WATERSHED MANAGEMENT

As reported last year, the variable water yields obtained after cutting timber stands at the Coweeta Hydrologic Laboratory have led to the conclusion that we cannot hope to predict cutting treatment responses reliably through unit watershed experiments alone, and must use some new approaches. This has been the main theme of recent reports—the latest an article by Hewlett and Hibbert in the September (1961) Bulletin of the International Association of Scientific Hydrology—and it reflects a major shift in the Coweeta program toward studies in depth of the soil-climatic-plant relationships affecting water behavior.

During the year, much of the Coweeta effort as well as the related work in the Piedmont at Union, S. C., continued to focus on soil moisture measurement as a technique for estimating runoff and evapotranspiration loss. Accomplishments include development of useful sampling techniques for measuring soil moisture change while holding errors to desired levels of precision. Soil moisture regimes at Coweeta and Union are now being effectively monitored to depths of 15 to 18 feet despite rocks and other difficulties; and large plastic-covered plots are used to control rainfall recharge, separate loss components, and afford a measure of evapotranspiration in situ from natural timber stands. In developing these techniques for water balance accounting purposes, we are trying, among other things, to determine how deeply tree roots withdraw soil moisture.

One contribution from recent work has been an analysis of some 14,000 soil moisture determinations over a 6-year period showing that about 18 inches of moisture (22 percent by volume) remains in the upper 7-foot profile during the driest part of an average growing season. Since this is some 6 to 8 inches above wilting point, it would seem to confirm that Coweeta vegetation on deep-well-drained soils seldom if ever suffers from true drought.

Neutron moisture metering equipment has been in use about 4 years at Coweeta and Union and has afforded a real breakthrough in soil moisture measurement. Since there remain operating difficulties, an important event in August was a 1-week symposium at Coweeta in which experienced technicians from all sections of the country compared results, appraised equipment and methodology, and recommended improvements.

One of the year's highlights was a start on new research at Charleston, S. C., to improve coastal plain wetlands for timber growing and other purposes. The wetlands cover approximately 20 million acres of coastal plain from Virginia to Florida. Some companies are testing ditches to increase productivity.

But perhaps the most intriguing finding of all at Coweeta in recent years is evidence that slow drainage from unsaturated soil profiles is sufficient to sustain and account for base flow of small headwater streams during dry spells. This research was started about 2 years ago, chiefly because the low water flows and behavior of Coweeta streams could not be explained logically by conventional concepts of groundwater hydrology. Some highlights are presented herewith.

Where Does the Water Come From?

Just how does rainfall become streamflow? Where, and how is it stored, and how fast do stored components move over or through the land mass to reach stream channels? In general, we know that most of the rain falling in the channel runs away immediately, whereas some of the water absorbed by land areas may not reappear for years. What happens in mountain country is always uncertain because of variable relief, the nature and depth of porous water-holding material overlying country rock, and other imponderables. The location and concentration of stored water are important considerations in water management, for these affect its availability for use by man and also the evaporative losses to the atmosphere. In short, what we can do to improve or augment supplies of mountain water depends a lot on where it is located and how fast it is moving.

The force of gravity literally "pulls" water out of the mountains and operates uniformly to move each molecule along a particular pathway to join groundwater or streamflow. Resistance determines the rate of flow; and forest cover, the soil mass, and topography provide the resistance. In humid country where annual precipitation exceeds evapotranspiration loss, the intermittent supply of rain produces a continuously varying rate of outflow as expressed in the stream hydrograph (graphical record of gauge height over time). Hydrologists commonly classify streamflow into two types, depending on the mode and rate of delivery of water to a gauging station; i.e., *stormflow* which runs off within a day or two after rainfall, both as overland and subsurface flow; and *base flow* which continues through and after storm periods and sustains streamflow until replenished by the next rain. Estimation of the two types of flow by hydrograph separation is rather arbitrary at best, particularly as applied to small mountain streams, and is chiefly a matter of subjective judgment rather than precise measurement.

Useful as these concepts have been in explaining and predicting the water responses of large drainages, the mechanics of flow in upstream areas is still poorly understood; and hydrologic procedures afford little help in interpreting stream performance. It may be helpful at this point to outline some rationalizations about waterflows which underlie recent work at Coweeta.

Some Ideas about Storm Runoff and Base Flow

When rain falls on porous forest soil, it enters the ground and either begins to migrate to the nearest stream or is held as "retained" water by the soil particles where, according to theory, it is relatively immobile and hence contributes nothing to streamflow. Whether it migrates or is held in place depends chiefly on the character and wetness of the soil, which in turn is usually related to its depth and position on slope. But rainfall recharge entering the soil on different parts of a watershed does not necessarily have the same degree of mobility. Where it sinks in near a stream and consequently can contribute more to immediate rises in streamflow, it generally will move faster than if it enters the drier slopes and ridges above.

Importance of this relationship is illustrated schematically in figure 18, a cutaway sketch of a mountain watershed. Rainfall influence in producing immediate runoff obviously diminishes with distance from the stream channel. This effect is easier to understand when it is realized that the drainage pattern and stream channel itself were formed under the rainfall-runoff regime peculiar to the area. As soil water moves downward and concentrates, it must finally saturate soil and then surface to make its contribution to streamflow and channel cutting. Subsequent rains deepen or extend the channel, until eventually an equilibrium is established between topography and precipitation.

Under prolonged and heavy rainfall, the stormflow-contributing area contiguous to stream channels may grow wider and wider, depending on the nature and depth of the earth mantle. However, at Coweeta the percentage of total rainfall appearing as stormflow (separated from base flow by the usual hydrograph approximations) seldom exceeds 35 percent. During an ordinary storm, say about 2 inches of rainfall in 24 hours, only 10 or 15 percent will normally be stormflow. As a useful approximation, this percentage can perhaps be assumed to be roughly equivalent to the relative watershed area serving as a primary source of stormflow, although logically, the contributing watershed area must be somewhat larger than this. Figure 19 shows graphically how this relationship might appear; i.e., the deeper the soil mantle the closer the curve will approach a 1:1 relation.

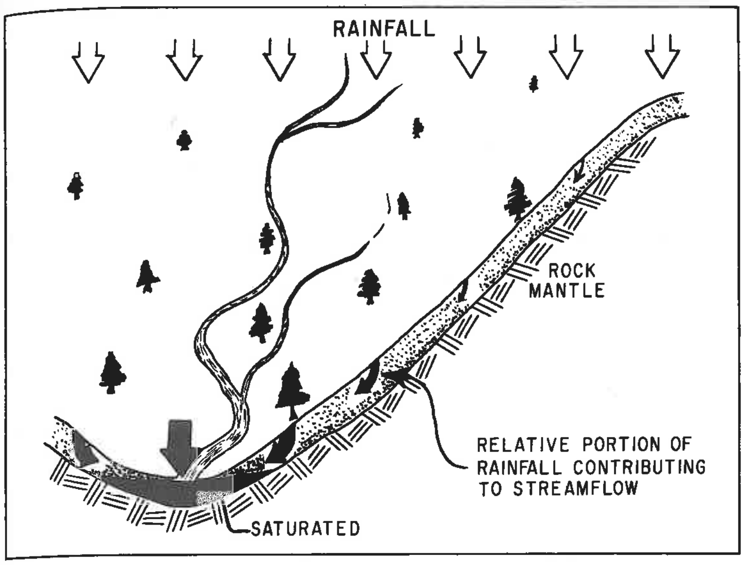


Figure 18.—Schematic cross section of a mountain watershed showing how the relative contributions of rainfall to stormflow vary with position of slope.

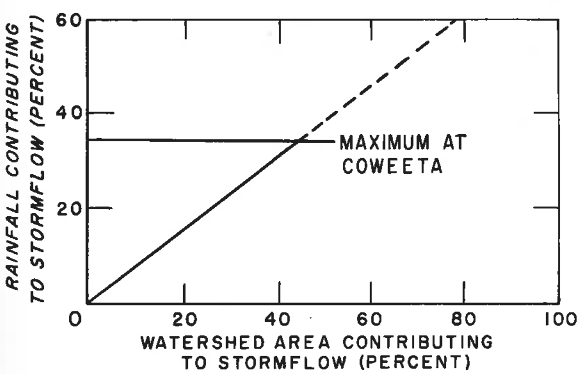


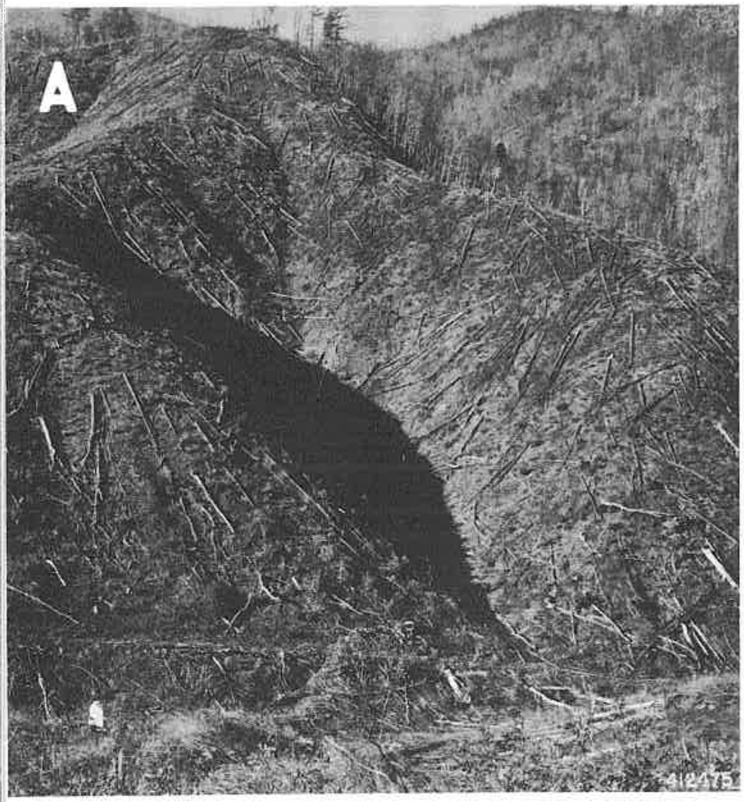
Figure 19.—Speculative relation between stormflow as percent of rainfall and the watershed area from which stormflow comes. The slope of the curve will vary with watershed morphology and condition.

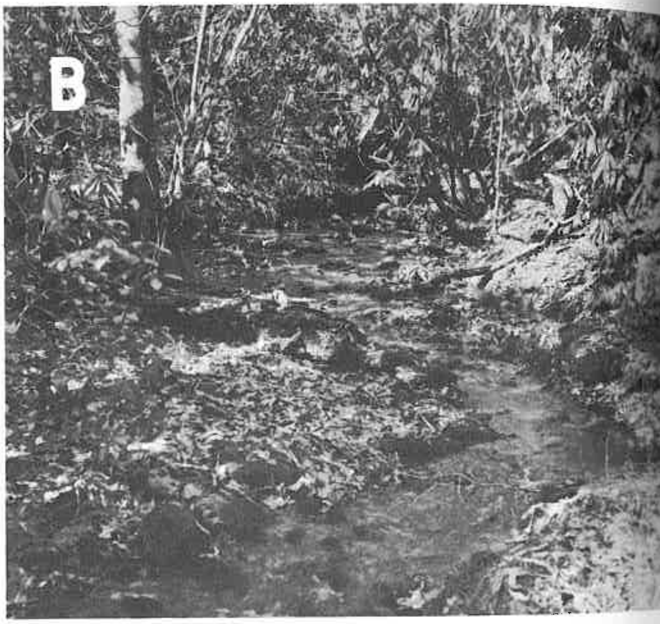
But what happens to the remainder of the water—the portion not reaching stream channels a day or two after rainfall? Of course a great deal of this evaporates or is transpired by plants and hence is lost to streamflow. But while this is happening, a substantial portion continues to migrate downward, eventually appearing as clear springs or streamflow. Thus, the soil mantle is able to moderate erratic rainfall into continuous outflow between storms. The deeper the soil, the better the moderation and the more valuable the watershed as a source of manageable water supply.

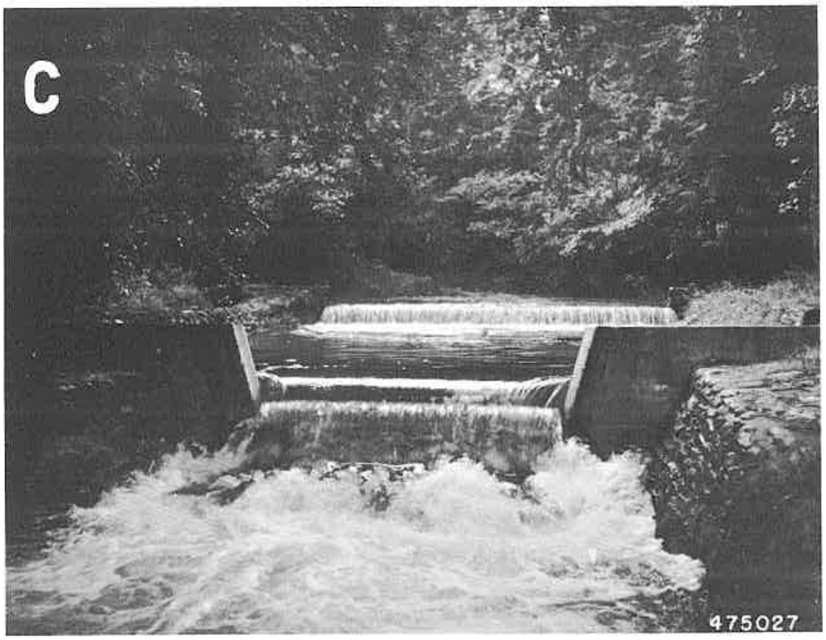
In lowlands or wide valley areas, baseflow is partly fed by the slow depletion of free-water, underground aquifers, i.e., the saturated material comprising or lying below a gently sloping water table. But in mountain country such as Coweeta, the soil mantle is sloped too steeply to retain large bodies of groundwater in water tables as commonly pictured. Indeed, considering the steep stream profiles and the precipitous upper valley slopes, it is difficult to visualize a groundwater aquifer big enough to supply streamflow throughout the growing season when current rainfall is generally no more than evapotranspiration loss. To apply groundwater theory to many of the small catchments—some with a thousand-foot range in elevation—free water aquifers would have to be held for many weeks at hundreds of feet of hydraulic potential along stream channels that drop away on 45 percent slopes. All this seems unlikely since the occurrence of extensive groundwater bodies has never been adequately demonstrated at Coweeta, even though some 28 groundwater wells were observed over a 20- to 25-year period.

Coweeta catchments are underlain by massive, water-tight material; and it seems unlikely that deep fissures in underlying rock, although possibly holding some water, are a major source of base flow. Also, the upstream water courses draining steep slopes are remarkably stable and maintain year-round flows which deplete proportionately throughout the upper reaches during dry spells.

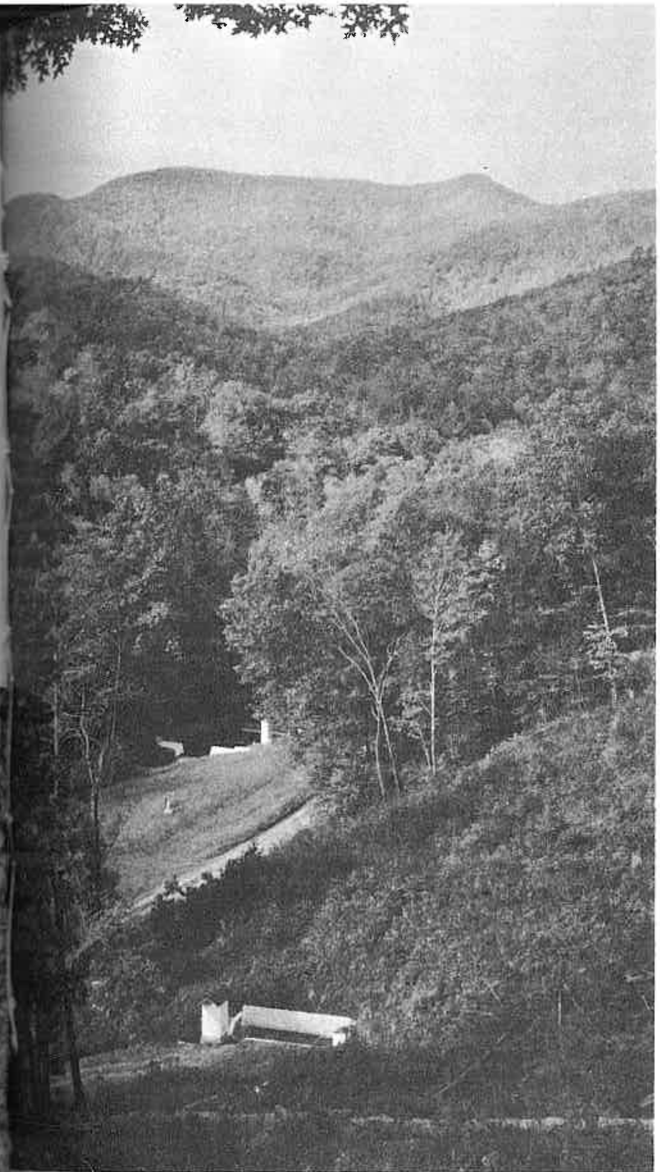
Accordingly, it was conjectured that unsaturated soils and moisture in the field capacity range must be supplying most of the dry-weather base flows. The deeply-weathered Coweeta soils are of variable depth averaging about 6 feet in most catchments; and after a heavy rain they can hold temporarily up to 30 area-inches of water (42 percent by volume). Perhaps drainage at almost imperceptible rates from this huge soil mass operating for long periods after recharge might produce enough water to sustain base flows. This had to be verified experimentally.







Variable features of Coweeta streams: A, small, steeply-pitched watercourses draining upper slopes and with year-long base flows; B, entrenched channel traversing narrow valley downstream; and C, fully-formed, gauged stream draining a valley flat below.



Some small Coweeta catchment areas have a thousand-foot range in elevation.

The Coweeta Soil Model Study

A large sloping model simulating a watershed segment was constructed of concrete on a 40 percent slope and filled to a depth of 3 feet with well-mixed, carefully-tamped forest soil so as to reproduce original bulk density. No water could escape except as drainage from an artificial sand-gravel "watertable" maintained at a fixed level by an outlet pipe at the base. Tensiometers, soil thermometers, and other instruments were installed upslope and access tubes were provided for measurement of soil moisture fluctuations by the neutron scattering method. A water level recorder gave a continuous record of drainage outflow from the model.

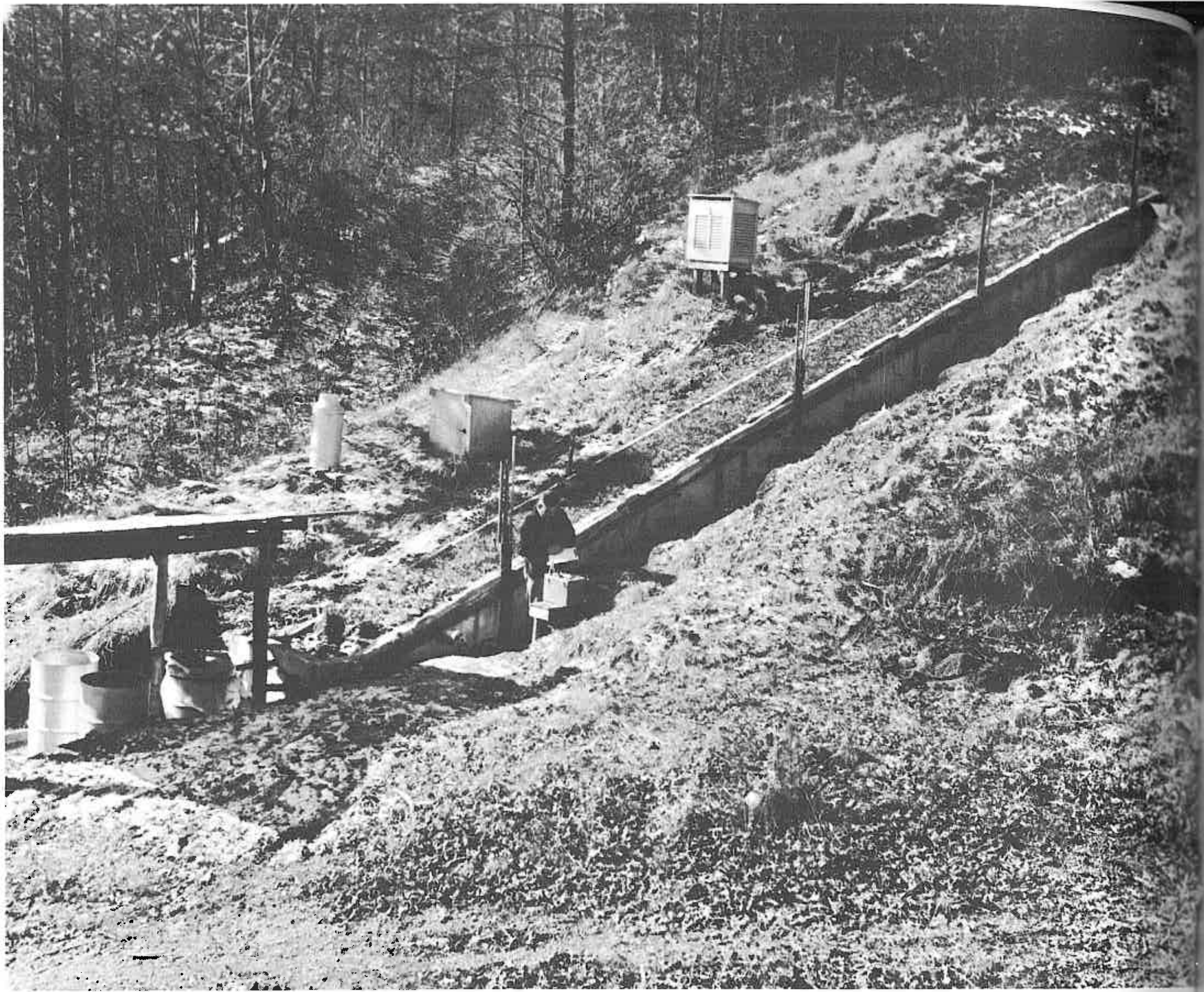
The first step in operating procedure was to soak the soil column thoroughly with artificial rainfall for about 48 hours to make sure it was fully charged as under sustained rainfall; and then the surface was covered with plastic sheeting to prevent evaporation.

With no additional water added to the 400 cubic feet of soil, the model produced measurable outflow at a continuously diminishing rate for 140 days. As expected, much of this drained off the first 2 days; but precise measurements of outflow and soil moisture demonstrated conclusively that virtually all the flow after that time, for 138 days, was slow drainage from unsaturated soil above the outletted water table. Interestingly enough, this slow drainage, when expressed in terms of the soil volume of a small Coweeta watershed, is in remarkably close agreement with the observed mean dry-weather flow of gauged streams.

The prevailing notion that all free water has drained off when soils reach field capacity must evidently undergo some revision. Field capacity, a somewhat arbitrary value at best, has been reported by various investigators at variable tensions; and within this tension range, the soils of the Coweeta experiment will hold roughly 7 percent of moisture by volume. This is equivalent to about 0.84 inch of water per foot of soil depth, which will be yielded slowly as drainage over long periods until the developing tension halts further movement.

Further illustrating the considerable water yield potential, some soil borings on a 9-acre Coweeta watershed revealed soil depths of from 3 to 10 feet on 90 percent of the area. Using best approximations of field capacity, the soils of this small catchment can store about 18 acre-feet of water or 6 million gallons. Moreover, calculations indicate that drainage of only 1 percent by volume would contribute 200,000 gallons to streamflow—a drainage yield from this small unit equivalent to about a 15-day flow at Coweeta during the winter season.

Accurate field plot measurements of soil moisture change by neutron scattering methods confirm that this slow downward movement of water occurs for many weeks after rainfall. Furthermore, a recent analysis shows close correlation between the annual trends in soil moisture and the base flow of Coweeta streams; and suggests that what is going on in seemingly well-drained soils high on mountain slopes may have a great deal to do with day-to-day streamflow rates. These indications that base flow of mountain streams does not come entirely from extensive underground reservoirs afford important clues for water managers; for some of it, apparently, drains from mountain slopes quite remote from the streams and hence is subject to day-to-day evapotranspiration loss and quite possibly management influence.



Large Coweeta soil model used to verify slow rates of drainage from moisture in the field capacity range. Photo taken of a later run, when in grass cover.

Much Yet To Be Learned About Water Movement

These and other Coweeta experiments are giving some new insights, but application to other mountain areas, other soils, and other climates must await further experience and development of better prediction methods than are now available.

Meanwhile, we can conclude with some confidence that a watershed manager in the southern Appalachians must consider, among other things, the variable distribution of the soil mass in relation to drainage pattern. Evidently, the same practice applied to two different segments of a watershed may have quite different consequences on water yield and on watershed damage as well. For instance, skidding logs which reduces water intake near streams is likely to have a disproportionate influence on stormflow rates and stream channel erosion, whereas the same practice on ridges may do much less damage. On the other hand, the same practice on slopes and ridges may well alter soil water storage relations as well as rate and direction of water movement, and hence may have greater influence on water yields, particularly the low flows.