# RESEARCH AT THE COWEETA HYDROLOGIC LABORATORY

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Here in the southeast, we occasionally feel the pinch of too little water or the miseries associated with too much water. These problems will be magnified with each passing year, particularly those associated with water shortage. In the future we will look to the west more and more for solutions to these problems. By west, I mean western North and South Carolina, and Virginia, since these forested upland regions supply much of the remaining clean, quality water for the municipal-industrial-recreational-agricultural need of nearly 50 million people. Management of these uplands will govern the amount of water that can be supplied, the delivery rate, and the quality.

Today I have the opportunity of reviewing for you the Forest Service hydrology research program for these headwater areas. Forest Service research activities in the mountains-piedmont of Georgia, South Carolina, North Carolina, and Virginia are centered at the Coweeta Hydrologic Laboratory near Franklin, North Carolina. My discussion today will be limited to a brief resume of over 30 years of work at Coweeta and our plans for future research in forest hydrology.

The Forest Service always has been vitally concerned with effects of forests and their management on streamflow. In fact, some National Forests were established primarily for regulation of flow of navigable streams under authority of the Weeks Law of 1911. But in the early 1900's, little was known about forest-water relations. People had become alarmed when severe erosion choked stream channels and decreased flows followed unregulated forest cuttings. Some concluded that removing forests decreased streamflow, others felt that forests merely regulated flow, while still others believed that forest increased streamflow. This early confusion stemmed from failure to distinguish between total yield and the quality, quantity, and timing of yield. The controversy ultimately led to the first American effort to measure rainfall and runoff from forest lands, at Wagon Wheel Gap, Colorado. Although carefully and thoroughly done, rainfall in that semiarid region was so slight that results only hinted that trees are important users of water and regulators of its flow from forest lands.

This early finding paved the way for the next important step in developing the Forest Service hydrology research program. In 1933, the 5,000-acre Coweeta basin was set aside as an experimental forest dedicated to the study of the hydrology of forest lands. This basin, ideally situated for studies that would show how forest affects the quality, quantity, and timing of flows, was completely forested, had deep soil, many streams, and most of all, lots of rainfall. The mountains around Coweeta receive more rainfall than any other region of eastern North America.

The program of the 1930's was directed toward instrumenting the basin. A road and trail system was built, and offices were constructed by the Civilian Conservation Corps (CCC). A network of 70 rain gages was established and soon showed that precipitation was indeed great, averaging 80 inches per year. Weirs were designed, calibrated, and installed on 31 watersheds, and the period of watershed calibration began. Ground water levels were monitored at 29 wells. Watersheds were surveyed, and forests were inventoried and mapped as the backlog of information needed to evaluate effects of forests on streamflow accumulated.

Meanwhile, measurements on large drainage basins of the southeast showed that only about one-third of the annual rainfall reappeared as streamflow; the remaining two-thirds presumably were lost to the atmosphere by evapotranspiration processes. Since the atmospheric losses (transpiration, interception, and evaporation from the soil) could not be measured individually, they were lumped into the single term, evapotranspiration. Ideally, this term is very simply calculated on watersheds with impervious bedrock by subtracting annual streamflow from annual rainfall. In practice, watersheds seldom are leakproof, and evaporative losses estimated in this manner were quite variable. Nevertheless, reduction of evaporative losses appeared to be one method of substantially increasing streamflow. By 1940, some watersheds were considered calibrated, since streamflow from one could be closely predicted from another, and an intensive testing program was begun, comparing effects of abusive land use and vegetative removal on streamflow.

Some treatments demonstrated effects of prevailing agricultural, logging, and woodland grazing practices. Although these practices were intuitatively known to be harmful, there was a need to dramatically quantify their destructive nature on watershed resources. Results showed greater damage than expected. Where once all water falling on the forest floor was quickly absorbed, now the soil lost its ability to take in water, and overland flow became a problem for the first time. Soil erosion from steep mountain fields increased yearly, and cattle's hoofs compacted surface soil, reducing infiltration capacity of soil and growth rate of forest stands. Logging roads rutted and gullied, and stream channels cut deeper. Sediment laden water clogged channels far downstream as these practices rapidly destroyed water, timber, and soil resources. Both timing and total water yield were changed. Today, 23 years after logging began, water from the exploitively logged watershed is still dirtier than flow from adjacent undistrubed forest.

Other experiments aimed at evaluating the effects on water yield of removing forest vegetation without disturbance to mineral soil. One watershed was cut, leaving all vegetation where it fell. Streamflow from that catchment increased over 17 inches the following year. During the next 15 years, vegetation was cut back annually, and the yield increases stabilized at about 11 inches per year. Similarly, cutting another watershed produced a 15-inch first year increase in streamflow, but here timber was allowed to regrow. As it regrew, the increase in flow over pretreatment levels became less and less, but calculations indicate that treatment effects may not disappear for 40 years. Studies at Coweeta have demonstrated yield increases following complete removal of vegetation that range from 6 to 17 inches annually. Partial cuttings removing as little as 12 percent of the basal area of the stands showed that any substantial reduction of vegetation tends to increase total water yield. And in contrast to the destructive land use demonstrations, increases were obtained without measurable changes in storm peaks or water quality. However, one must remember that treatments were applied in an area of plentiful rainfall, very permeable soils, and luxurious vegetation, and care was taken to minimize damage to the soil and water resource. In regions where soil, climate, and vegetative conditions are different, these treatments may give smaller yield increases and could cause serious erosion problems.

These yield increases may not seem impressive unless viewed in proper perspective. For example, cutting forest increased flow on a per-square-mile basis by an amount equal to the total flow of many river basins of the piedmont region. Perhaps more important, a favorable change in timing of yield occurred; i.e., percentage increases were greatest during the summer and fall months, when demand for water is greatest and streamflow is least. During some summer months, flow actually doubled.

Despite occasional shortages during drought periods, we often think of water as an inexhaustable resource and people may question the importance of these increases. Not so in the West! There, a plan has been proposed for using Canadian and Alaskan rivers which normally flow into the Pacific. Their flow would be diverted south through Canada and the Rocky Mountains to the arid southwest into Mexico and east to the Great Lakes. If adopted, the project, requiring 30 years to complete and costing about 200 times as much as the Panama Canal, would unquestionably be the greatest aqueduct program ever attempted by man.

In the southeast, water is becoming critically short, often limiting economic development. Here in South Carolina, for example, water demands in Greenville were approximately equaling supply by the late 1950's. Recognizing the need for a continuing adequate supply of water, the Greenville waterworks purchased a 26-square-mile watershed. They constructed a 1,080-acre reservoir and gravity pipeline to deliver water to the metropolitan area. Cost--$10 million. Benefit--an adequate supply of pure, clean water for the next 50 years. Their engineers say that the new reservoir nearly tripled the supply, but that escalating demands probably will have them out looking for a new water supply by the year 2000.

Salt water conversion plants are becoming common in coastal regions and produce water for less than $1 per 1,000 gallons. Pumping water uphill adds greatly to production costs. By comparison, at Coweeta we are producing cleaner water already at an elevation of 2,000 feet for 10 to 15 cents per 1,000 gallons. The value of this water in manufacturing or population centers is difficult to calculate because of the uncertainty of transporting it to points of use. However, the sale of extra water may add significantly to the mountain economy when piped to users below as petroleum products are transported the other way. The Swiss have proved that this is feasible. They are selling water and delivering it to Germany today through a gravity system.

Despite substantial yield increases on some of Coweeta's watersheds, increases from cutting other units are less impressive. We must generalize and tell the engineers that removing vegetation tends to increase yield, but we cannot tell them when the increase will come, how much increase, or how long it will last. This inability to predict water yield increases following forest treatment makes economic development difficult because planners have no sound basis for calculating cost-benefit ratios.

By 1955, we knew what happens when a unit watershed is cut, but it was apparent that a new approach was needed to answer questions concerning the volume and timing of yield increases. While past efforts were single observations, the new approach was to allow us to predict streamflow responses to a management practice on a variety of areas. We wanted to be within stated confidence limits, and to obtain the required confidence we had two alternatives. One was to initiate long-term experiments on paired watersheds replicating each study several times in various sections of the country to gain confidence in our predictions. This line of investigation was not economically possible because the cost of each pair of watersheds runs $50,000 to $100,000 depending on construction and treatment cost, maintenance cost, and duration of the study. Moreover, we would not have increased our understanding of the basic processes governing water yield.

The approach selected at Coweeta was to concentrate on <u>why</u> the watershed reacts as it does rather than <u>what</u> takes place following a cover change. We try to explain on a physical basis the movement of rainfall from the clouds to the stream or back into the air. As Dr. Hewlett, former Project Leader at Coweeta, says, "It is not enough to simply diagram this cycle; we seek a better understanding of the location and physical state of water, and the forces which cause it to move into the air or down into the stream." Under his direction, emphasis shifted from measuring responses to study of basic processes.

Our ultimate objective is to develop sound principles, prediction methods, and effective techniques for managing forest lands by studying the basic watershed relationships and processes affecting water behavior. The current program is built around four overlapping areas of investigation delineated by the hydrologic cycle. Investigation fields deal with water in the soil, the air, the plant, and the stream. Our present staff consist of one scientist in each field, but we ultimately hope to increase the number of specialists to ten. We are actively recruiting for micrometeorologist, plant physiologist, and a soil physicist. In the near future, we expect to build a modern, fully equipped laboratory to provide facilities for more basic studies in each of these four fields.

This reorganization has been helpful in focusing efforts on the main objective of our research program and has permitted a coordinated attack on interdisciplinary problems. The organization also allows a high degree of specialization within each field of investigation and has aided in identification of specific problem areas.

The objective of plant-water investigations is to answer questions about water use by various forest trees, shrubs, and cover types. Luxuriant vegetation, deep soils, and plentiful rainfall makes Coweeta an ideal location for studying the water physiology of forest trees and shrubs, water use by different sizes and compositions of plant cover, influence of rooting habit on water use, and rainfall interception by plant material.

A recent series of interception studies illustrates one phase of this work. An analysis of all available studies of rainfall interception by hardwood forests of eastern North America revealed that interception varies within surprisingly narrow limits regardless of species or location. Accepting the physicists' premise that atmospheric losses are controlled and can be explained on a mathematical and physical basis, we now estimate that transpiration, interception by foliage and litter, and direct evaporation from soil account for 56, 42, and 2 percent of the total vapor loss from forested watersheds respectively. We do not yet know how these vapor losses change after partial or complete removal of vegetative cover. While physiological processes govern water loss to some degree, the morphology of the stand, i.e., the height, density, and roughness of above ground parts, apparently influences its efficiency in trapping heat. Of necessity, plant-water studies must be closely coordinated with micrometeorology studies dealing with the heat budget of the watershed.

Our efforts in micrometeorology may clarify the behavior of water in the atmosphere and aid our understanding of the water balance of forest lands. Some studies deal with measurement and interpretation of rainfall, wind movement, solar radiation, and atmospheric vapor in mountain terrain. Through other studies we hope eventually to develop energy balance and vapor transport theories for predicting moisture losses from and additions to forested slopes.

Studies in the field of micrometeorology may help explain some of the inconsistencies observed in unit watershed studies. For example, we observed that the difference in yield increases obtained by forest cuttings was greatest on watersheds facing north and south. Cutting north slopes increased annual flow 15 to 17 inches, but the same treatment on the south slopes produced only a 6-inch increase. Theoretical considerations of energy available for evaporating water from these opposing, steeply sloping watersheds lead us to believe that greater energy input on south slopes might account for 9 inches more transpiration than from north slopes (the approximate difference in yield increase from cutting north and south facing watersheds). This theoretical work will be followed with measurement of energy actually received, retained, and reradiated from forested and clearcut north and south slopes.

Problems in the soil-water field center around tracing and interpreting movement of water from the time it enters soil until it joins free-flowing streams or returns to the atmosphere. Coweeta's plentiful, well-distributed rainfall, deep soils, and steeply sloping watersheds afford unique opportunities for studying infiltration and storage and movement of water flows. One productive area of this work deals with the soil mantle as the source of water from steep mountain watersheds. Recent soil model studies, the largest model being 4 feet wide, 7 feet deep, and 200 feet long, show that Coweeta's streams are fed primarily by slow unsaturated flow of water through the soil mantle, rather than from large, saturated aquifers. We hope to develop numerical solutions to flow equations which describe the unsaturated flow process when parameters of slope, depth, and length of the soil mass are known. A tilting platform to support soil models of various widths, depths, and lengths sloping at angles up to 27 degrees is being built to allow detailed study of the unsaturated flow process and for testing flow equations. Perhaps these studies will lead to refined equations which can be used to predict flow from unit watersheds.

Research in channel flow relations will afford a better understanding of the amount, timing, and source of storm and base flow. Coweeta's streamflow records, the longest, most accurate set of streamflow records from small upland watersheds in existence, provide a strong base for hydrograph and channel flow investigations. A large effort is going into developing new statistical and programing techniques, mechanizing streamflow data collection and compilation methods, studies of the timing of water yield, and evaluating the influence of vegetative cuttings and species conversion on water yield. Work also involves pilot testing of theories, ideas, and concepts originating from information gained mostly from fundamental studies of watershed processes.

One recent pilot test involved evaluating the effects of chemical closure of leaf stomates on streamflow. It is commonly believed that plants transpire a great deal more water than is necessary to maintain an adequate growth rate. Thus, chemicals which close stomates without damaging plant tissue offer a promising method of reducing evaporative loss and increasing water available for streamflow. Helicopter application of one such chemical was tested in a joint study by the Connecticut Agricultural Experiment Station and the Forest Service. Although a significant reduction in transpiration (or a significant increase in streamflow) was not detected, search for a more effective chemical continues.

In summary, early research efforts at Coweeta have made substantial contributions to the field of forest hydrology. This work involved developing techniques for gaging and calibrating watersheds, analysis of hydrologic data, developing knowledge of stream behavior, documenting watershed damage when mountain lands are abused, and demonstrating water yield responses from cutting timbered watersheds. These early findings provided the methods, techniques, and facts necessary for development of the current research program. Our objective now is to understand the mechanics of water behavior on forested lands so that we can develop sound principles, predicting methods, and effective techniques for managing watersheds for improved water yield.