Water Yield Changes after Converting a Forested Catchment to Grass

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Abstract. A 22-acre catchment in the southern Appalachians was cleared of hardwood forest in 1958 and 1959 and seeded to Kentucky 31 fescue grass in 1959 and 1960. The amount of evapotranspiration by the grass cover was closely related to the amount of grass produced. During years when grass production was high, water yield from the catchment was about the same as or less than the expected yield from the original forest. As grass productivity declined, water yield gradually increased until it exceeded the predicted yield from the forest by over 5 inches annually. The grass appeared to evaporate more water early in the spring and less water late in the summer than the original forest cover.

INTRODUCTION

In areas where water is scarce, land managers are searching for methods of increasing streamflow. Even in well watered forest areas, local water shortages are becoming common as municipal, industrial, and other demands for water exceed the supply from local sources. One method of increasing water yield on forest land is to cut the trees. *Hibbert*'s [1967] review of forest treatment effects on streamflow has shown that cutting forest vegetation can substantially increase streamflow. Another method of increasing streamflow is to convert forest stands to a less water-demanding cover. The difference in water use by the two cover types represents the water presumed to be available to augment streamflow. One possibility is to convert from forest to grass, because plot and lysimeter studies have shown that grass uses less water than trees and brush [*Law,* 1957; *Marston,* 1962; *Metz and Douglass,* 1959; *Patric,* 1961; *Rowe and Reimann,* 1961]. Experimental watershed studies have verified that streamflow on some watersheds does increase after moist forest sites are converted to grass [*Rich et al.,* 1961; *Rowe,* 1963]. In the most recent study a dense stand of oak trees and brush on a 12-acre watershed in California was killed chemically and replaced with annual grasses, forbs, and legumes [*Lewis,* 1968]. Streamflow during the next three years averaged 4.5 inches more than the predicted flow for the catchment.

Since forest-to-grass conversion offers a promising method of increasing man's water supply, an oak-hickory forest growing on a steep 22-acre catchment at the Coweeta Hydrologic Laboratory in western North Carolina was cleared, and the watershed was seeded to Kentucky 31 fescue grass (*Festuca arundinacea* Schreb.). It was expected that streamflow would increase after conversion, and the intent was to document the magnitude of the increase under Appalachian forest and climatic conditions.

DESCRIPTION AND HISTORY

Watershed 6 faces northwest and had deep, permeable soils derived from Carolina gneisses of the Pre-Cambrian origin. The mean elevation of the watershed is 2600 feet, and its slopes, which average 35%, formerly supported a predominantly oak-hickory forest cover. Mean annual precipitation is 73 inches (2% snow), and annual streamflow averaged 33 inches when the watershed was under forest cover. The Coweeta basin, which includes this watershed, was cut over between 1909 and 1923. From 1923 until 1942 the forest was undisturbed except by the chestnut blight which killed the remaining chestnut. In 1942 the forest consisted mostly of an

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oak-hickory stand of low quality with scattered openings occupied by mountain-laurel (*Kalmia latifolia* L.), rhododendron (*Rhododendron maximum* L.), and other low, shrubby species. Cove hardwoods were restricted to a narrow band immediately adjacent to the stream channel.

In July 1942, 12% of the catchment (2.7 acres) along the stream was cut to determine the effect on water yield of cutting streamside vegetation [*Dunford and Fletcher,* 1947]. Diurnal fluctuations of streamflow were damped for several weeks by this treatment, but the savings in evapotranspiration were not sufficient to be detected as a seasonal or annual increase in streamflow. By 1958 the streamside vegetation had regrown to a dense coppice forest containing a basal area of 20 square feet (2650 stems) per acre. The remaining nineteen areas supported a stand with a basal area of 95 square feet per acre in stems greater than 1 inch d.b.h. This is a less dense stand than is found on most other north-facing watersheds, which average about 110 square feet per acre. Except for 1.2 acres in roads and rain gage openings, the area was completely forested when the conversion from hardwoods to grass took place.

METHODS

Streamflow from watershed 6 (Figure 1) is measured by a sharp-crested V-notch weir. Watershed 14 serves as a control catchment and is partly visible to the right of watershed 6. In this experiment the techniques of calibrating and evaluating treatment effects on paired watersheds are basically those of *Wilm* [1943] and *Kovner and Evans* [1954]. However, streamflow was analyzed by months so that seasonal differences in the effect of treatment could be detected. Monthly streamflow prediction equations were derived from twelve years of calibration data by multiple regression. The analysis was carried out on a computer programed for a BMDO2R step-wise regression. This regression was developed by the Health Sciences Computing Facility, University of California, Los Angeles.

All independent variables in the regression were flow parameters for watershed 14: monthly flow, first, second, and third antecedent month's flow, monthly flow squared, second + third antecedent month's flow squared, first antecedent month's flow squared, all in inches; first 10-day average flow rate in cubic feet per second per square mile (cfsm); and second 10-day average flow rate (cfsm). In each of the twelve monthly equations, monthly streamflow on the control watershed was the most important independent variable. Monthly prediction equations included only those variables which significantly reduced the error term. In eight of the twelve months, the prediction equation included more than one variable; but no prediction equation included more than four variables.

The difference between predicted and measured streamflow during the treatment period was ascribed to the treatment if the streamflow difference was significant at the 0.95 confidence level. The error associated with monthly regressions (0.95 confidence level) varied from as little as 0.13 inch for May 1961 to as great as 0.47 inch for October 1964. Estimates of the treatment effect for each water year ending in March were obtained by summing the twelve monthly differences between predicted and measured flow. Likewise, the annual prediction error was obtained by summing the variances of the individual monthly regressions. A difference of approximately 0.73 inch was required to show a significant treatment effect for the water year.

The conversion to grass treatment began in 1958 when all merchantable timber was cut and removed. All remaining vegetation below the lower contour road (Figure 1) was cut, piled, and burned in the late summer. A seedbed was prepared by a combination of burning, grubbing, and harrowing, and in March 1959 three tons of ground limestone and one ton of 2-12-12 NPK fertilizer, and 20 pounds of fescue seed were applied to each acre. These same procedures were followed on the two upper areas. The area between the roads was seeded in July 1959, and the remaining four acres were cleared during the fall of 1959 and seeded in March 1960. A nitrogen deficiency became apparent in May 1960 and was corrected by applying 200 pounds per acre of 33.5% ammonium nitrate to the west-facing slopes and to the area above the upper road. By autumn a dense stand of grass 2 to 3 feet tall covered the entire catchment (Figure 1). During subsequent years the sprouting and regrowth of laurel, rhododendron, and other hardwood species were controlled by a foliar spray of 2, 4, 5-T in water. After the conversion to grass was completed, no treatment or maintenance except sprout control was done until 1965. Then in late March 600 pounds per acre of 30-10-0 NPK and 150 pounds per acre of 60% potash were broadcast over the watershed.

Grass weight on watershed 6 was sampled at roughly 2-month intervals at twenty-two sampling sites located at random on the catchment. All living and dead grass was clipped from each 1-meter-square plot and was oven-dried at 105°C. Only those samples taken during the growing season were used to get the average dry weight of grass for each year. Separation of current grass from grass which remained from the previous season was impractical, and seasonal averages contained a carry-over from the previous year. The carry-over was greatest for the 1961-62 water year and was least for the 1965-66 water year. The over-all effect of the carry-over was to indicate higher grass production each year than actually occurred, although relative production from year to year was not materially affected.

RESULTS

Streamflow on watershed 6 increased by 2.9 inches during the 17-month period of conversion from forest to grass (November 1958 to March 1960). Most of the increase came during periods of heavy rain in the late summer of 1959. Some overland flow was observed during this period on the newly seeded central portion of the catchment, but the amount of overland flow was only a small part of the total flow for the period. The increase in water yield during this period was much less than that which came immediately after other treatments at Coweeta, where hardwood forests were cut on entire watersheds [*Hewlett and Hibbert,* 1961].

Figure 2 shows monthly deviations from predicted streamflow on watershed 6 from 1958 to 1966. A negative deviation indicates less streamflow (greater water use), and a positive deviation indicates greater streamflow (less water use) from the watershed under the grass cover than would have occurred if the area had remained in forest. During the first water year after the grass was established (April 1960 to March 1961), a net decrease in streamflow of 0.67 inch was observed. The dense, vigorous grass completely shaded the ground and appeared to use substantially more water during the early part of the 1960 growing season than the hardwood forest it replaced.

From April through July the streamflow from watershed 6 was less than that predicted by the regression equations for the original hardwood cover. The decrease in streamflow was 0.37 inch in April, 0.39 inch in May, 0.33 inch in June, and 0.19 inch in July. Thereafter until the following April the streamflow recovered to precutting levels except for February 1961, when heavy rains fell and streamflow increased by 0.44 inch.

The results during the early growing season of the second water year were similar to those during the corresponding period of the first year; the streamflow was significantly less than that predicted for the forest cover during the months of April through July. Heavy rains in August, however, were followed by significant increases in streamflow during August and September. Furthermore it appears that soil water which otherwise would have been evaporated and transpired on watershed 6 during the growing season was rapidly flushed through to the stream by the heavy rains in December and January. These increases in streamflow more than offset the reduction in flow during the early growing season; when the second water year ended in March 1962, the total streamflow for the year was 1.84 inches above the predicted level. Again these fluctuations in streamflow indicate that the grass cover used substantially more water in the early part of the growing season and less water in the late part than the forest it replaced.

This seasonal pattern of water use by the grass persisted during the next several years, even though the average flow gradually increased to well above the predicted level. In the 1962–1963 water year the flow from watershed 6 from May through August was not appreciably different from that predicted for the original hardwood cover (small positive and negative deviations were not significant), but monthly increases from October through March were all significant at the 0.95 level of confidence. The water year ended with a net increase in streamflow of 2.51 inches.

Even larger increases in streamflow occurred

Fig. 1. This 22-acre catchment (watershed 6) in western North Carolina was cleared and seeded to Kentucky 31 fescue grass from 1958 to 1960 and maintained under grass until 1966. The control catchment is to the right of watershed 6.

in the 1963–1964 and the 1964–1965 water years: net increases in flow were 5.78 and 5.86 inches, respectively. Monthly deviations were positive for all months (Figure 2), although flow during several months was not significantly different from the predicted flow. The largest increase in flow usually appeared after midsummer. The exceptionally large increase (almost 3 inches) in October 1964 was caused by an unusually dry period from May through September followed by a record rainfall of nearly 19 inches in 5 days. During these dry months the grass-covered catchment probably lost substantially less water to the atmosphere than if the area had remained in hardwoods. As a result the water content of the soil profile remained relatively high on watershed 6 until the end of the dry period. Thus when the heavy rains came at the end of September, the soil profile was quickly recharged, and a much larger proportion of the rain became streamflow than would have been the case had the original hardwood forest remained. No overland flow was detected.

A strong inverse relationship was noted between the net changes in annual streamflow and grass production (Figure 3). This relationship is thought to account for the changes in annual water yield. Immediately after conversion the grass cover on watershed 6 was dense and vigorous. During this period, particularly in the early growing season, the grass used more water than the original hardwood cover would have; consequently streamflow decreased 0.67 inch for the 1960–1961 water year. The grass was not fertilized until 1965, and grass production declined each year. The decline was accompanied by a change to a lighter color, which

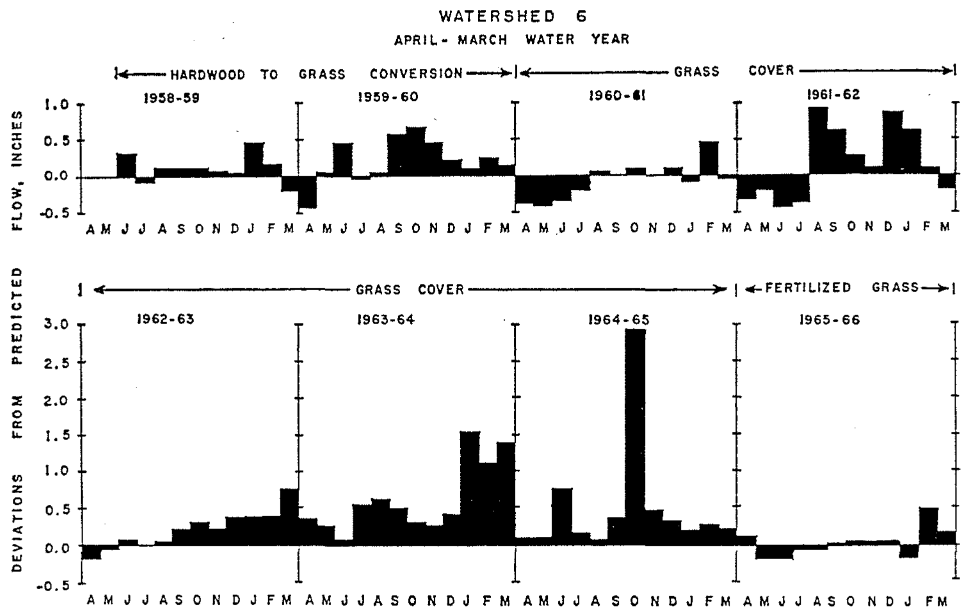

Fig. 2. Deviations of the monthly streamflow on watershed 6 from the predicted flow during the conversion from hardwood to grass and the six years under a grass cover.

may have helped to alter the rate of transpiration of the grass. This color change seemed to be caused by two factors: the yellowing of the living grass, and, as the density declined, an increasing amount of litter showing through the live grass canopy. The decline in grass was accompanied by a general increase in the levels of streamflow during all months of the year.

By 1964 the inverse relationship between grass production and water yield was so obvious that the grass was fertilized a second time. Restoration of the grass cover to its original vigor, it was felt, would confirm the theory that water use is closely tied to grass production and vigor. The fertilizer was applied in late March 1965, and the grass responded quickly with a vigorous, heavy growth that once more completely shaded the ground. In May and June the streamflow was significantly less than predicted for the first time since 1962; during most of the remaining months, streamflow was at or near preconversion levels (Figure 2). With only minor changes, the pattern of monthly flow differences during the 1965–1966 water year duplicated that of the 1960–1961 water year when grass production also was similar. The 1965–1966 water year ended in March with no real change from the predicted water yield.

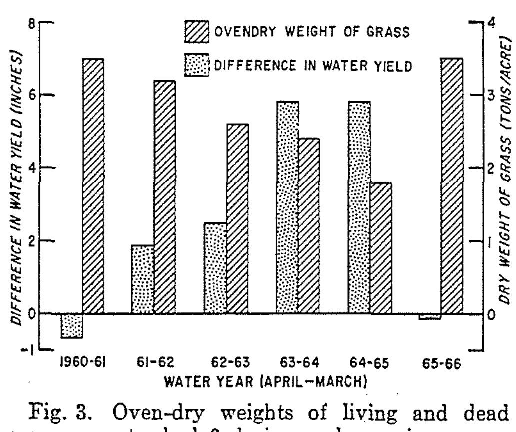

Fig. 3. Oven-dry weights of living and dead grass on watershed 6 during each growing season compared with the differences between the annual water yields from the watershed and those predicted for the original hardwood cover.

DISCUSSION

Just after the grass was established and again after it was fertilized in 1965, annual water use by the grass was essentially the same as use by the original forest. This was contrary to expectations, since all the watershed experiments cited earlier reported first year increases in streamflow after conversion to grass.

This apparent inconsistency in findings may be due to several factors.

First, the density of the original forest cover on watershed 6 was approximately 14% less than for average stands at Coweeta. Therefore water use by the original stand may have been less than average for typical Coweeta stands. Thus the comparison here is not between water use by the grass and by a typical hardwood forest but rather between water use by a grass cover on watershed 6 and by the original forest stand on that catchment. Also the grass cover on watershed 6 was probably more dense than grass on the watershed experiments conducted in the West. If so, water use by the grass at Coweeta may have been greater than use at the other sites.

Furthermore the watershed experiments in forest-to-grass conversions cited previously were conducted in semiarid regions where shallow-rooted grasses are dormant when moisture is limiting in the upper few feet of soil. In a dry environment if the soil is deeper than the grass-rooting depth and if rainfall is sufficient to recharge soil beyond the reach of grass roots, grass may use considerably less water than deep-rooted trees [*Rowe and Reimann,* 1961]. The implications of these findings are less valid in humid regions, where the upper few feet of soil are kept moist by frequent rains throughout the year and moisture is readily available to the grass.

But regardless of whether grass uses more or less water than forests, the significance of this experiment lies in the strong relationship between streamflow and grass production. Figure 3 shows that the water yield was inversely related to the general productivity of the grass from year to year and that 5 to 6 inches more water were yielded each year when grass production was low (1.8 tons per acre) than when it was high (3.5 tons per acre). The increased grass production when commercial fertilizers were applied and the subsequent sharp decline in streamflow leave little doubt that the relationship is real.

Of further interest is the seasonal use of water by the grass. Initially the grass used more water early in the spring and appeared to use less water later in the growing season than the original forest cover. It is uncertain whether this fluctuation resulted because the grass used water at a greater rate throughout the early growing season or simply because the grass began to use water earlier than the forest would have. At Coweeta, hardwoods do not reach full leaf until about May 15, whereas fescue grass begins to grow by April 1 or earlier. The time lag associated with water movement from the root zone into the streams seriously complicates attempts to tie changes in streamflow back to a specific period of water use and prevents direct comparison of rates of use. The lag in streamflow response varies with precipitation, season, and evapotranspiration rates, factors which control soil water content and ultimately the rate of water release to the stream.

The results of this single experiment should not be interpreted too broadly because they reflect a set of climatic, soil, and vegetative factors unique to the site. These findings, however, do add to the growing body of knowledge on water yield behavior after forest vegetation is altered. Carefully controlled investigations such as this one are essential in the field testing of findings reached in the laboratory and in plot studies.

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