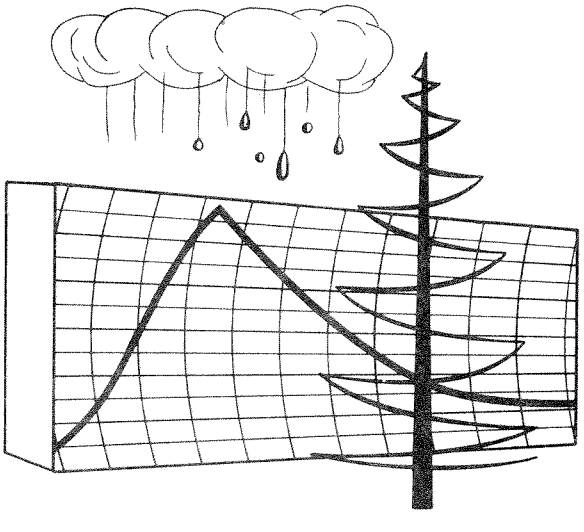
September 1957

A guide to the

Coweeta Hydrologic Laboratory



U. S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
Southeastern Forest Experiment Station
Asheville, N. C.

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Director

ACKNOWLEDGEMENT

This report represents the contributions of many researchers who have worked at the Coweeta Hydrologic Laboratory. Special acknowledgement is made to C. R. Hursh, M. D. Hoover, J. L. Kovner, J. A. Lieberman, and P. W. Fletcher, whose work has been drawn upon heavily in this compilation.

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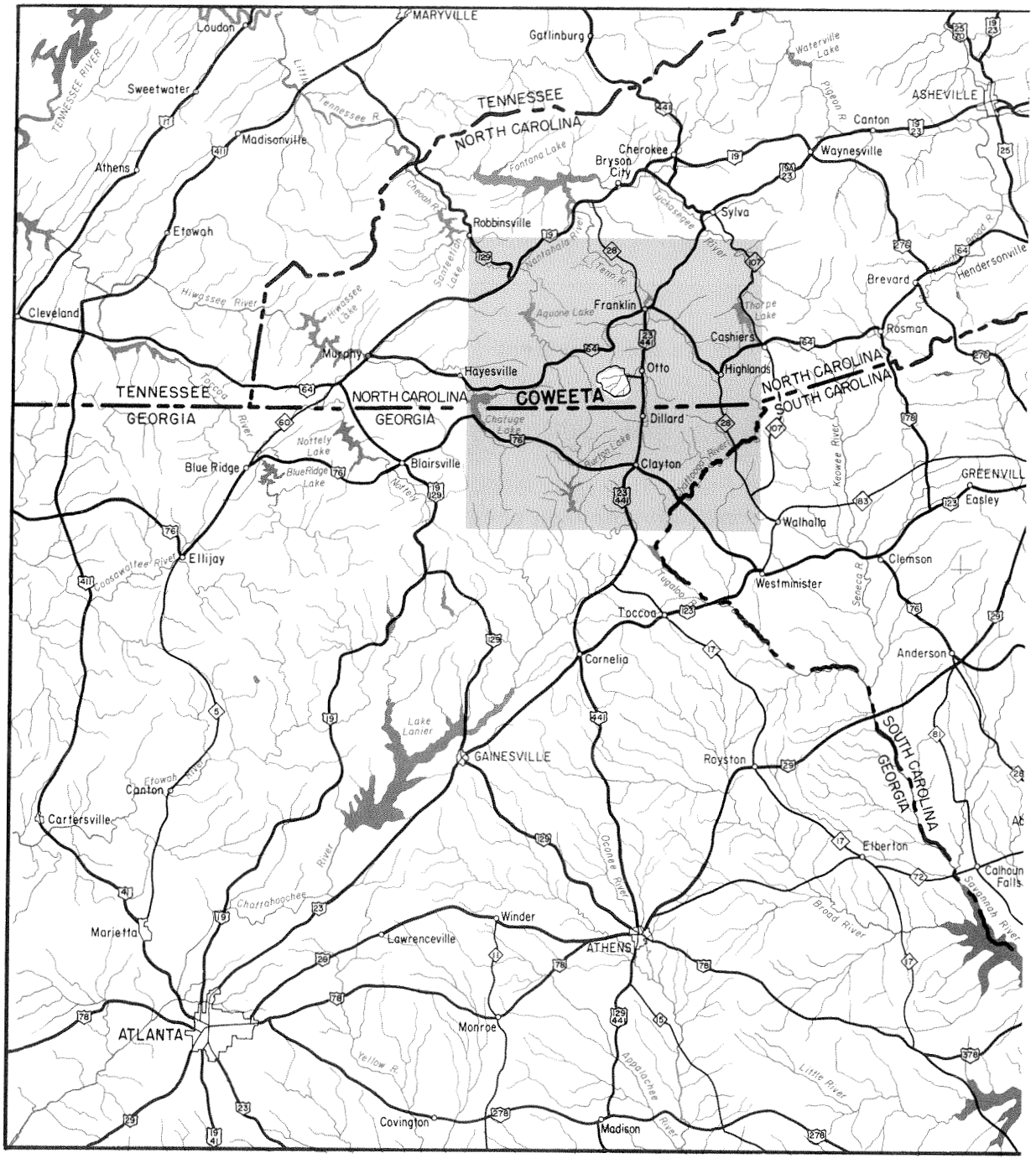
COVER PHOTO
Measuring rainfall, evaporation, temperature, humidity, and wind velocity on a treated watershed at Coweeta.

The Coweeta Hydrologic Laboratory is located in the Nantahala Mountains about 80 miles southwest of Asheville, North Carolina, and 120 miles northeast of Atlanta, Georgia.



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THE COWEETA HYDROLOGIC LABORATORY

by

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The rain falls on the land, and whether it races off doing little good or is stored to nourish springs and sustain the flow of streams often depends on how man handles the surface soil and vegetation. Rain and snow represent water income; streamflow, transpiration from plant leaves, evaporation, storage in the ground, and deep seepage through the rocks represent outgo. Measuring the balance between the two and finding ways to influence that balance is, in a nutshell, hydrology, or the science of watershed management.

To determine how forests and forestry practices affect water yields, water quality, and streamflow behavior in the Southern Appalachians, the U. S. Forest Service in 1934 established the 4,700-acre Coweeta Hydrologic Laboratory in Western North Carolina. A tract of approximately 1,400 acres known as Dryman Fork was added to the Laboratory in 1946 and is being made ready for future research.

Coweeta research has shown among other things how much and how quic ly poor land use can change streamflow, soil properties, and water quality.

The research program has developed in three phases. From 1934 throug 1940 measurements were made of water yield, water quality, and the timing or delivery of water as streamflow from undisturbed forested watersheds. Precipitation and other climatic factors were observed and recorded.

Following this 6-year period of standardization or calibration of the watersheds, the research program entered a second phase during which precipitation-runoff relationships for several land uses and cover types were studied. In 1940-41 one watershed was cleared and used for mountain farming; another was used for cattle grazing; and a third was logged according to prevailing local practices. On other experimental watersheds, cover was altered in various ways to measure transpiration requirements of forest vege tation. This second phase continued through 1953.

The third phase of the research program began in 1954. In line with major objectives of the Coweeta program, emphasis is on (1) observing rates of watershed restoration, (2) continuing and strengthening basic studies of water utilization by vegetation, and, (3) establishing sound principles for integrated management of timber and water.

RESEARCH METHODS

Various methods have been used in the Coweeta hydrologic and watershed investigations, including sample plots, unit and multiple watersheds, and pilot-plant-size areas.

The procedure for watershed studies provides first for a period of measurement under undisturbed forest conditions of precipitation and streamflow as well as study of vegetation and soil conditions. This calibration period varies according to the standard of accuracy desired. Following it, watershed cover or soils are altered or treated in various ways. Behavior of the stream after treatment is then compared with its original behavior in order to establish treatment effect. A control watershed under natural conditions is permanently used as a reference check to provide means by which variations due to climate and other factors not associated with the treatment may be minimized.

In interpreting results of watershed studies, supplemental observations and measurements are frequently desirable. Daily and seasonal changes in soil moisture have been measured on a plot basis, as well as measurements of infiltration and compaction of the surface soil from trampling and other uses. The Coweeta studies have disclosed need for much supplemental data, and future research will utilize plot and laboratory techniques increasingly.

DESCRIPTION OF THE AREA

Physical characteristics of the Coweeta area make it particularly suitable for fundamental research in hydrology and watershed management. Many individual drainage basins reasonably similar as to soils, geology, and topography are found in a relatively small area. Most of the abundant and well-distributed precipitation occurs as rain. The forest cover is like that in many parts of the eastern United States. Consequently, research in water resource management should have wide application.

Geology and Physiography

The laboratory is located in the Nantahala Mountains, a part of the Blue Ridge province in the Southern Appalachians. The underlying rock, classified as Carolina gneiss of pre-Cambrian origin, includes granite gneiss, mica gneiss, and mica schist. The formation has undergone complex folding and is deeply weathered in response to the humid climate. The parent material weathers to form a relatively deep and porous soil mantle, with bare outcrops appearing only on the steeper slopes at high elevations.

Topography is steep and rugged, with elevations ranging from 2,250 feet at the headquarters area to approximately 5,250 feet on Albert Mountain. Sharp-crested ridges form natural boundaries for more than 40 small watersheds with permanent streams. These single or unit watersheds are from 25

Figure 1.--Relief model of Coweeta showing the many small watersheds and the dendritic drainage pattern.

to more than 200 acres in size. The drainage pattern of the area is dendritic and stream channels are essentially V-shaped. Figure 1 gives a view of the topography and the 45 miles of permanent stream channel on the area.

Climate

The perhumid climate is characterized by abundant precipitation and moderate temperatures. The average annual precipitation is 80 inches. October is usually the driest month, with an average of slightly more than 3.5 inches, and March the wettest, with more than 7.5 inches.

The mean annual temperature averages 55° F. and the frost-free season varies from 175 to 185 days. Maximum summer temperatures in excess of 94° are rare and summer nights are cool with minimums averaging 55°. The thre coldest months, December, January, and February, average 39°. Periods o cold weather with temperatures below 20° are short in duration. Summer temperatures are generally consistent, but winter temperatures are characte istically variable.

Evaporation as measured by a standard U. S. Weather Bureau pan averages over 33 inches per year, varying from approximately 1 inch in December to more than 4 inches in May.

Soils

Due to variations in parent material, topography, and elevation, a wide variety of soils are found at Coweeta and throughout the Southern Appalachians. All three soil orders and five of the great soil groups are found here (table 1).

Table 1.--Soil series identified on the Coweeta Hydrologic Laboratory[1/]

Order	Great soil group	Series	Texture	Parent material
Zonal	Red-yellow podzolic	Hayesville	Clay	Granite, gneiss, or schist
		Clifton	Clay	Hornblende, gneiss, and schist
		Fannin	Clay loam	Mica schist or mica gneiss
		Rabun	Clay loam	Hornblende, gneiss, and schist
		Tate	Loam	Colluvium
	Gray-brown podzolic	Halewood	Light clay	Granite, gneiss, or schist
		Porters	Loam	Granite, gneiss, or schist
		Ashe	Fine sandy	Granite, gneiss, or schist
		Balfour	Light clay	Granite, gneiss, or schist
		Tusquitee	Heavy loam	Colluvium
		Watauga	Clay loam	Mica schist
Intrazonal	Brown forest	Burton	Light clay loam	Granite, gneiss, or schist
Azonal	Lithosol	Talladega	Silt	Mica schist or mica gneiss
		Chandler	Stony loam	Mica schist or mica gneiss
	Alluvial	Congaree	Fine sandy loam	Recent alluvium

1/ Identification by Soil Conservation Service technicians.

At elevations over 3,750 feet, virtually all the soils are in the Ashe or Porters series. At medium elevations, Hayesville, Halewood, and Chandler,

along with the Ashe and Porters series, comprise the bulk of the soils. Colluvial soils mapped on the area include the Tate and Tusquitee series. Small areas of Congaree soils consisting of recent alluvium are found along the main stream in the valley floor.

Except for the deeper colluvial and alluvial soils, soil depths generally vary from 36 to 60 inches. Virtually all of the soils have moderately high to high internal and external drainage. In nearly all soil series the soil profile is acid to strongly acid throughout. Organic-matter content varies from low to moderately high.

Vegetation

Forests consisting largely of American chestnut, oaks, and hickories originally covered the area. Chestnut, which formerly made up nearly half the timber stand, has virtually disappeared since 1930 as a result of the disastrous chestnut blight. Nearly 60 species of hardwoods are now found on the area. Native conifers are hemlock, pitch pine, and juniper or red cedar.

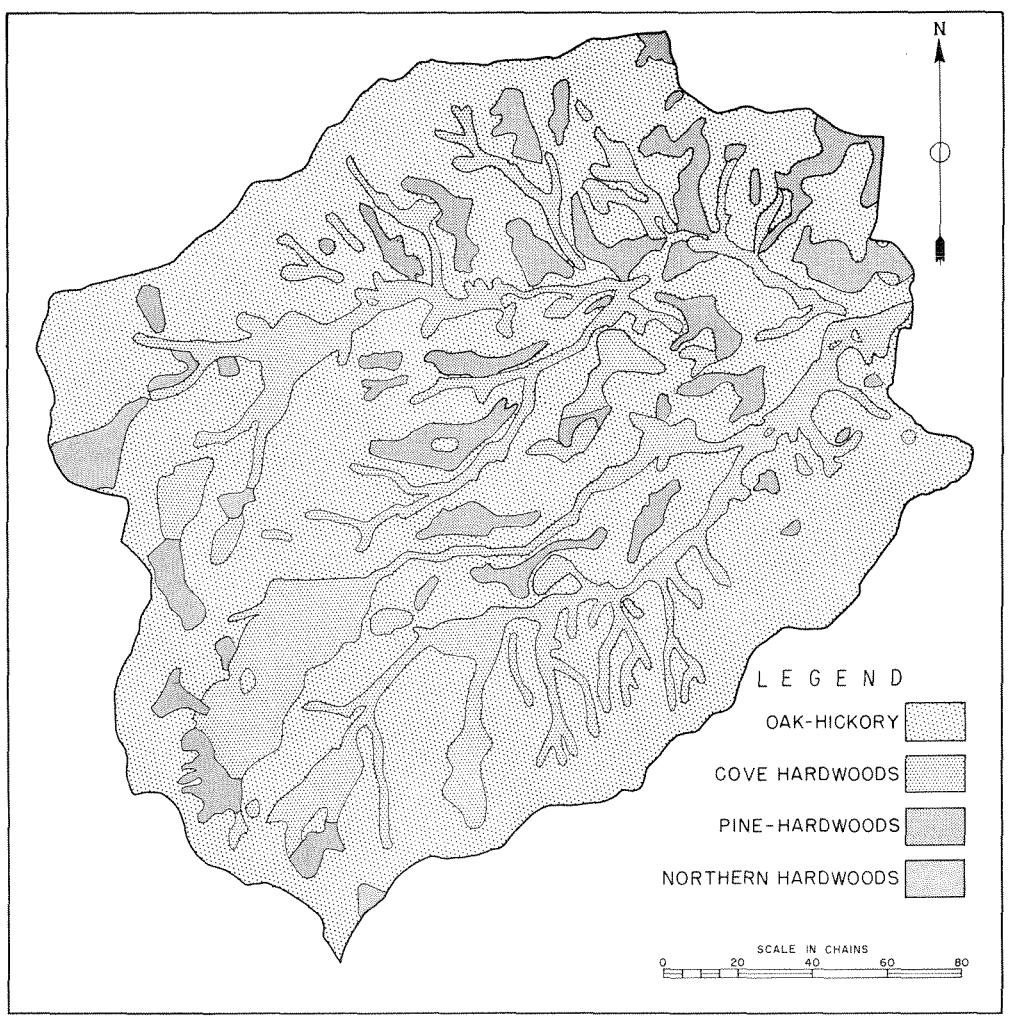

Figure 2.--Regional forest cover types on Coweeta watersheds.

Four regional forest cover types (fig. 2) are found: (1) northern hardwoods, (2) pine-hardwoods, (3) cove hardwoods, (4) oak-hickory. Oak-hickory is the most prevalent. The dominant oak-hickory type covers both north and south slopes and is typically 3-storied. Large trees form the upper or canopy layer, with trees on north-facing slopes generally being larger and more likely to form a closed canopy than those on south slopes. The understory is composed of oak and hickory saplings, frequently with an abundant to dense growth of rhododendron, laurel, azalea, red maple, black gum, sourwood, dogwood, and other less numerous small trees and shrubs. Ground cover includes grasses, anemones, asters, bedstraw, ferns, trilliums, violets, Solomon's seal, May apple, and mosses. In openings, various species of blackberry, blueberry, and huckleberry are common. This ground cover varies with the density of the layers above it and may be virtually absent where rhododendron and laurel form dense thickets.

In the coves and along the stream margins, cove hardwoods predominate. Here yellow-poplar, red oak, hickory, and hemlock are the primary species. At the high elevations, small areas of the northern hardwood type occur with its sugar maple, hemlock, yellow birch, basswood, and associated species. In both the cove and northern hardwood types, rhododendron and laurel often form dense understories. On the south and west facing ridges, the pine-hardwood type occurs. The pine is pitch pine and the hardwood component is largely oak.

Land Use

Prior to the first white settlement of the Coweeta area in 1848, it received limited use by the Cherokee Indian Nation. From 1848 to 1901, possibly as many as 10 homes were built on the present Coweeta area. Less than 200 acres were cleared for cultivation, principally along the main streams. As in most other localities, cattle, sheep, and hogs ranged without restraint.

During this period fires were frequently set by local inhabitants to improve forage conditions. On certain sites the burning was said to have increased the amount of palatable forage; on other sites the repeated fires are thought to have contributed to the formation of extensive areas of mountain laurel and rhododendron.

The settlers were moved from the area in 1902, when it was purchased by a large land company. It was subsequently sold to operating lumber companies. Logging began in 1909, with various small cutting operations continuing until 1918. Usually only the largest and best quality walnut, black cherry, chestnut, and yellow-poplar were logged. In 1918 the land was sold to the Forest Service with timber rights reserved. By agreement, no trees smaller than 15 inches in diameter on the stump were cut thereafter. The volume removed between 1918 and 1923 amounted to about 8 million board-feet.

The area became a part of the Nantahala National Forest in 1923; it was set aside as the Coweeta Experimental Forest in 1934 and renamed the Coweeta Hydrologic Laboratory in 1949.

Precipitation

A major consideration in the selection of Coweeta as a water resource research center was its location in the highest rainfall belt in eastern United States. Though annual precipitation averages close to 80 inches, more than 145 inches was measured in the southwest portion of the laboratory during one 12-month period. Approximately 98 percent of the water-income is rain, and the small amount of snow seldom remains on the ground for more than a few days. Average precipitation is well distributed throughout the year, as indicated in table 2. Monthly extremes for the entire drainage have ranged from 0.15 inch in October 1938 to 20.54 inches in November of 1948. The maximum storm on record yielded 11.7 inches of rainfall within a 17-hour period. Figure 3 shows the distribution of precipitation on the experimental area for the water year 1949, and the typically greater rainfall at higher elevations.

Table 2.--Precipitation summary
(in inches)

Month or year	High-elevation gage 1/			Low-elevation gage 2/		
	Average	Highest	Lowest	Average	Highest	Lowest
January	9.16	17.45	3.16	7.33	14.60	2.35
February	9.36	20.68	1.72	7.05	16.66	1.59
March	10.33	19.31	4.20	7.84	16.03	2.82
April	7.24	12.76	1.13	5.66	10.66	1.01
May	6.12	13.45	1.80	4.46	11.01	1.28
June	6.51	14.72	2.18	4.91	10.94	1.60
July	8.91	16.28	2.48	6.60	11.94	1.95
August	7.29	20.81	1.54	5.72	13.38	1.74
September	6.22	11.62	.93	4.23	10.08	.81
October	5.32	14.01	.20	3.47	9.46	.19
November	6.72	24.20	1.14	5.07	18.82	.70
December	9.44	17.77	4.18	6.92	13.33	2.75
Year	92.62	3/ 126.10	3/ 66.66	69.26	3/ 89.95	3/ 49.02

1/ 1935-1955 inclusive, Gage No. 8, elevation 3,870 feet.

2/ 1936-1955 inclusive, Gage No. 19, elevation 2,240 feet.

3/ The highest or lowest calendar year, not a total.

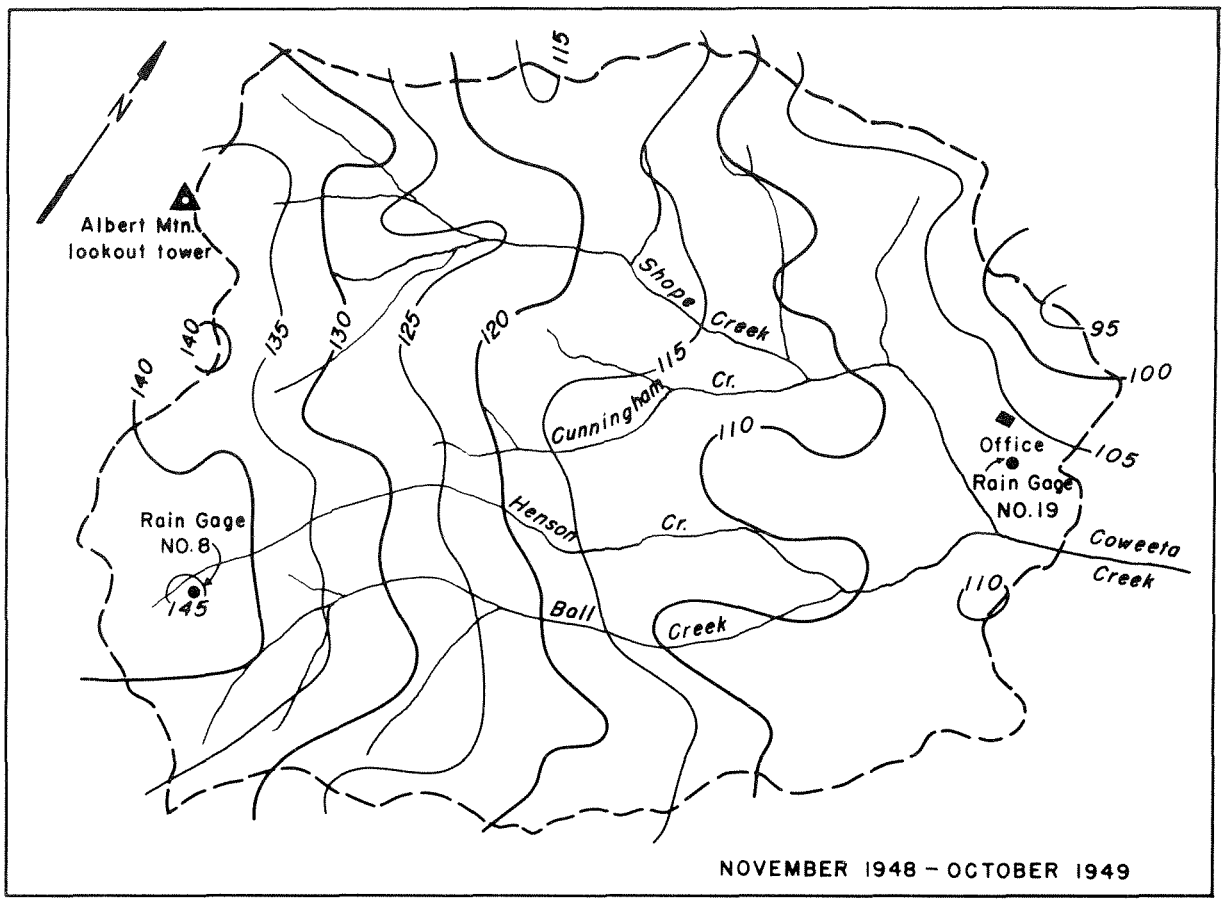

Figure 3.--Isohyetal map for maximum water year, showing total precipitation in inches.

Table 3.--Average and extreme number of storms per month, as recorded at precipitation gage near headquarters 1/

Month or year	Average	Highest	Lowest
January	9.5	16	5
February	9.3	16	4
March	10.5	14	7
April	8.9	12	3
May	12.1	18	3
June	14.4	21	9
July	15.8	20	9
August	15.3	21	6
September	8.6	14	4
October	7.5	13	3
November	7.5	14	3
December	8.5	13	4
Year	127.9	156 2/	98 2/

1/ 1935-1949 inclusive.
2/ The highest or lowest calendar year, not a total.

Approximately 128 individual storms occur per year, with convection thunderstorms accounting for the high precipitation in summer (table 3). On the average, 55 storms produce 90 percent of the total precipitation, each yielding over 0.30 inch of precipitation and increasing the streamflow sufficiently for hydrograph analysis.

Highest intensities observed have been at the valley floor or lower slope stations, while greatest amounts per storm have been measured at the higher elevation stations. Maximum precipitation intensities recorded for selected time intervals are given on the following page.

Time Interval (Minutes)	Precipitation Intensity (Inches per hour)
5	7.20
10	5.82
30	5.00
60	3.85

A network of 69 standard 8-inch Weather Bureau gages is used to measure gross precipitation. Sixteen recording gages measure precipitation intensities. Figures 4 and 5 show the location of these gages in small areas cleared of all major vegetation so that there is a clearance angle of approximately 45 degrees or more in all directions. Interception trough gages and stem flow gages are used in special studies to determine the net precipitation under forest canopies.

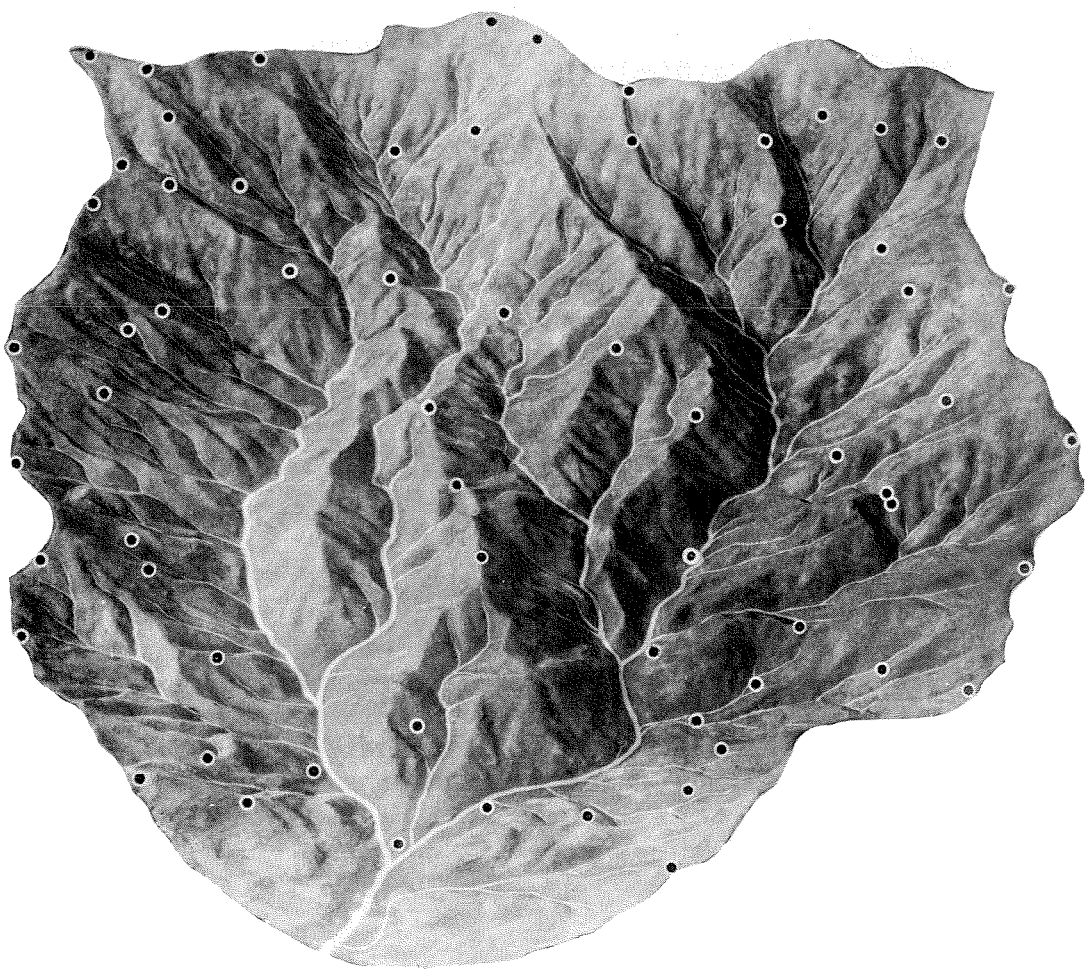

Figure 4.--Standard rain gage locations are shown by dots, excluding those in Dryman Fork. The gage network is designed to sample various elevations and all facets of the topography.

Figure 5.--Location of recording rain gages, excluding those in Dryman Fork.

Streamflow

The volume and rate of streamflow from a given watershed is a reflection of the amount, intensity, and distribution of precipitation received and of the characteristics of the watershed itself. With such records it is possible to establish precipitation-streamflow relationships.

An important characteristic of forested watersheds at Coweeta is the constancy of annual differences between total precipitation and total runoff, as illustrated in table 4. The column labeled "Precipitation minus runoff" represents chiefly evapotranspiration (including interception). Regardless of total precipitation, annual water losses to the atmosphere are remarkably constant. For the 16-year period, adjusted annual water losses vary within a range of only 6.96 inches, while precipitation and runoff show corresponding ranges of approximately 40 and 39 inches, respectively.

As the elevation increases, however, evapotranspiration decreases. For watersheds with average elevations of 2,700 feet, the average annual loss is 35 inches. At average elevations of 4,200 feet, approximately 20 inches is lost annually to the atmosphere.

Table 4.--Annual water balance values for Watershed 18
(in inches)

Water year 1/	Precipitation	Runoff	Precipitation minus runoff	Precipitation minus runoff adjusted for storage
1937-1938	63.26	24.70	38.56	37.42
1938-1939	86.79	50.43	36.36	32.44
1939-1940	48.91	20.38	28.53	34.43
1940-1941	60.24	24.65	35.59	36.27
1941-1942	63.17	24.22	38.95	34.48
1942-1943	75.37	40.46	34.91	35.19
1943-1944	77.62	39.14	38.48	33.71
1944-1945	62.21	30.41	31.80	38.13
1945-1946	80.78	39.97	40.81	36.43
1946-1947	64.22	34.64	29.58	34.16
1947-1948	73.31	36.37	36.94	31.17
1948-1949	83.82	52.39	31.43	32.51
1949-1950	88.87	59.47	29.40	32.18
1950-1951	68.14	35.06	33.08	31.38
1951-1952	81.75	48.48	33.27	31.30
1952-1953	63.18	31.79	31.39	36.09
Average	71.35	37.04	34.31	34.21
Range	39.96	39.09	12.28	6.96

1/ Water year begins April 1 and ends March 31.

Precipitation, vegetation, and soil conditions give rise to three hydrologic seasons. From December through March, precipitation is at its maximum. Evaporation and transpiration are at a minimum and soil moisture i at or near field capacity. Much of the precipitation, therefore, quickly becomes ground water and produces high streamflow.

April through September marks the period of maximum evaporation an transpiration. Streamflow recedes to the yearly low during this period as a result of the cumulative effects of withdrawals from the soil and ground wat reservoir by vegetation and evaporative processes.

The period of soil moisture recharge begins at the conclusion of the growing season in October, when both evaporation and transpiration rates decline. During this period soil moisture deficits are satisfied by precipita tion, and streamflow increases.

Streamflow is measured automatically at gaging stations by water-leve recorders. The recorders provide a continuous stream hydrograph showin depth of water flowing through a weir control section of known hydraulic cha acteristics (figures 6 and 7).

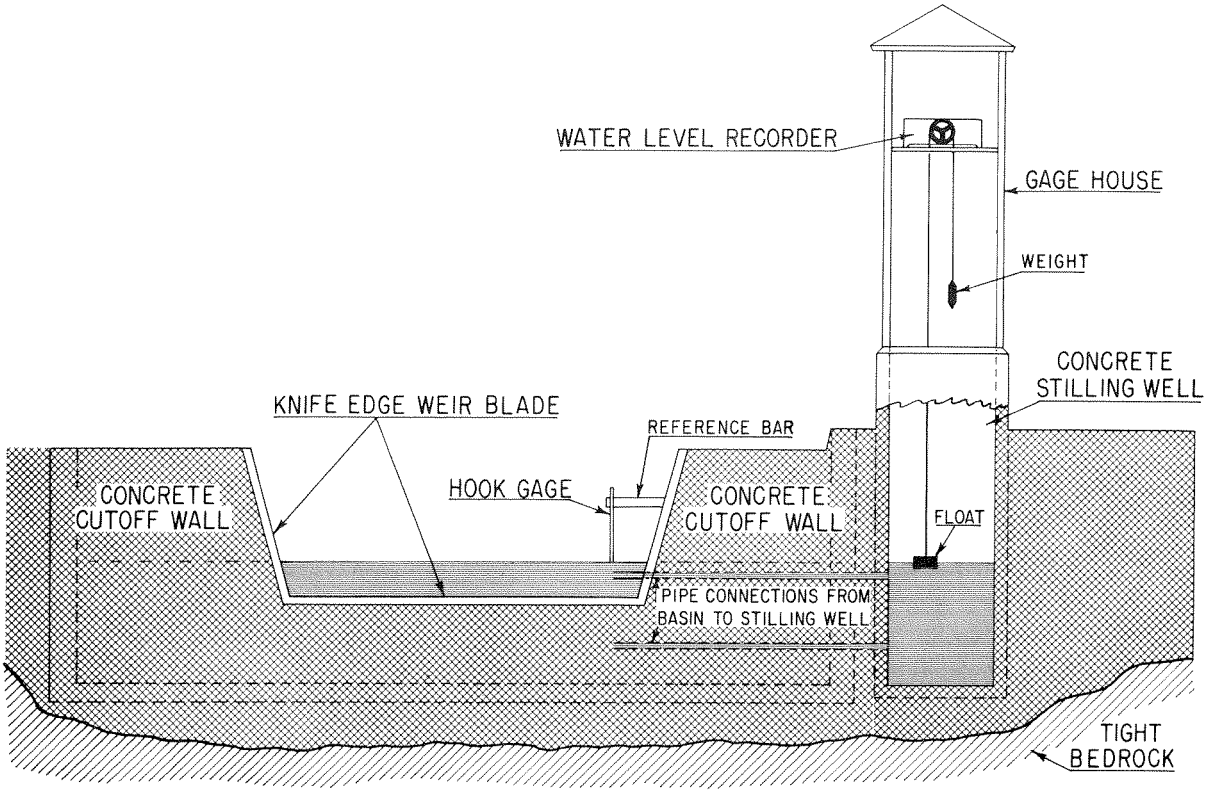

Figure 6.--A stream gaging installation.

Figure 7.--Working details of a typical Coweeta stream gaging station. This 6-foot rectangular weir is used on watersheds where the low flow is not likely to go below 0.70 cubic foot per second, and storm discharge is above 90 cubic feet per second. A, Knife-edge weir blade; B, Flood flow section; C, Bypass for carrying streamflow during periods of repair or maintenace; D, Drain plug for cleaning basin; E, Device for dampening wave action in ponding basin; F, Level wall to kill velocity of water entering ponding basin.

Thirty-one gaging stations are employed to measure the streamflow from 23 unit or single watersheds and 8 multiple or combination watersheds. Figure 8 shows the location of the gaged watersheds. Figures 9 through 12 picture four types of weirs in use. In table 5 all the stream gages at Coweeta are listed, together with their drainage basin areas, the dates of their installation, and other information.

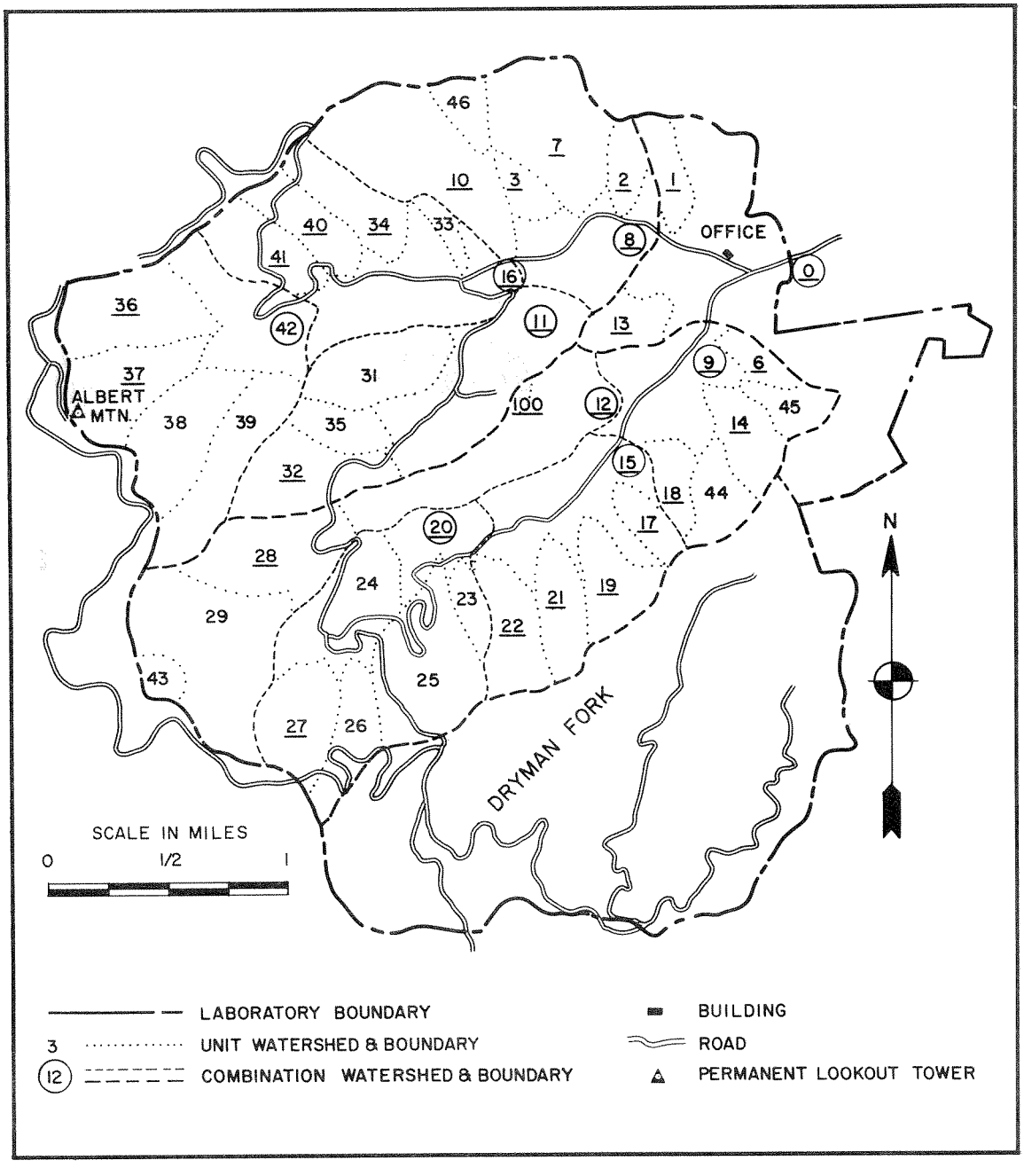

Figure 8.--Uncircled numbers represent single drainages used as experimental units. Circled numbers represent combinations of these units. Underlining indicates gaged watershed.

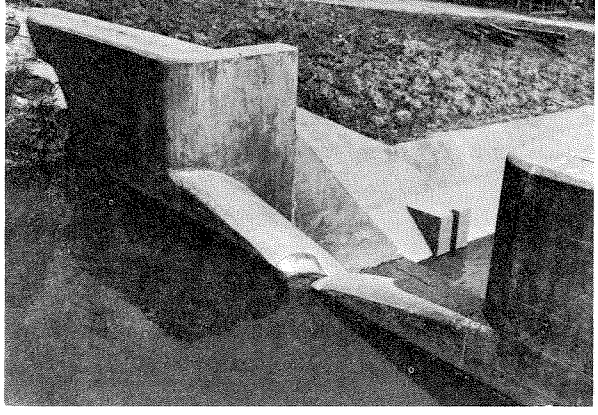

Figure 9.--Columbus deep notch weir with bronze notch liner gives accurate measurements for a wide range of flow. Convex weir throat permits passage of heavy debris loads without clogging.

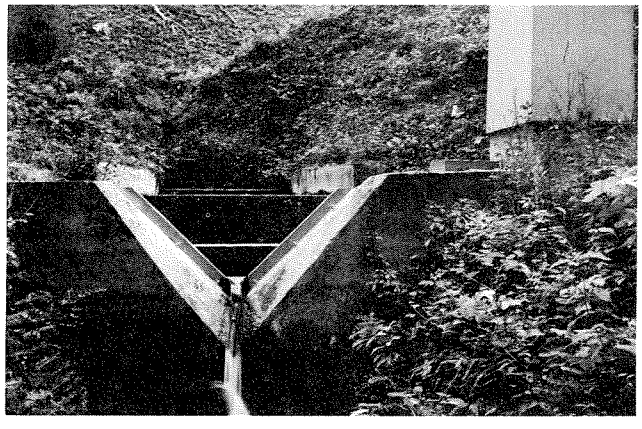

Figure 10.--90° V-notch weir is designed for accurate measurement of low to medium flows. Used on small watersheds of 5 to 50 acres where heavy debris loads are not likely to clog the notch.

Figure 11.--120° V-notch weir. Similar to 90° V-notch but covers larger range of flows. Used on watersheds of 40 to 200 acres.

Figure 12.--8-foot Cippoletti. Sharp-crested weir similar to the rectangular (fig. 7). Capacity much larger than deep or V-notch weirs. Used on multiple watersheds of 2000 acres or more.

Table 5.--Coweeta stream gaging installations

Weir and watershed number	Drainage basin above weir	Gage	First record	Discharge 1/	
				Maximum	Minimum
	Acres	Type	Date	C.s.m.2/	C.s.m.
UNIT WATERSHEDS					
1	39	90° V-notch	June 13, 1934	86	0.26
2	31	90° V-notch	June 22, 1934	83	.12
3	23	CIA deep-notch	July 5, 1934	1849	.23
6	22	90° V-notch	July 10, 1934	155	.25
7	145	CIA deep-notch	July 31, 1934	68	.59
10	212	120° V-notch	March 7, 1936	82	.71
13	40	120° V-notch	March 12, 1936	88	.44
14	152	120° V-notch	May 26, 1936	102	.51
17	33	90° V-notch	June 6, 1936	70	.19
18	31	120° V-notch	June 3, 1936	124	.28
19	69	120° V-notch	May 17, 1941	105	.78
21	59	120° V-notch	July 22, 1938	168	.64
22	88	120° V-notch	Feb. 18, 1937	161	.38
27	100	120° V-notch	Nov. 2, 1946	415	.23
28	350	6-ft. Rectangle	May 24, 1937	158	.64
32	102	120° V-notch	Oct. 25, 1941	115	.30
34	81	120° V-notch	Oct. 13, 1938	48	.67
36	114	120° V-notch	April 29, 1943	354	.54
37	99	120° V-notch	April 15, 1942	448	.41
40	50	90° V-notch	Dec. 4, 1938	63	.53
41	71	120° V-notch	Aug. 23, 1940	108	.55
100	7	90° V-notch	March 14, 1938	63	.06
COMBINATION WATERSHEDS					
0	4000	Control section	July 6, 1937		
8	1877	12-ft. Cippoletti	Oct. 6, 1934	108	0.65
9	1788	12-ft. Cippoletti	Oct. 12, 1934	117	.48
11	440	5-ft. Rectangle	Mar. 5, 1936	82	.48
12	501	6-ft. Cippoletti	Mar. 17, 1936	165	.64
15	940	8-ft. Cippoletti	Dec. 21, 1936	121	.48
16	943	6-ft. Rectangle	June 4, 1936	122	.13
20	511	6-ft. Rectangle	July 30, 1937	134	.52

1/ For period of record.

2/ Cubic feet per second per square mile.

Ground Water

Study of ground water is also essential in interpreting hydrologic processes. The depth of the water table varies widely, depending on such factors as elevation above and distance from the stream channel, surface relief, geologic formation, soils and vegetation, and season. Permanent water tables have been encountered on the Laboratory at depths varying from 3 to 30 feet below the surface.

Since most permanent water tables at Coweeta are less than 15 feet from the surface, they have the characteristics of shallow wells and exhibit frequent and extreme fluctuations. Rises of several feet following heavy rains are common. Fluctuations in ground-water levels have a marked influence on soil moisture relations, opportunities for water storage in the soil profile, rates of subsurface drainage, ground-water yields, and periods of low streamflow.

Figure 13 illustrates the correlation of water table levels in an observation well with streamflow and precipitation. The loss from storage amounted to approximately 2.5 feet from a high in March to the low in September and October. Note too that the changes in ground-water levels correspond closely to the three hydrologic seasons.

Seven ground-water wells (fig. 14) are used to record ground-water levels. Each well is housed to protect the automatic water level recorder.

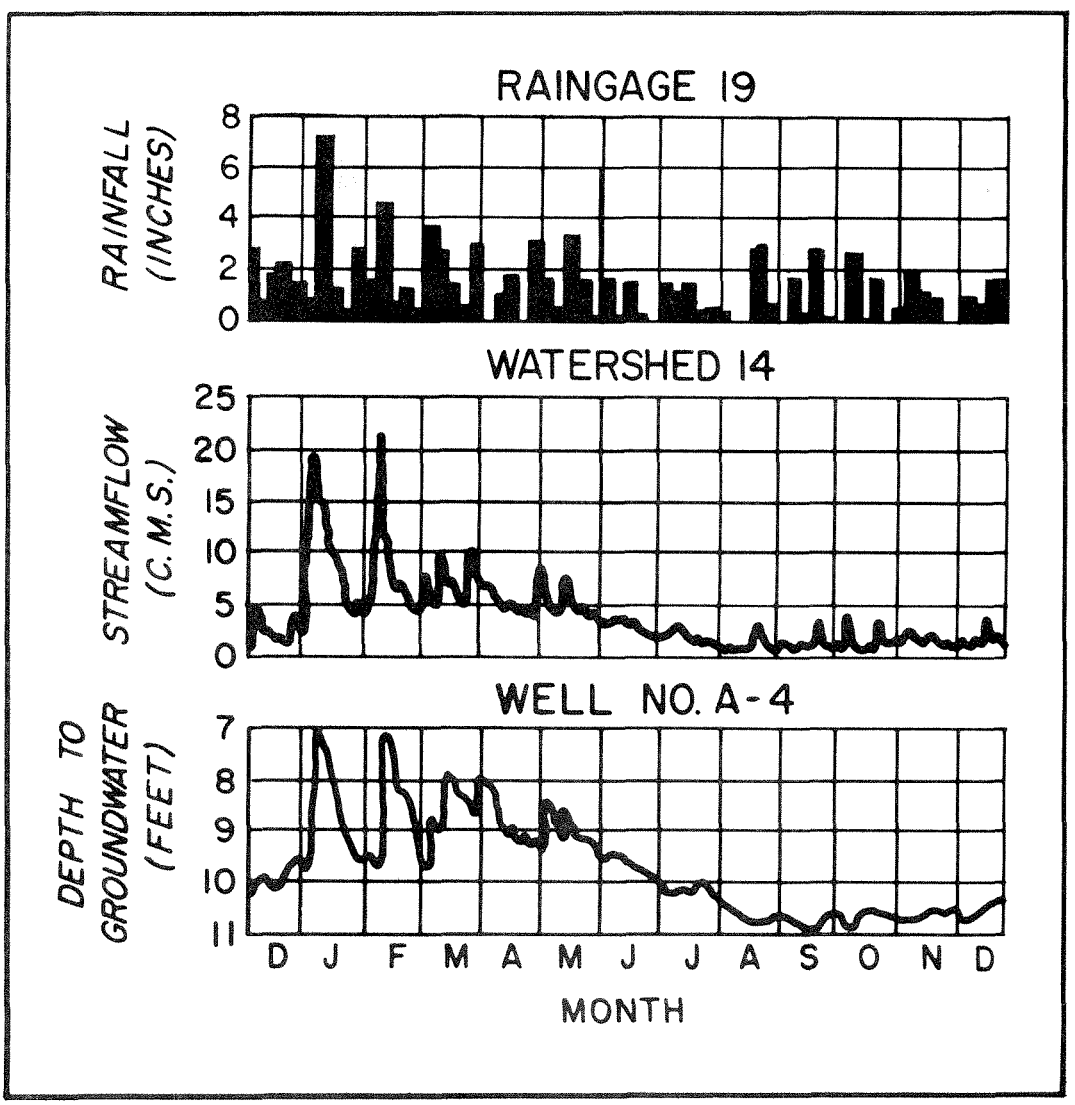

Figure 13.--Correlation of water table in observation well with streamflow and precipitation from December 1946 to December 1947. Observation well A-4, near office building, was used for comparison.

Figure 14.--Location of the 7 ground-water wells at Coweeta.

Soil Water

Depending upon its moisture content, the water storage capacity of soil is largely a function of the rate at which water enters it and the size, volume, and distribution of pores and voids within the soil, as well as its depth. Moreover, the rate at which water moves through the soil reservoir to ground wate or to subsurface flow depends upon such factors as antecedent moisture conditions, soil depth, porosity, and topography.

Infiltration rates are generally high in undisturbed forest. Except under conditions approaching saturation, measurements with a ring infiltrometer show rates in excess of 10 inches per hour--far greater than the observed maximum precipitation intensities. Soil porosity values derived from several forested watersheds indicate high permeability rates. When relatively dry, the water-holding capacity of the surface foot of the soil will vary from 4 to 6 inches. The values given in table 6 indicate the favorable soil-water relations for these soils.

The average volume weight or bulk density of the surface soil is about 0.90 gram per cubic centimeter. This value increases with soil depth to approximately 1.40 grams at the 48- to 60-inch level.

Because of steep topography and forest soils which characteristically exhibit excellent drainage, soil moisture fluctuates markedly. Studies are being made to measure these fluctuations under natural forest conditions and under subsequent watershed treatment. These and related investigations will afford useful information about soil properties indicative of water intake and storage capacity, soil stability, and other practical aspects of watershed management.

Table 6.--Soil moisture relations on Chandler Soil series, Watershed 2 (in inches)

Depth	Field capacity	Permanent wilting point	Total water available for plant growth
0-6	1.94	0.99	0.95
6-12	1.71	0.99	0.72
12-24	3.64	1.28	2.36
24-36	3.82	1.28	2.54
36-48	3.56	1.28	2.28
48-60	3.50	1.21	2.29
60-72	3.95	1.21	2.74

Water Quality

Stream turbidities are measured as an index of watershed treatment effect. Samples of water are collected manually, and turbidities are determined in parts per million (p.p.m.) from a turbidimeter in accordance with U. S. Public Health Service Drinking Water Standards. During storm periods, samples have been taken at intervals of 5 to 10 minutes for the entire period of the rise and fall of the stream. Turbidities from undisturbed forest streams are generally less than 2 p.p.m. during nonstorm periods. Even during most storm periods they range well under the 11 p.p.m. drinking water standard. Extreme conditions may produce turbidities as high as 80 p.p.m.

Stream temperatures have been taken periodically at a number of stations to record changes brought about by land clearing and by cutting streamside vegetation. Average monthly temperatures from an undisturbed forest stream are generally about 63° F. in August, and about 39° in February. These studies were undertaken principally to provide data on trout habitat.

Climatic Measurements Other Than Precipitation

One Class A weather station has been operated continuously since 1934 on the valley floor near the headquarters, about 1,000 feet above the confluence of the two major drainages forming Coweeta Creek. This station provides records of evaporation from a free water surface, air temperature, wind velocities, relative humidity, and microbarograph readings, in addition to precipitation data.

Seven additional climatic stations were operated from 1934 to 1939 at different elevations and aspects to provide a basis for understanding the climatic pattern for the area as a whole. Special climatic records are collected where watershed treatments may induce significant changes in microclimate and hence hydrology.

Mountain Farming, Watershed 3

Following a period of standardization for this 23-acre forested watershed from 1934 to 1939, the area was cleared for farming in 1940 to measure the effects of steep land agriculture on water and soil. In 1941, approximately 6 acres in the center of the area was fenced, plowed, and planted to corn. Farming was old-fashioned sidehill agriculture of the type that used to be quite common. Damage to the land in these studies was a foregone conclusion the main object being to test how much damage would occur, how soon. Of the 17 acres outside the cornfield, about 10 acres were too rough for pasture and were permitted to grow back into brush and trees (coppice forest). The remaining 7 acres were planted to a mixture of pasture grasses in 1942 and put to grazing use (fig. 15). Figure 16 shows the installations for measuring streamflow and soil losses from the watershed.

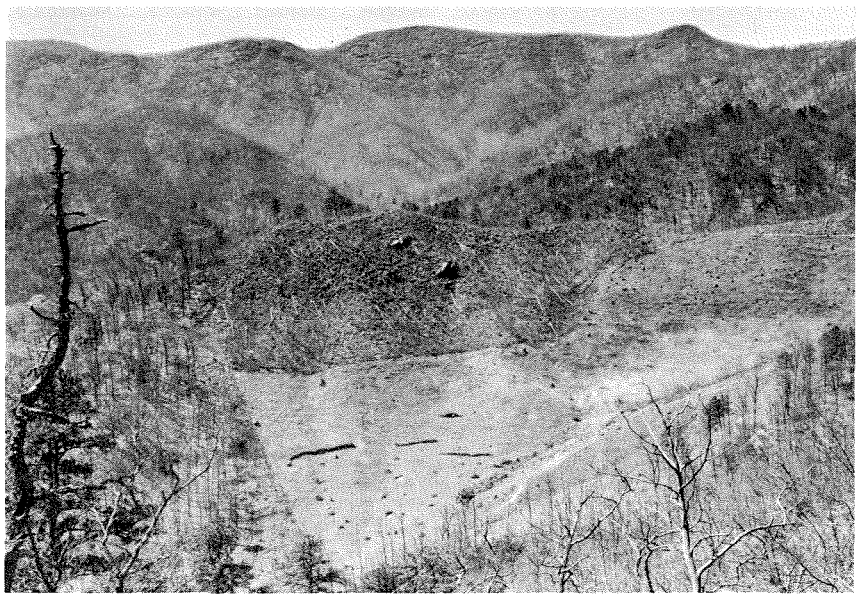

Figure 15.--A general view of the watershed after conversion to a mountain farm.

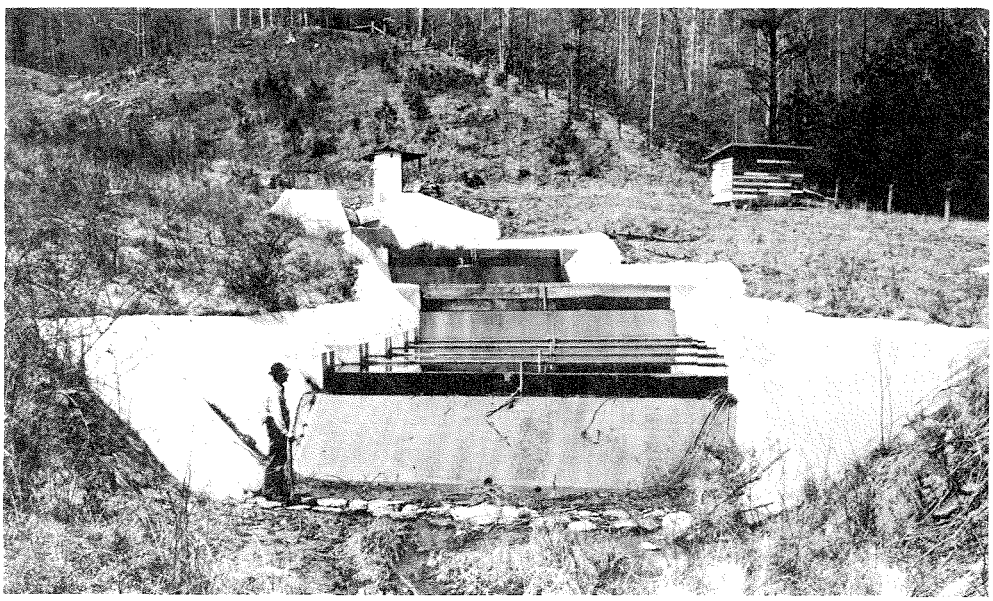

Figure 16.--Streamflo and soil losses from th watershed are measur by a CIA-deep notch w and a specially designe debris basin.

Corn cropping continued from 1941 through 1949 except for the 1944 and 1945 seasons, when the cornfield was permitted to lie fallow. By 1949, corn yields had decreased to the point where cultivation was no longer profitable, and the area was converted to pasture the following season. Figure 17 shows the corn yields for the 7 years of record.

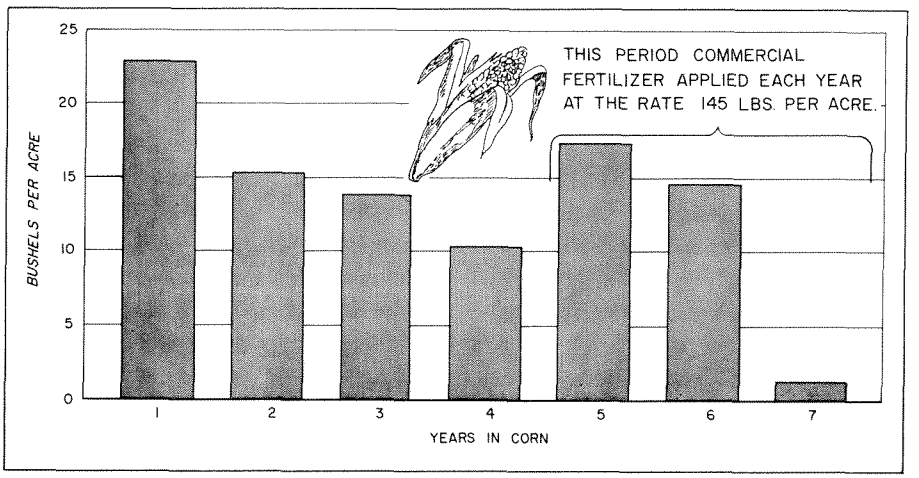

Figure 17.--Summary of corn yields from the mountain farm.

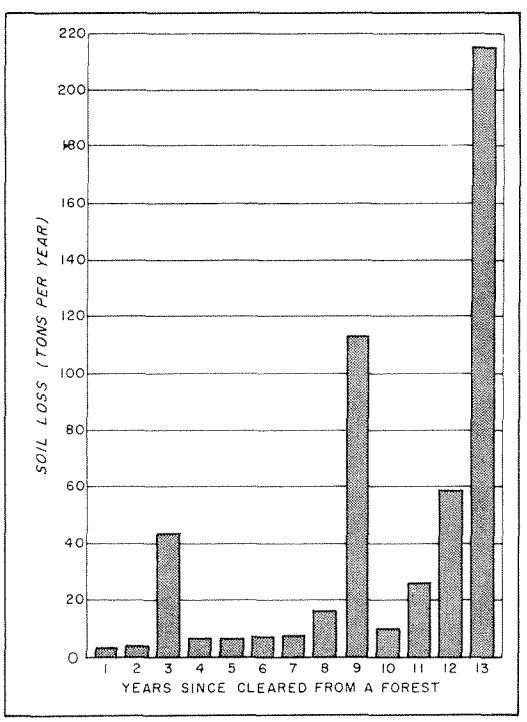

Figure 18.--Yearly soil losses from mountain farm watershed during the first 13 years after the forest was cleared in 1940.

From 1942 to 1949, cattle were alternately grazed on the pasture area and on an adjacent wooded watershed. After the 1949 season, the former cornfield was grazed along with the pasture until 1953, when it was felt that the degradation phase of the experiment was complete.

Prior to clearing, evidence of erosion was not visible on the area itself, although about 1.8 tons of sand and gravel on an average accumulated annually in the weir ponding basin. The thirteenth year after the land had been cleared, it lost more than 200 tons (fig. 18).

Changes in the water intake capacity on the mountain farm reflect the damage to soil structure. In 1949, the average infiltration rate for the trampled pasture was 0.56 inch per hour, as compared with rates in excess of 6.00 inches per hour for the portion in coppice forest. Moreover, when the cornfield was opened to grazing in 1950, the infiltration rate dropped from

3.02 inches per hour to 0.62 inch after only 30 animal-use days of grazing pe acre. Soil analysis in 1951 indicated a reduction in macro-porosity, permeability, and content of organic matter, as well as a decrease in the numbe and size of soil aggregates. The pastured portion of the watershed showed a much more marked degrading in soil characteristics than did the cornfield.

During the treatment period the stream channel began to widen, deepen, and cut its way upslope. By the tenth year the channel banks, originally rounded and clothed with vegetation, were cut away, leaving raw, vertical-sided walls which were then undermined by the increased runoff. Contributio from the channel itself probably account for a major part of the total sedimer production from the basin during the tenth to thirteenth years.

Equally significant were the changes in streamflow characteristics. Figure 19 illustrates the distribution of storm runoff from single summer storms for the watershed before and after treatment. Similarly, there was a very marked change in the frequency and magnitude of floods. After treatment, storms which normally would have occasioned minor rises in the stream produced storm runoff that overflowed stream banks.

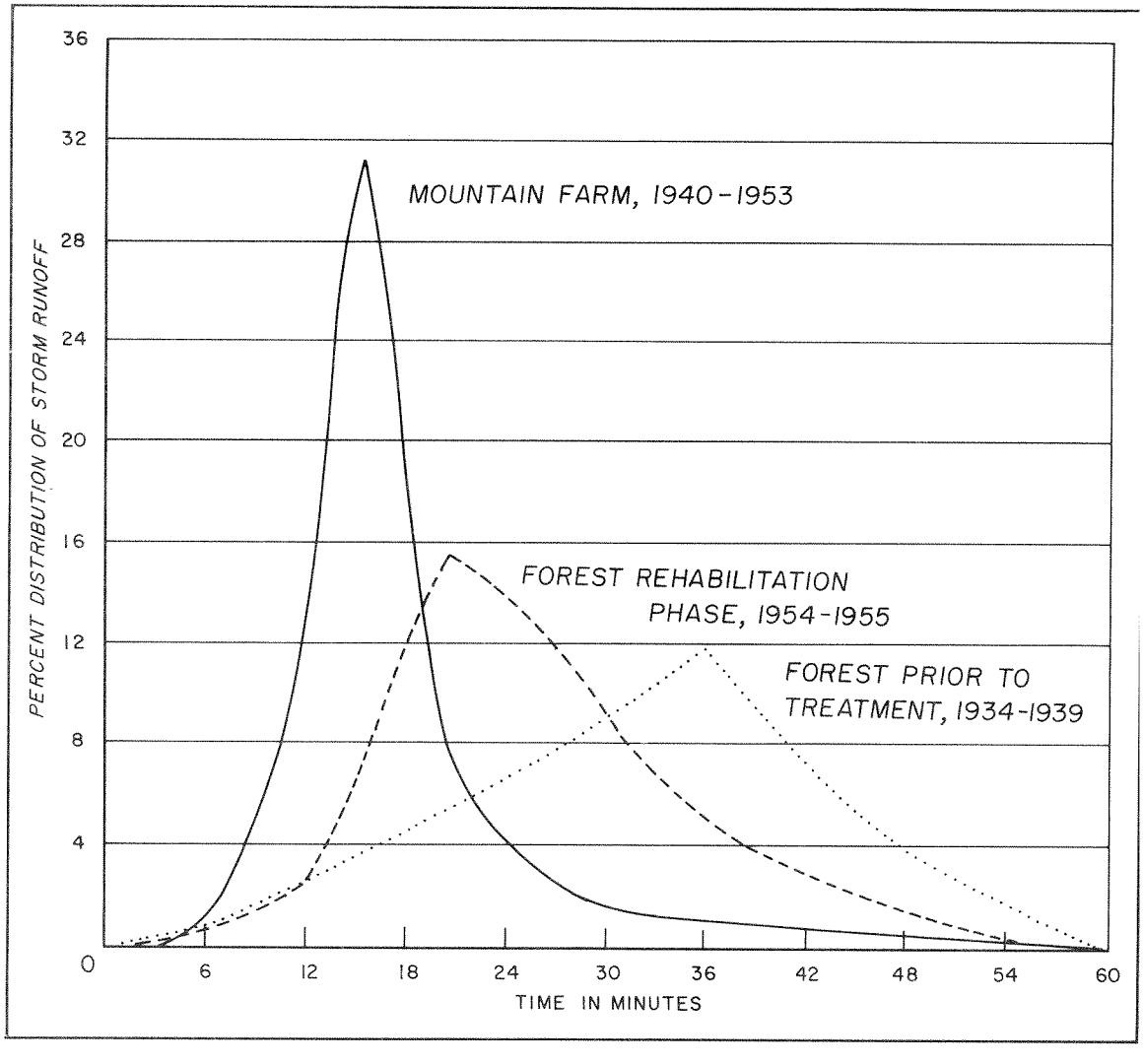

Figure 19.--Distribution of storm runoff for an average of typical summer storms under forest cover, mountain farming, and after 2 years of rehabilitation.

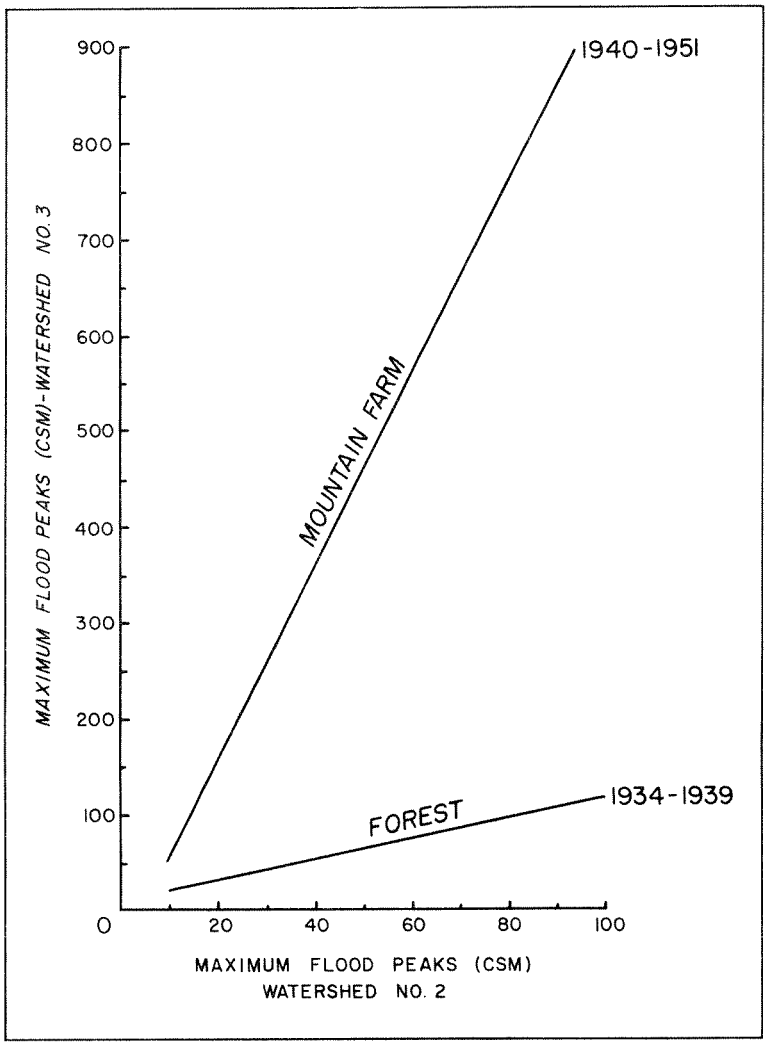

Figure 20.--Maximum flood peak relation between Watershed 3 and Control Watershed 2 before and after treatment.

Figure 20 shows maximum flood peak relations between Watershed 3 and adjacent control Watershed 2. During the calibration period a storm producing a flow of approximately 70 c.s.m. from Watershed 2 produced a flow of approximately 80 c.s.m. on Watershed 3. As a result of mountain farming on Watershed 3, however, a similar storm (still producing a flow of 70 c.s.m. on the undisturbed control area) produced a flow in excess of 650 c.s.m.--more than 8 times greater than the maximum peak that would have been expected had this area remained in forest.

Rehabilitation of the mountain farm was started in April 1954, when the area was seeded to oats and to Korean and Serecia lespedeza. After one season of rehabilitation, a 6-inch storm in December 1954 moved only 3 tons of sediment from the area, as contrasted with 1-inch storms of the previous winter which consistently carried off 20 to 30 tons each. In 1955, approximately half the former cornfield and pasture was planted to yellow-poplar and the balance to white pine.

Figure 21 shows the area before and after the start of rehabilitation measures.

Figure 21.--View across Watershed 3. Above, in the spring of 1954 at the conclusion of the mountain farming treatment. Below, in August 1956, following 2 years of rehabilitation.

Woodland Grazing, Watershed 7

It has been common practice in the Southern Appalachian mountain region for cattle to range in farm woodlands. In the agricultural census of 1950, 25 percent of all land area in the Western North Carolina counties, or about 1 million acres, is shown as grazed farm woodlands. Such woodlands are often fenced in with an adjacent idle field or pasture and generally receive very heavy use. The intent of the study of Watershed 7 was to measure the effects of grazing and trampling the watershed, as in typical grazed farm woodlots.

Watershed 7, consisting of 145 acres, was calibrated for 7 years under natural forest conditions. The watershed was then fenced and an average of 6 head of cattle was grazed for a 4-month period each year from May to September, beginning in 1941.

The experimental watershed supported three forest types, as shown in figure 22. The herbaceous ground cover on the cove site included a number of grasses, legumes, and other palatable species. The oak-hickory type along the slopes supported a similar though less dense ground cover, and the pitch pine oak type on the ridges had an understory consisting essentially of laurel, azalea, and huckleberry, not relished by cattle. Thirty-four control plots each 2 chains square were located at random over the watershed. Seventeen of these were fenced as controls, and the remainder were left open to unrestricted grazing. Detailed observations of both herbaceous and woody vegetation were made periodically on all plots.

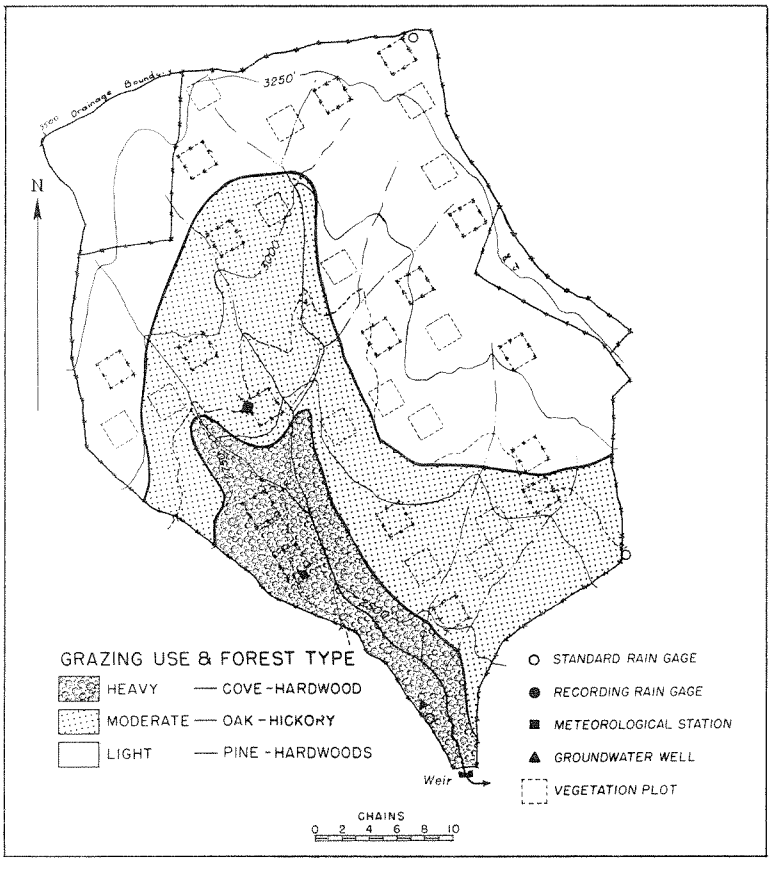

Figure 22.--Forest types and grazing use on the 145-acre woodland grazing experimental watershed.

Figure 23.--Six seasons of grazing in the cove-hardwood type produced this parklike appearance. Note the absence of reproduction and understory vegetation.

By the end of the first grazing season, practically all herbaceous forage and much of the hardwood understory had been consumed in the cove type and to a lesser degree in the oak-hickory type. In subsequent years, forage was so scarce that the cattle required supplemental feeding. Trees up to 15 feet in height and $2\frac{1}{2}$ inches in diameter were commonly ridden down and the tops eaten. Six seasons of grazing in the cove hardwood type produced a stand of parklike appearance (fig. 23). As browsing removed virtually all the understory in the cove type, cattle moved into the oak-hickory type on the slopes, where they ate much of the palatable forage within reach. Because the pine-hardwood type on the ridges contained little palatable feed, it was little graze

At the end of the ninth grazing season, growth measurements in the unfenced plots show that yellow-poplar in the 3- to 9-inch diameter class had 50 percent less diameter growth on the outside 5 rings, hickory 30 percent less, and red maple 27 percent less than similar trees in the fenced plots.

Soil samples showed an increase in volume weights of the surface soil and a marked reduction in soil porosity, permeability, and infiltration rate. The results of porosity, permeability, and infiltration tests are summarized in table 7.

Table 7.--Soil changes on grazed plots

Timber type and site	Total porosity 1/		Permeability		Infiltration (by ring test)
	0 to 2-inch depth	2 to 4-inch depth	0 to 2-inch depth	2 to 4-inch depth	
	Percent decrease				
Cove hardwood	42	56	70	91	91
Oak-hickory on slopes	15	12	32	32	67
Pine-oak on ridges	6	4	13	0	--

1/ This is the total storage opportunity for water in the soil and includes both field moisture (capillary) and free moving (noncapillary) water.

During the first 8 years of treatment, no noticeable change occurred in streamflow or in stream turbidity. From the start the effects on the ground cover and litter wherever the cattle concentrated were obvious. As bare areas increased in size, there was a gradual increase in the amount of storm water accumulating on the soil surface. Storm water moved into the natural drainage lanes and small ravines where forest litter normally accumulates to a considerable depth. For several years small litter dams filtered out the silt, enabling clear water to go into the soil before it reached the main water-course. As the amount of bare surface area increased and compaction progressed, the volume of surface storm water increased until it gained sufficient force to carry away the litter plugs along the natural drainage lines and develop uninterrupted channels to the main stream. Thus, it was not until the end of the eighth grazing season that storm runoff gained sufficient momentum to move overland directly into the main stream. Immediately there was a sharp upturn in the amount of sediment carried by the stream and in the frequency and magnitude of the peaks on stream hydrographs.

Higher intensities of grazing use over a prolonged period would doubtless have produced much more striking changes in streamflow.

Exploitive Logging, Watershed 10

Horses and oxen were commonly used to skid logs from the felling area to loading decks in early logging operations. Heavy logging trucks came into use after 1940, requiring the construction of more and more woods roads. The location and construction as well as maintenance of many of these haul roads have had little planning and supervision. Streams draining areas in which there are logging operations often become turbid and their channels silted.

Watershed 10, of 212 acres, was used for observations of the effect of local logging practices on streamflow and water quality. This watershed has steep, rather rough topography, with the merchantable trees distributed in scattered stands. Following a 6-year calibration period, timber was removed in several stages following the same general procedure practiced on other small local operations. Table 8 shows a schedule of timber removal on the area to date.

Table 8.--Schedule of logging operations on Watershed 10

Years	Product	Volume			
		Board feet	Cords	Tons	Posts
1942-1943	Sawtimber	85,700	0	0	0
1945-1948	Sawtimber	168,860	0	0	0
	Acid wood	0	1,220	0	0
	Dogwood	0	2	0	0
	Fence posts	0	0	0	200
	Chestnut-oak bark	0	0	36	0
1953-1954	Sawtimber	109,000	0	0	0
	Pulpwood	0	125	0	0
Total		363,560	1,347	36	200

In the initial sale the logs were skidded by horses and oxen an average of ½ mile to a landing by one of the main roads. During this period, no trucks were taken into the watershed. Between 1946 and 1948, the operator, with the assistance of an acid wood purchaser, had 2.3 miles of haul road punched into the watershed. During the 1954-1956 period, an additional 1.2 miles of road was constructed, primarily along the ridge forming the northwest boundary of the watershed. Figure 24 shows the location of the logging roads.

Logging in this manner caused extensive erosion from roads and skid trails and was the source of very high stream turbidities even in small storms. Figure 25 shows how the skid trails tend to channel stormwater.

For the period June 10 to September 21, 1946, when extract wood was being removed, stream turbidities averaged 94 parts per million as shown in figure 26. Maximum turbidity for the period, consisting largely of mineral soil, was 3,500 parts per million. By way of comparison, on the undisturbed control watershed average stream turbidity was 4 parts per million and the maximum--primarily organic content--was only 80 parts per million. In 1947, the year of most active logging, turbidities increased to a maximum of 5,700 parts per million. Impairment of water quality persisted after logging stopped in December 1948, the exposed clay subsoil on the skid trails and roads continuing to move into streams after every storm.

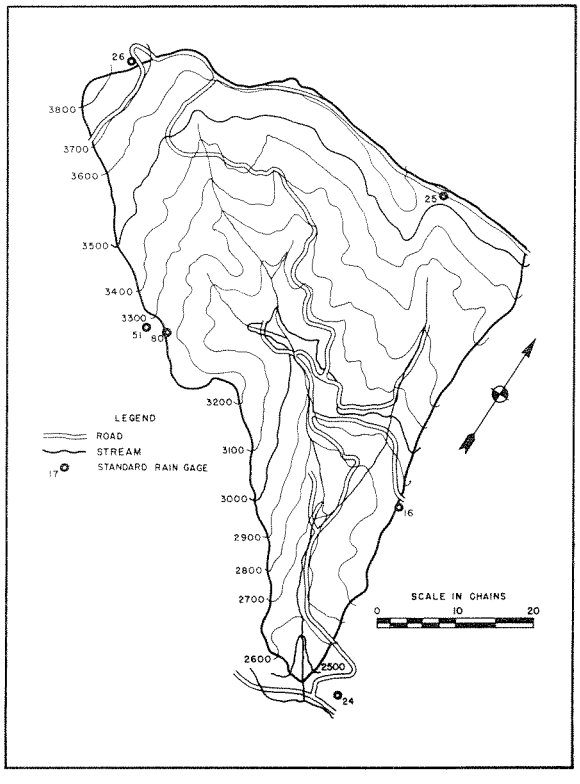

Figure 24.--Location of logging roads used to harvest the timber from Watershed 10.

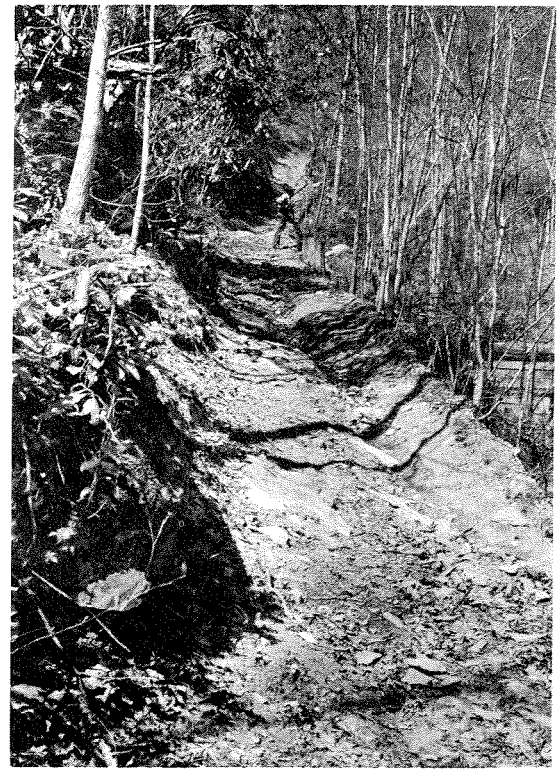

Figure 25.--Skid trails channel storm water and often cause gullies and high stream turbidities.

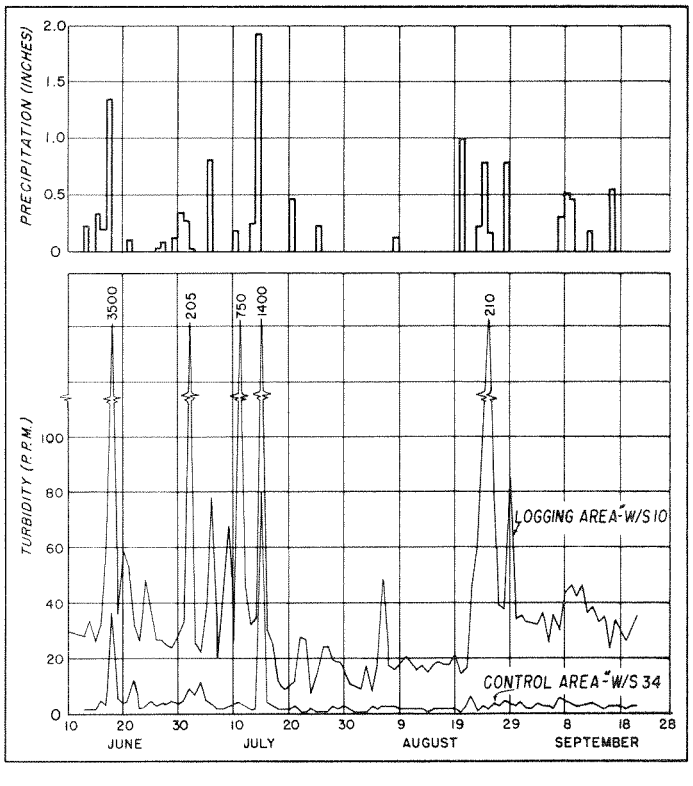

Figure 26.--Comparison of stream turbidities from undisturbed and logged watersheds, June 10 to September 20, 1946.

A single storm illustrates how such a logging operation may affect a stream system. Water samples were collected from the stream draining the experimental watershed, from the main stream just above, and from below the confluence with the logged drainage. Samples were also taken from anoth main stream in the experimental forest draining an unlogged area. The resul for this storm demonstrate that high turbidities in a larger stream may be traced to a relatively small and localized area:

Area	Turbidity (Parts per million)
Logged watershed (212 acres)	1,200
Main stream above logged watershed (731 acres)	25
Main stream below logged watershed (943 acres)	395
Another comparable main stream with no logging (1,800 acres)	25

Measurements of stream turbidities and of soil losses on the watershed show that skidways and roads were a principal source of sediment. Cross sectional measurements were made periodically to determine soil displacement on logging roads, as shown in figure 27. Such measurements indicate the quantities of soil that can move from an exposed road section, but are not a measure of soil loss from the watershed, since some of the soil moved in this manner is filtered out by leaf litter and does not reach the stream.

Figure 27.--Periodic cross-sectional measurements indicate the rate and volume of soil displacement from logging roads.

Cutting all Vegetation with Annual Slashing of Regrowth, Watershed 17

One of the more spectacular and widely known watershed experiments to date has been that on Watershed 17. Aim of this study was to determine the effects on streamflow from cutting all woody vegetation without soil disturbance. The experiment differed from practical cutting operations in that no wood products were removed. The forest stand, of which 93 percent was oak-hickory type and 7 percent cove hardwoods, was cut between January and March 1941 along with shrub undergrowth. Tops and limbs were lopped to lie close to the ground. Sprouts and shrubs were cut back annually from 1942 to 1955 inclusive, except for the war years 1943 to 1945. Figures 28 and 29 picture the watershed before and after cutting.

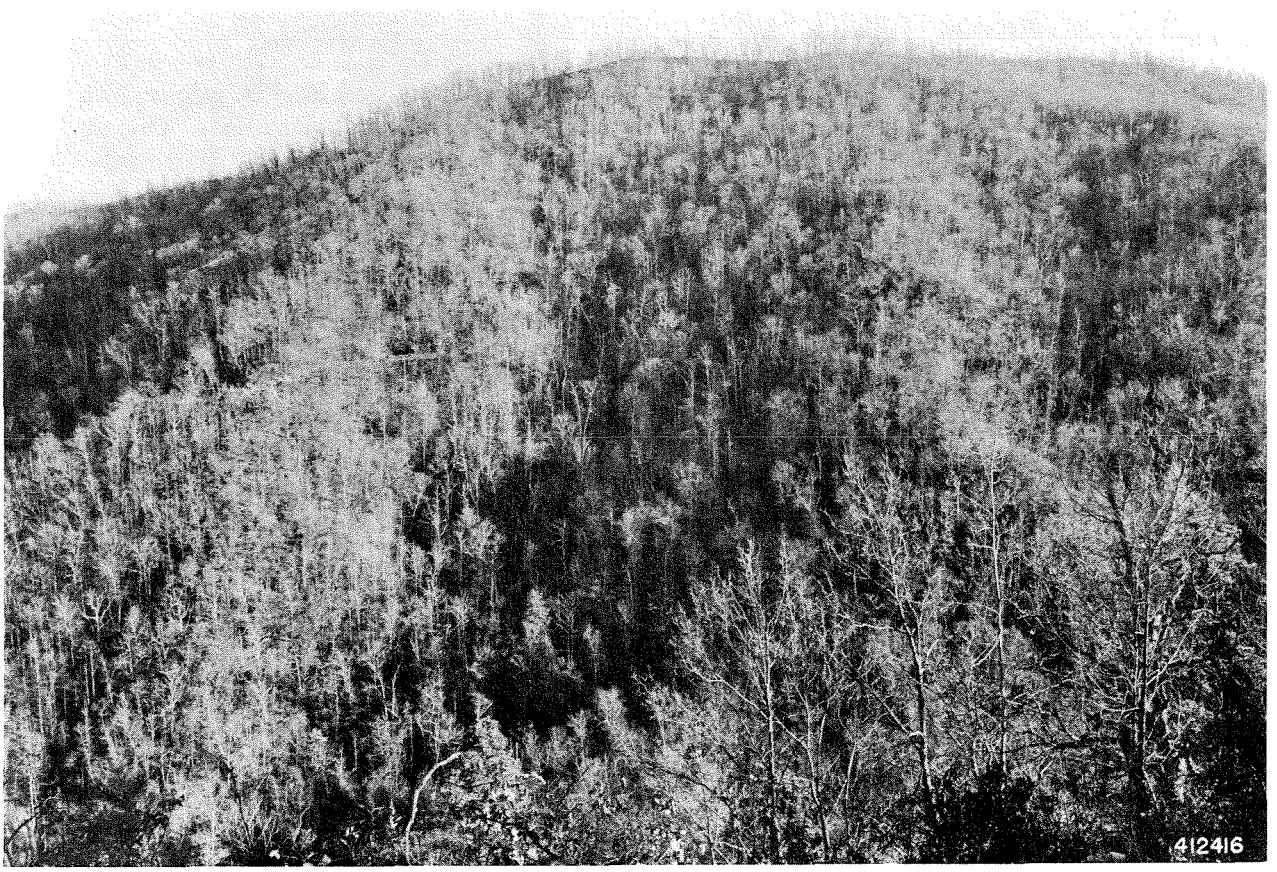

Figure 28.--Watershed 17 in the fall of 1940 prior to cutting.

During the first year, the water increase was equivalent to a volume 17 inches deep over the entire drainage basin. On the assumption that evaporation and interception were not greatly altered for the first year after cutting because of the effect of felled trees, it was considered that this increase in streamflow represented water that would normally have been transpired by the vegetation.

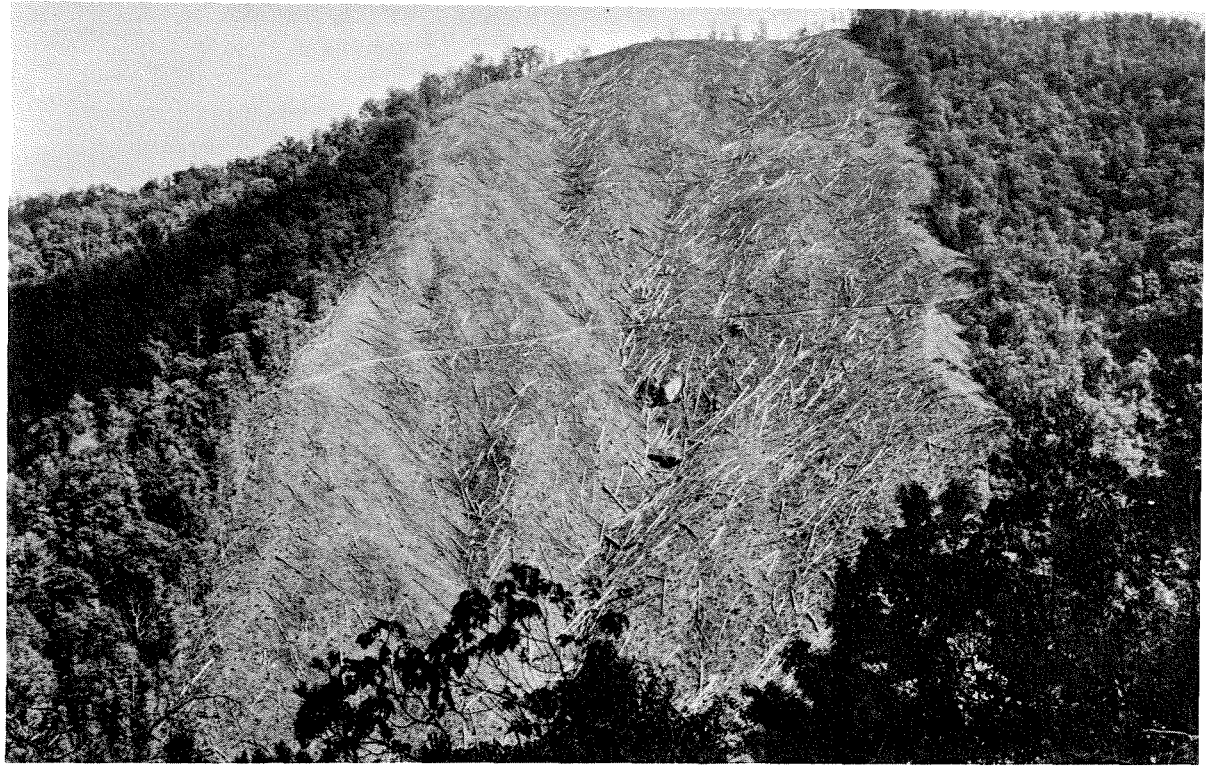

Figure 29.--View of Watershed 17 following cutting. Note that logs were left where they fell, and no roads or skid trails made.

In the second year, after regrowth was cut for the first time, many herbaceous plants began to invade the area. Under this cover the increase in water yield leveled off at about 11 area inches from the third to thirteenth years, as shown in figure 30. Figure 31 illustrates how the annual increase in streamflow is distributed throughout the year. The maximum increases came in the November to February period, but significant increases also occurred in July, August, and September--the period when municipal and industrial water shortages are most likely.

Maximum peak discharge during storm periods and the distribution of stormflow were not appreciably altered. As before treatment, approximately 92 percent of the total water yield was ground water or baseflow, and the balance storm runoff. Similarly, there has been no measurable change in stream turbidity. Air temperatures near the forest floor have increased markedly.

Analyses made in 1953 indicate a decrease in the organic matter content of the soil and in the degree of soil aggregation. However, volume weight and porosity tests, a permeability test, soil structure measurements, and field capacity and moisture equivalent determinations did not reveal any trends or differences.

The experiment demonstrates for this particular watershed that very substantial increases in water yield can be achieved by completely cutting old growth hardwood forest in the perhumid climate at Coweeta. It also affords a gross measure of how much water a hardwood forest uses. Inasmuch as this was not a practical timber cutting operation, the chief value of the experiment has been to document the water use requirements of a mountain forest and to strengthen knowledge of water balance relationships at Coweeta.

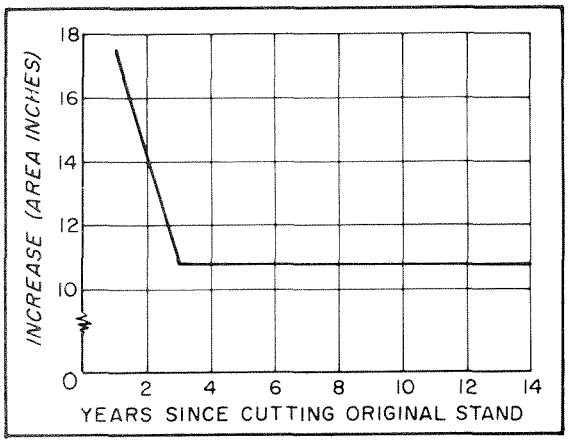

Figure 30.--Following the cutting of both hardwood forest and subsequent regrowth, the increase in annual water yield leveled off at about 11 inches after the third year.

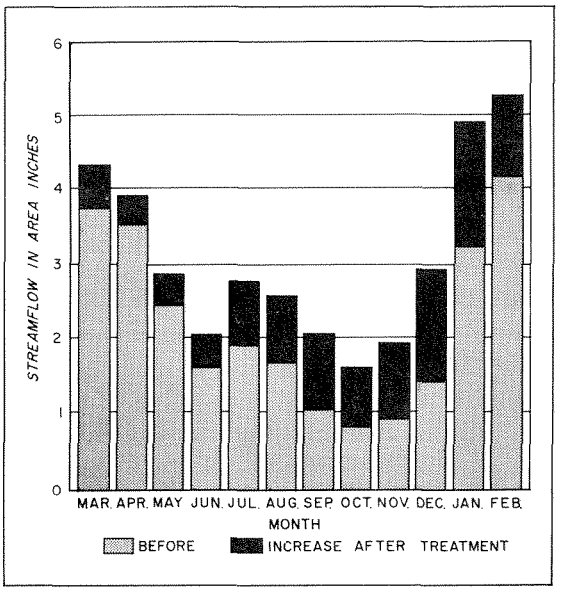

Figure 31.--Average increase in monthly water yield after removal of forest cover.

Cutting all Vegetation and Allowing Natural Regrowth, Watershed 13

On Watershed 13 (40 acres), all tree and shrub vegetation was cut in 1939-1940, but in this study the forest growth was allowed to grow back naturally. As in the other experiment, cutting was accomplished with minimum disturbance to litter cover and soil, and, with the exception of a few logs near the boundary, wood products were not removed. A timber cruise of the area indicated that the oak-hickory type covered 70 percent of the watershed, pine-hardwoods 20 percent, and cove hardwoods 10 percent.

The first year after treatment the increase in water yield was of about the same magnitude as that from Watershed 17. As the trees and shrubs grew back, however, increases in streamflow declined; but in 1955--15 years after cutting--the annual water yield was still more than 4 inches greater than the predictable pretreatment yield (fig. 32). As in the previous study, the greater increases occurred in the winter period. Projecting the results into the future suggests that treatment effect will become negligible after the 35th year.

Annual water losses to the atmosphere as measured in water balance studies show a close correlation with increased water yields (fig. 33). When losses for a given year following treatment are deducted from the average pretreatment losses, the resulting value approximates the increased water yield for that year (fig. 32).

As in the case of Watershed 17, there were no measurable changes in storm peaks, volume of stormflow, or in the distribution of storm runoff.

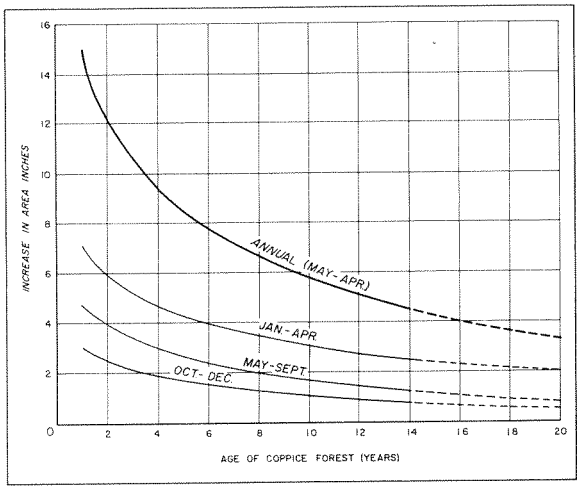

Figure 32.--Change in water yields after clearcutting a hardwood forest and permitting natural regrowth.

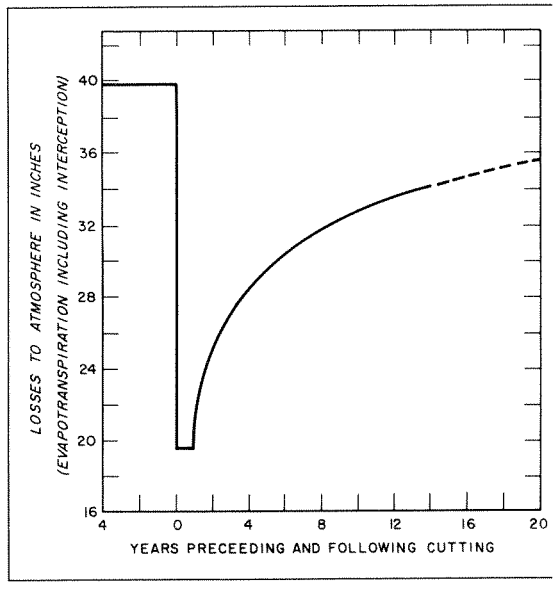

Figure 33.--Annual atmospheric water losses (precipitation minus runoff) for Watershed 13.

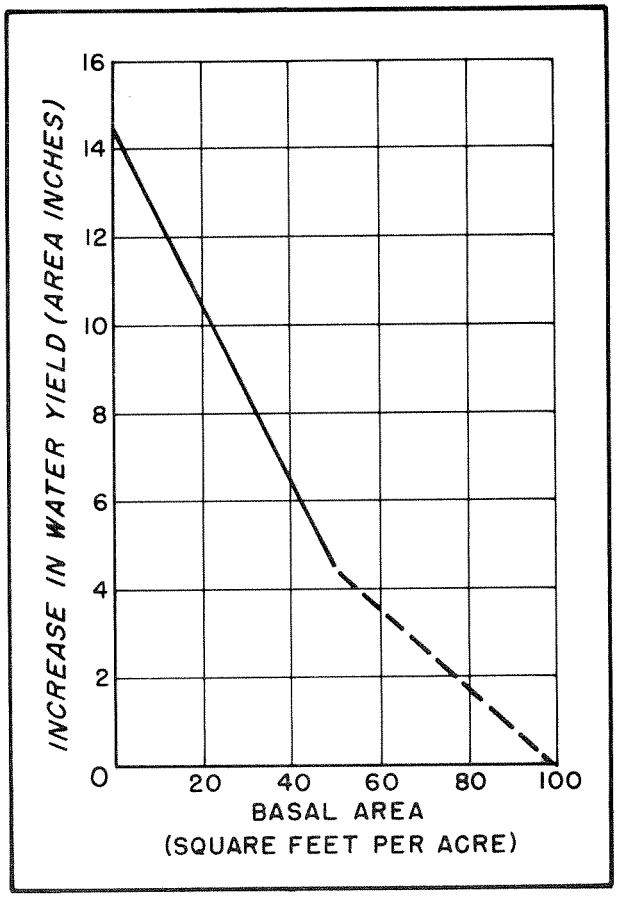

Figure 34.--Water yield in relation to basal area growth of a 15-year-old coppice forest.

Originally the forest stand had an average basal area of about 100 square feet per acre. Cutting reduced this to zero, but after 14 years of natural regrowth, largely sprout or coppice forest, it was approximately 50 square feet. During these 14 years, the average annual water yields decreased at a rate of 0.2 inch per square foot of basal area per acre, as shown in figure 34. From the 14th year until treatment effect theoretically becomes negligible, the indicated rate of decline is 0.1 inch per square foot. For conditions similar to those at Coweeta, this experiment illustrates that sustained increases in water yield can be achieved only by altering and keeping forest cover in a stabilized condition; but it also demonstrates that appreciable increases are produced years later even with substantial regrowth of forest stands.

Removal of Laurel and Rhododendron Understory, Watershed 19

The third in a series of experiments to measure the effects of forest cutting upon streamflow entailed the removal of a dense understory of rhododendron and laurel (fig. 35).

To measure water use by this type of vegetation, 70-acre Watershed 19 was selected for treatment, and between December 1948 and March 1949 all laurel and rhododendron was cut. Cruise data prior to treatment indicated a

Figure 35.--Cutting in a dense laurel-rhododendron understory on Watershed 19.

total basal area of 114 square feet per acre. Of this total, 11 square feet wa rhododendron and 14 square feet was laurel. Although stems were cut close to the ground, cutting did not kill the shrubs. Sprout growth from the stump was slow, and no cutting of the sprouts was undertaken during the course of the experiment.

The first year after treatment, streamflow increased 2.8 inches. Six years later the increase in yield was 1.3 inches. On a basis of present trend it is estimated that effects of the treatment will be negligible after 10 years (fig. 36). The increased yields were about equally divided between dormant and growing seasons. The removal of the laurel-rhododendron understory re sulted in an average annual increase in streamflow of 2 inches (4 percent) fo the first 6 years. The average annual evapotranspiration decreased correspondingly 2.0 inches (6 percent) following cutting.

Maximum flows during storm periods were not altered by cutting the understory; i.e., there was no change in proportion of total streamflow co tributed by stormflow or ground water. Again the difference between evapotranspiration losses before and after treatment as measured by the water balance equation was approximately equal to the measured increase in water yields. Average monthly maximum stream temperatures increased about 1.5° F. Minimum stream temperatures were not altered.

Cuttings of this sort, in comparison with removal of hardwood overstories, apparently afford limited opportunity to increase water supplies.

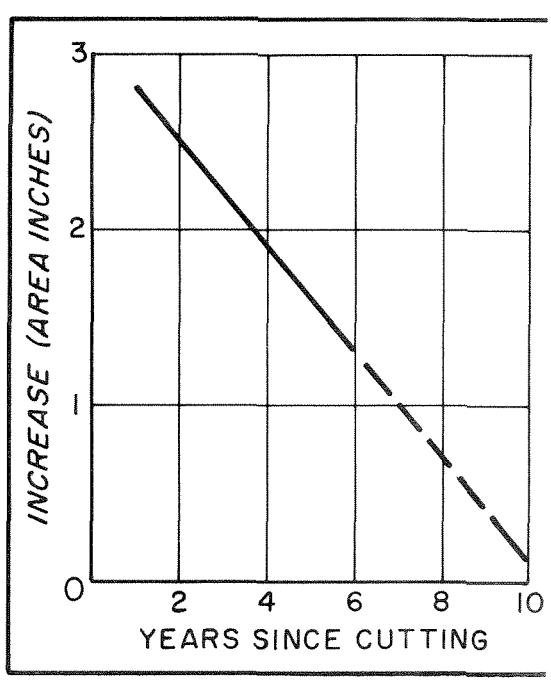

Figure 36.--Annual increases in streamflow after laurel-rhododendron understory had been cut on Watershed 19 (estimated after the 6th year).

Removal of Streamside Vegetation, Watershed 6

In a fourth study all vegetation on a strip adjoining the stream draining Watershed 6 was felled in order to observe streamflow effect. Observations during the growing season had shown that the rate of discharge from Coweeta streams was higher by night and lower about midday, and it was common to notice rocks submerged in the morning that were exposed in the evening. These fluctuations are attributed chiefly to transpiration during the sunlight hours by vegetation that has its roots in a zone of readily available water. The idea was that such vegetation might transpire much larger quantities of water than vegetation having a less available source.

To test this theory, all vegetation was cut on an arbitrarily chosen strip 15 feet in elevation above the stream channel. Cutting was completed during a 4-day period in July 1941. The 1,600-foot strip varied in width from 60 to 250 feet (fig. 37). The area cleared amounted to 2.62 acres, or 12 percent of the 22-acre watershed, and the operation removed deciduous trees and a small amount of laurel and rhododendron totaling about 85 square feet basal area per acre.

Figure 37.--View of the cleared strip after streamside vegetation had been cut.

Diurnal fluctuations on the stream hydrograph were eliminated; however within a few weeks after the cutting, the rapid recovery and regrowth of vegetation caused these fluctuations to reappear in modified form.

Increases in water yield during the growing season the first year following cutting amounted to 365 to 475 cubic feet per day. For the same period in the second year following cutting, average daily increases were from 135 to 200 cubic feet. By the third year, sprout vegetation had become so well established that streamflow had returned to pretreatment levels.

The increase in water yield following this cutting was comparable to that after clear cutting Watersheds 13 and 17, indicating that at least during the period immediately following cutting, withdrawals by streamside vegetation differed little on an area basis from withdrawals on the watershed as a whole. However, this needs further study.

CURRENT AND PLANNED RESEARCH

Land Use Studies

Much of Coweeta research has documented the rate and extent of watershed damage brought about by some poor land use practices. Since the time these studies were commenced, many agencies and individuals have helped farmers and landowners to practice conservation so that farm and forestry methods in the Southern Appalachians have noticeably improved in recent years. Reflecting this change is the trend toward more improved pasture, greater use of fertilizer and lime on most farms, and stepped up tree-planting programs. Opportunity for work in industrial plants has also eased pressure on the land. Thus, the first phase of Coweeta research is tapering off, although watersheds receiving poor-practice treatment will continue under study so that rates and degrees of watershed recovery following appropriate rehabilitation measures can be observed.

Two of the three "poor practice" watersheds at Coweeta are entering the third or recovery phase of the experiments. By 1953, the mountain farm had reached a degradation stage comparable to some local problem areas, though it was perhaps in better shape than the majority of them. Rehabilitation work was undertaken in 1954. A grass and legume mixture was sown in 1954 preparatory to planting yellow-poplar and white pine in 1955. Measurements will continue, so that recovery can be observed as forest cover reclothes the watershed.

Natural recovery will also be observed on adjacent Watershed 7. Woodland grazing was discontinued following the 1953 season, and data are now being collected on changes in vegetation, soil, and streamflow during the rehabilitation period.

The study of logging effects on Watershed 10, begun in 1940, has largely served its purpose and will be terminated after some of the effects of bedding down haul roads and skid trails have been observed.

Basic Studies of Water Yield

Since little is known concerning water use by forest stands, new studies are being started to provide guides for managing mountain hardwoods for optimum water production. Among other approaches, treatments will be applied to observe the effects of reducing forest cover to several density levels. A series of watershed units will also be used in a long-term study comparing evapotranspiration losses and water yields under different plant covers. In 1955, white pine was planted on Watershed 17, a north-facing unit, following the last annual slashing of sprout vegetation. White pines have also been planted on south-facing Watershed 1 following the clear cutting of hardwood stands. Watersheds 6 and 19 are scheduled for conversion from hardwood forest to grass and shrub cover, respectively.

Water yield response following complete removal of vegetation from Watersheds 17 and 13 has already been measured. To further document these relationships when stand density is reduced in varying degrees, 50 percent of the basal area on Watershed 22 was deadened in 1955. Further treatments are scheduled in which the forest cover on other watersheds will be reduced to approximately 25 to 75 percent of the original basal area. In addition, the experiment on Watershed 13 will be continued to observe the leveling-off effects of regrowth following clear cutting.

Integrating Forest and Water Resource Management

In a new and important phase of the Coweeta program, watershed units are being used in long-term test demonstrations of integrated management for water and timber production. In a study of comparative water yields under two systems of management, the first conversion cut was made in 1955 on paired Watersheds 40 and 41 preparatory to readying the timber stands for management. Watershed 41, a 70-acre drainage, is to be managed for maximum economic returns under a management system resembling that on National Forest lands; and Watershed 40, a 50-acre unit, will be managed for optimum yield of quality water plus some supplemental timber returns. The findings and principles developed in other Coweeta studies will be utilized in planning and applying management practices for Watershed 40 that are most likely to produce maximum water yields.

The first timber cut on the two watersheds was accomplished without impairing water quality, thus demonstrating that properly laid out systems of climbing and contour roads can be used in the Southern Appalachians to remove forest products with minimum disturbance to soil. To further explore the possibilities, pilot-plant demonstrations featuring proper location and layout of logging roads to minimize erosion are planned for certain National Forest timber sale areas.

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