experiment, 0.05 (5 percent) probability level for the F-value indicates a significant difference, and 0.01 (1 percent) probablility level for the F-value indicates a highly significant difference.

In the case of sediment yields, a one-tailed test for slopes was appropriate, as sediment yields were expected to increase with increasing of storm size. The hypotheses for testing slopes were therefore:

Ho: Slope of post-treatment $\leq$ slope of pre-treatment

Ha: Slope of post-treatment > slope of pre-treatment

If no differences were indicated in slopes between pre- and post-treatment sediment yield regressions, the second set of hypothesis was tested per the water yield example.

Ursic and Popham (1967) discussed statistical problems associated with violations of the assumptions which assure unbiased and reliable estimates of coefficients and confidence limits for least square regression. Violation of homoscedasticity, constant variance of the dependent variable at all levels of the independent variable, should not bias the regression coefficents. Ursic and Popham (1967) found that with their small watershed data, weighting of variables did not result in smaller residual mean squares, so unweighted watershed data provided the best coefficient estimates. Stormflow events are the result of

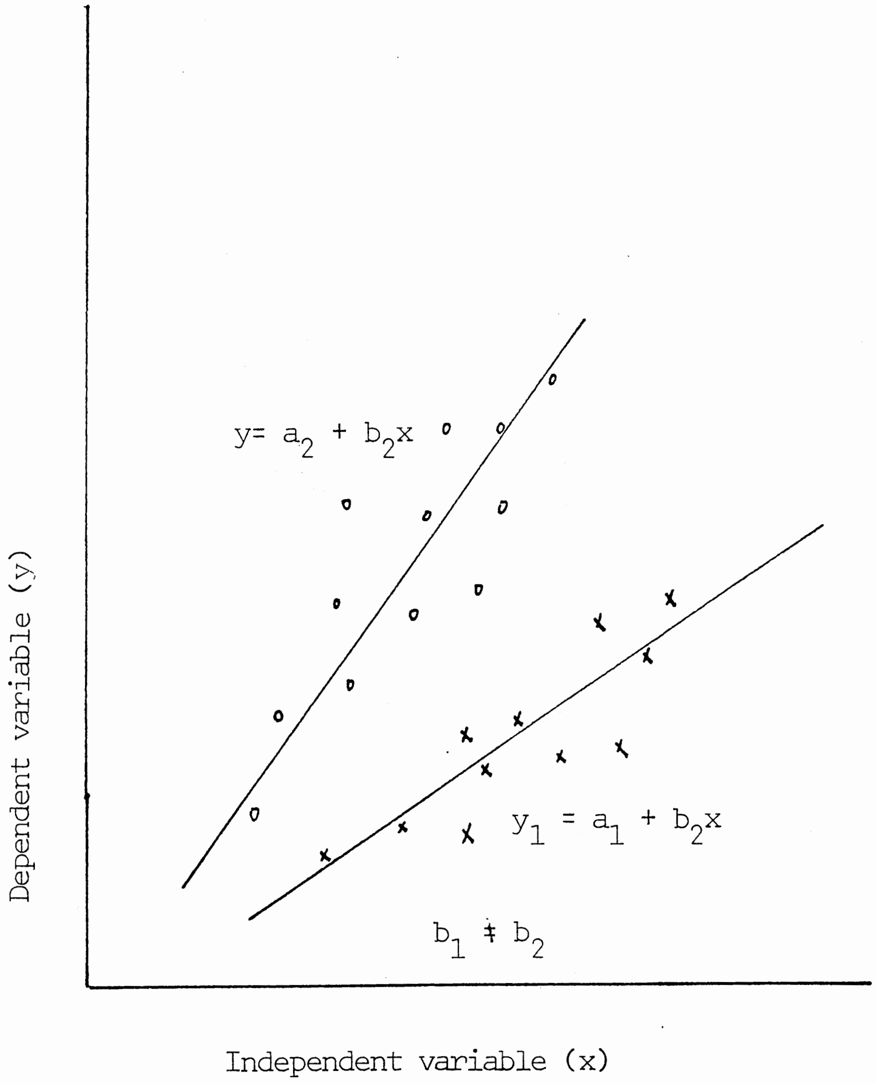


Figure 2. Graphical comparison between two regression lines having different slopes.

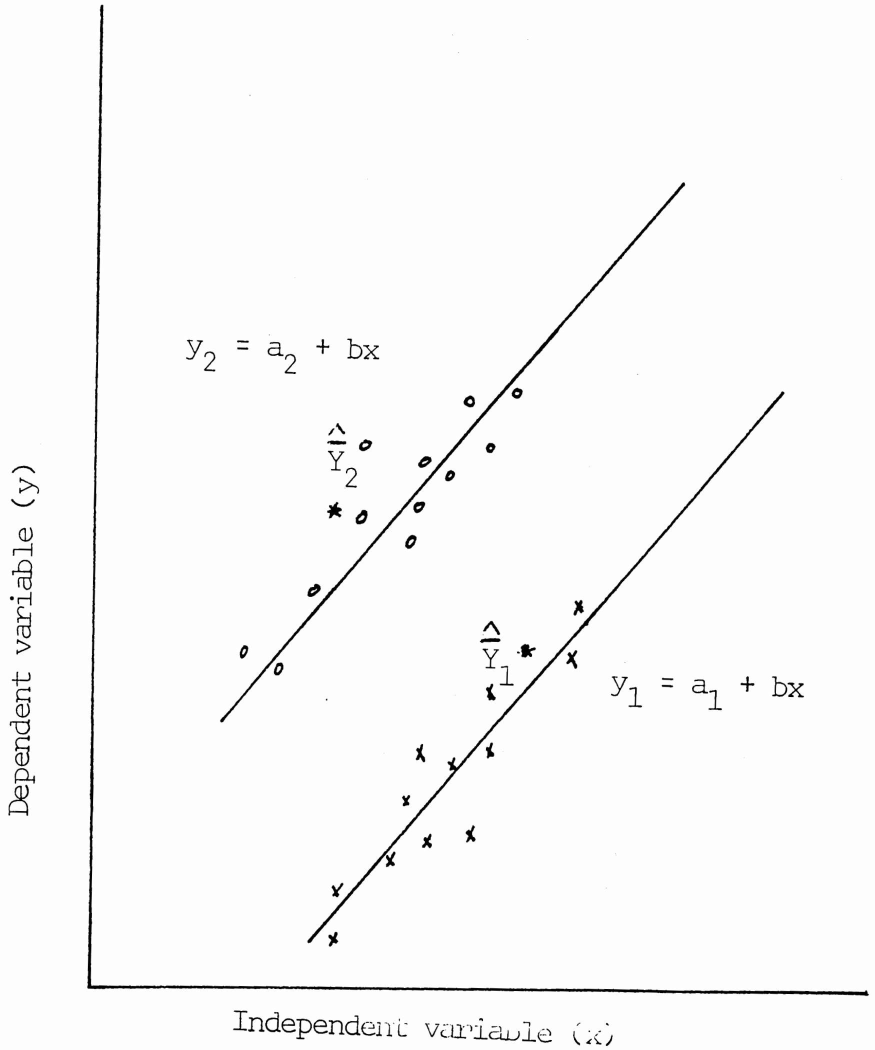


Figure 3. Graphical comparison between two regression lines having equal slopes but different intercepts or adjusted means Y values.

rainfall events which are clearly not independent. For most stormflow events, flow ceased prior to the initiation of the next storm. At least, components of flow from respective events were not included in previous or following events. Regardless, Ursic and Popham (1967) found no serial correlation on an example set of small watershed flow data similar to the data used in this study. The requirement for normality of residuals was dismissed by Fisher (1958) unless non-normality was pronounced. Finally, it is clear that the results of comparisons of pre- and post-treatment data sets only imply that the treatments were responsible for any differences. Confounding is a possibility. That is, factors other than the vegetative treatments could possibly have influenced the post-treatment outputs. Regardless, no observable or detectable changes in the watersheds or climate occured coincidental with the application of treatments.

Tests of these two sets of hypothesis could lead to several different conclusions. For example, when a slope change was not significant but the adjusted mean Y value for the post-treatment period was significantly greater than for the pre-treatment period, then treatment(s) increased the stormflow water yields (or sediment yield) constantly regardless of storm size. If an increase in slope was significant, then the treatment caused increasing levels of stormflow water yield or sediment yield as storm size increased. In other words, as the water or sediment yields from the control watershed became greater, the difference between treated and control watershed water or sediment yield increased. If a decrease in slope occured, stormflow water yield differences due to treatment would become smaller with increasing storm size or response. This would be a logical water yield response for storms of large magnitude on wet soils, conditions in which vegetative cover has been shown to have little influence.

For comparing the peakflow rates from the 3 watersheds, the peakflow discharge rates from each watershed were recorded for the 8 largest storm events which occured during the post-treatment period. Several statistical methods for multiple comparisons; such as LSD t-test, Tukey's test, Duncan's test, and Waller-Duncan's k-ratio t test; were applied to test the difference in the peakflow rates.

It should be recognized that statistically significant increases in peakflows, sediment yields or water yields do not necessarily indicate either positive or negative environmental impacts. For example, increases in peakflows for storms which do not cause flooding may be environmentally acceptable. Water yield increases in many cases are the primary objective of vegetation management and would be a benefit. However, increases in sediment yield, statistically significant or not, which cause site productivity loss may be environmentally unacceptable. Experimental results should therefore be examined both statistically and qualitatively.

7).Factors which May Affect the Results:

This experiment involves the evaluation of a new and unique mechanical harvesting system. It also includes a comparison of site preparation with and without soil ripping which may have a significant effect on erosion and stormflow water yields. Finally, this study will be conducted under different climatic inputs (precipitation) than occurred during the first phase of this study. This will also add to our knowledge of silviculture impacts. Rainfall distribution, harvesting methods, and geological conditions are the main factors which can affect the result of this study.

(1) Normally annual rainfall in McCurtain County is 54 inches, and monthly rainfall averages 4.5 inches, approximately. These amounts, however, change from year to year and month to month. It is certain that rainfall amounts and distribution of this study will be different from the first phase.

(2) In the first phase, skidding on the experiment site was applied after timber felling was done and the branches remained on the site where the delimbing was located. In the second phase of the experiment, tree felling and forewarding was accomplished in a single operation and no skidding occured. These two methods may have caused different levels of damage to the soil and the differences may cause differences in erosion and sedimentation. To compare first phase results with second phase results is one of the primary objectives of this study.

(3). The planned comparisons are between two time periods and among three treatments. Geological conditions and related factors should not be significantly different among treatments. The major concern in this experiment is the effect of ripping versus no ripping, and the effect of the herbicide application. The second phase results will be compared to the first phase, in which increases in sediment yields but decreases in water yields from clearcutting and ripping treatments were measured.

CHAPTER IV

RESULTS AND DISCUSSION

1). Rainfall record:

In 1983, the first year of treatment, the annual precipitation total was 42.02 inches, about 8.82 inches or 17 percent less than normal (Table I; APPENDIX). The whole water year (October 1, 1982 to September 30, 1983) remained relatively dry, and total monthly rainfalls were greater than the respective normal monthly totals only three months of the year. In 1984, annual precipitation was 49.97 inches, or about 1 inch (2 percent) less than the normal annual precipitation total. An extremely wet period occured in May of 1984, about 67 percent more than the normal May precipitation. Total precipitation in the 1985 water year was 52.72 inches, nearly two inches or about 3.5 percent more than the long term normal. This is the only year in the second phase of the experiment that the experimental watersheds received more rainfall than normal. However, this was the result of an extremely wet month, October 1984, in which rainfall was 290 percent or 11.82 inches above the normal monthly total. An extremely dry period occured from January to August 1985. In this period, total precipitation was only 23.04 inches, 12.4 inches or 35 percent less than normal for the period. In 1987 the precipitation amount was 43.88 inches, 14 percent or 6.96 inches below the average,

TABLE I

AVERAGE DISTRIBUTION OF PRECIPITATION
1982 - 1987

Water Year		*Average			
Month	1983	1984	1985	1987	1951-80
			inches		
October	2.96	5.24	15.91	6.03	4.09
November	6.20	3.70	5.82	3.07	3.34
December	5.82	3.29	3.60	2.46	3.58
January	1.67	1.45	1.00	2.71	3.06
Febuary	1.76	4.12	3.76	3.40	3.90
March	3.05	5.87	2.65	2.77	4.55
April	2.78	1.68	4.58	0.77	5.34
May	7.33	10.31	3.11	4.82	6.16
June	4.20	3.73	3.57	4.97	3.89
July	2.47	2.50	1.89	2.80	4.14
August	1.52	2.90	2.48	4.82	4.40
September	1.26	5.00	4.35	5.26	4.39
Total	42.02	49.79	52.72	43.88	50.84

Note: * recorded from Carter Mountain

with a dry period from December 1986 to July 1987 (Table I, APPENDIX).

2)Stormflow Water Yield:

Stormflow is the direct result of precipitation on small watersheds with ephemeral drains. Simple linear regression shows the relationship clearly between annual precipition and annual stormflow water yields from the control treatment (WS6) (Figure 4). The seasonal distribution of precipitation also influences stormflow water yield and the wide distribution of data points about the mean regression shows that seasonal as well as other precipitation and environmental variables, important in regulating annual stormflow amounts, are not accounted for in this simple analysis. For example, WS6 received similar amounts of precipitation in water years 1982 and 1987, and annual stormflow water yield was 14 inches in 1982 but only about 5 inches in 1987.

During the four year pre-treatment period, average annual stormflow water yield from the watershed to be clearcut (WS5) was 9.16 inches per year, about the same as from the control watershed (WS6), 9.13 inches per year (Table II). The average annual water yield for the pre-treatment period from the watershed to be clearcut and ripped, WS4, was 4.83 inches or 47 percent less than from WS6. The stormflow water yield relationship among the three experimental watersheds remained relatively similar in 1983, the year silvicultural treatments were applied, with the

TABLE II

ANNUAL WATER YIELDS FROM TREATED WATERSHEDS WATER YEAR 1979 TO 1987

Water Year	Precp. inch	CLEARCUT/RIP (WS4)	CLEARCUT (WS5)	UNCUT (WS6)
1979	55.89	8.25	15.68	13.52
1980	40.97	1.44	3.75	2.09
1981	47.98	3.61	6.99	6.78
1982	45.30	6.82	10.21	14.15
Average		4.83	9.16	9.13
Treatments Applied on March 1983				
1983	42.02	5.73	9.75	9.76
1984	49.79	11.78	19.69	10.21
1985	52.72	15.73	26.87	19.00
1987	43.88	5.58	11.19	3.71
Average (1984-87)		11.03	19.25	10.97

Units: inches-area

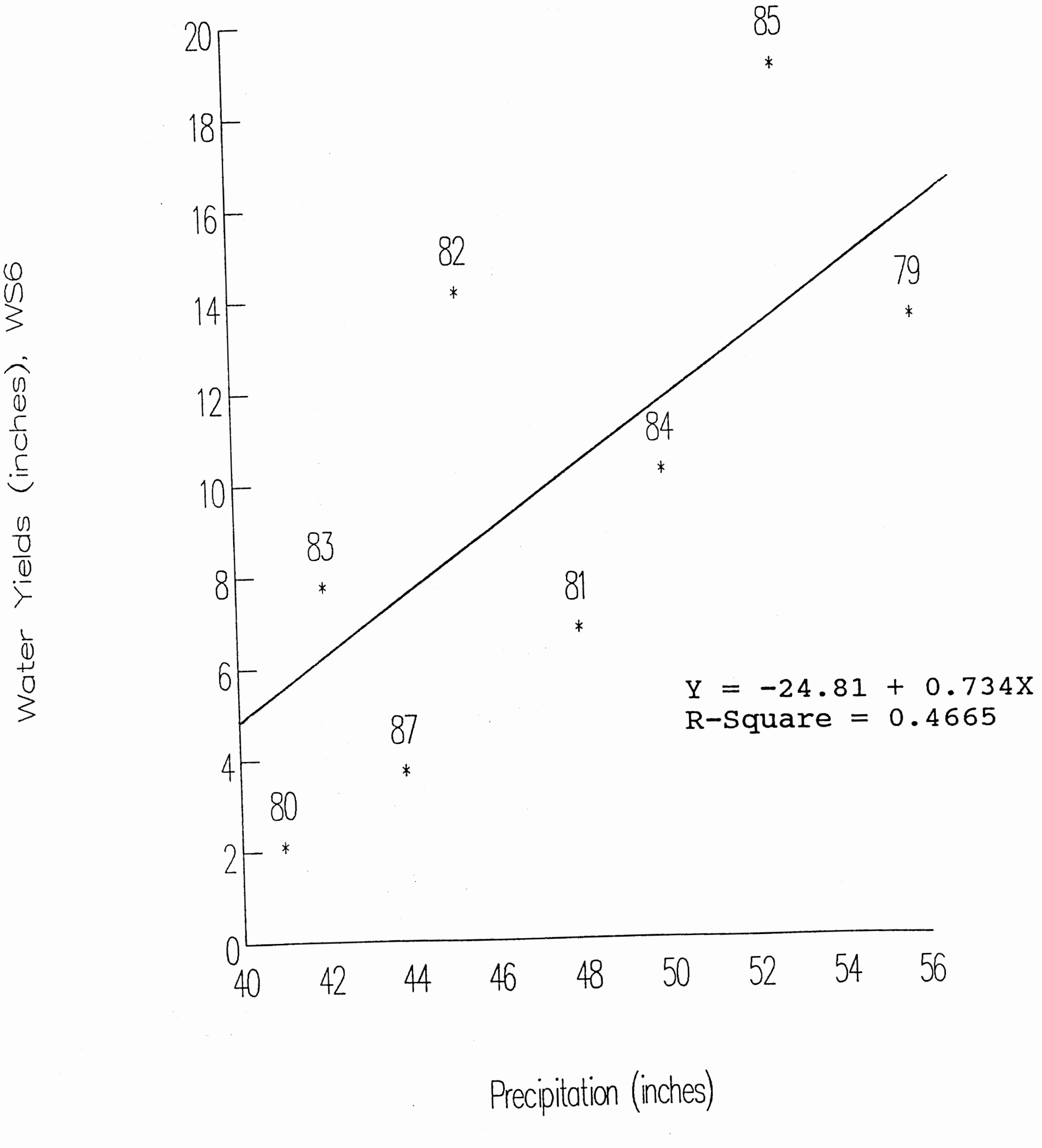


Figure 4. Relationship between annual precipitation and annual stormflow water yields from the forested control watershed (WS6), 1979-87.

clearcut and ripped watershed (WS4) yielding 5.73 inches, the clearcut watershed (WS5) yielding 9.75 inches, while 9.76 inches were yielded from the control watershed (WS6) (Table II).

During the post-treatment period of the study, the annual stormflow total from the control watershed (WS6) averaged 10.97 inches, only 1.84 inches more than for the pre-treatment period. But during the post-treatment period, the clearcut watershed (WS5) produced considerably more stormflow water yield, and averaged 19.25 inches per year, or 10.09 inches per year more than for the pre-treatment period (Table II). Post-treatment stormflow water yield averaged 11.03 inches, or 6.2 inches more than for the pre-treatment period on the clearcut and ripped watershed (WS4). The average increases in stormflow on the clearcut and contour rip watershed (WS4) were not as great as on the clearcut without ripping watershed (WS5) (Table II; Figure 5).

Simple linear regression was used to compare pre- and post-treatment annual total stormflow water yields for both treatments (Figure 6 and 7). Covariance analysis indicated that when the regression slopes were assumed to be equal, the adjusted mean Y (stormflow) values for the post-treatment period were significantly greater than for the pre-treatment period for both treatments. Pre-treatment regression equations were used to predict annual stormflow outputs for post-treatment years; stormflow amounts which

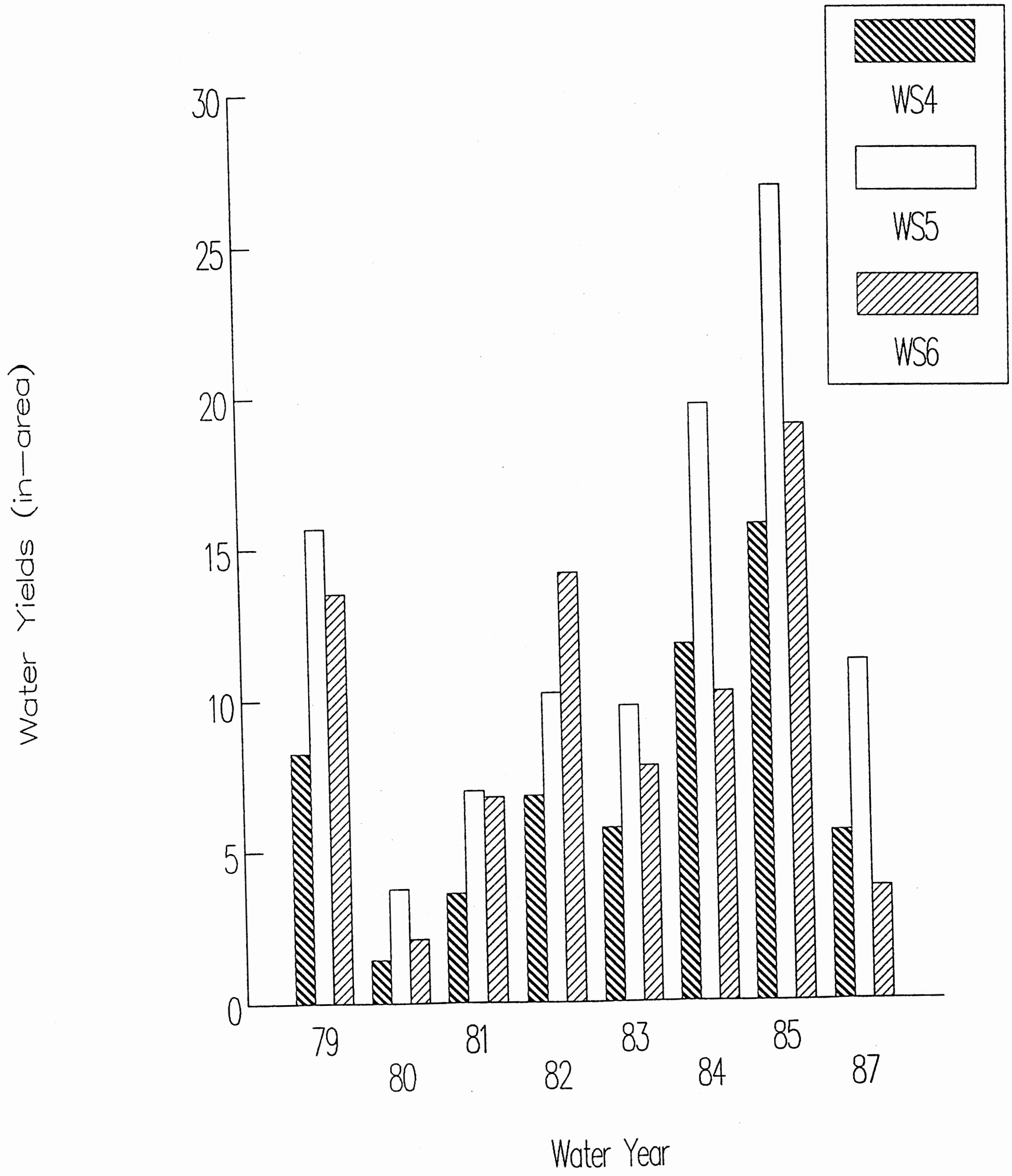


Figure 5. Annual stormflow water yield from the forested control (WS6), clearcut and ripped (WS4) and the clearcut without ripping (WS5) treatment (1979-87). Silvicultural treatments were applied in water year 1983.

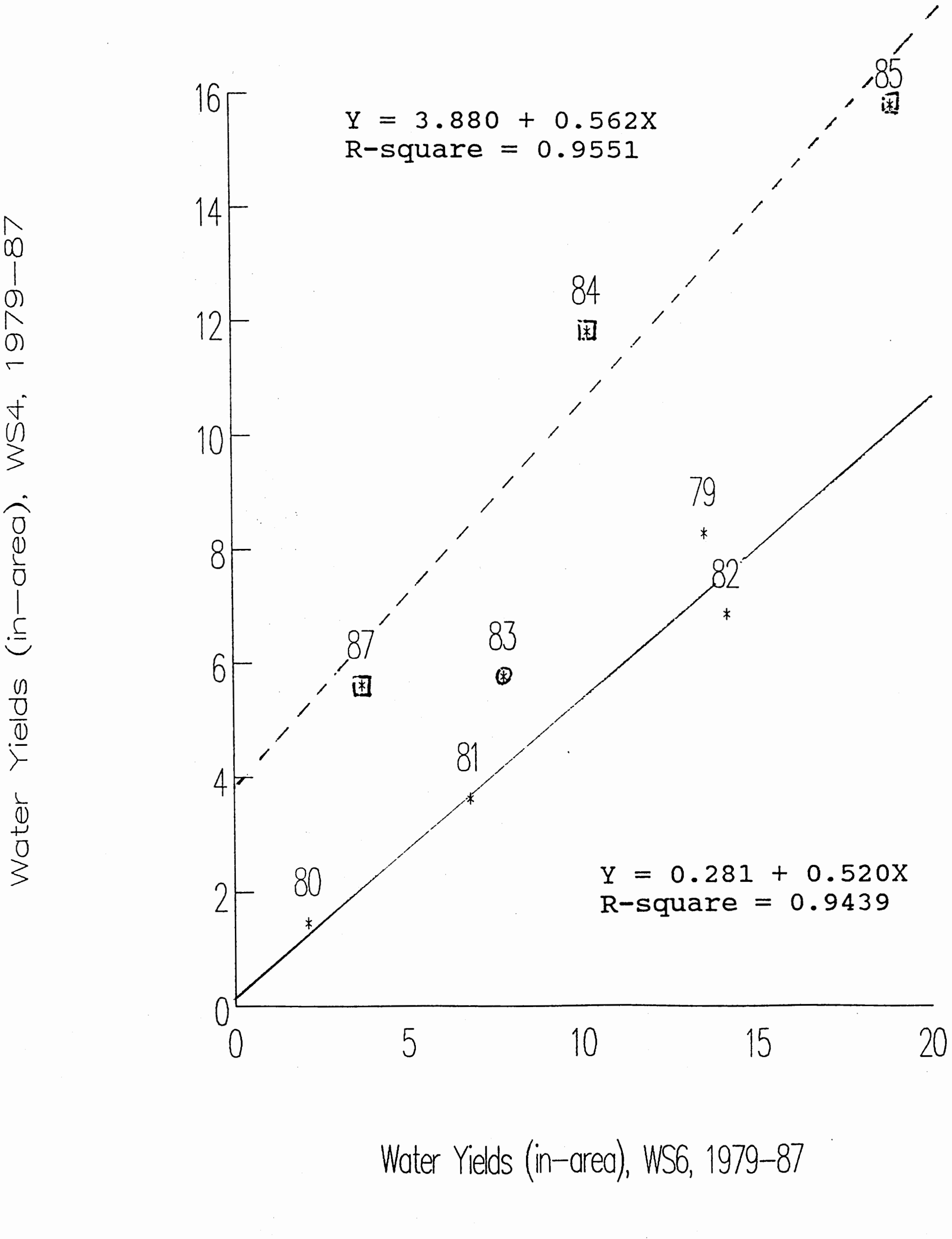


Figure 6. Annual stormflow water yield comparison between the forested control (WS6) and clearcut and ripped treatment (WS4), pre (1979-82) and post (1984-87) treatment periods. Water year 1983, the year the treatment was applied, not included in either regression.

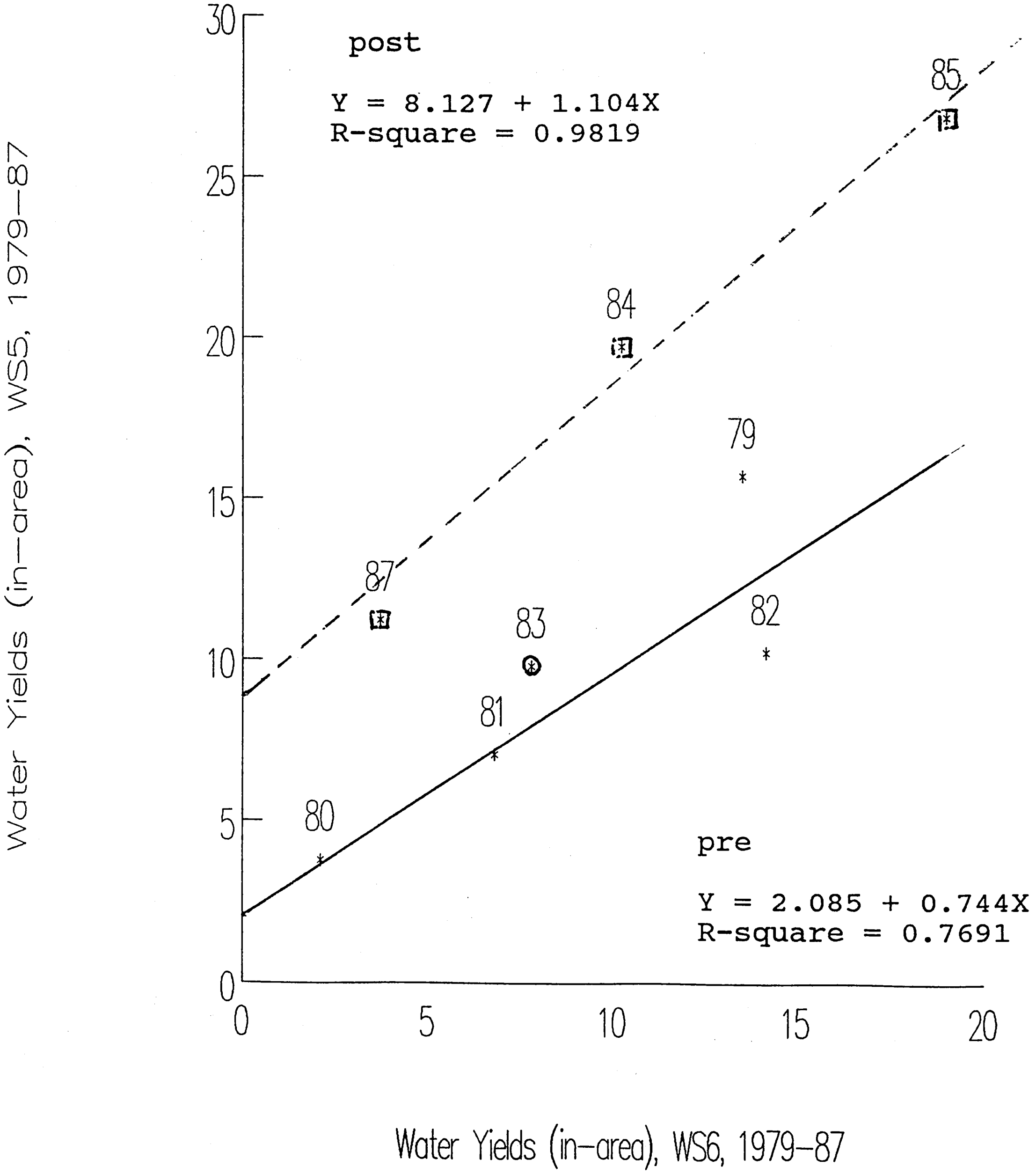


Figure 7. Annual stormflow water yield comparison between forested control (WS6) and clearcut without ripping watershed (WS5), pre (1979-82) and post (1984-87) treatment periods. Water year 1983, the year the treatment was applied, not included in either regression.

would have occured had treatments not been applied. These predicted annual stormflow outputs for both treatments were compared to actual annual stormflow outputs for all post treatment years (Figure 8 and 9). Annual stormflow increases were associated with the application of the harvest and site preparation treatments. Although in principle, other factors might be confounded with harvest and site preparation treatments, harvest and site preparation appeared to be the major difference associated with stormflow increases. Although limited annual data are available for this comparison, the trends are clearly shown by the data.

The lack of stormflow response to treatments in the first phase of the study (Miller, 1984) is in contrast to the results of the second phase. The lack of response in the first phase may have been due to differences in the total and seasonal distribution of precipitation or to the fact that herbicides were not applied and revegetation was rapid in phase 1. Weaknesses in the statistical design of the first phase of the experiment, made necessary by the need for quick results, may have affected the ability to detect post-treatment differences. The literature consistantly indicates annual water yield increases due to forest vegetation removal can be expected (Hewlett, 1982; Anderson, Hoover and Reinhart, 1976, Ursic, 1986). The annual stormflow results of the second phase are therefore not surprising.

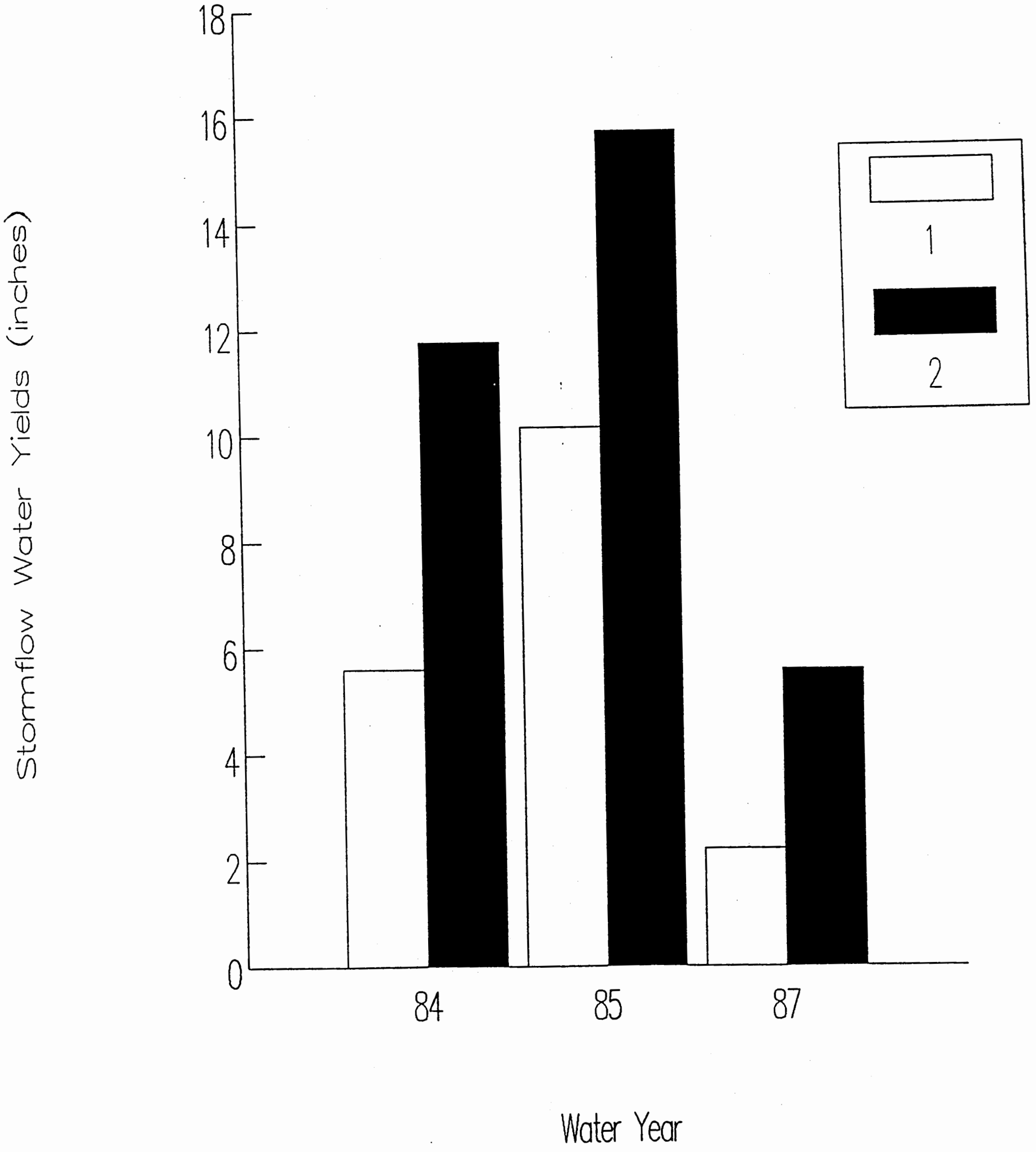


Figure 8. Annual stormflow water yields from clearcut and ripped watershed (WS4) after treatment. Empty bars represent the possible stormflow water yields if there had been no treatment with 1 standard deviation. Solid bars are the actural water yields after treatment.

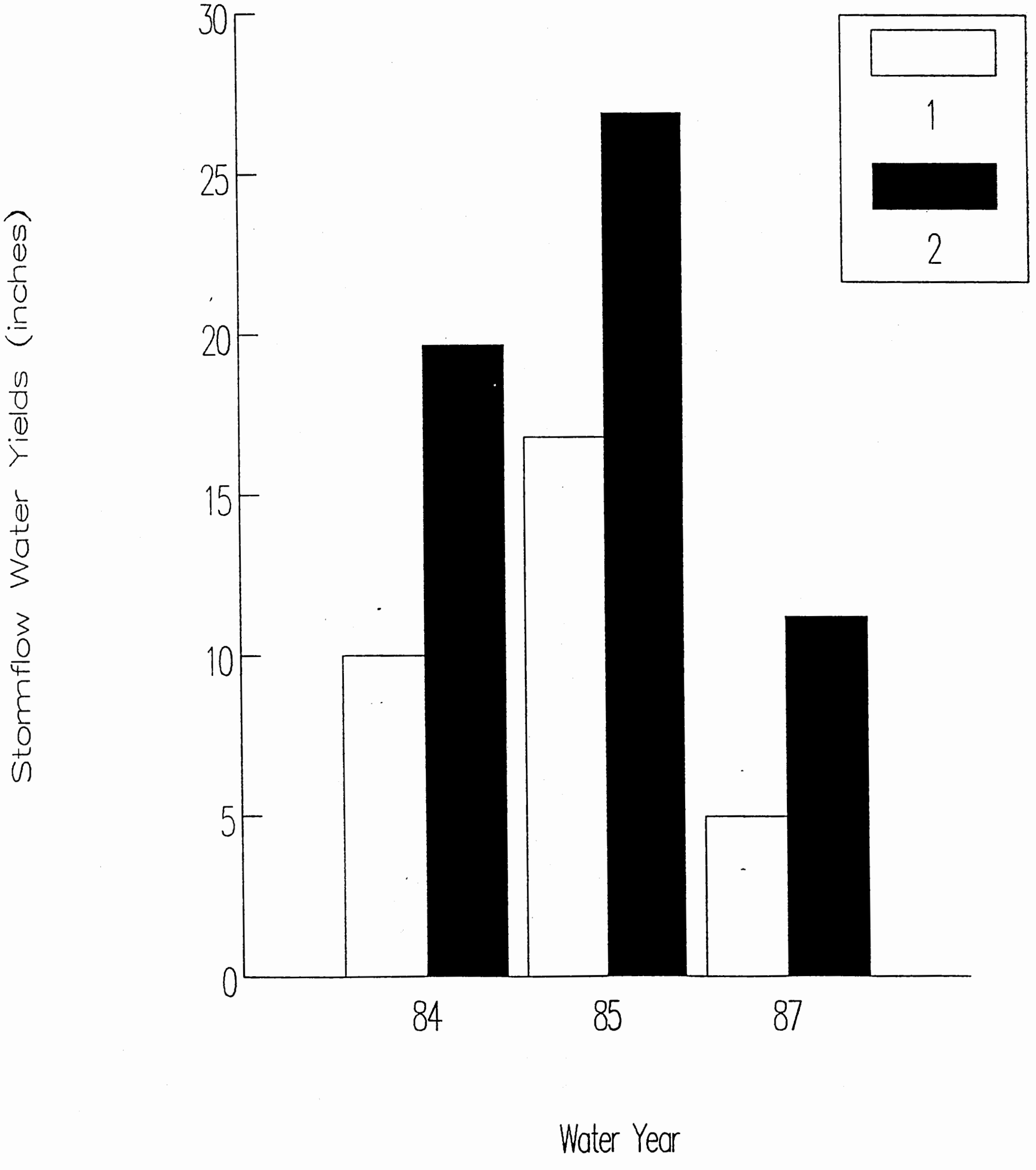


Figure 9. Annual stormflow water yields from clearcut and unripped watershed (WS5) after treatment. Empty bars represent the possible stormflow water yields if there had been no treatment with 1 standard deviation. Solid bars are the actural water yields after treatment.

A comparison of the number of measurable individual stormflow events was completed (Table III). A total of 82 stormflow observations were made during the pre-treatment period from October 1978 to September 1982 on the control watershed (WS6), 63 storms from WS4 and 59 from WS5, 23 percent and 27 percent less than WS6. The post-treatment comparison used total storms recorded in water years 1983, 1984 and 1987. A malfunction in a recorder prevented use of the 1985 data. A total of 75 storms were recorded from the control treatment (WS6), 74 from the clearcut treatment (WS5) and 73 on the clearcut with ripping treatment (WS4) in the three post-treatment years. Because the three watersheds had almost the same number of stormflow events during the post-treatment period, it appears that for both treatments the number of total stormflow events were increased by about 25 percent. The increase in numbers of stormflows after treatment was the result of additional small stormflow events.

Regression analysis or calibrated watershed comparisons for pre-treatment and post-treatment periods were made using the stormflow volumes of single stormflow events. Prior to treatment in 1983, the stormflow relationship between the forested control watershed (WS6) and the other two watersheds (WS4 and WS5) was stable and consistent. The pre-treatment regression relationships were determined using the full set or all years of pre-treatment data combined (Tables IV and V). R-squares for these pre-treatment

TABLE III

NUMBER OF STORMFLOW EVENTS PER WATERSHED AND AVERAGE BY TREATMENT FOR WATER YEAR 1979-87

Water Year	Clear and Ripping (WS4)	Clearcut (WS5)	Control (WS6)
Pre-treatment(79-82)	63	59	82
Average	15.8	14.8	20.5
Treatments Applied March, 1983			
1983	19	19	20
1984	29	27	27
1985	36	31	21*
1987	25	28	28
Average	27.3	26.3	24

Note: * recorder malfunction on WS6,
May through September, 1985

TABLE IV

REGRESSIONAL COMPARISON BETWEEN CLEARCUT WITH RIPPING AND CONTROL WATERSHEDS, STORMFLOW WATER YIELDS WATER YEAR 1979 TO 1987

Water Year	CLEARCUT/RIP(WS4) Y (cu-ft)	UNCUT(WS6) X (cu-ft)	R-SQUARE	No. Obs.
Pre-Treatment	Y = 148 + 0.26X		0.8881	84
Treatments Applied on March 1983				
1983	Y = -290 + 0.376X		0.8882	24
1984	Y = 3073 + 0.274X		0.3807	29
1985	Y = 1600 + 0.301X		0.7123	37
1987	Y = 1354 + 0.360X		0.3620	31
Post-Treatment	Y = 1512 + 0.314X		0.6260	121

Note: highly significant increase in slope of 1983 ($p < 0.01$)

significant increase in slope of post-treatment periods ($p < 0.05$).

highly significant increase in adjusted mean Y values of 1984, 1985, and 1987 ($p < 0.01$).

TABLE V

REGRESSIONAL COMPARISON BETWEEN CLEARCUT AND CONTROL WATERSHEDS, STORMFLOW WATER YIELDS WATER YEAR 1979 TO 1987

Water Year	CLEARCUT(WS5) Y (cu-ft)	UNCUT(WS6) X (cu-ft)	R-SQUARE	No. Obs.
Pre-Treatment	$Y = 4440 + 0.870X$		0.8315	84
Treatments Applied on March 1983				
1983	$Y = 5080 + 0.997X$		0.8223	24
1984	$Y = 14340 + 1.014X$		0.4919	29
1985	$Y = 7435 + 1.220X$		0.6816	37
1987	$Y = 9334 + 1.132X$		0.1955	31
Post-Treatment	$Y = 8969 + 1.131X$		0.5860	121

Note: highly significant increase in slopes of 1984, 1985, and post-treatment periods ($p < 0.01$).

significant increase in adjusted mean Y value in 1987 ($p < 0.05$).

regressions were high indicating that the control watershed (WS6) single stormflow yields explain a large proportion of the variation in stormflow yields from the watersheds yet to be treated (WS4 and WS5).

It is assumed that if no treatments had been applied, the stormflow relationship between the forested control watershed (WS6) and the clearcut with ripping watershed (WS4) or the clearcut watershed (WS5) would have remained as in the pre-treatment period. The effects of the treatments are inferred by comparing the regressional functions of the pre- and post-treatment periods, basically by comparing the regression slopes and intercepts. Since the untreated watershed data are used to construct regressions, physiological factors such as geology, soils and topograpy were integrated into the regression relationships, and unchanged by vegetative treatments, and only watershed treatments vary between pre- and post-treatment periods.

The post-treatment regression relationships are presented in Tables IV and V. Regression relationships were determined for individual post-treatment years including 1983, the year of treatment, and with the entire set of post-treatment stormflow water yields. Comparison of pre-treatment regression slopes and adjusted mean Y values were made to post-treatment regression slopes and adjusted mean Y values for individual post-treatment years and for the combined post-treatment years. As Ursic and Popham (1967) suggested if two regression's slopes are determined to be significantly different it is not appropriate to test the adjusted mean Y value. If the slopes are statistically equal, and the test of the difference between the two adjusted mean Y values is significant the regression lines are parallel and differ only in a constant value (Neter and Wasserman, 1974).

Using basic linear regression methods, the relationship between stormflows from the control watershed (WS6) (the independent variable) and the clearcut and ripped watershed (WS4) (the dependent variable) (Tables VI - IX) during pre-treatment period, October 1978 to September 1982, was $Y = 148 + 0.26X$, with R-square = 0.8881 (Table IV; Figure 10). The regression relationship between stormflows from the control watershed (WS6) and the clearcut without rip watershed (WS5) (Tables VI - IX) was $Y = 4440 + 0.87X$ with R-square = 0.8315 for the pre-treatment period (Table V, Figure 11).

A post-treatment comparison of stormflows from the clearcut and ripped watershed (WS4) and uncut watershed (WS6), using $Y = 148 + 0.26X$ as original stormflow relationship, shows an increase in slope (Table X; Figure 12) in water year 1983, the year of treatment, which is highly significant ($p < 0.01$). For the water years 1984, 1985 and 1987 (Tables XI - XIII; Figures 14, 16 and 18) the differences between pre- and post-treatment regression slopes are not significant ($p > 0.10$). Comparing the total post-treatment data, from October 1982 through September

TABLE VI

STORMFLOW WATER YIELDS OF WATER YEAR 1979
(OCTOBER 1, 1978 - SEPTEMBER 30, 1979)

Date Mo-Dt-Yr	WS4	WS5	WS6
11-15-78	29	3135	1480
11-16-78	280	3637	2251
11-26-78	*	*	671
12-06-78	54	526	2703
12-31-78	1899	29019	22540
01-18-79	4487	12756	4716
02-12-79	*	4069	*
02-22-79	5120	36712	15224
02-24-79	7003	60600	20540
03-02-79	4413	33797	4565
03-19-79	7629	32608	26212
03-22-79	23	9950	13615
03-26-79	2357	8173	10943
03-30-79	21834	66008	59650
04-01-79	6840	33433	25315
04-11-79	4543	17363	13227
05-03-79	383	427	1162
05-10-79	8876	31797	32905
05-11-79	4239	23417	17357
05-20-79	19239	61908	51397
05-21-79	26179	90266	63518
05-28-79	2140	13902	10984
06-01-79	120	1309	3325
06-02-79	2292	19956	30398
06-21-79	*	*	9
06-25-79	*	*	26
07-16-79	*	*	81
07-26-79	231	3053	1947
08-10-79	*	*	20
Total(cu-ft)	130224	597821	436781
Average(in/area)	8.25	15.68	13.52

Note: * no flow was recorded

TABLE VII

STORMFLOW WATER YIELDS OF WATER YEAR 1980
(OCTOBER 1, 1979 - SEPTEMBER 30, 1980)

Date Mo-Dt-Yr	WS4	WS5	WS6
10-30-79	147	*	400
12-12-79	38	574	638
12-22-79	1598	18709	8221
01-21-80	355	9080	3779
02-08-80	4922	31885	16628
04-12-80	90	132	930
05-15-80	2094	11574	4326
05-29-80	11906	52057	26663
06-19-80	*	*	204
09-27-80	768	18837	5885
Total(cu-ft)	21918	142848	67674
Average(in/area)	1.44	3.75	2.09

Note: * no flow was recorded

TABLE VIII

STORMFLOW WATER YIELDS OF WATER YEAR 1981
(OCTOBER 1, 1980 - SEPTEMBER 30, 1981)

Date Mo-Dt-Yr	WS4	WS5	WS6
10-17-80	18	*	250
10-27-80	1368	4180	3351
12-08-80	2474	22045	12501
01-31-80	33	*	*
02-09-81	3606	20147	9819
02-28-81	7766	29321	24184
03-03-81	2516	14845	42327
03-29-81	*	*	4
04-03-81	*	*	3
04-21-81	1850	6077	1761
05-05-81	*	*	7
05-09-81	4768	23026	9295
05-13-81	1032	9379	9757
05-23-81	1987	15612	717
05-29-81	2161	16873	4963
06-02-81	522	8599	8539
06-04-81	19204	66176	62330
06-06-81	5512	29395	24670
06-15-81	*	*	75
06-30-81	103	421	140
07-07-81	*	*	4
07-29-81	*	*	7
08-01-81	7	*	165
08-07-81	*	*	16
08-16-81	122	219	4266
08-26-81	*	3	18
Total(cu-ft)	55082	266318	219170
Average(in/area)	3.61	6.99	6.78

Note: * no flow was recorded

TABLE IX

STORMFLOW WATER YIELDS OF WATER YEAR 1982 (OCTOBER 1, 1981 - SEPTEMBER 30, 1982)

Date Mo-Dt-Yr	WS4	WS5	WS6
10-13-81	7	17	530
10-16-81	*	*	1008
10-31-81	1381	6189	7037
11-29-81	1421	4221	4118
01-20-82	2092	14075	27394
01-30-82	35242	123878	101750
02-15-82	1205	*	8270
02-25-82	*	*	7108
03-13-82	499	4915	9605
04-02-82	69	14	214
05-12-82	46000	145409	209772
05-22-82	20026	77958	68545
05-30-82	1370	*	*
06-01-82	1001	4146	5086
06-15-82	1080	8472	6570
06-25-82	*	*	26
07-10-82	*	*	13
07-30-82	*	*	50
08-27-82	*	*	86
09-13-82	*	*	24
Total(cu-ft)	111393	389294	457206
Average(in/area)	6.82	10.21	14.15

Note: * no flow was recorded

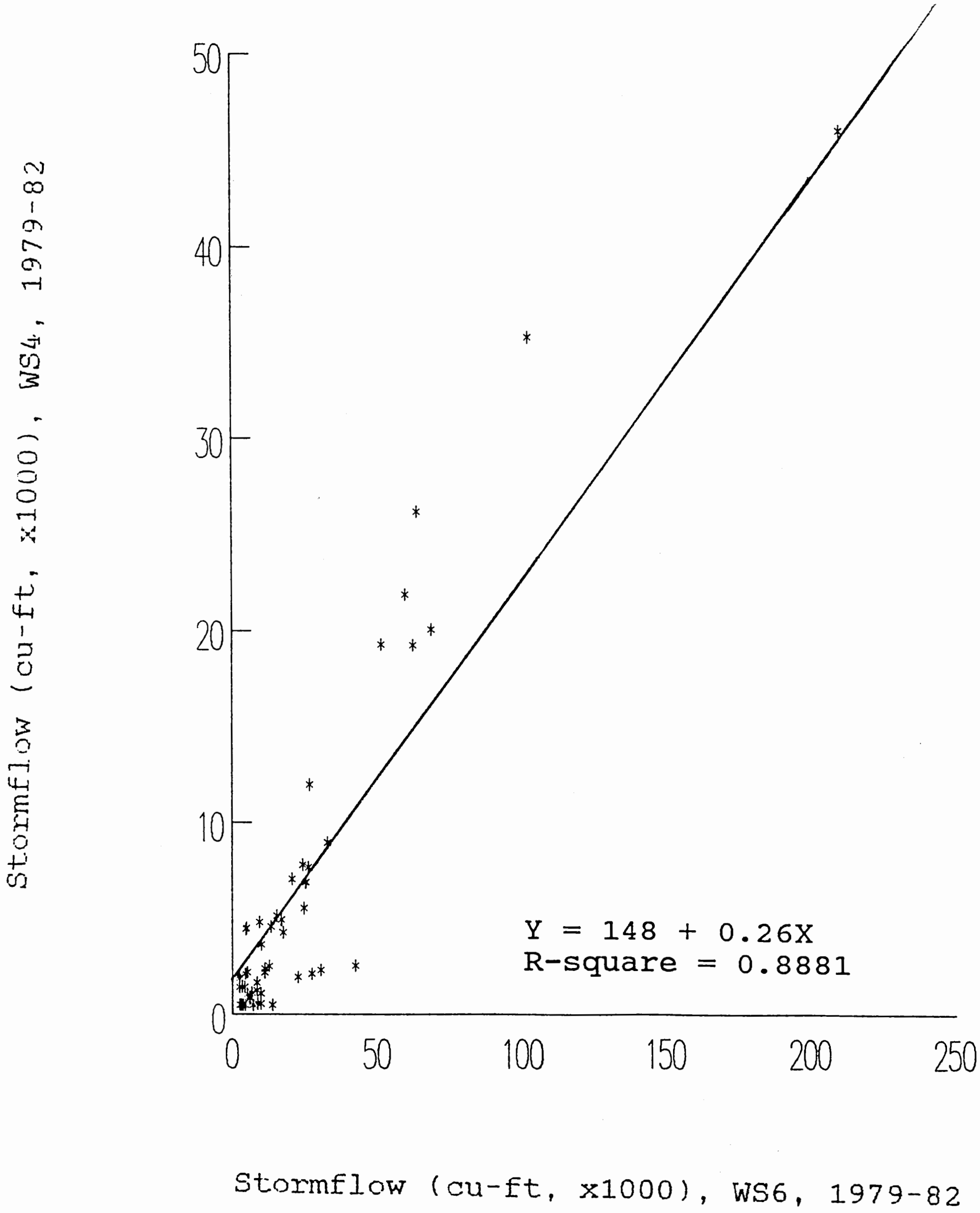


Figure 10. Single storm stormflow water yield comparison between the forested control (WS6) and the clearcut and ripped treatment (WS4) for the pre-treatment period (1979-82).

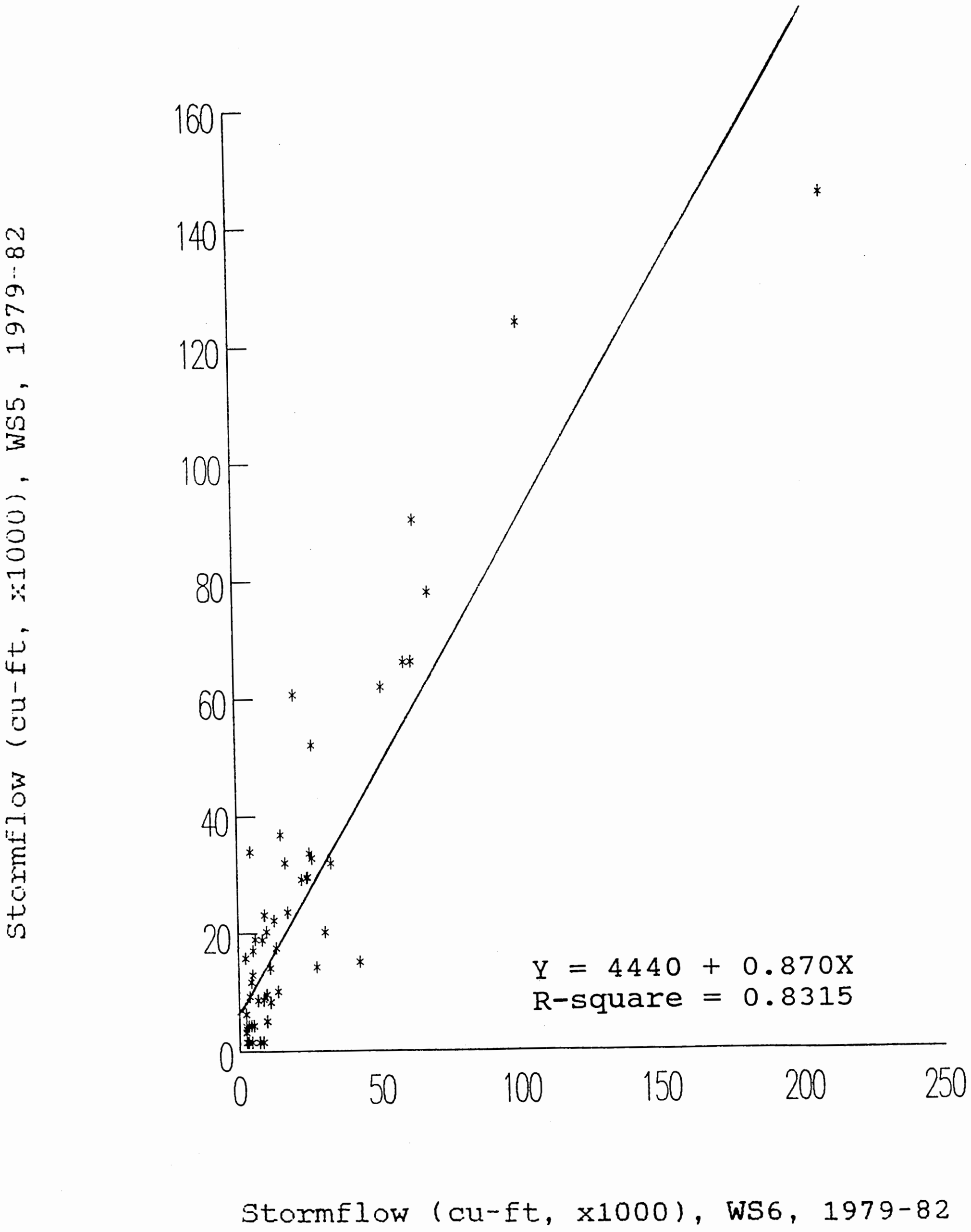


Figure 11. Single storm stormflow water yield comparison between the forested control (WS6) and the clearcut and unripped treatment (WS5) for the pre-treatment period (1979-82).

TABLE X

STORMFLOW WATER YIELDS OF WATER YEAR 1983
(OCTOBER 1, 1982 - SEPTEMBER 30, 1983)

Date Mo-Dt-Yr	WS4	WS5	WS6
11-26-82	1975	13972	5476
12-02-82	7770	47078	32585
12-10-82	1318	10538	6042
12-26-82	8861	36168	29915
01-26-83	*	*	432
01-31-83	30	*	3297
02-07-83	*	*	4132
02-20-83	*	*	310
03-03-83	9402	46750	37527
04-13-83	336	1793	900
04-22-83	1442	10667	160
05-01-83	9070	37004	18498
05-10-83	36	807	55
05-14-83	34530	74096	78428
05-17-83	2165	17087	15928
05-26-83	*	*	314
05-28-83	2984	25886	13611
06-05-83	356	2349	3030
06-27-83	6008	34034	10
07-15-83	424	3549	*
07-29-83	*	601	*
08-08-83	354	2308	*
08-12-83	131	4258	*
09-20-83	217	2853	55
Total(cu-ft)	87424	371798	250720
Average(in/area)	5.73	9.75	7.76

Note: * no flow was recorded

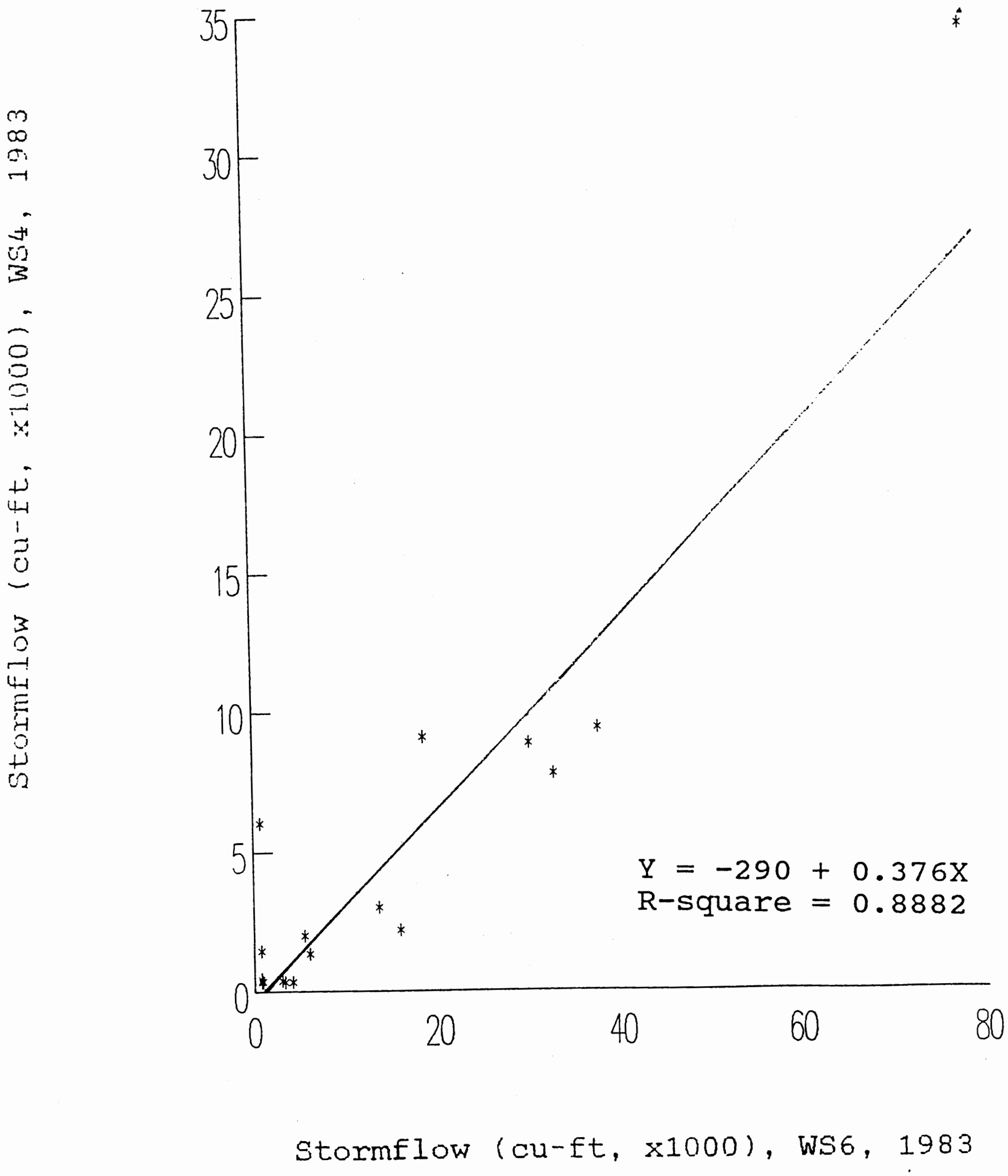


Figure 12. Single storm stormflow water yield comparison between the forested control (WS6) and the clearcut and ripped treatment (WS4) for water year 1983.

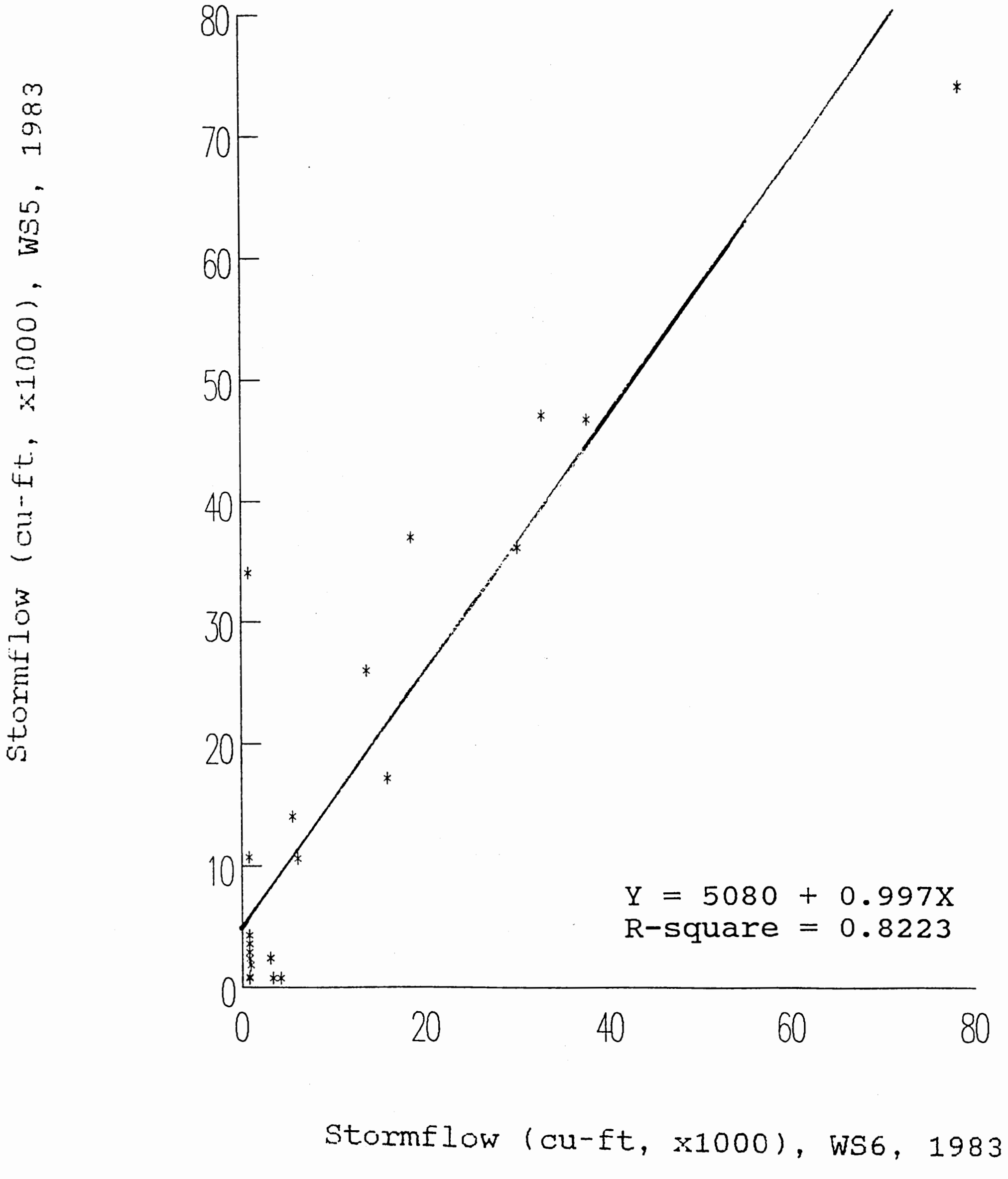


Figure 13. Single storm stormflow water yield comparison between the forested control (WS6) and the clearcut and unripped treatment (WS5) for water year 1983.

TABLE XI

STORMFLOW WATER YIELDS OF WATER YEAR 1984
(OCTOBER 1, 1983 - SEPTEMBER 30, 1984)

Date Mo-Dt-Yr	WS4	WS5	WS6
10-11-83	142	847	43
10-17-83	18776	74359	763
10-20-83	5459	28403	1106
11-19-83	933	10798	315
11-22-83	842	6991	695
11-25-83	881	7910	105
12-02-83	6202	35546	4106
12-10-83	7971	36788	7942
01-09-84	70	*	1079
02-11-84	4842	37754	31964
02-26-84	9730	70426	32259
03-11-84	8045	38742	30380
03-15-84	7921	28514	34307
03-23-84	8359	40513	40698
03-27-84	4507	26495	22019
04-02-84	1061	9502	6875
04-08-84	438	5722	2168
05-01-84	9633	45104	16283
05-05-84	1756	10207	5362
05-20-84	36350	94031	57835
05-27-84	7726	40022	32574
06-23-84	5720	15785	192
06-26-84	2162	5460	*
07-11-84	5596	17051	33
08-02-84	9095	21026	139
09-09-84	128	150	86
09-15-84	215	*	*
09-22-84	9493	25157	232
09-25-84	5523	17029	218
Total(cu-ft)	179590	750332	329778
Average(in/area)	11.78	19.69	10.21

Note: * no flow was recorded

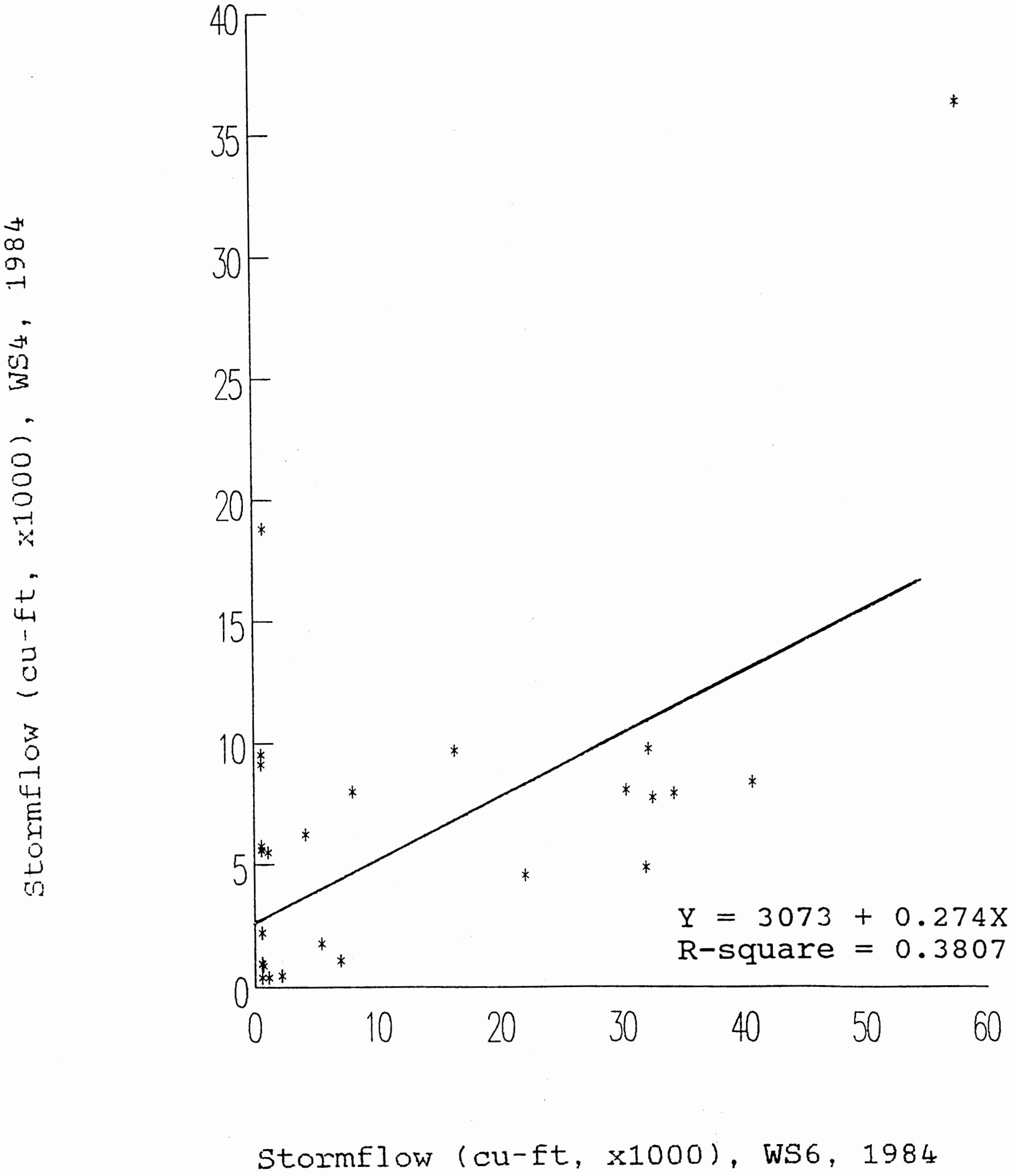


Figure 14. Single storm stormflow water yield comparison between the forested control (WS6) and the clearcut and ripped treatment (WS4) for water year 1984.

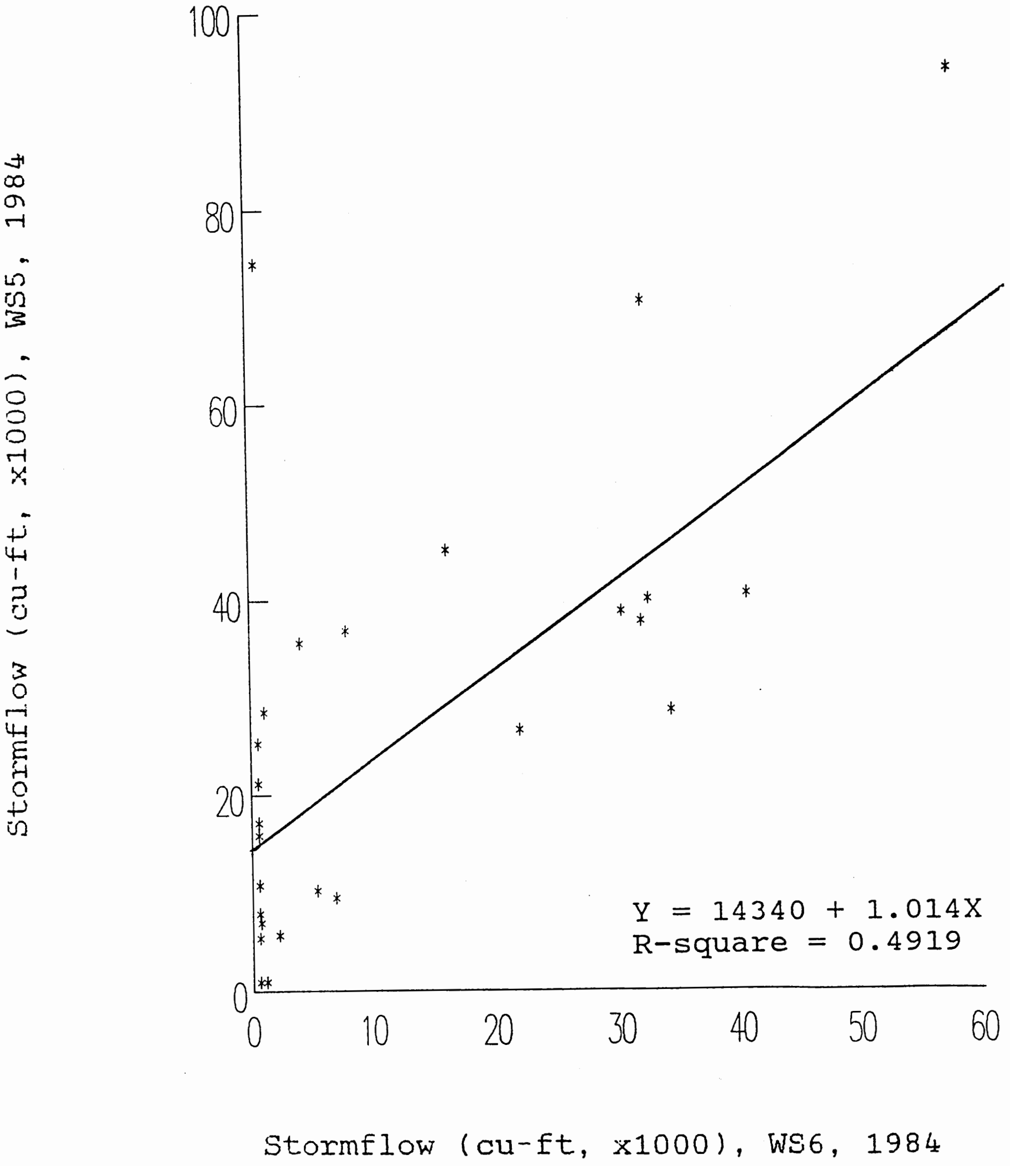


Figure 15. **Single storm stormflow water yield comparison between the forested control (WS6) and the clearcut and unripped treatment (WS5) for water year 1984.**

TABLE XII

STORMFLOW WATER YIELDS OF WATER YEAR 1985 (OCTOBER 1, 1984 - SEPTEMBER 30, 1985)

Date Mo-Dt-Yr	WS4	WS5	WS6
10-05-84	11455	45788	2440
10-06-84	28961	109185	30657
10-13-84	11816	51145	28760
10-16-84	8681	34785	19095
10-18-84	4408	19886	8301
10-20-84	27135	113579	73339
10-24-84	23628	104540	88583
10-31-84	22255	88390	53126
11-17-84	11135	46841	26682
11-25-84	9655	38877	33415
12-14-84	1225	11194	43977
12-16-84	769	71921	*
12-17-84	5853	*	*
12-21-84	3450	*	*
12-31-84	6856	34782	30025
01-05-85	297	67	*
01-08-85	104	*	*
01-26-85	115	1573	4007
02-06-85	*	1359	869
02-10-85	2118	12418	12577
02-22-85	22291	79424	73124
03-03-85	2086	11216	8625
03-20-85	11102	44973	26150
03-30-85	122	66	59
04-22-85	17998	72974	44662
04-26-85	717	3829	5408
04-30-85	467	3553	-
05-13-85	751	1398	-
05-21-85	172	*	-
05-30-85	670	1529	-
05-31-85	618	*	-
06-06-85	909	2704	-
06-18-85	117	126	-
08-14-85	1262	1632	-
08-24-85	511	78	-
09-13-85	112	*	-
09-29-85	4063	14179	-
Total(cu-ft)	239746	1024017	613912
Average(in/area)	15.73	26.87	19.00

Note: * no flow was recorded
- recorder malfunction, May through September

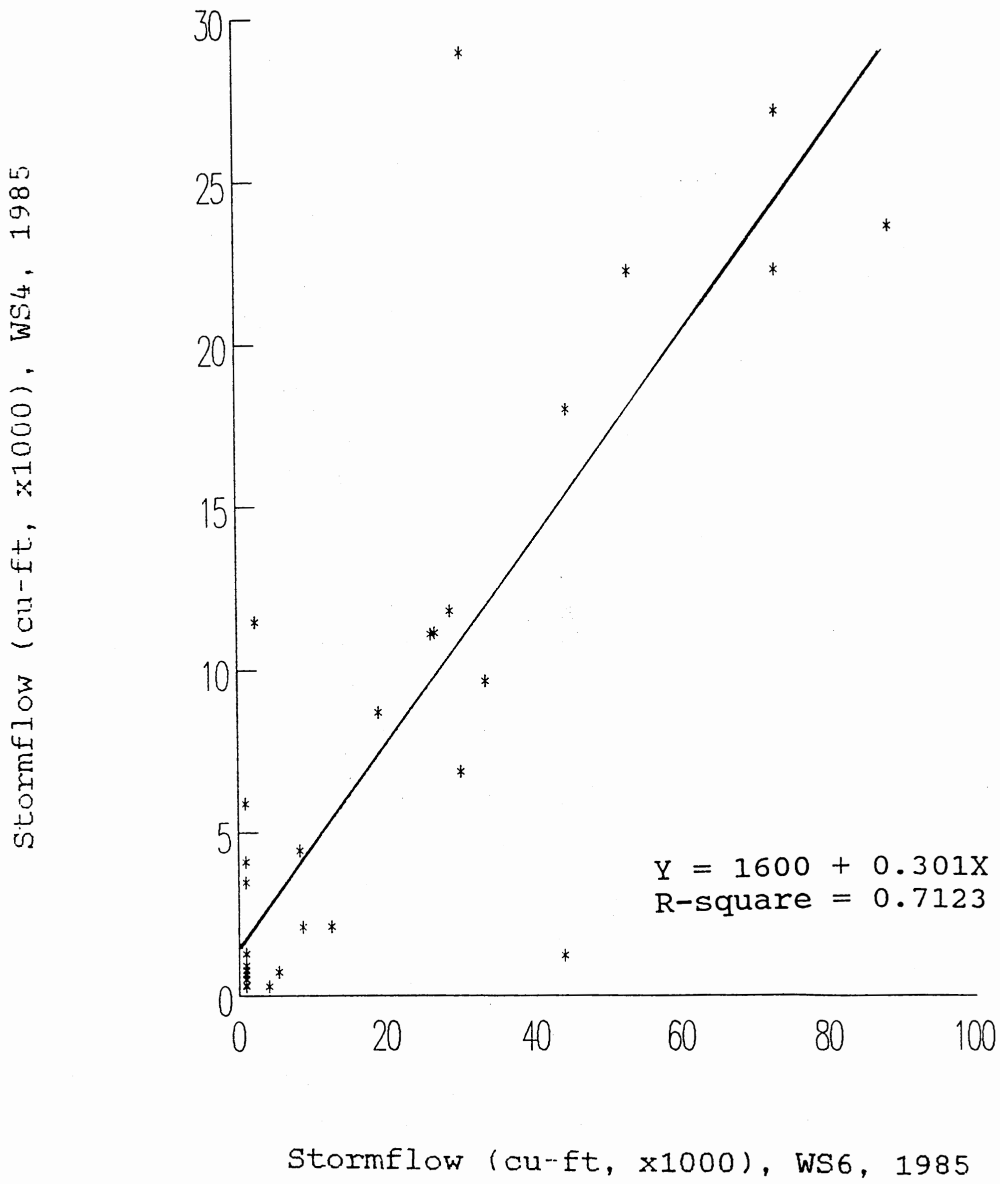


Figure 16. Single storm stormflow water yield comparison between the forested control (WS6) and the clearcut and ripped treatment (WS4) for water year 1985.

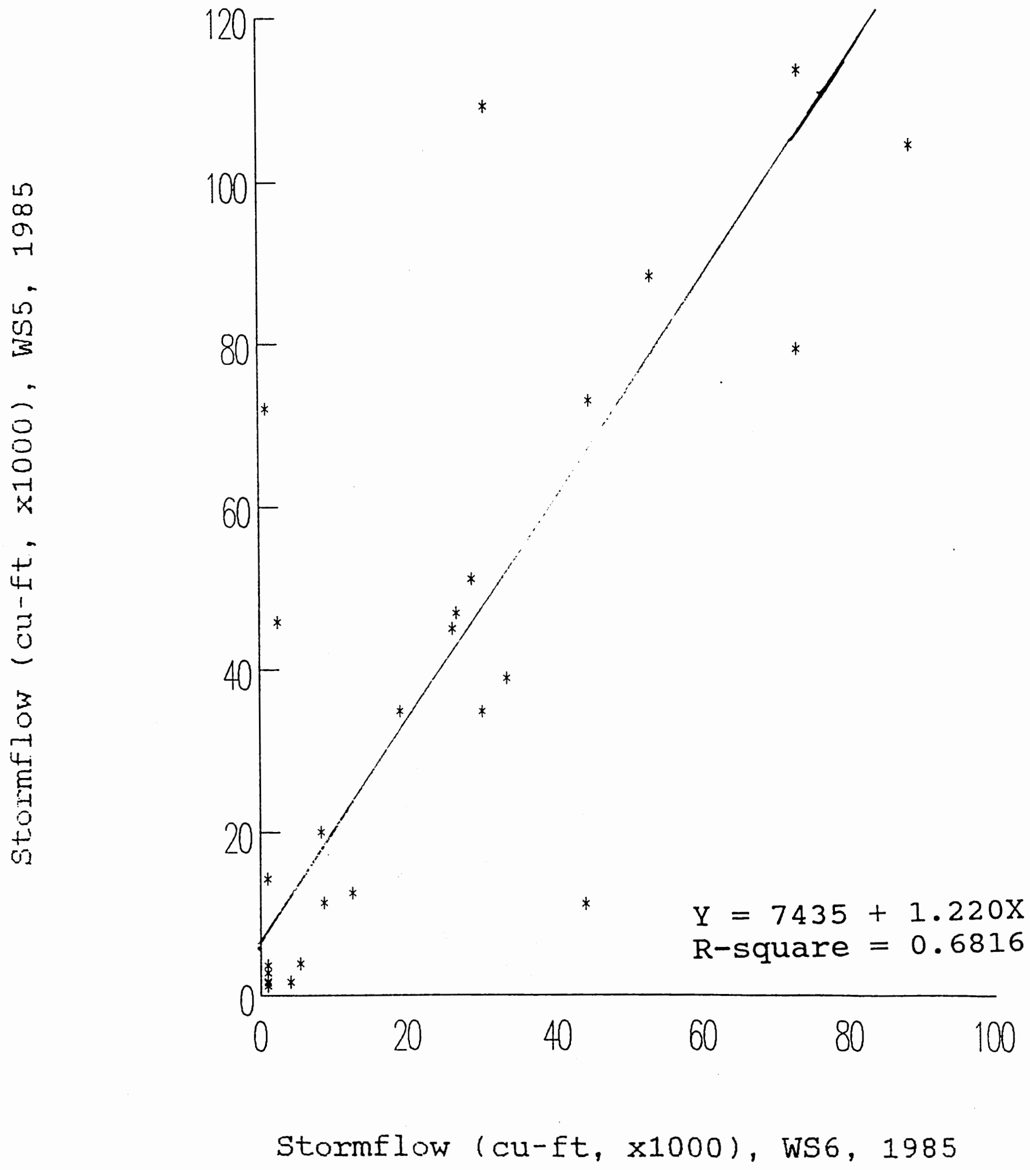


Figure 17. Single storm stormflow water yield comparison between the forested control (WS6) and the clearcut and unripped treatment (WS5) for water year 1985.

TABLE XIII

STORMFLOW WATER YIELDS OF WATER YEAR 1987
(OCTOBER 1, 1986 - SEPTEMBER 30, 1987)

Date Mo-Dt-Yr	WS4	WS5	WS6
10-04-86	21808	87940	8551
10-11-86	3179	20337	2038
10-22-86	411	4592	*
11-04-86	6062	33000	5618
11-10-86	3642	23267	5655
12-07-86	9125	40332	23997
12-18-86	116	770	*
01-03-87	232	1060	1
01-09-87	4333	22640	9046
01-18-87	*	6550	698
02-24-87	313	45348	142
02-26-87	8370	*	28727
03-16-87	10965	54689	31681
03-23-87	5	68	122
04-13-87	170	351	2
05-20-87	*	88	*
05-22-87	2	203	31
05-25-87	*	52	20
05-28-87	1379	24725	381
06-03-87	9	51	5
06-10-87	*	68	1
06-19-87	*	*	46
06-23-87	122	693	9
06-30-87	5	25	15
07-02-87	310	3866	1721
08-10-87	*	*	39
08-12-87	1	3	35
08-17-87	24	3	13
09-10-87	1	3	28
09-15-87	1174	5770	90
09-18-87	13349	48757	1119
Total(cu-ft)	85112	426686	119831
Average(in/area)	5.58	11.19	3.71

Note: * no flow was recorded

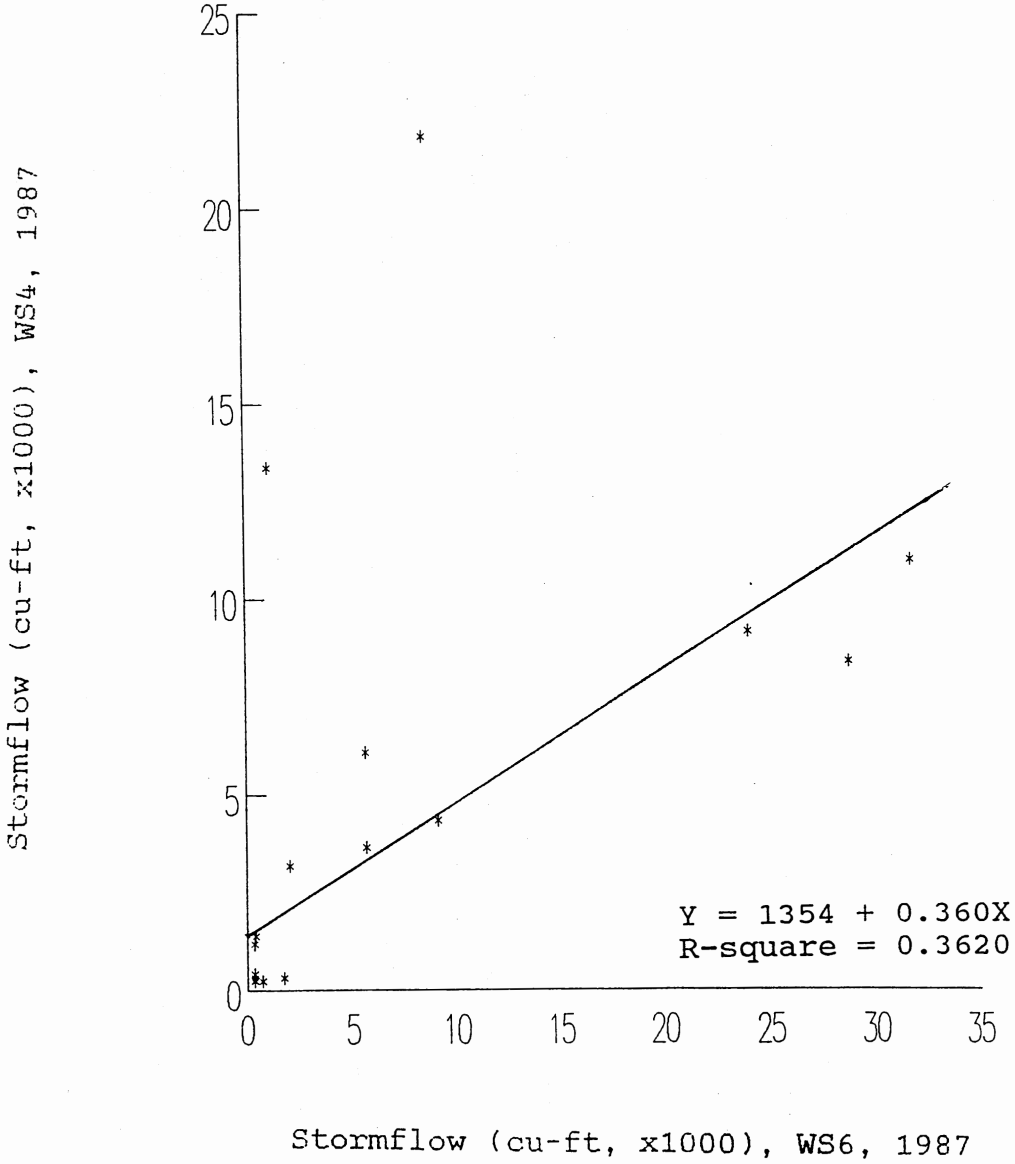


Figure 18. Single storm stormflow water yield comparison between the forested control (WS6) and the clearcut and ripped treatment (WS4) for water year 1987.

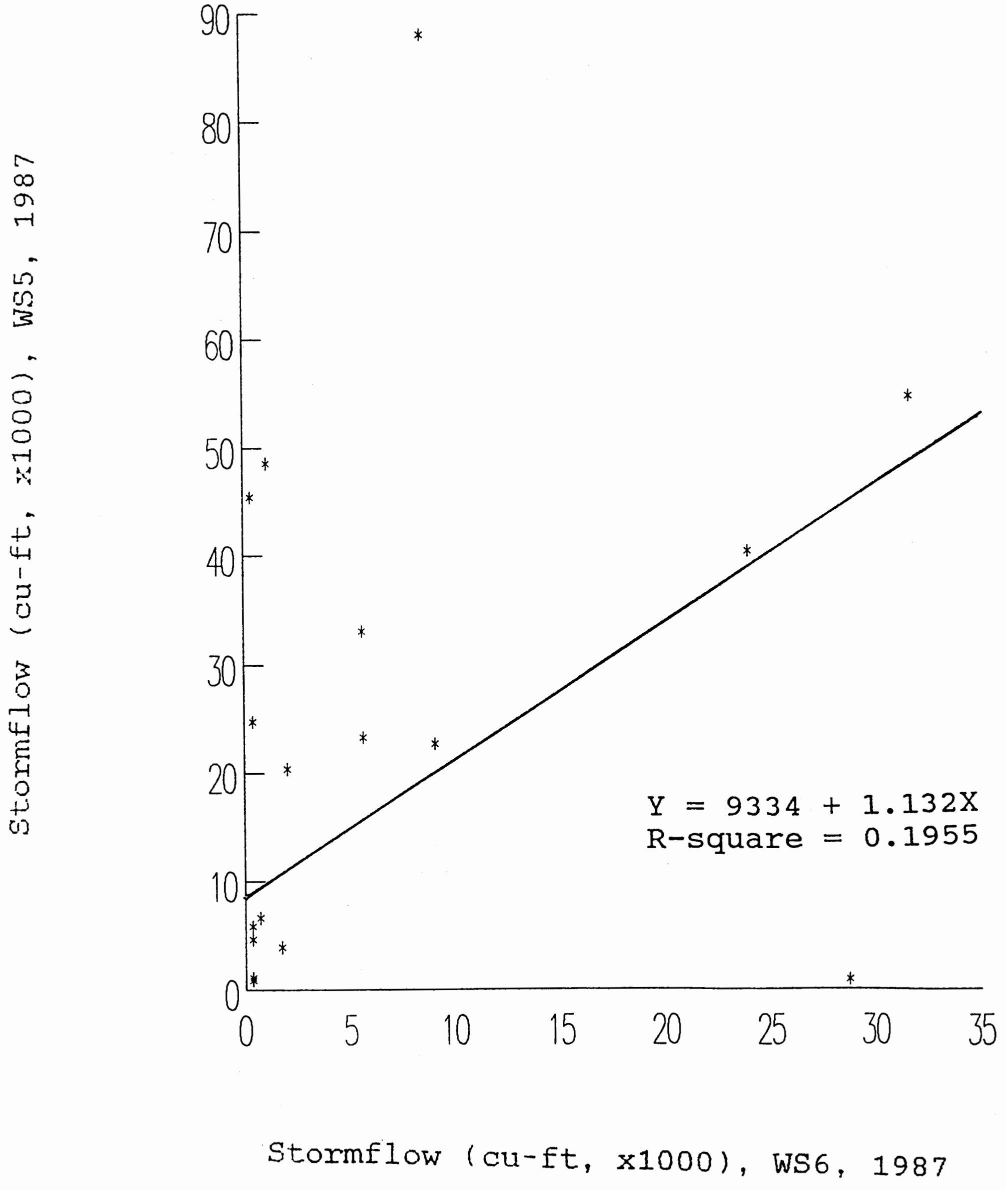


Figure 19. Single storm stormflow water yield comparison between the forested control (WS6) and the clearcut and unripped treatment (WS5) for water year 1987.

1987, with the pre-treatment period, there is a significant increase ($p < 0.05$) in slope (Figure 20). For the three non-significant years, adjusted mean Y values were significantly greater than in the pre-treatment period, but the differences decreased with time ($p < 0.01$).

Using $Y = 4440 + 0.87X$ as the pre-treatment single storm stormflow relationship between the control watershed (WS6) and the clearcut watershed (WS5), the slope for the year of treatment (Table X; Figure 13), water year 1983, was not significantly different than the pre-treatment slope ($p > 0.10$). In water years 1984 and 1985 (Tables XI and XII; Figures 15 and 17), there were highly significant increases in slope compared to the pre-treatment period ($p < 0.01$). In water year 1987 (Table XIII; Figure 19), no significant increase was found in slope ($p > 0.10$). For the whole post-treatment period, a highly significant increase was found ($p < 0.01$) in slope (Figure 21). In 1983, no significant difference ($p > 0.20$) was found between two adjusted mean Y values (pre-treatment and 1983). In 1987, a significant increase in adjusted mean Y value was obtained ($p < 0.05$).

In the first phase of this study, Miller (1984) reported that in January through June of 1979, the uncut watersheds consistantly yielded more flow than did the clear-cut and ripped watersheds, although the differences were not statistically significant. Stormflow water yields the first year following the treatments, averaged 9.02 and 12.48 inches on clearcut and uncut watersheds, respectively.

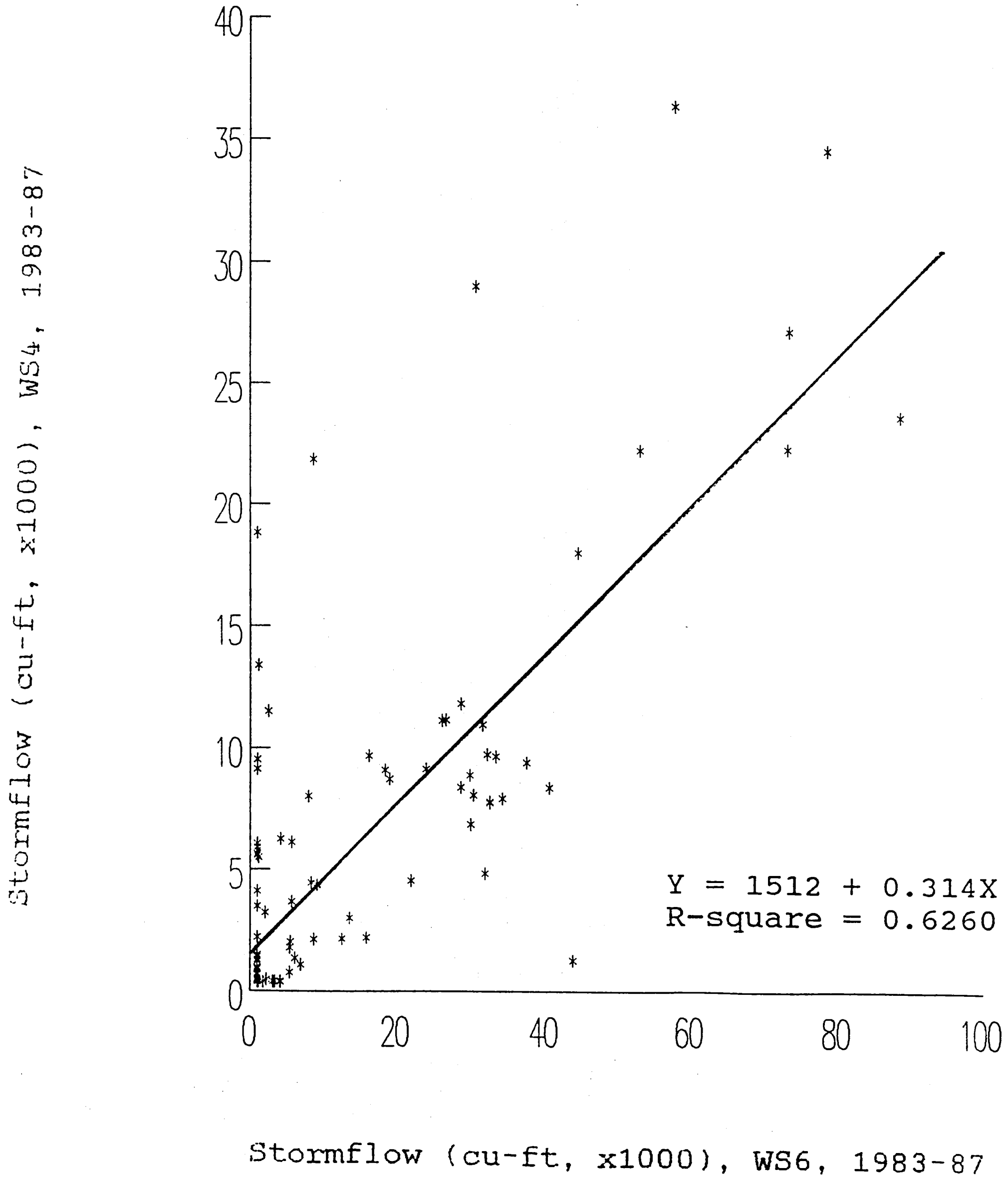


Figure 20. Single storm stormflow water yield comparison between the forested control (WS6) and the clearcut and ripped treatment (WS4) for the post-treatment period (1983-87).

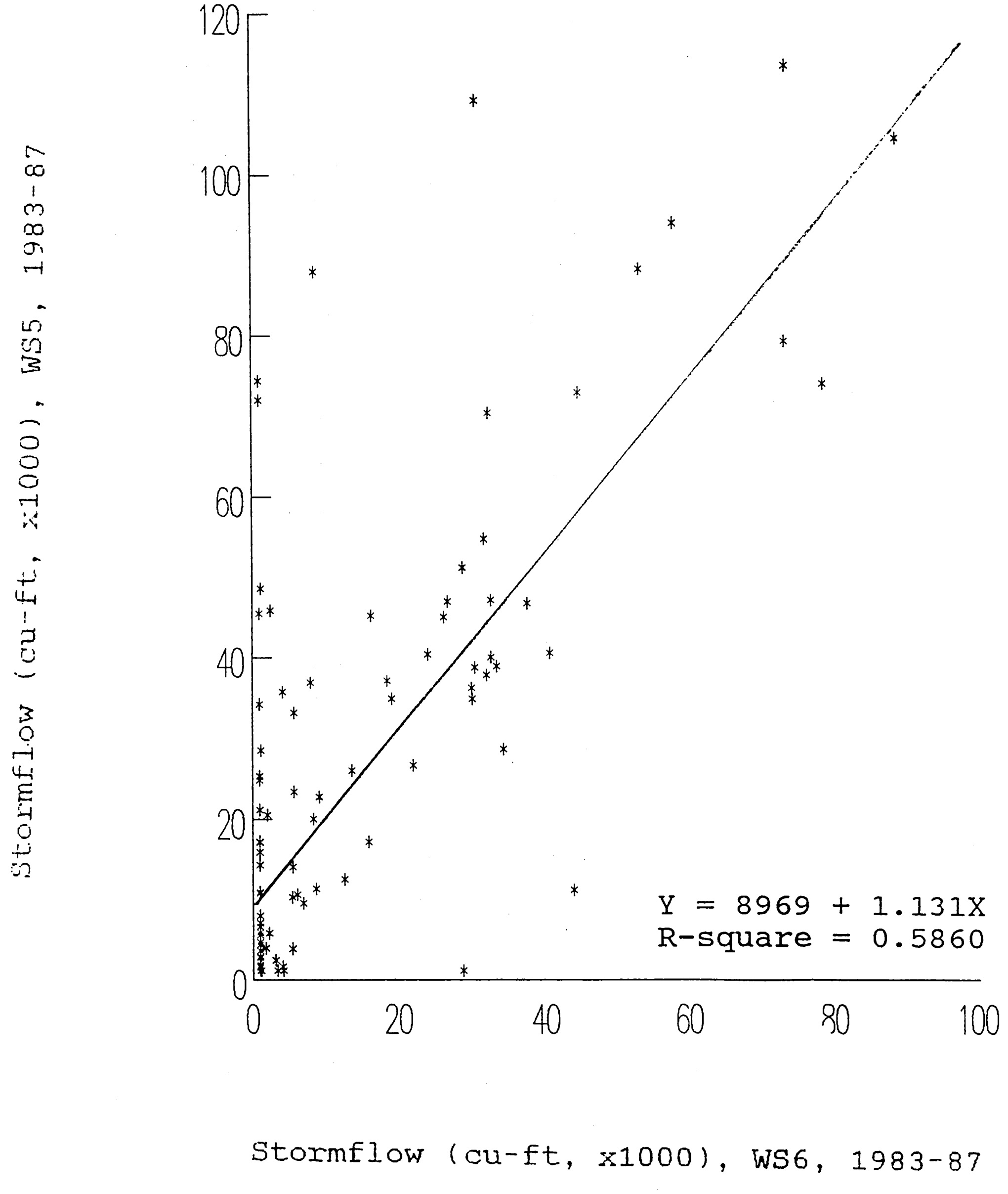


Figure 21. Single storm stormflow water yield comparison between the forested control (WS6) and the clearcut and unripped treatment (WS5) for the post-treatment period (1983-87).

Ripping on the contour on the experimental sites seemed to reduce first post-treatment year stormflow yields by creating on site storage, promoting infiltration and, perhaps, by sealing subsurface macro-channels (Miller, 1984; Miller, Beasley and Lawson, 1985).

In this, the second phase, both treatments increased the amounts of stormflow water yields, except that in 1983 no significant change was obtained from the clearcut treatment (WS5). Although harvesting with ripping increased the stormflow water yields the year of the treatment, stormflows soon returned to normal levels following the treatment. The influence of ripping was so strong in the first year, however, that it influenced the statistical test of treatment effect using the entire post-treatment data set. Clearcut without ripping created more stormflow than with ripping, even though in water year 1983, the year of treatment, there was no significant change. Apparently, compared to clearcutting alone, clearcutting and ripping on contour on the experiment sites seemed to reduce first post-treatment year stormflow yields by creating on site storage, promoting infiltration and, perhaps, by sealing subsurface macro-channels (Miller, 1984). On the clearcut watershed, infiltration may have been decreased and evapotranspiration was also reduced, so a larger percent of precipitation was yielded as stormflow.

The herbicide seemed to play an important roll in the second phase, for it kept treated sites exposed to the environment for almost two full growing seasons. After harvest and site preparation, revegetation would have enhanced the infiltration capacities and increased transpiration somewhat.

3). Peakflow Discharge:

Peakflow discharge rates per unit area were compared for the eight storms which had highest precipitation total on a single storm basis during the four-plus years post-treatment period (Table XIV). Based on all the multiple comparison results, Waller-Duncan, Duncan's, LSD and Tukey's test, there was a significant difference ($p < 0.05$) in discharge rates between the clearcut watershed (WS5) and control watershed (WS6) peakflows, but there was no difference found between the clearcut with ripping watershed (WS4) and the control watershed (WS6) peakflows. There was also no significant difference in peakflows between the clearcut with ripping watershed (WS4) and the clearcut without ripping watershed (WS5). Based on a numerical comparison, both treatments increased peakflow discharge rates.

There were noteable low peak discharge rates despite high rainfalls on October 17, 1983 and September 22, 1984 (Table XIV). There were long dry periods in the growing seasons before these storms occurred. Statistical comparison using the 6 remaining storms showed there was no significant difference in peakflow discharge rates ($p > 0.20$) among the three treatments. Therefore, it appears that

TABLE XIV

PEAKFLOW DISCHARGE OF EIGHT LARGEST STORMS OF PRE- AND POST-TREATMENT PERIODS (OCTOBER 1, 1979 TO SEPTEMBER 30, 1987)

Date Mo-Dt-Yr	Average Prcp. (in.)	Clearcut/rip (WS4)	Clearcut (WS5)	Uncut (WS6)
		unit: cfsm		
05-10-79	2.29	99	146	216
05-20-79	3.06	183	241	190
05-21-79	2.56	568	692	597
05-30-79	1.37	238	412	102
06-05-81	1.83	173	240	194
01-30-82	3.50	396	531	458
05-12-82	3.50	363	412	458
05-13-82	1.25	657	782	531
Treatments Applied on March 1983				
05-14-83	3.17	1747	1612	1338
10-17-83	2.94	652	1116	15
05-20-84	3.43	1664	1762	786
09-22-84	2.76	642	886	1
10-06-84	2.68	945	1369	182
10-21-84	2.55	233	398	132
04-22-85	3.25	123	168	126
10-04-86	3.48	615	1192	111

the treatments have little influence on peakflow discharge rates at least when soils were wet.

Inspection of statistical comparisons of the eight largest single storm indicates that peakflows showed no significant effect ($p > 0.06$) in any of the four years following treatment in the first phase of this study (Miller, 1984; Miller, Beasley and Lawson, 1985). The reason for the significant differences based on the 8 storm comparison in the second phase is probably related to the seasonal effect on water deficit. In the growing season, evapotranspiration is higher from forested watersheds than from unvegetated watersheds. This difference created a higher soil water deficit in the forest stand than in the open. When rainfall occured, water infiltrated into soil profiles, satisfying the water deficit, before stormflow could begin. With forest cover, tree crown interception also has the effect of reducing and delaying soil water intake. This was also a factor which may have affected the peakflow discharge rates. Unfortunately, there were not any rainfall events large enough to provide a flood flow situation during the post-treatment period in the second phase of the study.

4). Sediment Yields:

During the four year pre-treatment period, the total sediment yields averaged 9.77, 18.16 and 19.30 pounds per acre per year from WS4, WS5 and WS6 respectively (Table XV). In 1983, the year that harvest and site preparation

TABLE XV

ANNUAL SEDIMENT YIELDS FROM TREATED WATERSHEDS WATER YEARS 1979 TO 1987

Water Year	Clearcut/Rip (WS4)	Clearcut (WS5)	Uncut (WS6)	Avg. Ph. 1
1979	15.56	39.21	38.24	251.20
1980	4.26	9.36	6.72	31.34
1981	3.31	4.01	4.67	13.58
1982	15.94	20.15	27.56	38.44
Average	9.77	18.16	19.30	83.64
Treatments Applied on March 1983				
1983	48.61	60.82	8.28	26.37
1984	319.01	797.14	10.91	23.53
1985	891.98	1223.37	22.54	40.84
1987	117.82	144.33	17.59	NR
Average(1984-87)	442.94	721.61	17.01	32.18

Units: pounds per acre

Note: NR no record

treatments were applied, the sediment yields were 48.61 pounds per acre from the clearcut with ripping treatment (WS4), 60.82 pounds per acre from the clearcut treatment (WS5), and 8.28 pounds per acre from the forested control treatment (WS6). Increases in the amounts of sediment yield were measured the next two years also. In water year 1984, the clearcut and rip treatment (WS4) produced sediment losses of 319.01 pounds per acre, the clearcut treatment (WS5) produced 797.14 pounds per acre while the untreated control watershed (WS6) produced only 10.91 pounds per acre. In water year 1985, these amounts increased to 891.98, 1223.37 and 22.54 pounds per acre from the clearcut-rip, clearcut and control treatments, respectively. No data is available for water year 1986, but in water year 1987, the sediment yields decreased dramatically to 117.82, 144.33 and 17.59 pounds per acre from the respective treatments (Table XV; Figure 22).

Comparing the pre- and post-treatment annual total sediment yields from the three watersheds, it is clear that both harvesting and site preparation treatments increased sediment yields, as clearcut with contour ripping sediment yields grew from an average of 9.77 pounds/acre/year to 48.61 pounds/acre in water year 1983, the year of treatment, and averaged 442.94 pounds/acre/year from 1984 to 1987, an increase of 433.17 pounds/acre/year. The clearcut watershed (WS5) yielded 18.16 pounds/acre/year from water years 1979 to 1982, 60.82 pounds/acre in 1983 and averaged 721.61

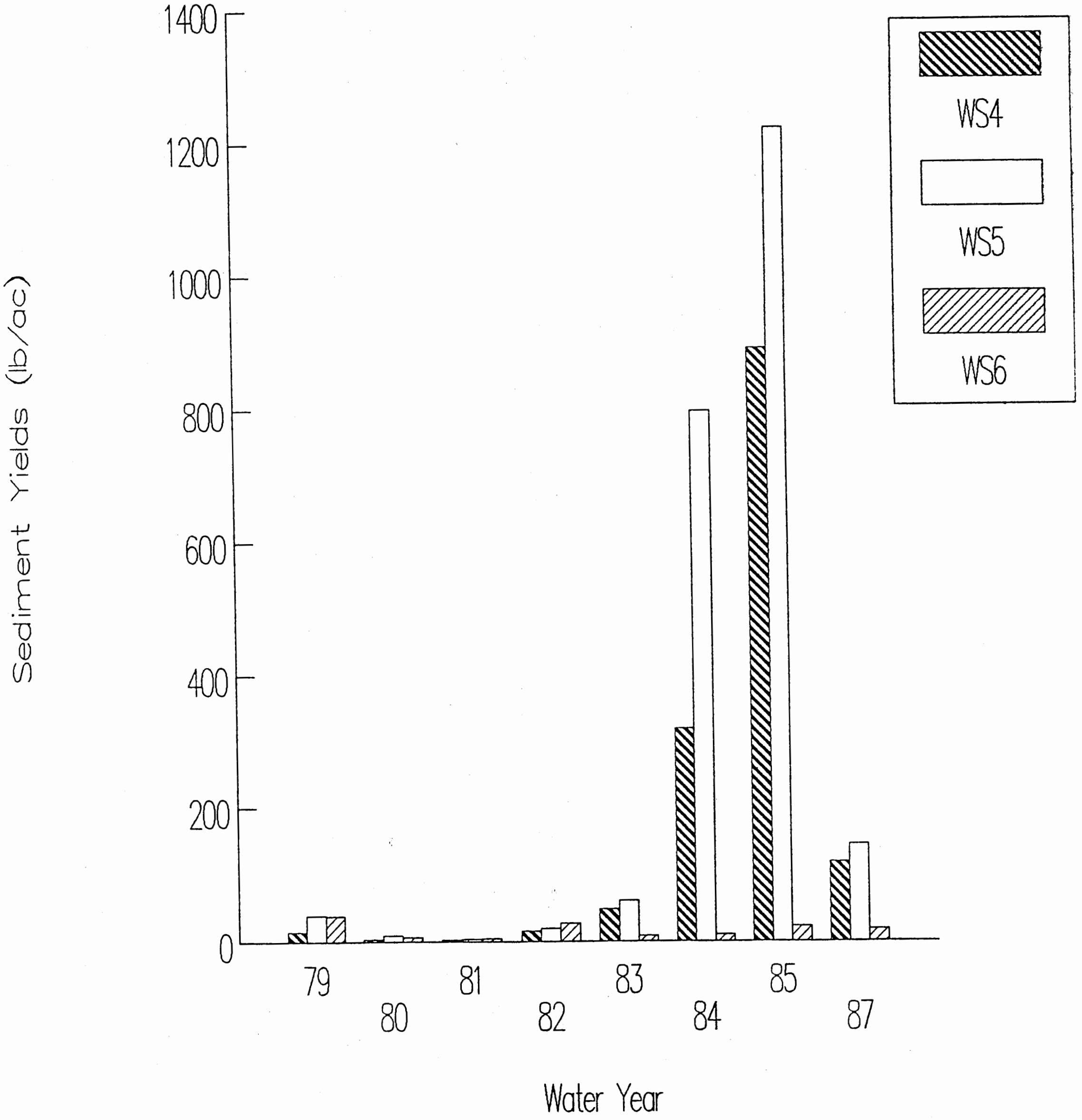


Figure 22. Annual sediment yield losses from the forested control (WS6), clearcut and ripped (WS4) and the clearcut without ripping (WS5) treatment (1979-87). Silvicultural treatments were applied in water year 1983.

pounds/acre/year from 1984 to 1987, an increase of 703.45 pounds/acre/year (Table XV, Figure 22).

In the first phase of this study, Miller (1984) found that the sediment yields in water year 1979, the first year following clearcut and site preparation with ripping treatments averaged 251 lb/ac and 32 lb/ac from uncut watersheds. There was a decreasing trend in annual sediment yields from the clearcut and rip watersheds every year after treatment, averaging 31.3 lb/ac in 1980, 13.6 lb/ac in 1981 and 38.4 lb/ac in 1982. Sediment yield increases were not significant in any year after treatment except 1979, the first year after treatment (Figure 23).

The reasons for the different responses in sediment losses between the two phases of this experiment may relate to the differences in site preparation and weather conditions. In first phase, no herbicide treatment was applied on the clearcut and ripped watersheds. The clearcut watersheds were soon revegetated after treatment with natural annual and perennial plants. With winter site preparation and planting in March of 1979, much of this revegetation occured during the first full growing season after site preparation. In the second phase, the treated watersheds (WS4 and WS5) remained relatively bare to the environment for two full growing seasons after harvest because of the timing of the treatments and the effects of the herbicide. Although pine seedlings were planted on WS4 and WS5 in January 1984, they had little effect on early

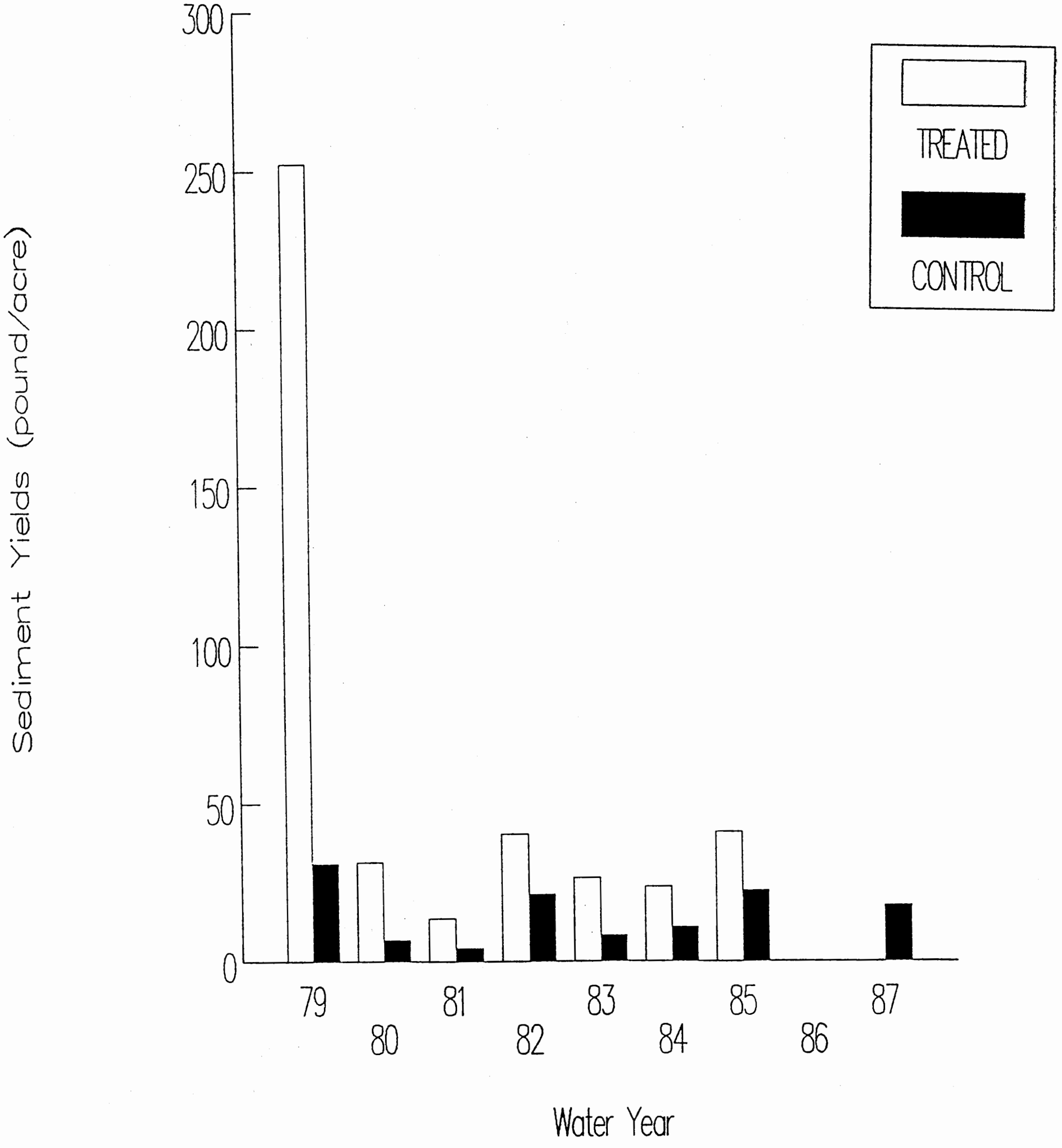


Figure 23. Average annual sediment losses from clearcut and ripped (treated) and forested control treatments, phase 1 of the Oklahoma small watershed study (three watersheds per treatment). No data available on treated watersheds after 1985. After 1982, forest control values from uncut watershed (WS6) only.

vegetative site cover.

Except in water year 1979, the year-of-treatment of the first phase, annual precipitation after treatment was relatively low. This was especially true in 1980, the second year following treatment. In the second phase, the experimental sites received high rainfall amounts in the period from May to November 1984, about 15 inches more than the normal precipitation, and the clearcut and ripped site (WS4) yielded 53 percent of the total sediment losses of the four year experimental period and 59 percent was yielded from the clearcut watershed (WS5). After revegetation fully covered the soils and rainfall distribution returned to a more normal pattern, amounts of sediment losses from the two treated watersheds decreased dramatically.

Simple linear regression was used to compare pre- and post-treatment annual sediment yields for both treatments (Figures 24 and 25). The regression relationship between single storm total sediment yields (pounds) from the control watershed (WS6) (independent variable) and the clearcut with contour ripping watershed (WS4) (dependent variable) for the pre-treatment period is $Y = 0.11 + 0.246X$ (Table XVI, Tables XVIII - XXI; Figure 26), with R-square = 0.8101. The pre-treatment relationship between WS6 and WS4 on single storm total sediment yields was stable and consistant. The relationship between the control watershed (WS6) (indepedent variable) and the clearcut watershed (WS5) (dependent variable) is $Y = 0.72 + 1.050X$ and R-square = 0.8797 (Table

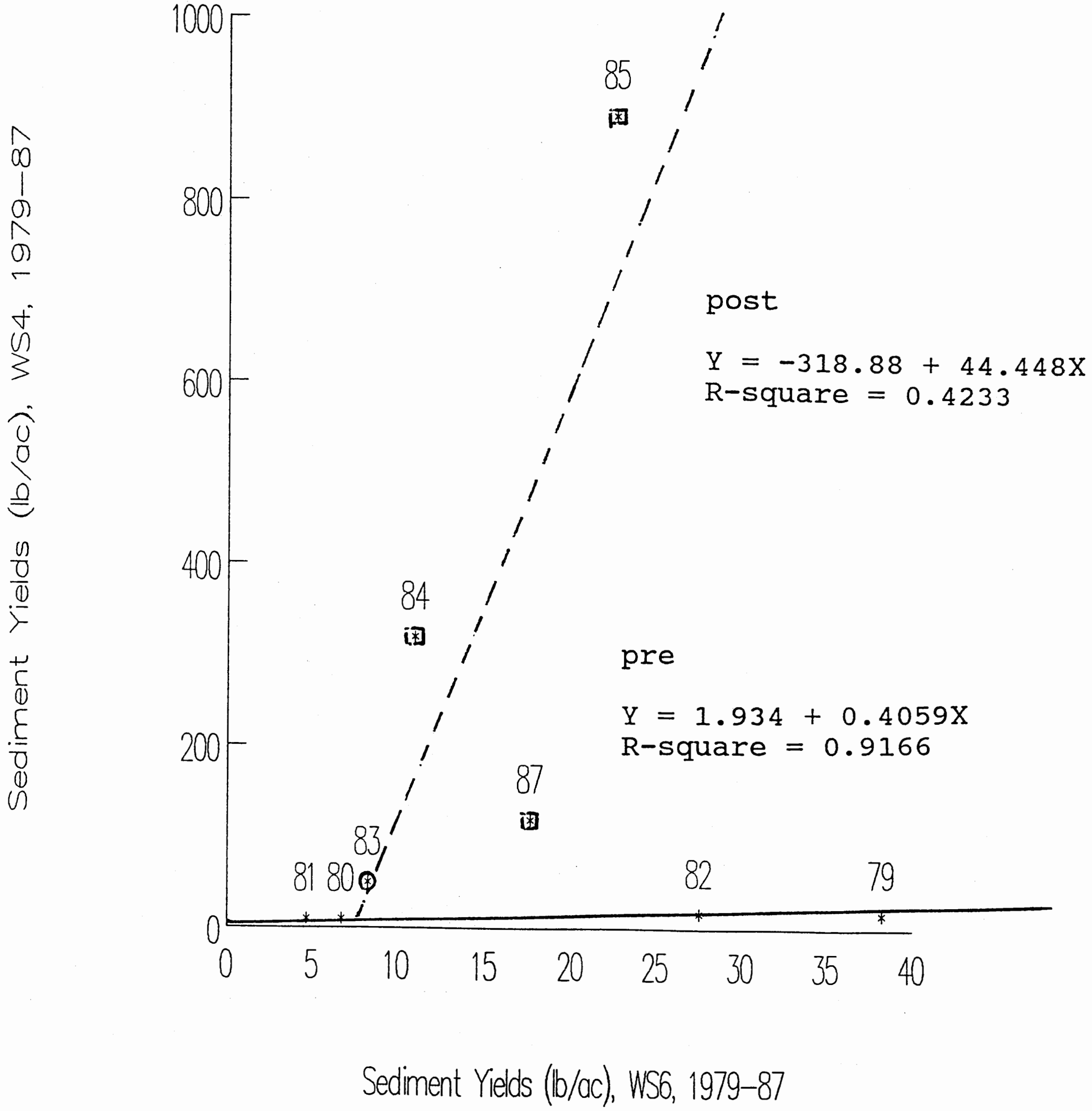


Figure 24. Annual sediment yield loss comparison between forested control (WS6) and clearcut and ripped treatment (WS4) pre (1979-82) and post (1984-87) treatment periods. Water year 1983, the year treatments were applied, not included in either regression.

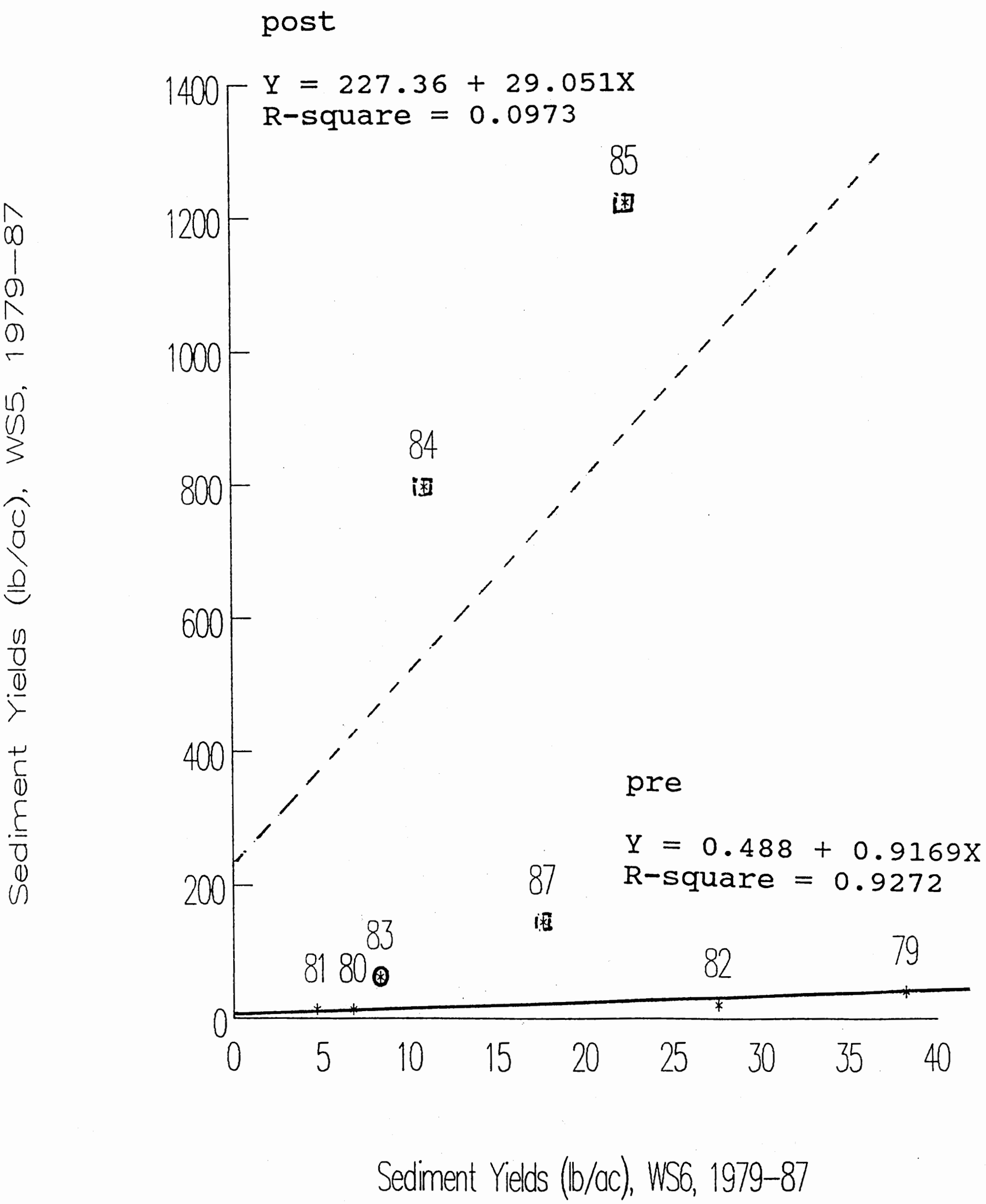


Figure 25. Annual sediment yield loss comparison between forested control (WS6) and clearcut and unripped treatment (WS5) pre (1979-82) and post (1984-87) treatment periods. Water year 1983, the year treatments were applied, not included in either regression.

TABLE XVI

REGRESSIONAL COMPARISON BETWEEN CLEARCUT WITH RIPPING AND CONTROL WATERSHEDS, SEDIMENT YIELDS WATER YEAR 1979 TO 1987

Water Year	CLEARCUT/RIP(WS4) Y (pound)	UNCUT(WS6) X (pound)	R-SQUARE	No. Obs.
Pre-Treatment	Y = 0.11 +	0.246X	0.8101	58
	Treatments Applied on March 1983			
1983	Y = -6.88 +	6.568X	0.5913	20
1984	Y = 42.70 +	1.057X	0.0343	29
1985	Y = 17.69 +	15.412X	0.6875	37
1987	Y = 11.38 +	1.054X	0.0869	29
Post-Treatment	Y = 25.94 +	5.535X	0.2358	115

Note: highly significant increase in slopes of 1983, 1985, and post-treatment periods ($p < 0.01$).

highly significant increase in adjusted mean Y values in 1984, and 1987 ($p < 0.01$).

TABLE XVII

REGRESSIONAL COMPARISON BETWEEN CLEARCUT AND CONTROLL WATERSHEDS, SEDIMENT YIELDS WATER YEAR 1979 TO 1987

Water Year	CLEARCUT(WS5) Y (pound)	UNCUT(WS6) X (pound)	R-SQUARE	No. Obs.
Pre-Treatment	Y = 0.720 +	1.050X	0.8797	58
Treatments Applied on March 1983				
1983	Y = -19.83 +	19.905X	0.5903	20
1984	Y = 269.20 +	5.800X	0.0202	29
1985	Y = 80.40 +	52.374X	0.2950	37
1987	Y = 35.17 +	3.165X	0.0529	29
Post-Treatment	Y = 125.56 +	18.985X	0.1039	115

Note: highly significant increase in slopes of 1983, 1985, and post-treatment periods ($p < 0.01$).

highly significant increase in adjusted mean y value of 1984 ($p < 0.01$).

significant increase in adjusted mean Y value of 1987 ($p < 0.05$)

TABLE XVIII

SEDIMENT YIELDS OF WATER YEAR 1979
(OCTOBER 1, 1978 - SEPTEMBER 30, 1979)

Date Mo-Dt-Yr	WS4	WS5	WS6
11-15-78	0.00	0.64	0.70
11-25-78	*	*	0.11
12-06-78	*	0.70	2.90
12-30-78	0.95	13.99	12.52
01-18-79	*	9.94	4.03
02-22-79	12.32	72.51	20.50
03-02-79	7.04	35.77	47.30
03-19-79	4.80	70.73	69.26
03-29-79	4.91	17.07	16.17
04-11-79	0.22	*	0.00
05-10-79	3.39	25.76	19.45
05-20-79	36.17	135.32	106.55
05-28-79	2.68	10.65	7.92
06-01-79	1.80	17.12	31.94
07-26-79	0.00	0.55	0.22
Total(lb)	74.51	411.70	340.34
Average(lb/ac)	16.56	39.21	38.24

Note: * no flow was recorded

TABLE XIX

SEDIMENT YIELDS OF WATER YEAR 1980
(OCTOBER 1, 1979 - SEPTEMBER 30, 1980)

Date Mo-Dt-Yr	WS4	WS5	WS6
10-30-79	0.18	*	0.24
12-12-79	0.04	0.53	0.35
12-22-79	1.19	11.88	10.76
01-21-80	0.33	5.98	3.70
02-08-80	3.21	20.53	8.93
04-13-80	0.11	0.11	0.11
05-15-80	2.29	10.36	4.91
05-29-80	11.77	48.66	30.67
Total(lb)	19.16	98.28	59.80
Average(lb/ac)	4.26	9.36	6.72

Note: * no flow was recorded

TABLE XX

SEDIMENT YIELDS OF WATER YEAR 1981
(OCTOBER 1, 1980 - SEPTEMBER 30, 1981)

Date Mo-Dt-Yr	WS4	WS5	WS6
10-17-80	0.00	*	0.31
10-27-80	1.28	2.46	2.77
12-08-80	0.53	3.56	3.59
01-31-81	0.02	*	*
02-09-81	0.62	3.63	1.83
02-28-81	3.34	5.70	9.48
03-03-81	0.18	0.92	2.90
04-21-81	0.88	0.86	0.44
05-09-81	1.10	5.46	1.91
05-13-81	0.20	2.33	5.83
05-23-81	1.25	3.45	0.44
05-29-81	0.70	4.31	0.70
06-02-81	0.09	1.08	1.96
06-04-81	3.94	6.18	4.66
06-06-81	0.68	1.83	1.54
06-15-81	*	*	0.02
07-01-81	0.02	0.13	0.04
08-01-81	0.00	*	0.04
08-16-81	0.04	0.07	2.99
Total(lb)	14.91	42.07	41.56
Average(lb/ac)	3.31	4.01	4.67

Note: * no flow was recorded

TABLE XXI

SEDIMENT YIELDS OF WATER YEAR 1982 (OCTOBER 1, 1981 - SEPTEMBER 30, 1982)

Date Mo-Dt-YR	WS4	WS5	WS6
10-13-81	0.00	0.00	0.18
10-16-81	*	*	0.33
10-31-81	0.84	2.88	4.55
11-29-81	0.92	1.83	1.54
01-20-82	1.08	4.09	6.86
01-30-82	28.73	133.83	132.42
02-15-82	0.37	*	1.39
02-25-82	*	*	0.26
03-03-82	0.00	0.00	0.59
03-13-82	0.15	2.20	4.97
04-02-82	0.00	0.00	0.07
05-12-82	20.83	24.46	54.85
05-22-82	11.88	33.00	27.81
05-30-82	0.42	5.10	3.54
06-01-82	0.31	1.61	2.90
06-15-82	1.43	2.57	3.01
Total(lb)	67.12	212.05	245.84
Average(lb/ac)	14.92	20.20	27.62

Note : * no flow was recorded

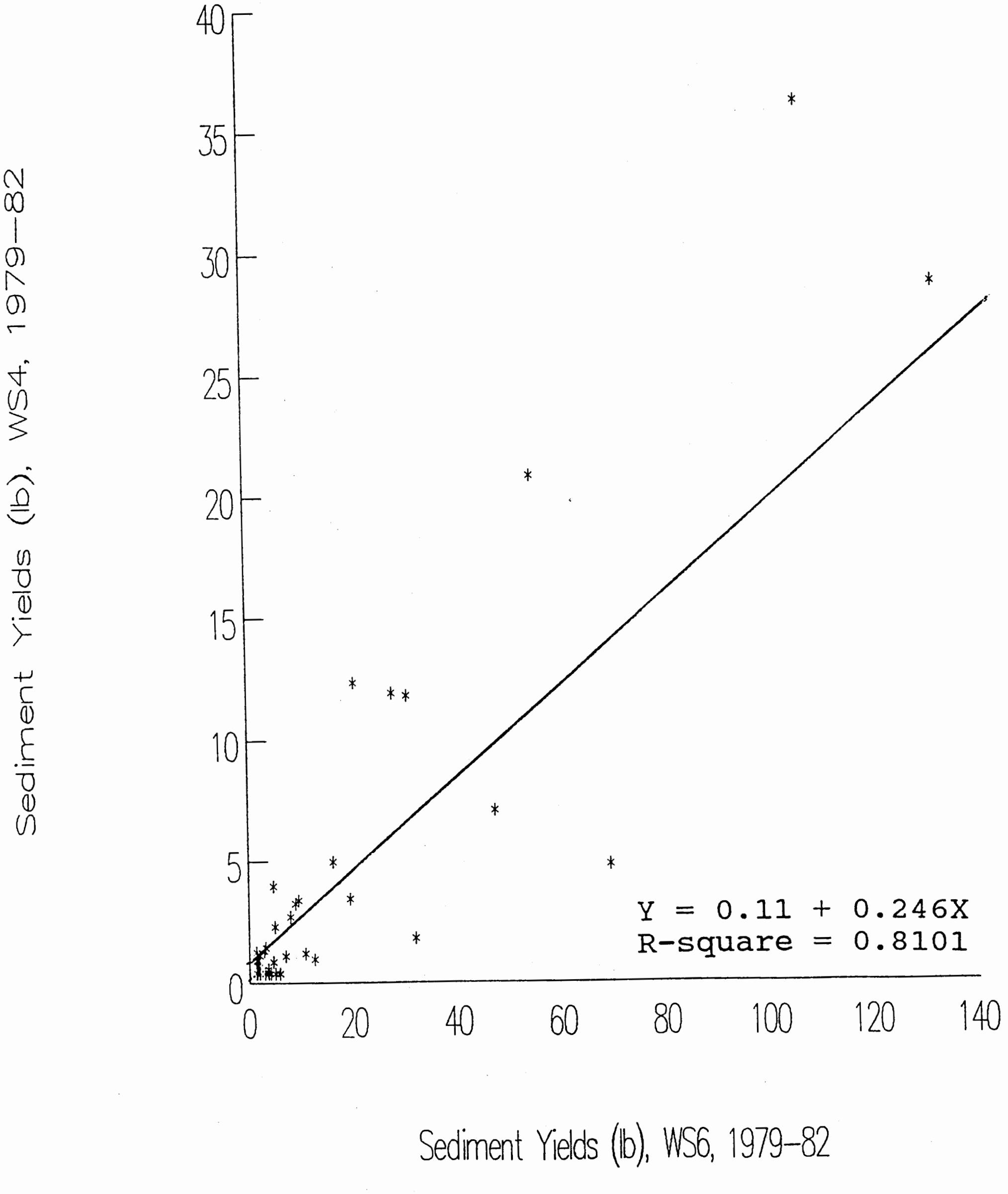


Figure 26. Single storm sediment yield comparison between the forested control (WS6) and the clearcut and ripped treatment (WS4) for the pre-treatment period (1979-82).

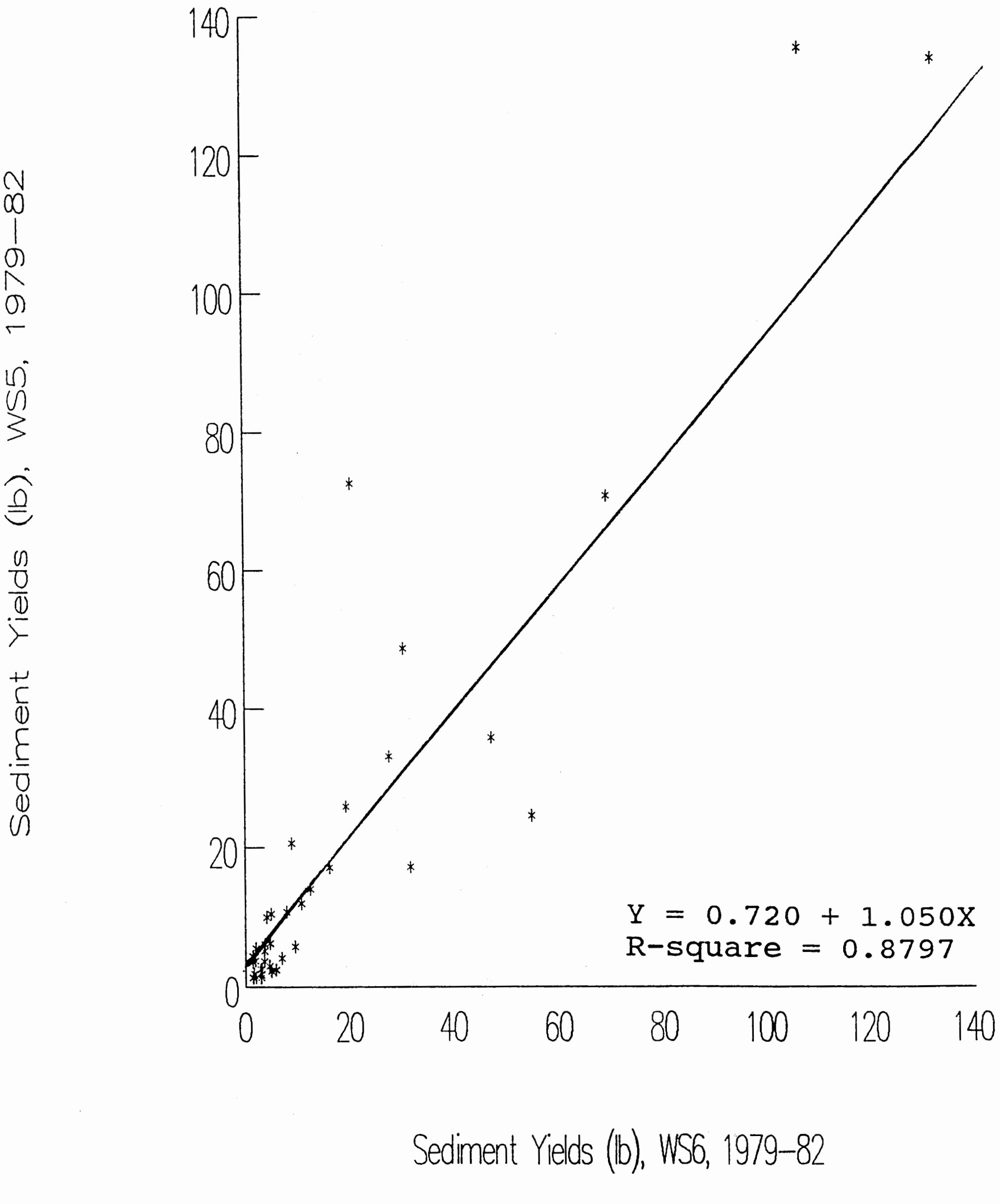


Figure 27. Single storm sediment yield comparison between the forested control (WS6) and the clearcut and unripped treatment (WS5) for the pre-treatment period (1979-82).

XVII, Tables XVIII - XXI; Figure 27). The pre-treatment relationship between WS6 and WS5 sediment yields was also stable and consistant.

The post-treatment sediment yield regression results are shown in Tables XVI and XVII. The increase of the regression slope of sediment yields between WS4 and WS6 in the water year 1983 (Table XXII; Figure 28), the year of treatment, was highly significant ($p < 0.01$). In water year 1984 (Table XXIII; Figure 30), the difference between the two slopes was not significant ($p > 0.10$). A highly significant increase in slope was found ($p <0.01$) again in water year 1985 (Table XXIV; Figure 32), and in 1987 (Table XXV; Figure 34), there was no significant change in slope ($p > 0.10$). In both 1984 and 1987, poor regression R-squares were obtained, due to high varibility in the sediment yields from WS4. Since the regression relationships were strongly influenced by a few high sediment yields, the use of the equations to predict sediment yields and provide a meaningful test of the differences between the treatments was not considered to be reliable. Comparing the total data from October 1982 through September 1987 (post-treatment period) with the pre-treatment period, a highly significant increase ($p < 0.01$) in slope (Figure 36) was calculated. Comparing the adjusted mean Y values between pre- and post-treatment period, it was found that in both 1984 and 1987, highly significant increases were obtained ($p < 0.01$).

For WS5 and WS6, in water year 1983, the year of

TABLE XXII

SEDIMENT YIELDS OF WATER YEAR 1983 (OCTOBER 1, 1982 - SEPTEMBER 30, 1983)

Date Mo-Dt-Yr	WS4	WS5	WS6
11-26-82	0.22	1.65	0.40
12-02-82	2.35	10.34	5.19
12-10-82	0.48	2.42	0.73
12-26-82	2.24	6.69	4.38
01-26-83	*	*	0.05
01-31-83	*	*	0.55
02-07-83	0.00	*	1.30
02-20-83	*	*	0.06
03-03-83	4.47	12.85	13.64
04-13-83	0.09	0.37	0.73
04-22-83	0.57	1.56	0.02
05-01-83	4.64	17.78	1.85
05-10-83	0.00	0.02	0.00
05-14-83	184.05	559.15	17.93
05-17-83	1.19	3.61	1.06
05-26-83	*	*	0.04
05-28-83	1.43	9.09	2.97
06-05-83	0.11	0.26	1.25
06-27-83	0.68	3.72	*
07-15-83	0.73	*	*
07-29-83	*	0.18	*
08-08-83	0.15	2.55	*
08-12-83	0.13	4.71	*
09-20-83	0.44	1.89	0.00
Total(lb)	204.16	638.66	73.66
Average (lb/ac)	48.61	60.82	8.28

Note: * no flow was recorded

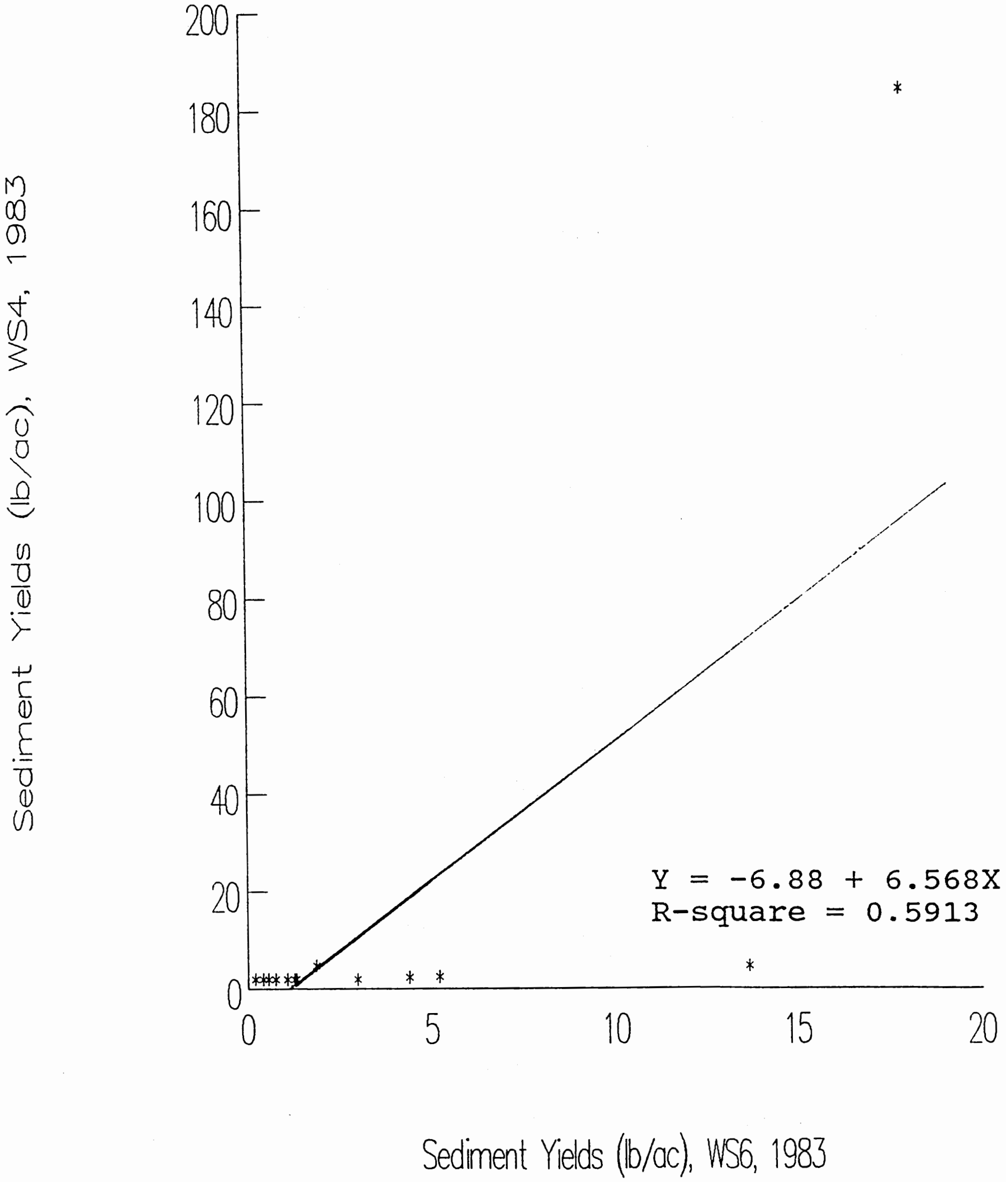


Figure 28. Single storm sediment yield comparison between the forested control (WS6) and the clearcut and ripped treatment (WS4) for water year 1983.

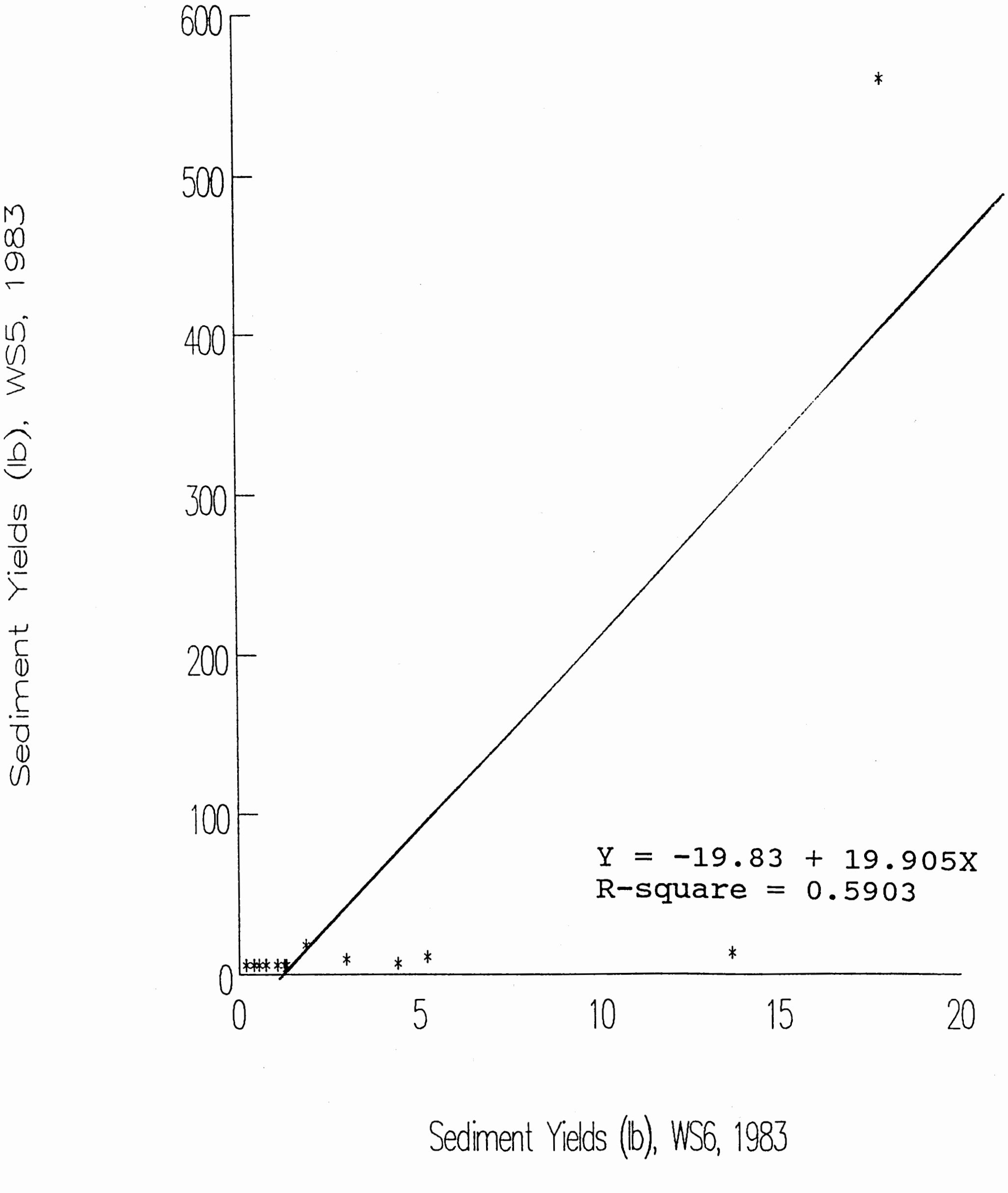


Figure 29. Single storm sediment yield comparison between the forested control (WS6) and the clearcut and unripped treatment (WS5) for water year 1983.

TABLE XXIII

SEDIMENT YIELDS OF WATER YEAR 1984
(OCTOBER 1, 1983 - SEPTEMBER 30, 1984)

Date Mo-Dt-Yr	WS4	WS5	WS6
10-11-83	0.02	1.12	0.00
10-17-83	259.76	1651.00	0.28
10-20-83	13.79	110.79	0.24
11-19-83	0.16	8.92	0.10
11-22-83	0.06	4.09	0.12
11-25-83	0.09	1.64	0.03
12-02-83	3.52	16.90	0.09
12-10-83	88.60	1523.97	0.87
01-09-84	0.00	*	0.34
02-11-84	22.12	441.72	7.86
02-26-84	13.32	305.06	2.18
03-11-84	25.87	203.40	3.88
03-15-84	21.18	750.78	1.98
03-23-84	37.62	487.24	6.29
03-27-84	5.02	131.36	0.78
04-02-84	12.07	476.41	1.89
04-08-84	0.46	96.59	0.35
05-01-84	85.90	815.70	0.69
05-05-84	78.69	60.49	0.43
05-20-84	119.12	557.62	55.50
05-27-84	17.79	142.28	12.98
06-23-84	80.48	93.55	0.06
06-26-84	30.42	32.36	*
07-11-84	78.73	101.06	0.00
08-02-84	127.96	124.62	0.00
09-09-84	1.80	0.89	0.00
09-15-84	3.02	0.00	*
09-22-84	135.56	149.10	0.07
09-25-84	77.71	81.31	0.07
Total(lb)	1339.84	8369.97	97.08
Average(lb/ac)	319.01	797.14	10.91

Note: * no flow was recorded

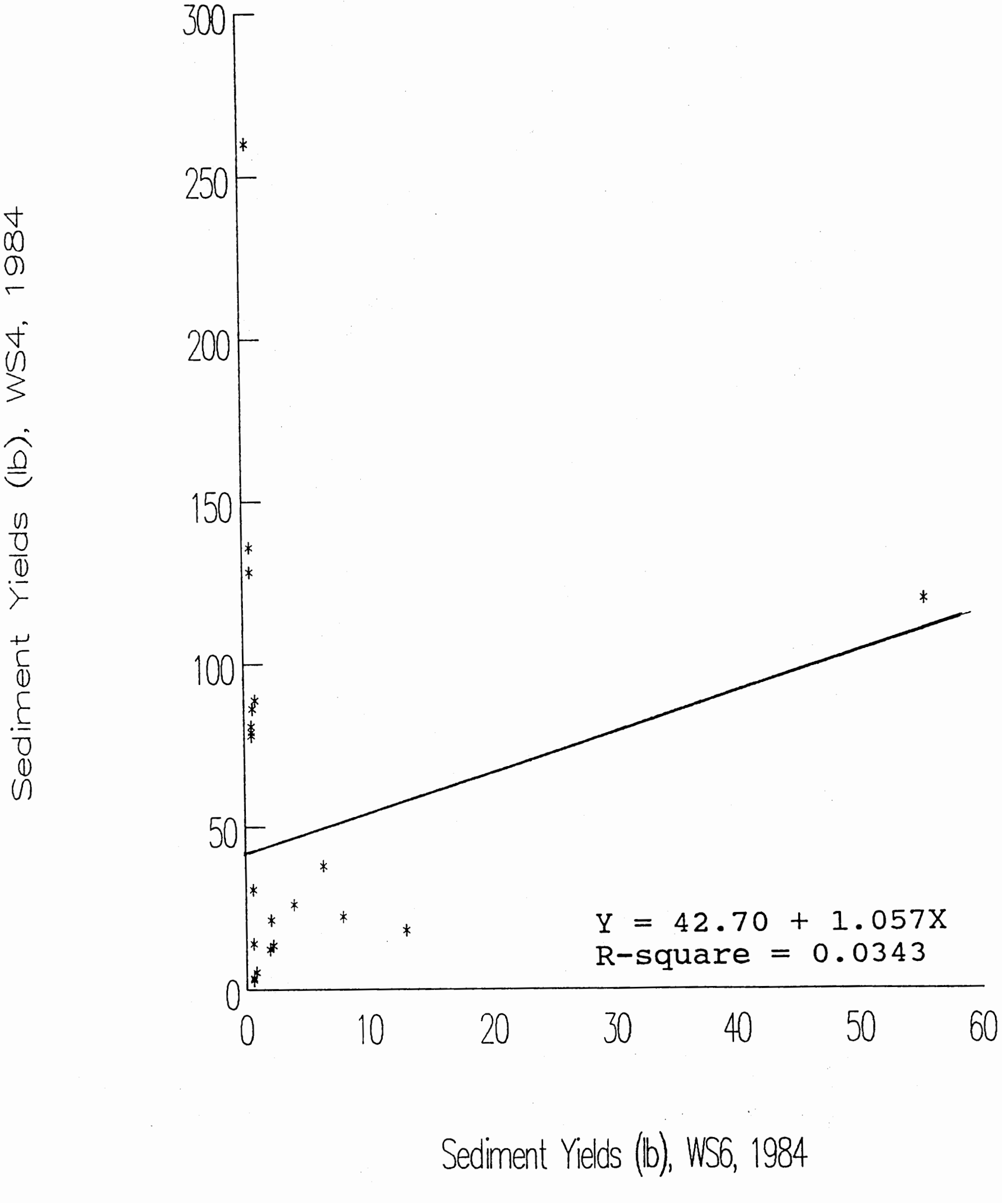


Figure 30. Single storm sediment yield comparison between the forested control (WS6) and the clearcut and ripped treatment (WS4) for water year 1984.

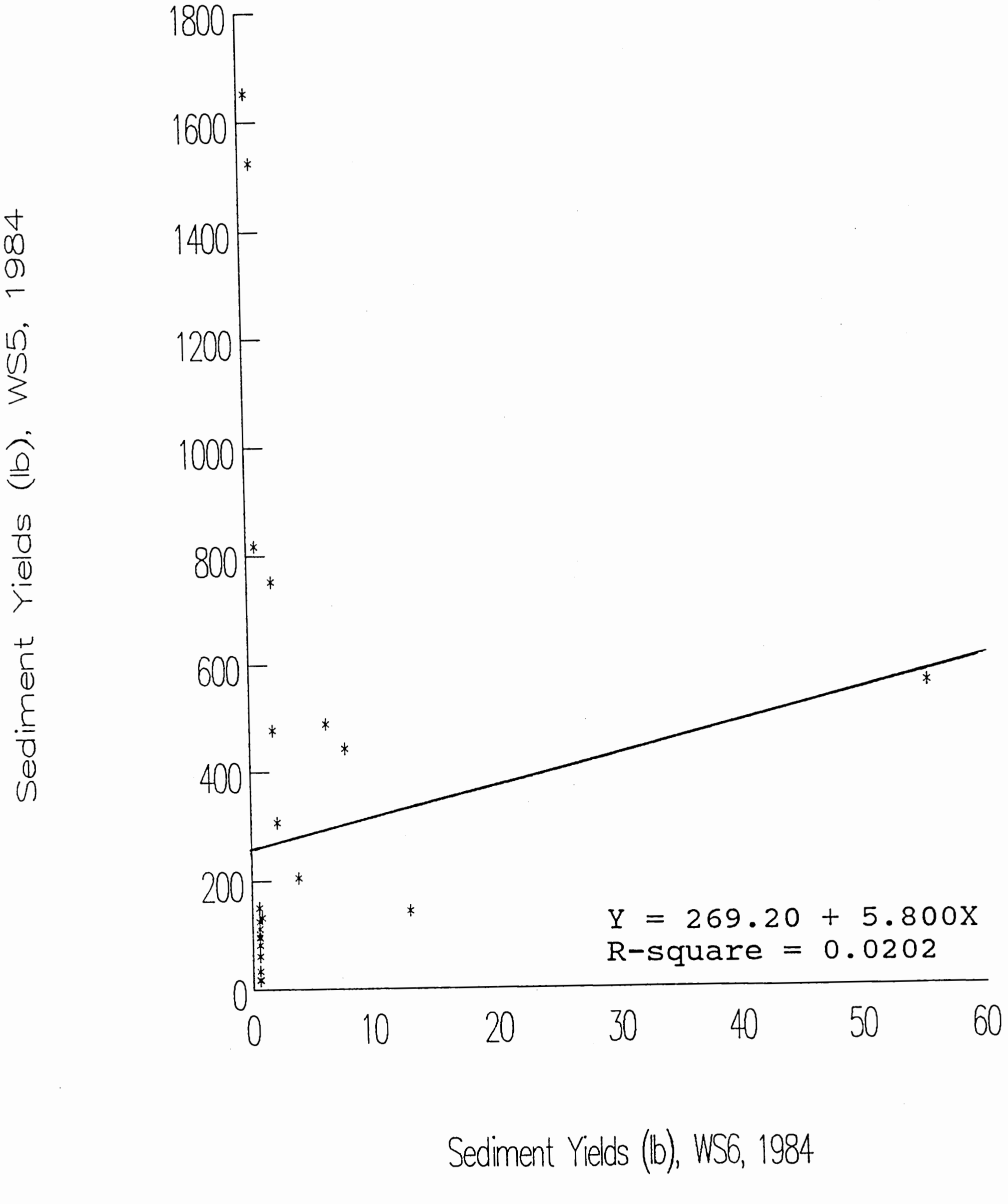


Figure 31. Single storm sediment yield comparison between the forested control (WS6) and the clearcut and unripped treatment (WS5) for water year 1984.

TABLE XXIV

SEDIMENT YIELDS OF WATER YEAR 1985
(OCTOBER 1, 1984 - SEPTEMBER 30, 1985)

Date Mo-Dt-Yr	WS4	WS5	WS6
10-05-84	161.17	482.47	1.08
10-06-84	407.47	4766.51	15.09
10-13-84	166.24	651.08	9.78
10-16-84	122.14	1133.05	13.90
10-18-84	62.02	350.98	1.55
10-20-84	381.78	1628.33	23.99
10-24-84	123.34	788.05	0.87
10-31-84	313.12	1403.37	32.73
11-17-84	357.20	376.33	14.91
11-25-84	138.84	117.03	13.96
12-14-84	19.48	22.56	14.07
12-16-84	6.25	70.54	*
12-17-84	22.76	*	*
12-21-84	10.50	*	*
12-31-84	52.35	160.11	7.61
01-05-85	0.53	0.02	*
01-08-85	0.06	*	*
01-26-85	0.07	1.96	2.50
02-06-85	*	1.70	0.22
02-10-85	5.85	34.62	4.96
02-22-85	795.20	937.11	31.29
03-03-85	0.01	15.00	0.41
03-20-85	106.40	167.10	5.29
03-30-85	0.11	0.02	0.01
04-22-85	204.81	182.85	5.71
04-26-85	1.17	6.09	0.68
04-30-85	0.79	5.93	-
05-13-85	7.89	*	-
05-21-85	0.28	*	-
05-30-85	100.03	4.05	-
05-31-85	11.93	*	-
06-06-85	46.87	7.94	-
06-18-85	0.73	0.08	-
08-14-85	17.76	18.23	-
08-24-85	8.61	0.03	-
09-13-85	0.61	*	-
09-29-85	91.93	147.90	-
Total(lb)	3746.30	12845.35	200.60
Average(lb/ac)	891.98	1223.37	22.54

Note: * no flow was recorded
- recorder malfunction, May through September

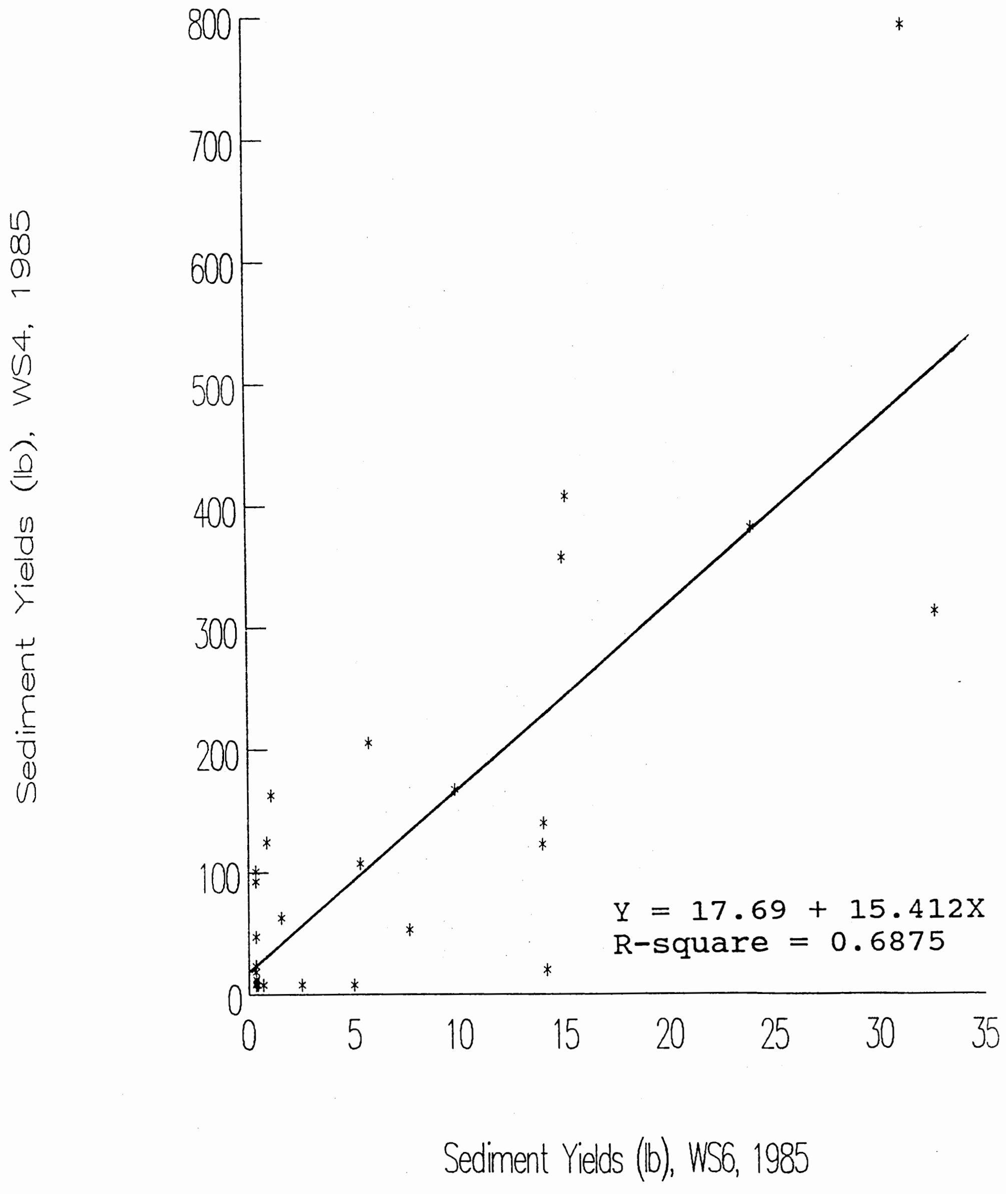


Figure 32. Single storm sediment yield comparison between the forested control (WS6) and the clearcut and ripped treatment (WS4) for water year 1985.

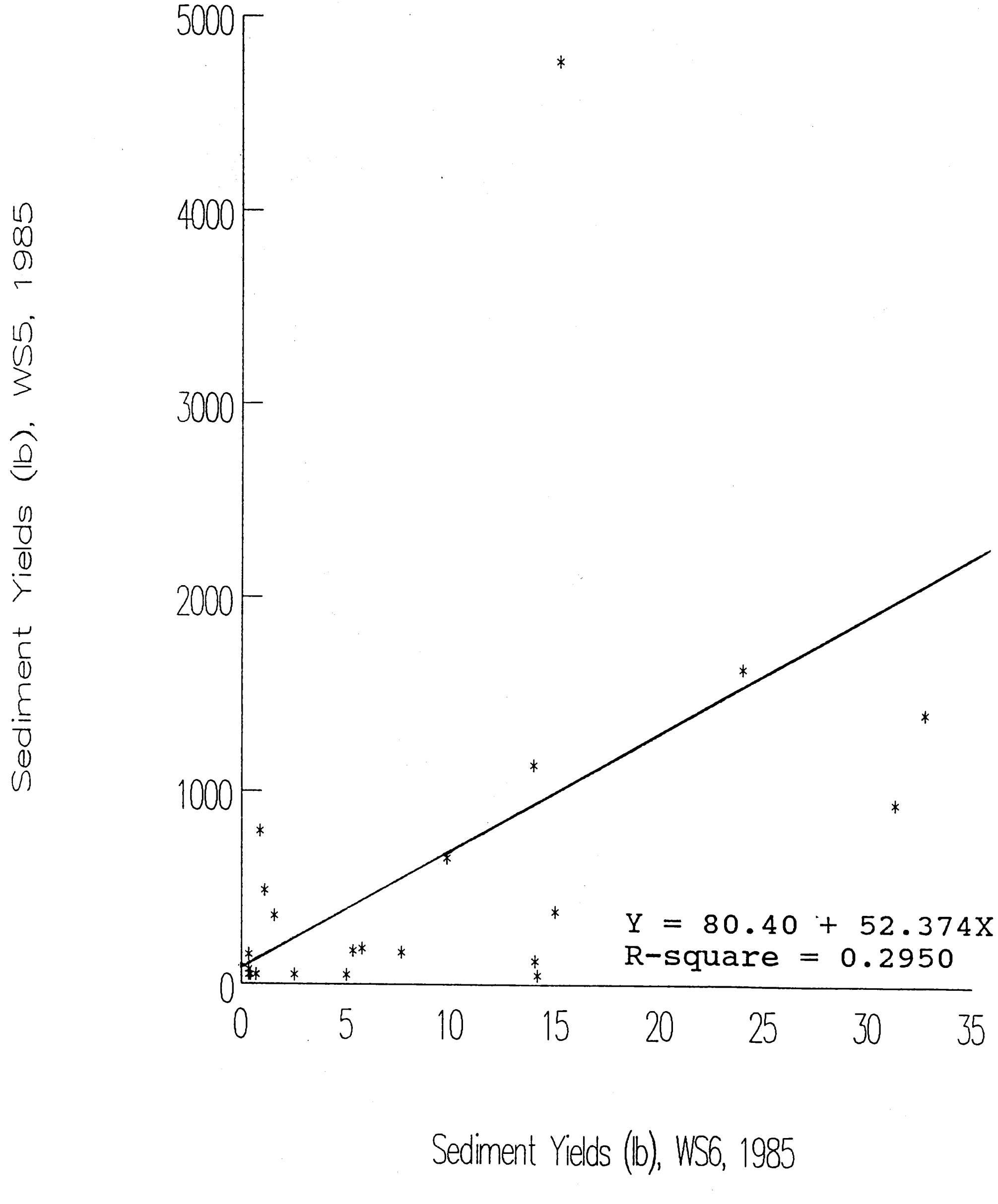


Figure 33. Single storm sediment yield comparison between the forested control (WS6) and the clearcut and unripped treatment (WS5) for water year 1985.

TABLE XXV

SEDIMENT YIELDS OF WATER YEAR 1987
(OCTOBER 1, 1986 - SEPTEMBER 30, 1987)

Date Mo-Dt-Yr	WS4	WS5	WS6
10-04-86	195.46	847.00	11.20
10-11-86	8.21	47.79	6.08
10-22-86	1.01	7.21	*
11-04-86	26.46	117.24	8.89
11-10-86	15.33	37.58	7.39
12-07-86	32.11	79.16	32.70
12-18-86	0.14	0.85	*
01-03-87	0.43	1.78	0.01
01-09-87	15.44	45.19	12.37
01-18-87	*	10.71	0.91
02-24-87	1.39	73.72	0.19
02-26-87	28.72	*	21.04
03-16-87	37.36	105.02	50.03
03-23-87	0.01	0.13	0.16
04-13-87	1.41	1.64	*
05-20-87	*	0.17	0.01
05-22-87	0.01	0.38	0.01
05-25-87	*	0.10	0.01
05-28-87	9.99	51.37	0.50
06-03-87	0.01	0.10	0.00
06-19-87	*	*	0.02
06-23-87	0.76	1.06	0.01
06-30-87	0.00	0.03	0.02
07-02-87	3.65	8.84	3.32
08-12-87	0.00	0.00	0.01
08-17-87	0.04	0.00	0.00
09-15-87	7.54	14.46	0.05
09-18-87	109.40	63.82	1.65
Total(lb)	494.86	1515.48	156.54
Average(lb/ac)	117.82	144.33	17.59

Note: * no flow was recorded

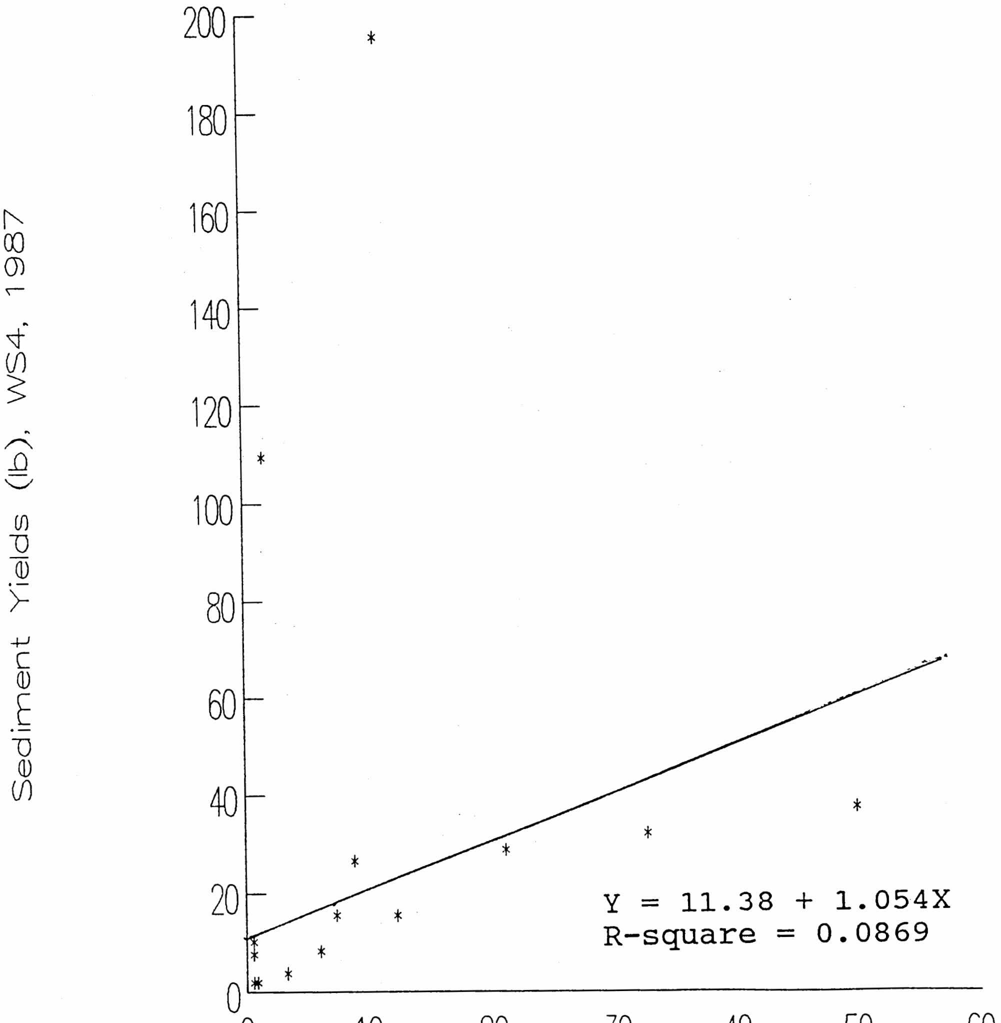


Figure 34. Single storm sediment yield comparison between the forested control (WS6) and the clearcut and ripped treatment (WS4) for water year 1987.

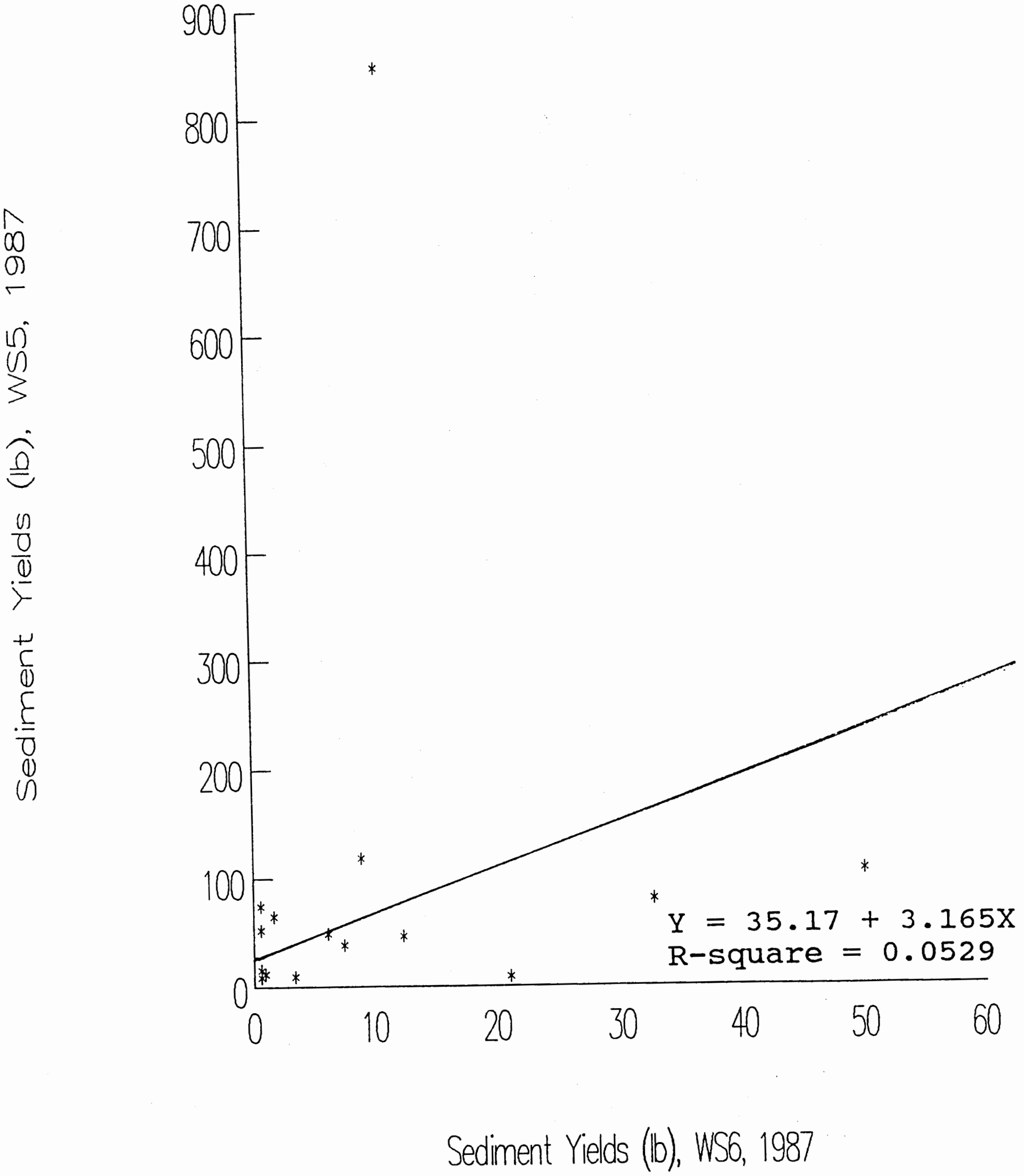


Figure 35. Single storm sediment yield comparison between the forested control (WS6) and the clearcut and unripped treatment (WS5) for water year 1987.

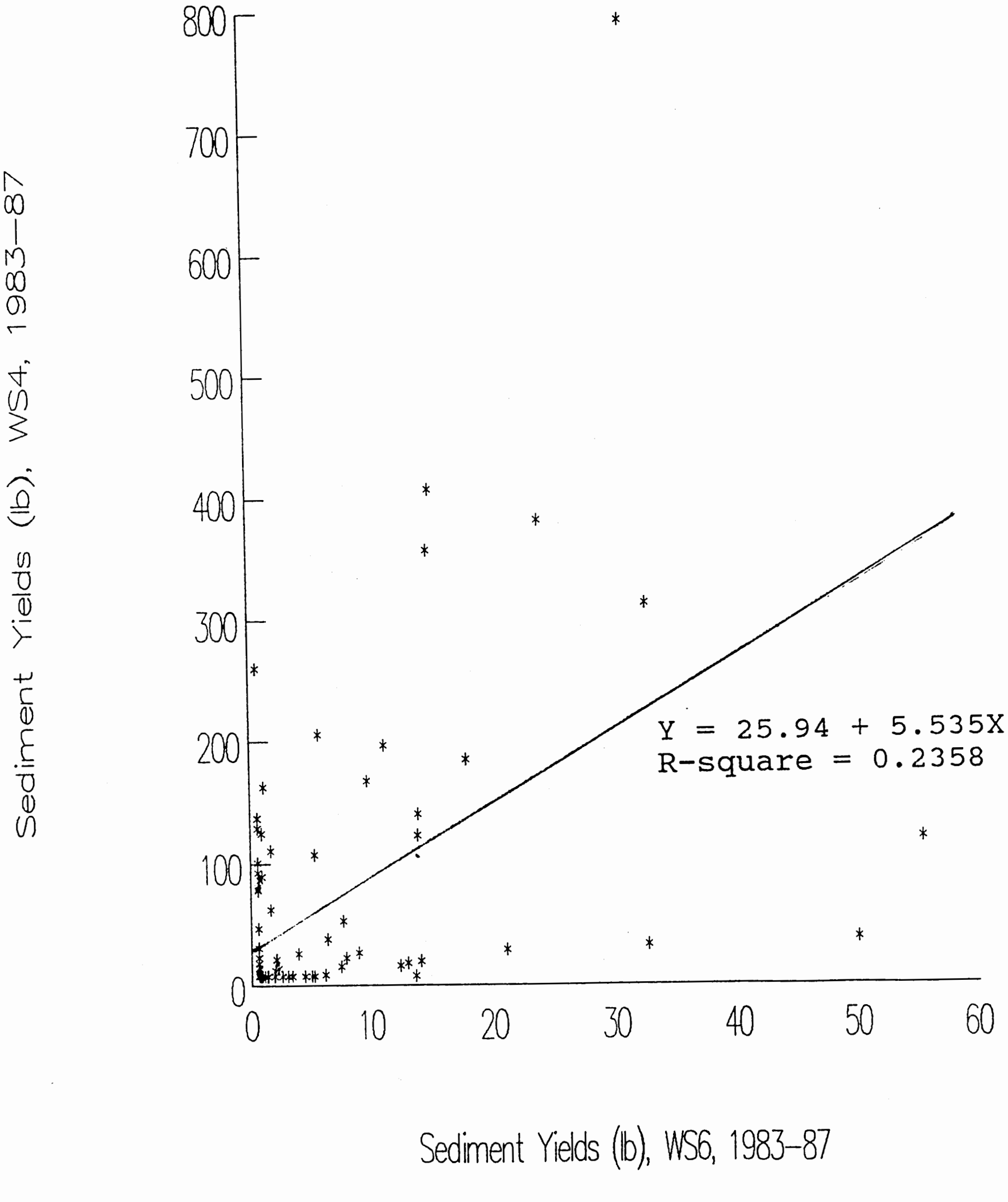


Figure 36. Single storm sediment yield comparison between the forested control (WS6) and the clearcut and ripped treatment (WS4) for the post-treatment period (1983-87).

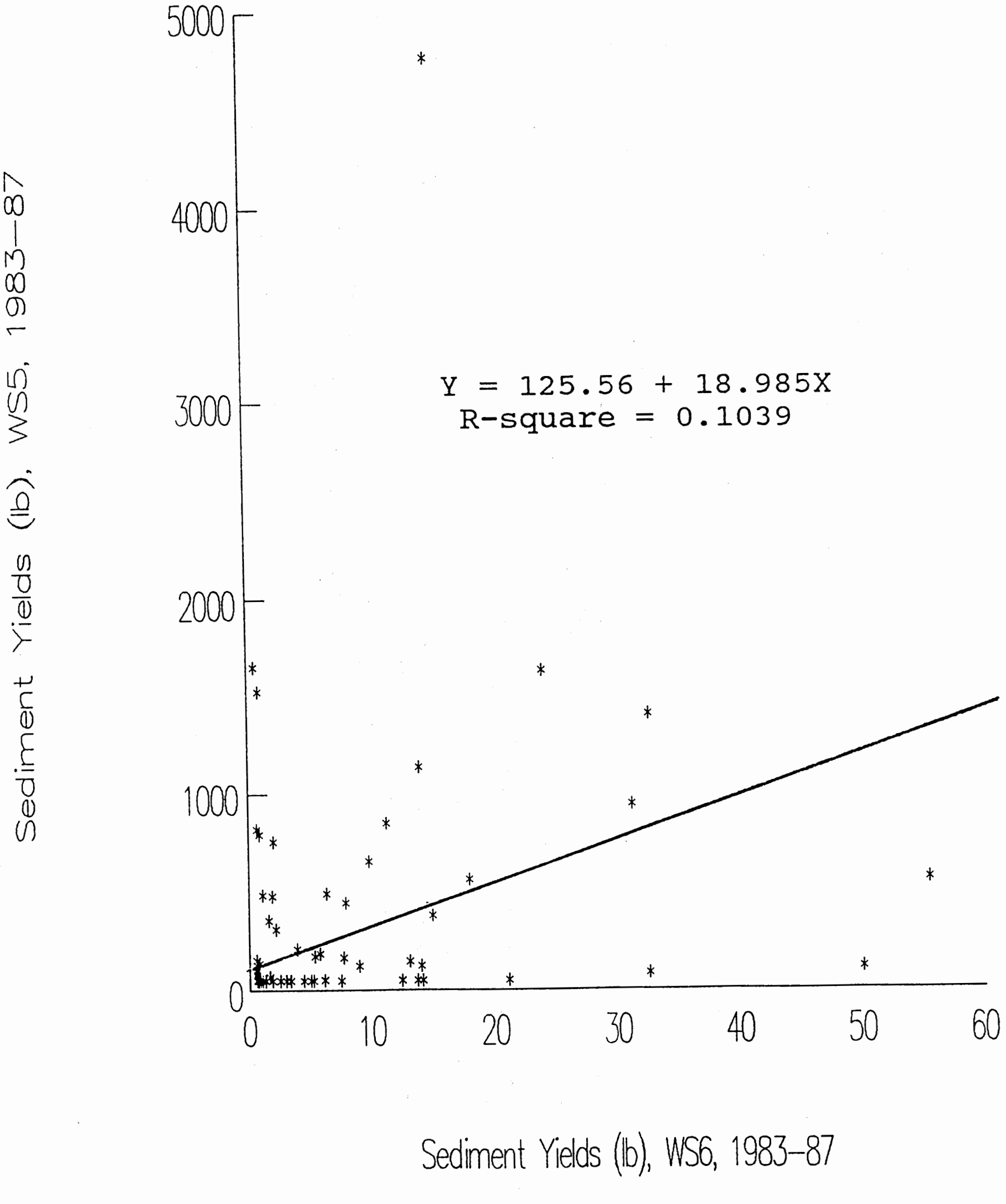


Figure 37. Single storm sediment yield comparison between the forested control (WS6) and the clearcut and unripped treatment (WS5) for the post-treatment period (1983-87).

treatment, a highly significant increase in slope (Table XXII; Figure 29) was found ($p < 0.01$). In water year 1985 (Table XXIV; Figure 33), there was also a highly significant increase in slope compared to the pre-treatment slope ($p < 0.01$). In water years 1984 (Table XXIII; Figure 31) and 1987 (Table XXV; Figure 35), no significant differences in slope were found ($p > 0.10$), but poor R-square values were obtained for both years. For the whole post-treatment period, a highly significant increase in slope (Figure 37) was found ($p < 0.01$) over the pre-treatment period. A comparison of adjusted mean values showed highly significant increases in 1984 ($p < 0.01$) and significant increase in 1987 ($p < 0.05$).

In the first phase, sediment yields from clearcut and site prepared watersheds were significantly higher than from unharvested control levels in 1978, 1979, and 1981 ($p < 0.01$) but not in 1982 ($p > 0.25$), based on single-storm comparisons (Miller, 1984; Miller, Beasley and Lawson, 1985). The poor single storm regression results based on values of R-square in the second phase, reduced the value of the single-storm sediment yield regression comparison as a test of treatment effects. Fortunately, a comparison of the annual sediment yields provides an adequate measure of the treatment effects on sediment yields.

In the first phase, Miller (1984) found, in any given year, only a few storms produced the bulk of annual sediment yield. A similar situation was found in the second phase.

For example, one storm which occured in May 14, 1983, produced 90 percent of the total annual sediment losses, 184.05 pounds of the 204.16 pound annual total, from WS4 and 88 percent of the total annual sediment losses, 559.15 pounds of the 638.66 pound annual total, from WS5. But for the same storm, only 39 percent, 34530 cubic feet of the 87424 cubic foot annual total stormflow water yield, and 20 percent, 74096 cubic feet of the 371798 cubic foot annual total stormflow water yields were measured from WS4 and WS5, respectively. In October 4, 1986, one storm caused about 40 percent of the annual sediment yields (195.46 pounds of a total 494.86 pounds) from WS4 and 56 percent (847 pounds of a total 1515.48 pounds) from WS5, while only 26 percent (21808 cubic feet of a total 85112 cubic feet) and 20 percent (87940 cubic feet of a total 426686 cubic feet) of annual stormflow water yields from respective watersheds. On the control watershed (WS6), the percentage sediment yield due to a few large storms was lower, but the trend was the same.

In the first phase of this study, the treatment effect on sediment yields persisted for three years, but sediment yield increases due to the clearcut and rip treatment were not statistically significant except in 1979, the first year of treatment. Sediment discharges at the watersheds outlets were primarily suspended material. Annual sediment yields were low on control and treated areas in the first phase for a number of reasons: 1) natural rock pavement of soil surface and rock armored stream channels; 2) fine root mats in upper soil horizons and high organic content on soil surface; 3) maintenance of high infiltration rates after treatment; and 4) rapid revegetation of clearcut watersheds. Sediment concentration in stream water were significantly increased by clearcutting but high concentration were associated with peakflows which were of short duration (Miller, Beasley and Lawson, 1985).

In the second phase, the trend was the same, but with the soils on the treated sites exposed to the environment for over two years, the results were different than in the first phase. When treated watersheds were fully covered by herbacious and forest vegetation, the sediment yield differences decreased substantially. But, even in 1987, four years after treatment and the last year of this experiment, average sediment yields from the two treated watershed were still higher than the control level. It is apparent that both treatments in the second phase, clearcut with and without ripping, were strongly affected by the herbicide application which extended the period of time mineral soils were exposed on the sites. Ripping on contour had lower sediment yields than the clearcut by creating detention storage and infiltration at a time of minimal vegetative cover. Rip furrows were often full of water during rains that produce stormflow; while the clearcut watershed (without ripping) had neither vegetative cover nor on site storage. It was also found that most sediment yields occured during the period with a higher rainfall intensity or high rainfall total which caused extremely high amounts of stormflow. These included May of 1984, September through November 1984, Feburary to April 1985 and October 1986. Without the high amounts sediment yield from treated sites for these periods, the treatment influence would not have been as pronounced.

CHAPTER V

SUMMARY

Forest harvest by clearcutting with intensive site preparation including a contour ripping treatment increased annual total stormflow water yields significantly. Annual stormflow totals averaged 4.83 inches per year before treatment and were 11.78 inches in 1984, 15.73 inches in 1985 and 5.58 inches in 1987, The increases were 6.19 , 5.57 and 3.37 inches more than would have occured in 1984, 1985 and 1987 respectively, if there had been no treatment applied. A comparison of pre- and post-treatment simple linear regressions of single storm stormflow indicated the stormflow increases were significant during the entire post-treatment period. The clearcut treatment contour ripping yielded about the same stormflow water yield during water year 1983, the year of treatment, as during the pre-treatment period, 9.75 vs. 9.16 inches per year, respectively. However, in following years the total annual stormflow water yields increased significantly to 19.69 inches and 26.87 inches in 1984 and 1985, respectively. In 1987, the clearcut site (WS5) yielded 11.19 inches. The annual stormflow amounts were 9.70, 10.07 and 6.23 inches more than would have occured in 1984, 1985 and 1987 respectively, if no treatment had been applied. A comparison of pre- and post-treatment linear regressions of single-storm stormflows show that the clearcut treatment produced significantly more stormflow than would have been produced without the harvest and site preparation treatment. The forested control watershed stormflows were fairly constant over the study period and varied directly with annual precipitation. Stormflow water yields decreased as the treated sites were revegetated, but at the end of water year 1987, the level of increases were still statistically significant. Both clearcut treated watersheds had more stormflow events during the post-treatment period than would have occured under forest cover.

Both treatments increased the peakflow discharge rates for the four-year post-treatment period, based on a comparison of the eight largest storms which occurred during the post-treatment period. Two peakflow events which occured following lengthy dry periods influenced this statistical comparison. Disregarding these two storms, the peakflow increases were not significant. Unfortunately, flood producing storms did not occur after forest harvest treatments were applied.

The clearcut with contour ripping treatment (WS4) increased annual total sediment yields from an average 9.77 pounds/acre/year over the pre-treatment period to 48.61 pounds/acre in 1983, 319 pounds/acre in 1984, 892 pounds/acre in 1985 and 118 pounds/acre in 1987. Annual total sediment yields from the clearcut treated watershed (WS5) increased from an average 18.16 pounds/acre/year during pre-treatment to 61 pounds/acre in 1983, 797 pounds/acre in 1984, 1223 pounds/acre in 1985, and 144 pounds/acre in 1987. Due to the varibility of the sediment yields for single storm events, a comparison of pre- and post-treatment regressions did not provide a effective test of treatment effects. However, the annual increases provided a clear indication of treatment effect. The losses measured do not represent a serious threat to long term site productivity.

It is apparent that both treatments had strong impacts on stormflow water yields, and sediment yield losses. It also appears that the clearcutting with contour ripping treatment reduced the total stormflow water losses and sediment losses below those from clearcutting alone by creating on site storage and by promoting infiltration and sealing subsurface macrochannels. Herbicide applied on the experimental sites apparently influenced the treatment effects significantly as it created the opportunity for increased stormflow water yields and sediment yield losses by exposing soils on the watersheds to the environment. However, ripping compensated for the herbicide effect somewhat by creating detention storage and increasing infiltration at the time of minimal vegetative cover. Both treatments had lower stormflow water yields and sediment losses as revegetation was re-established on the experimental sites. Even in the worst sediment losses case, the 1223 pound per acre soil loss from the clearcut watershed (WS5) in 1985, the erosion was still well below the USDA's standard acceptable soil loss for fragile soils, 1 ton per acre per year (USDA, 1977).

Forest cover is, as commonly indicated in the literature, important in regulating stormflow regimen and maintaining high water quality through protection against erosion, overland flow, sedimentation and leaching of nutrients. It is important for forest researchers and forest managers to develop better management methods to prevent detrimental levels of soil loss from harvesting and site preparation activities. Many studies have been established to help meet this requirement since the early 1930's, and the results have been well examined and widely used in the management of commercial forest lands. The need for forest products increases our requirements for knowledge of the relationship between sivilcultural activities and water quality. Environmental concerns by the public makes clearcutting a less acceptable operational tool. It is our wish that this study can help provide the type of information on forest practices for the central and southwest regions of the U.S. to evaluate the impacts of clearcutting from a technical and factual viewpoint.

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APPENDIX

PRECIPITATION RECORDS FROM OCTOBER 1, 1982 TO SEPTEMBER 30, 1987

TABLE I
PRECIPITATION RECORD
Station 20, Water Year 1983

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1		↓	0.15				0.04	0.26		0.35		
2		1.72	↓	0.33						0.01		
3			2.18			↓			0.06			
4			0.11			1.54	0.12			↓		
5						0.19				0.40	0.30	
6	0.23											
7											0.01	
8	1.36										0.17	
9	0.01						0.02				0.06	
10			↓					0.47				
11		0.23	1.24					0.01				
12			0.02				0.07				0.51	0.12
13							0.63			0.32		
14		0.01						2.32		0.02		
15										0.29		0.22
16										0.01		
17		0.01										
18								0.01			0.01	0.07
19	0.45	0.04		0.01		0.08					0.01	0.23
20				0.01	0.05							0.76
21							0.16					
22		0.91					0.57		0.05			
23			0.67									
24			0.02									
25									0.15		0.03	
26		↓	↓	0.37		0.38			0.12		0.01	
27		3.31	1.67						0.01			
28	0.86	0.01							1.28			
29							0.09		1.06	0.65		
30						0.02	0.13				0.34	
31				0.35								

Unit = Inch
↓ = *precipitation carryover from day-to-day*
* = *Chart Error*

TABLE II
PRECIPITATION RECORD
Station 50, Water Year 1983

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1		↓	0.04	↓	0.03		0.09	0.14		0.36		0.09
2		1.87	0.12	0.35				1.50		0.01		
3			1.87			↓			0.11			
4						2.29	↓				0.26	
5					0.06	↓	0.48		0.76	0.52	0.02	
6	0.29					0.07	0.01		0.01		0.06	
7	1.78										0.47	
8							0.02				0.08	
9					0.10		0.07					
10			↓					0.66				
11		0.23	1.15					0.21	0.02			
12							0.12				0.32	↓
13							0.66			0.42		0.05
14		0.01					0.24	3.58	0.11	0.29	0.07	
15										0.29	0.79	
16										0.05		
17		0.03										
18												↓
19	0.16	0.07		0.02		0.22	0.04				0.02	0.05
20		0.01		0.01	0.26			0.01				0.14
21					0.08			0.98				
22		0.64					0.93		0.06			
23		0.40				0.01		0.02				
24		0.01	0.78									
25									↓			
26			↓	0.65		0.80		0.25	0.49		0.01	
27			1.60						0.01			
28	0.97			0.01			0.02	1.02	1.43			
29	0.01						0.11	0.24	1.21	0.74		
30						0.22		↓		0.02		
31				0.55				0.41				

Unit = Inch
↓ = *precipitation carryover from day-to-day*
* = *Chart Error*

TABLE III
PRECIPITATION RECORD
Station 60, Water Year 1983

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1			*	↓	0.87		↓	0.44		0.74		
2		↓	*	0.38			0.34	0.87		0.02		
3		1.99	*			1.90			0.14			
4			*				↓					
5			*		0.05	↓	0.58		1.27	0.52	0.27	
6	0.32		*		↓	0.30						
7	↓		*		0.74			0.01			0.03	
8	1.07		*				0.03				0.17	
9	1.01		*				0.07				0.14	
10			*					0.67				
11		0.27	*					0.18	0.01			
12	0.02		*				0.08				0.78	0.01
13			*				0.99	0.01		0.32		
14			*					3.61	0.10	0.12		
15										0.23		0.25
16		0.01								0.01		
17		0.22						↓				
18								1.06				
19	0.36	0.06		0.02		0.27	0.03					0.15
20		0.02		↓	↓							0.82
21		0.01		0.66	0.66		0.25	0.51				
22		0.02					0.75		0.06			
23		0.01	↓			0.06		0.02				
24		0.04	0.68									
25						0.01			↓			
26		0.02	↓			0.83		0.67	0.33		0.05	
27		0.01	1.87									
28	0.96	0.01					0.01	1.25	1.41			
29	0.01	*				↓	0.16	0.22	1.20	0.12		
30		*				0.18	0.22	↓		0.05		
31		*						0.37			0.29	

Unit = Inch
↓ = *precipitation carryover from day-to-day*
* = *Chart Error*

TABLE IV
PRECIPITATION RECORD
Station 20, Water Year 1984

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1								1.38				*
2							0.74	↓			1.99	*
3						0.02		0.85				*
4						0.30				↓		*
5								1.10	0.01	0.28		*
6		0.05							0.26		0.51	*
7	0.06						↓	0.15	0.02			*
8	0.07				↓		0.90					*
9		0.48		0.43	0.24							*
10			1.50			0.08	0.15					*
11	0.90				↓	1.56	0.01			↓		*
12					1.48					1.35		
13			0.03									
14					0.02			0.03				
15				↓		0.45						0.51
16			0.14	0.33		↓				0.32		
17	2.80					0.74				0.03		
18					0.14	0.45						
19	0.14							0.88	0.17			
20	↓						0.15	3.78				
21	1.00											↓
22											0.01	2.87
23									↓	0.04	0.01	
24									1.76		*	
25					↓					0.03	*	
26					2.28	0.01		0.30	0.85	0.20	*	
27					0.01	↓		1.89		0.08	*	
28						1.25		0.01			*	
29							0.20		0.29		*	
30											*	
31											*	

Unit = Inch
↓ = *precipitation carryover from day-to-day*
* = *Chart Error*

TABLE V
PRECIPITATION RECORD
Station 50, Water Year 1984

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1								↓				
2			↓		0.01			↓			1.74	↓
3			1.57			0.01		2.75				0.16
4						0.29				0.32		
5			0.05					1.10	0.03			
6		0.11							0.24			
7	0.06	0.01					↓	0.19	0.02			
8	0.08				↓		0.94				0.04	
9		0.60	0.01	0.83	0.27	0.11					0.36	
10			1.50				0.19					1.28
11	1.04				1.73	↓				↓		
12						1.85				1.65		
13			0.06									
14								0.03				
15					0.01	0.49						0.66
16			0.14			0.02	0.03			0.26		
17	2.77		0.06			0.61				0.03		
18					0.19	0.47						
19	0.16							1.09	0.27			
20	↓						0.16	3.07				
21	1.01							0.03				↓
22				↓							0.09	0.26
23				0.50		1.60			↓	0.05		0.01
24									1.78			
25										0.03		1.10
26					↓	0.02		0.24	1.04	0.42		0.14
27					2.37	0.38		1.75		0.25		
28												
29							0.18		0.31			
30												
31												

Unit = Inch
↓ = *precipitation carryover from day-to-day*
* = *Chart Error*

TABLE VI
PRECIPITATION RECORD
Station 60, Water Year 1984

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1			0.65					↓				
2			↓	0.07			0.45	1.67			1.80	
3			0.92	0.12		0.02		0.77				
4						0.20				↓		
5								0.35		0.29		
6		0.10							0.26		1.12	
7	0.06						↓	0.17	0.01			
8	0.09				↓		0.37				↓	
9		0.65	0.07		0.34	↓					0.21	
10			1.43	1.06		0.14	0.09					
11	0.88				0.50	↓				↓		
12						1.30				1.28		
13			0.05									
14								0.02				
15					0.05							
16			↓			1.20	0.05			0.40		
17	3.25		0.08			0.70				0.05		
18					0.21	0.47	0.03					
19	0.05	1.39					0.15	0.66	0.26			
20	1.29							0.34				
21								0.05				↓
22				0.01				0.04				2.65
23		0.90		0.15		1.87			↓			
24						0.01			2.52			
25										0.10		1.61
26					1.50	0.03		0.09	0.75	0.05		0.26
27		↓			0.02	↓		↓				
28		0.72				0.97	0.01	2.17	0.34			
29							0.24					
30		0.02										
31												

Unit = Inch
↓ = *precipitation carryover from day-to-day*
* = *Chart Error*

TABLE VII
PRECIPITATION RECORD
Station 20, Water Year 1985

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1		2.48				*	*	0.01			0.04	
2						*	*			0.11		
3						*	*			0.16		
4			0.18		0.01	*	*					
5	2.22				0.02	*	*		↓			
6	2.44					*	*		1.10		0.05	
7	0.01	0.01				*	*	0.15			0.04	
8					0.03	*	*					
9					0.11	*	*					0.05
10	0.03					*	*		0.24			
11	↓					*	*	0.01	0.06			0.45
12	0.37		0.02			*	*					0.03
13	0.43		0.03			*	*	0.99		0.12		0.95
14	1.24					*	*				1.55	
15		0.19	0.21		0.01	*	*					
16	0.96					*	*			0.30		
17		↓	0.26			*	*					
18	0.77	1.91			0.03	*	*		1.35			
19			0.09	0.28	0.02	*	*					
20	2.40					*		0.17		0.02		
21	0.12		0.23		1.58	*	↓	0.44		0.03		
22	↓				*	*	2.83		0.23			
23	0.41				*	*				0.02		
24	0.03				*	*					1.25	0.01
25			0.02		*	*						
26	0.10	1.31			*	*	0.17					0.46
27	0.06	0.01		0.27	*	*	0.11	0.96				
28	0.08				*	*						
29			↓	0.01		*	0.07			0.03		2.61
30			0.27			*	0.22					
31	1.00		0.63			*						

Unit = Inch
↓ = *precipitation carryover from day-to-day*
* = *Chart Error*

TABLE VIII
PRECIPITATION RECORD
Station 50, Water Year 1985

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1		1.20						0.04			0.02	
2					0.04					↓		
3						↓				0.82		
4			↓			0.40				0.01		
5	2.22		0.50		0.04		0.07		↓			
6	2.66								1.48		0.06	
7								0.20			0.21	
8												
9		0.03		0.32								
10					0.19		↓		0.42	0.07		
11	↓			0.11			0.25	0.05	0.12			0.34
12	0.46		↓									0.01
13	↓		0.72			0.22	0.12	1.09				
14	1.93										1.75	
15			0.02									
16	1.05		0.28									
17			0.58									
18	0.188				0.02				1.12			
19			↓		0.10	↓						
20	2.85		0.06			1.58		↓			0.03	
21	0.11		0.14		0.09			1.27				
22	↓				↓				0.38			
23	0.44				1.80	0.01						0.02
24	↓										0.03	
25	↓											
26	2.67	1.26										
27	0.09	0.02	0.06	0.32		0.01						
28	0.07				0.12							
29			0.38	0.01		0.03				0.01		
30			0.01			0.45	0.21					
31	1.00		0.05									

Unit = Inch
↓ = *precipitation carryover from day-to-day*
* = *Chart Error*

TABLE IX
PRECIPITATION RECORD
Station 60, Water Year 1985

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1		1.74				0.34		0.02			0.02	
2				0.03						0.31		
3						0.07				0.57		
4			↓			0.18	0.04					
5	2.58		0.49						1.80		0.04	
6	2.93				0.02			0.19	0.28		0.10	
7	0.01		0.14		0.16							
8					0.10							
9	0.04			↓	↓							0.16
10				0.62	0.76		↓	0.05	0.37	0.15		
11	↓						0.31		0.16			0.74
12	0.48		↓									0.01
13	0.66		1.01			0.32	0.13	1.07		0.82		1.04
14	1.26		0.05					0.01			1.26	
15		0.18	0.01		0.09							
16	1.13		0.52									
17		↓	↓									
18	0.86	2.41	0.89		↓				1.14			
19			0.02		0.41	↓						
20	↓		↓			1.14	↓	0.30		0.06		
21	2.39		1.05		0.27		3.67	↓		0.07		
22	↓				↓			1.26	0.24			
23	0.46				2.76	0.01		0.01	0.11			
24	0.07					0.17		1.03	0.03		0.98	
25	3.10	0.39							0.01	0.16		
26	0.09	↓				0.03	0.52		0.05			
27	0.06	1.68	0.13	0.96			0.33		0.01			
28	0.08		0.01									
29			0.69	#		↓	0.17			0.18		
30			0.06	0.08		0.67	0.59					
31	0.96		1.00									

Unit = Inch
↓ = *precipitation carryover from day-to-day*
* = *Chart Error*

TABLE X
PRECIPITATION RECORD
Station 20, Water Year 1987

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	0.24				0.42							
2										1.18		
3				0.80				0.30	0.36			
4	3.74	1.58						0.03				
5								0.20				
6												
7		0.07	1.20					0.08				
8	0.22		0.75	↓								
9	0.01			1.08					0.31			
10		↓							0.15	0.01		0.70
11	1.09	0.99							0.04			
12								0.06	0.08		1.02	
13	0.07						0.63			0.94		
14			↓		↓							↓
15			0.26	↓	0.56				0.02			↓
16			0.04	0.12		↓		0.04				2.21
17			0.09	↓		2.27				0.01	0.74	
18			0.21	0.53							0.24	2.03
19				0.01					0.87			
20					0.18			0.26				
21												
22	↓				0.03	0.03		0.28				
23	1.06					0.38				0.45		
24					0.38			0.07				
25								0.64				
26					0.45							
27					0.05							
28					0.82	0.01		2.00				
29												
30									0.75		0.13	
31											0.04	

Unit = Inch
↓ = *precipitation carryover from day-to-day*
* = *Chart Error*

TABLE XI
PRECIPITATION RECORD
Station 50, Water Year 1987

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1					0.86					*		*
2					0.01					1.08		*
3				0.84				0.41	0.48	0.03		
4		↓						0.06				
5		1.73						0.19				
6					0.04			0.11			0.12	
7		0.12	↓					0.10			0.04	
8			2.10	↓								
9				1.17					↓		0.12	
10		1.12							0.47		0.23	0.00
11	1.21								0.20			
12	↓			0.01				0.04	0.20		1.20	
13	0.12						1.16			1.11	0.01	
14			↓	0.01	0.51		0.02					2.96
15			↓	0.19	0.25			0.18				0.32
16			0.38	0.01		↓		0.40				2.44
17			0.10	↓		2.15				0.03	0.53	
18			0.21	0.65							0.35	2.51
19									*		*	
20			0.01		0.29			0.37	*		*	
21									*		*	0.02
22	↓				0.07	0.05		0.32	*		*	
23	1.19				0.01	0.01		0.22	*	0.81	*	
24					0.52			0.19	*		*	
25								0.43	*	0.01	*	
26					0.66				*		*	
27					↓				*		*	
28					0.98	0.02		↓	*		*	
29						0.01		1.53	*		*	
30						0.02			*		*	
31											*	

Unit = Inch
↓ = *precipitation carryover from day-to-day*
* = *Chart Error*

TABLE XII
PRECIPITATION RECORD
Station 60, Water Year 1987

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	0.24		•	•	0.58	•						
2			•	•		•				1.44		
3			•	•	•	•		0.33	0.87	0.02		
4	3.22	↓	•	•	•	•		0.04				
5		2.16	•	•	•	•		0.37				
6	0.01		•	•	•	•		0.01			0.02	
7		0.11	•	•	•	•		0.01				
8	0.23		•	•	•	•						
9			•	•	•	•			↓			
10		1.14	•	•	•	•			065		1.42	
11	1.40			•	•	•			0.17			
12	↓			•	•	•		0.13	0.37		1.48	
13	0.06			•	•	•	0.49			1.21		
14				•	•	•						
15			↓	•	•	•			0.17			2.47
16			0.35	•	•	•		0.01				
17			0.12	•	•	•		0.04			0.72	
18			0.27	•	•	•					0.28	2.08
19				•	•	•			1.06			
20				•	•	•		0.15	0.01			
21					•	•						0.01
22	0.31				•	•		0.53				
23	0.18		•		•	•		0.57	1.33	0.08		
24			•		•	•		0.01	0.01			
25			•		•	•		0.14				
26			•		•	•		0.85				
27			•		•	•					0.37	
28			•		•	•		↓				
29			•			•		2.57				
30			•			•		0.01	1.39		0.35	
31			•								0.18	

Unit = Inch
↓ = *precipitation carryover from day-to-day*
• = *Chart Error*

VITA 2

Jiann-Shyng Heh

Candidate for the Degree of

Master of Science

Thesis: THE EFFECTS OF MECHANICAL HARVEST AND SITE PREPARATION ON STORMFLOW WATER YIELDS AND SEDIMENT YIELDS FROM FOREST WATERSHEDS IN OUACHITA MOUNTAINS OF OKLAHOMA

Major Field: Forest Resources

Biographical:

Personal Data: Born at Kaohsiung, Taiwan, ROC, July 27, 1960, the son of Yu-Chern and Hsie-Hwa Heh.

Education: Graduate from Tsihsing High School, Taipei, Taiwan, ROC, in June, 1978; received Bachelor of Science degree in Forestry from National Taiwan University in June, 1982; completed requirements for Master of Science degree at Oklahoma State University in July 1989.

Professional Experience: Graduate Research Assistant, Department of Forestry, Oklahoma State University; January, 1987 to December, 1988.