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INCREASING WATER YIELDS BY CUTTING FOREST
VEGETATION

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GENTBRUGGE, 61, RUE DES RONCES (BELGIQUE)
INCREASING WATER YIELDS BY CUTTING FOREST VEGETATION

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Abstract

Forest cutting to reduce evapotranspiration loss has its advocates during water shortages. But underlying such proposals is little research to guide prescriptions or enable predictions of response. Controlled experiments at the Coweeta Hydrologic Laboratory, North Carolina, show large streamflow increments from clear cutting mountain hardwood forests on two small watersheds, first-year increases being 15 and 17 area inches, all as regulated base flows. The yearly increase leveled off at 11 inches after the 3rd year where all regrowth was cut back annually; but it declined progressively on the other unit where a young coppice forest grew back. Cutting a shrub-understory increased annual yield about 2 inches. Other experiments are measuring water yield response from stand density reduction, cutting cove hardwoods, and converting the native forest to pine and other cover types. Learning how to favorably influence water yields for specific situations will require much more basic research, particularly study of water use requirements of forest trees and of the related plant-soil-climatic factors governing the evapotranspiration process.

Résumé

La coupe des bois en vue de reduire l’évapotranspiration trouve en période de sécheresse un certain nombre de disciples. Il existe cependant peu de travaux à ce sujet qui pourraient servir de base et fournir quelques indications quant aux résultats à obtenir. Des expériences contrôlées effectuées au Laboratoire Hydrologique de Coweeta en Caroline du Nord indiquent que dès la première année un accroissement important du courant d’entrée de deux bassins de l’ordre de 15 à 17 pouces à débit régulier est produit par la coupe d’éclaircissement de bois durs en forêt de montagnes. Après la troisième année cet accroissement s’arrête à environ 11 pouces sur les terrains recoupés chaque année, mais s’efface progressivement où l’on a laissé grandir le taillis. La coupe d’arbustes produit un accroissement d’environ 2 pouces. L’accroissement du débit des eaux par éclaircire, coupe d’arbres à bois dur et implantation de pins et autre végétation en remplacement des essences indigènes fait l’objet d’autres recherches. Pour apprendre comment influencer favorablement le débit des eaux pour chaque cas particulier il faudrait davantage de recherches élémentaires, notamment en ce qui concerne les besoins utiles en eau d’arbres forestiers et des facteurs relatifs végétation-sol-climat qui contrôlent le processus d’évapottranspiration.

Forest vegetation, much valued as watershed cover, levies heavy toll on water supplies as the price for keeping soils stable and in optimum condition for water intake and storage. And critical water shortages in the United States, as elsewhere, are prompting proposals to cut forests to obtain greater water yields. An example in the arid Southwest is the large-scale program under way for modifying forest-range vegetation in the Salt River Watershed in Arizona (Barr, et al., 1956). As yet, there is little real research knowledge anywhere to guide cutting prescriptions or from which to postulate probable response. As one contribution, this paper presents results from studies at the Coweeta Hydrologic Laboratory in western North Carolina—the first con-
trolled watershed experiments, it is thought, which show conclusively that water yields were substantially increased by forest cutting without producing attendant increases in stormflow or soil loss.

In the United States, a growing body of research results have documented unfavorable effects of deforestation with respect to soil impairment, sediment production, and the quantity and timing of stormflows. But controlled experiments have produced little evidence that watershed treatment induces much if any change in total water yield. This is not surprising, since there are few such studies, and complex processes and measurement problems are involved.

Two studies in Colorado—the classical Wagon Wheel Gap experiment (Bates and Henry, 1928) and a more recent preliminary study (Goodell, 1958)—report increases in snow-fed streams, chiefly as spring freshets, from cutting high-elevation timber stands. But other findings in the humid eastern United States indicate little if any change in total water yield some 15 and 19 years, respectively, after two critically eroded watersheds were completely reforested (Tennessee Valley Authority, 1951, 1955). Thus Coweeta results have unique, early value in indicating some treatment possibilities and for guiding much-needed work in this neglected phase of water management research.

The Coweeta Watershed Studies

The Coweeta Hydrologic Laboratory is a 5600-acre outdoor installation of the U.S. Forest Service where research has been under way since 1934 to develop principles of managing forest lands for water production and control. The Laboratory is in an 80-inch high rainfall belt of the Southern Appalachian Mountains; and its many small drainage catchments, from 25 to 200 acres each, occupy a rugged terrain of steep slopes and narrow ridges lying at elevations of 2200-5200 feet. Soils, chiefly weathered schists and gneisses, are relatively deep and porous and overlie rather tight bedrock. A dense, secondgrowth, deciduous hardwood forest supporting a rich flora of understory plants is dominant with scattered pines on the drier ridges. There has been no logging or other disturbance since about 1923.

In earlier years Coweeta research pioneered in studies of timing and delivery of flows from undisturbed forest; and later in measuring streamflow response when forest land is badly used. The program is now largely geared to study of water yield processes, the factors affecting them, and how they may be modified by watershed management. Basic instrumentation at Coweeta has been precipitation-streamflow measurements prior to and following treatment of small unit watersheds, with treatment response gauged through changes in flow, using an undisturbed watershed as a permanent control. By calibrating test-unit performance against that of the control, reliable estimates of altered flow due to treatment can be made, and variations due to climate and other extraneous factors greatly minimized.

Two well-known, classical experiments at Coweeta afford conclusive evidence that cutting all forest vegetation can produce very substantial increases in water, delivered as usable, regulated flows. A third study, in which the shrub understory was cut, gave similar, though lesser, water-yield response. This paper, in the main, interprets results from these three key investigations; and discusses some indicated needs which prompt additional studies.

Watershed 17, a 33-acre, north-facing unit, was cut over in 1941 after a 5-year calibration period to measure maximum streamflow response when
all woody vegetation was cut (Fig. 1). (Preliminary results were reported by Hoover, 1944). Logs and slashings were left in place and no wood products removed; and subsequently all sprouts and invading growth were cut back each year except in three war years, 1943-1945.

Watershed 13, a nearby 40-acre catchment, was similarly clear-cut in 1939-40 after calibrating performance for 3 years; but a young coppice forest was allowed to grow back (Kovner, 1956). The original cover, as on Watershed 17, was predominantly oak-hickory forest with basal area averaging 111 square feet per acre. By leaving lopped material in place, soil disturbance was kept to a minimum; and a dense tree sprout cover took over the first year after cutting.

Watershed 19, a 70-acre tract, was treated in 1948-49 by cutting the dense understory of mountain-laurel (Kalmia latifolia L.) and rhododendron (R. Maximum L.) (Johnson and Kovner, 1956). This widely-prevalent, evergreen cover averaged about 10 feet in height and accounted for some 20 percent of total woody basal area on the unit. Some stems were 85-100 years old and up to 9 inches d.b.h.

Comparative increases in annual yield—Large increments in streamflow were produced in each instance by clear cutting Watersheds 17 and 13, the increases totalling 17 and 15 area inches respectively the first year (Fig. 2). These represent measured over predicted flows by regression analyses, and are for the Coweeta water year, May 1-April 30. They came largely as regulated base flows without measurable changes in peak discharge, stormflow, or turbidity; as before treatment, less than 10 percent of total water yield was storm discharge, none of which reached streams as overland flow.

On Watershed 17, the annual increases declined to about 11 area inches after the third year and were maintained at that level for the rest of the period. This was response to partial re-establishment of water-demanding plant cover due to lush growth of sprouts and invading woody plants which sprang up the first year and have grown back each year to heights of 5-8 feet after cutting. Observations show no significant changes in soil properties, though surface accumulations of litter are somewhat less than those on the forested control. Thus Watershed 17, though clear cut repeatedly, remains essentially in top hydrologic condition with a forest soil channeled by vigorous root growth and receiving yearly renewal of litter from leaf fall and sprout-cutting operations. In no sense does it resemble a logged, denuded area.

On Watershed 13, cut in a similar manner but with forest regrowth permitted, water yield increases, similarly large at first, have declined with re-establishment of a vigorous, young coppice forest. But it will be noted that the increase was still a substantial 5 inches the 13th year after cutting, at which time basal area of the new stand was 52 sq. feet per acre—about half that of the original forest. Apparently, increases will be negligible after the 35th year and should return to pretreatment levels in about the 50th year.

This particular experiment is of key significance not only in demonstrating that well regulated increases in streamflow were produced by cover manipulation but also that they are progressively responsive to growth increments of the vegetation. Moreover, it affords impressive evidence of a substantial streamflow response long after one cutting operation, a response which will extend through much of a timber rotation.

Cutting the dense shrub understory on Watershed 19 produced a streamflow increase of 2.8 inches the first year, and yearly increases averaging about 2.0 inches for the 6 post-treatment years. Again there was no obser-
—(Upper). General view of the Coweeta area; and of Watershed 13 soon after cutting with a young coppice forest getting established. (Lower). Watershed 17, similarly cut, with logs and slashings left and regrowth cut back annually.
viable change in proportion of flow contributed by stormwater. Although the increases seem small, it should be noted that cutting the shrubs—about 20 percent of total basal area—gave added flow somewhat proportional to the 11 area inches obtained by cutting everything on Watershed 17.

Obviously, the greater water yields obtained in these test cuttings are response to lessened transpiration draft. Under conditions of treatment, with slash continuing to have an insulating effect, evaporation loss from the forest floor probably has changed very little; and the interception losses, though doubtless reduced, have not been eliminated.

Indicative of this relationship is evidence (Kovner, 1956) of close correlation between measured water yield increases and annual water losses as calculated from the water balance equation: Evapotranspiration = Precipitation — Streamflow ± Storage changes (difference in groundwater storage at beginning and end of year) (Table 1). Thus when calculated evapotrans-

TABLE 1 — Streamflow increases compared with reduced evapotranspiration loss, Watershed 13

<table>
<thead>
<tr>
<th>Year since cutting</th>
<th>Flow increase (regression analysis)</th>
<th>Reduced water loss (water balance equation)</th>
</tr>
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<tr>
<td></td>
<td>Inches</td>
<td>Inches</td>
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<tr>
<td>1</td>
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<td>13</td>
<td>4.99</td>
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<tr>
<td>13-yr. mean</td>
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<td>8.20</td>
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</table>
piration loss for a given year is deducted from the average pretreatment loss (38 inches), the value obtained (Col. 3) approximates the increased water yield as measured for that year. These reciprocal values—flow increase and reduced water loss—when averaged for the 13 years of record are in remarkably close agreement.

One important contribution of these studies is the gross measures they afford of how much water a well-supplied, mesophytic, high forest may use. In all probability, the transpiration draft exceeds the first-year 17- and 15-inch flow increases reported herein, since it is evident total transpiration was interrupted only briefly the first summer while tree sprouts were beginning to grow back. Nevertheless, these approximations, obtained from natural drainage units supporting well-watered forest cover, afford important benchmark values in water balance and evapotranspiration research.

Seasonal distribution of increases—Monthly distribution of streamflow increases after cutting Watersheds 13 and 17 reflects the hydrology of Coweeta watersheds and suggests some water-yielding, treatment possibilities as well. Figure 3 shows for Watershed 17 the mean increases in monthly water yield after cutting, based on 15 years of record. There are appreciable streamflow increases for every month, including those of the spring-summer period when evapotranspiration draft is greatest and considerably exceeds rainfall accretion.

Fig. 3 — Mean monthly streamflow increases after cutting, Watershed 17.
Fig. 4 — Water yield increases by seasons while a coppice forest re-established itself.

Percentage-wise the increases are greatest (exceeding 90 percent) in fall months, September-December, when streamflow normally is lowest and water shortages most acute. But quantitatively, the biggest increases are in the dormant season, December-April, also the period of groundwater recharge. Surprisingly, more than half the total increase, approximating 11 inches annually from this watershed, comes in the winter, when evapotranspiration as such can be little influenced by forest cutting. Obviously, there is a pronounced seasonal lag relationship operating here through soil reservoir storage.

Trends in seasonal water yields from Watershed 13, where a coppice forest grew back, are shown in Figure 4. As for Watershed 17, the greater increases were in the dormant period.

Seasonal distribution of the increases can be rationalized in part by considering Coweeta water cycle relationships. Mid-April, when trees leaf out and watersheds have been fully recharged, ushers in a 6-month water deficit period of maximum evapotranspiration. Streamflow recedes steadily with the declining water tables and is recharged only by the occasional larger storms of spring and summer; and with less-demanding watershed cover (hence a somewhat lower soil moisture deficit) these few storms may produce some streamflow increase during growing-season months.

Beginning with October rains, this trend is reversed, though streamflow may continue to drop during autumn months. Frosts remove foliage, and
water losses to the atmosphere decline with this and cooler weather. Soil moisture build-up proceeds rapidly and by December the soil mantle usually is at "field capacity"; and during the ensuing winter recharge period, streamflow responds promptly and directly to rainfall accretion. Thus, inferentially, a watershed cover of lesser water demand must make cumulative contributions during summer months toward a build-up in soil moisture and water tables which carries over to and pays off in greater streamflow months later during the groundwater recharge period, December to April.

Other water yield studies—Watershed treatment experiments afford only a gross measure of net treatment response in terms of streamflow and have other definite limitations, also. But since little is known about water use by forest stands, other Coweeta unit watersheds are being utilized in cover-alteration pilot tests to guide more basic research. Stand density-water yield relationships are getting special attention in tests to gauge immediate response from partial cuts or tree-eliminating treatments. In 1955, half the basal area on an 88-acre watershed was deadened by chemical basal spraying; and other reductions in basal area are planned on companion units. The preliminary indication is that the first-year increase in water yield was somewhat less than half that measured the first year on Watersheds 17 and 13.

Other possibilities have been explored, notably cutting the more valuable cove hardwoods. This type occupies the deeper, better-watered, more productive soils—the areas most likely to sustain base flows and hence produce greater water yields when in forest cover of lesser water demand. Early results are inconclusive but suggest no particular advantage in cutting this type.

Another major Coweeta study, started in 1955, compares water yield responses from a series of 5 calibrated watersheds averaging about 30 acres and representing: (1) native hardwood forest (control); (2) white pine (P. strobus L.) planted on north and on south-facing watersheds, respectively; (3) perennial grass; and (4) a low shrub cover. This is a long-term pilot study in type conversion to measure differential water yield responses from natural drainage units; and to afford suitable locale for supporting studies of soil-site change, plant rooting habits, seasonal use of water, and other aspects affecting water gains and losses. Among developments prompting the latter study are large-scale pine planting programs in the region, and the questions these pose whether shifting hardwood sites to pine may unfavorably affect soil and water relations.

Some Indicated Needs

Whether forest cutting or other manipulation of cover can produce more water for specific situations of terrain, soil, and climate must remain largely outside the realm of accurate prediction at this stage. Use of natural drainages, as at Coweeta, to test cover alteration-streamflow response is a highly useful approach; but unfortunately it can afford only partial answers. And much of the knowledge to enable reliable prediction of yield must be sought in more basic studies of cover-soil-climatic relationships and how these operate or can be modified to influence hydrologic processes.

Essentially, this means study of water use requirements of forest stands and of factors governing evapotranspiration losses. Hence, the future Coweeta program calls for much study of the plant itself, its moisture requirements, and regulating mechanisms; of climatic factors such as solar radiation, temperature, and wind as modified by plant cover; of condensation, interception,
<table>
<thead>
<tr>
<th>Time</th>
<th>Stand attributes</th>
<th>Stream increase over prior year [tons]</th>
<th>Area increase [acres]</th>
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<tbody>
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<td>111</td>
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<td>1453</td>
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<td>13th year</td>
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</tr>
<tr>
<td>40th year</td>
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<td>1443</td>
<td>0</td>
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</table>

Note: The table shows the streamflow increase with a developing coppice forest, Watershed 13 and its control.
meteorological factors; and much additional research will be needed to assess the many microclimatic effects of forest cutting.

A related need in water yield prediction is research to improve empirical formulae and techniques for estimating evapotranspiration from climatic variables or by energy-budget and other procedures. Coweeta, with an elevational range in evapotranspiration of about 40 to 20 inches annually and a combination of climate, soils, and forest cover which apparently maintains atmospheric water losses at or near “potential” values, affords unique opportunity for this. Not the least of the advantages are the measurement standards afforded of total evapotranspiration loss from natural watershed units as approximated in the Watershed 17 experiment.

This paper, in reporting evidence from some 20 years or more of controlled experimentation at Coweeta, affords some values which may approach the upper limits of regulated, water-yield increase where soils are known to be deep and porous, the climate humid, and the cutting treatment drastic. But perhaps it serves best to point up difficulties and some research needs in working toward development of reliable prediction methods to guide cutting prescriptions. Quantitative yield values, though precisely developed for small experimental watersheds, are not directly transposable as such to other areas; nor will large-scale cutting operations of a trial-and-error nature afford many answers. It will take a great deal more fundamental research to understand the nature and mechanics of water disposal processes on forest lands. Moreover, these studies are needed soon if we are to exploit the water-yielding possibilities of forest cutting or avoid ill-founded attempts to get more water in this manner.

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