HYDROLOGIC RESPONSES TO SILVICULTURAL PRACTICES IN PINE-HARDWOOD STANDS IN THE OUACHITA MOUNTAINS[1]

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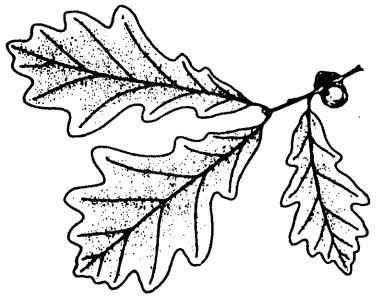

ABSTRACT.--Thinning and clearcutting management practices were applied to shortleaf pine-mixed hardwood watersheds calibrated by the paired-watershed method. The year following thinning of pine to 60 ft^2/acre, growing season soil water deficits were reduced by 2 to 3 inches, annual runoff was increased by 4.3 inches, and sediment losses were increased by 23 lb/acre. In the year following clearcutting, growing season soil water deficits were reduced by 3-4 inches, annual runoff was increased by 10.2 inches, and sediment losses were increased by 104 lb/acre. Both practices continued to affect soil water deficits and runoff through the 7-year post-treatment period, but only influenced sediment losses in the year following treatments.

INTRODUCTION

Management of our forests for optimum timber, water, wildlife, and recreational resources is a complex problem for forest managers. The effects of various management practices must be known if we are to manage our forest resources wisely, since demands on our forest resources are greater and more complex today than ever before.

Water is one of the key resources of our forests. Altering forest vegetation by thinning, clearcutting, or changing from one forest type to another influences soil water, streamflow, and sediment. Soil water is a vital factor in timber growth and yield. Water from our forests is an important source of municipal water supplies, irrigation water, and hydroelectric power. Year-round supplies of high-quality water are necessary for fish and wildlife populations. Recreational areas with streams and lakes are considerably more popular than those without water.

In the Ouachita Mountains of central Arkansas, shortleaf pine (Pinus echinata Mill.) and mixed hardwoods commonly grow together. Mixed hardwoods usually will succeed pines on many sites in the region without the intervention of natural disturbances, such as fire, or management practices. Forest industries are currently favoring pine over hardwoods in the Ouahita Mountains and are converting pine-hardwood stands to pine. Therefore it is important to understand the effects of management practices favoring pine on the hydrology of pine-hardwood forests.

The objectives of this study were to determine how thinning and clearcutting affects hydrology in the Ouachita Mountains of central Arkansas. The results provide basic information on the effects of thinning and clearcutting on soil water, runoff, and sediment losses and provide a data base for hydrologic modeling.

STUDY AREA

The three watersheds used in this study are located on the Alum Creek Experimental Forest north of Hot Springs, Arkansas, in the Ouachita Mountains. They range from 1.28 to 1.63 acres in area. The watersheds are on a northeast aspect between 1,300 and 1,500 feet in elevation and have a slope of 15 percent (fig. 1). They have similar soils and topography. Soil types are Bismark, Carnasaw, and Pirum stony silt loams. The Bismark soils are classified as loamy-skeletal, mixed, thermic Typic Dystrochrepts. Carnasaw soils are clayey, mixed, thermic Typic Hapludults and the Pirum are fine-loamy, siliceous, thermic Typic Hapludults. The soils are shallow, 2.5 to 3 feet deep, and moderately permeable. Water storage capacity is low, due to coarse

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[1] A paper presented at the Fifth Central Hardwood Forest Conference held at Urbana, Illinois, on April 15-17, 1985.

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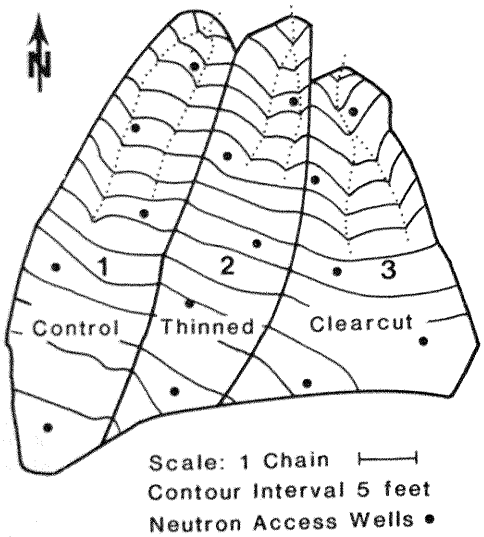

FIGURE 1.--Alum Creek Watersheds.

fragment content and the thin solum. Parent material is predominantly uplifted shale with some sandstone interbedding.

In the study area, summers are hot, and the short winters are moderately cold. Annual precipitation at the Alum Fork climatological station, 10 miles east of the watersheds, averaged 52.2 inches during the 46 years (1938-83) of record (U.S. Department of Commerce 1983). Precipitation is distributed fairly evenly throughout the year. Almost all precipitation is in the form of rain, but light snow usually falls a few times each year. Mean annual temperature is 62.1°F, the January mean is 42.3°F and the July mean is 81.6°F. The average growing season is 214 days from March 30 to October 30.

Instrumentation and Methods

Precipitation was measured throughout the study with recording and standard rain gages located at the head and foot of the watershed complex. Precipitation values used in this paper are the average of the two sets of gages.

Soil water was measured in five access wells on each watershed with a neutron probe system. The wells were installed to bedrock, 30 to 36 inches, at selected slope positions (fig. 1). Measurements were made at approximately weekly intervals at a depth of 9 inches and at 6-inch increments below that depth to bedrock. Average soil water deficits on each watershed were used as a measure of soil water. Soil water deficits were defined as the difference between soil water values on a given measurement date and maximum values measured during the pretreatment period (1967-69).

Runoff from the watersheds was measured in 3-foot H-flumes. Stages were measured with FW-1 water level recorders and were converted to cubic feet per second and area inches for each storm. Runoff from the watersheds was ephemeral, occurring only during and shortly after precipitation events.

Sediment suspended in runoff from the watersheds was measured with Coshocton samplers and filtering devices. The instruments were set to begin sampling runoff at a discharge rate of 0.0471 ft^3s^{-1} because discharges of less than this value contained very little sediment. Measurements were also made of sediment deposited in the flumes and approach sections. The sum of oven-dry suspended and deposited materials was used as the measure of sediment loss.

The paired-watershed method was used to evaluate posttreatment effects. Predicted runoff was calculated from regression relationships, developed during the pretreatment period, between the control and each of the two watersheds to be treated. Differences between the posttreatment measured and predicted runoff values were attributed to the treatments.

Treatments

The vegetative cover prior to treatment consisted of a shortleaf pine overstory basal area of 105 ft^2/acre and a mixed hardwood understory of 35 ft^2/acre. The overstory had 275 stems and the understory 1,085 stems per acre. Pine-hardwood litter covered the forest floor to a depth of 2 inches.

Treatments or management practices were applied during the spring of 1970 to watersheds 2 and 3, and watershed 1 was retained as the control for the paired-watershed analyses. The pine overstory on watershed 2 was thinned to a basal area of 60 ft^2/acre. The hardwood understory was injected with 2,4,5-T[1]. The watershed was sprayed annually for 3 years with 2 lb a.e./acre of 2,4,5-T to prevent hardwood sprouting. The pine overstory on watershed 3 was clearcut and the hardwood understory injected with 2,4,5-T. The watershed was sprayed annually for 3 years with 4 lb a.e./acre of 2,4,5-T to prevent hardwood sprouting.

Grasses became established on both watersheds after treatment. After 3 years the grasses were very dense and the thinned watershed (watershed 2) also had abundant natural shortleaf pine regeneration. Grasses were luxuriant on both watersheds 7 years after treatments, and on the thinned one shortleaf pine was 2 to 2.5 feet in height.

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[1] This paper reports research involving the use of herbicides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of herbicides must be registered by appropriate state or federal agencies before they can be recommended. Label directions should be followed and precautions heeded. Mention of names is solely to identify materials used and does not imply endorsement by USDA.

PRETREATMENT RESULTS

Annual precipitation during the 1961-69 calibration period averaged 52.5 inches and ranged from 39.3 to 66.0 inches. This average is very similar to the long-term average of 52.2 inches (table 1). Precipitation was evenly distributed throughout the year, with 26.6 inches or 51 percent falling during the May through October growing seasons, and 25.9 inches or 49 percent during the November through April dormant seasons.

TABLE 1.--Average monthly precipitation in the study area.

Month	Alum Fork 1938-1983	Alum Creek Pretreatment 1961-1969	Alum Creek Posttreatment 1970-1976
	----------inches----------		
January	4.06	3.57	3.42
February	3.65	3.70	3.21
March	5.36	5.40	6.31
April	5.25	4.70	5.25
May	5.83	5.68	5.32
June	4.58	3.77	6.15
July	3.91	5.41	3.68
August	3.24	4.81	4.45
September	4.40	4.22	5.31
October	3.28	2.68	5.88
November	4.41	4.52	4.72
December	4.23	3.99	5.06
Annual	52.20	52.45	58.76

Soil Water

The maximum soil water measured on the watersheds was 12.5 inches in May 1968. This was about 0.5 inch greater than the estimated field capacity of 12.0 inches. Minimum soil water recorded was 6.9 inches in September 1969. Therefore the available soil water was 5.6 inches.

Soil water deficit values for all three watersheds were very similar in the years before treatment. This similarity is shown for calendar years 1968 and 1969 (figs. 2 and 3). Figure 2 illustrates a typical year of deficits on a forested site with shallow soils. Deficits increase in May as the growing season begins and forest vegetation transpires large amounts of soil water. Deficits were temporarily reduced throughout the growing season by summer thunderstorms. At the end of the growing season, transpiration rates were much lower, and rainfall reduced the soil water deficits. Deficits were in the 0 to 2 inch range for most of the November through April dormant period, when 70 percent of the runoff occurred. During the growing season, runoff normally took place only when soil water deficits were an inch or less. Figure 3 is another example of typical seasonal deficits, except for the lower than normal deficits in late July. These were caused by nearly 8 inches of precipitation in the 2 week period preceeding measurements.

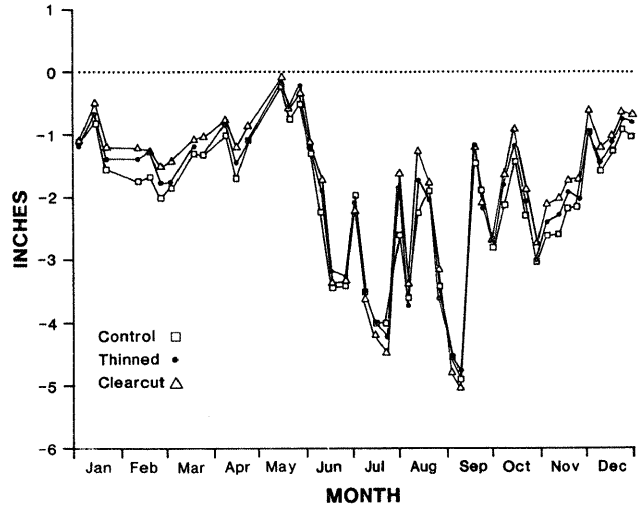

FIGURE 2.--Pretreatment soil water deficits for Alum Creek watersheds, 1968.

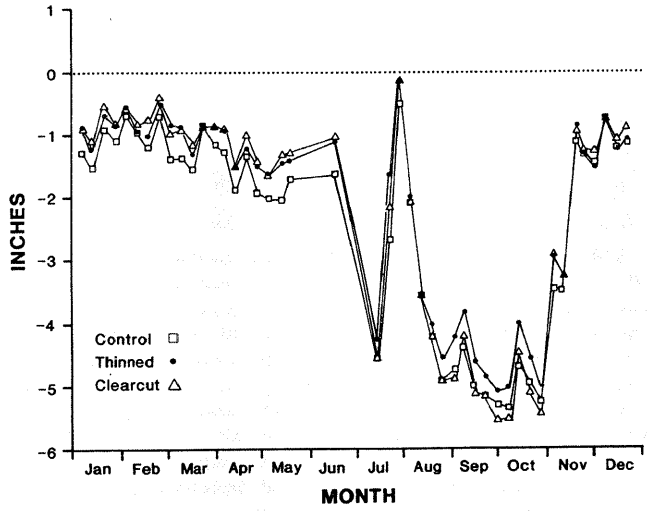

FIGURE 3.--Pretreatment soil water deficits for Alum Creek watersheds, 1969.

Runoff

Runoff from the watersheds was ephemeral, and 0.35 to 2.0 inches of precipitation were usually required to initiate runoff, depending on soil water deficit values at the onset of the storm. Runoff normally stopped within the 2-hour period after the end of precipitation. All three watersheds showed similar patterns in the amounts of runoff. During the 9 years of pretreatment measurements, annual runoff ranged from 3.1 to 9.4 inches. Runoff was low during the growing season even though precipitation was well distributed throughout the year (fig. 4). Growing season runoff only averaged 1.8 inches or 30 percent of the average annual runoff. Runoff during the dormant season averaged 4.2 inches or 70 percent of the average annual runoff. Low runoff during the growing season was attributed to increas-

ed soil water deficits caused by evapotranspiration losses. Evapotranspiration, as calculated by the Thornthwaite method (Thornthwaite and Mather 1957), was 28.3 inches during the May through October period, or 83 percent of the annual evapotranspiration, while evapotranspiration from November through April was only 5.8 inches or 17 percent.

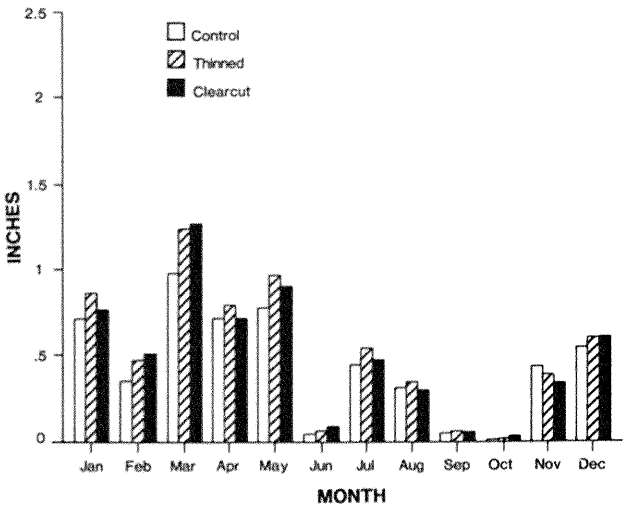

FIGURE 4.--Pretreatment average monthly runoff for Alum Creek watersheds, 1961-1969.

Sediment

Sediment losses from the three catchments averaged 11.9 pounds per acre per year during the pretreatment period. Annual losses ranged from 4.3 lb/acre on watershed 2 in 1963 to 28.7 lb/acre on watershed 3 in 1967 (fig. 5). Variances in annual losses are attributed to year-to-year differences in storm sizes, rainfall intensities, and discharge rates. Discharge rates in excess of 0.5 ft^3s^{-1} occurred in only 11 percent of the runoff producing storms, but they accounted for 68 percent of the sediment losses. The remaining 89 percent of storms with runoff produced only 32 percent of the sediment losses.

POSTTREATMENT RESULTS

During the 1970-76 posttreatment period, precipitation averaged 58.8 inches and ranged from 45.5 to 82.7 inches. Figure 6 illustrates the range in annual precipitation during the study. The annual posttreatment mean is over 6 inches greater than the long-term and pretreatment means. Average monthly precipitation during the posttreatment period was over an inch greater in the months of June, September, October, and December than the pretreatment period (table 1). Likewise, July was the only pretreatment month that exceeded the posttreatment average by more than an inch.

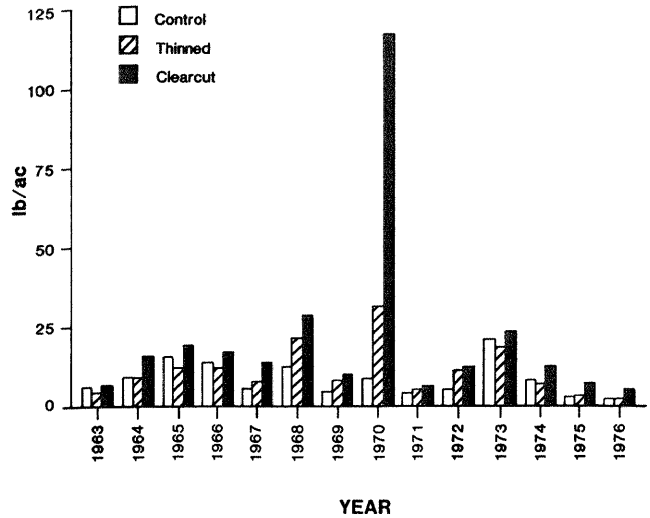

FIGURE 5.--Sediment losses for Alum Creek watersheds, 1963-1976.

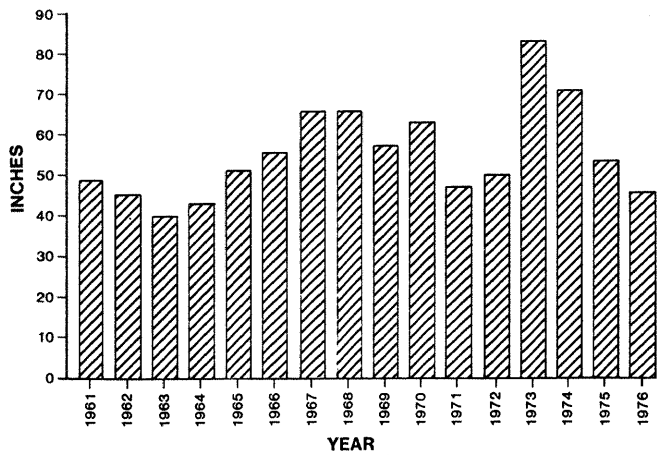

FIGURE 6.--Annual precipitation for Alum Creek watersheds, 1961-1976.

Soil Water

Following thinning and clearcutting in May 1970, growing season soil water deficits were reduced 2 to 3 inches for the thinned and 3 to 4 inches for the clearcut watershed (fig. 7). These reductions on both the thinned and clearcut watersheds continued for several years (fig. 8). Then as the the crowns and root systems of the residual pines expanded on the thinned watershed, the deficits moved toward pretreatment values (fig. 9). Likewise, as grasses became established on the clearcut watershed and transpiration rates increased, the deficits moved toward pretreatment values. However, even after 7 years the growing season deficits had not returned to pretreatment values for either watershed. Dormant season soil water deficits after thinning and clearcutting treatments remained similar to deficits on the control watershed and pretreatment deficits.

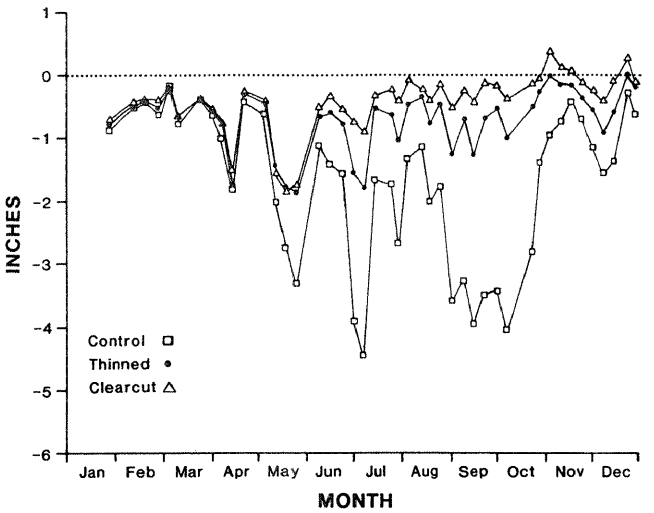

FIGURE 7.--Postreatment soil water deficits for Alum Creek watersheds, 1970.

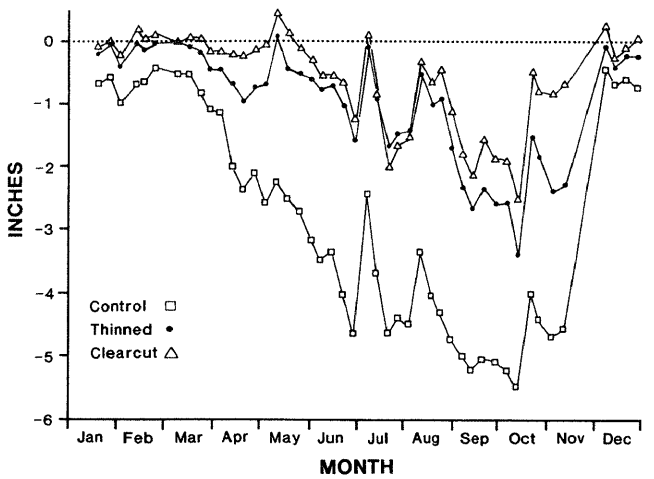

FIGURE 8.--Posttreatment soil water deficits for Alum Creek watersheds, 1971.

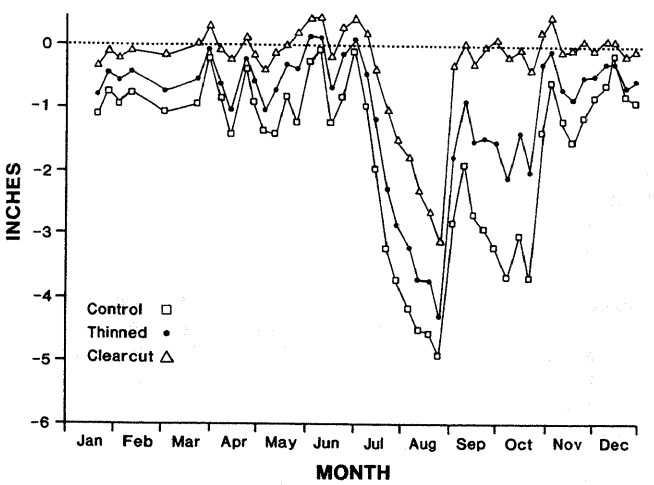

FIGURE 9.--Posttreatment soil water deficits for Alum Creek watersheds, 1976.

Runoff

Runoff was significantly increased by both treatments. The thinned watershed produced 4.3 inches or 79 percent more runoff than would have been expected without thinning the first year after treatment (fig. 10). In the 7 years following thinning, runoff averaged 2.3 inches or 23 percent more per year than prior to thinning. Fifty-two percent of the runoff increases occurred during the growing seasons (fig. 11). These increases were attributed to lower year-round transpiration rates resulting from the thinning. Hibbert (1981) reported that evapotranspiration can be significantly reduced by removing all or part of the vegetation cover, and this increases streamflow.

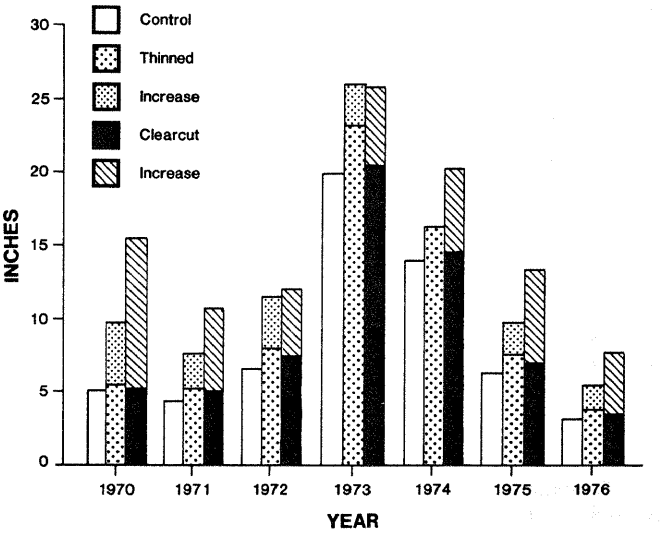

FIGURE 10.--Posttreatment annual runoff for Alum Creek watersheds, 1970-1976.

The clearcut watershed produced 10.2 inches or 193 percent more runoff than would have been expected without clearcutting the first year after treatment (fig. 10). Patric (1980) reported a water yield increase of 9.9 inches during the first year after cutting in West Virginia. At Hubbard Brook in New Hampshire, Hornbeck (1975) found that cutting increased annual streamflow 9.1 to 13.8 inches. Runoff for the 7 years following clearcutting averaged 6.0 inches or 67 percent more per year than prior to clearcutting. Sixty-one percent of the runoff increases occurred during the growing seasons (fig. 11). These increases resulted from almost no transpiration the first year after treatment, with the grasses transpiring at a lower rate than the forest vegetation in the remaining years. Figure 10 illustrates the posttreatment annual runoff differences between the control, thinned, and clearcut watersheds.

The thinned and clearcut watersheds were sprayed with 2 and 4 lb a.e./acre of 2,4,5-T respectively for 3 years following treatment to control the hardwood vegetation. Lawson (1976) reported on the presence of the herbicide in runoff from the watersheds. The herbicide was detected in only two runoff events after the first application. The first event, 3 weeks after application, had concentrations

of 1.0 ppm on the thinned and 2.1 ppm on the clearcut. Two months after application, 0.2 ppm was detected in samples from both watersheds. None of these concentrations are considered as being toxic to man or fish.

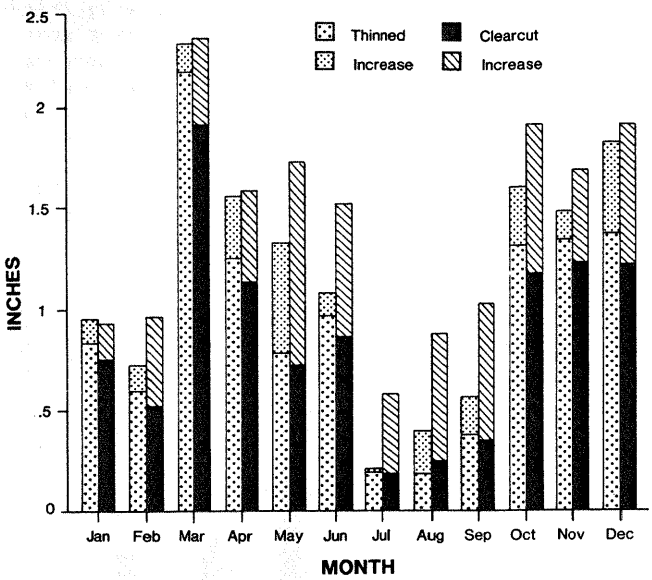

FIGURE 11.--Posttreatment average monthly runoff for thinned and clearcut watersheds, 1970-1976.

Sediment

Thinning and clearcutting increased sediment losses only during the year following treatment (fig. 5). Following thinning, first-year sediment losses were 31 lb/acre, four times greater than expected without thinning. Average losses the next 6 years were slightly less than the pretreatment average. Clearcutting produced losses of 117 lb/acre in the year following treatment, about 10 times the losses predicted without clearcutting. Losses during the rest of the posttreatment period were less than pretreatment values.

Even in the year following treatment, sediment losses were small when compared with the 10,800 to 17,800 lb/acre lost annually from farmlands in central Illinois (Stall 1972). Both pretreatment and posttreatment losses were less than those reported from other forested areas. Ursic (1970) reported average sediment yields of nearly 200 lb/acre from low-quality upland hardwoods in northern Mississippi, and following burning and injection with 2,4-D, sediment yield was increased to 1,024 lb/acre, 428 lb/acre more than expected without treatment. Miller (1984) reported losses of 32 lb/acre from shortleaf pine watersheds in southeastern Oklahoma. These losses increased to 252 lb/acre following clearcutting and site preparation.

Sediment losses are difficult to predict, and nearly all sediment losses from the study watersheds were the result of material flushed from the stream channel. Losses were highly variable, and a few storms accounted for the majority of the losses.

CONCLUSION

The management practices of thinning and clearcutting on pine-hardwood watersheds in the Ouachita Mountains produced hydrologic changes similar to those found in other areas in the eastern United States. Soil water deficits were reduced by both the thinning and clearcutting practices. The smaller soil water deficits were the major reason for runoff increases. Both practices affected soil water deficits and runoff throughout the 7 year posttreatment period. The practices also caused increased sediment losses, but only during the year of treatment. Even these sediment losses were very small when compared with those from farmlands and other forested areas. Current management practices of thinning and clearcutting used in the Ouachita Mountains, if properly adhered to, will not cause flooding, detrimental sediment losses, and loss of site quality.

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