Increasing Water Yield By Cutting Forest Vegetation*

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What is the effect of cutting forest vegetation on streamflow? To find out the maximum range of effects that can be obtained through cutting, four treatments have been investigated on an experimental watershed basis at the Coweeta Hydrologic Laboratory in the Southern Appalachian mountains of western North Carolina. This completely forested 5700-acre area was selected by the U. S. Forest Service in 1931 in the superhumid part of the southeastern United States specifically for watershed management research.

Each of the experimental watersheds has continuous streamflow with an average annual yield around 30 to 40 inches. Average rainfall of 70 to 75 inches is well distributed throughout the year and favorable for high transpiration. The average annual temperature is 55°, while for 5 growing season months of May to September it is 68°. The soils derived from weathering of underlying acid crystalline rocks are relatively deep and permeable. Ground water tables are sufficiently close to the surface to be observed in shallow wells.

The experimental procedure for each treated watershed includes first taking continuous measurements of streamflow, precipitation and temperature for a period of five to ten years under the natural forest cover. This is considered to be a period of calibration and standardization during which the streamflow characteristics are established. Changes in the vegetative cover are then made and the same streamflow and other measurements are continued as during the first period of observation. Annual climatological differences are accounted for by maintaining one or more control watersheds under natural conditions permanently to be used as reference check areas. From these records it is possible to determine the effect on streamflow from cutting forest vegetation using regression methods.

Effect of Complete Clear Cutting with Annual Cutting of Natural Regrowth

This basic study was initiated to find out what would be the maximum effect on streamflow that could be brought about by removal of all tree and shrub vegetation.

The forest types on this 33-acre watershed (Watershed 17) consisted of 93 percent oak-hickory and 7 percent cove hardwood. Rhododendron and mountain laurel formed a dense understory on 60 percent of the area. The forest stand had a basal area per acre of 80 sq. ft., of which 76 sq. ft. was deciduous, 1 conifer and 3 laurel rhododendron. Approximately 1900 stems one-half inch diameter breast height and larger, plus minor woody shrubs and vines growing on the 33-acre watershed, were cut between January 6 and March 31, 1941. The cutting was done with a minimum disturbance to the litter cover and soil. No wood products were removed. Logs and slashings were all left on the ground. Because of the large amount of cut material on the ground, it is estimated that evaporation from soil and interception by tree branches remained about the same as before cutting. The first summer after cutting, all regrowth was cut again. Except during the 1943-1946 period, all regrowth has been cut each growing season.

Hoover (2) reported the increased yield of high quality water for the first year, April 1941—March 1942, was 17 inches or 65 percent. The value for the first year, having been obtained under minimum plant cover, approximates transpiration that would have occurred under natural forest. During late summer months when water shortages usually occur, the increase in useable base flows of the stream amounted to 100 percent.

After the first cutting of all regrowth, a plant cover of herbaceous species, low briars and vines invaded the area. The annual water increases under this cover have now leveled off to around 10-11 area inches (Fig. 1).

Ground water storage is at a maximum both on treated and untreated watersheds during late winter and early spring. At this time, influence of clear cutting is minimized. Starting with maximum storage during March, the ground water depletes slower under a clear-cut condition than under natural forest during the growing season. With reduction in transpiration, summer rainfall is sufficient to raise the soil to field capacity so that free water may pass through the soil to recharge ground water.

Lieberman and Hoover (3) found the flow frequency curves of mean daily discharge after cutting the forest vegetation showed the general level of streamflow was raised,

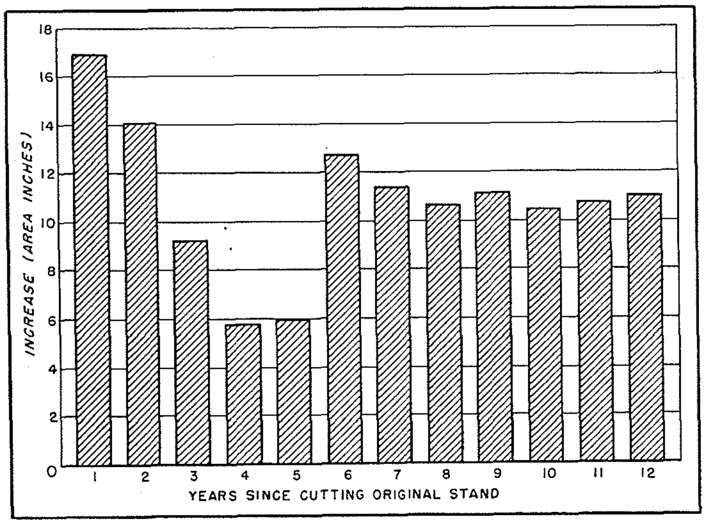

Figure 1.—Increase in water yield following cutting dense hardwood stand and subsequent cutting of all woody sprouts, Watershed 17. Manpower shortage prevented the cutting of sprouts in the third, fourth and fifth years.

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with most noticeable increases occurring in lower ranges of flow (Fig. 2). Mean daily flow at the 16 percent level was increased 124 percent, and at the 84 percent ordinate, 45 percent. The median value was increased 83 percent. Changes in flow above 5 c.s.m. do not appear to be significant, since they usually occur in spring when ground water storage is at a maximum. Increase in flow below 5 c.s.m. is attributed to eliminating transpirational draft of forest vegetation and resulting increased recharge to ground water; which in turn contributes to higher base flows toward the end of the growing season.

Before cutting, the forest canopy completely covered the stream channel. After cutting, the stream was exposed so rains fell directly into the channel. Even with this treatment, maximum flows during storm periods have not been appreciably changed. For many storms, increased storm flows may be accounted for by the higher base of streamflow. Because of the protection given to the soil, no overland flow has occurred during the first 12 years, and flow is still from rapid seepage and ground water.

There has been no change in stream turbidity in the 12 years since cutting the original forest vegetation. It must be remembered, however, that no forest products were removed. All cut material was left where it fell.

The results to date indicate that forest stands on the lower elevation watersheds with a north exposure in the Southern Appalachian mountains annually transpire from 17 to 22 inches of water. This basic study indicates the maximum effect that may be achieved by reducing forest cover in a superhumid climate. A treatment of this type with continued annual cutting of natural regrowth is not a recommended watershed practice. The primary purpose is to aid in determining limits for practical methods of manipulating forest stands to regulate streamflow.

Effect of Complete Clear Cutting with Natural Regrowth

Another treatment was started on Watershed 13 in a similar manner with the cutting of all tree and shrub vegetation. However, in this case, the forest was allowed to come back through sprouting and natural regrowth.

The forest trypes on this 40-acre watershed consisted of 70 percent oak-hickory, 20 percent pine-hardwood, and 10 percent cove hardwood. The forest stand had a basal area of 109 sq. ft. per acre[1], of which 96 was deciduous and 13 conifer. The stand in the coves and lower slopes was composed of vigorous second growth about 40 years old. Along the upper slopes and ridges there were old growth pitch pine hardwoods. Between September 1939 and March 1940, approximately 1100 stems per acre one-half inch diameter breast height and larger, plus minor woody shrubs and vines growing on the watershed, were cut. The cutting was done with minimum disturbance to the litter cover and soil.

Comparing the watershed with itself and also a nearby undisturbed watershed indicated that increases in water yield were not static. It is interesting to note that the increase for the first year of 57 percent was in the same magnitude as on the other clear-cut watershed. Figure 3 shows the percent increase in stream flow by years after cutting. The most rapid change in flow took place in the first three years following cutting and is associated with development of a forest canopy. After the canopy closed, the rate of change leveled off considerably.

[1]In this study laurel and rhododendron were omitted from the cruise.

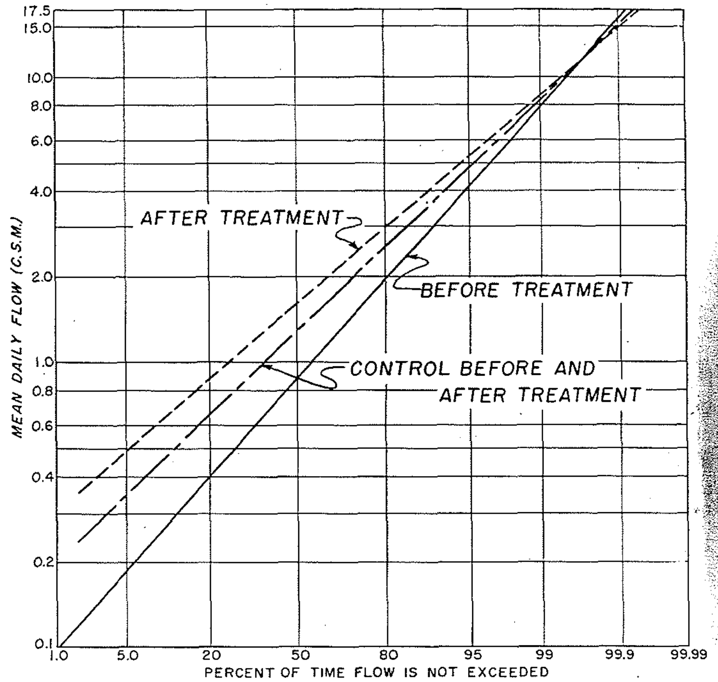

Figure 2.—Flow frequency curves for control and treated watersheds by before and after treatment periods, Watersheds 17 and 18.

After the 12th growing season, a cruise showed the stand averaged 2000 stems ½-inch d.b.h. or larger per acre, had a basal area of 65 sq. ft., and was around 25-40 feet high. At this time, the increase in water yield amounted to 15 percent annually. Projecting this trend line suggests that when the forest stand becomes 20-25 years old, the watershed may operate with approximately the same water yields as during the pretreatment period.

Flow frequency curves of mean daily discharge indicate streamflow increased after cutting the forest vegetation (Fig. 4). The mean value of flow at the 16 percent level was increased 62 percent and at the 84 percent ordinate 17 percent, while the median value increased 41 percent. Since these values are an average for the first seven years after cutting, the changes in streamflow are of a lesser amount than on Watershed 17.

Ground water storage is at a maximum on this watershed during the later winter and early spring. Starting with maximum storage during March, the ground water depletes during the growing season. Even with a 7-11 year coppice forest, the summer rainfall at Coweeta is sufficient to raise the soil to field capacity so that free water may move through the soil to recharge ground water.

Maximum peak discharges have not been changed by this treatment. No overland flow has occurred during the first 13 years and flow is still controlled by ground water conditions. Likewise, there has been no change in stream turbidity since cutting the original forest vegetation in 1939.

The results to date indicate the relative decreases in water yield as a clear-cut forest grows back naturally in a superhumid climate. This illustrates that on forested watersheds water yields can be materially increased or decreased with changes in forest cover.

Effect of Cutting Dense Laurel-Rhododendron Understory

Forest stands of the Southern Appalachian mountains are distinctly three-storied. They consist of crown canopy and understory, which are made up of woody plants, and a shrubby or herbaceous ground cover. Because laurel and rhododendron grow to a height of 10 to 20 feet and have an extensive foliage area, it was believed that large quantities of water were intercepted and used by this vegetation. Since these woody species bring little or no economic return, and compete aggressively with valuable timber, an experiment was designed to determine whether or not removal of this understory would have an effect on streamflow.

The forest stand had a basal area of 114 sq. ft. per acre. Basal area in square feet per acre was distributed as follows:

Deciduous	87
Conifer	2
Rhododendron	11
Laurel	14

Between December 28, 1948 and March 2, 1949, all laurel and rhododendron growing on this 70-acre watershed were cut. All vegetation was cut as close to the ground as possible. The larger shrubs were lopped and scattered to keep the depth of branches less than four feet. This form of cutting did not kill the laurel and rhododendron, but sprout regrowth from stumps was very slow. No cutting of the sprouts was undertaken.

The average increase in water yield for the first 2 years was 3.6 inches, for the third, 2.4 inches, and for the 4th year approximately 1 inch. During the 5th year the change in annual water yield due to this treatment was insignificant.

An analysis of the water balance for this watershed indicates that by complete clear-cutting yields of water may be increased as much as 17 inches. With only 3.6 inches increase from cutting understory vegetation, this suggests that for Coweeta conditions the greatest increases in water yield are by manipulating tree growth forming the crown canopy.

There have been no increases in maximum storm flows from cutting this understory; also, no change in turbidity.

Effect of Cutting a Strip Along the Water Course

A hydrograph feature which showed up on undisturbed forest watersheds during the growing season was the diurnal fluctuation in streamflow and changes in ground water table elevations on some wells located near streams.

These daily variations suggest that vegetation immediately adjacent to the stream has material effects on streamflow and ground water contributing directly to it. It is known through laboratory studies that when water is readily available, many types of vegetation use water at a relatively high rate. Use of water in locations where vegetation has direct access to the ground water continues at high rates during the growing season and reaches a maximum during rainless periods when use of water by vegetation on drier areas is limited by lowered water tables. This suggested that during the growing season greater gains in water yield per unit area may be produced by cutting a strip of riparian vegetation, as compared with vegetation over the balance of the watershed.

It was decided to cut a strip of vegetation on a small head-water drainage area. The treatment area was defined by assuming that vegetation up to 15 feet in elevation above the permanently flowing stream channel had access to the water table. The length of this strip was 1600 feet and the width varied from 50 to 250 feet, which made an area of 2.62 acres or 12 percent of the drainage area.

Cove areas that did not have a permanently flowing stream were excluded by using the strip technique. Later investigation suggested these areas with deep moist soils should have been included.

A 100-percent cruise of the clear-cut strip showed that the forest stand had a basal area of 85 sq. ft. per acre, of which 82 was deciduous and 3 laurel-rhododendron. Approximately 1400 stems one-half inch d.b.h. and larger, plus minor woody shrubs and vines, were cut between July 21 and 25, 1941. The cutting was done with minimum disturbance to litter and soil. No wood products were removed, and logs and slash were left where they fell except for slash which fell in or over the stream channel and this was removed. No further cutting was done following the original treatment and a vigorous sprout forest quickly became established.

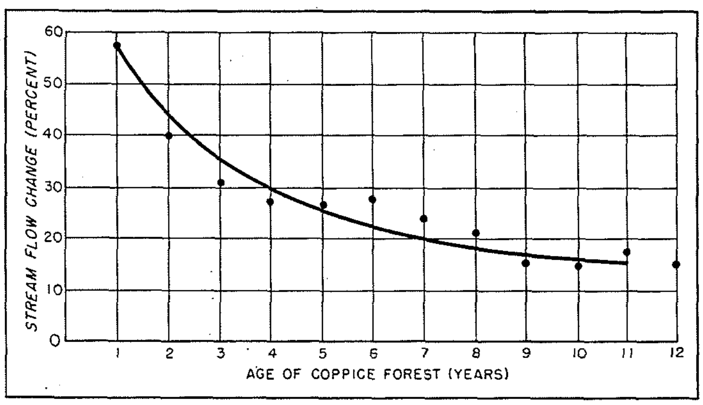

Figure 3.—Clear cutting Watershed 13 brought a 60-percent gain in streamflow. Eleven years after the cutting, annual water yield from the coppice forest was still 15 percent above pretreatment flow.

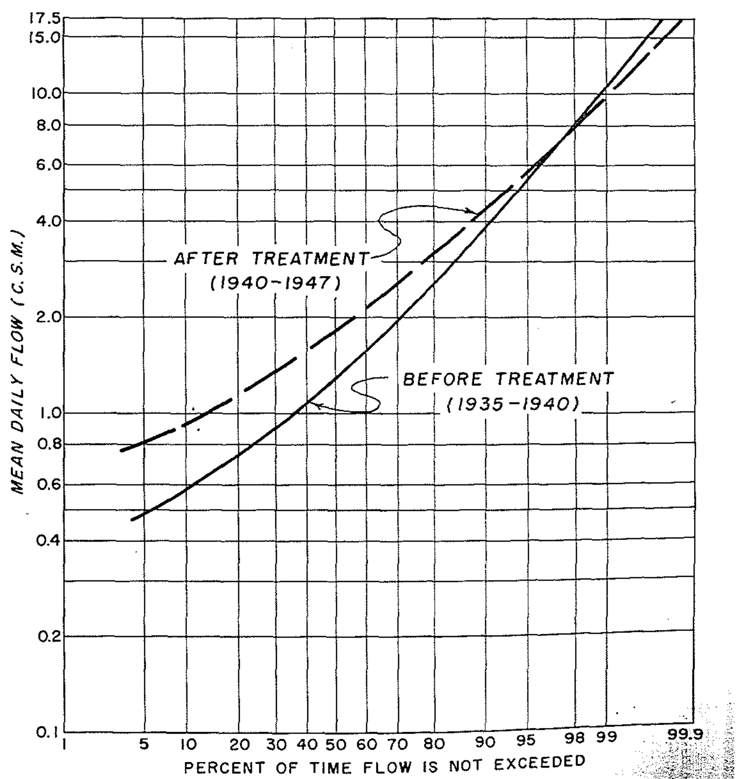

Figure 4.—Flow frequency curves before and after treatment, Watershed 13.

Dunford and Fletcher (1) reported that for a 10-day rainless period the effect of cutting streambank vegetation increased streamflow from 3.8 to 19 percent with an average of 12 for the period. Using the control watershed approach, it was possible to calculate daily regressions for each month during the growing season and predict runoff during rainless periods on the treated watershed. Average daily gains of 365 to 475 cubic feet in water yield for rainless days were obtained during the growing season of the first year. For the same period in the second year after cutting, average daily gains were from 135 to 300 cubic feet. By the third year, sprout vegetation had become well established and no significant increases were detected.

As on the clear-cut watershed, cutting of the riparian vegetation has not increased maximum storm flows; nor has there been a change in turbidity.

This study suggests that water yields may be increased some in the Southern Appalachians during the growing season by eliminating the transpirational draft of streambank vegetation. This may be of much practical value for municipal and industrial watersheds during drought periods when even small increases in yield are important.

Summary

Results to date show that cutting of old growth hardwood stands definitely increases total water yields under the high rainfall conditions of the Southern Appalachian mountains. It does not follow that similar changes in water yield would be obtained under different soil and climatic conditions. Some of the increases appear small, but may be of much practical value during drought periods, when even small changes in yield are important. For example, an inch increase from 1 acre is equivalent to 27,000 gallons. The initial reduction in forest cover was not detrimental to water quality or supply, since the cutting of forest vegetation on these watersheds was in a way that left the forest floor undisturbed and forest soil unimpaired.

The following summary of results obtained through cutting in mountain hardwoods provides an index of the magnitude and duration of increases in water yield by cutting forest vegetation:

(1) The largest sustained increase in water yield was measured where all trees and other woody vegetation was cut, and where regrowth has been cut each growing season. Streamflow was increased 17 inches the first year and for the growing season water yields increased more than 100 percent. With annual cutting of natural regrowth, increases in water yields are maintained at 10-11 inches.

(2) On another watershed all vegetation was cut, but then the forest was allowed to grow back naturally. The increase for the first year of 57 percent was in the same magnitude as in the other clear-cut watershed. The increase in water yield became less in succeeding years as the natural regrowth of the forest took place. For the climate and vegetation at Coweeta, this suggests when the forest stand becomes 20-25 years old, the watershed may operate with approximately the same water yields as during the pretreatment period.

(3) Where the dense laurel and rhododendron understory was cut from an old growth hardwood stand, the average increase in water yield for the first two years was 3.6 inches. The third year it was 2.4 inches, and for the fourth year approximately 1 inch. During the fifth year the change in water yield was insignificant.

(4) Cutting a strip of streambank vegetation definitely increased streamflow on rainless days.

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Use And Construction Of Aerial Photo Base Maps*

(Data as of August, 1954)

By Robt. G. Pruitt, Jr.**

The aerial photograph has long been used by geologists in the study of geology and to illustrate certain geological phenomena in the field. Within the last ten years new fields have adopted the aerial photograph and today widespread use is made of aerial photos in compiling topographic maps, studying flood control, planning highways, and federal regulation of farm acreage, to mention only a few examples. As a direct result aerial photos have become more available to the public, mostly as a service of agencies of the federal government. Today over 90% of the United States is covered by aerial photography suitable for geological purposes. Many areas such as the southeastern states have been photographed by more than one agency. These aerial photos are readily available to the public, and they can be purchased at only a fraction of their actual cost. It is now possible to use aerial photographs in the study of geology in ways never before practicable. The subject of this article deals with aerial photos and their use in the construction of base maps, especially in areas where the existing maps are not suitable for detailed geologic mapping.

Aerial Photos are Maps

An aerial photo map, also known as a mosaic, is essentially a composite picture map of an area, made by assembling overlapping aerial photos together on a flat surface. It re-

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