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SOIL AND SURFACE RUNOFF CHARACTERISTICS O

A WATERSHED BROUGHT ABOUT BY FOREST

CUTTING AND SUBSEQUENT MOUNTAIN FARMING

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CHANGES IN SOME VEGETATION, SURFACE SOIL AND SURFACE RUNOFF CHARACTERISTICS OF A WATERSHED BROUGHT ABOUT BY FOREST CUTTING AND SUBSEQUENT MOUNTAIN FARMING

by

Robert E. Dils

A DISSERTATION

Submitted to the School of Graduate Studies
of Michigan State College of Agriculture
and Applied Science in partial fulfillment
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

DEPARTMENT OF SOIL SCIENCE

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Robert Earl Dils

candidate for the degree of

Doctor of Philosophy

Final Examination:

Dissertation: Changes in Some Vegetation, Surface Soil and Surface Runoff Characteristics of a Watershed Brought About by Forest Cutting and Subsequent Mountain Farming.

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Minor Subjects: Geology, Forestry

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PURPOSE AND SCOPE

With the increasing demands made on our water supplies within the past few decades has come the realization that fundamental research concerning this natural resource which is basic to our national economy is woefully lacking. Because the water resource is so closely linked with climate, it was the consensus of opinion for many centuries that man could alter it no more than he could alter the weather. This is not entirely true, for, in addition to climate, the available water supplies may be affected by the vegetation and by soil factors. Through his use of the land, man exerts a very significant influence on both the vegetation and the soil. As a result, he also modifies the water resource, but the nature and extent of this modification has been a subject of much speculation and controversy.

Because of the lack of hydrologic data, it has been impossible in the past to establish a scientific basis for the management of water as a natural resource. Currently, an increasing demand for such information is being made by many public and private interests. Industry requires a dependable supply of clean water. Municipalities demand an adequate, pure water supply. Many public and civic agencies require information for flood control programs and power projects. The recreation and tourist trades lean heavily upon the nation's water resource. Fish and wildlife interests are dependent upon clear, cool streams for the production of fish and game.

In recent years, many ambitious projects have been inaugurated; new factories have been built, cities have doubled their facilities for supplying water to an increasing population, sports and recreation areas have been developed--all at tremendous expense and all making tremendous demands on the local water resources. If the water supply is found to be adequate, clean and pure, such ventures prosper. Unfortunately, many of these efforts have been hampered by muddy streams and unexpected stream behavior. When these occur, the land-use pattern of the watershed in question is immediately examined in order to locate the source of the difficulty. Frequently, the watershed will not be entirely in natural forest, but will show a mixed pattern of usage. Small areas may be farmed, grazed or logged. This immediately occasions much heated controversy as to just which area is the cause of the trouble. When mountain farming is one of the factors which appears in a mixed land-use pattern, the decreased value of the development often has been attributed primarily to this practice. Just how deleterious the cultivation of small patches of steep land may be has been the subject of much speculation.

Thousands of acres of steep forest land have been cleared for use as cropland or pasture in the Southern Appalachians. To farm such land successfully requires great skill and care.

Many authorities claim that much of it should never be farmed at all. It is common knowledge that individual farmers may "wear out" many such mountain farms in a lifetime.

It is the intent of this dissertation to determine the effects of clearing and cultivating steep forested slopes on certain surface runoff characteristics as well as to study some of the resultant biologic and edaphic changes in the watershed.

Numerous studies have been made on cultivated and forested watersheds and indirect comparisons made therefrom. To the writer's knowledge, however, there has been no report in which a forested watershed has been calibrated, clearcut and cultivated and a direct comparison made.

In this study, carried out on the Little Hurricane Watershed on the Coweeta Hydrologic Laboratory in Macon County, North Carolina, the forested watershed was calibrated from 1934 to 1940. In 1940 the area was clearcut and from 1941 to date has been subjected to mountain farming typical of the Southern Appalachian region. As nearly as possible the land has been treated as though a mountain family lived near the stream and tended the area to make its livelihood.

If the effects of clearing steep forest land on the hydrologic behavior of a small watershed can be adequately determined, it should serve as a guide to the land-use questions on larger drainages and basins.

PAST WORK

Numerous investigations have been undertaken in many localities throughout the country for the purpose of measuring runoff and erosion. Many of these studies, however, have been confined to cultivated areas and others have been made on a small plot or lysimeter scale. The literature has become so voluminous that no attempt is made here to review it all. Instead only selected representative projects which provide a particularly pertinent background to the present study will be cited. In no case, however, has the writer found reference to a forested watershed being calibrated, cut-over and put into agricultural land use.

Since 1930 the United States Department of Agriculture has established 19 soil conservation experiment stations including numerous cooperative projects with state Agricultural Experiment Stations. Similarly, the Forest Service, United States Department of Agriculture maintains 14 stations where research in watershed management is currently being conducted. In addition, at least nine other watershed research centers are conducting studies under the jurisdiction of other federal and state agencies including the Corps of Engineers in the Department of the Army, the Weather Bureau in the Department of Commerce, the Geological Survey in the Department of the Interior, the Tennessee Valley Authority and the New York and Michigan State Departments of Conservation. Following, a list of watershed research centers in the United States prepared by Frank and Netboy (14) is presented.

WATERSHED RESEARCH CENTERS IN THE UNITED STATES[1] (AS OF JANUARY 1, 1950)

U. S. Department of Agriculture

Forest Service (primarily in forest, brush, or range areas)
- Sierra Ancha, Globe, Ariz.
- San Dimas (southern California), Glendora, Calif.
- Continental Divide, Fraser, Colo. (Bureau of Reclamation, Department of Interior, co-operating on snow-cover relations phase).
- Front Range, Woodland Park, Colo.
- Western Slope, Delta, Colo.
- Coweeta Hydrologic Laboratory (southern Appalachian Mountains), Dillard, Ga.
- Boise Basin, Boise, Idaho
- Buckeye, Athens, Ohio
- Delaware Basin, Bethlehem, Pa.
- Central Piedmont, Union, S. C.
- Great Basin, Ephraim, Utah
- Wasatch, Farmington, Utah
- Tallahatchie, Oxford, Miss.
- Mountain State, Elkins, W. Va.

Soil Conservation Service (in agricultural areas)
- Watkinsville, Ga.
- Edwardsville, Ill.
- Lafayette, Ind.
- Iowa City, Iowa
- Boonsboro, Md.
- College Park, Md.
- East Lansing, Mich.
- Hastings, Nebr.
- Ithaca, N. Y.
- Coshocton, Ohio
- Guthrie, Okla.
- Waco, Tex.
- Blacksburg, Va.
- Chatham, Va.
- Staunton, Va.
- LaCrosse, Wis.
- Fennimore, Wis.

Department of the Army and Department of Commerce

Corps of Engineers, in co-operation with Weather Bureau
- Central Sierra Snow Laboratory, Soda Springs, Cal.
- Upper Columbia Snow Laboratory, Marias Pass, Mont.
- Willamette Snow Laboratory, Blue River, Ore.

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[1] Frank, B. and A. Netboy, Water, Land and People. Knopf, Inc., New York, 331 pp., 1950.

U. S. Department of the Interior

Geological Survey
Central New York, Albany, N. Y. (in co-operation with New York State Department of Conservation)
Green River, Tacoma, Wash. (in co-operation with city of Tacoma, Wash.)

Tennessee Valley Authority

Chestuee Creek, Athens, Tenn.
White Hollow, Norris, Tenn.
Copper Basin, Copper Hill, Tenn.
Henderson County, Tenn.

Stations at Statesville, North Carolina (5) and Watkinsville, Georgia (32), both on the Piedmont, are engaged in cropping and erosion control measures, and measure runoff from small plots, lysimeters and field watersheds. Included in the studies conducted at Statesville are plots on two wooded watersheds. A comparison of land use practices at the former station indicates decreasing soil losses in the following order: fallow, continuous cotton, rotation (cotton and corn with winter cover crops), grass, woods burned annually and unburned woods.

In surface runoff the trends are the same except that the burned woods area yields a higher percent of precipitation appearing as surface runoff than does the grass area. In the case of the fallow area, over 17½ percent of the precipitation appears as surface runoff as compared with 0.7 percent for the unburned woods.

The first experimental watershed project of the Soil Conservation Service was established near Coshocton, Ohio in the Muskingum Watershed Conservancy District (25, 32). Intensive studies are being made there on the effects of land use and erosion-control practices on the conservation of soil and moisture and on flood flows for 44 complete watersheds supporting various cover types. These watersheds range in size from three to 4,600 acres. An analysis of soil water relationships on four small watersheds at Coshocton was made by Dreibelbis and Post (11) in 1941. A comparison among a wooded, pastured and two cultivated watersheds all on similar soils showed a much lower volume of surface runoff for the wooded area. On the wooded watershed only 0.11 inch or 0.2 percent of the precipitation ran off compared with 0.60 inch and 1.4 percent for the pastured area and 6.35 inches or 15.0 percent runoff for one of the cultivated areas.

A 250 acre experimental tract near Zanesville, Ohio, including three gaged watersheds, was established in 1933 to study the effect of land use on runoff and erosion. Included in this study is a 2.23-acre wooded watershed. For the five-year period from 1934-1938, Borst and Woodburn (8) noted the average soil loss from this watershed as 0.017 tons per acre per year. The average annual runoff was noted as .1246 inches which amounts to approximately 0.34 percent of the average annual precipitation.

Near LaCrosse, Wisconsin (17) a 160-acre tract contains three gaged watersheds: a pasture cleared of timber, a grazed hardwood forest and a typical ungrazed woodlot. An analysis of eight intense storms occurring in 1935 indicated that about 8½ and 3 percent of the precipitation appeared as surface runoff on the timbered-grazed and cleared-grazed watersheds respectively while on the ungrazed wooded area runoff occurred only twice and then in quantities so small as to be insignificant. The same trends were indicated for soil losses from the watersheds.

An experimental watershed project for the Blacklands region has been established on the Brazos Drainage Basin near Waco, Texas (32) where erosion, land use, hydrologic and soil data are being studied on thirty watersheds. Included in these studies are several wooded plots. An analysis of soil losses and surface runoff indicate similar results to those obtained at Statesville, N. C. Plots on virgin woodlot yielded only 0.122 percent surface runoff and 0.002 tons per acre soil loss compared with nearly 30 and 10 percent surface runoff and 65 and 23 tons per acre per year soil loss for fallow and continuous cotton plots respectively.

A project designed to study the effects of land use and cultural practices on surface runoff was established in 1940 jointly by the Soil Conservation Service and the Purdue University Agricultural Experiment Station at Lafayette, Indiana (4). Included in the twenty gaged drainage areas ranging in size from two to four and one-half acres are two wooded watersheds. Up to 1949, however, no treatment of the wooded watersheds had been attempted.

A similar study involving two small agricultural watersheds and one wooded watershed was initiated in 1940 by the Soil Conservation Service in cooperation with the Michigan State College Agricultural Experiment Station near East Lansing, Michigan (15, 27). This project is unique in that the majority of the installations on the two cultivated watersheds are designed to record the results directly on one master recorder and switch panel. The primary objective of this investigation is the study of the hydrology of farm lands under winter conditions of snow-cover and frozen soil. Results of the investigations to date indicate a marked difference in soil losses between the wooded watershed and the two agricultural watersheds. Total soil losses from the wooded watershed for a ten-year period amounted to only 64 pounds as compared with many tons from the two cultivated watersheds. Similar differences in surface runoff were noted except under conditions of frozen ground and snow cover. A commercial clearcut treatment was applied to the wooded watershed in 1951, however, results of this treatment will not be available for at least five years.

Experimental watershed studies by the Forest Service, United States Department of Agriculture, are being conducted at six of the Forest Experiment Stations: Southeastern, California, Southwestern, Rocky Mountain, Intermountain, and Northeastern (32).

At the Southeastern Station, hydrologic studies are being made at the Bent Creek Experimental Forest near Asheville, North Carolina, the Calhoun Experimental Forest near Union, South Carolina, and at the Coweeta Hydrologic Laboratory near Franklin, North Carolina. Nearly all of the watershed work, however, is currently being conducted by the Coweeta station (30). In addition to the study covered in this dissertation, research projects include the determination of the effects of the following treatments upon water yield and water quality: (a) permanent complete removal of all major vegetation, (b) temporary complete removal of all major vegetation, (c) removal of riparian vegetation, (d) local logging practices, (e) woodland grazing, (f) removal of understory vegetation (laurel and rhododendron), (g) temporary defoliation by gas, and (h) forest fires.

The results of these investigations are summarized below: (a) permanent complete removal of vegetation increases water yields by 17 area inches annually, (b) temporary complete removal of all major vegetation increases water yields by approximately 17 inches and this increase becomes progressively less as the vegetal cover increases, (c) the removal of riparian vegetation tends to eliminate diurnal fluctuations in stream flow, (d) local logging practices, particularly poorly located and constructed logging roads, effect a marked increase in erosion and stream turbidity, (e) woodland grazing brings about a marked increase in overland storm runoff and erosion and shows that the cattle grazed on the watershed failed to thrive (21), (f) the removal of an understory of laurel and rhododendron effects an increase in water yield of approximately three area inches per year, (g) preliminary observations indicate that temporary defoliation of vegetation by gas may be used as an emergency measure in extreme drought periods to reduce transpiration and thus increase water yields and (h) no significant change in streamflow resulted from a forest fire, probably because the soil under the litter layer was very moist and new leaf growth and sprouting helped to protect the soil from rainfall impact before intense storms occurred.

The major work center for the California Forest and Range Experiment Station is the San Dimas Experimental Forest near Los Angeles. Projects are under way here to study the disposition of rainfall as influenced by watershed conditions, including vegetation, soils, geology and topography; and to develop methods of watershed management, including the treatment of areas denuded by fire, to assure maximum yield of usable water and satisfactory regulation of flood runoff and erosion. Installations include 17 watersheds, 18 experimental plots and 26 large lysimeters.

Forest influences and watershed management investigations at the Southwestern Forest and Range Experiment Station are carried out on the Sierra Ancha Experimental Forest near

Globe, Arizona. Work projects there are designed to determine the influence of vegetation (forest, evergreen shrub, and range) on stream flow, water uses, water losses, erosion and sediment production. Gaged watersheds, plots, and natural lysimeters are utilized. In addition to the Sierra Ancha Experimental Forest, experimental plots are located in representative areas throughout the Salt River Watershed. Plot studies on range land on the Sierra Ancha station demonstrated that ungrazed range land with good plant cover produced higher water yields and much greater soil losses than overgrazed range with poor ground cover. (31).

Hydrologic investigations of the Rocky Mountain Forest and Range Experiment Station are carried out at the Fraser Experimental Forest near Grand Lake, Colorado; the Manitou Experimental Forest near Colorado Springs, Colorado; and at the Western Slope Research Center near Delta, Colorado. At the Manitou station, studies are being made on the influence of grazing, timber cutting, and revegetation of depleted watershed lands upon water supplies and more particularly upon erosion and sedimentation. Experiments at the Fraser Experimental Forest are designed to show the influence of lodgepole pine and spruce-fir forests and of the cutting of this timber upon the yield of water largely from stored snow. At the Western Slope Research Center major effort is devoted to the analysis of range and watershed problems for drainage basins of western Colorado. Small grazing and reseeding projects have been established and plans are being drawn for studies of the effects of vegetation and grazing on infiltration and erosion.

At the Intermountain Forest and Range Experiment Station (4) tests are under way to study the effects of forest, brush and herbaceous plant cover in natural, depleted and restored condition on the infiltration, storage, fertility, biology and stability of forest and range land soils; to determine land use practices for stabilizing eroding watershed soils and for maintaining soil stability under the impact of grazing, logging and other wildland uses. Studies are being conducted on coarse, granitic soils of southwest Idaho; various soils on steep slopes of the Wasatch Mountains in northern Utah; and on heavy limestone soils on the Wasatch Plateau in central Utah.

A surface infiltration study made on the Uinta National Forest in Utah in 1951 indicates that infiltration rates averaged from 5 to 50 percent lower on grazed sites than on ungrazed areas. Storm runoff from the grazed plots ranged from 50 to 100 percent more than on the ungrazed areas and soil losses on the grazed plots averaged six to eight times more than on ungrazed areas (35).

At the Northeastern Forest Experiment Station, a study was initiated in November, 1948 on the Lehigh-Delaware Experimental Forest (28) of about 1800 acres to determine the influence of the present scrub-oak cover on runoff. After a period of calibration it is planned to convert the cover from scrub-oak to a better forest type by forest management and protection measures and to evaluate the effect of these changes in cover on runoff and ground water.

The earliest hydrologic investigation in this country concerned with the influence of forests on streamflow and run-off was initiated in 1909 by the U. S. Forest Service and the U. S. Weather Bureau at Wagon Wheel Gap, Colorado. Bates and Henry (6) reported in 1927 that the cutting of forest cover increased the total annual water yield, increased water yield from snow and produced increased erosion. They further indicated that the results were not too conclusive due to porous soils, thin original cover and prolific sprouting of aspen.

One of the earliest investigations was that initiated by Ramser in 1917 near Jackson, Tennessee. He worked with six watersheds varying in size from 1.25 to 112 acres, five of which were in mixed land use and contained forest cover varying from 14 to 55 percent. Ramser reported in 1927 (24) that forest cover has a decided influence in reducing the rate of runoff from a watershed except when antecedent rainfall has been high in which case the influence is slight.

In 1932 a study was started by the Geological Survey, United States Department of Interior in cooperation with the State of New York Conservation Department to determine the influence of reforestation on stream flow in state forests in central New York. Submarginal lands were purchased and planted to coniferous tree species. Ayer (2) reported in 1949 that up to that time practically no significant change in runoff had been effected.

One of the most recent reports is that of the White Hollow Watershed in Union County, Tennessee published by the Tennessee Valley Authority in 1951 (29). The 1715-acre White Hollow Watershed was set aside for watershed studies in 1936. Following acquisition, watershed management included extensive erosion-control operations and tree planting. The study shows the following changes in surface runoff and other hydrologic characteristics as a result of 15 years of improvement and management: (a) The improvement in forest cover which occurred resulted in greater watershed protection without measurable decrease in water yield. (b) There was no shift in the seasonal runoff pattern as a result of land-use changes. (c) No measurable change took place in the total quantity of evapo-transpiration plus other losses. Apparently, since a greater density of vegetal cover must be supported by greater water use through transpiration, balancing factors were in operation. (d) Peak discharges during the summer season were markedly reduced. Reductions in winter peak discharge rates were not appreciable. (e) The greater part of the peak discharge reduction occurred in the first two or three years of investigations, smaller reductions continuing after that time. (f) Modification of summer peak discharges were so great that the frequency of peaks during the latter years was much less than during the earlier years. (g) The time distribution of surface runoff was materially changed. Surface runoff discharge was prolonged to produce a more sustained flow. (h) Comparison of sediment records based upon manually collected samples during early years with records obtained during the past year (1950) by means of an automatic sampler shows clearly that there has been a very material reduction in sediment load during the 15-year period of observations.

It is apparent, after a review of the literature, that a direct comparison of the results of this study with any previously reported is virtually impossible. Many studies have demonstrated that watersheds or plots with undisturbed forest cover yield less surface runoff and produces less soil loss than grazed or burned forests, pastures and croplands. In few cases, however, have attempts been made to show changes in surface runoff except in terms of total surface runoff expressed as a percent of the precipitation.

The study made in this dissertation is unique in that the watershed was calibrated under forest conditions, the forest cover was removed and land use practices then applied. In addition, an adjacent watershed with similar characteristics was maintained in continuous forest cover thus providing a further control. Consequently, an opportunity was provided to study more detailed changes in surface runoff.

THE COWEETA HYDROLOGIC LABORATORY

With the recognition of the need for additional research in watershed management came the realization also that the selection of sites for such research would be complicated and difficult. Foresters, hydrologists and engineers contributed rigid specifications which had to be fulfilled if the findings were to be valid and of more than local significance.

One area which met every important requirement was a 5,600-acre tract in the Nantahala Mountains of western North Carolina. This tract, established in 1933 by the United States Forest Service, is now internationally known as the Coweeta Hydrologic Laboratory. Several factors combine to make the area ideal as a natural laboratory suitable for fundamental hydrologic research. Rainfall is high, averaging 72 inches per year, and is rather uniformly distributed throughout the year. Because of the frequency of storms and the uniformity of the storm pattern, it is possible to obtain valid results in much shorter time than in an area of less precipitation. Approximately 98 percent of the precipitation occurs as rain so there is little snow to complicate the studies. Seepage losses are virtually eliminated as the deep and porous soils of the area are derived from weathered granite.

Topographically, this particular section is also ideal in that its steep slopes and sharp ridges form natural boundaries for the many small drainage basins--each an independent hydrologic unit--necessary for research of this type. Elevations vary from 2,200 to 5,200 feet within the boundaries of the station.

Although over half of the Coweeta area was cutover 25 years before the government acquired ownership, land use practices have altered the character of the forest itself very little. A dense mixed-hardwood forest, typical of much of eastern United States, is predominant at Coweeta. The cutover lands support second-growth forest and the remainder of the land is in old growth. Chestnut was formerly the major species but has been wiped out by the blight. The largest part of the forest is now in oak-hickory. Another 15 percent is in cove hardwoods: yellow poplar and northern red oak intermixed with hemlock along the streams. Sugar maple, yellow birch, beech and pitch pine occur occasionally at the lower elevations.

Because of the similarity of this area to many other parts of the country and because of the favorable pattern of precipitation, data derived from studies on the Coweeta tract can be applied elsewhere. Consequently, research conducted here in water behavior and management has national as well as regional and local significance.

Figures 1, 2 and 3 give the location, drainage pattern and individual drainage areas respectively of the Coweeta Hydrologic Laboratory.

Figure 1.

Location of the Coweeta Hydrologic Laboratory.

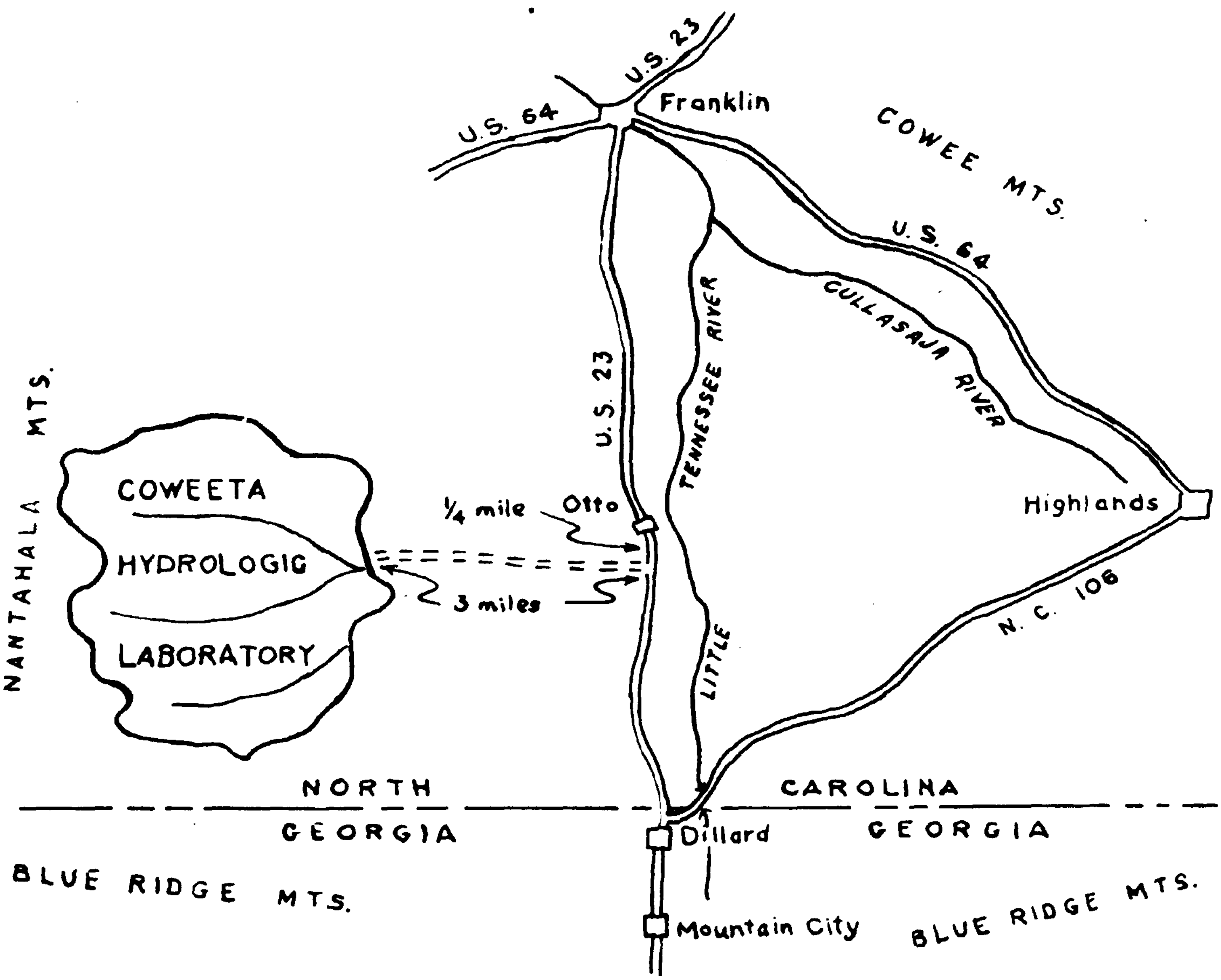


Figure 2.

DRAINAGE PATTERN
Coweeta Hydrologic Laboratory
(Dryman Fork excluded)

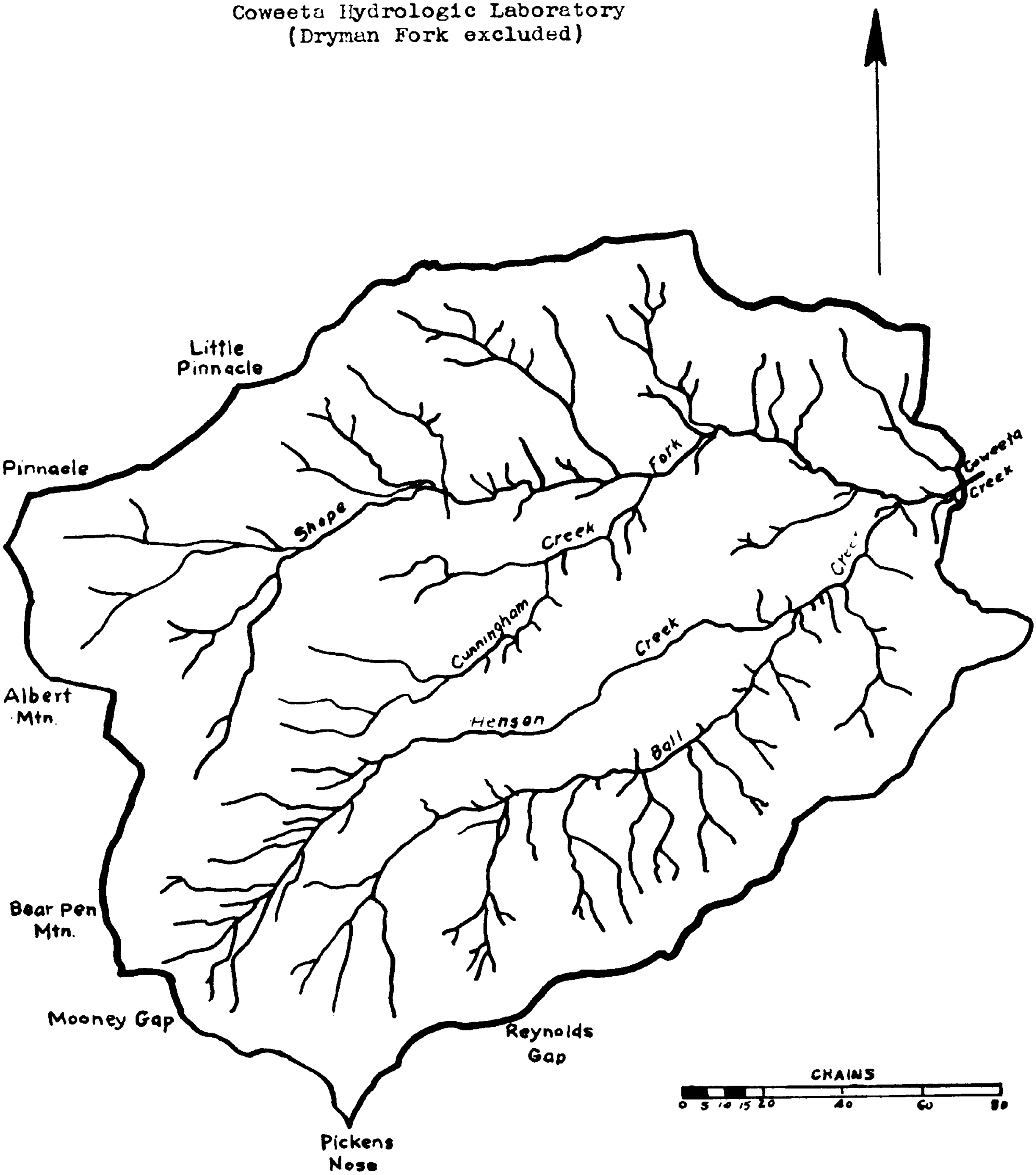
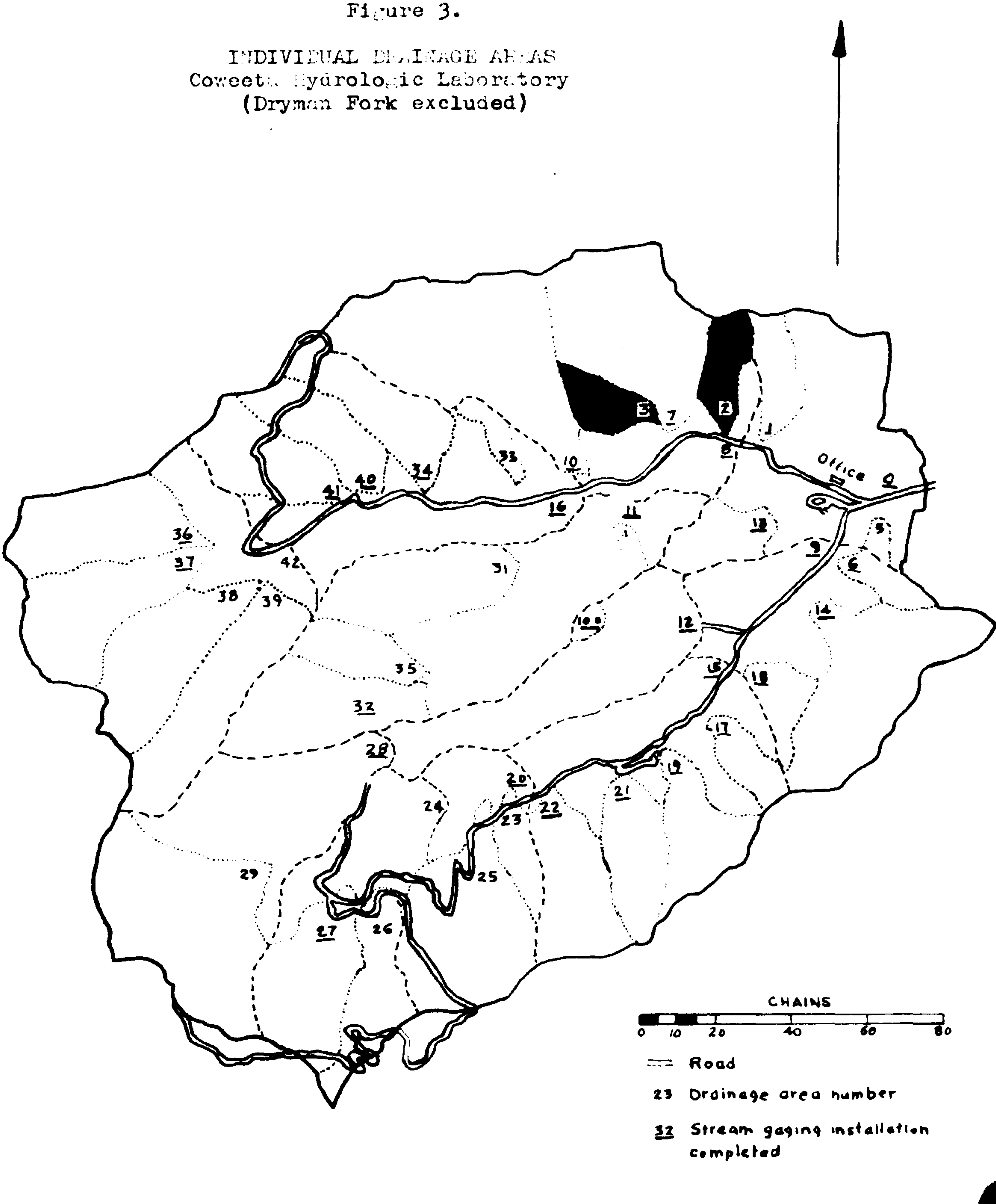


Figure 3.

INDIVIDUAL DRAINAGE AREAS
Coweeta Hydrologic Laboratory
(Dryman Fork excluded)



THE LITTLE HURRICANE WATERSHED

The Little Hurricane Watershed, designated as drainage No. 3, is located in the Coweeta Hydrologic Laboratory, Macon County, North Carolina. Its location within the Coweeta area is shown in Figure 3. The waters of Little Hurricane Branch flow into Shope Creek and thence into Coweeta Creek which is a tributary of the Little Tennessee River.

The watershed contains 22.79 acres and assumes the shape of an isosceles triangle. The aspect or exposure is essentially southeast. Figure 4 shows an overall view of the watershed, and Figure 5, a map of the Little Hurricane Drainage.

Land Use History

Prior to 1857 the area was included in the lands of the Cherokee Indians and used primarily as a range for livestock. In order to improve the quality of grazing the Indians practiced spring and fall burning of the woods. By eliminating the undergrowth and litter, both the Indians and the livestock could find nuts and acorns more readily. Furthermore, burning the woods was thought to eliminate milk-sick, an ailment of stock that evidently caused much concern among the Indians as well as the white settlers who followed because it not only killed the stock but was con-

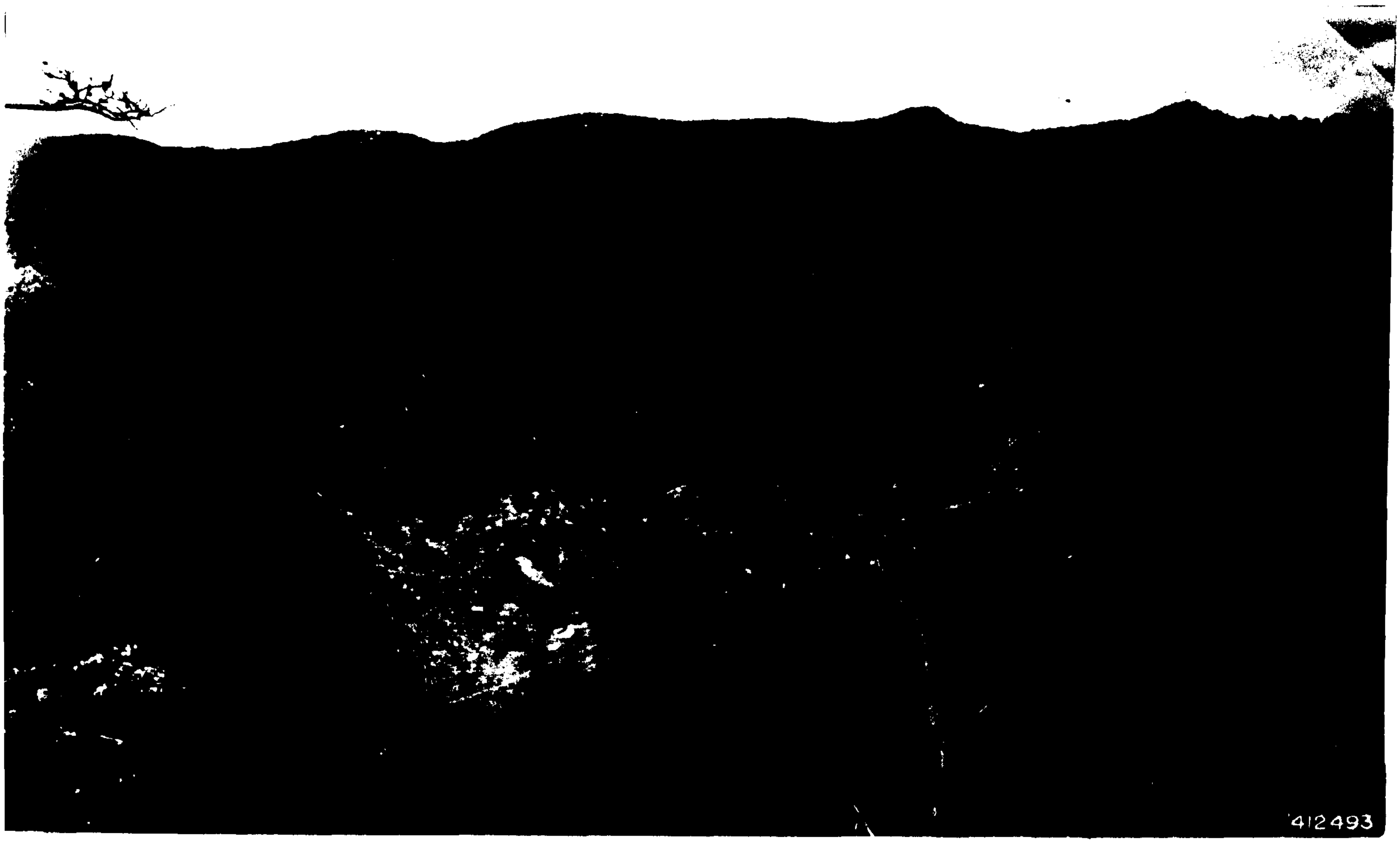


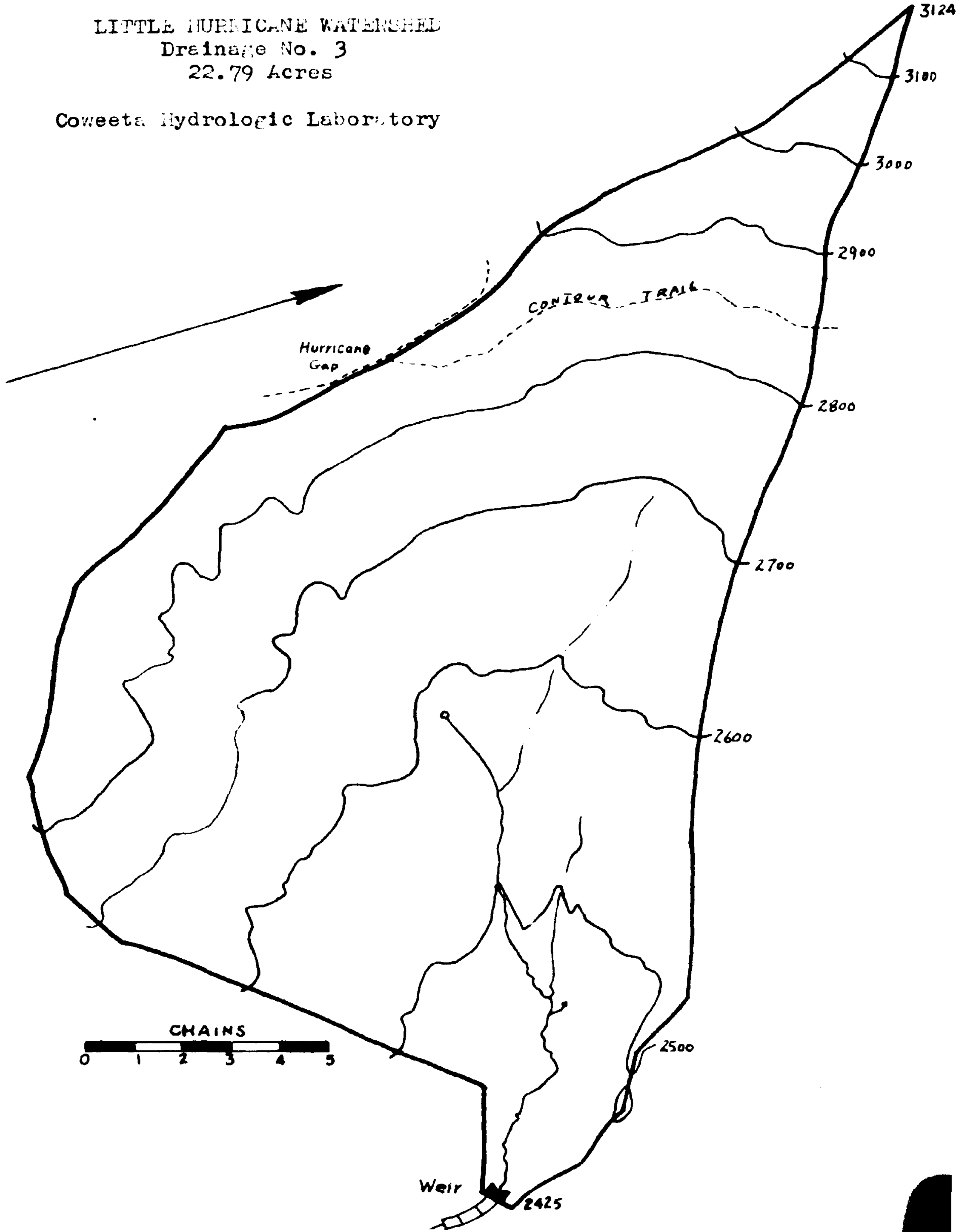
Figure 4.

The Little Hurricane Watershed.

Figure 5.

LITTLE HURRICANE WATERSHED
Drainage No. 3
22.79 Acres

Coweeta Hydrologic Laboratory



tracted by human beings as well. It was believed that stock contracted the disease in the dark, damp coves and that burning would remove the cause.

The Cherokees were removed from this section of the country in 1837 by the Federal Government and were placed on the Qualla Indian Reservation.

In 1835 a hurricane is reported to have levelled all the timber in the Little Hurricane and the Hurricane drainage adjacent to it; hence the name of the watersheds. From 1835 to 1857 white settlers pushing into this region grazed the drainage area to some extent and practiced semi-annual burning much as the Indians before them had done. In 1857 the second-growth timber on the lower ten acres of the watershed was cleared for farming and the area was cultivated until 1887. This includes nearly all of the areas which are now the lower pasture and abandoned cornfield. The yields became so low that the fields were then used only for grazing until 1900.

In 1901 the area was included in the land purchased by the Nantahala Company, a land speculation group. From 1901 until 1940 "third growth" timber, largely of the oak-chestnut and cove hardwood types re-established itself. By 1934 the dominant trees were 18-20 inches in diameter. The chestnut, however, had dropped out because of the blight.

Only the best quality oak, chestnut and yellow-poplar was logged from the second growth forest adjoining the old field in 1914. The operation was handled by the Gennette Brothers according to the terms of the Ritter Lumber Company which had acquired the tract in the meantime. The remaining trees were left unharmed except for the damage occasioned by the logging.

The U. S. Forest Service acquired the area in 1923 and it became a part of the Nantahala National Forest. In 1934 the drainage was included in the area set aside as the Coweeta Experimental Forest. This name was officially changed to the Coweeta Hydrologic Laboratory in 1949.

After a period of standardization or calibration starting in 1934, the watershed was clearcut in 1940 preparatory to the "mountain farming" treatment. Figure 6 shows cutting operations by CCC enrollees during the winter of that year.

Geology and Physiography

The Little Hurricane Watershed lies in the Blue Ridge province of the Southern Appalachians. The underlying rock is the Archean Carolina gneiss and schist. The thickness of this formation, which was enormous, was greatly increased by complex folding. As a result of folding and the absence of open faults and fractures, there is little likelihood that continuous channels exist which would permit the subterranean escape of water through the rock.

The parent material weathers to form a relatively deep soil mantle with bare outcrops of rock appearing only on the

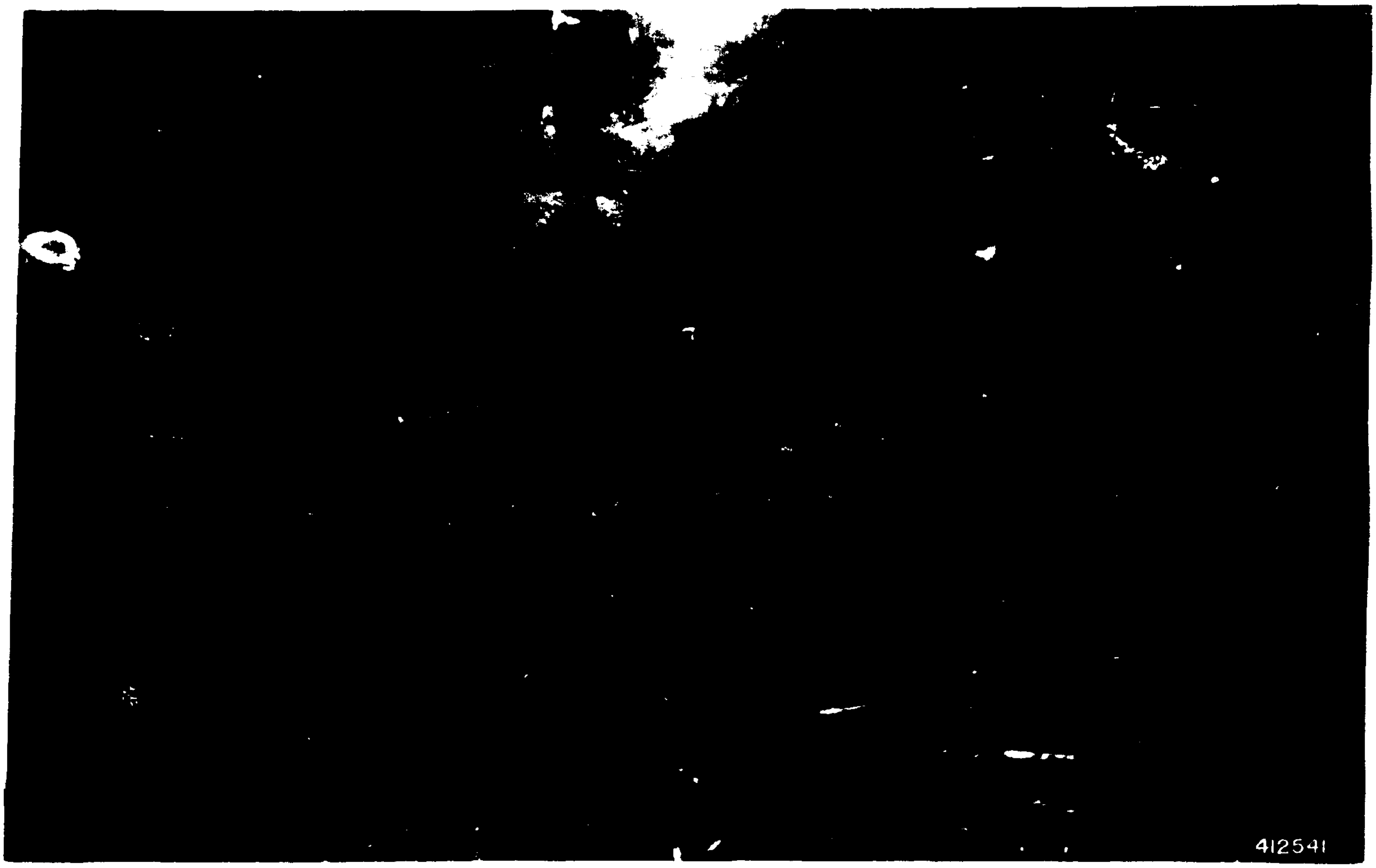


Figure 6.

Clearing Operations by CCC Enrollees, 1939-1940.

steeper slopes at high elevations. Two small outcrops occurring on the upper slopes of the drainage are shown in Figure 4.

The topography of the area is steep and rugged. The mean sea level elevations range from 2,425 feet at the base or weir to 3,124 feet at the top. The distance from the base to the top is about one-third mile. The land slopes are quite steep with north-south averages 46 percent and east-west averages 58 percent. The mean slope for the watershed is 51 percent and the range is from 10 percent near the bottom to nearly 80 percent at the head of the drainage.

The drainage pattern of the Little Hurricane Branch is dendritic, the stream channel is V-shaped and the slopes are concave, all indicating the youthful stage of the stream. The permanent stream channel is 436 feet long with a drop of 65 feet. The average stream gradient is 14.9 percent.

The ground water table is only slightly less steep than the general slope of the land surface, and at four observation wells ranges from 8 to 16 feet below the soil surface.

Climate[2]

The climate of the Coweeta area is characterized by moderate temperatures and abundant rainfall. The mean annual

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[2]All climatic values given here are based on 15 years record at weather station #1 (Headquarters area) Coweeta Hydrologic Laboratory, U.S.F.S.

temperature is 55°F. and the normal frost-free season extends from April 17 to October 23, a period of 189 days. The average temperature during the growing season is 65°F. Recordings of 90°F. are rare and summer nights are cool with minimums averaging 58°F. The three coldest months, December, January, and February average 39°F. Periods of cold weather with temperatures below 20°F. are short in duration. The highest and lowest recorded temperatures are 94°F. and -15°F. respectively.

The average annual rainfall over the Coweeta Hydrologic Laboratory is 77 inches. Figure 7 shows the rainfall distribution pattern for the Southern Appalachian Region and indicates that rainfall is well-distributed throughout the year. For the past 15 years, precipitation has averaged 3.2 inches in October, the driest month, and 7.2 inches in March, the wettest month. The greatest amount of rainfall is received in the southwest portion of the area and the least in the northeast corner. The difference between these two zones is about 20 inches a year.

The average monthly evaporation, measured by a standard U. S. Weather Bureau evaporation pan, varies from 0.98 inches in December to 4.10 inches in May. The average total evaporation for the year is 33.56 inches, or 2.80 inches per month.

Climatic summaries indicating mean, mean maximum, mean minimum, absolute maximum and absolute minimum temperatures as well as evaporation rates from a free water surface by

Figure 7.
MEAN ANNUAL PRECIPITATION

INCHES

- 35-40
- 40-50
- 50-60
- 60-70
- 70 +
- o Coweeta Hydrologic Laboratory

years and months are given in the Appendix. Precipitation summaries are given for the Little Hurricane Watershed in the section on hydrologic data, page 120.

Soils

The soils on the watershed are derived from Archean granite gneiss and schist. The parent rocks weather to form a relatively deep soil mantle. A colluvial fill which is more than 20 feet thick occurs on the lower portion of the drainage. On the upper slopes the soil mantle ranges from 5-10 feet in thickness. Two rock outcrops and evidence of an old landslide are present. The lower pasture land shows the effects of former cultivation more noticeably than the area recently cropped.

Except for the colluvial fill at the base of the watershed the soils are classified as Porters loam (10)[3]. In the colluvial fill they are Porters loam, colluvial phase. The surface soil of Porters loam ranges from 6 to 12 inches in depth and consists of mellow and friable brown loam. The subsoil, to a depth of 20-28 inches, is a red to reddish-brown, friable and crumbly clay-loam. Below this is a reddish-brown mixture of clay loam and disintegrated rock.

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[3]The entire watershed was mapped by Devereux et al in 1929 as Porters stony loam. After the examination of numerous soil profiles throughout the area and more recent descriptions of the Porters stony loam, Porters loam and Porters loam, colluvial phase, it is believed that the above classification is more nearly correct.

Porters loam, colluvial phase, is similar in color to typical Porters loam but is much deeper and in some places practically no difference exists between the surface soil and the subsoil. This soil contains a fairly high content of rock fragments which have rolled down from the mountain sides.

According to Devereux et al (10) Porters loam is considered as one of the better agricultural soils of the county. If it occupied more favorable relief probably all of it would be cultivated, but under existing conditions only a small part is in such use. The principal crop is corn and yields range from 15 to 40 bushels per acre. Cabbage, potatoes, snap beans, and pumpkins do well also. Porters loam is one of the good pasture-grass soils of western North Carolina. Soils of the colluvial phase are used for the production of corn, cabbage and potatoes, and the yields are about the same as those obtained on typical Porters loam.

Vegetation

Previous to clearing, the primary forest vegetation consisted of second-growth forest of the oak-chestnut type, with cove-hardwood and yellow pine-hardwood types on smaller areas. Figure 8 indicates the type map made in 1934. The scale for the merchantable timber cut on ten acres below the contour trail during clearcutting operations in 1940[4] is

[4]Survey by A. E. Radford and E. D. Marshall, August, 1940. From the files of the Coweeta Hydrologic Laboratory, USFS.

given below (Scribner Decimal C rule with allowance for defect):

Species	Board Feet
Pitch pine	2,040
Yellow poplar	7,750
Black oak	2,310
White oak	420
Chestnut	250
Basswood	590
Red oak	560
Total (141 logs) -	13,920

To determine what herbaceous cover comes in naturally following clearing, an observational survey was made of the ground cover in August, 1940. Species were identified and mapped according to relative preponderance. The following species were identified:

1. Herbaceous weeds:

Cacalia atriplicifolia	- Pale Indian plantain
Havenaria ciliaris	- Long-spur orchis
Viola papilionacea	- Wood violet
Ambrosia artemisiifolia	- Ragweed, hotweed, bitterweed
Eupatorium purpureum	- Joe-pye weed
Acalypha virginica	- Three-seeded mercury
Oxalis stricta	- Wood sorrel
Amaranthus hydridus	- Pigweed, tumbleweed
Setaria lutescens	- Yellow foxtail, pigeon grass
Panicum lanuginosum	- Switch grass
Eleocharis obtusa	- Spike rush
Scirpus strovirens	- Green bulrush
Scirpus cyperinus	- Wool grass
Phegopteris hexagonoptera	- Broad beech fern
Pteridium latiusculum	- Bracken fern
Kyllinga pumila	- Dandy or thin-leaved sedge
Ludwigia alternifolia	- Seedbox (false loosestrife)
Bidens bipinnata	- Spanish needles
Bidens frondosa	- Beggars tick
Plantago major	- Common or broad-leaved plantain
Trautvetteria carolinensis	- Tassel-rue or false bugbane

Cimicufuga racemosa - Black snakeroot, black cohosh
Eupatorium urticaefolium - White snakeroot

2. Robinia pseudocacia, Sassafras varifolium, Smilax glauca and Vitis bicolor seedlings.

3. Vitis bicolor-Robinia pseudoacacia seedlings.

4. Liriodendron tulipifera, Cornus florida, and Acer rubrum tridens seedlings.

5. Acer rubrum tridens, Diospros virginiana, Sassafras varifolium seedlings.

6. Sassafras varifolium.

7. Cover herbs and seedlings of trees:
   Polystichum acrostichoides- Dagger fern
   Adiantum pedatum - Maiden-hair fern
   Phegopteris hexagonoptera - Broad beech fern
   Dryopteris noveboracensis - New York fern
   Sanguinaria canadensis - Bloodroot
   Liriodendron tulipifera - Tulip poplar, yellow poplar
   Cornus florida - Flowering dogwood

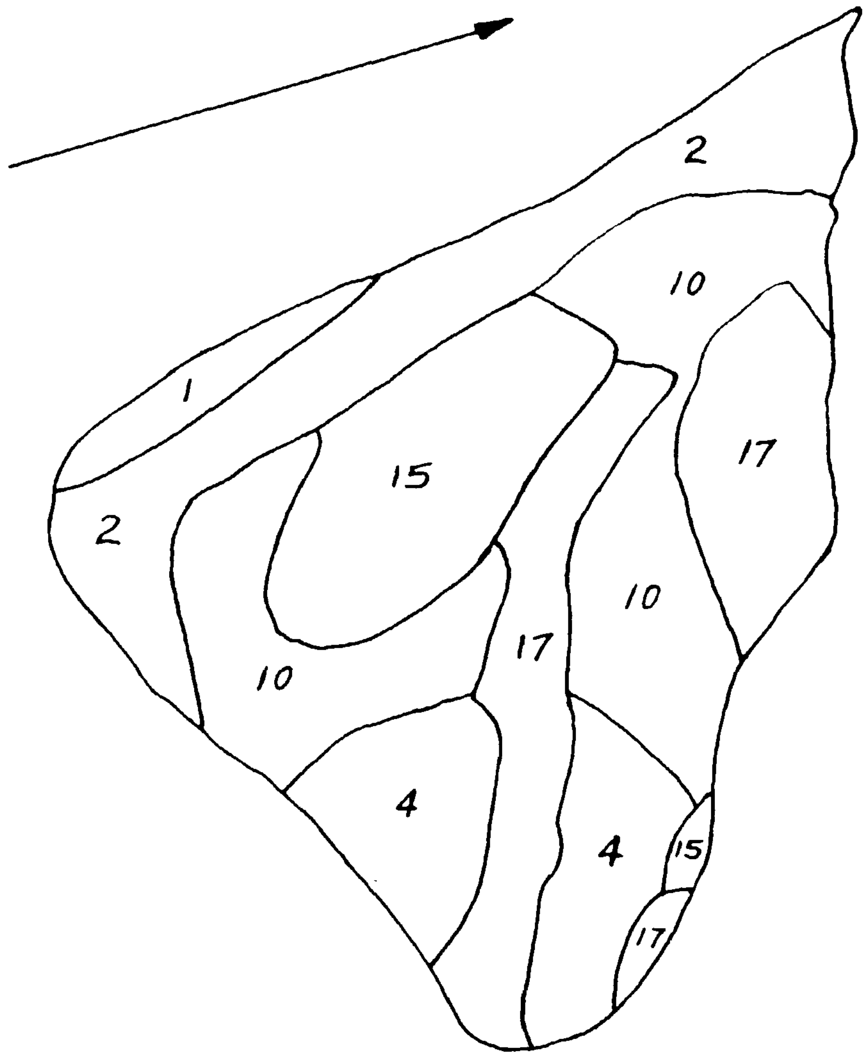
8. Rhus coppalina, Rhus typhina and herbaceous weeds.

9. Oxydendrum arboreum, Robinia pseudoacacia, Carya sp., Castanea dentata seedlings sprouts (Originally an oak-chestnut type).

Figure 9 shows the post-clearing vegetation map.

Figure 8.
LOCAL FOREST TYPES
(Mapped in 1934)

Watershed No. 3 - Little Hurricane Branch
Coweeta Hydrologic Laboratory



Legend

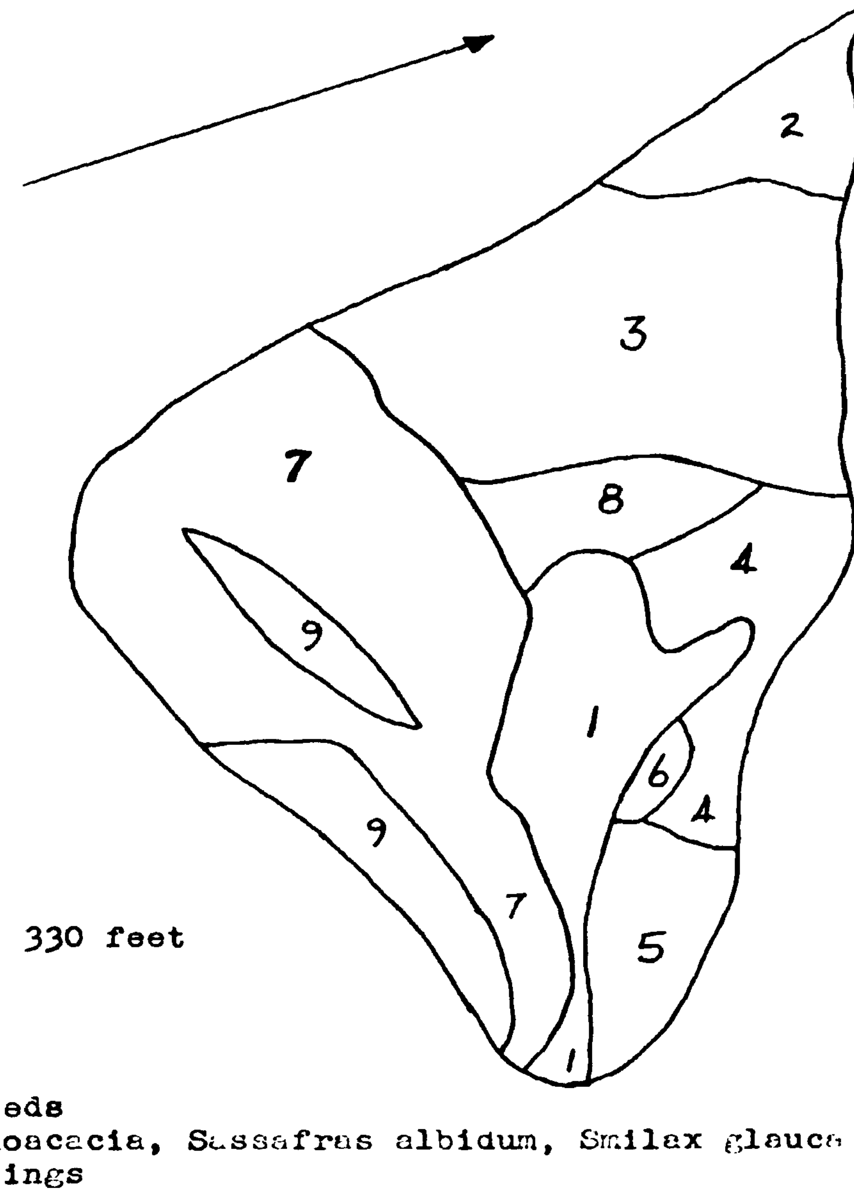
1 Pitch pine-scarlet oak-chestnut oak
2 Scarlet oak-chestnut oak-black oak
4 Scarlet oak-black oak-white oak
10 Red oak-chestnut oak-scarlet oak
15 Yellow poplar-red oak-hickory
17 Yellow poplar-red maple-white oak

Scale: 1 inch = 330 feet

Figure 9.

POST CLEARING VEGETATION MAP*

Watershed No. 3 - Little Hurricane Branch
Coweeta Hydrologic Laboratory



Scale: 1 inch = 330 feet

Legend

1 Herbaceous weeds
2 Robinia pseudoacacia, Sassafras albidum, Smilax glauca and Vitis bicolor seedlings
3 Vitis bicolor and Robinia pseudoacacia seedlings
4 Liriodendron tulipifera, Cornus florida and Acer rubrum tridens
5 Acer rubrum tridens, Diospyros virginiana, Sassafras albidum
6 Sassafras albidum
7 Coverherbs, cove tree seedlings
8 Rhus copallina, Rhus typhina and herbaceous weeds
9 Oxydendrum arboreum, Robinia pseudoacacia, Carya sp., and Castanea dentata (originally oak-chestnut)

* Survey made August, 1940 by Albert E. Radford and Eugene D. Marshall.

HISTORY OF THE EXPERIMENT

Instrumentation - Installations

<u>Precipitation</u>. Precipitation or recharge to the watershed is measured by three standard rain gages, numbers 16, 20 and 67. Gages 16 and 20 have been in operation continuously since July 4, 1934. Gage 67 was installed on June 9, 1940 and has been in continuous operation since that date. Previous to the installation of gage 67, measurements from standard rain gage 21 were also applied to the area.

Until June 9, 1940, rainfall intensities were measured by recording rain gage 1, located on the adjacent drainage area No. 7. Gage 10 has been used since its installation on June 9, 1940. Recording rain gage 10 and standard rain gage 67 are located adjacent to each other in order to provide a check against the accuracy of the former. Figure 10 pictures recording rain gage 10.

Charts are changed at least once a week on the recording rain gage and it is completely serviced and checked at least once each year. The standard rain gages are read following each storm or as nearly so as possible.

Standard rain gage data are summarized and tabulated by months, hydrologic seasons, calendar years and hydrologic years. Data for the three gages servicing the watershed as well as the weighted areal precipitation is given in the Appendix.

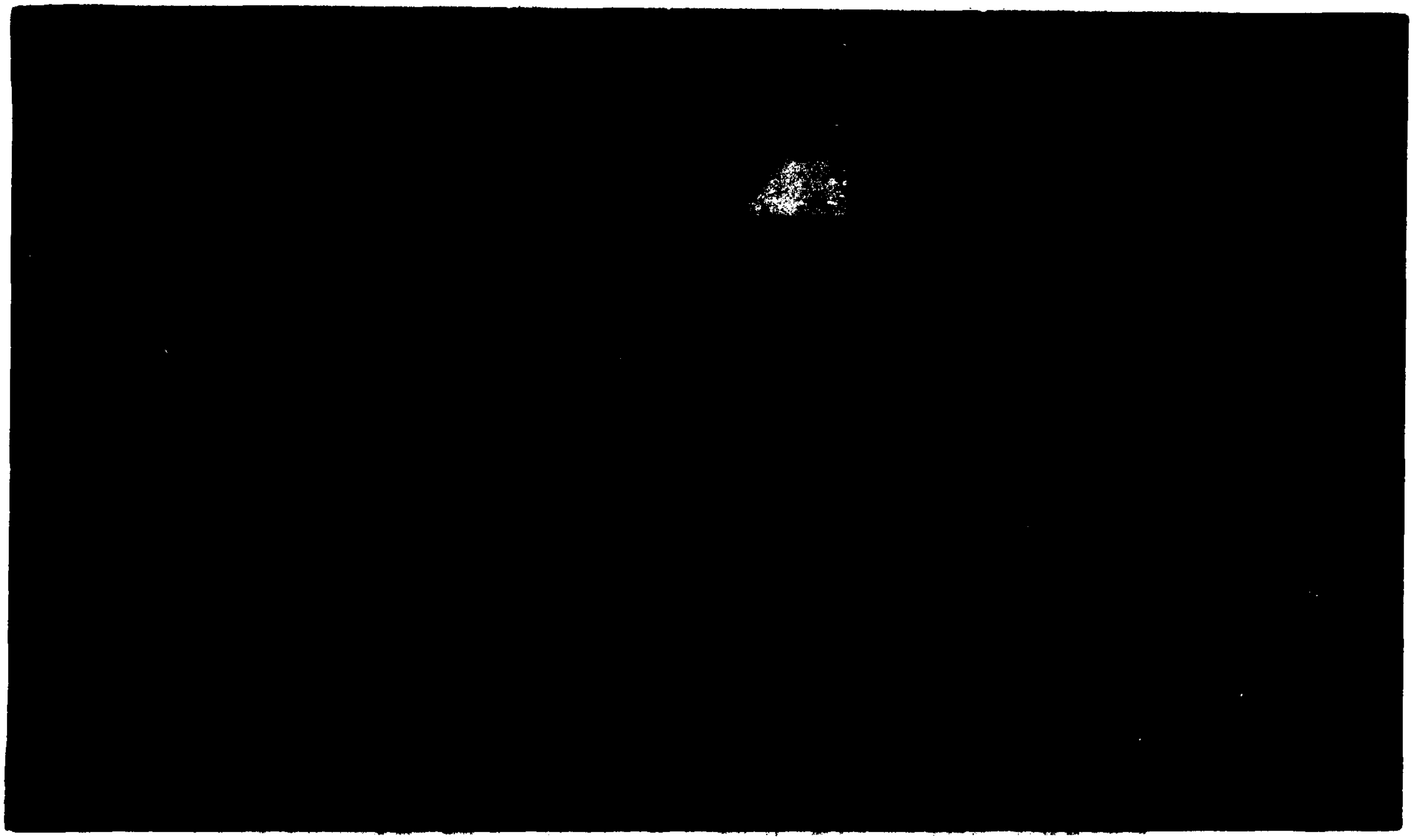


Figure 10.

Recording rain gage used for rainfall intensity determinations.

To compute the total areal precipitation of the watershed, the Horton-Thiesen Means method (19) of weighting precipitation is used. Figure 11 shows the geometric division of the watershed for these calculations, as well as the location of the different installations.

Precipitation intensities are computed from the recording rain gage charts. These data are then tabulated on precipitation intensity records and corrected to agree with the reading of the standard rain gage located adjacent to it. Since the area of the watershed is only approximately 23 acres, a single recording rain gage is used for intensity determinations.

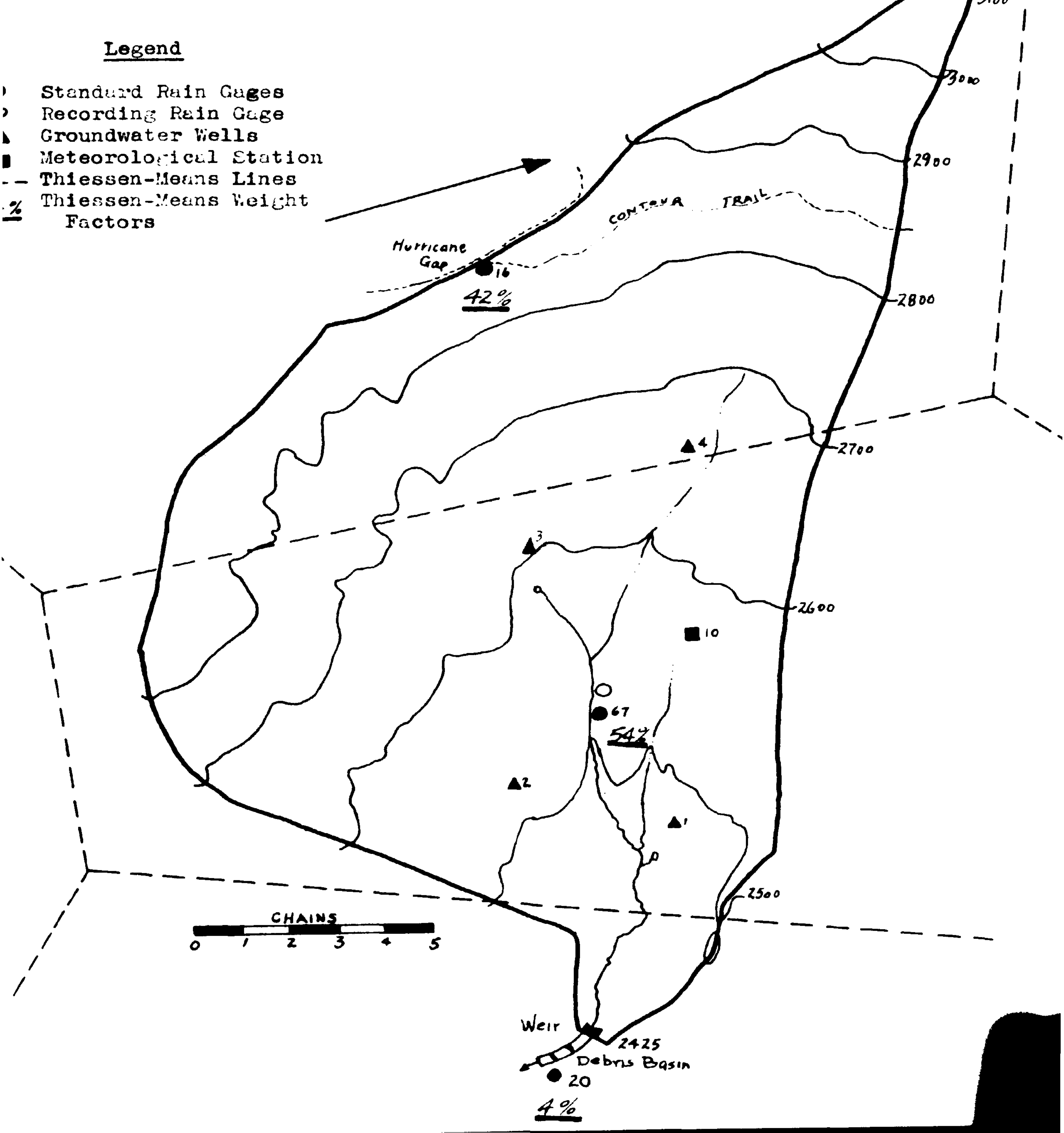
<u>Stream flow</u>. To measure the discharge from the watershed a 90-degree V-notch weir with a 35½ inch blade, similar to that pictured in Figure 10, with a continuous water stage recorder, was installed on July 5, 1934. The stilling basin was 6'10" x 4'11" x 1'5", with wooden walls and bottom and a log wall between the silting and stilling basins.

In order to measure a wider range in streamflow and to accommodate greater debris loads, anticipated as a result of the watershed treatment, the 90-degree V-notch control was replaced with a Columbus CIA deep notch control in December, 1939. Figure 14 pictures the latter stream control. In addition, a concrete stilling well was installed. The maximum capacity of the blade on the Columbus control is 2,500 c.s.m.

Figure 11.

Rain Gage Service Areas.

Little Hurricane Branch
Coweeta Hydrologic Laboratory



To convert the streamflow data into usable form, the head and time readings are taken from the water level charts and then converted into volume values, i. e., cubic feet per second (c.f.s.) and cubic feet per second per square mile (c.s.m.). For special storm studies inches per hour is used as well. Volume data are, as in the case of precipitation data, summarized by days, months, hydrologic seasons and years as well as by individual storms. For special storm studies volume values are plotted over time to give the storm hydrographs.

Water stage recorders are completely serviced and overhauled at least once per year. Recorder charts are changed at least once per week and frequently following major storms.

Sample calculations and recording forms for both precipitation and streamflow data are given in the Appendix.

Soil losses. In August of 1941 the concrete debris basin shown in Figure 17 was constructed to measure soil losses from the watershed. The design of the debris basin was based upon Stokes Law of the settling velocity of particles in a liquid. The basin consists of three individual basins each with five baffles. The basin obviously catches all but the finest materials as evidenced by the absence of sediment in the stream channel below the basin.

The debris basin is cleaned each spring if required or more frequently in seasons with major storms producing heavy soil losses. The water is diverted around the basin from the weir spillway permitting continuous streamflow measurements. Samples of sediments from each basin and within each baffle are taken for volume determinations. The sediment is permitted to dry, then it is measured and removed. From the dry weight of the samples and the volume of silt applying to each sample an estimate is made of the dry weight of the sediments trapped in the basin.

Prior to the installation of the debris basin estimates of soil losses were made from samples taken from the silting basin.

Ground water. To study fluctuations in the ground water surface, four wells were installed during the summer of 1941. Daily measurements of the water elevations in the wells were made until November 1, 1942. At that time water stage recorders were installed on wells 1 and 2. Weekly measurements of the water levels in wells 3 and 4 were made until April 24, 1944 when, due to a shortage of funds and labor, water level readings in these two wells were discontinued.

Because of the restricted scope of this dissertation and the time limits imposed, no attempt was made to include ground water studies.

Period of Standardization, 1934-1939

On July 3, 1934 a 90-degree V-notch stream control was put into operation along with two standard rain gages

(16 and 20). Figure 12 pictures a 90-degree V-notch weir similar to that originally installed on this watershed. A recording rain gage of the float type (1) and another standard rain gage (21) were installed on October 18 in the adjoining drainage (Hurricane or area No. 7). A survey of the area was made during the summer of 1934.

On August 3, 1939 the V-notch weir was removed and on December 20, 1939 a modified Columbus type 1-A deep-notch stream control was installed in order to measure a greater range of flows and to accommodate greater debris loads.

The maximum rate of runoff measured before clearing was 110 c.s.m. following a rain of 4.67 inches in November of 1938. The maximum intensity of this rain was 2.12 inches per hour.

Before clearing, the rate of sediment movement, based on accumulation in the weir pond, was 914 pounds per day.

Clearing Operations, 1940

Logging and clearing operations were started in November, 1939 and were completed in July, 1940. Figures 6 and 13 show the watershed in two stages of clearing. The merchantable timber on the area below the contour trail was sold to a local firm and logged to simulate local practices. The balance of the watershed was cleared by CCC enrolees. On the lower portion, stumps over 16 inches in diameter were pulled and the brush was piled and burned around the larger

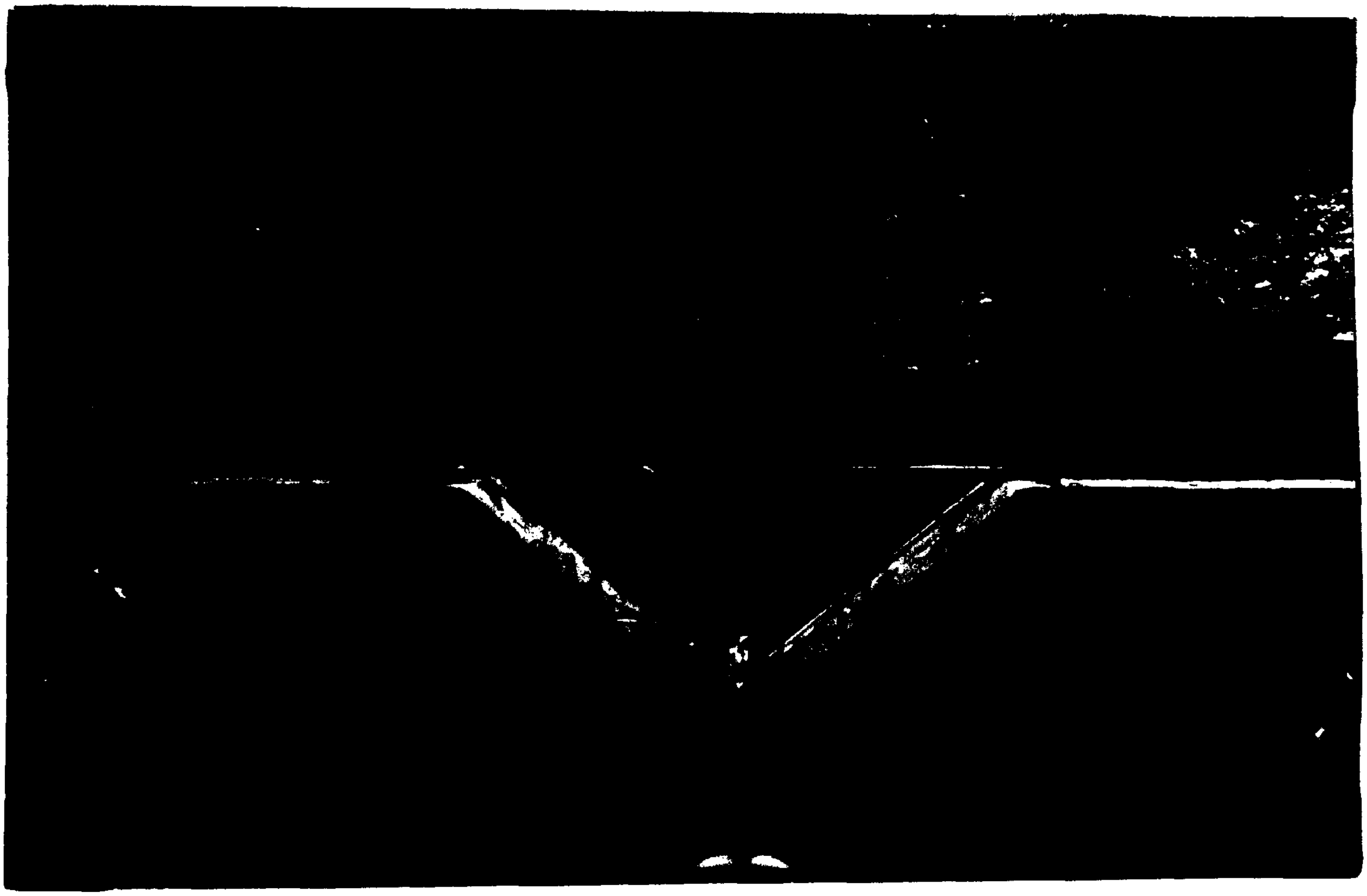


Figure 12.

90° V-notch weir installation on Coweeta Watershed No. 1, similar to that originally installed on Watershed No. 3.

Figure 13.

Clearing operations nearly complete, spring 1940.

stumps which remained. On the upper portion the trees were cut and the slash scattered over the ground to form a mulch. About two acres of the area above the contour trail was burned over by a forest fire which occurred on July 2, 1940.

A recording rain gage (No. 10) and a standard rain gage (No. 67) were installed near the center of the drainage area on June 19, 1940.

Mountain Farming Treatment, 1941-1951

<u>1941</u>. In the spring of 1941 an area of 5.6 acres was plowed using a bull tongue or single foot plow. Figures 14 and 15 show the cornfield during and following plowing. The field was planted to Hickory King corn with no fertilizer used. It was cultivated by hoe during May and June and the crop of 132½ bushels was harvested in November.

A concrete debris basin was put into operation on August 28 and four ground-water wells were installed during the summer. Soil mantle depths were measured on cross-drainage lines and volume soil samples were taken from eight selected pits. Figures 14 and 15 give views of the Columbus CIA deep notch weir as well as the concrete debris basin.

<u>1942</u>. The field was plowed again with the single foot plow in 1942 and Hickory King corn planted. Because of a wet summer the corn was worked only once. Windstorms blew down much of the corn. The yield was 84 bushels or 15.3 bushels per acre. The watershed was fenced during the summer with stock fence and a hog-proof fence was put up around the cornfield.

Figure 14.

Plowing cornfield for first crop of corn, April 1940.

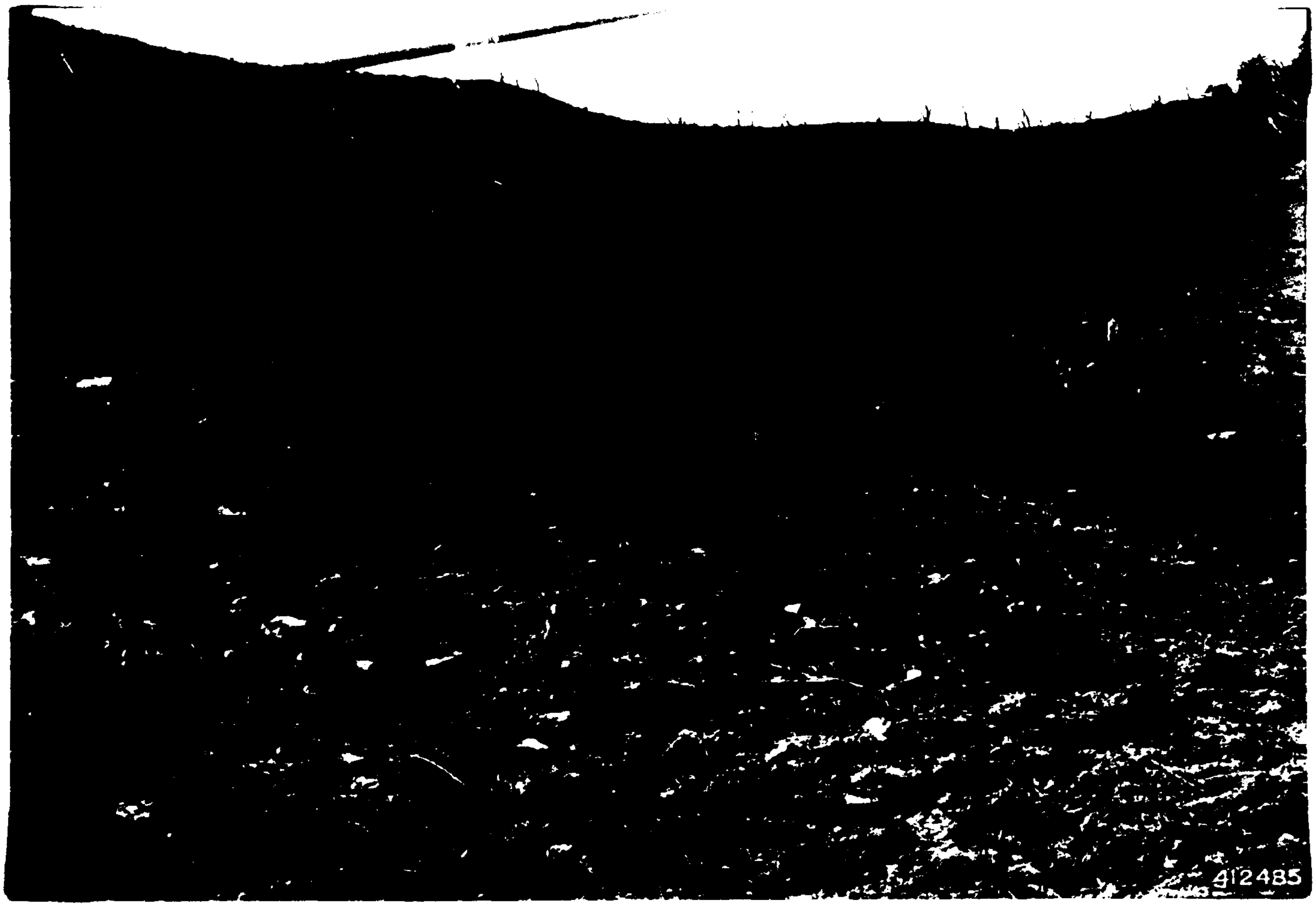


Figure 15.

Cornfield in foreground, following plowing with bull tongue or single-foot plow.

Of the 17 acres outside the cornfield about 10 acres was too rough or brushy for pasture and was permitted to grow up into coppice forest. One hundred pounds of Cherokee pasture seed mix was sown on the remaining 12 acres. Competition from trees and shrubs prevented a good catch of grass.

Cattle were alternated between this pasture and the adjacent wooded watershed (No. 7). In all there were 336 animal days of grazing on watershed No. 3. Herbaceous vegetation was estimated to be 80 percent utilized by September 21 and evidence of trampling was conspicuous.

1943. The debris basin was cleaned on May 28. This was the first measurement of the eroded material trapped by the debris basin since it was placed in operation on August 28, 1941. Water was diverted around the basin on May 4 and by May 28 the material had dried so that it could be shoveled out. Before cleaning, 200 C.C. samples were collected from each baffle and the total volume of silt measured. From the dry weight of these samples and the volume of silt applying to each sample, an estimate was made for the dry weight of the silt trapped in the basins. A total of 437 cubic feet or 13,928 pounds of dry soil material was removed. Prorated over the period from August 28, 1941 to May 4, 1943, the soil losses amounted to 22.7 pounds per day.

The cornfield was again plowed and this year planted to Golden Prolific corn. The corn grew well except on the red clay "scalds" on the ridges of the portion below the recording rain gage. The corn on the steepest slopes suffered from washing during thunder storms. The corn yield was 14.6 bushels per acre.

On pasture, eight animals were grazed for 67 days. The sprouts below the contour trail were cut back in August. The portion below the recording rain gage was picked almost clean but sprout growth on the extreme upper slopes was untouched. One hundred pounds of a mixture of Italian Rye grass and Red Top were sown over the pasture in March.

The season of 1943 was marked by abundant rainfall in early summer. Particularly important were very intense thunder-storms occurring during June and July. The first notable washing of the field occurred on June 13 when 1.10 inches of rain fell, largely within a 25 minute period. This rain fell at a rate of approximately 5 inches per hour for a five minute interval and 4 inches per hour for a ten minute period. On June 14 another storm almost identical in rates and amount occurred. As evidenced in Figures 18 and 19 these two storms removed large volumes of soil from the field. The weir basin was completely choked but records of peak discharge were obtained. Less severe thunderstorms were common in the following days. Another very severe storm occurred on July 5 after five days of light showers. This rain again caused great erosion and gave the highest peak discharge recorded for this area.

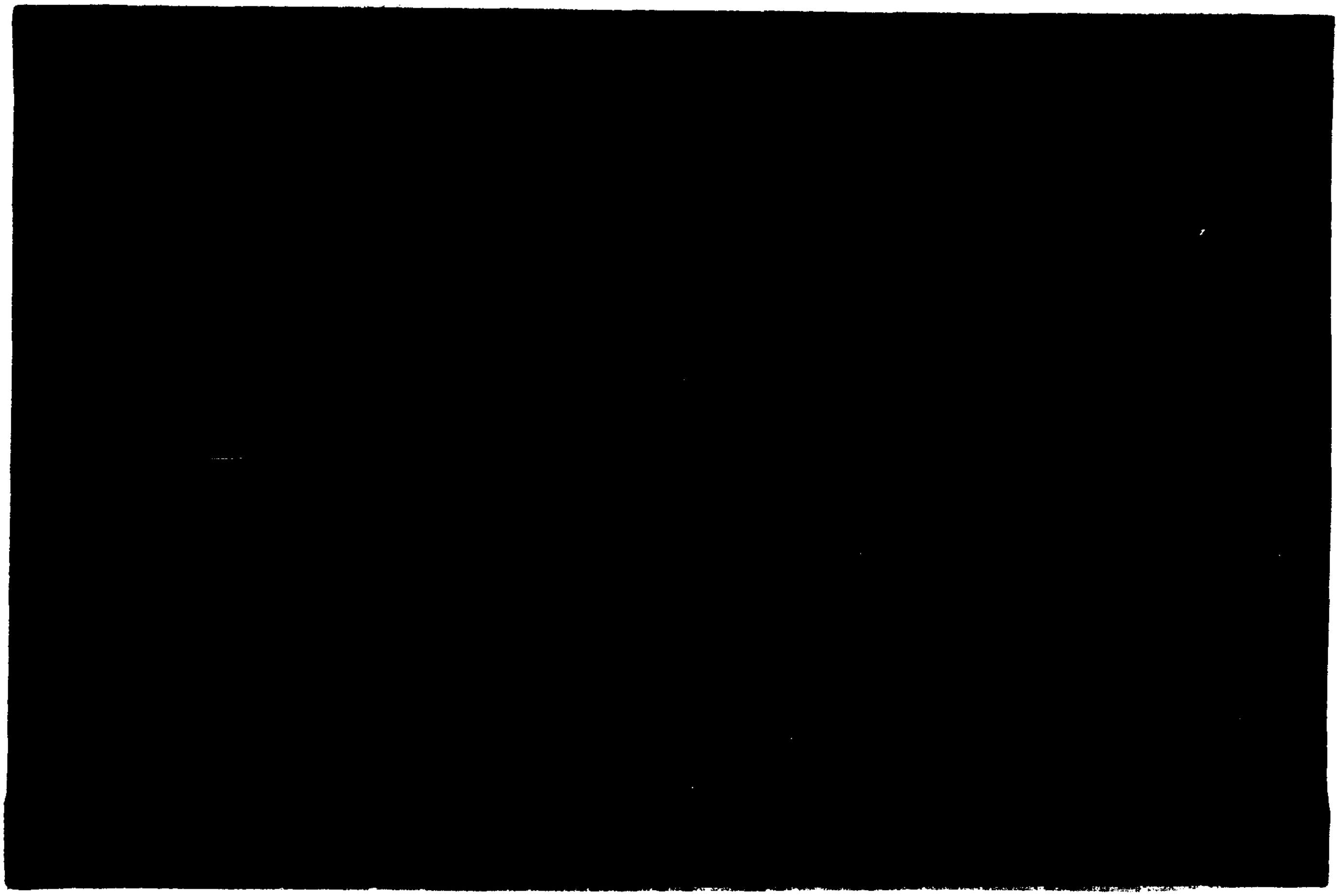


Figure 16.

Columbus CIA deep notch weir.
(Debris carried down by storm of June 16, 1949)

Figure 17.

Concrete debris basin and Columbus deep notch control.

Figure 18.

View of weir and ponding basin
after storms of June 13 and 14, 1943.

The erosion and discharge of Area 3 for these storms was greatly in excess of that for any other Coweeta area. The great accumulation of silt and debris made it impossible to secure completely satisfactory records for the falling stages of the stream discharge. However, the rising and peak stages were obtained.

As a result of the erosion which took place during June and July, the debris basin was again cleaned out on September 15-17. The water was diverted on September 8. The results indicated the enormous increase in erosion in 1943, showing soil losses amounting to 1732 cubic feet or a total of 79,058 pounds for the period from May 28 to September 8. This amounts to 627 pounds per day.

Because of reduction in personnel it was not possible to continue daily observations of the well elevations. After November 1, 1942 the depth to ground water was measured weekly. Water stage recorders, however, were installed on wells 3-1 and 3-2.

1944. The cornfield was permitted to grow up into weeds and shrubs due to lack of funds and labor. Cattle, however, were excluded from it.

A drift fence was built just below and to the right of the recording rain gage to control grazing and prevent concentration on the lower portion of the pasture. Cattle were alternated between the two portions (designated upper and lower pastures). Five head of cattle were kept continuously on the area from May 8 to September 22 for a total of 685 animal days. Nearly all available forage was consumed in the lower pasture and the soil surface was severely trampled and compacted. The remaining perennial herbaceous vegetation was considerably reduced by frost-heaving the following winter.

On the cornfield the most abundant weedy species which became established were ragweed and cinquefoil. Blackberries were abundant along the fence line. Seedlings and sprouts of locust and yellow poplar also became established. Only on the "scalds" and in the washes formed in 1943 was any soil washing observed.

Weekly readings of the water level in the observational wells 3-3 and 3-4 were discontinued April 24.

1945. Cultivation of a corn crop was postponed for another season because of shortage of funds and labor. The shrubs and woody growth which came in on the area in 1944 continued to develop since livestock again were excluded. This cover apparently afforded considerable protection against soil washing as none was noted on the area itself and very little silt was transported into the stream channels. The "scalds" which developed during cultivation were still quite apparent but showed some evidence of healing.

1946. On April 16 the debris basin was again cleaned. This measurement applied to the period of September 8, 1943 to April 16, 1946, during which the field was not in cultivation. The net volume of the sediment was 971 cubic feet and the dry weight was 44,185 pounds. For the 952-day period

Figure 19.

View of lower portion of cornfield after storms of June 13 and 14, 1943.

this is a rate of accumulation in the basin of 37 pounds per day.

The cornfield was cleared of weeds and woody vegetation and plowed again. Hybrid U. S. 13 yellow corn was planted without fertilizer. Figure 20 shows brush burning and plowing in April of 1946. The harvest was 65 bushels or 11.6 bushels per acre. This corn was apparently poorly adapted to the area. Deer and ground hogs took a heavy toll of the crop, also. Figure 21 pictures the cornfield and lower pasture in September, 1946.

The fence between Areas 3 and 7 was opened and the cattle were alternated between the upper pasture of Watershed 3 and all of No. 7. There was a total of 1,377 days of grazing on both areas. Observations indicated that two-thirds of the use was on Area 3 and 85 percent of the food came from that area.

On May 7, one hundred pounds of lespedeza seed were sown on the lower pasture and the upper pasture below the contour trail. The extremely dry weather in August apparently eliminated most of the seedlings established from this planting.

No intense thunderstorms occurred on the area and no severe soil washing was observed.

1947. The debris basin was cleaned in April to determine soil losses during crop year 1946. The total net volume of sediment was 383 cubic feet with a dry weight of 13,507 pounds. The average daily sediment accumulation was 37 pounds per day.

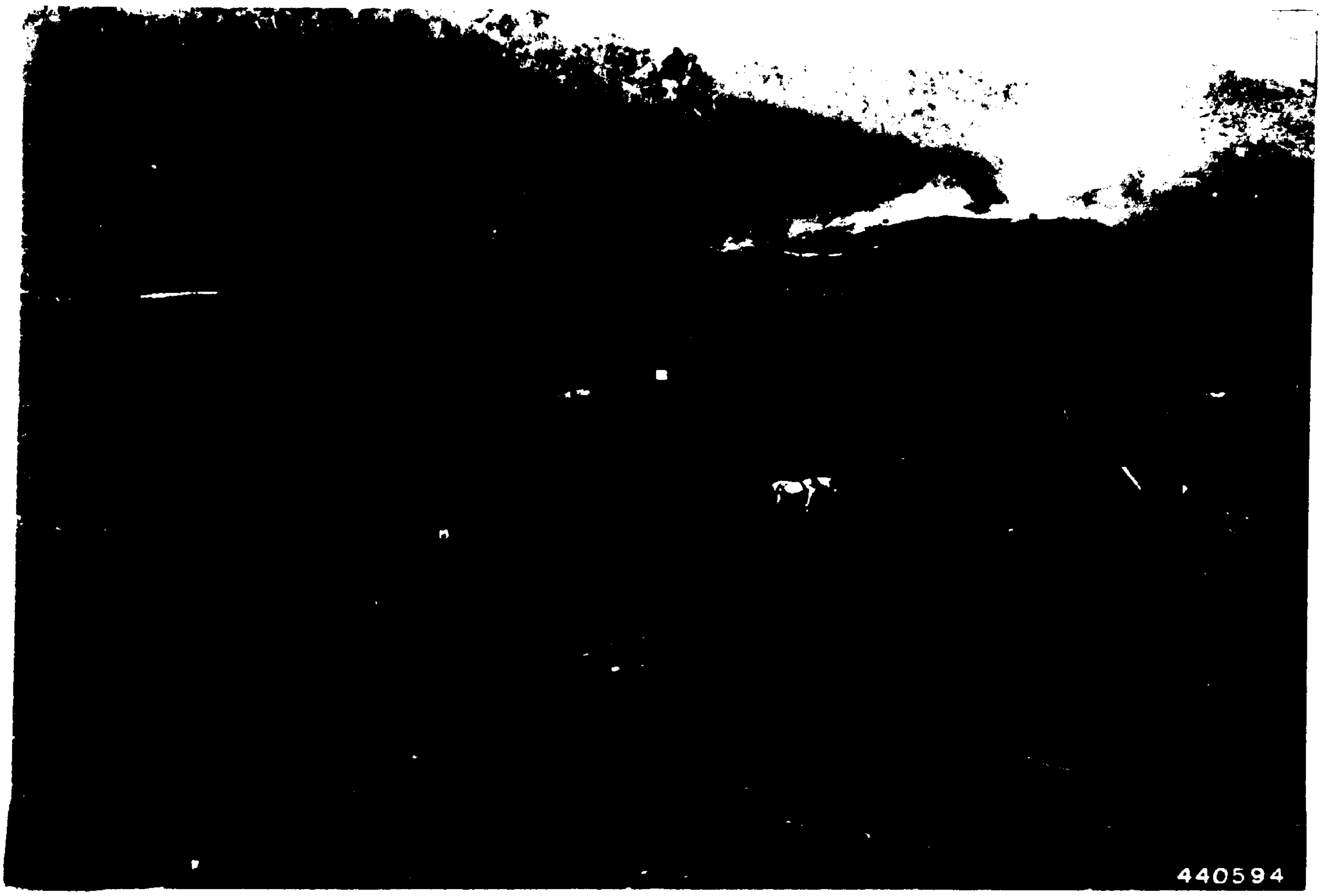


Figure 20.

Brush burning and plowing in preparation for fourth corn crop, April 1946.

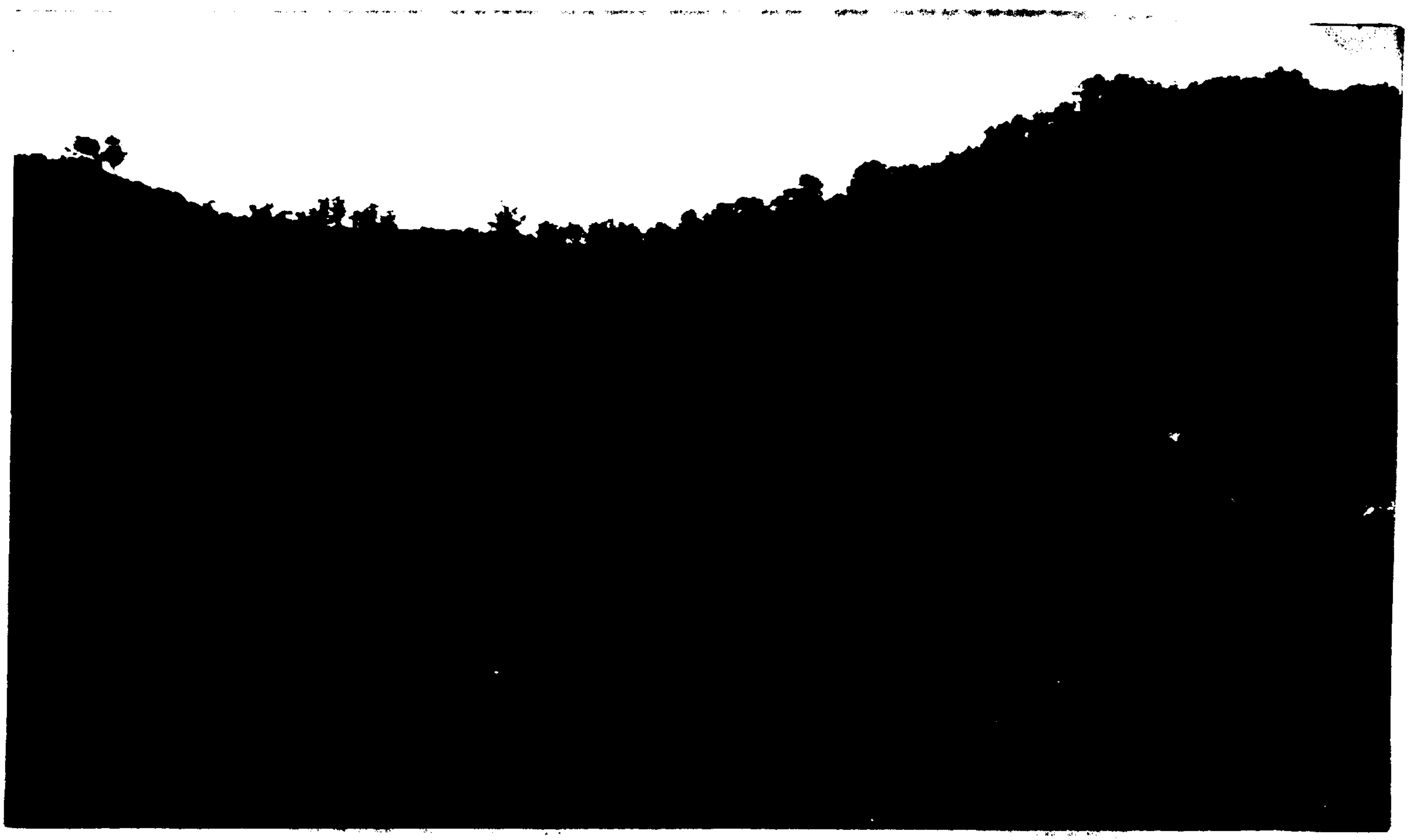


Figure 21.

View of watershed in September 1946.

During this year, the lower slopes of the cornfield were plowed with a hillside turning plow and the upper slopes with a single foot. Fertilizer was used for the first time. The total amount used was 800 pounds of 4-10-4. Hickory King corn was planted again and the yield was 90 bushels or 16 bushels per acre.

Three head of cattle were kept continuously on the watershed pasture area from May 26 to September 29 for a total of 588 days of grazing. Woody sprouts were cut back in February on the lower pasture.

1948. The sediment in the debris basin was measured on April 13, 1948. This measurement applied to the period starting on April 2, 1947. The basin held 426 cubic feet of material which had an estimated dry weight of 16,186 pounds representing a soil loss of 42 pounds per day.

The cornfield was again plowed, this year with two one-horse side-hill turning plows and planted to Hickory King corn; 800 pounds of 4-10-6 fertilizer were applied as evenly as possible.

After the corn was planted, a very dry period prevailed until the latter part of June. The corn, however, made good growth and at no time did the leaves indicate that the crop was suffering from insufficient moisture. The total yield of 80.6 bushels or 14.4 bushels per acre is lower than that of 1947 even though this was a bumper corn crop year elsewhere in this area. Figure 22 shows the harvesting of the 1948 corn crop.

Figure 22.

Harvesting 1948 corn crop, yield 14.4 bushels per acre.

An average of four head of cattle grazed continuously on the two pastures and were given supplemental feed the last two weeks on the area.

The storm producing the maximum discharge for the year occurred on August 2 when a peak of 141 c.s.m. was recorded. The hydrograph reflected every burst of precipitation by having sharp rises, peaks and recessions, indicating the sensitivity of the watershed.

Overland flow from the corn field to the creek occurred July 12, August 2, November 19 and November 29. Observations made during the above and other storm periods indicated that most of the turbidity increase came from the cattle paths located near the center of the watershed. The good weed cover that became established after the last cultivation of the cornfield in July apparently kept the soil from being displaced at a rapid rate.

Exploratory infiltrometer ring tests indicated the influence of trampling on the pastured portion of the watershed when it took 2 area inches of water 20-30 minutes to seep into the soil.

On December 10 a thermograph, with one thermocouple in the stream and one in the air, was installed 10 feet above the log coping at the approach end of the ponding basin.

1949. A cleaning of the debris basin was made April 8 before planting and again following the July 10 storm. Soil losses amounted to 32,879 and 185,875 pounds respectively or 91 and 1,998 pounds per day.

The cornfield was again cultivated in 1949. Hickory King corn was planted and fertilizer applied for the third time. The soil displacement that had taken place since clearing had exposed large numbers of rocks which accumulated on the surface. Fourteen truckloads of medium-sized rock equalling 21 tons were removed.

After the corn was planted in April, numerous intense storms occurred that rilled the soil. The 67 percent above normal rainfall kept the ground very wet. Following a storm of May 22, replanting of some areas of the field was necessary in order to get a stand of corn. Rilling of the steeper portions after the May 22 and 30 storms extended several inches below the plow line and a cultivation which followed was not able to obliterate the rills. Figures 23 and 24 show the cornfield following the May 22 storm.

The yield of one bushel per acre is in line with yields along the Little Tennessee River which were one-sixth to one-tenth of those of 1948. Figure 25 summarizes the corn yields for the seven years of record.

An average of four cattle grazed continuously on the pasture areas from May 9 to October 10 and were rotated by two week intervals between the upper and lower pastures. The animals were given supplemental feeding after August 1.

Several severe storms occurred on Watershed No. 3 during this year. The outstanding storm was that of July 10 when a record peak of 1,850 c.s.m. was recorded. It is estimated

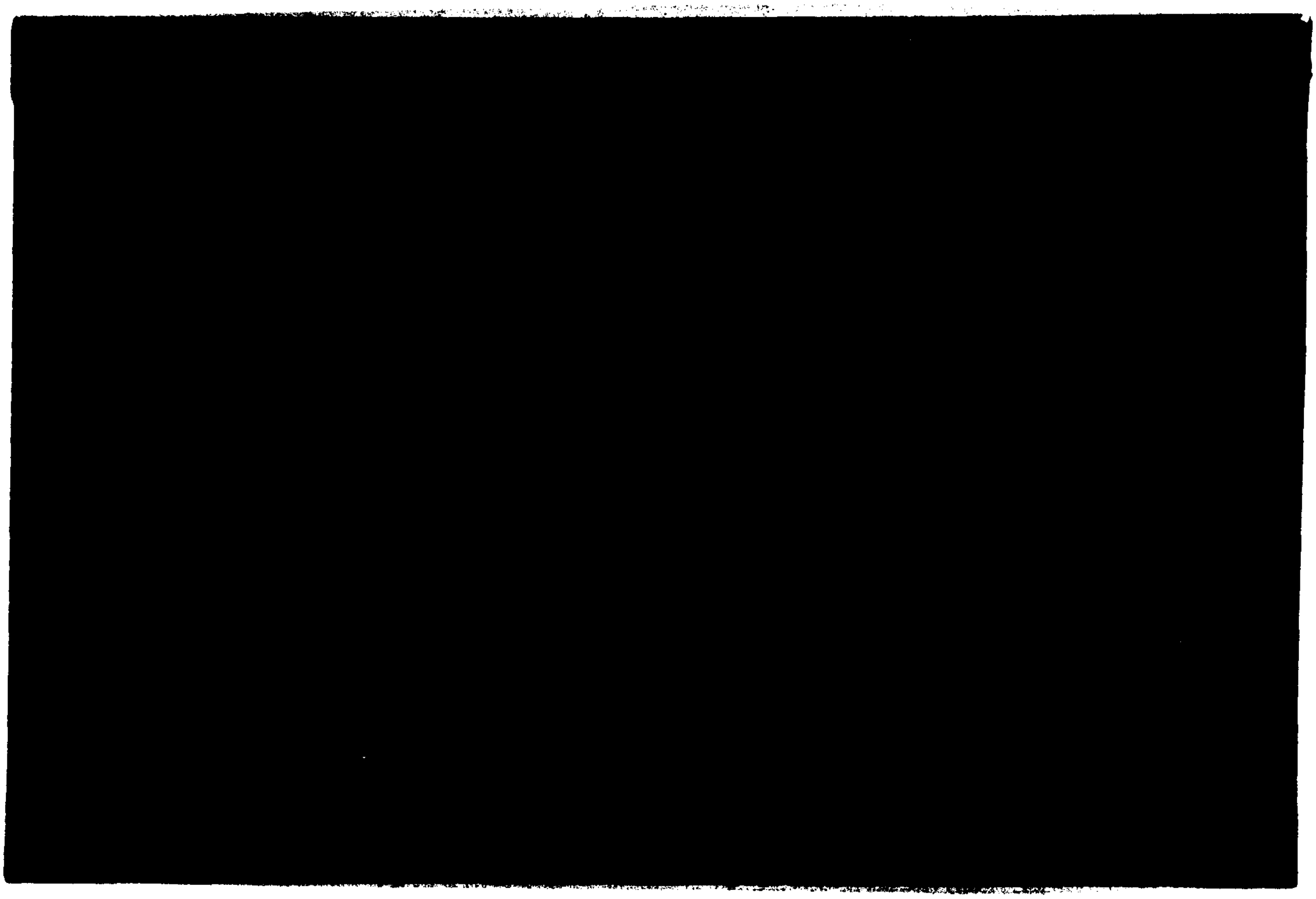


Figure 23.

Appearance of cornfield following May 22, 1949 storm.

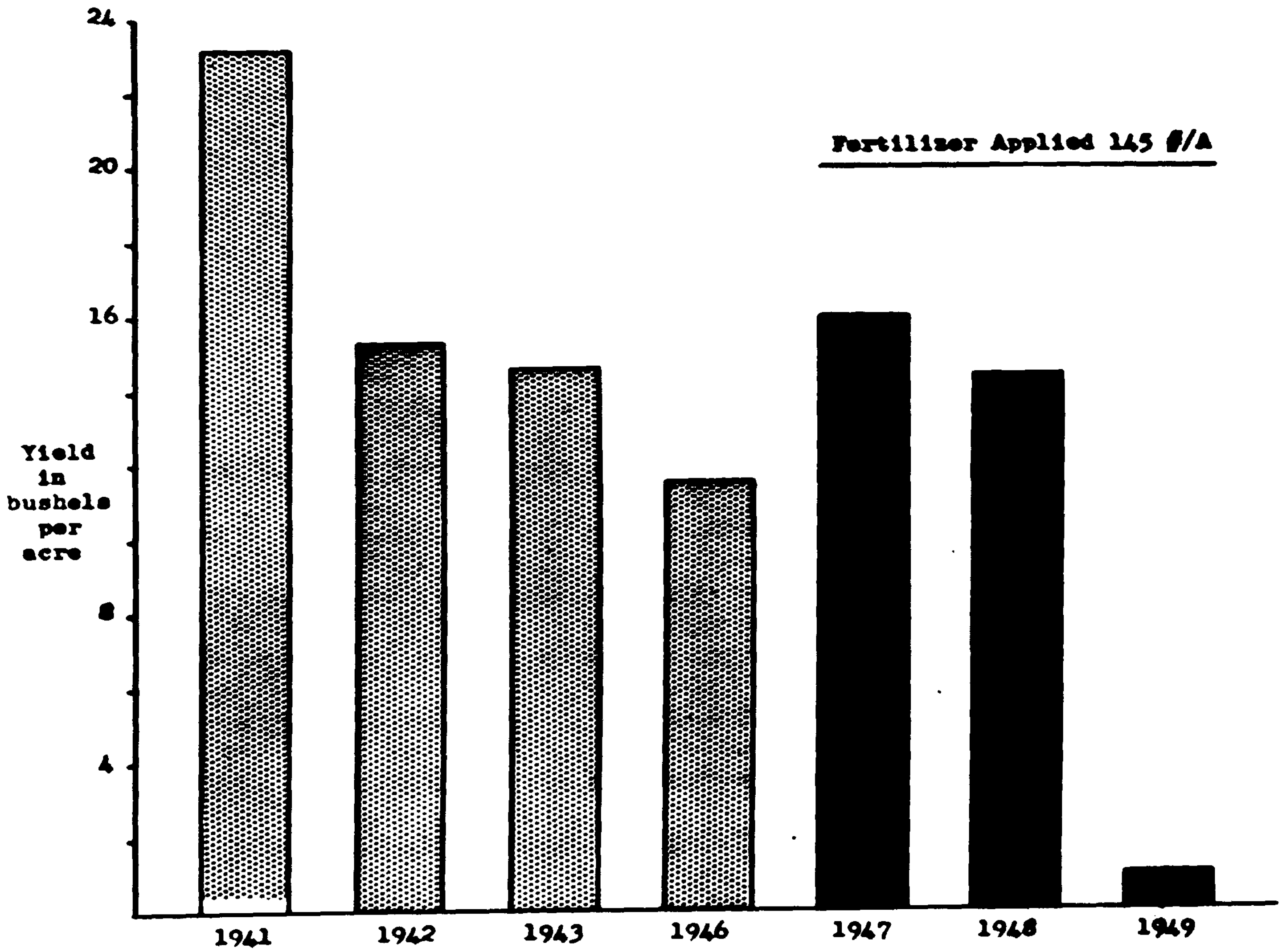
Figure 24.

Rilling in cornfield following storm of May 22, 1949.

Figure 25.

SUMMARY OF CORN YIELDS, 1941-1949

Watershed No. 3
Coweeta Hydrologic Laboratory



that 76 tons of soil and debris came off the drainage in 30 to 40 minutes during this storm. Figures 26, 27 and 28 picture the debris and sediment carried down by this storm. Fifteen storms were reported with flows greater than 15 c.s.m. during the year.

Overland flow from the cornfield to the creek occurred during all major storm periods. Observations during storm periods indicated that highly turbid water flowed through the cornfield gate and into the main channel. Two gullies were formed in the two natural swales during the May 22 storm and were enlarged during the June 16 and July 10 storms to a length of several hundred feet and a width of 4 feet with holes up to 15 inches deep. Overland flow with water running down these gullies into the permanent channel occurred during each following major storm. Observations again this year indicated that most of the turbidity, during all but the major storm periods, came from the cattle paths located near the center of the watershed.

A surface infiltration study was made in July. The stream and air temperature thermograph, installed in December, 1948, was operated all year and discontinued on December 31, 1949. Stream profile surveys made in July from the confluence with Shope Creek indicated considerable variation in temperature along open stream beds, due to shading by forest and brush.

Figure 26.

Rock deposit in ponding basin carried down by storm of July 10, 1949. Note inlet to stilling well kept clean in order to get record of runoff.

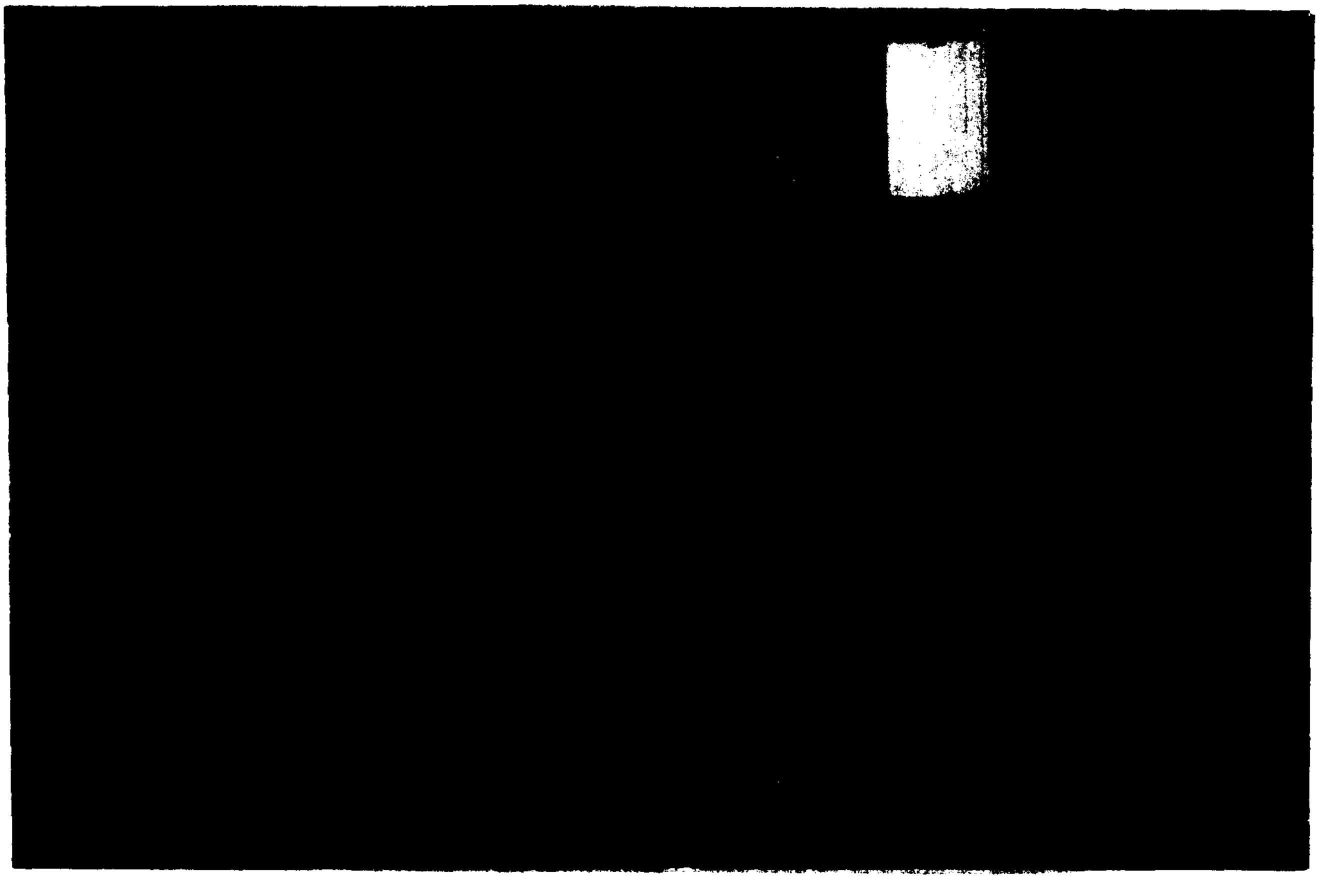


Figure 27.

Rock and soil moved in July 10, 1949 storm.

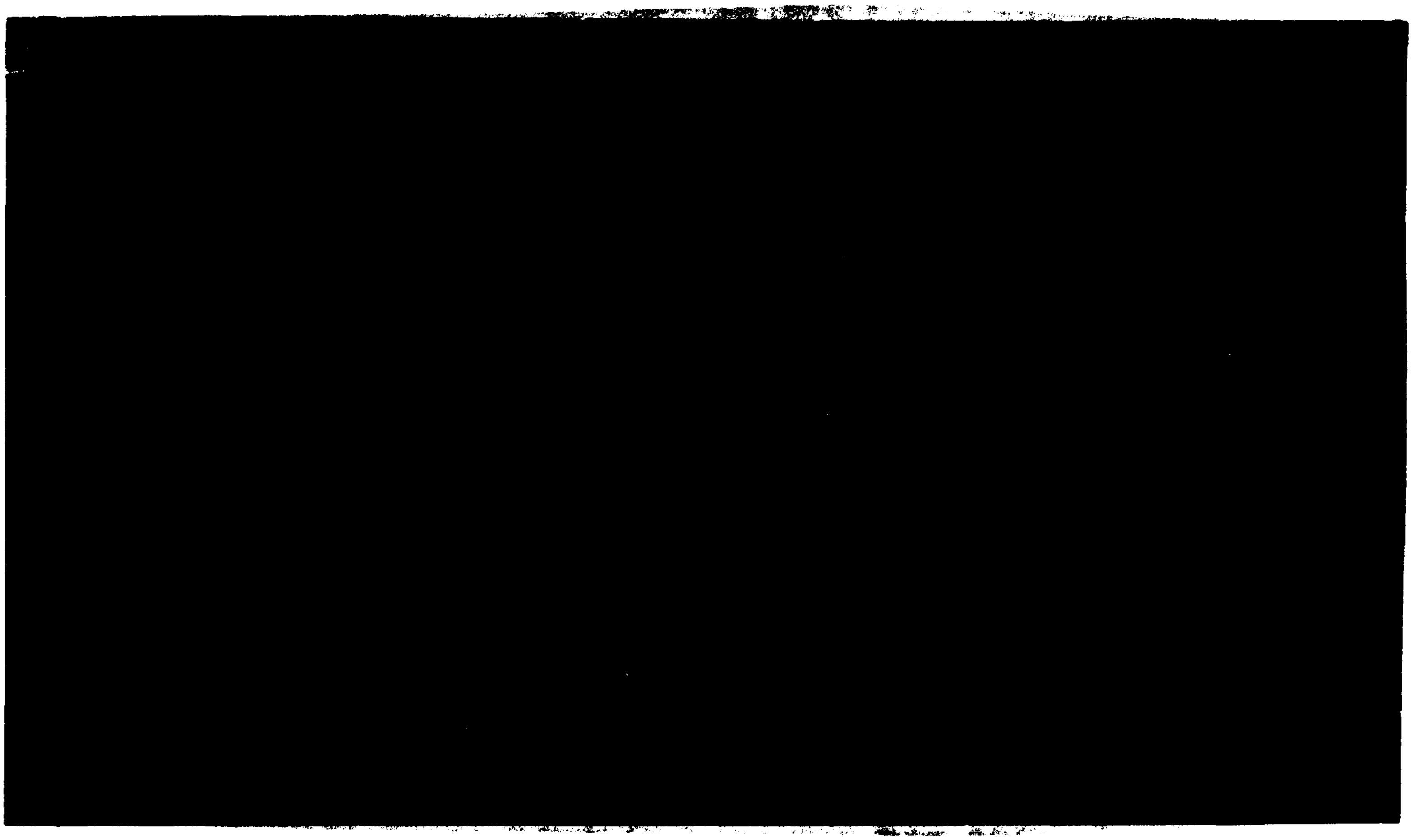


Figure 28.

Sediment carried into debris basin by storm of July 10, 1949.

<u>1950</u>. On April 8 of this year the debris basin was again cleaned showing soil losses from July 13, 1949 to April 10, 1950 as 42,330 pounds or 156 pounds per day.

The cultivation of corn in the field was discontinued. The original objective was to crop this steep land in accordance with prevailing mountain agricultural practices, continuing the cropping until yields were below those on other cropped fields in this section.

In lieu of cultivation and cropping, the area, along with the upper and lower pastures, was grazed under a rotatioonal grazing system. Before grazing started on the abandoned field a surface infiltration study (10 inch cylinder test) was initiated over the entire cultivated area and this was repeated after each period of rotational grazing. The total grazing use of the watershed for 1950 consisted of 881 animal days. The cattle were periodically rotated between the permanent pastures and the old cornfield.

Figure 29 pictures one of the gullies in the abandoned cornfield along with the volunteer vegetation in August, 1950.

<u>1951</u>. On April 11 the debris basin was cleaned and yielded 21,361 pounds of sediment. This is an accumulation of 85 pounds per day for the period beginning April 8, 1950.

Both pastures and the abandoned cornfield were grazed on a rotational grazing system.

A vegetation survey was made of the entire watershed on August 6. During August, the shrubs, weeds and tree sprouts

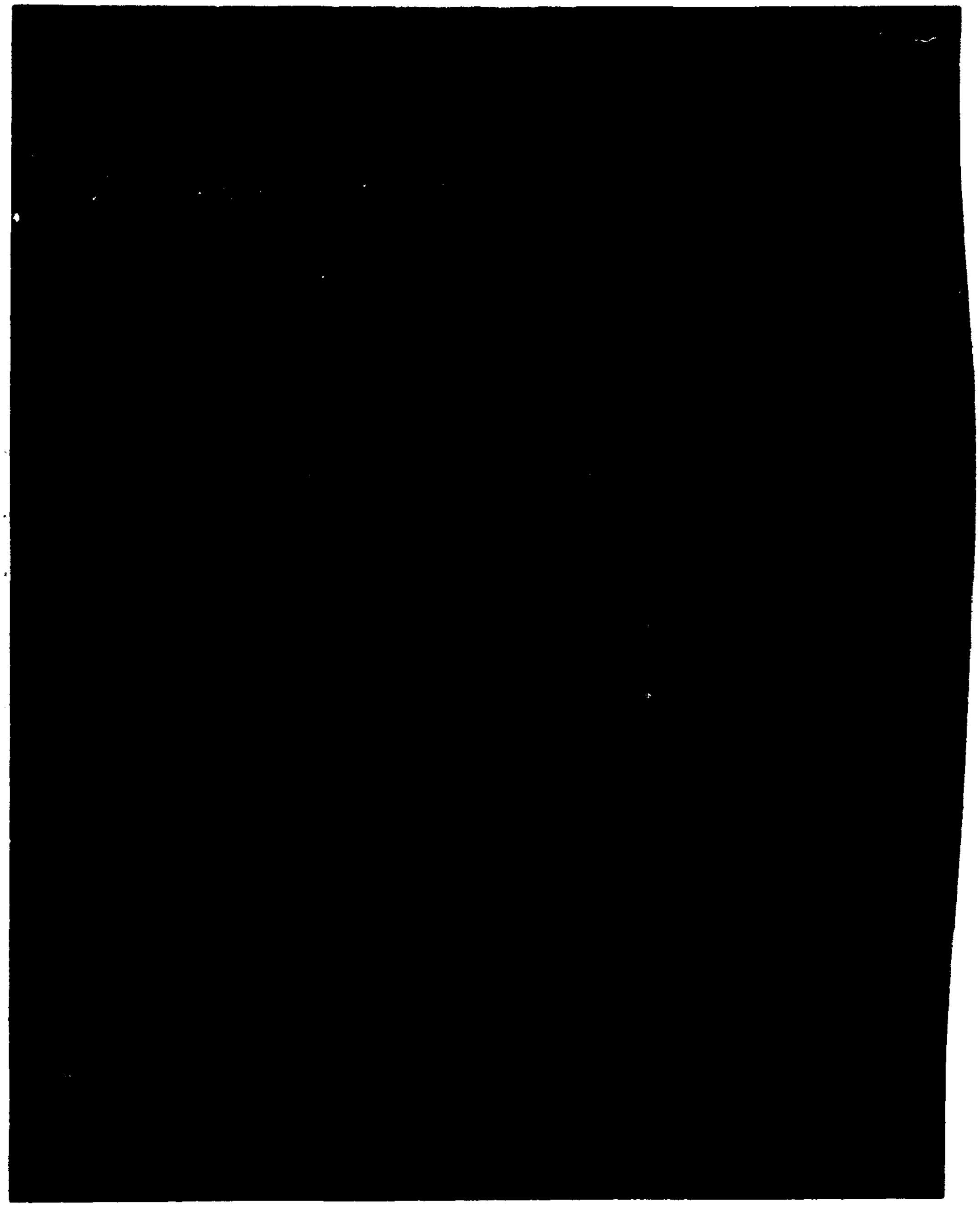


Figure 29.

Gully in abandoned cornfield, August 1950.

were cut back, stacked and burned in an effort to improve the pasture conditions.

The maximum flood peak for the season to September 1 occurred on July 15 when a peak of 126 c.s.m. was recorded following a brief, intense thunderstorm. Overland flow was observed in the abandoned cornfield and particularly in the lower portion of the lower pasture during several storms producing flows of less than 5 c.s.m.

Figure 30 shows the control plots established in the abandoned cornfield as well as stacks of brush cut off the old cornfield. Some of the trees in the right foreground had attained heights of seven feet since the field had been abandoned in 1949.

Infiltration ring studies were continued on the old cornfield as well as on the other segments of the watershed.

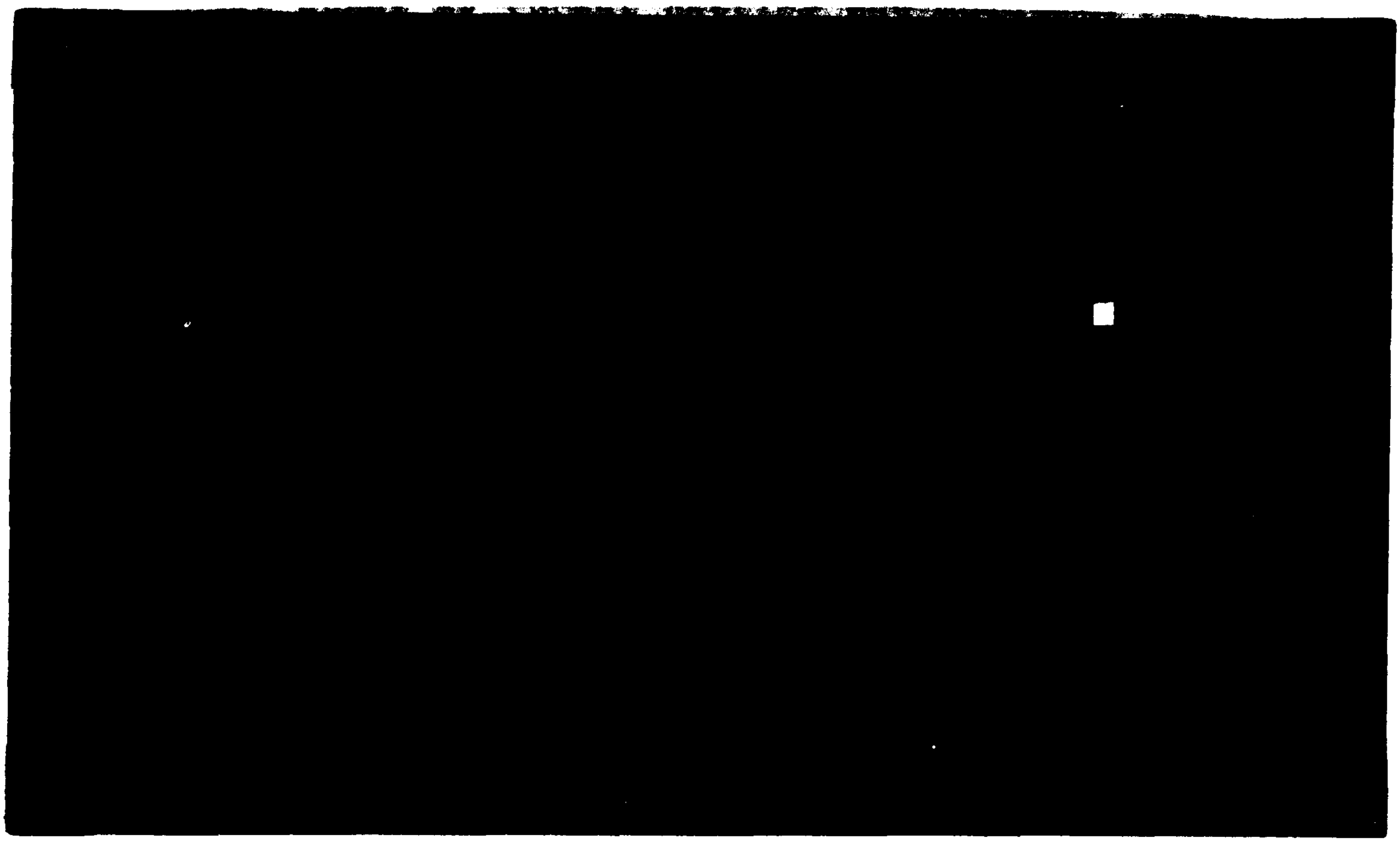


Figure 30.

Fenced control plots in abandoned cornfield, August 1951. Note stacks of brush cut in an attempt to improve the grass cover.

CHANGES IN SOME BIOLOGIC AND EDAPHIC CHARACTERISTICS OF THE WATERSHED AS A RESULT OF LAND USE

Vegetation Changes

To observe the changes in the vegetal cover on the watershed brought about by forest cutting and mountain farming treatment, a vegetative survey was made on August 6, 1951. Due to the heterogeneous mixing of the species through the area, no attempt was made to construct a type map. In lieu of a type map, the vegetation was observed and identified and its relative abundance was noted according to the different land use elements. Figure 31 indicates the different land uses in 1951.

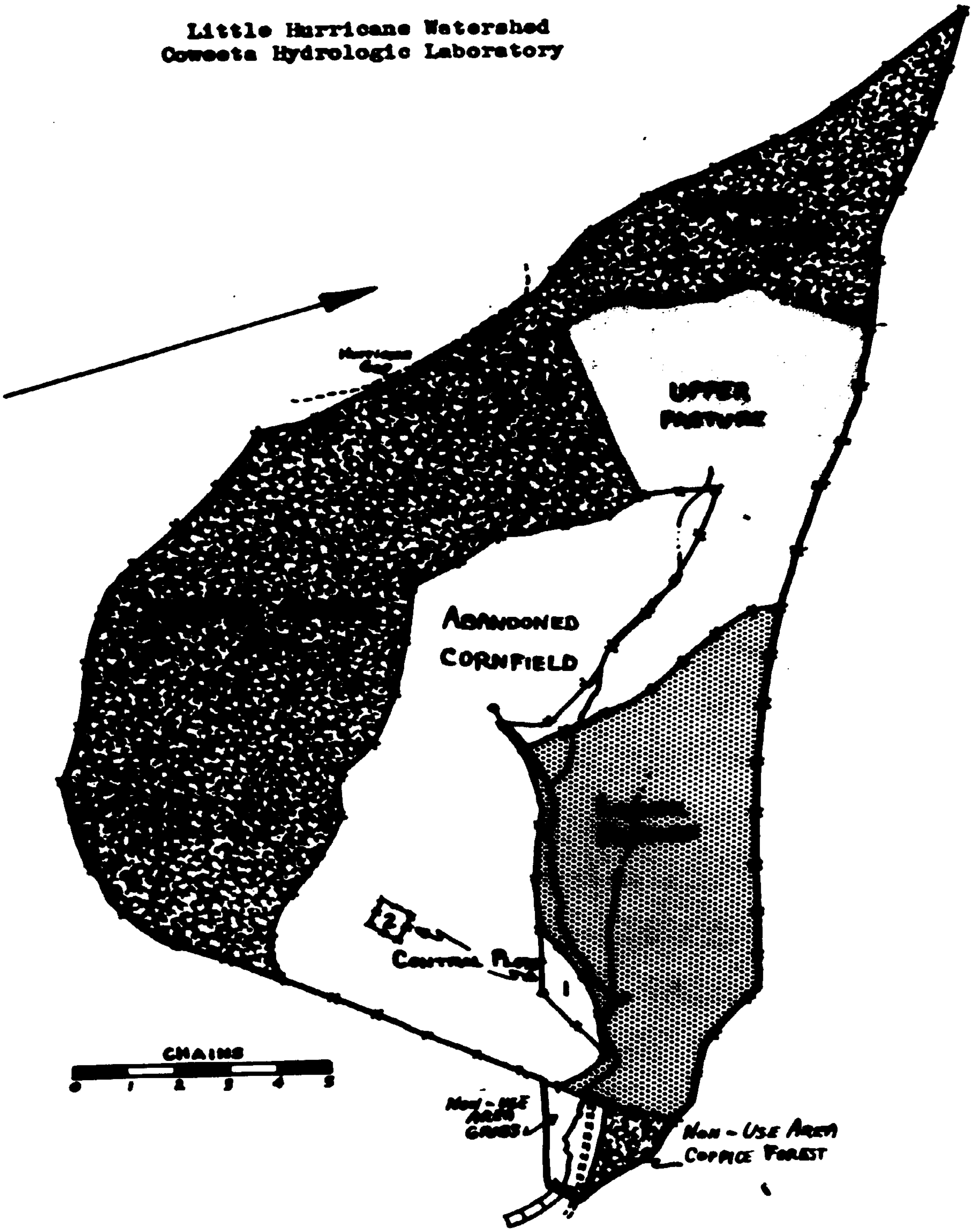
Coppice Forest. In Figure 31 two areas of coppice forest are noted. Coppice forest "A" was cut in 1939-1940 and has not been cut back or sprouted. Coppice forest "B" was cut at the same time but was sprouted back in 1941. The forest and herbaceous cover of the two coppice areas was so similar in size, density and species composition that they were treated as one. Since a large portion of the tree stems were of sprout origin the area was classified as coppice forest.

Except along the ridges, the forest cover was so dense that a ground cover of shrubby and herbaceous vegetation was almost excluded. Along the ridges and in a few openings, greenbrier and wild grape

Figure 31.

Land Use Complexes, 1951

Little Hurricane Watershed
Coweeta Hydrologic Laboratory



were still abundant. On the slopes, however, these species were much less common although plant remains indicated that they had been quite abundant there until a few years before.

As indicated above, species were so mixed that no attempt was made to make a type map. All species listed below with the exception of blackjack oak and eastern hemlock occurred throughout the two coppice areas. Blackjack oak was found only on the ridges and one hemlock was found just above the contour trail in coppice area "B". Along the ridges, pitch pine, white oak and chinquapin were more common and tulip poplar less abundant than on the lower slopes.

Rhododendron and mountain laurel occurred rather commonly near the ridges and to a lesser degree on the slopes. In the adjacent undisturbed forest areas a moderate understory of these species occurs. Rhododendron and laurel appear to be slow in re-establishing themselves.

The dominant trees were approximately 3 to 3.5 inches in d.b.h. and 12-15 feet in height. The forest tree species as well as the shrubby and herbaceous vegetation observed along with their relative abundance are listed below:

<u>Forest Tree Species</u>[5]

Tulip poplar	Liriodendron tulipifera <u>L</u>.	Abundant
Dogwood	Cornus florida <u>L</u>.	

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[5]All scientific names from <u>Gray's Manual of Botany</u>, Eighth Edition, edited by M. L. Fernald, American Book Company, N. Y. 1632 pp. 1950.

Sweet hickory	Carya glabra Mill.	
Chestnut	Castanea dentata (Marsh.) Borkh.	
Red Maple	Acer rubrum tridens Wood.	
Northern red oak	Quercus rubra var. borealis (Michx.f) Farw.	
Black locust	Robinia pseudoacacia L.	
Pitch pine	Pinus rigida Mill.	
Persimmon	Diospyros virginiana L.	Common
Sassafras	Sassafras albidum (Nutt.) Nees.	
Sourwood	Oxydendrum arboreum (L.) DC.	
Chestnut oak	Quercus prinus L.	
Blackjack oak	Quercus marylandica Muench.	
Scarlet oak	Quercus coccinea Muench.	
Black oak	Quercus velutina Lam.	
Chinquapin	Castanea pumila (L.) Mill.	
Yellow birch	Betula lutea Michx.f.	Moderately Common
Bitternut hickory	Carya cordiformis (Wang.) K. Koch	
Wild plum	Prunus americana Marsh.	
Hawthorn or thornapple	Crataegus sp. L.	
White oak	Quercus alba L.	
Staghorn sumac	Rhus typhina L.	
Spicebush	Benzoin aestivale (L.) Nees.	
Eastern hemlock	Tsuga canadensis (L.) Carr.	Rare

Shrubby and Herbaceous Vegetation

Blackberry	Rubus sp. L.	Common
Highbush blueberry	Vaccinium atrococcum (Gray) Heller	
Mountain laurel	Kalmia latifolia L.	
Rhododendron	Rhododendron maximum L.	
Wild grape	Vitis bicolor Le Conte.	
Greenbrier	Smilax glauca Walt.	
Rattlesnake weed	Hieracium venosum L.	Moderately Common
Wood Sorrel	Oxalis stricta L.q	
Maidenhair fern	Adiantum pedatum L.	
Bracken fern	Pteris aquilina L.	
Trillium	Trillium erectum L.	
Star flower	Trientalis borealis L.	
Ox-eye daisy	Chrysanthemum leucanthemum var. pinnatifidum Lecoq and Lamotte	
Daisy fleabane	Erigeron sp. L.	
Yellowfringed orchis	Habenaria ciliaris (L.) R. Br.	Rare
Lopseed	Phryma leptostacha L.	
Wood violet	Viola papilionaceas Pursh.	

Pastures. The vegetation of the upper and lower pastures and of the old cornfield is quite similar. The vegetal cover observed, along with its relative abundance in both the abandoned cornfield and the two pastures is listed below. There is no apparent relationship to the vegetative types mapped in 1940. Nearly all species listed occur throughout the three areas.

Tree seedlings and sprouts observed in 1951 which were not indicated in the 1940 survey include hawthorn, swamp willow, yellow oak, blackjack oak, green ash, spicebush, yellow birch, black walnut and butternut. The black walnut and butternut were probably carried into the area by squirrels or groundhogs. All species observed in 1940, however, were present on the area in 1951.

A much more marked change took place in the shrubby and herbaceous vegetation. Of those species observed in 1940 only nine were found in 1951: switch grass, broad-leaved plantain, Joe-pye weed, ragweed, wood sorrel, spike rush, green bulrush, wool grass and yellow foxtail. On the other hand, a total of thirty-three species were identified which were not listed as present in 1940. It is significant, too, that many of these invading species, such as yarrow, smartweed, mullein, Canada thistle, nettle and purslane are usually associated with land abuse.

Abandoned Cornfield. As indicated previously, the species composition of the abandoned cornfield is virtually the same as that of the two pastures even though it had been only two years since the area was cultivated. The vegetation density of the abandoned cornfield as well as of the two pasture areas varies from practically zero on several of the "scald" areas to about thirty to forty percent ground cover on the best areas.

The two control plots indicated in Figure 31 were fenced off in 1949 following the harvest of the last corn crop. Cattle have been excluded from these two plots and they have not been sprouted back. The vegetation here is nearly the same as that of the cornfield in species composition. In the lower plot (No. 1) blackberry and wild strawberry are the two most abundant species. The ground cover in this plot is nearly complete but in spots consists solely of wild strawberry. In the upper plot (No. 2) the same species are represented but the ground cover varies from 65 to 80 percent. It is apparent that in both plots tree species will soon take over. Numerous stems, particularly in the lower plot, are over 6 feet in height.

__Shrubby and Herbaceous Vegetation__

Species		Abundance*	
Common Name	Scientific Name	Cornfield	Pastures
Blackberry	Rubus sp. L.	VA	VA
Mullein	Verbascum thapsus L.	A	C

*Legend for species abundance:
VA - Very abundant
A - Abundant
MC - Moderately common
C - Common
R - Rare
Abs - Absent

Yarrow	Achilles milliforium L.	C	C
Strawberry	Fragaria virginiana Duchesne.	VA	A
Wild grape	Vitis bicolor Le Conte.	C	C
Horsemint	Monarda punctata L.	C	C
Crab grass	Digitaria sp. Heist.	A	C
Switch grass	Panicum sp. L.	MC	C
Red baneberry	Actaea rubra (Ait.) Willd.	Abs	R
Canada thistle	Circium arvense (L.) Scop.	Abs	R
Greenbrier	Smilax glauca Walt.	A	A
Broad-leaved plantain	Plantago major L.	C	C
Ox-eye daisy	Chrysanthemum leucanthumum var. pinnatifidum Lecoq & Lamotte.	MC	C
Pokeberry	Phytolacca decandra L.	A	C
Boneset	Eupatorium perfoliatum L.	C	C
Leafcup	Polymnia uvedalia L.	C	C
Gentian	Sabatia angularis (L.) Pursh.	C	MC
Star grass	Hypoxis hirsuta (L.) Coville.	Common along stream	
Selfheal	Prunella vulgaris L.2	C	MC
Tick trefoil	Desmodium paniculatum (L.)DC.	C	C
Joe-pye weed	Eupatorium purpureum L.	MC	MC
Smartweed	Persicaria hydropoper L.	C	MC
Ragweed	Ambrosia artemisiifolia L.	A	C
Horse nettle	Solanum carolinense L.	C	C
White clover	Trifolium repend L.	MC	Abs
St. Johns wart	Pypericum perforatum L.	C	MC
Beggars lice	Lappula virginiana (L.)Greene	C	MC
False pennyroyal	Isanthus brachiatus (L.)BSP.	C	MC
Evening primrose	Oenothera biennis L.	A	MC
Wood sorrel	Oxalis stricta L.	MC	R
Lopseed	Phryma leptostachya L.	MC	R
Spike rush	Eleocharis obtusa (Willd.) Schultes	Abundant along stream	
Green bulrush	Scirpus sp. L.	Common along stream	
Wool grass	Scirpus cyperinus (L.)Kunth.	Common along stream	
Yellow foxtail	Setaria lutescens Weigel	MC	MC
Mountain laurel	Kalmia latifolia L.	Abs	MC
Agrimony	Agrimonia sp. L.	MC	R
Purslane	Portulaca oleracea L.	MC	MC
Yellow-fringed orchis	Habenaria ciliaris (L.)R.Br.	Abs	MC
Partridge pea	Cassia fasciculata Michx.	VA	VA

Forest Tree Seedlings and Sprouts

Species		Abundance	
Common Name	Scientific Name	Cornfield	Pastures
Black locust	Robinia pseudoacacia L.	VA	A
Staghorn sumac	Rhus typhina L.	VA	VA
Tulip poplar	Liriodendron tulipifera L.	VA	VA
Persimmon	Diospyros virginiana L.	A	C
Sassafras	Sassafras albidum (Nutt.) Nees.	A	A
Dwarf sumac	Rhus coppalina L.	C	C
Northern red oak	Quercus rubra var. borealis (Mich. f.) Nees.	A	C
Hawthorn	Crataegus sp. L.	MC	MC
Dogwood	Cornus florida L.	A	A
Sweet Hickory	Carya glabra Mill.	C	MC
Green ash	Fraxinus pennsylvanica var. subintegerrima (Vahl.) Fern.	MC	R
Swamp willow	Salix sp. L.	Along stream channels	
Pitch pine	Pinus rigida Mill.	MC	C
Chestnut or yellow oak	Quercus prinus L.	MC	R
Spicebush	Benzoin aestivale (L.) Nees.	MC	MC
Chestnut	Castanea dentata (Marsh.)Borkh.	C	MC
Yellow birch	Betula lutea Michx.F.	MC	Abs
Red maple	Acer rubra tridens Wood.	MC	MC
Black walnut	Juglans nigra L.	R	R
Butternut	Juglans cinera L.	R	R
Scarlet oak	Quercus coccinea Muench.	MC	MC
White oak	Quercus alba L.	R	R
Blackjack oak	Quercus marylandica Muench.	MC	MC
Black oak	Quercus velutina Lam.	R	R

Trout Habitat

As a result of the mountain farming treatment, the Little Hurricane Branch was changed considerably as a trout stream. Trout are known to be able to withstand a wide range of acidity, alkalinity and carbon dioxide tension.

They are, however, quite sensitive to changes in turbidity, sedimentation and stream temperatures.

Turbidity tests comparing the water of the Little Hurricane Branch with that of Bee Branch, from a forested watershed, were made from 1946 to 1950. The results of these tests are shown in Table I on the following page which shows the average monthly turbidity values in parts per million for the two streams. The U. S. Public Health Service Standard for turbidity for potable water is ten parts per million. From the results of this study it is apparent that the waters of the Little Hurricane Branch fall below this standard from April to October inclusive.

The increased sediment load carried by the Little Hurricane Branch following forest cutting and treatment is shown in Table III.

Trout are especially sensitive to thermal fluctuations in their environment, particularly when these changes occur near their upper limit of tolerance. Needham's (23) "Ideal and Maximum Temperature Limits for Trout" are given below.

TABLE II

IDEAL AND MAXIMUM TEMPERATURES FOR TROUT (AFTER NEEDHAM)

Species	Ideal Temperature in degrees F.	Maximum Temperature in degrees F.
Rainbow (Salmo gairdnerii)	70-80	83
Eastern Brook (Salvelinus fontinalis)	66	75
Brown or Loch Leven (Salmo trutta)	70-80	81

TABLE I

COMPARISON OF TURBIDITY VALUES IN PARTS PER MILLION FROM A FOREST AND A MOUNTAIN FARM STREAM

Year	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Coweeta No. 3 - Little Hurricane Branch, Mountain Farm Stream												
1947			8	9	17	16	20	13	12	10	12	6
1948	5	5	8	18	28	26	23	13	20	14	10	6
1949	14	6	5	11	10	16	22	11	17	11	6	6
1950	6	4	4	11	23							
Average	8	5	6	12	19	19	22	12	16	12	9	6
Coweeta No. 34 - Bee Branch, Forest Stream												
1946						6	6	2	3			
1947			3	5	7	5	8	5	16	2	3	2
1948	2	1	2	1	3	5	8	5	6		4	
1949	3	3	3	3	5	5	7	4	3	4	5	3
1950	4	4	3	5	10							
Average	3	3	3	4	6	5	7	4	7	3	4	2

During 1948-1949, a stream temperature study was conducted by Greene (16) at the Coweeta Hydrologic Laboratory in which the Little Hurricane Branch was compared with a stream from a forested watershed. The results of this study are summarized in Figure 32.

Prior to the treatment of the watershed, local inhabitants had observed the presence of trout in the stream. In 1951, however, no trout were seen by the writer, nor were there any reports of trout having been observed by personnel of the laboratory within the past few years.

It appears evident then that the changes in sedimentation, stream turbidity and stream temperature brought about by the cutting of the forest and the subsequent mountain farming treatment, have virtually rendered the Little Hurricane Branch barren as a habitat for trout.

Edaphic Changes

Many factors, such as climate, vegetation density, type of vegetation, slope, geologic substrata, land use practices and the physical characteristics of the soil combine to determine the stream flow characteristics for a given watershed. The amount of precipitation that goes into streamflow is to a large degree determined by the physical properties of the soil. The characteristics of the plow layer of the soil is strongly influenced by the vegetation it supports. For this reason, any practices which change the nature of

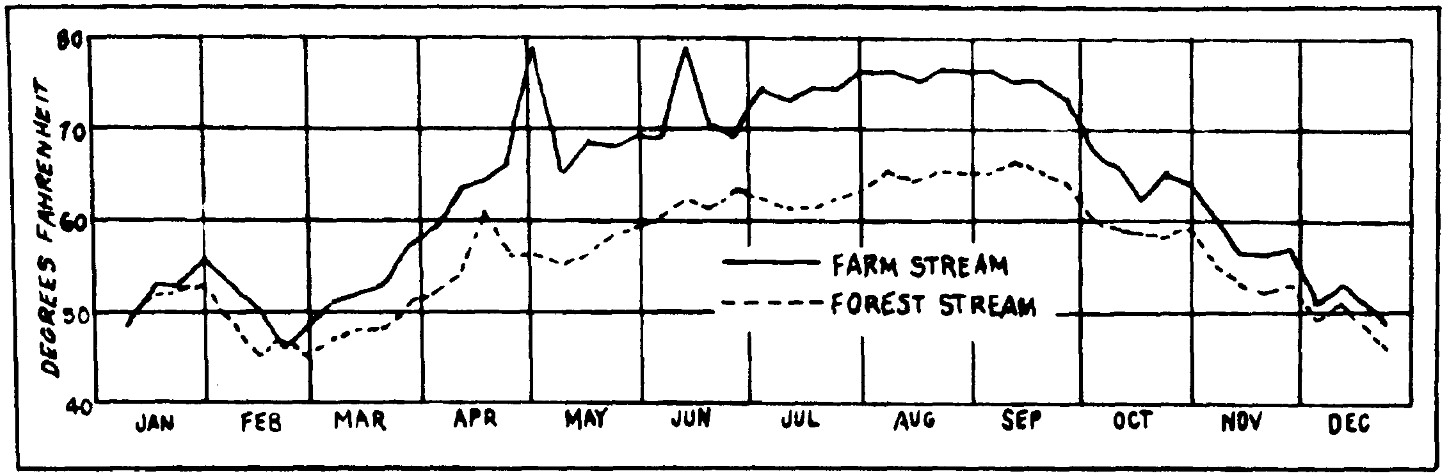


Figure 32.

Weekly maximum temperatures for the farm and forest stream. (after Greene) the vegetation may in turn bring about changes in the physical characteristics of the surface soil and consequently in streamflow.

As a result of the treatment applied to the watershed, the natural equilibrium among the vegetation, the soil and surface runoff would necessarily have suffered dynamic changes. Consequently, a study of the changes in surface runoff characteristics would be incomplete without an investigation of the changes in the physical characteristics of the surface soil.

One of the most obvious expressions of soil changes is in the degree of soil erosion or in the determination of soil losses following the treatment of the watershed. Measurements of the soil losses from the watershed have been made since the initiation of the project and are summarized in this section.

Another measure used to determine gross changes in soil characteristics, particularly as they affect water relations, is that of changes in their infiltration rates. Exploratory tests on infiltration were made using the cylinder ring test method in 1949 and 1950 and are summarized in the following pages. During the summer of 1951 a large scale infiltration study of the entire watershed was initiated. The results of this investigation, however, will not be available for several seasons.

In order to determine more detailed changes in the physical characteristics of the surface soil, soil core and sack samples were collected for analysis. Cylindrical cores three inches in diameter by three inches long and approximately one-pint sack samples were collected from the 0-3 and 3-6 inch layers from six sites. Five samples were collected from each of the following sites from both layers; undisturbed forest (from control plots in adjacent watershed, same soil type), coppice forest, upper pasture, lower pasture, abandoned cornfield and control plots within the old cornfield. The sampling plots were randomly selected from numbered grid cross-sections except from the control plots in both the undisturbed forest and the abandoned cornfield. The latter were stratified at right angles to the contour.

From the sack samples mechanical analyses and organic matter determinations were made. The core samples were used to measure permeability, capillary, non-capillary, total porosity, volume weight and aggregate analyses. The results of these various determinations are presented in the following pages.

Soil Losses. As indicated previously, soil losses since 1941 have been measured using the specially designed debris basin. Prior to the installation of the debris basin, soil losses were measured from deposits in the silting basin.

In making these measurements, the water is allowed to pass over the weir blade before it is diverted into a trough which by-passes the debris basins, thus providing a continuous record of stream discharge. Samples of two hundred cubic centimeters of sediment are taken from each baffle within each of the three debris basins after the sediments have dried. Following volume measurements in each baffle, the debris is removed. The total soil losses are then computed from the dry weight of the samples and from the volume measurements applying to each division of the basin.

The total soil losses measured from the inception of the experiment on July 3, 1934 to the measurement made on April 11, 1951 are summarized in Table III. It is apparent that soil losses have increased tremendously following the treatment of the watershed. The actual increase amounts to over 12 times as much soil loss per acre per year. Before the installation of the debris basin (watershed in forest cover until the winter of 1939-1940) the total soil loss amounted to 1,081 pounds per acre or 154 pounds per acre per year. A portion of this amount can be attributed to the treatment since the debris basin was not installed until nearly two years after the clearcutting of the watershed was started. Since the installation of the debris basin, an average loss of over 1,900 pounds or nearly 1 ton per acre per year has been measured. The maximum soil

Table 3. III

Summary of Soil Losses.

Period	No. days	Treatment	Total loss dry weight in pounds	Average loss pounds per day	Average loss pounds per acre per year
7-3-34/8-27-41	2557	Forest cover and initial treatment	24,637	9.6	153.7
8-28-41/5-4-43	644	Corn, pasture	13,928	21.6	345.7
5-5-43/9-8-43	126	Corn, pasture	79,058	627.4	10,043.9
			Average	118.1	1,890.6
9-9-43/4-16-46	1185	Fallow, pasture	44,085	37.2	595.5
4-17-46/3-28-47	345	Corn, pasture	13,507	39.2	627.5
3-29-47/4-13-48	381	Corn, pasture	16.186	42.5	680.0
4-14-48/4-8-49	359	Corn, pasture	32,879	91.6	1,466.4
4-9-49/7-11-49	93	Corn, pasture	185,875	1,998.6	31,995.1
			Average	210.9	3,377.7
7-12-49/4-10-50	272	Pasture	42,330	155.6	2,491.8
4-11-50/4-11-51	365	Pasture	21,361	85.5	936.5
			Average	100.0	1,600.8

Total soil loss 8-28-41 to 4-11-51 449,209 pounds

Average loss 8-28-41 to 4-11-51 1,933 pounds per acre per year loss was measured in 1949 when precipitation ranged well above average. For the 93 day period from April 9 to July 11, a total loss of 185,875 pounds or an average of 1,998.6 pounds, one ton, per day was measured for the entire area.

As indicated previously, an estimated 76 tons of soil and debris came off the watershed in a period of 30 to 40 minutes during the storm of July 10, 1949 when a record peak of 1,850 c.s.m. was recorded. Figures 24, 25 and 26 indicate the magnitude of soil losses resulting from this storm.

These data indicate that the greatest soil losses were sustained while the cornfield was under cultivation. From September, 1941 to September, 1943 the average soil loss amounted to nearly 1 ton per acre per year. Following this period, the cornfield was permitted to lie idle until the 1946 season. The pastures, however, were grazed. A decrease to approximately 600 pounds per acre was noted for this period. From 1946 to 1949 the cornfield was again cultivated. Soil losses mounted to over 2½ tons per acre per year. After the 1949 season the cornfield was converted to pasture. A decrease in soil losses was noted from August, 1949 to April, 1951 to 1,600 pounds per acre per year.

If the losses from the cornfield and the lower pasture could be analyzed separately it undoubtedly would be found that by far the greatest percentage of the total loss was contributed by these two areas. Evidence indicating this is found in the numerous scalds in the cornfield and the lower pasture in which the topsoil has been completely removed exposing the red subsoil. The analysis above also offers further proof.

On several occasions during the 1951 season, storms which produced peak discharges of less than 5 c.s.m. were observed to produce turbid overland flow in the abandoned cornfield and in the lower pasture. In ten years of field observations during and following storms, overland flow or evidence of overland flow has never been observed in the coppice forest area.

Infiltration. A surface infiltration study made on the watershed in July, 1949 demonstrated how the small, heavily trampled area of the lower pasture might be the source of more than half of the total storm runoff.

To measure the infiltration rate a steel cylinder ten inches in diameter and approximately six inches in height was driven into the ground for a depth of several inches. Two area inches of water were poured into the cylinder and the time required for the water to disappear from the soil surface was noted. The values thus derived were converted to inches per hour infiltration. Figure 33 shows the equipment used to determine the infiltration rate in this manner.

The results of this study are indicated as follows:

Infiltration Rates*

Land use	Average rate of infiltration in inches per hour
Channel area	.0
Lower pasture	0.56
Upper pasture	3.00
Cornfield	4.00
Coppice forest	6.00

Before grazing started on the abandoned cornfield in 1950 a similar infiltration study was made over the entire area and was repeated after each period of rotational grazing. Data in the following table show that it does not require many animal use days to decrease the ability of the soil to take in water.

Changes in Infiltration Rates Following Grazing*

Rate in Inches per hour	Period of Use
3.02	Before grazing
1.55	After 15 animal use days per acre
0.62	After 30 animal use days per acre

A similar surface infiltration study was initiated in 1951. The entire watershed was gridded and monthly infiltration tests were made during the summer months on more than one hundred plots. These observations are to be continued for several seasons and the data are to be used as the basis for a special investigation on infiltration.

*From unpublished data from the files of the Coweeta Hydrologic Laboratory

Figure 33.

Equipment used in making infiltration measurements.

Mechanical Analysis. The objective of a mechanical analysis is to determine the size distribution of the individual particles within the soil. These results may be expressed by soil texture. Soil texture, other things being equal, influences the amount of surface area of the soil particles, which in turn affects the water holding capacity of a soil. Retention storage, or water held in the capillary pores of mineral soils against the pull of gravity, is greater in silts and clays since the surface area exposed to water is many times greater than in sands. On the other hand, a high content of sand frequently provides greater opportunity for the development of large non-capillary pores and thus increases detention storage. The American Society of Civil Engineers (1) indicates that clay can hold 9 times as much water as fine sand against the force of gravity, but this varies greatly with the kind of clay. The retention storage capacity in inches depth of water per foot depth of soil for fine sand is given as 0.5 as compared with 2.5 for silt loam and 4.5 for clay. It is apparent that the mechanical composition of soils and consequently soil texture is of hydrologic significance.

In preparing the samples for the mechanical analysis, the larger clods and aggregates were broken down and the entire sample placed on a 2 mm. sieve. The weights of the material which remained on the sieve after shaking, largely pebbles, rock fragments and concretions were noted. From these weights and from the total weight of the sample, percentages were calculated and are shown in column 2 of Table IV.

To determine the mechanical composition of the portion of the samples passing through the 2 mm. sieve, the Bouyoucos (9) hydrometer method of mechanical analysis was employed. Table IV summarizes the results of these analyses.

From these data it appears that the treatment applied to the watershed has not effected any large scale changes in the mechanical composition of the less than 2 mm. fraction of the soil. There is little variation indicated in either soil layer among the average values for each site. The undisturbed forest and the coppice forest show the highest content of sand and the coppice forest has the lowest values for fine clay. The pastured areas are lowest in sand content and highest in fine clay. The greatest variation is found in the fine clay content in the 3-6 inch layer. The highest value of 24.5 percent was found in the lower pasture samples and the lowest of 10.7 percent in the coppice forest, a difference of 13.8 percent. In view of the discussion above the two forested areas should show higher detention storage and lower retention storage than the pastured areas and the cornfield should be intermediate between these extremes.

However, if the materials greater than two millimeters have an influence similar to sand then the undisturbed forest might be in a less favorable situation since it

TABLE IV

SUMMARY OF RESULTS OF MECHANICAL ANALYSES

Soil layer and land use	Percent of sample greater than 2 mm.	Sum of sand and coarser fractions in percent	Mechanical composition of less than 2 mm. fraction			
			Percent sand	Percent silt	Percent clay	Percent fine clay
<u>0-3 inch layer</u>						
Undisturbed forest	15.5 ± 3.6	81.7	66.2 ± 7.3	18.0 ± 2.9	3.7 ± 1.3	12.1 ± 4.3
Coppice forest	27.2 ± 9.3	91.4	64.2 ± 5.5	23.0 ± 2.4	3.0 ± 1.9	9.8 ± 3.6
Upper pasture	36.1 ± 7.7	99.6	63.5 ± 4.8	15.3 ± 6.0	3.7 ± 3.8	17.5 ± 7.9
Lower pasture	35.9 ± 7.3	97.7	61.8 ± 10.8	16.9 ± 4.7	4.7 ± 5.2	16.6 ± 7.7
Cornfield	35.1 ± 8.6	99.1	64.0 ± 5.9	21.4 ± 2.5	1.7 ± 1.7	12.9 ± 5.2
Control plots	28.6 ± 7.3	91.0	62.4 ± 5.2	20.4 ± 2.3	2.8 ± 1.9	14.4 ± 3.7
<u>3-6 inch layer</u>						
Undisturbed forest	20.3 ± 4.5	82.8	62.5 ± 9.3	17.5 ± 2.9	3.0 ± 2.3	17.0 ± 7.9
Coppice forest	33.2 ± 9.1	97.4	64.2 ± 3.1	19.0 ± 5.2	6.1 ± 4.3	10.7 ± 1.6
Upper pasture	39.8 ± 5.7	95.8	56.0 ± 1.9	17.0 ± 3.8	3.6 ± 1.2	23.4 ± 5.1
Lower pasture	34.8 ± 8.6	90.4	55.6 ± 6.4	17.6 ± 3.1	2.3 ± 1.1	24.5 ± 6.4
Cornfield	33.7 ± 3.1	95.6	61.9 ± 3.9	22.0 ± 4.2	2.2 ± 1.5	13.9 ± 4.5
Control plots	30.8 ± 12.8	89.9	59.1 ± 10.5	18.8 ± 3.7	4.1 ± 4.7	18.0 ± 6.9

contains much less of this coarser fraction than any of the other plots as shown in column 3 of Table IV. The undisturbed forest samples show the lowest values for the sum of the sand and material larger than 2 mm. for both soil layers. In the surface layer the highest values are indicated for the upper pasture and the cornfield, 99.6 and 99.1 respectively, as compared with 81.7 percent for the undisturbed forest. In the 3-6 inch layer the highest values were found for the coppice forest, upper pasture and the abandoned cornfield.

According to the United States Department of Agriculture, textural classification, the samples from the undisturbed forest, coppice forest and the cornfield fall into the sandy loam class. The upper and lower pasture samples are sandy clay loams while the control plots show sandy loam in the surface samples and sandy clay loam in the subsurface layer.

The small degree of variation noted in the mechanical analyses would appear to substantiate the classification of the fine portion of the surface soils of the watershed into one textural class, loam (according to more recent standards, this would be classified as sandy loam).

<u>Aggregate Analyses</u>. One of the primary objectives of an aggregate analysis is the determination of the extent to which the finer mechanical separates are aggregated into coarser fractions. An aggregate analysis thus provides a

measure of soil structure. Soil-water relations and aeration conditions are both strongly influenced by soil structure. For example, porosity, air capacity, water holding capacity, volume weight and permeability to water and air are influenced by soil structure. The total percentage of aggregates or "state of aggregation" as suggested by Baver (7), gives a good indication of the erodibility of soils. If, for example, the state of aggregation is high, i. e., the soil contains a high content of water-stable aggregates, susceptibility to erosion is considerably lower than in the case of low aggregate stability. In the latter case there is little binding together of the particles into granules, consequently falling raindrops and surface flow tend to disperse the soil. Under such conditions the soil takes up water more slowly and is obviously highly erosive. These two conditions are highly unfavorable from a hydrologic viewpoint, both from the standpoint of flood control and watershed management for increased water yields.

In making aggregate analyses of the samples used in this study Yoder's (37) dunker or wet-sieving method was employed. The five oven-dry core samples from each site and each layer were mixed and two composite samples extracted. Aggregate analyses were then made on the composite samples. A summary of the results is presented in Table V. Variations within the samples were very small except for the surface soil samples representing the coppice forest and the cornfield.

The results given in Table V indicate that the treatment of the watershed has effected a marked change in the stability of soil aggregates and consequently, soil structure. In both the surface and sub-surface layers, but particularly in the surface, the undisturbed forest shows a considerably higher content of water stable aggregates greater than 2 mm. in diameter than all other sites except the coppice forest. Even here in the surface layer a difference of over 10 percent exists. These differences are particularly significant when one considers that the undisturbed forest contained much smaller quantities of particles greater than 2 mm. in diameter than the other sites studied. These values are somewhat lower in the 3-6 inch layer than in the 0-3 inch layers of the forested areas and the upper pasture, however, they do not show so much variation in the case of the upper pasture as in the forested areas. The differences between the two layers in the control plots, the cornfield and the lower pasture are not marked, probably due to the fact that these areas have been cultivated.

An analysis of the degree of aggregation in the fine earth material is presented in column 5 of Table VI. The undisturbed forest shows an even higher aggregation here than in the case of total water stable aggregates. In the

TABLE V

SUMMARY OF THE RESULTS OF AGGREGATE ANALYSES

Site	Average Percent of Aggregates and Particles by Size Classes (in millimeters)						
	Over 4.	2.-4.	1.-2.	.5-1.	.25-.5	.105 -.25	Under .105
Surface layer, 0-3 inches							
Undisturbed forest	85.52	7.76	3.28	1.40	1.36	1.12	2.56
Coppice forest	73.20	8.30	4.96	3.84	2.48	2.54	4.68
Upper pasture	64.10	10.50	7.00	5.66	4.40	2.36	5.98
Lower pasture	53.92	12.72	9.92	8.16	7.18	3.86	4.24
Cornfield	59.00	12.22	7.00	6.26	5.62	3.20	6.70
Control plots	46.24	13.76	9.36	8.96	8.80	5.64	7.24
Sub-surface layer, 3-6 inches							
Undisturbed forest	73.84	6.68	3.74	3.76	3.94	2.64	5.40
Coppice forest	63.54	11.50	6.76	5.68	4.72	2.80	5.00
Upper pasture	48.58	12.30	10.98	9.04	7.54	3.90	7.66
Lower pasture	56.72	11.68	7.90	7.76	7.92	4.26	3.76
Cornfield	62.16	12.48	8.26	6.48	4.56	2.62	3.44
Control plots	40.06	16.24	12.32	11.50	10.08	4.72	5.08

0-3 inch layer the undisturbed forest shows over 25 percent higher aggregation than all other sites except the coppice forest where the difference is approximately 16 percent. In the 3-6 inch layer only the undisturbed forest is markedly better aggregated than all the other areas. The relative trends for both layers are quite similar to the values for total water stable aggregates over 4 mm. in diameter.

From field observations the greatest part of the soil loss from the watershed is obviously from the cornfield and the lower pasture. The changes in aggregation or structure of the surface soil (0-3 inch layer) have no doubt contributed to these differences in soil losses. In the differences between the two pastures this is probably the major factor.

The marked changes in soil structure as indicated by aggregation contribute materially to the changes in permeability and consequently to runoff characteristics which are noted later in this section.

Soil Organic Matter. The presence of a high content of organic matter in a soil has considerable significance from a hydrologic view. A high content of organic matter has a marked influence on the storage capacity that a soil has for water.

Detention storage, i. e., water detained temporarily in the large non-capillary pores, is increased by the

TABLE VI

DEGREE OF AGGREGATION OF FINE EARTH MATERIAL

Soil layer and land use	Aggregates over 2 mm. in percent (whole soil basis)	Primary particles over 2 mm. (whole soil basis) percent	Aggregates of fine earth over 2 mm. (whole soil basis) percent	Aggregates of fine earth as percent of fine earth percent (fine earth basis)
<u>0-3 inch layer</u>				
Undisturbed forest	93.3	13.4	79.9	92.3
Coppice forest	81.5	21.4	60.1	76.5
Upper pasture	74.6	26.5	48.1	65.4
Lower pasture	66.6	26.4	40.2	54.6
Cornfield	71.2	26.0	45.2	61.1
Control plots	60.0	22.2	37.8	48.6
<u>3-6 inch layer</u>				
Undisturbed forest	80.5	16.9	63.6	76.5
Coppice forest	75.0	24.9	50.1	66.8
Upper pasture	60.9	28.4	32.5	45.4
Lower pasture	68.4	25.8	42.6	57.4
Cornfield	74.6	25.2	49.4	66.0
Control plots	56.3	23.5	32.8	42.9

inclusion of organic matter because of its influence on soil structure. Decaying roots and greater biological activity also result in the formation of the large hydraulic pathways which channel water through the soil profile and eventually to ground-water.

Similarly, retention storage, that water retained or held in the soil and made available for plant growth, is usually increased through the incorporation of additional organic matter. Organic matter has a high moisture-adsorptive capacity. In the colloidal state it takes up as much as 4.4 times its own weight of water. When decomposed and mixed with the soil, it coats the soil particles with a gel-like, porous and highly adsorptive substance. Clinging to the particles, this material, in effect, increases their surface areas and thus their storage capacity (22).

Organic matter, as mentioned above, affects the properties of the soil which in turn exert their influence on the storage and transmission of water. Organic matter aids also in the formation and maintenance of water-stable aggregates thus reducing soil dispersion and consequent erosion.

In this study, a determination was made of the organic matter contained in the samples collected from the watershed. In making these determinations, the dry combustion method patterned after the work of Schollenberger (26) was employed, i. e., measuring the amount of carbon dioxide evolved in the combustion of the soil and converting the carbon dioxide content into percent organic matter using a conversion factor of .471. A summary of the results obtained is given in Table VII below. The values for all individual samples are given in the Appendix.

TABLE VII

AVERAGE CONTENT OF ORGANIC MATTER FROM THE DIFFERENT LAND USE COMPONENTS OF THE WATERSHED

Site	Percent Organic Matter
Surface Layer, 0-3 inches	
Undisturbed forest	7.03
Coppice forest	8.97
Upper pasture	7.62
Lower pasture	4.00
Cornfield	4.40
Control plots in cornfield	7.28
Sub-surface Layer, 3-6 inches	
Undisturbed forest	4.87
Coppice forest	5.51
Upper pasture	4.41
Lower pasture	2.43
Cornfield	4.58
Control plots in cornfield	4.62

In the surface layers, all areas except the lower pasture and the cornfield show values greater than 7 percent organic matter. This is probably the result of contributions to the litter by the slash accumulation and the heavy herbaceous cover following clearcutting. Similarly, the upper pasture and the control plots in the abandoned cornfield show a higher content of organic matter than the undisturbed forest. In the case of the upper pasture, this is probably due to minimum usage by cattle, heavy herbaceous and shrubby ground cover and to the fact that the vegetation is cut back or sprouted periodically, thus increasing the amount of litter accumulated on the soil surface. The high average value for the control plots in the cornfield is apparently the result of two seasons abandonment permitting the development of a good ground cover and consequent litter accumulation. For the surface layer, this value is considerably higher in comparison with the cornfield which has been grazed since abandonment. In the sub-surface layer it is noted that the values for the two areas are approximately equal.

In comparison, the lower pasture and the cornfield show values considerably lower than the undisturbed forest and less than half the content of the coppice forest. The results of row cropping and over-grazing are thus apparent in the differences in soil organic matter.

In the sub-surface layer, 3-6 inches, all values are lower by one and a half to over three percent than in the surface layer, except in the cornfield where the similarity of organic content in the two layers is the result of their mixing by the recent plowing and cultivation. The sub-surface layer of all plots, except the lower pasture, have similar organic contents. The organic content of the sub-surface of the lower pasture is only about one-half as great as in the other plots. This difference together with the lower content of organic matter in the surface of this area as compared to the upper pasture indicates differences in the soils of these areas that are not due to current management differences.

Porosity. Soil porosity is undoubtedly one of the most significant of all physical soil properties in hydrologic studies. From a hydrologic standpoint, the primary function of a soil is that of a storage reservoir. This storage reservoir acts in the same fashion as a large dam project. In the case of floods on dam-protected streams, the flood waters accumulate first in the reservoir. After satisfying the initial storage in the reservoir, the water continues to accumulate in the overflow reservoir and is detained temporarily until it can be safely released to the stream below. Following the storm period the temporary storage is released as rapidly as possible until normal storage capacity is reached. The water left in the reservoir is retained and released slowly for use as irrigation water, for power generation, municipal supply and other uses.

A good soil reservoir should act in the same manner. The storage capacity of a soil or its pore volume (porosity) is divided into two classes, i. e., capillary and non-capillary. The non-capillary or large pores in the soil correspond to the overflow reservoir in the dam-reservoir system. The non-capillary pores consist of those spaces between the soil particles or soil aggregates that are so large that absorption and film forces cannot retain all the water in them against the pull of gravity. Thus, water is held in them only temporarily, similar to the overflow reservoir. Such storage is termed detention storage by the hydrologist.

The small capillary pores in the soil provide the hydrologist's retention storage. Water in the capillary or retention storage reservoir is held against the force of gravity but is subject to the pull of evaporation near the surface of the soil and transpiration at any depth where living roots occur. The water thus retained in the soil is that which is utilized by plant growth or is dissipated from an area by evaporation. This retention storage reservoir in the soil then acts as the normal reservoir of a river system.

To determine the porosity values for the samples used herein the 3 x 3 inch soil cores were saturated, weighed and placed on a tension table for approximately 24 hours at a tension of 40 centimeters. The weights were recorded and these values were used in determining non-capillary or detention storage. After weighing, the samples were oven-dried at 105°C. to determine capillary or retention storage as well as volume weight. The average values obtained for non-capillary, capillary and total pore space are presented in Table VIII.

TABLE VIII

PERCENT CAPILLARY, NON-CAPILLARY AND TOTAL PORE SPACE

Site	Percent Capillary Pore Volume	Percent Non-capillary Pore Volume	Percent Total Pore Volume
Surface Layer, 0-3 inches			
Undisturbed forest	36.1	20.7	56.8
Coppice forest	36.0	24.5	60.5
Upper pasture	39.0	14.9	53.9
Lower pasture	37.9	14.6	52.5
Cornfield	40.1	16.0	56.1
Control plots (cornfield)	29.2	24.6	53.8
Sub-surface Layer, 3-6 inches			
Undisturbed forest	32.6	22.3	54.9
Coppice forest	37.0	20.1	57.1
Upper pasture	37.7	18.5	56.2
Lower pasture	35.4	15.1	50.5
Cornfield	40.5	15.6	56.1
Control plots (cornfield)	37.9	13.1	51.0
Surface Soil, 0-6 inches average			
Undisturbed forest	34.5	21.5	55.8
Coppice forest	36.5	22.3	58.8
Upper pasture	38.5	16.7	55.1
Lower pasture	36.5	14.8	51.5
Cornfield	40.3	15.8	56.1
Control plots (cornfield)	33.5	18.8	52.4

In terms of total porosity little difference is noted among the sites for either the surface or the sub-surface layer. Higher total porosity values are indicated in the surface layer for the two forested areas, although the differences are not great, than in the other four areas.

More significant than total porosity, however, are the percentages of capillary and non-capillary porosity which determine retention and detention storage, respectively. In the surface soil layers, the lowest values for capillary pore volume were found in the control plots in the abandoned cornfield and in the two forested areas. These are the areas and layers showing the lowest sum of sand and greater than 2 mm. particles by mechanical analysis. In the sub-surface layer the undisturbed forest gave the lowest value, although the differences in no case were greater than 8.2 percent. Apparently the coarser textured sites and layers have higher capillary pore space, or moisture retention. The structure seems to be more important than the texture in these areas. The fact that the cornfield shows the highest values might indicate a favorable influence of cultivation on this property, however, the significance of differences of these magnitudes is doubtful.

In relation to surface runoff, the most important values are for detention storage or non-capillary pore volumes. In the surface layer the highest values are indicated for the control plots and the two forested areas. In the sub-surface layer the two forested areas show the highest non-capillary pore volume while the control plots show the lowest. This would appear to indicate that any improvement in the porosity conditions in the control plots as a result of abandoning the cornfield have been effected only in the surface layer.

The minimum non-capillary porosity of any layer is the limiting factor in determining the rate at which water moves through the total soil. In this case the two forested areas show minimum values of 20.7 and 20.1 while the minimum values for the other four areas range from 13.1 to 15.6, suggesting greater permeability rates for the two forested areas.

Although the differences are not marked, the average non-capillary porosity values for the 0-6 inch layer are highest for the two forested areas. The treatment of the watershed has apparently effected a decrease in non-capillary porosity and an increase in capillary porosity. There has been an increase in the amount and force of precipitation reaching the soil as a result of clearcutting the forest. These changes, as well as changes in other physical characteristics of the soil, particularly the aggregate stability and permeability, have resulted in significant modification of the runoff characteristics of the watershed.

Volume Weight. Volume weight may be defined as the ratio between the dry weight of a given mass of undisturbed soil and its volume. The usual method of determining volume weight, or, as it is frequently termed, the apparent specific gravity or bulk density, is to divide the oven-dry weight of the undisturbed soil in grams by the volume of space which this soil occupies in cubic centimeters.

The volume weight of a soil is dependent for the most part on structure and organic matter content. Ordinarily very compact soils with low pore volume and low aggregation possess high volume weights. On the other hand porous, well aggregated soils show low volume weights. Similarly, soils with a high content of organic matter have a lower specific gravity as well as a lower volume weight than those with a low content of organic matter. Forested soils, because they usually have a higher content of organic matter, show lower volume weights in their surface layers than grazed or cultivated soils.

Consequently, soils which possess low volume weights should show good soil-water relations. Conversely, those with high values for volume weight would tend to show a low infiltration rate, poor aeration and attendant low detention storage capacity.

In determining the volume weights the oven-dry weights of the soil cores in grams were divided by the volume of the core in cubic centimeters. Where soil cores were not full, volume corrections were made by filling the depressions with sand then measuring the volume of sand utilized.

Table IX indicates the average values for the six sites for both the surface and sub-surface layers. Individual values are included along with porosity determinations in the Appendix.

Table IX

AVERAGE VOLUME WEIGHT VALUES

Site	Average Volume Weight: Surface layer 0-3 inches	Average Volume Weight: Sub-surface layer 3-6 inches
Undisturbed forest	.88	1.05
Coppice forest	.82	.98
Upper pasture	1.03	1.07
Lower pasture	1.11	1.28
Cornfield	.93	1.06
Control plots (cornfield)	.98	1.06

The average results given in Table IX indicate that in the surface layer both the undisturbed forest and the coppice forest areas have more favorable soil-water relations than the other areas. The highest values in both the surface and sub-surface layers were found in the lower pasture. This is partly due to soil compaction resulting from heavy grazing use, and partly due to the lower organic matter content there. In the sub-surface layer, although the two forest areas show slightly lower values, the variations are small except for the lower pasture, which has a higher volume weight. All values for the sub-surface layers are somewhat higher than in the surface layer of the same area. The results tend to indicate a poorer physical condition of the surface layers in the lower pasture which would substantiate field observations on surface runoff conditions.

Permeability. The permeability of a soil is ordinarily considered to be the rate at which water moves through the soil column. It differs from infiltration in that the latter is concerned only with the rate at which water enters the soil and may be concerned with only the immediate surface of the soil. It is evident then that infiltration and permeability together provide the most important measures of physical soil characteristics from the standpoint of surface runoff phenomena. A soil may have a high infiltration rate and a low permeability rate or the permeability rate may be high and a "surface bottleneck" may be present, giving a low infiltration rate. In either case, or if both values are low, comparatively little water can be stored and transmitted through the soil and high surface runoff results.

Since soil moisture deficits must be satisfied before water starts permeating or percolating through the soil column, permeability determinations were made on saturated soil cores. As nearly as possible a one-half inch head of water was maintained on the soil core for a period of one hour. The permeability rate was determined by measuring the amount of water which percolated through the soil core in that time. In extremely permeable cores one-half hour was used and the resulting values were doubled. Table X shows the average permeability rates for the six sites. Since 100 millimeters of water are approximately equivalent to one inch in the 3 x 3 cores, permeability rates were converted to inches per hour by dividing millimeters by 100. Figure 34 shows graphically the permeability rates and the corresponding infiltration rates in inches per hour. The permeability values for individual samples are given in the Appendix.

TABLE X

AVERAGE PERMEABILITY RATES

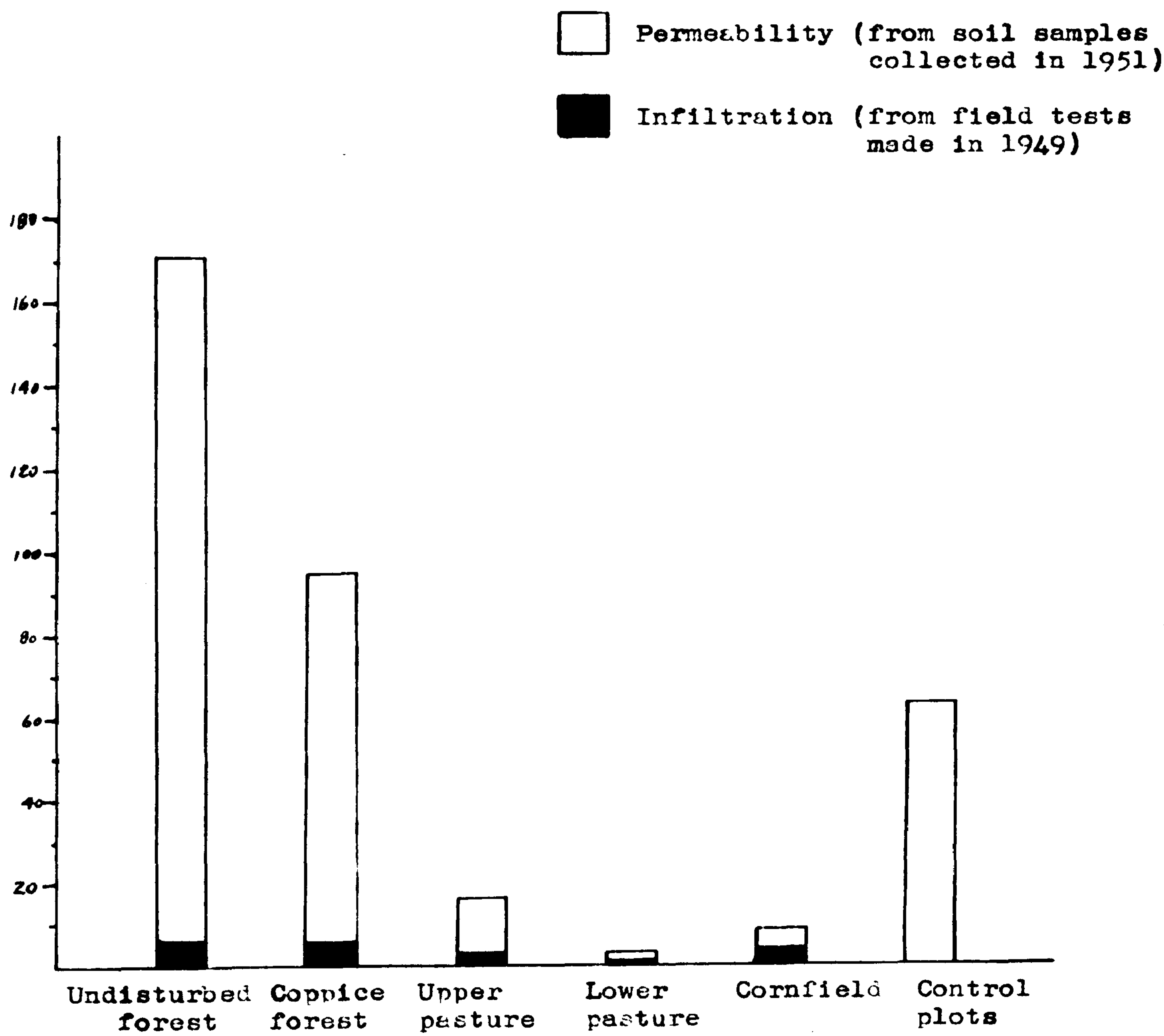
Site	Permeability in millimeters per hour	
	Surface layer 0-3 inches	Sub-surface layer 3-6 inches
Undisturbed forest	17,112	6,417
Coppice forest	16,293	9,468
Upper pasture	2,021	1,685
Lower pasture	660	274
Cornfield	1,241	888
Control plots (cornfield)	8,503	6,405

The permeability tests show much greater difference in the land-use areas than the other physical soil analyses. Both forested areas show very high permeability rates in both the surface and sub-surface layers. The upper pasture, cornfield and, particularly, the lower pasture show very low rates in comparison. The rates indicated for the control plots approach those of the forest areas which appar-

Figure 34.

Average Permeability and Infiltration Rates in Inches per Hour.

Little Hurricane Watershed
Coweeta Hydrologic Laboratory



ently reflects the effects of two years of abandonment. By far the lowest rates in both layers are those for the lower pasture, undoubtedly the result of over-grazing with its consequent compaction.

According to Baver (7), Lassen, Lull and Frank (22) and Fletcher (13) permeability or percolation is dependent upon the non-capillary pore volume. As indicated previously, non-capillary porosity decreased as a result of the treatment to the watershed although the decrease was only in the magnitude of approximately 6 percent. Assuming that non-capillary pore space determines permeability, from these data it appears that relatively small changes in this pore volume may effect very marked changes in the permeability rate.

The values noted for the infiltration rate in Figure 34 indicate a trend similar to that for the permeability rate. The changes indicated for both the infiltration rate and the permeability rate indicate a close relationship with the changes in surface runoff noted in the sections which follow. However the much lower infiltration rates than permeability rates show that the immediate surface of the soil is the limiting factor in moisture detention and is causing surface runoff. It is probable that the shipping of the soil cores contributed in some degree to the high permeability values noted.

HYDROLOGIC DATA

The basic data in nearly all hydrologic investigations are measures of precipitation or recharge and streamflow or discharge. The volume and rate of discharge from a given watershed or hydrologic unit is a reflection of the amount and intensity of precipitation which it receives and the characteristics of the watershed. The manner in which these factors are measured on the Little Hurricane Watershed and the methods employed in converting the raw data into usable form has been noted previously.

Precipitation

The total areal precipitation received by the watershed, as measured by the three standard rain gages servicing the area, is summarized by hydrologic years in Table XI. Figure 35 indicates the average monthly areal precipitation as well as the area inches of stream discharge by months and by hydrologic seasons.

Precipitation, vegetation and soil conditions are all reflected in the discharge curve shown in Figure 35. From January through March precipitation is at its maximum. Evaporation and transpiration are at a minimum and soil moisture conditions are at their peak. Much of the precipitation which occurs during these months filters rather rapidly through the soil reservoir into ground water since soil

Figure 35.

Average Monthly Areal Precipitation and Streamflow.

Watershed No. 3
Coweeta Hydrologic Laboratory

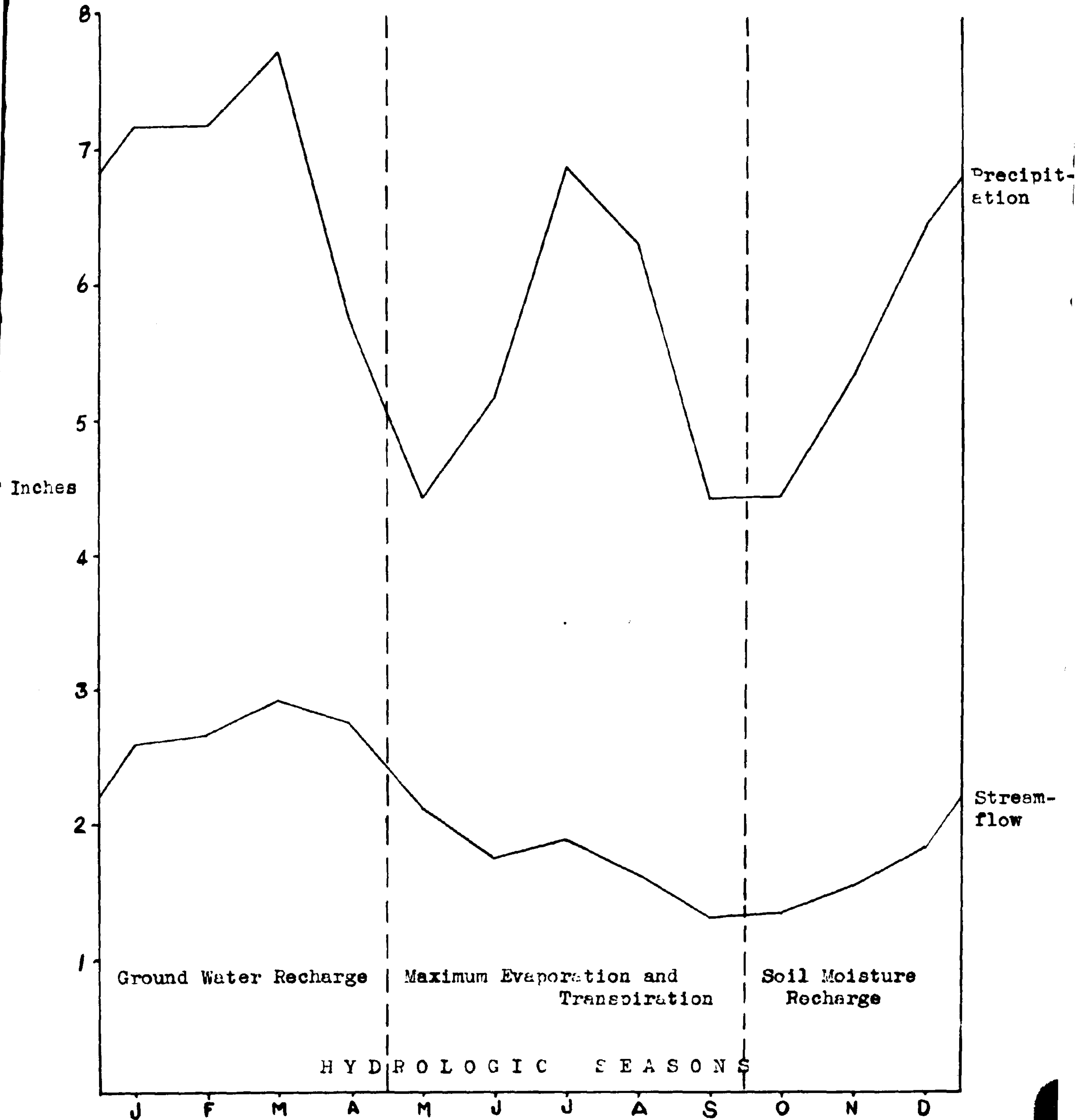


TABLE XI

SUMMARY OF AREAL PRECIPITATION BY HYDROLOGIC YEARS

Hydrologic year*	Precipitation in inches
1935	61.94
1936	84.84
1937	72.85
1938	63.72
1939	74.76
1940	56.79
1941	50.33
1942	67.81
1943	77.70
1944	66.64
1945	65.21
1946	79.13
1947	69.00
1948	71.08
1949	107.18
1950	76.22
Average**	71.54

* Hydrologic year from November to October
** Data for 1934 and 1951 incomplete

moisture deficits are very low. Consequently, stream discharge is at its highest level. A large portion of the water appears as clean, non-turbid water from sub-surface and ground water flow. The majority of the storms during this season produce low intensity precipitation and snow which ordinarily does not accumulate to great depths to form flood hazard conditions.

Throughout April and continuing into May, precipitation steadily declines. At the same time vegetation commences growing, temperatures increase and consequently losses to evaporation and transpiration increase. Starting in May and continuing throughout June and part of July precipitation increases rather sharply. Likewise evaporation and transpiration are increasing and the discharge curve indicates only a slight rise as a result of the increased precipitation. Starting in July and continuing through October precipitation steadily declines as evaporation and transpiration continue to make heavy demands. This is indicated in the discharge curve in that stream discharge is at its lowest ebb during September.

October marks the end of the growing season and with it comes a sudden decrease in both evaporation and transpiration. At the same time the precipitation curve swings sharply upward. Stream discharge shows a more gradual climb until the soil moisture deficits, resulting from the heavy use by vegetation and evaporation, are satisfied. The cycle is completed in the winter months when soil moisture deficits are met and ground water recharge again occurs.

In studies of individual storms and their effects on stream discharge a measure of precipitation intensities as well as a measure of total amounts are required. Recording rain gages 67 and 1 were used to obtain precipitation intensities. The precipitation intensity values as well as the mass or accumulated precipitation values are taken from the precipitation intensity records (see Appendix) and are shown graphically along with stream discharge for representative storms used in this study in Figures 36 through 44.

An examination of individual storms shows that prior to treatment bursts of precipitation usually resulted only in a continued steady increase in stream flow. Following the clearcutting of the forest and the initiation of mountain farming, relatively small bursts of precipitation resulted in immediate and sharp increases in stream flow. The treatment of the watershed has thus resulted in producing stream flow of extremely "flashy" characteristics.

Stream Flow

Gage height readings recorded for the weirs used in measuring discharge from the watershed are converted to cubic feet per second from rating tables calculated for the respective stream controls. Since precipitation is expressed in inches and in inches per hour, the cubic feet per second values were converted to inches per hour to aid in graphical presentation and analysis. The discharge values in inches per hour (see Record of Runoff, Appendix) were plotted over time to give the storm hydrographs for individual storms. Hydrographs for representative storms used herein are given in Figures 36 through 44.

The average monthly discharge values for the entire period of record are presented graphically in Figure 35 and

Figure 36.

Precipitation hyetograph, mass precipitation and stream hydrograph for a unit or single summer storm (6/13/43).

Watershed No. 3
Coweeta Hydrologic Laboratory

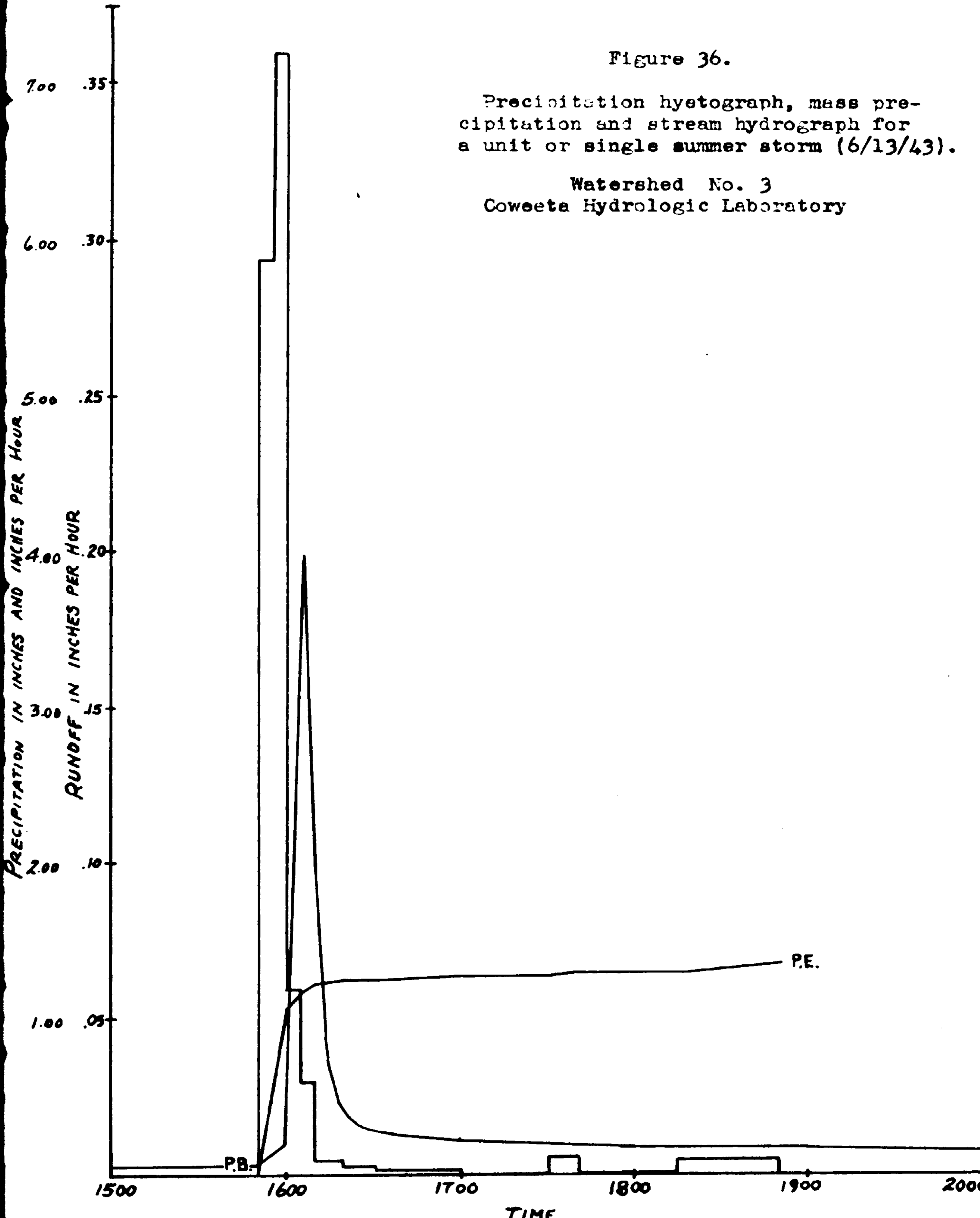


Figure 37.

Precipitation hyetograph, mass precipitation
and stream hydrograph for a multiple storm (8/2/48).
Watershed No. 3
Coweeta Hydrologic Laboratory

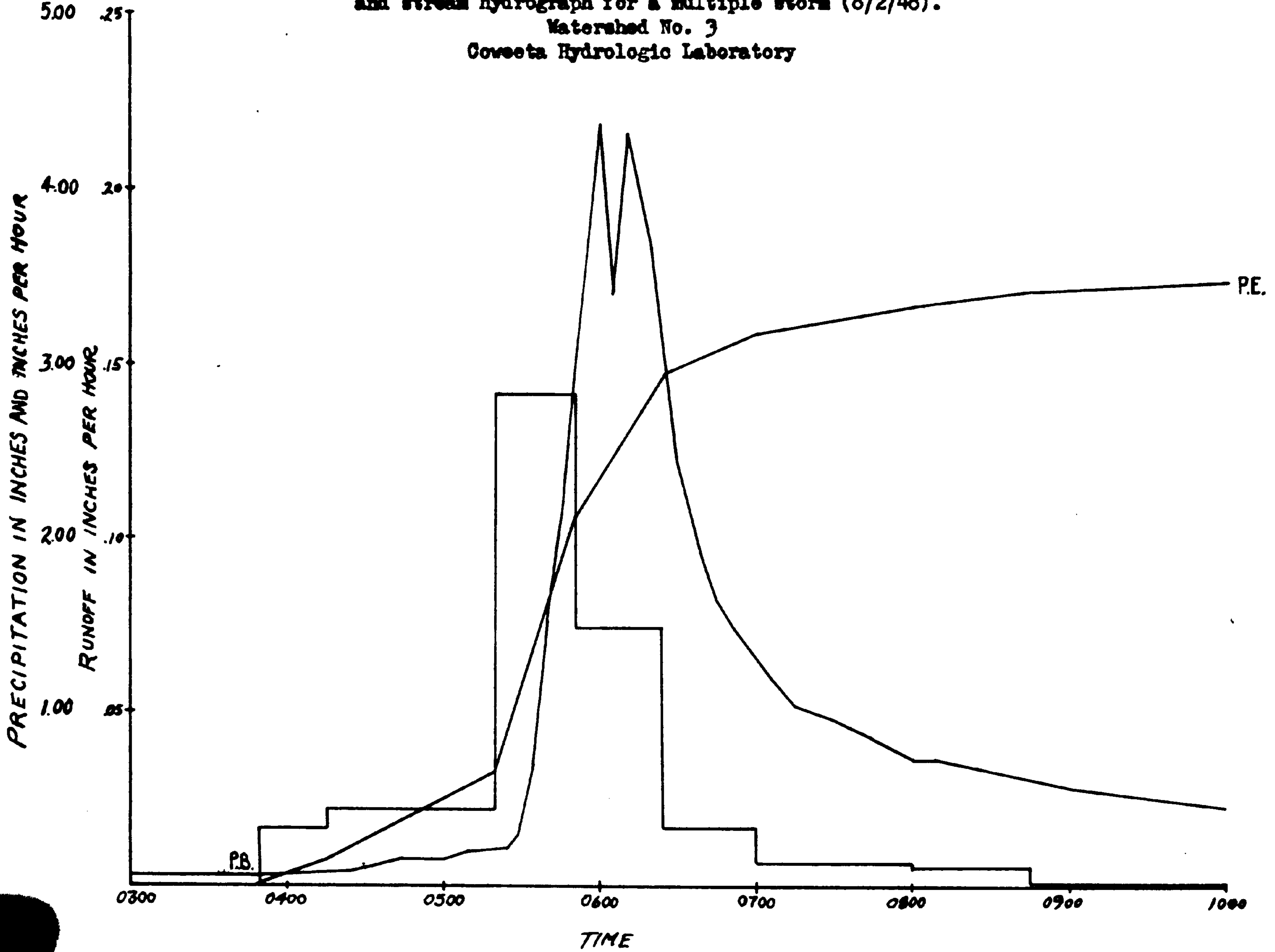
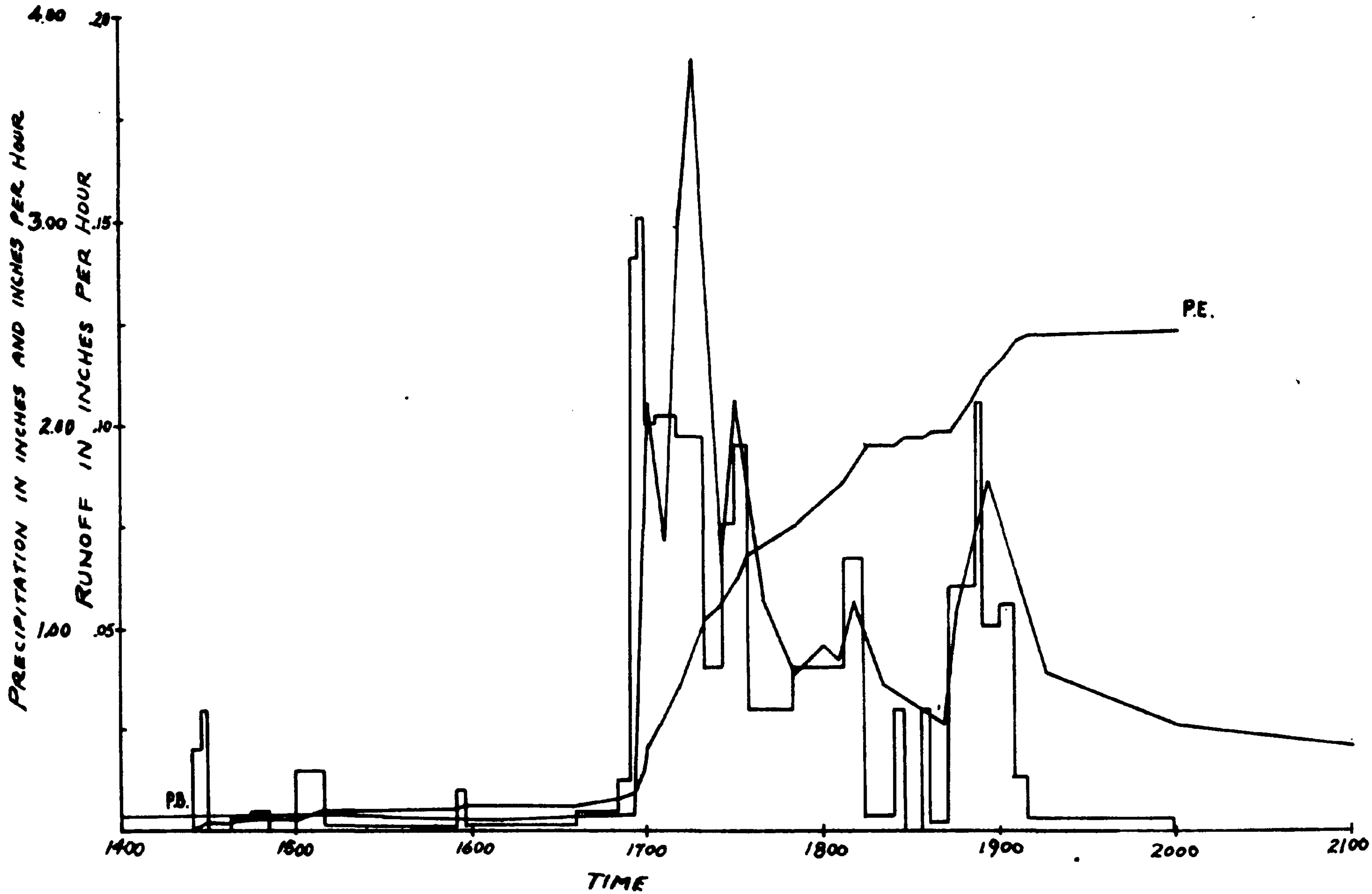


Figure 38.

Precipitation hyetograph, mass precipitation and stream hydrograph for an intermediate type storm (8/12/43).

Watershed No. 3
Coweeta Hydrologic Laboratory



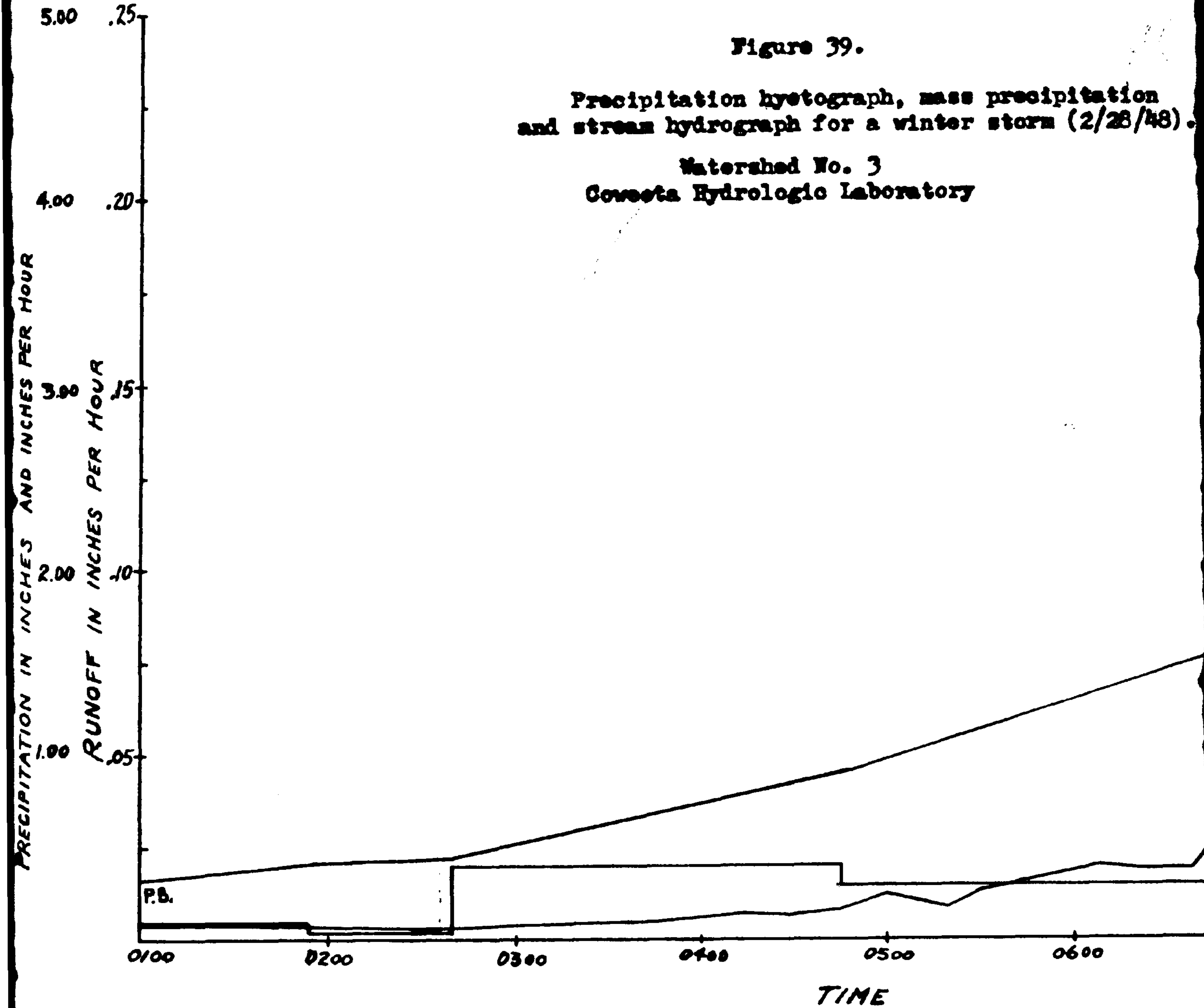
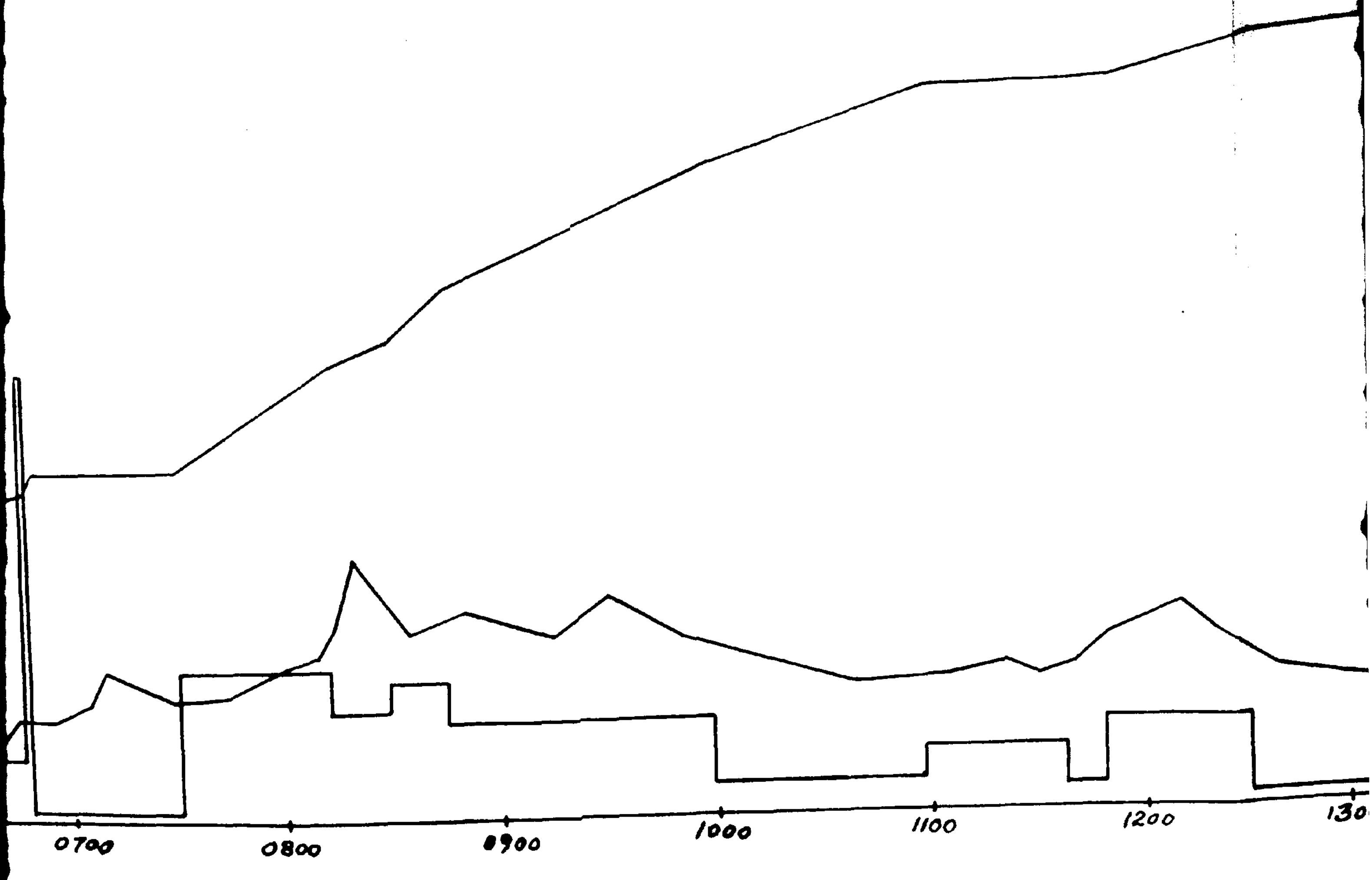


Figure 39.

Precipitation hyetograph, mass precipitation and stream hydrograph for a winter storm (2/28/48).

Watershed No. 3
Coweeta Hydrologic Laboratory


0700
0800
0900
1000
1100
1200
130

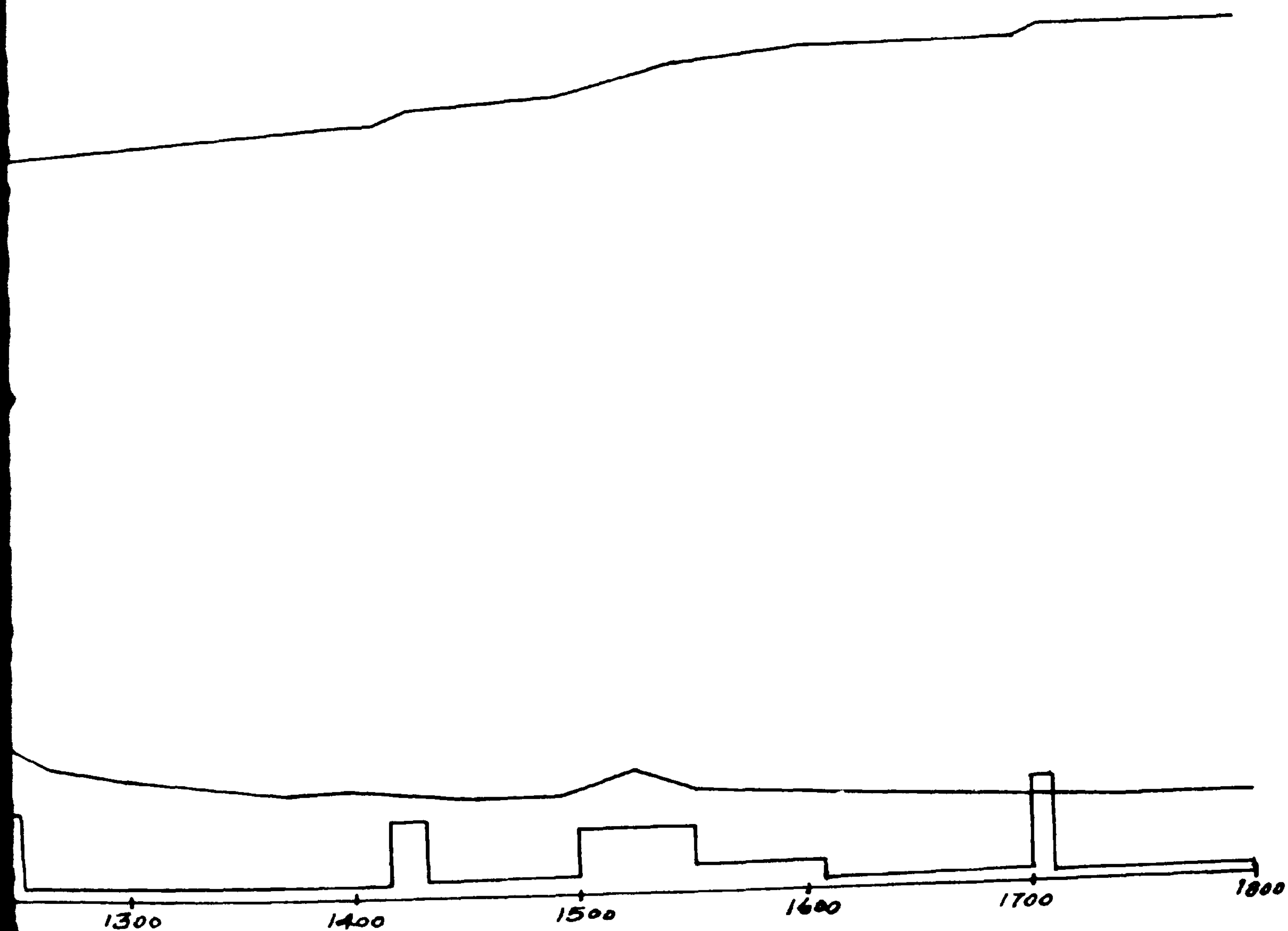
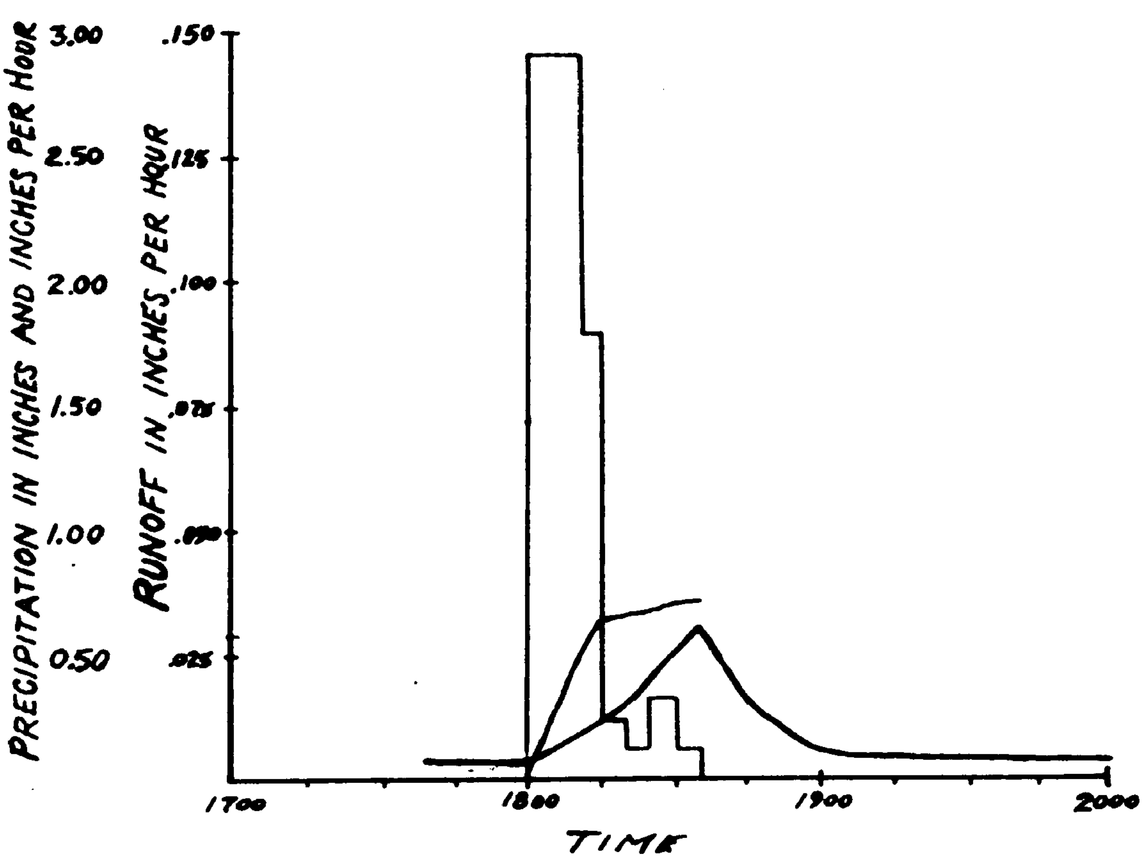

1300
1400
1500
1600
1700
1800

Figure 40

Precipitation hyetograph, mass precipitation and stream hydrograph for storm of June 15, 1937 (Summer)

Watershed No. 3
Coweeta Hydrologic Laboratory



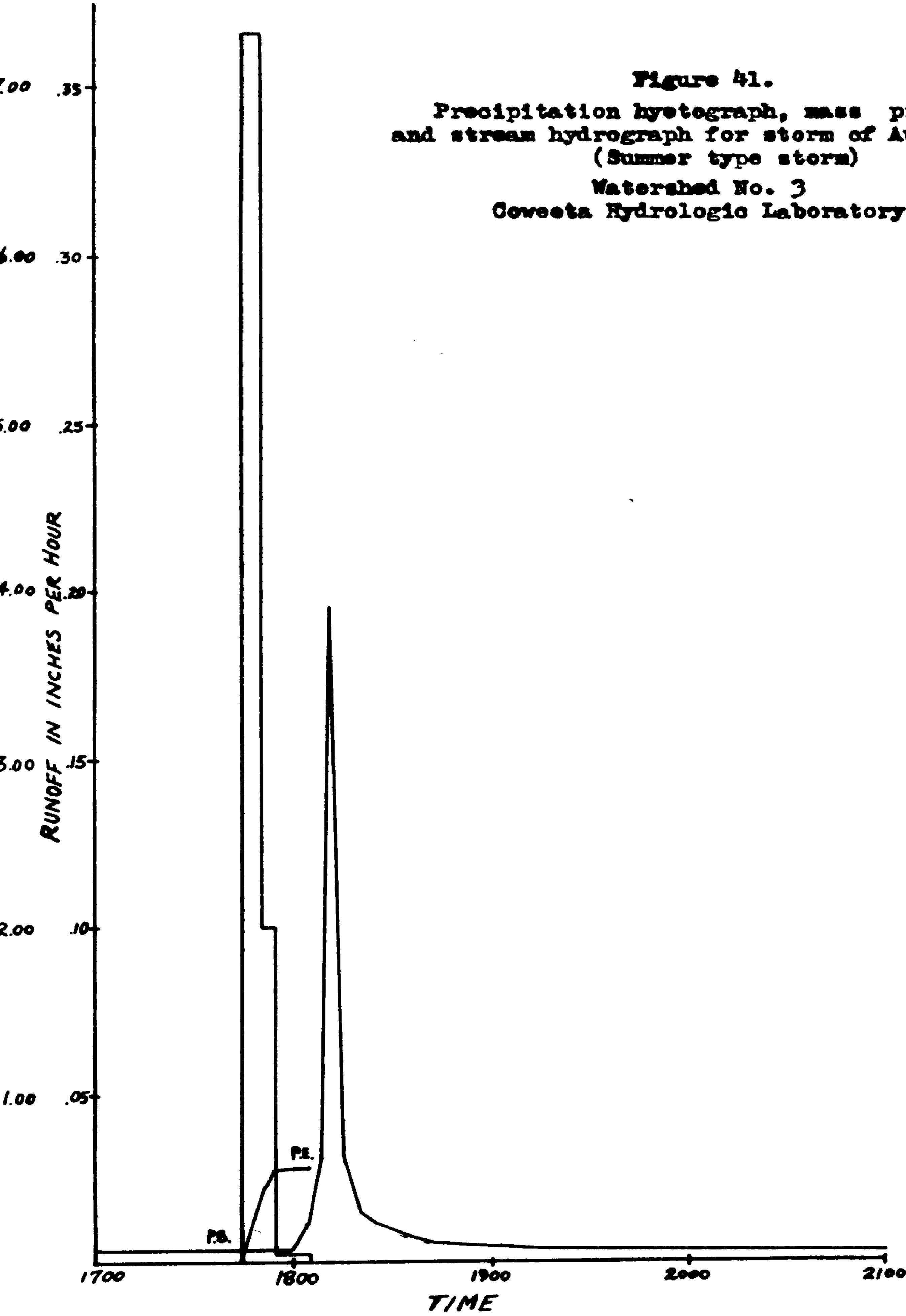
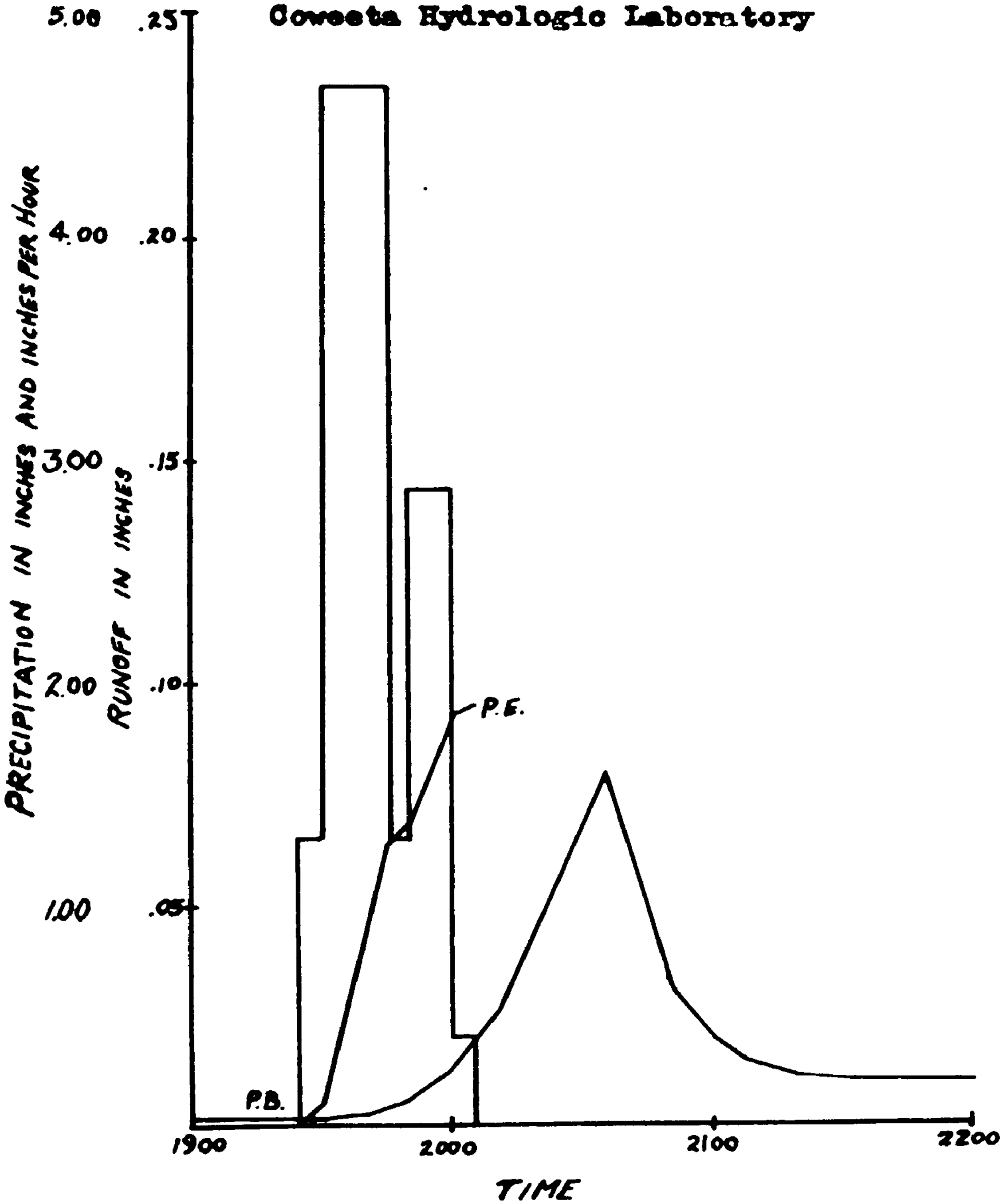


Figure 41.

Precipitation hyetograph, mass precipitation and stream hydrograph for storm of August 4, 1943.
(Summer type storm)
Watershed No. 3
Coweeta Hydrologic Laboratory

Figure 42.

Precipitation hyetograph, mass precipitation and stream hydrograph for storm of August 22, 1935.
(Unit summer storm)
Watershed No. 3
Coweeta Hydrologic Laboratory



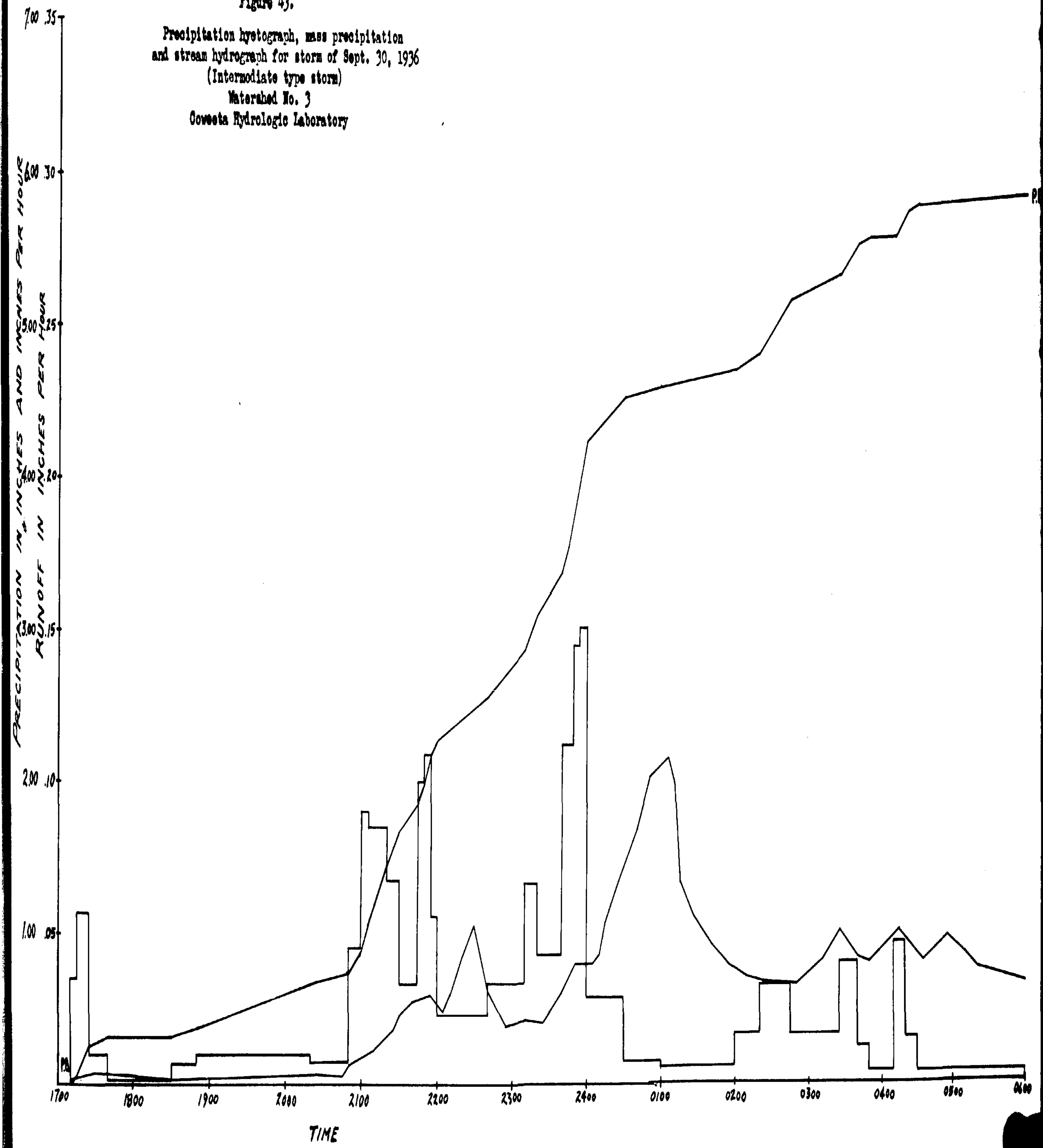
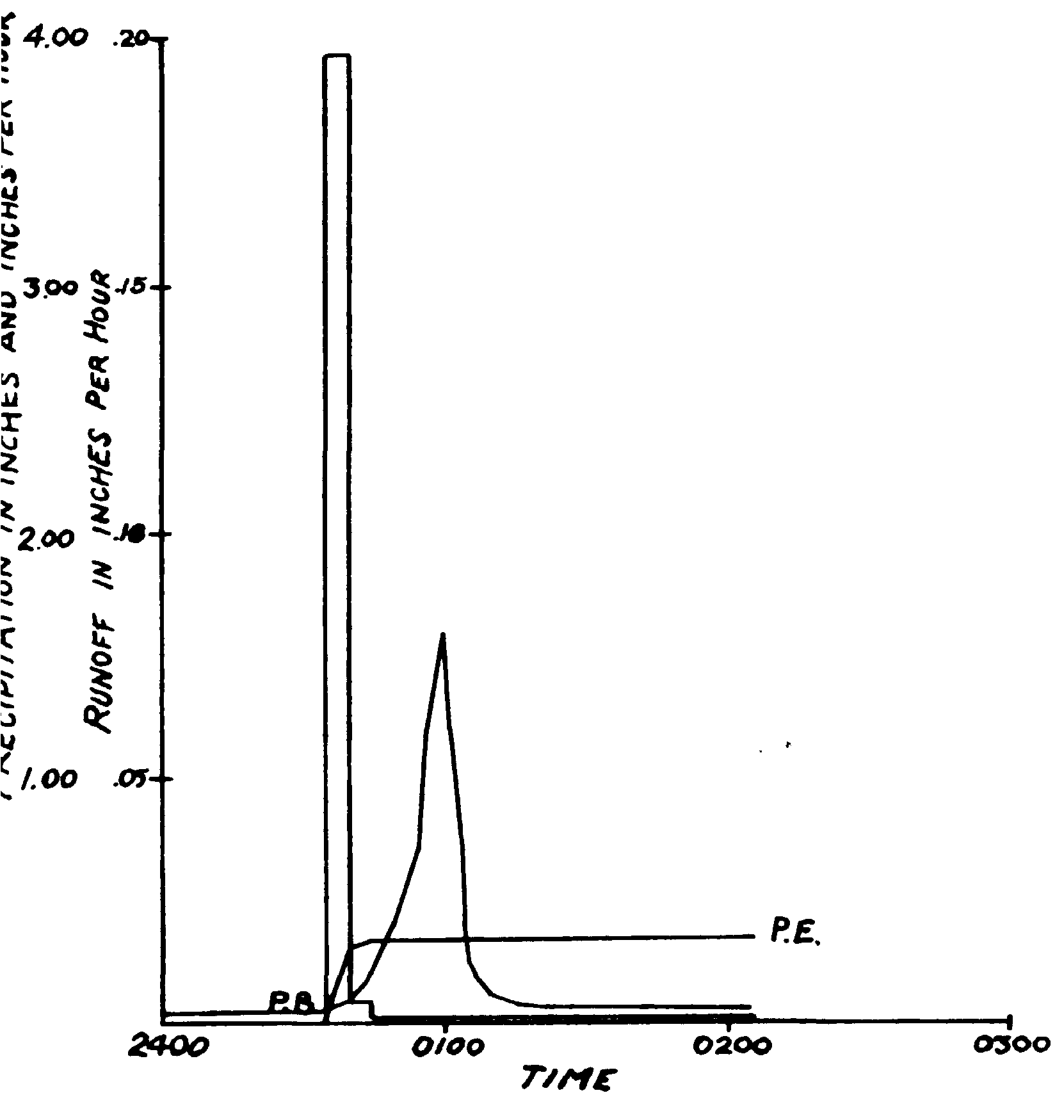


Figure 43.

Precipitation hystograph, mass precipitation and stream hydrograph for storm of Sept. 30, 1936 (Intermodiate type storm) Waterhed No. 3 Coweeta Hydrologic Laboratory

Figure 44.

Precipitation hyetograph, mass precipitation and stream hydrograph for storm of August 20, 1949.
(Summer type storm)
Watershed No. 3
Coweeta Hydrologic Laboratory



have just been discussed. The average monthly discharge values in inches are summarized by years in the Appendix.

Definition of Storms

Frequently precipitation is received in such small amounts and at such low intensities that it produces no perceptible change in the stream hydrograph. All or the greater part of it may be intercepted by vegetation. Sufficient precipitation must occur to satisfy initial depression storage (water required to fill the small depressions on the soil surface) as well as vegetation interception before it can run off or otherwise enter the stream. Many small rises in stream hydrographs following a brief low-intensity period of precipitation are the result of precipitation falling in the channel or stream itself rather than from surface runoff or some form of sub-surface flow. Unless an investigation is concerned with total water yields, the inclusion of all periods of precipitation is impractical. Consequently, for individual storm studies, there must be some dividing line or definition of what constitutes a storm.

After examining all the precipitation and streamflow data, the arbitrary standard of a maximum 30-minute intensity of at least 0.90 inch per hour was selected. An exception was made in one case in which the maximum 30-minute precipitation intensity was less than 0.90 inch per hour where the peak stream discharge greatly exceeded "normal" for the amount and intensity of precipitation received. The catalog of storms falling into this category are listed in the Appendix.

Classification of Storms

Streams, particularly from small watersheds, respond quite differently to different storms. Consequently, based upon the patterns of precipitation and the stream hydrographs resulting therefrom, all storms were classified naturally into three categories: summer, winter and intermediate. Summer storms are characterized by short but intense periods of rainfall. They are usually occasioned by frontal activity or convection storms. Summer storms are further subdivided into unit or single storms and multiple storms. The unit summer storm yields nearly all of its precipitation in bursts which are bunched closely together and produces a single peak on the hydrograph. The multiple summer storm produces intense precipitation bursts which are separated by a period of time not exceeding six hours, in which rainfall may stop entirely or be of low intensities. A hydrograph of two or more peaks results. Figures 36 and 37 show the precipitation patterns and the resultant hydrographs of the unit and multiple summer storms respectively.

The intermediate storm is characterized by precipitation which comes alternately in short intense bursts followed by periods of precipitation of more moderate intensities. It usually yields a greater amount of precipitation than most summer storms and is usually associated with the spring and fall seasons. The tropical hurricanes which reach this area fall into this classification. The hydrographs produced by such storms are marked by a series of peaks and troughs. Figure 38 illustrates a typical intermediate type storm.

The winter storm gives a relatively large volume of precipitation which usually does not come at the higher intensities associated with summer storms. However, the winter storm is usually of much longer duration as it is most frequently the result of cold front activity. Figure 39 illustrates the precipitation pattern and hydrograph of a characteristic winter storm.

Distribution of Storms

An analysis of a listing of storms producing peak flows exceeding 9 cubic feet per second per square mile made by Johnson[6] in 1949 and continued through August, 1951 by the writer, indicates that from the standpoint of the distribution of flood-producing storms, the summer storm is the most significant. Figure 45, illustrating the distribution of flood producing storms shows that over 39 percent of all flood-producing storms occur in June, July and August.

---

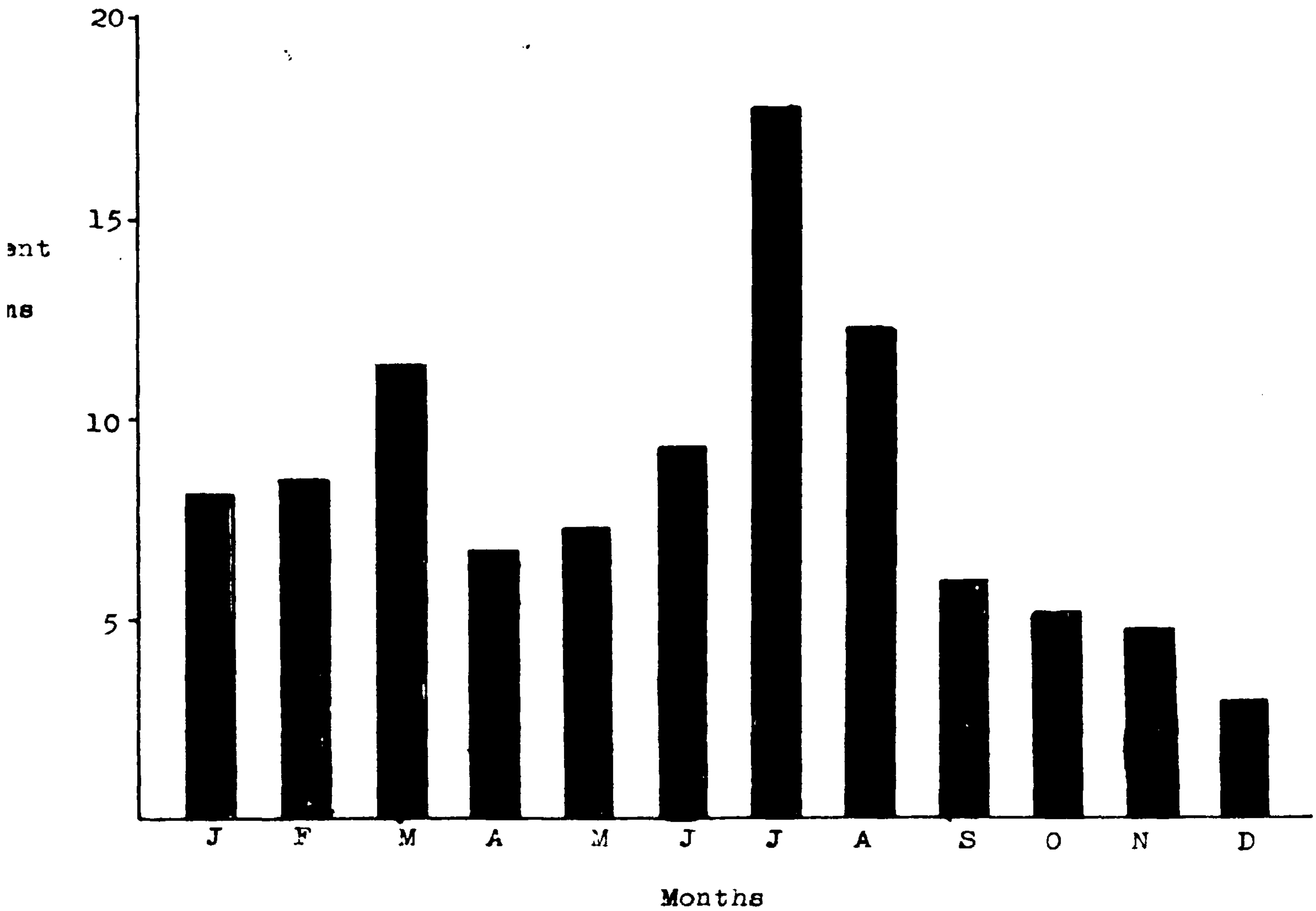
[6]Johnson, E. A., Summary of Flood Peaks over 9 c.s.m., Watershed No. 3, 1949. (Unpublished compilation, Coweeta Hydrologic Laboratory)

Similarly, 12 of the recorded 14 flood peaks which exceeded 100 c.s.m. resulted from summer storms, indicating the importance of this type storm.

Figure 45.

DISTRIBUTION OF FLOOD-PRODUCING STORMS BY MONTHS

Watershed No. 3
Coweeta Hydrologic Laboratory



CHANGES IN RUNOFF CHARACTERISTICS

Probably the most important single tool of the hydrologist or watershed manager is a knowledge of the stream flow and runoff characteristics for a given drainage area. A knowledge of these characteristics guides the engineer or land manager in planning flood control measures or permits municipalities to select and manage watershed lands as well as to regulate consumption. Considerable attention has been given to the study of stream flow characteristics on large basins, particularly within the past ten years, by the United States Department of Agriculture and the United States Corps of Engineers. Numerous investigations have been made to determine primarily gross runoff characteristics from small watersheds and plots.

It is the intent of this study to determine not only the percent of total runoff, but to evaluate any changes in surface or storm runoff in terms of flood peaks, the frequency of floods and the manner in which storm water actually runs off a small watershed. No attempt has been made, however, to study any changes in base or sub-surface flow or total water yields.

Percent of Precipitation Appearing as Surface Runoff

One frequently used method of expressing surface runoff is runoff percent or the calculation of the percentage of total precipitation which comes off the drainage area in the form of overland flow. To evaluate the gross changes in surface runoff an analysis of the runoff percent for the watershed in forest cover and following treatment was made.

For this study all storms as defined previously were used. Storm runoff volumes for the individual storms were derived by planimetering the storm runoff hydrographs and converting to area inches. Table XII gives the derivation of the percentages of precipitation which appeared as surface runoff for the individual storms as well as the average values for all storms and summer storms only. Interception and stem flow values, derived from data compiled by the Coweeta Hydrologic Laboratory, are indicated for the pre-treatment period.

The total storm runoff for all storms from the watershed while in forest cover (1934-1939) averaged 2.66 percent of the precipitation. Following forest cutting and mountain farming, this value increased to 4.50 percent. For summer storms only, the difference is more marked. For the before period a runoff percent of 1.53 was noted compared with 4.79 percent following the treatment. This represents an increase of 3.26 percent which at first may appear rather insignificant, however, in terms of volume for a 2-inch storm as defined herein, this amounts to over 5,500 cubic feet. Table XIII shows corresponding values for 0.5-, 1-, 3-, 4- and 5-inch storms as well as the 2-inch class.

TABLE XII

SURFACE RUNOFF EXPRESSED AS PERCENT OF PRECIPITATION
(BASED ON FLOOD-PRODUCING STORMS ONLY)

Date of Storm	Square Inches under Storm Hydrograph	Cubic Foot Volume of Surface Runoff	Area Inches of Surface Runoff	Area Inches of Precipitation	Precipitation Intercepted in Inches	Percent of Precipitation Appearing as Runoff	Storm Class
1934-1939							
Aug 22, 1935	1.06	3136	.037	1.91	.20	2.04	S
Apr 2, 1936	2.86	8462	.100	2.38	.22	4.20	I
Jun 12, 1936	.28	828	.010	.85	.13	1.17	S
Aug 24, 1936	.30	888	.011	.94	.13	1.17	S
Sep 30, 1936	4.26	12604	.149	5.30	.55	2.81	I
Jun 15, 1937	.27	814	.010	.73	.11	1.37	S
Nov 5, 1938	2.65	7840	.093	3.33	.29	2.79	I
Total, Summer storms			.068	4.43	Average, Summer storms		1.53
Total, All storms			.410	15.44	Average, All storms		2.66
1940-1951							
Jun 13, 1943	.74	2189	.026	1.26		2.06	S
Jul 5, 1943	1.66	4911	.058	1.10		5.27	S
Jul 30, 1943	7.50	22190	.263	1.20		21.92	S
Aug 12, 1943	3.86	11420	.135	2.34		5.77	I

(continued on next page)

TABLE XII (continued)

Date of Storm	Square Inches under Storm Hydrograph	Cubic Foot Volume of Surface Runoff	Area Inches of Surface Runoff	Area Inches of Precipitation	Precipitation Intercepted in Inches	Percent of Precipitation Appearing as Runoff	Storm Class
Jul 11, 1946	.48	1420	.017	.76		2.24	S
Jul 15, 1946	.57	1686	.020	1.68		1.19	S
Aug 25, 1947	1.79	5296	.063	2.51		2.50	S
Apr 8, 1948	.72	2130	.025	.71		3.52	S
Aug 2, 1948	5.06	14971	.177	3.42		5.18	I
Aug 14, 1948	.46	1361	.016	1.13		1.42	S
Nov 19, 1948	1.42	4201	.050	1.10		4.54	I
Nov 28, 1948	3.26	9645	.114	2.95		3.86	W
May 22, 1949	.80	2367	.028	.52		5.38	S
Jul 10, 1949	9.61	28433	.336	2.66		12.63	S
Aug 4, 1949	.45	1331	.016	.56		2.86	S
Aug 20, 1949	.37	1095	.013	.35		3.71	S
Sept 6, 1949	1.10	3255	.039	1.18		3.31	I
Sep 18, 1949	1.52	4497	.053	1.57		3.38	S
Oct 6, 1949	2.00	5917	.070	1.84		3.80	I
Oct 16, 1949	.46	1361	.016	.90		1.78	S
Jun 3, 1950	.75	2219	.026	1.10		2.45	S
Aug 29, 1950	1.07	3166	.037	1.68		2.20	I
Aug 30, 1950	1.86	5503	.065	2.25		2.89	I
Jun 12, 1951	.55	1627	.019	1.25		1.52	S
Jul 15, 1951	1.79	5296	.063	1.75		3.60	S
Jul 16, 1951	.33	976	.012	.57		2.11	S
Jul 27, 1951	.89	2633	.031	1.40		2.21	S
Total, Summer storms			1.101	22.98	Average, Summer storms		4.79
Total, All storms			1.788	39.74	Average, All storms		4.50

TABLE XIII

INCREASED VOLUME OF PRECIPITATION APPEARING AS STORM RUNOFF

Storm Precipitation in Inches	Increased Volume of Surface Runoff in Cubic Feet for Summer Storms
0.5	1398
1	2756
2	5512
3	8268
4	11024
5	13780

In Table XIV a comparison of runoff percentages reported from different stations is noted. It is obviously difficult to make a direct comparison among these data, particularly the Little Hurricane values in comparison with the other values since the Little Hurricane is a permanent stream and the runoff percent is based upon only flood-producing storms. The values for the other stations represent data from plot studies or extremely ephemeral streams where all flow registered is surface runoff.

The values obtained from other stations all show a marked difference between runoff percent under forest conditions and other land uses. In all cases cited for forest conditions, the runoff value was considerably under 1 percent indicating the superiority of forest cover and forest soils for retarding surface runoff.

TABLE XIV

COMPARISON OF RUNOFF PERCENTAGES
FROM VARIOUS STATIONS

Station	Runoff Percents for Forest Conditions	Runoff Percents for Other Land Uses
Little Hurricane Watershed, Coweeta Hydrologic Laboratory*	2.66	4.50 (forest, pasture corn)
La Crosse, Wisconsin	0.15	9.00 (grazed woodlot)
Statesville, N. C.	0.70	13.24 (continuous cotton)
Temple, Texas	-	12.86 (continuous corn)
Tyler, Texas	0.122	10.21 (continuous cotton)
Coshocton, Ohio	0.2	15.00 (cultivated)
Zanesville, Ohio	0.34	-

*Based on flood-producing storms only

<u>Area of watershed contributing to overland flow</u>. As indicated previously, overland flow or evidence of overland flow in the form of small silt deposits and minute dams formed by debris accumulation have never been observed on the coppice forest portion of the watershed. Similar observations have been made on another watershed of the

Coweeta area which is entirely covered with coppice forest of the same age class. Coweeta watershed No. 17 was clear-cut approximately 12 years ago and has been cut back or sprouted annually. Even though the slopes of the latter are considerably steeper than on the Little Hurricane Watershed and it is cut back annually, there has been no indication of overland flow. Consequently, it was assumed that during the "before treatment" period, all the stream flow in addition to the base flow consisted of channel interception and some form of sub-surface flow.

For the period following treatment it was assumed that the area in coppice forest cover was not contributing to overland flow, thus, the increase in surface runoff was assigned to the remainder of the watershed, approximately 12 acres. Similarly, as indicated by field observations made in 1951 and substantiated by the soil analyses reported herein, the lower pasture and the abandoned cornfield are probably contributing the major portion of storm runoff or overland flow. These areas, along with the lower portion of the upper pasture, actually constitute less than half the area of the entire watershed. This would suggest that from 6 to approximately 12 acres were actually contributing overland flow to the stream.

On the basis of these observations and assumptions a calculation was made to show the increases in the volumes and percentages for 6, 8, 10 and 12 acres, assuming that they were contributing all of the surface runoff. The total surface runoff for the "before" period for all storms and summer storms only, i. e., 2.66 and 1.53 percent respectively was assumed to be channel interception and possibly some form of sub-surface flow. In order to determine the increase in overland flow for the "after" period storms, 2.66 and 1.53 percent of the all storm and summer storm precipitation respectively was deducted from total storm runoff. Table XV shows the increased runoff in volume and percent thus derived assuming that 6, 8, 10, 12 and 22.79 acres were contributing all the overland flow for all storms and summer storms only.

TABLE XV

EFFECT OF WATERSHED TREATMENT ON THE VOLUME AND PERCENT OF STORM RUNOFF ASSUMING THAT VARIOUS ACREAGES ARE CONTRIBUTING ALL THE RUNOFF

Acreage Contributing	Increase in Volume of Storm Runoff in Area Inches		Increase in Percent of Storm Runoff	
	All Storms	Summer Storms	All Storms	Summer Storms
22.79 (total area)	.731	.749	1.84	3.26
12	1.389	1.423	3.50	6.19
10	1.667	1.708	4.20	7.43
8	2.083	2.135	5.24	9.29
6	2.778	2.846	6.99	12.39

From observations made by the writer and as indicated by the results of this analysis, it is highly probable that the small overtrampled and mis-used portions of the watershed are the significant flood source areas and consequently have an effect on total watershed conditions far out of proportion to their actual area.

Changes in Flood Peaks

Storm runoff or flood peak magnitudes and frequencies are both valuable tools used to express and evaluate the effects of various land use practices. These factors are both used frequently to aid in the determination of the economic design of engineering structures and in flood control programs.

Flood Peak Magnitudes. One of the most pronounced changes in surface runoff occurring as a result of forest cutting and subsequent mountain farming is the increase in the magnitude of flood peaks. To obtain a measure of this change, a flood peak magnitude study was made. Similar studies were made on this watershed in 1949 and 1950 (33, 34). After an examination of the previous analyses however, it was believed that the results therefrom were not entirely satisfactory.

The first step in the initiation of such a study is the collection and cataloging of storms on some rational basis. In the earlier studies a specified minimum peak was used as a basis for storm comparison. The writer believed that a more satisfactory basis for comparison was the storms themselves, i. e., a certain amount and intensity of precipitation. Consequently, for this study, storms with a maximum 30-minute rainfall intensity of over 0.90 inch per hour were arbitrarily selected. The list of storms in this category occurring on the watershed, showing date of storm, peak discharge, total precipitation, maximum precipitation intensities and storm class, as well as corresponding flood peaks recorded on the control watershed, is given in the Appendix.

An orientation analysis was made in which the peak discharges in cubic feet per second per square mile were plotted against the maximum 30-minute precipitation intensities by periods. Three periods were selected: 1934-1939, 1940-1945 and 1946-1951. The 1934-1939 period represents the pre-treatment period in which the watershed was in forest cover; 1940-1945, the intermediate period, in which the mountain farming treatment was applied and in which the soil gradually lost its original structure, organic content and fertility; and 1946-1951, the after period, in which the maximum effects of land use were in evidence.

From these graphs it was apparent, particularly in the pre-treatment period, that intermediate and winter storms gave considerable spread to the points. A further examination of the storm data indicated that some of the summer storms were multiple storms, i. e., producing multiple peaks on the storm hydrograph. These, too, were responsible for considerable dispersion of the points. An attempt was made to evaluate further the data on the basis of antecedent moisture conditions. Due to time limitations, additional analyses of antecedent moisture conditions will be made a subject of a future special study by the Coweeta Hydrologic Laboratory.

Using only the selected storms, i. e., single or uniform summer storms, a new listing of storm peaks and corresponding precipitation intensities was made by periods and for maximum precipitation intensities of 15-, 20-, 30- and 60-minute intervals. For ease in handling, the data was grouped into 25 c.s.m. groups or classes (0-25, 26-50, etc.) and averages computed. The average c.s.m.'s for the group or class were then plotted against the class average precipitation intensities for each of the four precipitation intensity intervals for each of the three periods.

Least square linear regressions were calculated for all plottings and straight line curves fitted to the data. A sample linear regression is given in the Appendix.

The standard error of the estimate for the regressions was calculated for all four rainfall intensity intervals in the 1946-1951 period and the 15-minute interval gave the lowest standard. The time of concentration for the watershed following treatment was approximately 15 minutes, consequently, this interval was selected as the best for purposes of comparison.

To show that the changes were not the result of changes in storm characteristics and precipitation patterns, the corresponding storm peaks from a control watershed were plotted against the rainfall intensities applied to Watershed No. 3 for the 15-minute precipitation interval for the three periods. The resulting maximum discharge rate-precipitation intensity relation curves for both watersheds for the three periods are given in Figure 46.

It is obvious, from the curves for the treated watershed, that a marked increase in the magnitude of flood peaks has been effected. Similarly, the curves for the control watershed indicate that there has been no decided change in climatic conditions which might effect this increase. Consequently, the changes in flood peaks are attributed to forest cutting and subsequent land use.

It is apparent that the change between the pre-treatment and both post-treatment periods is significant. To test the difference between the 1940-1945 and the 1946-1951 periods, an analysis of co-variance was calculated. This analysis indicated a significance to about the 4.5 percent level according to Snedecor's "F" test. These computations are given in the Appendix.

The increase in flood peaks brought about by the treatment of the watershed for the maximum 15-minute period of rainfall at 2, 3, 4 and 5 inches per hour are summarized in Table XVI by actual flood peaks in c.s.m. as well as in percentage increases.

Figure 46.

THE EFFECT OF FOREST CUTTING AND SUBSEQUENT MOUNTAIN FARMING ON THE MAXIMUM DISCHARGE RATE - PRECIPITATION INTENSITY RELATION

From selected uniform summer storms having a maximum 30-minute precipitation intensity over 0.90 inches per hour

——— Treated watershed (No. 3)
----- Control watershed (No. 2)

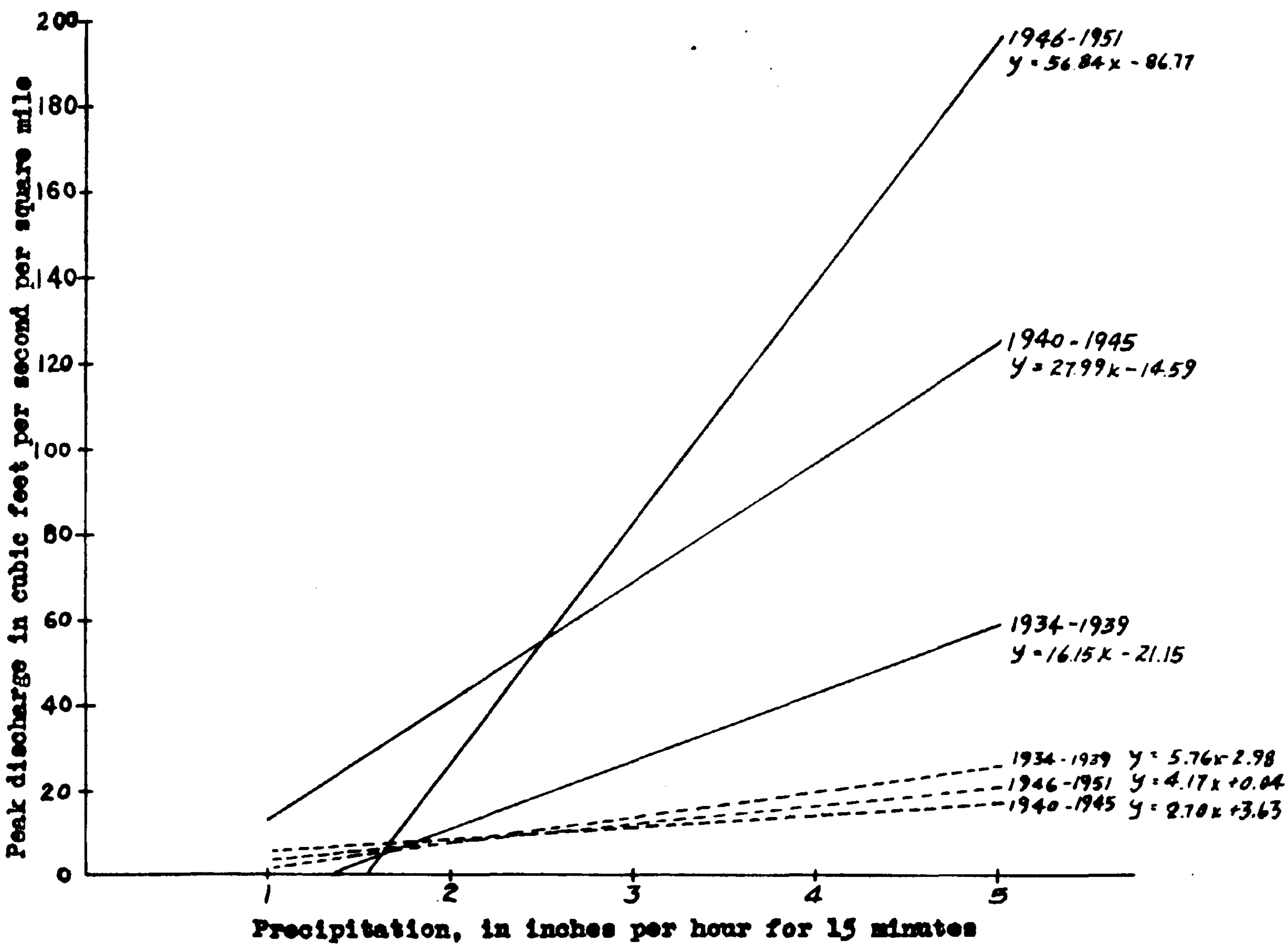


TABLE XVI

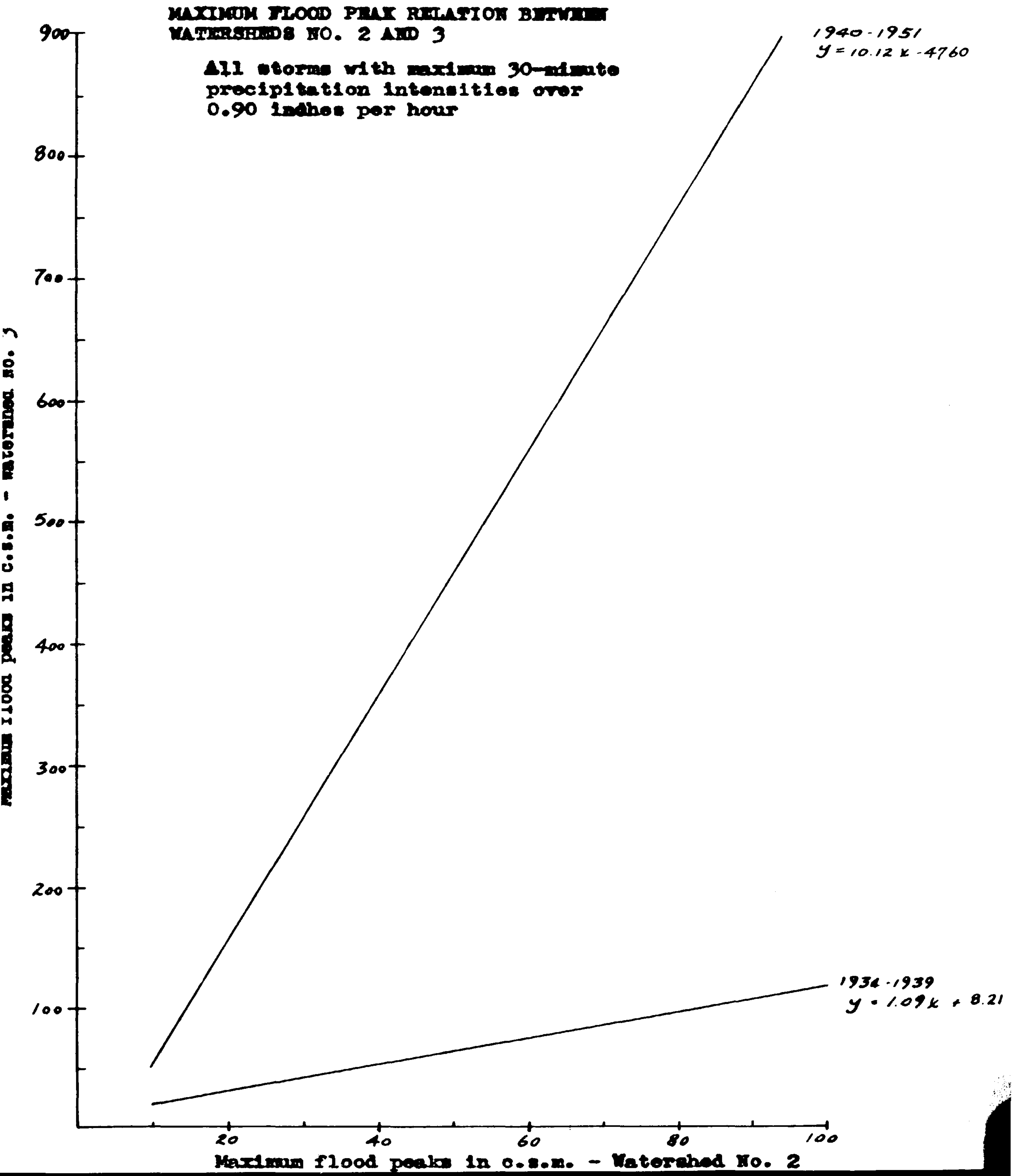
CHANGES IN FLOOD PEAKS FOLLOWING FOREST CUTTING AND MOUNTAIN FARMING

Inches Per Hour Precipitation for 15 Minutes	Peak c.s.m. 1934-1939	Peak c.s.m. 1940-1945	Percent Increase Over 1934-1939	Peak c.s.m. 1946-1951	Percent Increase Over 1934-1939
2	11	42	382	27	245
3	27	70	260	84	311
4	43	97	226	141	328
5	59	126	213	197	334

An additional study was made to show the changes in the magnitudes of flood peaks using all storms with maximum 30-minute precipitation intensities exceeding 0.90 inch per hour. In this study the maximum flood peaks in cubic feet per second per square mile from Watershed No. 3 were plotted against the maximum peaks recorded for the control watershed (No. 2) for the same storms for the 1934-1939 and 1940-1951 periods. Least square linear regressions were calculated and straight line curves fitted to the data. The results of this analysis are presented in Figure 47.

The increased magnitude of flood peaks is even more marked than in the case when only unit summer storms were used. Prior to the treatment of watershed No. 3, a storm producing a flood peak of 30 c.s.m. on watershed No. 2 showed a peak of 41 c.s.m. on watershed No. 3. Similarly, a storm producing a peak of 70 c.s.m. on watershed No. 2

Figure 47.



MAXIMUM FLOOD PEAK RELATION BETWEEN
WATERSHEDS NO. 2 AND 3
All storms with maximum 30-minute
precipitation intensities over
0.90 inches per hour
1940-1951
y = 10.12 x -47.60
1934-1939
y = 1.09 x + 8.21
900
800
700
600
500
400
300
200
100
20
40
60
80
100
Maximum flood peaks in c.s.m. - Watershed No. 3
Maximum flood peaks in c.s.m. - Watershed No. 2

produced a peak of about 85 c.s.m. for watershed No. 3. Following forest cutting and mountain farming, the peaks from watershed No. 3 corresponding to 41 and 85 values for the 1934-1939 period had increased to over 360 and 670 c.s.m. respectively.

In examining the individual storms and the resultant flood peaks, the highest flood peak recorded for the period that the watershed was in forest cover ~~noted~~ was 109 c.s.m. In the eleven-year period following forest cutting and mountain farming 12 floods occurred which exceeded this former maximum peak. The highest peak recorded was that of July 10, 1949 which exceeded 1850 cubic feet per second per square mile. The two highest 5-minute precipitation intensities recorded during the 17 years of record, however, both occurred prior to 1940 while the watershed was forest covered.

From these analyses it is apparent that the treatment of the Little Hurricane watershed has effected striking increases in the magnitude of flood peaks.

Flood peak frequencies. Even a cursory examination of the data reveals a marked change in the frequency of floods following forest cutting and treatment of the watershed. To get a quantitative measure of this change, a flood peak frequency study was made. The same standard used in the flood peak magnitude study, i. e., floods resulting from storms having a maximum 30-minute precipitation intensity of over 0.90 inch per hour, was used as the basis for this study, except that all storms, winter, intermediate and multiple as well as summer, were included.

The flood peaks for the watershed for the period in which the watershed was in forest cover, 1934-1939, and the treatment period, 1940-1951, were classified separately into 10 c.s.m. groups and arranged in order of magnitude. These values are given in column 2, Table XVII and are presented graphically in histograms of the flood peaks, Figure 48. Mass totals were then calculated in order of descending magnitude. From these values occurrence percentages were computed. The mid-points of the c.s.m. classes were then plotted against their corresponding percentages on a logarithmic scale and smooth curves fitted to the data to give the frequency curves in Figure 49. A logarithmic scale was selected for the ordinate in order to emphasize the maximum flood peaks since these are the values which are of greatest importance in watershed management and flood control work as well as in engineering structures for water and erosion control.

It is apparent from Figure 49 that a decided increase in flood frequencies has been effected. Assuming an average of 50 storms of flood magnitude in 10 years, 12 flood peaks over 50 c.s.m. could be expected with the watershed in forest cover. Compared with this, 25 flood peaks in excess of 50 c.s.m. should occur following forest cutting and subsequent mountain farming. On the same basis, at the 100 c.s.m.

TABLE XVII

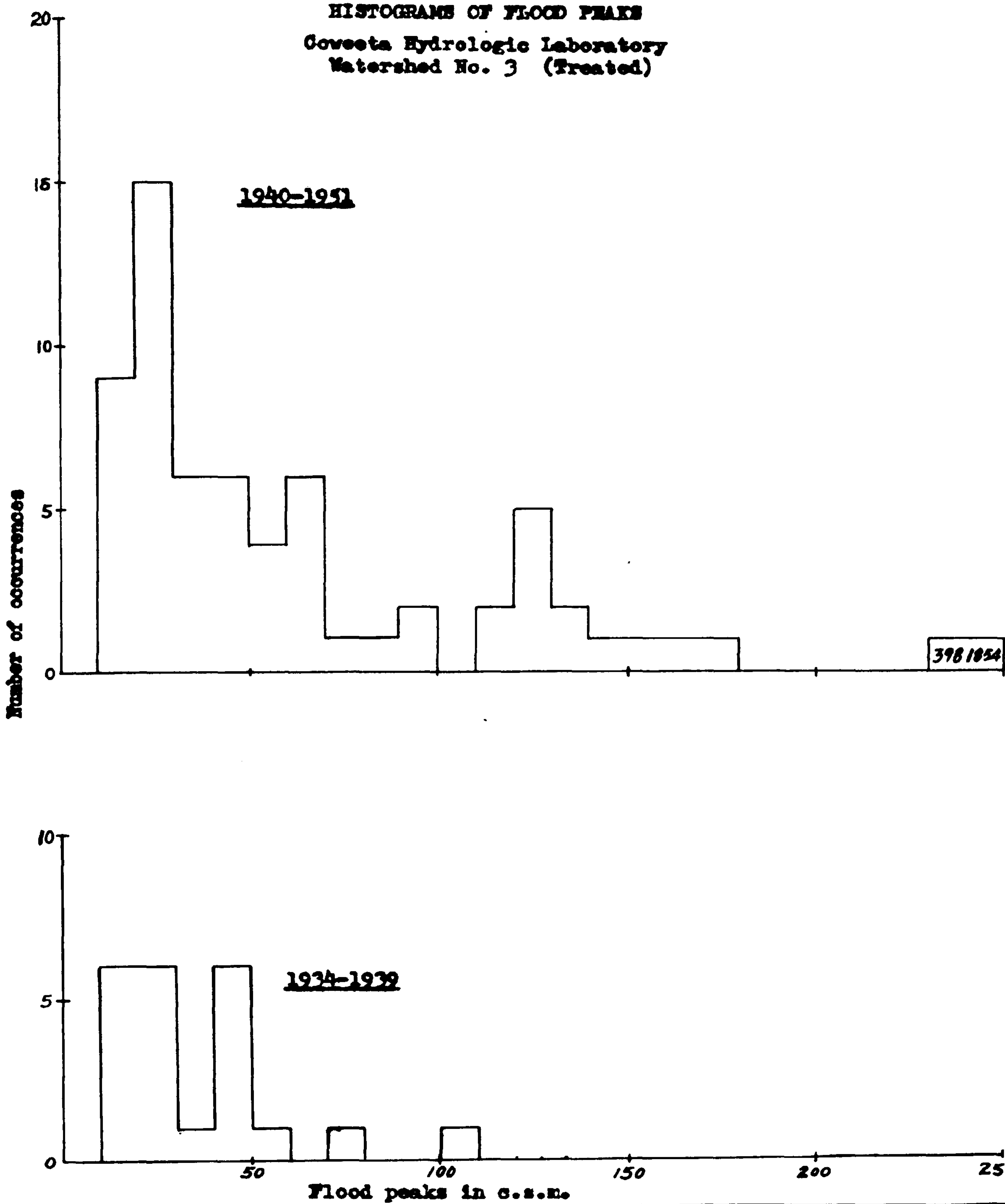
FLOOD PEAK FREQUENCY DATA, WATERSHED NO. 3

Flood Peak Classes in c.s.m.	Number of Occurrences		Mass Totals		Percentage of Total Occurrences	
	1934-1939	1940-1951	1934-1939	1940-1951	1934-1939	1940-1951
10-19	6	9	22	63	100	100
20-29	6	15	16	54	72.7	85.7
30-39	1	6	10	39	45.4	61.9
40-49	6	6	9	33	40.9	52.4
50-59	1	4	3	27	13.9	42.9
60-69		6		23		36.5
70-79	1	1	2	17	9.1	27.0
80-89		1		16		25.4
90-99		2		15		23.8
100-109	1		1		4.5	
110-119		2		13		20.6
120-129		5		11		17.5
140-149		2		6		9.5
170-179		1		4		6.3
190-199		1		3		4.8
390-399		1		2		3.2
1850-1859		1		1		1.6

Figure 48.

HISTOGRAMS OF FLOOD PEAKS

Coweeta Hydrologic Laboratory
Watershed No. 3 (Treated)



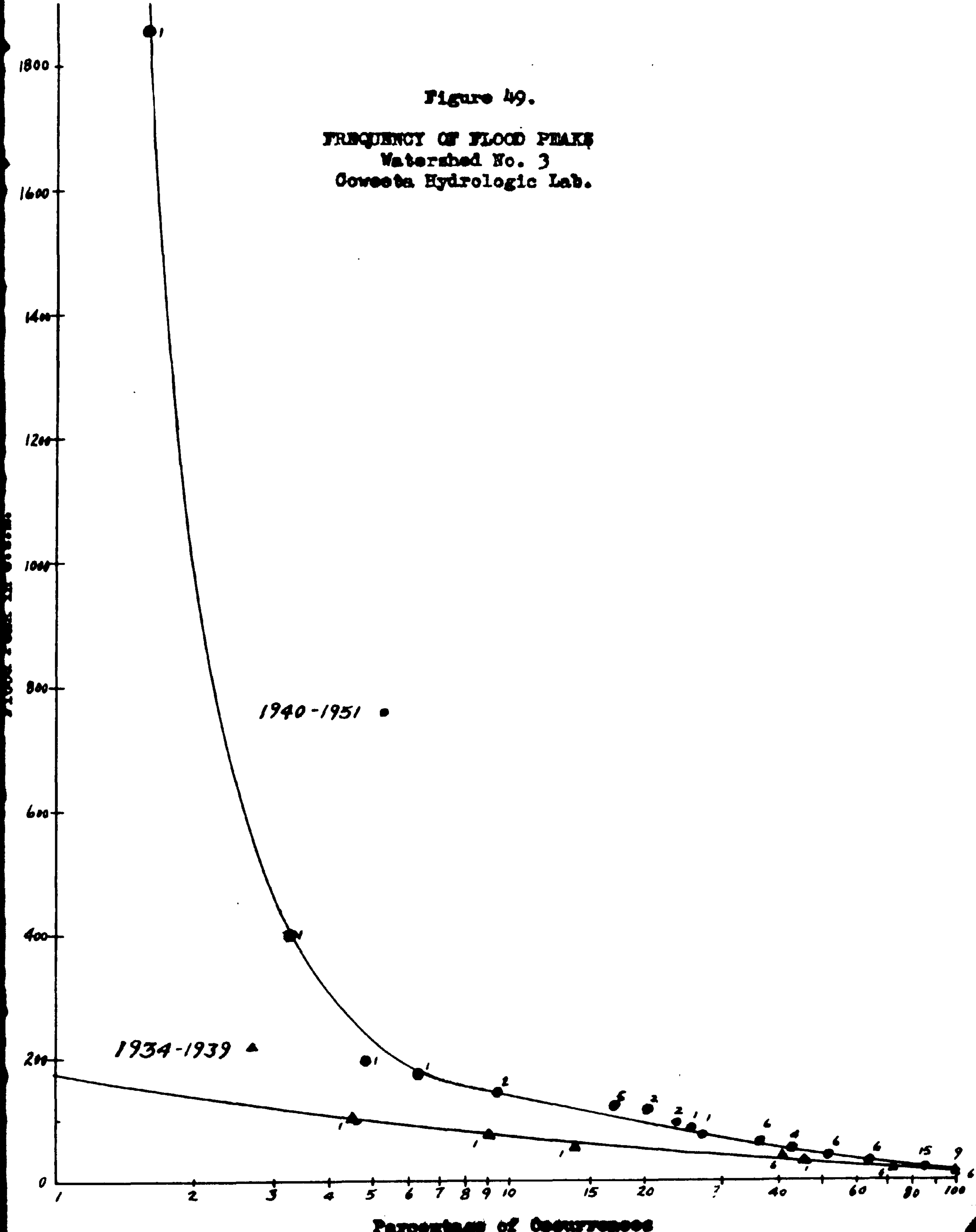


Figure 49.

FREQUENCY OF FLOOD PEAKS
Watershed No. 3
Coweeta Hydrologic Lab.

level, only 2 to 3 flood peaks from the forested watershed could be anticipated as compared with at least 10 flood peaks in excess of 100 c.s.m. from the treated watershed.

To show that the changes are a result of the treatment rather than of climatic fluctuations during the treatment period, the same procedure was followed for the control watershed which was in forest cover for the entire period, except that 5 c.s.m. classes were used to better define a curve in graphic presentation. These results are given in Table XVIII and Figures 50 and 51.

The corresponding curves for the control watershed, Figure 51, show that no great change has taken place in the precipitation pattern. Actually, the 1934-1949 period shows higher flood frequencies than the post-treatment period, indicating that possibly, had climatic conditions been even more alike for the two periods, the changes brought about on the treated watershed would probably have been even more marked.

Table XIX summarizes the changes in flood peaks at the 1, 2, 5, 10, 20, 50 and 80 percent levels for the Little Hurricane Watershed.

This increase in flood frequency, along with the increased magnitude, aids in explaining why channel bank vegetation is being removed and why the vegetation which starts growing on this site is washed away before it has an opportunity to become firmly established. It shows, too,

TABLE XVIII

FLOOD PEAK FREQUENCY DATA, CONTROL WATERSHED NO. 2

Flood Peak Classes in c.s.m.	Number of Occurrences		Mass Totals		Percentage of Total Occurrences	
	1934-1939	1940-1951	1934-1939	1940-1951	1934-1939	1940-1951
0-5		9		58		100
6-10	6	20	21	49	100	84.5
11-15	3	14	15	29	71.4	50.0
16-20	3	8	12	15	57.1	25.8
21-25	2		9		42.8	
26-30	1	2	7	7	33.3	12.1
31-35	1	1	6	5	28.6	8.6
36-40	1	1	5	4	23.8	6.9
41-45	2	1	4	3	19.0	5.2
51-55		1		2		3.4
56-60	1		2		9.5	
66-70		1		1		1.7
81-85	1		1		4.8	

Figure 50.

HISTOGRAMS OF FLOOD PEAKS
Coweeta Hydrologic Laboratory
Watershed No. 2 (Control)

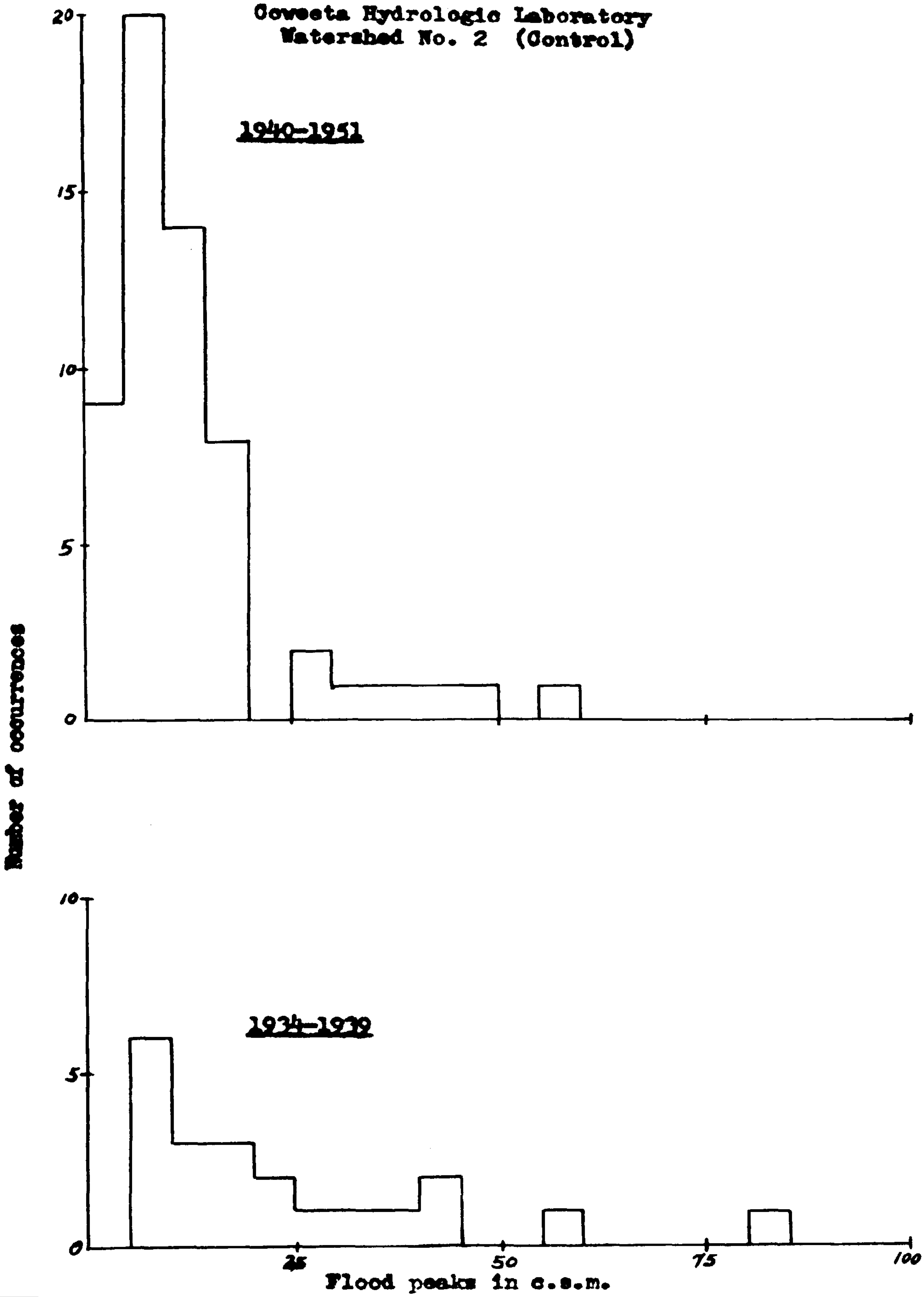
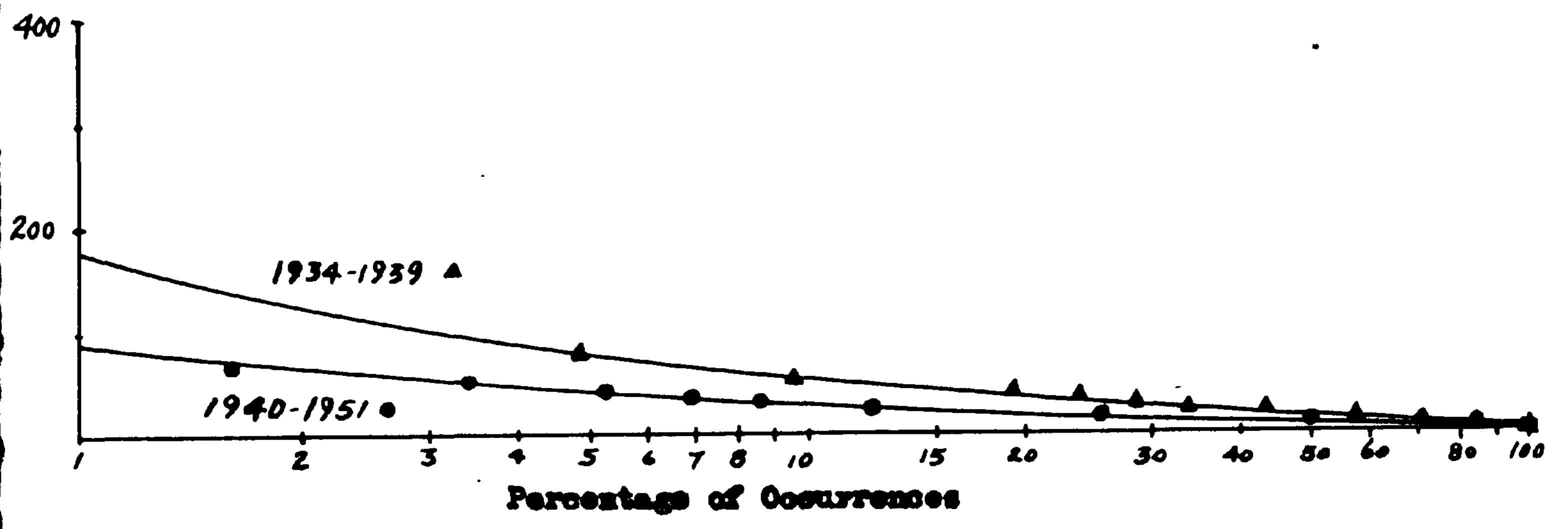


Figure 51.

FREQUENCY OF FLOOD PEAKS
Watershed No. 2
Coweeta Hydrologic Laboratory



why farmers of this area, in increasing numbers, are converting their first bottom-lands from truck and corn cultivation to permanent pastures.

TABLE XIX

FREQUENCY OF FLOOD PEAKS BEFORE AND AFTER FOREST CUTTING AND SUBSEQUENT MOUNTAIN FARMING

Period	Percent of Observations						
	1	2	5	10	20	50	80
	Maximum flood peak in c.s.m. exceeds						
1934-1939	175	135	100	75	55	30	20
1940-1951	2000+	1000	230	130	100	60	30

Distribution of Storm Runoff

To show the effects of forest cutting and subsequent mountain farming on the manner in which storm runoff comes off the experimental watershed, distribution graphs were made for the two periods: 1934-1939, in which the watershed was in forest cover, and 1940-1951, the mountain farming treatment period. The method outlined by Wisler and Brater (36) was used to prepare the storm runoff distribution graphs.

Five storms, two for the "before" period and three for the "after" period were selected for this study on the basis of similarity in storm type and precipitation amount and intensity. The bases of the hydrographs were divided into three-minute intervals and the total flow and the base flow were calculated for these intervals. Three-minute intervals were selected to give a total of approximately 20 equal intervals or points for subsequent graphical analysis. Storm runoff was obtained by subtracting base flow from total flow (unit hydrographs). Storm runoff percentages were then computed for each three-minute interval. Tables XX through XXIV show the calculations for the individual storms.

The values for the "before" and "after" periods were then averaged to give the composite distribution graph data which is shown in Tables XXV and XXVI. These data were then plotted to give the final distribution graphs for the two periods which appear in Figure 52.

To show the differences in the volume of storm runoff coming off the watershed at maximum flood stage, a time period equal to one-tenth the base of the hydrograph (three-minute interval on each side of the actual peak) was marked off on the distribution graphs and the percentages for these intervals were determined by planimeter. These results are indicated on Figure 52.

It is obvious from these graphs that a definite change has taken place in the distribution of the storm runoff. One notable effect is the change in the time of concentration (time that runoff began to the maximum peak) for the watershed. While the watershed was in forest cover, the peak occurred approximately 35 minutes from the time storm runoff first began. Following forest cutting and mountain farming

TABLE XX

DERIVATION OF DATA FOR DISTRIBUTION GRAPH FOR STORM OF JUNE 12, 1936

1 3-Minute Interval Number	2 Total Head in In./Hr. Inst.	3 Ave.	4 Volume in Cubic Feet (Interval)	5 Base Flow Head in In./Hr. Inst.	6 Ave.	7 Volume in Cubic Feet (Interval)	8 Storm Runoff Volume in Cubic Feet	9 Percent of Total Storm Runoff
0	.0070			.0070				
1	.0082	.0076	31.43	.0073	.00715	29.57	1.86	.29
2	.0096	.0089	36.81	.0076	.00745	30.81	6.00	.95
3	.0110	.0103	42.60	.0079	.00775	32.05	10.55	1.67
4	.0124	.0117	48.39	.0081	.00805	33.29	15.10	2.39
5	.0136	.0130	53.77	.0084	.00825	34.12	19.65	3.12
6	.0162	.0149	61.63	.0087	.00855	35.36	26.27	4.16
7	.0194	.0178	73.62	.0090	.00885	36.60	37.02	5.87
8	.0210	.0202	83.55	.0093	.00915	37.84	45.71	7.25
9	.0240	.0225	93.06	.0096	.00945	39.09	53.97	8.56
10	.0274	.0257	106.30	.0099	.00975	40.33	65.97	10.46
11	.0302	.0288	119.12	.0102	.01005	41.57	77.55	12.29
12	.0298	.0300	124.08	.0104	.01030	42.60	81.48	12.91
13	.0210	.0254	105.05	.0103	.01035	42.81	62.24	9.87
14	.0182	.0196	81.07	.0102	.01025	42.39	38.68	6.13
15	.0160	.0171	70.73	.0100	.01010	41.77	28.96	4.59
16	.0144	.0152	62.87	.0098	.00990	40.95	21.92	3.48
17	.0130	.0137	56.66	.0096	.00970	40.12	16.54	2.62
18	.0120	.0125	51.70	.0094	.00950	39.29	12.41	1.98
19	.0100	.0110	45.50	.0092	.00930	38.46	7.04	1.12
20	.0090	.0095	39.29	.0090	.00910	37.64	1.83	.29
Totals			1387.23			756.48	630.75	100.00

Conversion Factor: Inches per hour to cubic feet for 3 minutes equals 180/.04352 equals 4136.

TABLE XXI

DERIVATION OF DATA FOR DISTRIBUTION GRAPH FOR STORM OF JUNE 15, 1937

1	2	3	4	5	6	7	8	9
3-Minute Interval Number	Total Head in In./Hr. Inst.	Ave.	Volume in Cubic Feet (Interval)	Base Flow Head in In./Hr. Inst.	Ave.	Volume in Cubic Feet (Interval)	Storm Runoff Volume in Cubic Feet	Percent of Total Storm Runoff
0	.0022			.0022				
1	.0045	.00335	13.86	.0024	.0023	9.51	4.35	.49
2	.0065	.00550	22.75	.0026	.0025	10.34	12.41	1.40
3	.0080	.00725	29.99	.0028	.0027	11.17	18.82	2.13
4	.0100	.00900	37.22	.0030	.0029	11.99	25.23	2.86
5	.0120	.01100	45.50	.0032	.0031	12.82	32.68	3.70
6	.0135	.01275	52.73	.0035	.00335	13.86	38.87	4.40
7	.0155	.01450	59.97	.0039	.0037	15.30	44.67	5.06
8	.0190	.01725	71.35	.0042	.00405	16.75	54.60	6.18
9	.0220	.02050	84.79	.0046	.0044	18.20	66.59	7.54
10	.0260	.02400	99.26	.0049	.00475	19.65	79.61	9.01
11	.0290	.02750	113.74	.0052	.00505	20.89	92.85	10.51
12	.0290	.02900	119.94	.0052	.0052	21.51	98.43	11.14
13	.0240	.02650	109.60	.0052	.0052	21.51	88.09	9.97
14	.0200	.02200	90.99	.0051	.00515	21.30	69.69	7.89
15	.0150	.01750	72.38	.0051	.0051	21.09	51.29	5.81
16	.0127	.01385	57.28	.0051	.0051	21.09	36.19	4.10
17	.0115	.01210	50.05	.0051	.0051	21.09	28.96	3.28
18	.0090	.01025	42.39	.0050	.00505	20.89	21.50	2.43
19	.0075	.00825	34.12	.0050	.0050	20.68	13.44	1.52
20	.0050	.00625	25.85	.0050	.0050	20.68	5.17	.59
Totals			1233.76			350.32	883.44	100.00

Conversion Factor: Inches per hour to cubic feet for 3 minutes equals 180/.04352 equals 4136.

TABLE XXII

DERIVATION OF DATA FOR DISTRIBUTION GRAPH FOR STORM OF JULY 11, 1946

1	2	3	4	5	6	7	8	9
3-Minute Interval Number	Total Head in In./Hr. Inst.	Ave.	Volume in Cubic Feet (Interval)	Base Flow Head in In./Hr. Inst.	Ave.	Volume in Cubic Feet (Interval)	Storm Runoff Volume in Cubic Feet	Percent of Total Storm Runoff
0	.0045			.0045				
1	.0085	.0065	26.88	.0055	.0050	20.68	6.20	.45
2	.0300	.0198	81.89	.0065	.0060	24.82	57.07	4.10
3	.0950	.0625	258.50	.0075	.0070	28.95	229.55	16.49
4	.0900	.0925	382.58	.0073	.0074	30.61	351.97	25.29
5	.0675	.0788	325.92	.0072	.0072	29.78	296.14	21.28
6	.0400	.0538	222.52	.0071	.0072	29.37	193.15	13.88
7	.0260	.0330	136.49	.0070	.0070	28.95	107.54	7.73
8	.0150	.0205	84.79	.0068	.0069	28.54	56.25	4.04
9	.0125	.0138	57.08	.0067	.0068	28.12	28.96	2.08
10	.0115	.0120	49.63	.0066	.0066	27.30	22.33	1.60
11	.0100	.0108	44.67	.0064	.0065	26.88	17.79	1.28
12	.0085	.0092	38.05	.0063	.0064	26.47	11.58	.83
13	.0075	.0080	33.09	.0062	.0062	25.64	7.45	.54
14	.0068	.0072	29.78	.0061	.0062	25.64	4.14	.30
15	.0060	.0064	26.47	.0060	.0060	24.82	1.65	.12
Totals			1798.34			406.57	1391.77	100.01

Conversion Factor: Inches per hour to cubic feet for 3 minutes equals 180/.04352 equals 4136.

DERIVATION OF DATA FOR DISTRIBUTION GRAPH FOR STORM OF MAY 22, 1949

1 3-Minute Interval Number	2 Total Head in In./Hr. Inst.	3 Ave.	4 Volume in Cubic Feet (Interval)	5 Base Flow Head in In./Hr. Inst.	6 Ave.	7 Volume in Cubic Feet (Interval)	8 Storm Runoff Volume in Cubic Feet	9 Percent of Total Storm Runoff
0	.0060			.0060				
1	.0080	.0070	28.95	.0065	.0062	25.64	3.31	.13
2	.0110	.0095	39.29	.0070	.0068	28.12	11.17	.45
3	.0190	.0150	62.04	.0075	.0072	29.78	32.26	1.30
4	.0800	.0495	204.73	.0078	.0076	31.43	173.30	6.97
5	.1890	.1345	556.29	.0080	.0079	32.67	523.62	21.06
6	.1050	.1970	814.79	.0080	.0080	33.09	781.70	31.44
7	.0530	.0790	326.74	.0079	.0080	33.09	293.65	11.81
8	.0420	.0475	196.46	.0079	.0079	32.67	163.79	6.59
9	.0330	.0375	155.10	.0078	.0078	32.26	122.84	4.94
10	.0280	.0305	126.15	.0078	.0078	32.26	93.89	3.78
11	.0230	.0255	105.47	.0077	.0078	32.26	73.21	2.94
12	.0200	.0215	88.92	.0076	.0076	31.43	57.49	2.31
13	.0170	.0185	76.52	.0075	.0076	31.43	45.09	1.81
14	.0150	.0160	66.18	.0075	.0075	31.02	35.16	1.41
15	.0125	.0138	57.08	.0074	.0074	30.61	26.45	1.06
16	.0110	.0118	48.80	.0074	.0074	30.61	18.19	.73
17	.0090	.0100	41.36	.0073	.0074	30.61	10.75	.43
18	.0085	.0088	36.40	.0073	.0073	30.19	6.21	.25
19	.0080	.0082	33.92	.0072	.0072	29.78	4.14	.17
20	.0078	.0079	32.67	.0071	.0072	29.78	2.89	.12
21	.0076	.0077	31.85	.0071	.0071	29.37	2.48	.10
22	.0074	.0075	31.02	.0070	.0070	28.95	2.07	.08
23	.0072	.0073	30.19	.0070	.0070	28.95	1.24	.05
24	.0070	.0071	29.37	.0069	.0069	28.54	.83	.03
25	.0068	.0069	28.54	.0068	.0068	28.12	.42	.02
Totals			3248.81			762.66	2486.15	99.98

Conversion Factor: Inches per hour to cubic feet for 3 minutes equals 180/.04352 equals 4136.

TABLE XXIV

DERIVATION OF DATA FOR DISTRIBUTION GRAPH FOR STORM OF AUGUST 4, 1949

1	2	3	4	5	6	7	8	9
3-Minute Interval Number	Total Head in In./Hr. Inst.	Ave.	Volume in Cubic Feet (Interval)	Base Flow Head in In./Hr. Inst.	Ave.	Volume in Cubic Feet (Interval)	Storm Runoff Volume in Cubic Feet	Percent of Total Storm Runoff
0	.0040			.0040				
1	.0080	.0060	24.82	.0048	.0044	18.20	6.62	.49
2	.0180	.0130	53.77	.0054	.0051	21.09	32.68	2.40
3	.1150	.0665	275.04	.0064	.0059	24.40	250.64	18.44
4	.1500	.1325	548.02	.0068	.0066	27.30	520.72	38.31
5	.0260	.0880	363.97	.0064	.0066	27.30	336.67	24.77
6	.0180	.0220	90.99	.0063	.00635	26.26	64.73	4.76
7	.0145	.01625	67.21	.0062	.00625	25.85	41.36	3.04
8	.0124	.01345	55.63	.0061	.00615	25.44	30.19	2.22
9	.0105	.01145	47.36	.0060	.00605	25.02	22.34	1.64
10	.0100	.01025	42.39	.0060	.0060	24.82	17.57	1.29
11	.0085	.00925	38.26	.0059	.00595	24.61	13.65	1.00
12	.0075	.0080	33.09	.0058	.00585	24.20	8.89	.65
13	.0065	.0070	28.95	.0057	.00575	23.78	5.17	.38
14	.0062	.00635	26.26	.0057	.0057	23.58	2.68	.20
15	.0060	.0061	25.23	.0056	.00565	23.37	1.86	.14
16	.0058	.0059	24.40	.0056	.0056	23.16	1.24	.09
17	.0057	.00575	23.78	.0055	.00555	22.95	.83	.06
18	.0056	.00565	23.37	.0055	.0055	22.75	.62	.04
19	.0055	.00555	22.95	.0054	.00545	22.54	.41	.03
20	.0054	.00545	22.54	.0054	.0054	22.33	.21	.02
Totals			1838.03			478.95	1359.08	99.97

Conversion Factor: Inches per hour to cubic feet for 3 minutes equals 180/.04352 equals 4136.

TABLE XXV

COMPOSITE DISTRIBUTION GRAPH DATA FOR "BEFORE" PERIOD - 1934-1939

Interval Number	Percent of Total Storm Runoff — Date of Storm: 6/12/36	6/15/37	Average
1	.29	.49	.39
2	.95	1.40	1.18
3	1.67	2.13	1.90
4	2.39	2.86	2.62
5	3.12	3.70	3.41
6	4.16	4.40	4.28
7	5.87	5.06	5.46
8	7.25	6.18	6.72
9	8.56	7.54	8.05
10	10.46	9.01	9.74
11	12.29	10.51	11.40
12	12.91	11.14	12.02*
13	9.87	9.97	9.92
14	6.13	7.89	7.01
15	4.59	5.80	5.20
16	3.48	4.10	3.79
17	2.62	3.28	2.95
18	1.98	2.43	2.20
19	1.12	1.52	1.32
20	.29	.58	.44

*Flood peaks matched

TABLE XXVI

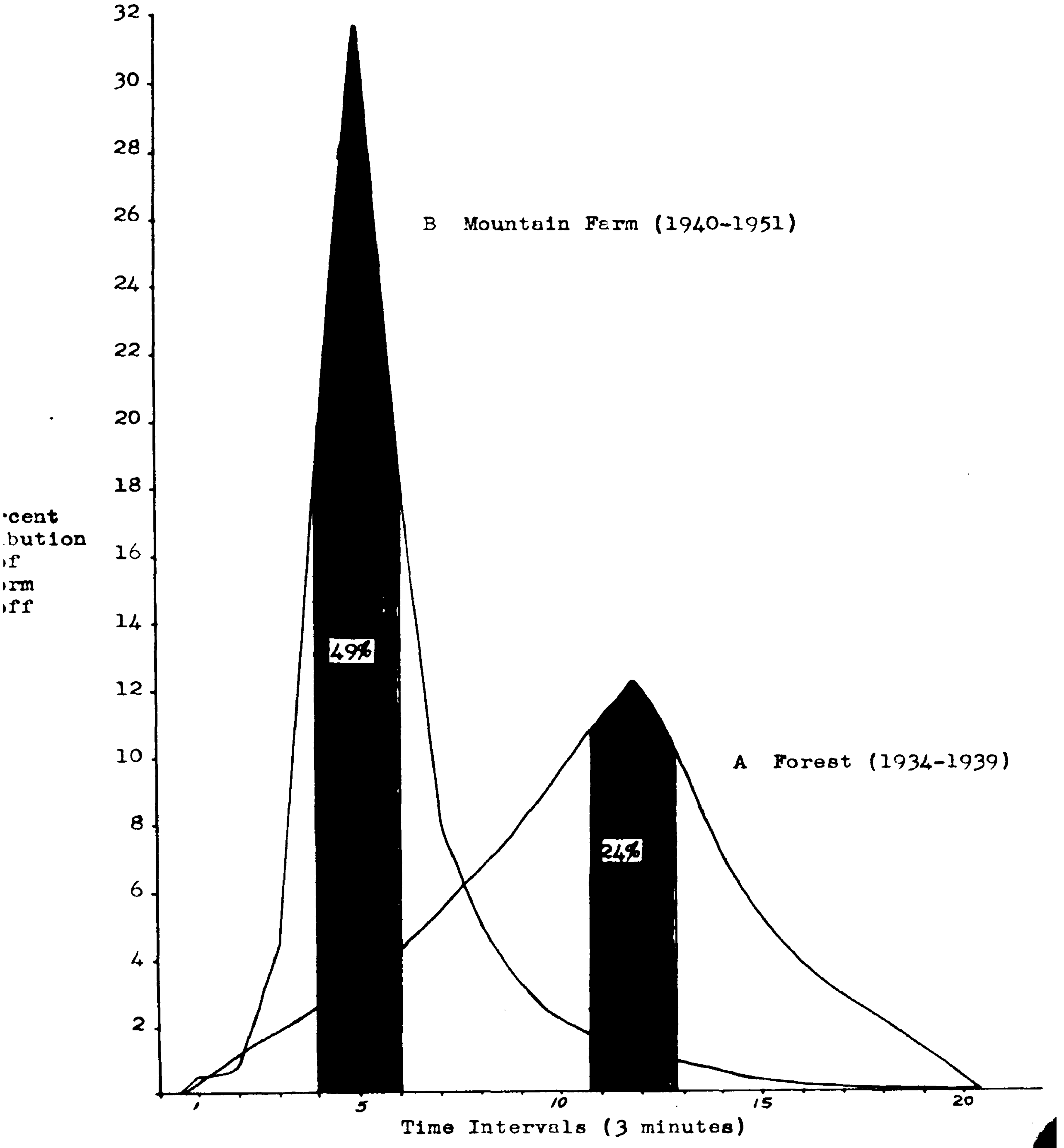
COMPOSITE DISTRIBUTION GRAPH DATA
FOR "AFTER" PERIOD - 1940-1951

Interval Number	Percent of Total Storm Runoff			Average
	Date of Storm			
	7/11/46	4/22/49	8/4/49	
		.13		.04*
1		.45		.15
2	.45	1.30	.49	.75
3	4.10	6.97	2.40	4.49
4	16.49	21.06	18.44	18.66
5	25.29	31.44	38.31	31.68**
6	21.28	11.81	24.77	19.29
7	13.88	6.59	4.76	8.41
8	7.73	4.94	3.04	5.29
9	4.04	3.78	2.22	3.35
10	2.08	2.94	1.64	2.22
11	1.60	2.31	1.29	1.73
12	1.28	1.81	1.00	1.36
13	.83	1.41	.65	.96
14	.54	1.06	.38	.66
15	.30	.73	.20	.41
16	.12	.43	.14	.23
17		.25	.09	.11
18		.17	.06	.08
19		.12	.04	.05
20		.10	.03	.04
		.08		.03*
		.05		.02*
		.03		.01*
		.02		.01*

*Values dropped to give 20 intervals
**Flood peaks matched

Figure 52

THE EFFECTS OF FOREST CUTTING AND SUBSEQUENT MOUNTAIN FARMING ON THE DISTRIBUTION OF STORM RUNOFF.
Coweeta Hydrologic Laboratory
Watershed No. 3



the peak occurred on the average of 15 minutes after runoff began. In a few cases with short, intense summer storms, the time from the start of runoff to the peak was observed to be as little as 10 minutes.

It is apparent, too, that the peak percentage itself was more than doubled as a result of the treatment. While in forest cover, the maximum value was approximately 12 percent; following cutting and treatment, this value jumped to approximately 32 percent. Apparent, too, is the change in shape of the hydrograph to an almost needle-shaped storm hydrograph.

Significant, too, is the change in the peak percentage based on the maximum discharge for a time period equal to one-tenth the base of the storm hydrograph. For the "before" period, indicated as "A" in Figure 52, this amounted to 24 percent of the total storm runoff. As a result of the treatment, the peak percentage "B" in Figure 52 increased to 49 percent.

SUMMARY

For many years it has been a common practice in the Southern Appalachians to clear off the native forest cover on steep slopes and then to attempt to farm the area. In this study a determination of the effects of this use of land on some of the biologic, edaphic and surface runoff characteristics of a 23-acre watershed was made with the following results.

Biologic Changes

By clearcutting the forest cover and applying different land use practices to the watershed a marked change in the vegetation was produced. Nearly half of the watershed, approximately 10 acres, was permitted to grow back into natural forest cover. Eleven years after cutting and negligible use by cattle, the dominant sprouts and seedling trees are approximately 3 to 3½ inches in diameter at breast height and 12 to 15 feet in height. By examining adjacent uncut areas and timber cruise data it was found that there is little change in species composition except for the presence of wild plum, hawthorne and staghorn sumac on the cutover area. These invading species will probably disappear within a few years following complete canopy closure.

Shrubby and herbaceous cover in the coppice forest area is very sparse except along the ridges and in a few openings. Many species associated with forest openings were observed although most of these will probably disappear within a few years. In the more dense portions of the coppice area blackberry, for example, has virtually disappeared although there is ample evidence of its former occupation. In most of the adjoining forest area there is a moderate understory of mountain laurel and rhododendron. It is apparently much slower in becoming re-established than many other species since it is fairly common only near the ridges in the coppice forest area.

In the two pasture areas as well as in the abandoned cornfield, the most marked changes are those in vegetation density and in species composition of the shrubby and herbaceous cover. On all three areas vegetation density is low, particularly in the lower pasture. Changes in species composition were marked by the appearance of such more or less noxious or unpalatable species as mullein, yarrow, Canada thistle, smartweed, nettle and purslane -- all frequently associated with land abuse. The forest tree seedlings and sprouts observed in 1951 consisted of about the same species which were represented on the area prior to clearcutting. Invading species included green ash, hawthorne, black walnut and butternut.

In the control plots, established in the cornfield at the time it was abandoned in 1949, the ground cover is nearly complete after only two years. The most abundant species in these two plots are blackberry and wild strawberry. It is obvious in both plots that tree species will soon take over. Numerous stems in both plots exceed 5 feet in height.

In the absence of forest vegetation, stream temperatures increased to the point where they were higher than the maximum limits for trout. Similarly, stream turbidities were increased by approximately three times. Consequently, due to changes, the stream is no longer suitable for trout habitation.

Edaphic Changes

The physical characteristics of the soil influence the rate at which precipitation enters and is transmitted through the soil and these factors in turn affect stream flow. A summary of the physical properties of the soils on different parts of the watershed are presented in Table XXVII. In addition, infiltration studies were made in 1949 and 1950 by the Coweeta Hydrologic Laboratory.

The results of the surface infiltration study made in 1949 showed marked differences in the infiltration rates of the portions of the watershed used in different ways. In all the forested plots sampled on the Coweeta area, including the coppice forest portion of the Little Hurricane

TABLE XXVII

SUMMARY OF PHYSICAL CHARACTERISTICS OF THE SOIL

Site	Volume Weight	Total Porosity	Capillary Porosity	Non-Capillary Porosity	Perme-ability	Organic Matter Content	Sand and Coarser Material	Aggregates over 4 mm.
		Percent	Percent	Percent	In./Hr.	Percent	Percent	Percent
<u>0-3 inch layer</u>								
Undisturbed forest	.88	56.8	36.1	20.7	171.1	7.03	81.7	85.5
Coppice forest	.82	60.5	36.0	24.5	163.0	8.97	91.4	73.2
Upper pasture	1.03	53.9	39.0	14.9	20.2	7.62	99.6	64.1
Lower pasture	1.11	52.5	37.9	14.6	6.6	4.00	97.7	53.9
Cornfield	.93	56.1	40.1	16.0	12.4	4.40	99.1	59.0
Control plots (cornfield)	.98	53.8	29.2	24.6	85.0	7.28	91.0	46.2
<u>3-6 inch layer</u>								
Undisturbed forest	1.05	54.9	32.6	22.3	64.2	4.87	82.8	73.8
Coppice forest	.98	57.1	37.0	20.1	94.7	5.51	97.4	63.5
Upper pasture	1.07	56.2	37.7	18.5	16.9	4.41	95.8	48.6
Lower pasture	1.28	50.5	35.4	15.1	2.7	2.43	90.4	56.7
Cornfield	1.06	56.1	40.5	15.6	8.9	4.58	95.6	62.2
Control plots (cornfield)	1.06	51.0	37.9	13.1	64.0	4.62	89.9	40.1

Watershed, the average infiltration rate invariably exceeded six inches per hour. The values noted for the cornfield, upper pasture and lower pasture respectively in 1949 were 4.00, 3.00 and 0.56 inches per hour. Since the majority of storms on the Coweeta area show precipitation intensities in excess of 0.56 inches per hour, high surface runoff rates would be anticipated from the lower pasture. Similar infiltration tests made on the abandoned cornfield immediately before and following grazing in 1950 indicated that even short periods of grazing caused sharp decreases in the infiltration rate.

As indicated by samples collected from adjacent undisturbed forest plots, the permeability of the soil averaged approximately 171 inches per hour in the 0-3 inch layer and over 64 inches per hour in the 3-6 inch zone. Tests after treatment indicate a marked decrease in these rates, ranging as low as those in the lower pasture, where the average rates were 6.6 and 2.7 inches per hour for the 0-3 and 3-6 inch layers respectively.

The percent of water-stable aggregates likewise showed a marked decrease, from 85.5 and 73.8 percent of aggregates over 4 mm. in size in the surface and sub-surface layers for the undisturbed forest respectively, to a low of 46.2 and 40.1 in the control plots in the abandoned cornfield. The soil dispersion resulting from the decrease in aggregation is undoubtedly responsible for increases in soil losses from the watershed and indirectly for the increases in surface runoff. An analysis of the aggregation of the fine earth material indicated similar results.

Differences in organic matter content, volume weight and porosity are also evident. The effect of former cultivation in the abandoned cornfield is evidenced in that the organic matter content of both surface and sub-surface layers are nearly the same. In the control plots in the abandoned cornfield the organic content of the sub-surface layer is approximately the same as in the cornfield. However, the two years protection offered the control plots appears to have been sufficient to increase the organic matter content materially in the surface layer. The lowest organic matter content in both layers is noted for the lower pasture. Apparently grazing has effected soil compaction and thus inhibited the incorporation of litter and humus. It is probable, too, that earlier cultivation of this area may have brought about soil changes in the lower pasture. The coppice forest area shows the highest content of organic matter in both layers. This is probably the result of an accumulation of litter from slash and from a heavy herbaceous cover following clearcutting and the decaying of root systems from the trees formerly occupying the area.

The greatest differences in volume weight in both layers were found between coppice forest and lower pasture, indicating a close relationship between organic matter content and volume weight. In the surface layer, volume weight values range from 0.82 to 1.11. In the sub-surface layer all values are very nearly the same except in the lower pasture where volume weight was 1.28, again showing the effects of heavy trampling. These values, as well as those noted for organic matter content, suggest that the most marked changes in the physical characteristics of the soil occur in the 0-3 inch layer.

In porosity values, a slight decrease in total and non-capillary porosity and an increase in capillary porosity, in comparison with undisturbed forest conditions, is indicated. In non-capillary porosity a decrease of approximately 6 per-cent by volume is shown. According to many writers, non-capillary porosity determines permeability. From the results of these determinations, small changes in the large pore volume, then, may effect marked changes in permeability rates.

One of the greatest changes in the soil as a consequence of the treatment is in soil losses from the watershed. During the calibration period, 1934-1939, and until August, 1941 the average soil losses amounted to about 154 pounds per acre per year. Following the cutting of the forest and the application of mountain farming practices, the average soil losses increased to well over a ton per acre per year. A small portion of this increase might perhaps be attributed to a change in the method of collecting soil losses. However, virtually all the increase should be assigned to the treatment of the watershed.

Cultivation alone appears to be responsible for marked increases in soil losses. These losses increased sharply for a two-year period following the cutting of the forest cover in which the cornfield was cultivated and the pasture areas were grazed. During 1944 and 1945 the cornfield was protected and permitted to lie idle while the pastures were being grazed. During this period, soil losses dropped noticeably. Following this period, the cornfield was again cultivated for four years and the soil losses mounted to a high in 1949 or over 2½ tons per acre per year. In 1950 and 1951 the cornfield was abandoned for cultivation and grazed along with the two pasture areas and again soil losses declined.

Runoff Changes

A study made on the Little Hurricane Watershed indicated an average runoff percent of 2.66 for all storms with a maximum 30-minute precipitation intensity over 0.90 inches per hour for the period in which the area was in forest cover. Following forest cutting and mountain farming this was increased to 4.50 percent. Summer storms alone gave percentages of 1.53 and 4.79 for the before and after periods, respectively.

From field observations and from the results of infiltration and permeability tests it was felt that the coppice forest area and possibly portions of the upper pasture as well, were not contributing materially to the total volume of surface runoff. Based on this assumption the runoff percentages were calculated on the basis that 6, 8, 10 and 12 acres were contributing all the surface runoff. It is highly probable that the small heavily-grazed and cultivated areas are the significant flood source areas and consequently have an effect on total watershed conditions far out of proportion to their actual area.

A very significant change in the magnitude of flood peaks occurred as a result of the land use treatment applied. Unit summer storms yielding precipitation at the rate of three inches per hour for 15 minutes, for example, showed an increase in the resulting maximum flood peak from 27 to 84 cubic feet per second per square mile. At the rate of five inches per hour for 15 minutes the increase theoretically would be from 59 c.s.m. to approximately 335 c.s.m.

A study of flood peak frequencies for the watershed indicated similar marked changes. Histograms of the flood peaks show that during the period of standardization (land in forest cover), 1934-1939, only three floods occurred with maximum peaks over 50 c.s.m. (three per five years). From 1940 to 1951, after clearing and cultivation, 25 floods with maximum peaks in excess of 50 c.s.m. were noted (more than ten per five years). A similar analysis of data from a control watershed actually indicated lower frequency values for the later period.

One of the most significant changes in surface runoff brought about by forest cutting and subsequent mountain farming is the manner in which the runoff water comes off the watershed. Runoff distribution graphs for the before and after periods show that the peak runoff occurs about 15 minutes after the beginning of a storm, since the area has been cleared and farmed. Before clearing, the peak runoff did not occur until about 35 minutes after the beginning of a storm. For both periods the duration of runoff was approximately 60 minutes. Prior to treatment approximately 12.5 percent of the storm flow came off the watershed during the peak 3-minute interval. Following treatment, this value jumped to nearly 32 percent.

PRACTICAL IMPLICATIONS FOR LAND USE

As a result of increasing population and economic pressures, thousands of acres of steep forest land within the Southern Appalachian region have been cleared for use as pasture or cropland. The advisability of this practice has been extremely questionable from an agronomic and, particularly, from a hydrologic standpoint. The results of this study show that forest cutting and the application of average to poor farming practices have a very deleterious effect upon the physical properties of the surface soil and increase surface runoff during storms.

The common practice in this region is to cut off the forest cover, plow the selected area and plant it to row crops. Within a short period of time after cultivation is begun, the organic constituents and natural structure of the former forest soil begins to break down, leading to soil dispersion and resultant accelerated erosion. In cultivating row crops on steep land the exposed topsoil washes away increasingly with each year and fertility declines until, after a period of approximately 10 to 15 years, yields have decreased to the point where the venture is no longer profitable.

Since the farmer invested a great deal of labor in the original clearing he frequently decides to convert the worn-out area to pasture instead of allowing it to return to forest cover.

All too frequently the land now becomes over-grazed, resulting in rapid compaction of the already eroded soil due to trampling by the cattle. Infiltration and permeability rates quickly decline and the soil loses its capacity for water storage. The cumulative effect of these abuses is to increase the volume of surface runoff and to multiply the frequency and magnitude of floods many times over that which would have occurred under natural forest conditions.

At first glance, it might appear that the injury is confined to an already worn-out area and thus is of minor consequence. However, once these floods begin to occur in increasing number and magnitude, it becomes clear that the damage is much more extensive and much more serious.

The increased erosion produces sediment which silts in reservoir systems. When such lands are part of a watershed contributing to a municipal water supply, increased turbidity of the streams may result in a necessity for purification.

Such flood source areas produce erosion on lower lands which normally would not be subject to serious soil washing. Within the past ten years many farmers in this region, who depended on the cultivation of row and truck crops in the first bottom lands along the streams for their greatest source of income, have been forced to convert their first bottom lands to permanent pasture which can withstand increased flooding.

Results such as these could probably be expected from average to poor farming practices in other areas with similar topography and soils. It might be suggested that better farming methods could alleviate the situation. Corn might be rotated with clover and small grains and the amount of fertilizer used could be increased to advantage. Less damage from trampling would occur if fences were erected and a more restricted number of cattle permitted to graze. However, all these improved practices are difficult and expensive on such steep land.

When stream conditions in undisturbed forests are observed, one is convinced that good forests, good soils and good water go hand in hand. Soil conditions under undisturbed forest encourage storage of water and make possible the control of erosion. It is reasonable to believe that through the ages there has developed an harmonious adjustment of vegetation, soil and water. This natural adjustment, however, appears to be in delicate balance. It is impossible to disturb the forest without disturbing this equilibrium.

It is obviously impractical, however, to leave all land in forest no matter how excellent the supply of water thus assured would be. Land must be used, but must also be carefully managed in order to husband its potentialities for human satisfaction. As we come to understand all of the physical forces which must be kept in balance, we will be better able to develop land management practices which will permit us to utilize all resources without exploiting any one at the expense of another.

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APPENDIX

Coweeta Hydrologic Laboratory
Southeastern Forest Experiment Station
Watershed No. 3
Catalog of Storms Having Maximum 30-minute Precipitation Intensity over 0.90 Inches Per Hour

	Peak Runoff					
	CFS	CSM	"/Hr.	Time	Peak Type	Total Precipitation inches
Before Period 1934-1939						
1 Aug. 22, 1935		48	.07446	2035	S	1.91
2 Apr. 2, 1936		46	.07129	0210	M	4.10
3 Jun. 12, 1936	.7494	21	.03261	1450	S	0.91
4 Jul. 12, 1936	1.5160	43	.06598	1600	S	1.83
5 Aug. 24, 1936	.8305	23	.03614	2010	S	0.94
6 Sep. 20, 1936	1.9060	54	.08295	1510	M	1.85
7 Sep. 30, 1936	2.4770	70	.10780	0105	M	5.85
8 Nov. 5, 1938	3.9050	110	.16995	0255	M	4.67
Intermediate Period 1940-1944						
9 June 13, 1943	4.5720	128	.19898	1605	S	1.35
10 July 5, 1943	6.8000	191	.29594	1805	D	1.29
11 July 30, 1943	14.1600	398	.61626	1730	S	1.83
12 Aug. 12, 1943	4.3300	122	.18845	1715	M	2.46
13 Feb. 17, 1944		46	.07181	2200	D	2.24
14 July 11, 1946	2.4480	69	.10654	1710	S	0.76
15 July 15, 1946	2.4260	68	.10558	1630	S	1.73
16 Aug. 25, 1947	4.0200	113	.17496	1330	D	2.33
17 Apr. 8, 1948	1.7220	48	.07494	0325	D	0.88
18 Aug. 2, 1948	5.0200	141	.21848	0600	D	3.81
19 Aug. 14, 1948	1.7220	48	.07494	1230	S	1.23
20 Nov. 19, 1948	1.8830	53	.08195	1330	M	3.52
21 Nov. 28, 1948	1.4260	40	.06206	0820	M	3.85
22 May 22, 1949	4.3300	122	.18844	2300	M	1.17
23 July 10, 1949	66.0390	1849	2.86609	1705	M	2.88
24 Aug. 4, 1949	4.4830	126	.19511	1810	S	0.57
25 Aug. 20, 1949	1.8150	51	.07898	0050	S	0.35
26 Sep. 6, 1949	1.7970	50	.07821	0505	M	3.03
27 Sep. 18, 1949	3.4010	96	.13253	1245	M	1.63
28 Oct. 6, 1949	2.4260	68	.10529	1725	M	3.33
29 Oct. 16, 1949	1.4005	40	.06095	0205	S	1.81
30 June 3, 1950	2.1800	61	.09487	0035	M	1.12
31 Aug. 29, 1950	2.8100	79	.12229	2305	M	1.73
32 Aug. 30, 1950	3.2710	92	.14235	1605	M	2.18
33 June 12, 1951	1.8780	53	.08176	1905	M	2.31
34 July 15, 1951	5.1150	144	.22260	1301	S	1.75
35 July 16, 1951	1.5160	43	.06598	1617	S	0.57
36 July 27, 1951	4.500	126	.19584	1615	S	--

uration of Precip.--Hrs.-No. Min.						Storm Description					
Total			RB - MP			Storm	10	Precip.	Inten- sities	"/Hr.	
rom	To	Min.	From	To	Min.	Class	Min.	15 min.	20 min.	30 min.	60 min.
925	2005	40	1930	2035	65	S	5.70	5.24	4.23	3.90	2.01
925	0525	1260	0925	0240		W	3.90	2.60	1.95	1.50	0.84
200	1513	193	1200	1450	170	S	3.00	2.80	2.40	1.60	0.89
			1435	1600	85	S	5.58	4.52	4.41	3.32	1.96
910	2025	75	1915	2010	55	S	2.64	2.36	2.25	1.58	0.90
325	1630	185	1325	1510	105	S	4.92	4.32	3.72	2.54	1.47
710	0600	770	1710	0105	475	I	2.94	2.68	2.58	2.00	1.47
530	0240	670	1530	0255	685	W	2.70	2.12	1.86	1.40	1.09
550	1850	180	1545	1605	20	S	6.42	4.64	3.66	2.48	1.26
420	1830	250	1350	1805	255	S	2.64	2.56	1.98	1.42	1.00
800	1900	660	0820	1730	550	S	4.98	3.92	3.06	2.16	1.13
425	2000	335	1655	1715	20	S	2.40	2.24	2.16	1.78	1.50
			1700	2200	1140	I		1.63	1.59	1.38	0.75
650	1705	15	1650	1710	20	S	3.72	3.04	2.28	1.52	0.76
520	1900	220	1520	1630	70	S	3.00	3.00	3.00	2.40	1.47
305	1530	145	1305	1330	25	S	5.10	5.00	4.50	3.70	2.25
155	0905	490	0255	0325	30	I	1.98	1.72	1.68	1.36	0.70
020	1000	580	0030	0550	320	S	3.06	2.68	2.52	2.48	2.13
205	1545	220	1205	1230	25	S	3.72	3.28	2.49	2.10	1.15
100	2015	1395	2125	1330	965	I	1.26	1.16	1.08	0.94	0.83
0100	1930	1110	0000	0820	500	W	0.96	0.80	0.72	0.58	0.48
2107	2322	135	2110	2300	110	S	2.28	1.80	1.43	1.18	0.57
1535	1915	220	1642	1705	23	S	4.44	4.20	4.11	3.46	2.47
1745	1805	20	1800	1810	10	S	3.06	2.20	1.65	1.10	0.55
0035	0205	90	0025	0050	25	S	2.04	1.36	1.02	0.68	0.34
1730	1603	1353	1300	0505	965	S	1.44	1.08	1.02	0.78	0.69
1135	1635	300	1120	1245	85	S	3.06	2.28	2.16	1.62	1.27
2345	0515	1770	1430	1725	175	S	2.82	2.20	1.95	1.32	0.68
2330	2100	1290	0155	0210	15	S	2.04	1.96	1.65	1.34	0.80
0020	0400	220	0020	0035	15	S	3.60	2.48	1.92	1.32	0.53
2100	0420	440	2100	2310	130	S	3.12	2.20	1.68	1.20	0.74
1210	2300	650	1225	1605	210	S	2.60	2.08	2.04	1.70	1.17
1610	0010	480	1610	1905	175	S	3.24	2.60	2.20	1.64	1.10
1239	1500	141	1230	1301	31	S	4.74	4.40	3.78	2.60	1.66
1543	1617	34	1545	1617	32	S	2.28	1.88	1.62	1.12	0.56
1605	1700	55	1605	1615	10	S	5.04	4.12	3.36	2.54	1.37

Coweeta Hydrologic Laboratory
United States Forest Service

File No. 5.31

EVAPORATION FROM U. S. WEATHER BUREAU PAN AT WEATHER STATION NO. 1

Computed by C. Curtis 11/16/50
Checked by B. Rogers 2/51

Evaporation expressed in inches per month

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
1936							4.33	3.61	3.03	2.35	1.64	0.55	
1937	0.77	1.39	2.80	3.31	3.98	2.91	2.99	2.51	2.77	1.98	1.40	0.65	27.46
1938	0.72	1.28	2.16	2.90	3.00	2.87	2.63	3.40	2.83	2.76	1.46	1.00	26.91
1939	1.56	2.22	3.10	4.58	3.96	3.82	4.43	3.83	2.99	2.70	1.75	1.47	36.41
1940	1.40	1.46	2.70	3.78	4.26	4.17	3.76	3.84	3.36	2.24	1.78	1.19	33.94
1941	1.67	1.86	3.14	3.77	4.88	4.63	3.76	3.91	3.53	2.73	1.71	1.67	37.26
1942	1.14	1.72	3.86	4.43	5.95	4.68	3.90	3.36	2.91	2.31	1.77	1.24	35.27
1943	1.39	1.86	2.09	3.94	4.47	4.59	4.12	3.77	3.42	2.59	1.86	1.01	35.11
1944	0.90	1.90	3.25	3.78	4.16	5.00	4.52	3.92	3.28	3.04	0.89	0.84	35.48
1945	1.49	1.56	3.12	4.12	4.61	4.47	4.36	4.07	3.52	3.05	2.11	0.57	37.05
1946	1.08	2.01	2.87	3.75	3.90	4.32	4.18	4.34	3.20	2.77	1.90	1.19	35.51
1947	1.37	1.66	2.31	3.25	4.79	3.92	4.56	3.90	3.26	2.19	1.90	0.90	34.01
1948	0.82	1.25	2.48	3.88	4.29	3.93	4.28	3.78	2.90	2.51	1.64	1.16	32.92
1949	1.21	1.83	2.65	3.39	3.84	3.55	4.11	3.60	3.12	2.10	1.91	1.01	32.32
1950	0.64	1.55	2.99	3.83	3.31	3.58	3.96	3.30	2.35	2.53	1.81	0.82	30.67
AVERAGE	1.15	1.68	2.82	3.83	4.10	4.03	3.99	3.67	3.09	2.52	1.70	0.98	33.56

Elevation 2425
Rise 889
Azimuth 215°
Slope Distance 2291
File No. 3.134

Coweeta Hydrologic Laboratory
United States Forest Service

Computed by
Checked by

STANDARD RAIN GAGE NO. 20

Monthly precipitation in inches

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
1935	7.23	4.11	5.77	6.35	4.48	2.75	7.16	9.42	1.29	2.67	6.76	3.61	64.60
1936	14.64	9.43	6.76	10.65	2.25	4.16	8.09	5.06	10.33	4.75	1.80	11.11	89.03
1937	13.03	5.92	2.97	7.79	2.56	6.03	5.12	4.62	3.02	9.19	2.96	5.81	69.01
1938	5.35	2.71	9.74	4.40	5.94	7.19	12.67	2.46	2.91	0.14	11.23	3.58	68.32
1939	7.97	16.74	8.32	5.37	3.05	4.32	5.77	5.86	1.20	1.13	0.85	4.06	64.64
1940	3.16	7.67	5.31	6.86	2.46	7.54	3.93	12.72	0.80	2.17	5.97	5.07	67.66
1941	3.63	1.57	5.59	3.54	2.81	3.57	10.17	3.01	3.17	3.26	4.59	8.14	53.05
1942	5.90	6.76	10.21	1.08	8.81	2.99	7.92	3.91	6.21	3.52	2.63	13.53	73.36
1943	6.50	5.20	10.11	6.30	3.98	6.09	11.04	5.12	4.57	2.69	2.20	4.55	68.35
1944	4.54	12.46	11.65	7.29	4.19	1.25	3.70	6.97	6.95	1.33	5.69	7.66	73.88
1945	2.54	8.69	5.23	8.42	3.56	2.78	3.91	3.98	8.07	5.18	4.76	9.21	66.23
1946	11.11	7.83	11.25	4.83	9.55	4.93	5.03	3.69	4.10	4.47	4.21	4.80	75.68
1947	12.63	3.57	5.94	5.56	4.26	5.28	3.66	6.35	4.00	8.90	6.59	4.58	71.22
1948	6.19	8.85	12.49	2.76	5.10	4.49	7.32	8.77	4.14	1.04	19.13	7.72	87.95
1949	9.64	6.69	5.86	8.31	6.62	10.13	7.76	8.43	6.35	11.14	2.69	6.42	90.04
1950	6.19	9.05	7.57	2.38	5.55	5.00	8.76	10.77	5.62	6.05	2.34	6.48	75.76
1951	4.28	5.47	8.21	6.23	1.07	11.96							

Elevation 2855
Rise 655
Azimuth 170°
Slope Distance 2977
File No. ____________

Coweeta Hydrologic Laboratory
United States Forest Service

Computed by ____________
Checked by ____________

STANDARD RAIN GAGE NO. 16

Monthly precipitation in inches

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
1935	7.35	4.17	5.64	6.37	4.25	2.66	7.02	8.26	1.32	2.62	6.67	3.79	60.12
1936	14.44	9.25	6.45	10.73	2.64	4.60	7.59	4.65	9.68	4.68	1.77	11.07	87.05
1937	12.40	6.10	2.97	7.69	2.57	5.93	5.05	4.88	3.21	9.25	3.07	5.74	68.76
1938	5.55	2.64	10.16	5.48	6.19	6.98	12.56	2.89	2.81	0.12	10.82	3.85	69.92
1939	7.77	16.39	8.29	5.31	3.24	4.24	4.72	7.01	1.28	1.25	1.32	4.16	64.98
1940	7.14	7.35	5.34	6.78	2.33	6.09	3.92	12.60	0.78	2.08	5.85	5.29	65.55
1941	3.59	1.60	5.25	3.35	2.39	2.61	10.11	3.04	3.27	3.16	4.44	8.27	51.07
1942	5.64	6.17	9.54	1.04	8.12	2.98	7.97	4.06	6.12	3.50	2.53	13.38	71.05
1943	6.53	4.96	9.93	6.37	3.93	5.59	11.16	4.93	4.65	2.73	2.16	4.64	67.57
1944	4.58	12.65	11.45	6.81	3.98	1.00	3.58	7.13	7.04	1.30	5.73	7.74	72.99
1945	2.53	8.54	5.23	8.17	3.57	2.80	4.00	3.81	7.96	4.93	4.74	9.07	65.35
1946	11.43	7.59	10.79	5.02	9.90	4.13	4.52	3.17	3.97	4.65	4.27	5.02	74.46
1947	12.68	3.43	5.81	5.53	4.38	5.33	3.51	6.00	4.10	9.25	6.56	4.33	70.91
1948	5.98	8.97	12.06	2.68	5.12	4.35	7.36	8.87	4.39	1.12	19.04	7.75	87.59
1949	9.67	6.73	6.01	8.16	6.74	10.26	7.85	8.44	6.36	11.45	2.75	6.69	90.81
1950	6.37	9.11	7.62	2.50	5.53	4.87	9.05	11.39	5.94	6.35	2.52	6.28	77.53
1951	4.21	5.59	8.49	6.39	0.76	11.97							

Elevation 2515
Rise 755
Aximuth 60°
Slope Distance 2368
File No.

Coweeta Hydrologic Laboratory
United States Forest Service

Computed by
Checked by

STANDARD RAIN GAGE NO. 67

Monthly precipitation in inches

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
1941	3.85		5.76	3.63	2.57	3.80	11.06	3.36	3.60	3.25	4.29	8.27	
1942	5.50	6.19	9.69	1.01	8.19		7.87	4.10	6.17	3.52	2.94	12.76	
1943	6.43	5.05	9.83	6.18	3.74	6.30	11.01	5.27	4.48	2.65	2.10	4.53	67.57
1944	4.36	12.49	11.36	6.88	3.83	1.20	3.77	7.08	6.87	1.40	6.29	7.49	72.02
1945	7.49	8.61	5.23	8.05	3.62	2.81	3.90	4.15	7.95	5.02	4.70	9.23	65.76
1946	11.50	7.53	11.10	4.87	9.70	4.24	4.57	3.25	4.03	4.65	4.31	4.14	74.49
1947	12.75	3.56	5.72	5.65	4.10	5.30	3.43	6.40	4.08	8.82	6.43	4.12	70.36
1948	5.70	8.75	11.99	2.86	5.01	4.51	7.25	8.73	4.13	1.02	18.44	7.53	85.92
1949	9.07	6.91	5.53	8.39	6.48	9.88	7.82	3.54	6.45	11.13	2.64	6.31	89.15
1950	5.76	8.55	7.47	2.34	5.50	4.68	8.82	10.74	5.87	6.06	2.24	6.05	74.08
1951	4.00	5.10	7.87	6.12	0.97	12.12							

Coweeta Hydrologic Laboratory
United States Forest Service

File No. 3.134

Computed by
Checked by Dils

STANDARD RAIN GAGE NO. 21

Monthly Precipitation in Inches

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
1935	6.50	4.00	5.35	6.49	4.65	2.72	7.04	8.91	1.31	2.52	6.30	3.44	59.23
1936	14.08	8.86	6.69	9.74	2.73	4.16	7.78	4.23	10.16	4.72	1.66	10.68	85.53
1937	12.33	5.86	2.82	7.49	2.52	6.43	5.00	4.74	3.88	8.87	2.73	5.09	67.76
1938	5.22	2.56	9.88	5.35	6.19	7.26	12.34	2.54	3.09	0.15	9.64	3.25	67.47
1939	7.20	15.49	7.90	5.24	3.22	4.81	3.98	5.69	1.30	0.92	0.82	3.78	60.35
1940	4.77	6.93	5.26	6.11	2.25	6.53	3.95	12.65	0.74	2.15	5.36	4.64	61.34
1941	3.61	1.51	5.33	3.49	2.31	3.78	10.52	3.70	3.29	3.26	4.30	7.60	52.70
1942	5.32	6.23	9.60	1.13	8.13	3.07	7.51	4.34	6.26	3.60	2.45	12.71	70.35

Coweeta Hydrologic Laboratory
United States Forest Service

File No 3.231

Computed by Dils
Checked by

WATERSHED NO. 3

Monthly weighted areal precipitation in inches

Water year	TOTAL	Nov	Dec	Jan	Feb.	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1934												2.33	1.45
1935	61.94	9.32	4.35	5.68	4.06	7.16	4.84	4.38	2.75	7.05	8.43	1.32	2.61
1936	84.84	6.62	3.69	14.41	9.21	6.56	10.22	2.58	4.42	7.77	4.73	9.92	4.71
1937	72.85	1.76	11.04	12.57	6.02	2.89	7.69	2.57	4.02	5.08	4.79	3.23	9.19
1938	63.92	3.01	5.71	5.45	2.66	8.98	6.45	6.15	7.01	12.28	3.03	2.86	0.13
1939	79.76	10.82	3.70	7.78	17.42	8.26	5.33	3.17	4.31	5.02	6.54	1.24	1.17
1940	56.79	0.85	4.09	3.70	7.40	5.34	6.91	2.14	6.89	3.95	12.65	0.77	2.10
1941	5a33	4.81	5.15	3.60	1.56	5.36	3.41	2.50	3.62	10.16	3.09	3.25	3.82
1942	67.81	3.85	8.16	5.70	6.35	9.75	1.06	8.33	2.96	7.92	4.05	6.17	3.51
1943	77.10	2.55	13.37	6.55	5.05	9.99	6.31	3.94	5.79	11.12	5.08	4.64	2.71
1944	66.64	2.17	4.62	4.55	12.69	11.50	6.96	4.04	1.13	3.60	7.06	7.00	1.32
1945	65.21	5.70	7.70	2.53	8.58	5.24	8.24	3.58	2.80	3.97	3.88	7.98	5.01
1946	79.13	4.75	9.08	11.28	7.65	10.91	4.97	9.80	4.15	4.65	3.27	4.03	4.59
1947	69.00	4.24	4.94	12.63	3.51	5.76	5.60	4.22	5.31	3.47	6.23	4.09	9.00
1948	71.08	6.49	4.23	5.80	8.85	12.04	2.79	5.06	4.44	7.30	8.79	4.24	1.06
1949	107.18	10.72	7.63	9.34	6.83	5.74	8.29	6.59	10.05	7.83	8.49	6.41	11.26
1950	76.22	2.69	6.47	6.03	8.81	7.54	2.41	5.51	4.77	8.91	11.01	5.89	5.81
1951		2.36	6.16	4.10	5.32	8.14	6.24	0.99	12.05				
AVERAGE	71.54	5.34	6.47	7.16	7.17	7.72	5.75	4.44	5.20	6.88	6.32	4.43	4.44

Coweeta Hydrologic Laboratory
United States Forest Service

Computed by

Checked by

File No. 3.134

WATERSHED NO. 3

Monthly area inches runoff

Water Year	TOTAL	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1934											0.51	0.41	1.00
1935	14.36	1.16	1.25	1.81	1.20	1.79	1.66	1.38	0.82	0.79	1.24	0.65	0.60
1936	29.97	1.15	0.97	3.98	3.55	2.78	5.94	2.48	1.80	1.81	1.58	1.96	1.97
1937	26.32	1.37	2.46	4.69	3.16	2.55	2.90	2.16	1.56	1.32	1.13	1.13	1.90
1938	19.47	1.25	1.64	1.76	1.41	2.41	2.46	1.50	1.63	2.23	1.54	0.90	0.75
1939	27.12	1.95	1.33	2.05	5.12	4.74	3.40	2.48	1.93	1.72	1.25	0.58	0.56
1940	16.21	0.50	0.77	1.28	1.72	1.56	2.06	1.32	1.47	1.14	2.18	1.30	0.90
1941	13.44	1.24	1.32	1.37	0.96	1.26	1.24	0.95	0.75	1.96	0.88	0.74	0.77
1942	21.15	0.98	1.92	1.83	2.22	3.25	1.81	2.21	1.41	1.43	1.31	1.38	1.30
1943	32.30	1.19	3.27	3.09	3.09	3.64	3.04	2.42	2.39	3.56	3.04	1.97	1.61
1944	27.81	1.55	1.56	2.14	3.31	4.31	3.82	2.64	1.90	1.69	1.75	1.69	1.45
1945	19.00	1.48	1.91	2.04	2.13	2.08	2.12	1.80	1.15	0.97	0.91	1.33	1.08
1946	32.72	1.25	2.17	3.89	3.48	4.21	2.94	3.98	2.80	2.53	1.98	1.75	1.75
1947	22.62	1.59	1.61	3.96	2.24	2.26	2.29	1.68	1.41	1.26	1.34	1.07	1.91
1948	28.49	2.30	1.94	1.89	3.44	4.02	3.53	2.22	1.70	2.30	2.81	1.38	0.95
1949	35.99	3.45	2.71	3.47	2.89	2.39	2.68	2.87	3.70	3.59	2.48	2.68	3.07
1950		2.42	2.44	2.59	2.84	3.60	2.34						
AVERAGE		1.55	1.83	261	268	2.93	2.76	2.13	1.76	1.99	1.62	1.31	1.35

RI-SE
WATER RELATIONS
Precipitation

File No. 3.231

PRECIPITATION INTENSITY RECORD

Rain Gage No. 10 Type Ferguson
Chart Depth 0.5 Precip. 2 hrs. Time
Time and Date of Storm July 16, 1951
EST
Elevation MSL 2515 Feet

Experimental Area COWEETA
Watershed #3 22.79
Lat. Long.
Sec. Tp. Range
Total Precipitation 0.57 inches

July Date	Time H M (2)	Time Interval (3)	Depth Recorded (4)	Increment Recorded (5)	Increment Corrected (6)	Rate per Hour Inches per Hr (7)	Remarks (8)
16	1543		.43				P.B.
	1550	7	.48	.05	.05	.43	
	1553	3	.57	.09	.09	1.80	
	1559	6	.58	.01	.01	.10	
	1605	6	.90	.32	.33	3.30	
	1610	5	.98	.08	.08	.96	
	1617	7	.99	.01	.01	.08	P.E.
Totals							

Correction Factor = Mean Basin Precipitation SRG 67 / Recording Rain Gage Precipitation = 1.03 / 1.00 = 1.03   Storm Class S

Maximum Depth and Intensity for Given Time Intervals

Duration Min.	2	5	10	15	20	30	60	120	240	6 hrs
Depth Inches			.38	.47	.54	.56	.56			
Intensity In/Hr			2.28	1.88	1.62	1.12	.56			

Tabulated by DILS Date 7/20/51 Checked by Date
Computed by DILS Date 7/20/51 Checked by Date
Sheet 1 of 1 Sheets

WATER RELATIONS
Streamflow

RECORD OF RUNOFF

Station designation COWEETA WS # 3 Discharge rate from rating table ... : CIA

Date (JULY 1951)	Time	Time interval	Gage height	Discharge rate for gage height	Discharge rate average for interval		Runoff for interval					Remarks
1	2	3	4	5	6	7	8	9	10	11	12	
	Hr. min.	Min.	Ft.	c.f.s.	c.f.s.							
15	0900	540	.260	.0430	.0430	.00187	1393					
	1000	60	.259	.0420	.0425	.00183	153					
	1100	60	.257	.0410	.0415	.00179	149					
	1130	30	.253	.0400	.0405	.00174	73					
	1200	30	.254	.0400	.0400	.00174	72					
	1230	30	.255	.0410	.0405	.00178	73.					SRB
	1235	5	.260	.0430	.0420	.00187	13					
	1240	5	.300	.0620	.0525	.00270	16					
	1245	5	.475	.2370	.1495	.01031	45					
	1250	5	.650	.6510	.4440	.02833	133					
	1253	3	.795	1.3420	.9965	.05840	179					1253 TO 1340 GAGE HT. VALUES TAKEN FROM FIELD OBSERVATION BY DILS & JOHNSON
	1254	1	.850	1.7700	1.5560	.07703	93					
	1255	1	.875	2.0000	1.9950	.08704	113					
	1256	1	.910	2.3600	2.1800	.10270	131					
	1257	1	.930	2.5800	2.4700	.11228	148					
	1258	1	.960	2.9300	2.7550	.12751	165					
	1259	1	1.020	3.7200	3.3250	.16189	[illegible]					
	1300	1	1.070	4.5360	4.1280	.19741	248					
	1300:45	:45	1.090	4.8500	4.6930	.21107	211					
	1301	:15	1.100	5.0200	4.9350	.21547	74					
	1301:30	:30	1.105	5.1150	5.0675	.22260	152					MP
	1302	:30	1.098	4.9960	5.0505	.21699	152					
	1302:30	:30	1.080	4.8500	4.9130	.21107	148					STILL RAINING
	1302:45	:15	1.088	4.8160	4.8330	.20960	72					
	1303	:15	1.082	4.7140	4.7650	.20515	71					
	1303:30	:30	1.072	4.5360	4.6250	.19741	139					
	1304	:30	1.060	4.330	4.4330	.18844	133					RAIN EASING UP ↓
	1304:30	:30	1.048	4.1400	4.2350	.18017	127					
	1305	:30	1.033	3.9150	4.0275	.17038	121					
	1306	1	1.010	3.5700	3.7425	.15537	225					
	1306:30	:30	.975	3.2450	3.4075	.14122	102					
	1307:10	:40	.955	2.8700	3.0575	.12490	122					
	1307:30	:20	.943	2.7260	2.7980	.11864	56					
	1307:45	:15	.933	2.6130	2.6700	.11372	40					
CONT'D	1308:15	:30	.918	2.4400	2.5300	.10654	76					

Tabulated by DILS Date 7/16/51
Checked by DILS Date 7/16/51

LEAST SQUARE LINEAR REGRESSION

WATERSHED No. 2
1934-1939
15-MINUTE INTERVAL

Coweeta Hydrologic Laboratory
United States Forest Service

File No.

Computed by DILS 8/26/51
Checked by

	x	y	x^2	xy	y^2
	2.50	8	6.2500	20.00	64
	3.40	28	11.5600	95.20	784
	2.16	11	4.6656	23.76	121
	2.80	10	7.8400	28.00	100
	4.52	23	20.4304	103.96	529
	2.60	7	6.7600	18.20	49
	2.22	9	4.9284	19.98	81
	4.39	19	19.2721	83.41	361
	2.80	13	7.8400	36.40	169
	1.87	11	3.4969	20.57	121
Σ	29.26	139	93.0434	449.48	2378

$SSx\bar{x} = \Sigma x^2 - (\Sigma x)^2/N$

$= 93.0434 - 29.26^2/10$

$= 93.0434 - 85.6148$

$= 7.4286$

$SPxy = \Sigma xy - (\Sigma x \Sigma y/N)$

$= 449.48 - 29.26 \times 139/10$

$= 449.48 - 406.71$

$= 42.77$

$B = SPxy / SSx\bar{x}$

$= 42.77/7.43$

$= 5.76$

$A = (\Sigma y/N) - B(\Sigma x/N)$

$= 139/10 - 5.76(29.26/N)$

$= 13.9 - 5.76 \times 2.93$

$= 13.9 - 16.88$

$= -2.98$

$y = Bx \pm A$

$= 5.76x - 2.98$

x "/HR	y C.S.M.
1	2.78
2	8.54
4	20.06

DERIVATION OF STANDARD ERROR
(FROM REGRESSIONS)
WATERSHED NO 3 - 1946-1951
15-MINUTE INTERVAL

Coweeta Hydrologic Laboratory
United States Forest Service

File No.

Computed by DILS, AUG. 1951
Checked by

$SS\,x\bar{x} = 9.81$

$SP\,xy = 557.64$

$SS\,y\bar{y} = 36232$

$$S^2 dyx = SS\,y\bar{y} - \frac{(SP\,xy)^2}{SS\,x\bar{x}}$$

$$= 36232 - \frac{(557.64)^2}{9.81}$$

$$= 36232 - 310962.4/9.81$$

$$= 36232 - 31698$$

$$= 4534$$

$$S^2 y = \frac{S^2 dyx}{N-1}$$

$$= 4534/24$$

$$= 188.92$$

$$S^2 \bar{y} = \frac{S^2 y}{N}$$

$$= 188.92/25$$

$$= 7.5568$$

$$S\bar{y} = \sqrt{7.56}$$

$$= 2.75$$

Maximum discharge rate precipitation intensity relation - 15 minute precipitation period
File No

ANALYSIS OF COVARIANCE
WS #3
Between periods 1940-1945 and 1946-1951

Coweeta Hydrologic Laboratory
United States Forest Service
Computed by DHS 8/51
Checked by

Selected uniform summer storms having maximum 30 min. precipitation intensity over 0.90 "/hr.

PERIOD	Σx	Σy	Σx²	Σxy	Σy²	N
1940-1945	22.57	471	60.2621	1356.81	31595	11
1946-1951	61.49	1325	161.0544	3816.61	106457	25
TOTAL	84.06	1796	221.3165	5173.62	138052	36

	VARIANCE WITHIN				ERROR OF ESTIMATE	
PERIOD	D/F	Σx²	Σxy	Σy²	B REGRESSION	D/F
1940-1945	10	13.95	390.40	11429	27.99	
1946-1951	24	9.81	557.64	36232	56.34	
AVERAGE WITHIN LEVELS	34	13.49	733.28	43181	54.36	33
TOTAL	35	19.43	860.14	45892	44.27	34

SOURCE OF VARIATION	D/F	SS	MS	F
OVERALL	34	7815	—	
(-) WITHIN	33	3322	1.01	
BETWEEN ADJUSTED MEANS	1	4493	4493	4.4485

FROM SNEDECOR'S "F" TABLE

% LEVEL

n	.05	.01
34	4.13	7.44
32	4.14	7.47

SIGNIFICANT AT 5% LEVEL

SOIL ORGANIC MATTER VALUES
Watershed No. 3
Coweeta Hydrologic Laboratory

Site	Sample number	Percent organic matter	
		0-3 inch layer	3-6 inch layer
Undisturbed forest	1	7.77	4.99
	2	4.48	2.94
	3	4.71	2.12
	4	10.24	10.24
	5	7.96	4.08
	Average	7.03	4.87
Coppice forest	1	6.67	2.94
	2	3.41	1.67
	3	9.12	6.85
	4	16.68	10.69
	5	9.00	5.40
	Average	8.97	5.51
Upper pasture	1	6.29	3.34
	2	10.12	6.90
	3	9.30	4.59
	4	5.30	2.71
	5	7.06	4.52
	Average	7.62	4.41
Lower pasture	1	9.06	4.94
	2	2.66	1.30
	3	2.48	2.00
	4	2.94	2.23
	5	2.88	1.65
	Average	4.00	2.42
Cornfield	1	4.48	2.12
	2	4.83	5.06
	3	.24	5.30
	4	5.88	3.65
	5	6.60	11.54
	Average	4.40	4.58
Control plots	1	7.77	6.12
	2	6.94	2.48
	3	9.66	6.36
	4	6.36	4.71
	5	5.65	3.42
	Average	7.23	4.62

VOLUME WEIGHT VALUES
Watershed No. 3
Coweeta Hydrologic Laboratory

Site	Sample number	Volume weight	
		0-3 inch layer	3-6 inch layer
Undisturbed forest	1	.77	1.00
	2	.88	.97
	3	.91	1.10
	4	.96	1.04
	5	.88	1.14
	Average	.88	1.05
Coppice forest	1	.80	1.12
	2	.91	1.11
	3	.82	.93
	4	.63	.79
	5	.93	.95
	Average	.82	.98
Upper pasture	1	1.18	1.31
	2	.95	.89
	3	.90	.87
	4	1.22	1.24
	5	.88	1.04
	Average	1.03	1.07
Lower pasture	1	.95	1.25
	2	1.20	1.24
	3	1.16	1.43
	4	1.23	1.16
	5	1.03	1.33
	Average	1.11	1.28
Cornfield	1	.94	1.21
	2	1.13	1.12
	3	1.01	1.18
	4	.84	1.03
	5	.71	.77
	Average	.93	1.06
Control plots	1	1.00	1.04
	2	1.33	1.16
	3	.79	.81
	4	.93	1.30
	5	.83	1.00
	Average	.98	1.06

POROSITY VALUES (in percent)
Watershed No. 3
Coweeta Hydrologic Laboratory

Site	Sample number	Capillary	Non-Capillary	Total	Capillary	Non-Capillary	To
		0-3 inch layer			3-6 inch layer		
Undisturbed forest	1	41.8	19.9	61.7	39.4	18.2	57
	2	41.2	15.9	57.1	39.2	16.4	55
	3	39.8	18.1	57.9	33.4	20.2	53
	4	28.2	24.8	53.0	26.0	30.8	56
	5	29.4	25.0	54.4	25.1	25.9	51
	Average	36.1	20.7	51.8	32.6	22.3	54
Coppice forest	1	30.7	29.3	60.0	34.3	17.3	51
	2	38.6	19.1	57.7	37.4	15.3	52
	3	39.4	19.1	58.4	36.1	25.6	61
	4	32.6	35.0	67.6	34.0	24.5	58
	5	39.1	19.9	59.0	43.3	17.6	60
	Average	36.0	24.5	60.5	37.0	20.1	5
Upper pasture	1	38.1	6.9	45.0	34.9	15.3	40
	2	43.2	17.9	61.1	43.2	21.9	65
	3	36.1	21.3	57.4	36.6	20.5	5
	4	37.2	8.3	45.5	34.9	19.0	53
	5	40.3	20.2	60.5	39.2	15.6	54
	Average	39.0	14.9	53.9	37.7	18.5	56
Lower pasture	1	49.4	10.9	60.3	39.2	12.7	51
	2	42.6	12.1	54.7	47.3	7.5	54
	3	39.0	14.0	53.0	22.8	22.8	4
	4	30.2	16.5	46.7	39.2	13.6	52
	5	28.2	19.6	47.8	28.8	18.7	4
	Average	37.9	14.6	52.5	35.4	15.1	50
Cornfield	1	34.3	18.7	53.0	38.0	17.0	5
	2	43.8	10.1	53.9	44.0	11.5	5
	3	44.1	13.0	57.0	39.7	13.0	52
	4	33.8	19.8	53.6	33.3	19.7	53
	5	44.4	18.7	63.1	47.5	17.0	64
	Average	40.1	16.0	56.1	40.5	15.6	56
Control plots	1	35.0	18.8	53.8	31.6	15.1	46
	2	17.3	10.2	27.5	51.4	9.5	60
	3	26.5	32.0	58.5	29.8	27.2	5
	4	35.1	20.6	55.7	40.8	1.0	41
	5	31.9	41.5	73.4	36.1	12.5	4
	Average	29.2	24.6	53.8	37.9	13.1	51

PERMEABILITY RATE VALUES
Watershed No. 3
Coweeta Hydrologic Laboratory

Site	Sample number	Permeability rate in milliliters per hour	
		0-3 inch layer	3-6 inch layer
Undisturbed forest	1	9572	3102
	2	16600	3060
	3	28600	16200
	4	24000	3932
	5	6800	5792
	Average	17112	6417
Coppice forest	1	20203	1100
	2	17712	1275
	3	20974	1300
	4	28426	40200
	5	8856	1467
	Average	19232	9468
Upper pasture	1	420	145
	2	3500	1400
	3	3000	5100
	4	284	578
	5	2900	1200
	Average	2021	1685
Lower pasture	1	600	440
	2	26	28
	3	300	134
	4	1900	538
	5	473	231
	Average	660	274
Cornfield	1	1590	429
	2	430	618
	3	385	400
	4	1900	1800
	5	1900	1100
	Average	1241	888
Control plots	1	10368	10496
	2	5184	5400
	3	11940	5760
	4	9072	5551
	5	13608	10476
	Average	10035	7537