Conversion of Hardwood-Covered Watersheds to White Pine Reduces Water Yield

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Abstract. Mixed mature hardwoods were cleared from two Southern Appalachian experimental watersheds, and the areas were planted with eastern white pine in 1956-1957. Once the pine crowns began to close, streamflow steadily declined at a rate of 1 to 2 inches per year. By 1967, water yield was 3.7 inches less from a 10-year-old pine stand on a south-facing watershed than expected water yield from the original hardwood forest. Most of the water yield reduction occurred during the dormant season and was attributed mainly to greater interception loss from white pine than from hardwoods. Because interception differences increase as white pine matures, an even greater reduction in streamflow is expected. (Key words: Water yield; watershed management; interception; basins; white pine)

Perhaps without fully realizing it, the watershed manager may play an important part in developing water resources through his management of the forests. For example, research has shown that harvesting forest products can substantially increase streamflow [Hibbert, 1967; Lull and Reinhart, 1967] and that, unless care is exercised during road construction and logging, water quality will suffer [Packer, 1967]. Water yield may also be influenced in less obvious ways; for example, in the choice of tree species to be grown.

Hewlett [1958] presented reasons why streamflow from pine- and hardwood-covered watersheds might differ and described the studies at the Coweeta Hydrologic Laboratory, where two catchments were cleared of native hardwoods and planted to white pine (Pinus strobus L.). This paper presents results from ten years of streamflow measurement following the cover type conversion of these Southern Appalachian watersheds. Results provide hydrologists and municipal watershed managers with conclusive evidence of some early effects on water yield when mixed hardwood forests are converted to pine.

History of Experimental Area

The experimental watersheds are located in the high precipitation (2% snow) region of western North Carolina and are characterized by deep, permeable soils. Slopes are steep, and prior to treatment oak-hickory was the prevalent forest type (Table 1).

Watershed 1 is 40 acres in size and slopes at 45% to the south. Rainfall averages 68 inches annually, and streamflow during the 10-year calibration period beginning in 1944 averaged 31 inches. In 1954, all vegetation within the cove type (25% of the watershed area) was deadened with chemicals. The entire watershed was clearcut during October-December 1956; slash was scattered and partially burned, and white pine seedlings (2-0 stock) were planted at a 6- by 6-foot spacing during the winter of 1957. Initial survival was only 00%, and dead seedlings were replaced in 1958. Thereafter, competing hardwood sprouts were cut or sprayed with 2, 4, 5-T as required to release the pine. In 1967, the pine averaged 20 feet in height (Figure 1), contained 32 square feet basal area with a stocking of 720 trees per acre, and had attained a mean breast height diameter of 2.9 inches.

Watershed 17, in contrast to Watershed 1, is 33 acres in size and slopes 57% to the northwest (Figure 2). Annual precipitation averages 76 inches, and streamflow for the four-year calibration period averaged 27 inches. All shrub and forest vegetation was cut during January-
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TABLE 1. Cruise Summary of Coweeta Watersheds 1 and 17

<table>
<thead>
<tr>
<th>Species</th>
<th>Basal Area (Ft²/Acre)</th>
<th>Watershed 1 (1954 cruise*)</th>
<th>Watershed 17 (1941 cruise*)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>17</td>
<td>25</td>
</tr>
<tr>
<td>White Oak Group</td>
<td></td>
<td>27</td>
<td>20</td>
</tr>
<tr>
<td>Red Oak Group</td>
<td></td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Hickory</td>
<td></td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Laurel and Rhododendron</td>
<td></td>
<td>26</td>
<td>20</td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td>84</td>
<td>80</td>
</tr>
<tr>
<td>Total Original</td>
<td></td>
<td>32</td>
<td>42</td>
</tr>
</tbody>
</table>

March 1942 without removal of timber products. Thereafter, annual sprout growth was cut back most years between 1943-1955, and a low herbaceous and shrub cover developed. White pines were planted in 1956, one year before Watershed 1 was planted; survival averaged over 90%, and dead seedlings were replaced the following year. Hardwood sprout control was similar to that on Watershed 1. By 1967, Watershed 17 had 1/3 more basal area (42 square feet total) than Watershed 1. Stocking was 685 trees per acre with a mean diameter of 3.4 inches, and height averaged 25 feet.

RESULTS

Figures 3 and 4 show the annual difference between actual and predicted water yield for calibration and treatment periods on Watersheds 1 and 17, respectively. Analysis is based on monthly streamflow prediction equations derived from a calibration period during which a control watershed and the watershed to be treated were in an undisturbed condition. Annual treatment effects are the sums of deviations from twelve monthly calibration regressions (actual minus predicted flow).

The effects on streamflow of clearcutting these watersheds were discussed in detail by Hoover in 1944, Hewlett and Hibbert in 1961, and Hibbert in 1967. The most striking contrast in early results is the nearly threefold difference in yield increase observed when these north- and south-facing basins were cut. The large difference in yield response with aspect is consistent with findings from other watershed cutting experiments at Coweeta [Hibbert, 1967]. Swift [1960] calculated that the theoretical extraterrestrial radiation on Watershed 1 is 38% greater than on Watershed 17, and Douglass [1967] suggested that these radiation differences may be a major factor in the different yield response to clearcutting.

Changes in streamflow from the treated catchments remained relatively constant from the second year after pine was planted until about the sixth year. Thereafter, streamflow additions from the clearcutting treatment steadily declined as the crowns of the white pine closed. By 1966, water yield from Watershed 1 was 1.9 inches less than predicted for the original hardwood cover. The next year the white pine basal area had reached 32 square feet per acre and streamflow dropped 3.7 inches below that predicted for the original (84 square feet) hardwood stand. Annual streamflow is significantly different at the 0.95 probability level if it differs from the predicted flow by more than ± 1.2 inches for Watershed 1 in 1967. This error term was derived from the sum of the variances for the twelve monthly streamflow estimates.

Watershed 17 showed a net decrease in streamflow from the calibration period of only 1.3 inches (±1.7 inches is required for significance) in 1967, but total reduction in water yield has been greatest on this catchment. Comparison of total yield reductions can be made if a period can be selected when vegetation was similar on both catchments. Preceding reforestation, cutting operations were different; at time of planting, shrub cover was much greater on Watershed 17. However, one might assume minimum vegetation differences between catchments in the third and fourth years following planting, because release measures had reduced shrub cover to similar levels, and pines were just beginning rapid growth. Thus, using the average deviation in streamflow for the third and fourth years as a reference point, the change in streamflow deviations from regression by 1967 was 10.9 inches on Watershed 17 and 5.6 inches on Watershed 1. The increase in pine basal area during the same period has also been greatest on Watershed 17.

The sharp decline in streamflow for the past
five years has averaged more than 2 inches per year on Watershed 17 and 1 inch per year on Watershed 1; thus far, there is no evidence that the rate of change in annual streamflow from either watershed has begun to taper off. In contrast, Kovner [1956] reported a gradual decline in the rate of streamflow reductions following early regrowth of a clearcut hardwood forest at Coweeta.

Reductions in monthly water yields for Watershed 1 in 1966 and 1967 were greatest during the dormant season, even though most months contributed to the yearly decrease (Figure 5). In the months of May and June and November through March 1967, streamflow was significantly less (0.95 probability level) than predicted for the previous hardwood cover. A pattern of increasing monthly streamflow reductions from year to year was also evident in data from preceding years. On Watershed 17, a significant
decrease in streamflow occurred only in the month of January; however, the same pattern of progressively falling yields in most months for successive years was likewise found on this catchment (Figure 5). Watershed 17 had a comparatively short (four-year) calibration period, which contributed to the large confidence intervals for streamflow estimates. For example, streamflow decreases in May and April are large, but they are not yet significant.

**DISCUSSION**

These experiments provide the first conclusive evidence of how streamflow changes when hardwood stands are converted to white pine. The implications are far-reaching. Streamflow levels began dropping six years after conversion, and, after only ten years of growth, annual evapotranspiration losses were greater from white pine than from the hardwoods it replaced. A greater, perhaps much greater, reduction in
streamflow is expected as the plantations mature. We suggest that the reduced flow results primarily from increased interception loss by the pine.

Summaries of forest interception studies [Zinke, 1967; Kittredge, 1948] indicate that higher interception losses could be expected from white pine during the dormant season, since the intercepting surface in a hardwood stand is drastically reduced following leaf fall.

Fig. 3. Actual minus predicted annual streamflow for Coweeta Watershed during calibration and treatment periods (May-April water year).

Fig. 4. Actual minus predicted annual streamflow for Coweeta Watershed during calibration and treatment periods (May-April water year).
This is confirmed by experiments conducted near Coweeta, which show that 10-year-old white pine intercepts more precipitation than mature hardwoods [Helvey, 1967], and most of the difference occurs during the period when hardwoods are leafless. Monthly differences in interception loss for these two forest types were calculated from equations derived by Helvey [1967] and Helvey and Patric [1965]. Since interception varies with frequency and amount of rainfall, actual precipitation received on Watershed 1 during 1967 was used in calculating 10-year-old pine and mature hardwood values (Figure 6). The figure shows that interception differences between young pine and mature hardwoods are closely correlated with observed reductions in water yield from Watershed 1 during November through
March. Water yield reductions are insignificant in the period July through October, when both stands are in full leaf and interception differences are small. Streamflow deviations and interception differences for the period of July through March are highly correlated ($r = 0.92$). Watershed 1 was selected for the above discussion because the precision of predicting yield changes is greater there than on Watershed 17. The interception-water yield reduction pattern was similar but less distinct on Watershed 17.

Interception loss appears to account for only part of the negative deviations in streamflow during April, May, and June (April 1967 represents an unusual event, since previous years showed consistent reductions in water yield for this month). Streamflow reductions during these months might be partially attributed to transpiration differences, since pine foliage is transpiring water before and during leafing out of hardwoods. Differences in stage of development of transpiring surfaces have largely disappeared by the end of June. From Raber's [1957] summary of transpiration studies, it appears that during summer transpiration rates of hardwoods per unit of leaf area are 2 to 3 times greater than conifers. However, Kramer and Kozlowski [1960] point out that, for trees of similar size, transpiration per tree may be higher for conifers because of a greater total leaf area. Quantitative data on transpiration differences between conifers and hardwoods during winter months are limited, but most studies indicate that rates per unit surface area for conifers are only slightly greater than for hardwoods [Kozlowski, 1943; Weaver and Mogensen, 1919]. Comparative measurements of seasonal transpiration and transpiring surface area are needed before convincing statements can be made about the effect of transpiration differences on water yield. As these catchment experiments at Coweeta continue, physiological studies will be made in an effort to clarify further the relative importance of transpiration and interception.

We hypothesize that streamflow from these white-pine-covered watersheds will continue to decline, and that even greater differences in water use are inevitable. There is evidence from previous Coweeta studies that as hardwood stands regrow in diameter and height after cutting, evapotranspiration increases and streamflow progressively decreases [Douglass, 1967; Hewlett and Hibbert, 1961; Hibbert, 1967; Konner, 1950]. A similar response is expected as the pine stands mature. The hypothesis is further supported by Helvey's [1967] interception work, which shows an average annual interception difference of 9 inches between 60- and 10-year-old white pine stands. The data in Figure 6 indicate that large interception differences between pine and hardwoods may eventually appear during both winter and summer months.

The results and supporting evidence presented here are of practical significance to watershed managers. Conversion from mixed hardwoods to white pine has lowered water yield, and all evidence indicates that substantially larger reductions in yield must be expected. Although results reflect a specific set of climatic, vegetative, and soil conditions, and identical water yield reductions would not be expected elsewhere, the evaporative processes involved are universal. Thus, a trend toward reduction in total water yield should also be expected in other regions.

Most of the flow reduction has come during the dormant season, when high flows fill storage reservoirs. In drought years, when streamflow is insufficient to refill reservoirs, water shortages will be aggravated by hardwood to pine conversion. The ultimate impact of conversion on the low flow period is uncertain, but continuation of the current monthly trend of flow reduction will adversely affect flow during this period. Thus, where water is the resource of primary concern, as it is on municipal watersheds, it would appear wise to consider carefully the effect on water yield of converting from hardwood to white pine.

REFERENCES

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