Pine and Hardwood Forest Water Yield

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Rainfall over the Appalachian Mountains furnishes some fifty million people with a large proportion of their municipal, industrial, and agricultural water supplies. Future management of such a vast area for both timber and water will raise many questions about the influence of different forest types on water yield. For example, will there be differences in the quantity of water flowing from a hardwood forest when converted to pine? This article tells of one experimental effort to make the conversion and find out.

TWO MOUNTAIN WATERSHEDS comprising 70 acres at the Coweeta Hydrologic Laboratory in western North Carolina have been cleared of native hardwoods and planted to white pine. The experiment is one of a series to show the influence of vegetation on streamflow, and as such is one of the largest of its kind ever attempted.

The success of the project depends greatly on the control afforded by the watershed network enclosing the two drainages. The experimental area is an interlocking system of small distinct drainages, selected by hydrologists after careful search through the Southern Appalachian region. Deep, well-drained soils, dense vegetation, and a superabundant rainfall—nearly 80 inches annually—provide ideal conditions for certain types of hydrologic research. The research installations and results have attracted the attention of scientists the world over.

Measurements of rainfall and streamflow constitute the core of hydrologic investigations, and these and other climatic factors have been recorded for many years on twenty-two forested watersheds at Coweeta. This 5600-acre research laboratory of the United States Forest Service has been in operation since 1934, providing fundamental information about the influence of forests and forest land-use on water supplies.

Studies of Comparative Water Yield

Research now in progress at Coweeta includes studies of comparative water yield from several types of vegetal cover. Mature mountain hardwood forest is the base from which the comparisons are made. For example, one study demonstrated large increases in streamflow from a 33-acre drainage area when the native hardwood forest was cut down (Hoover 1944). Another showed a smaller increase when a dense understory of laurel and rhododendron was removed from a 50-acre watershed (Johnson and Kovner 1956). Current plans call for conversion of a hardwood forest to grass cover to determine the differential effect of these two cover types on water yield.

These experimental treatments have shown that drastic reductions in forest cover can increase streamflow temporarily up to 65 per cent. How radical do the changes have to be to result in a minimal but significant increase? Does a shift from one forest type to another offer opportunity for manipulating streamflow? Such changes may take place gradually as a result of purposeful management, or more rapidly, as in cases of severe insect infestation or fire. Differences in water yield from similar forest types are difficult if not impossible to demonstrate, and generally require more sensitive field experiments than have been designed up to this time. On the other hand, obvious structural differences between pine and hardwood stands suggest some differential effects on water yield large enough to be detected by conventional experimental techniques. These effects may also be large enough to influence decisions in practical efforts to manage forest land for more and better quality water.

There are many important reasons for converting hardwood to pine and testing the differences in water yield. Three major considerations are:

First, pine and mixed stands in which pines predominate cover large areas in the eastern United States. Pine forests are not restricted to the southern pine belt and Piedmont areas, but occur also on the watersheds of the Appalachian Mountains (Fig. 1). Some of these pine stands are native; others are the result of natural reseeding or planting of abandoned farmland and logged areas. The practice of planting old fields to pine has increased steadily since the early thirties. Efforts are now being made to convert still other areas of mountain

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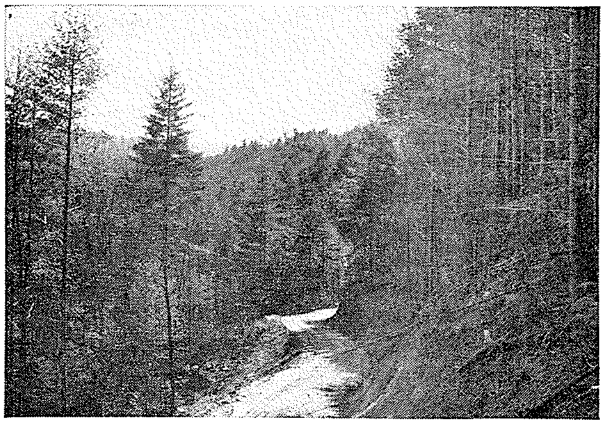


Figure 1. Pure and mixed pine stands cover large areas in the Southern Appalachians.

Figure 2. Planting white pine on a clear-cut watershed. Hardwood sprouts will be cut back annually to insure a pure pine cover.

land now in unproductive low-grade hardwoods to more valuable stands of pine.

Second, many managed municipal watersheds, including those which are strictly reserved for single-purpose use, are partly or wholly in some types of coniferous forest cover. Pines are among the favorite species to plant on such watersheds because they are fast growing, easy to establish and manage, and usually are available at low cost from forest nurseries. If the current trend continues toward producing sustained-yield harvests of timber as well as water from municipal watersheds, management for pine stands may increase. The question will arise as to which should be favored, pine or hardwood, for best yields of clean, quality water.

Third, if future managers of these pinelands and potential pinelands are to have the information they need, the slow processes of hydrologic experimentation must start now. Experiments in which the effects of large-scale vegetation changes on streamflow are determined from rainfall and runoff records require many years to complete. To begin with, we must know the behavior of the stream from a study area before any changes are made. Owing to variations in climate—particularly rainfall—and fluctuating soil water storage, one or two years' record from a watershed is of limited value in assessing the effects of treatment. As a general rule, pre-treatment and post-treatment records should not be less than five years each, and in some cases must be longer.

Evapotranspiration from Pine and Hardwood

In any study of water yield, the amount of rainfall reaching the stream on a water-tight drainage is equal to the precipitation minus the water losses from various evaporative processes. The monthly, seasonal, or annual water loss from vegetated land surfaces is the integrated effects of a dynamic interaction between meteorologic, biologic, and edaphic factors. Meteorologic conditions, including rainfall, humidity, temperature, solar radiation, and wind movement, are thought to exert the largest effect on evaporation rates, and thus on the amount of water released to the streams. However, several experiments have shown that limited control over streamflow can be attained by changes in vegetal cover. The evidence is against spectacular differences in water yield from pine and hardwood, but the possibility of detectable differences still remains.

The respective influence of pines and hardwoods on disposition of rainfall has been the subject of much discussion among hydrologists. Among other things, pines differ from hardwoods in density of crowns and stems, growth form, depth of rooting, total leaf areas, and in the seasonal shedding of leaves. Where pines and hardwoods occur on similar sites, these factors might affect water yield.

Kramer (1942) has shown that white, red, loblolly, and slash pine on the average transpired at about 25 per cent of their maximum transpiration rates when soil temperature was artificially reduced to 32 degrees Fahrenheit. White pine alone, apparently better adapted to northern climates, transpired 40 percent of its maximum rate when the soil was approaching the freezing point. No direct comparison between pine and hardwood is available, but since winter transpiration losses from deciduous trees must take place through twigs and bark, it seems reasonable to assume that more opportunity for transpiration exists in pines than in hardwoods, particularly during mild winter weather.

Plant physiologists suspect that transpiration rates under some conditions are associated directly with total leaf surfaces exposed to the atmosphere. It has been calculated that pines have total numbers of leaves, as well as total leaf areas, several times those of comparable-size hardwoods (Kramer 1952). In addition to the effect on transpiration rates, the greater leaf areas of pine imply more loss of rainfall by direct interception and evaporation from needle surfaces. Estimates of interception losses for forests in different climates have ranged from about 10 to 38 per cent of precipitation. To be sure, this variable loss is mostly a function of rainfall characteristics, such as size and intensity of storms, but sufficient latitude exists to allow vegetation characteristics to exert some influence on interception.

The depth of rooting is another factor which may affect the total amount of water removed from the soil by vegetation. Unless soil depth is limiting, there may be a general tendency for either pines or hardwoods to develop relatively deeper root systems. In dry times, trees with deeper roots will, naturally, have access to and use greater quantities of stored water than trees with shallow roots.

Some characteristics of dense pine stands may tend to inhibit water loss. Deeper crowns and stem densities, particularly of white pine, may reduce wind velocities and light intensities within such stands. At the same time, the heavy litter accumulation typical of some pines affords greater insulation to ground surfaces. Evaporation from the forest floor, an appreciable loss of water in hardwood stands with thin litter, may be reduced by the blanketing effect of pine vegetation.

These conflicting and perhaps compensating tendencies toward water loss or conservation are impossible to isolate and measure separately, at least under natural conditions. Plant physiologists working under controlled conditions have learned much about the behavior and capabilities of individual plants, but are frank to admit that the water relations of plant communities in nature cannot be predicted with sufficient certainty to be useful in water yield studies. For the present, at least, field studies on gaged watersheds seem to offer the best approach to practical information about the water relations of forest communities.

The Coweeta Study

The study described herein was begun in 1955 on a watershed formerly clear-cut to determine the influence of hardwood removal on streamflow (Hoover 1944). In 1956 a second watershed unit was also cleared and planted. Both drainages were gaged for nearly 20 years prior to planting.

White pine was selected as the species most likely to succeed; and seedlings were set out by hand at 6 ft. by 6 ft. horizontal spacing (Fig. 2). Need for routine release cuttings is anticipated for several years. One treated watershed faces north and the other south, affording an opportunity to compare results on opposing aspects. Each cleared and planted watershed is associated with a control drainage on which an undisturbed mature hardwood forest will be maintained throughout the course of the study.

The methods used in this particular study have become standard in hydrologic investigations. The basic instruments are rain gages and the weirs that intercept and measure streamflow. The relative accuracy of rainfall estimates depends on the number and proper location of gages. The performance of a weir depends in no small part on design factors and how well it is constructed. The selected watershed should be neither too large to treat experimentally, nor so small as to allow minor variations in underground water divides to be a proportionally large source of error. The unit watersheds in this experiment average about 35 acres, more than sufficient to sustain permanent streamflow even in the driest years.

Use of a control watershed is essential in studies which aim at showing variations in streamflow due to vegetation changes. It is preferable to have controls adjacent to treated watersheds, a condition admirably satisfied in the study reported here (Fig. 3). The more similar the rainfall, soils and climate on treated and control watersheds, the more sensitive will be the test of changes in streamflow.

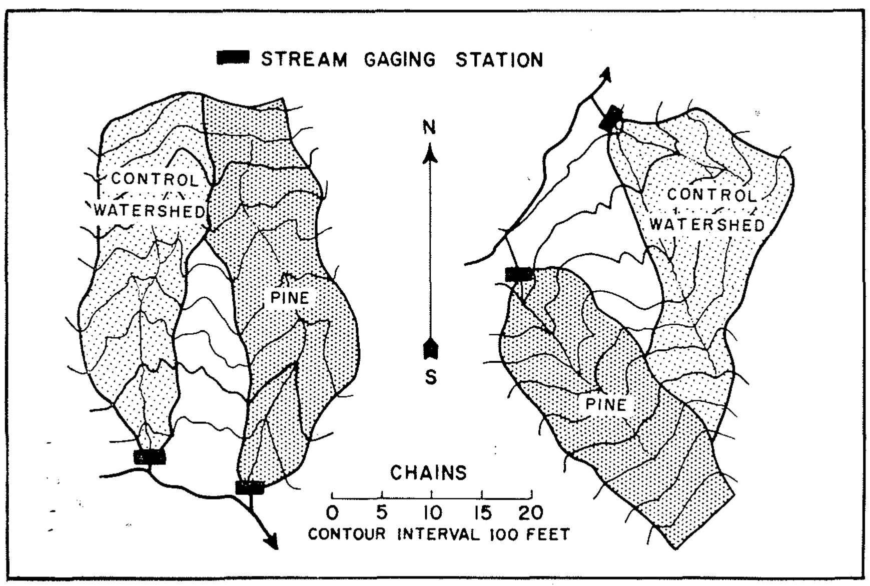


Figure 3. Map showing orientation of the test watersheds and the adjacent controls.

Precipitation and streamflow were measured for many years on the two control watersheds and the two converted watersheds before any clearing was done. By deducting streamflow from precipitation, the relative magnitude of water losses under native hardwoods was established. This was roughly 38 area inches annually, averaged for all four watersheds. Establishment of regression relations between treated and control units showed that the streamflow from one watershed can be predicted from another to within 5 per cent accuracy, limited by the range of precipitation experienced during the calibration (pre-treatment) period. During subsequent months, seasons, or years, streamflow on the treated drainage is predicted from the control. If the actual flow is significantly different from the predicted flow, the difference is said to be due to the treatment.

A basis for a preliminary analysis of the effects of the hardwood conversion to white pine will be provided within ten years, or when the pine plantations have completed crown closure. It is expected that the study will continue through the management phases of pine to an ultimate comparison of mature stands. Methods of managing white pine on watersheds will presumably become an integral part of the later stages of the study.

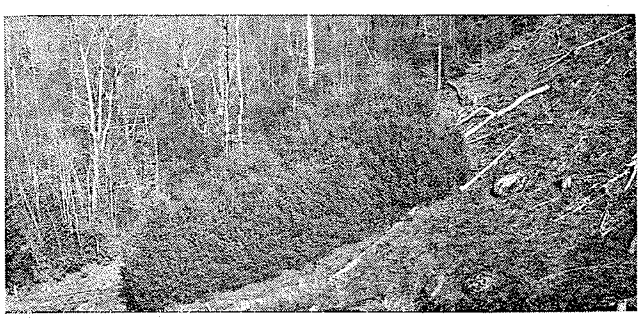
White Pine Test Planting: A Preview

In anticipation of the experiment outlined above, three small test plots were planted to pine on the north-facing watershed in 1945. The plots, now containing trees up to 25 feet in height, afford a preview of conditions on the entire watershed in ten years time (Fig. 4).

Dense young pine stands with heavy needle-fall are proficient in eliminating understory vegetation once crown closure is accomplished. Accumulated litter, low light intensities, and a tendency toward acidity in the developing humus create conditions generally considered unfavorable to the activity of soil micro-fauna and low-growing shrubs and herbaceous plants. Some of the trends in forest floor development and understory vegetation are already quite apparent in the 12-year-old test plots as illustrated (Fig. 5).

Figure 4 *(Below)*. Test plot of white pine planted in 1945. Some stems exceed 25 feet in height.

Figure 5 *(Right)*. Interior of one of the white pine plots. Note dense crowns and litter buildup.



A comparison of the test plots with nearby hardwood stands shows some changes in the upper layers of the soil. Although there appears to be less humus incorporated with mineral soil under pine, the total depth of litter and unincorporated humus tends to be greater through most of the year than under hardwoods. This leaves little reason to believe that storm peaks or soil movement will increase as the stand develops. On the contrary, with less seasonal fluctuation in litter depth, the soil on these experimental watersheds may have better protection throughout the year under pine cover.

The two large plantations stand as a living laboratory in which to investigate the value of pine on mountain watersheds of Eastern United States. Little is known about possible effects of deeper litter on interception losses. Converting a hardwood site to pine may have long-range effects on the permeability of humus and the upper layers of the mineral soil beneath. The greater combustibility of pine litter and the consequent danger of severe burns on pine-covered watersheds are conditions which may affect watershed management objectives. These and other important influences of pine on the watershed are to be investigated as part of this long-term research problem.

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