THE EFFECTS OF A COMPLETE CUTTING OF FOREST VEGETATION AND SUBSEQUENT ANNUAL CUTTING OF REGROWTH UPON SOME PEDOLOGIC AND HYDROLOGIC CHARACTERISTICS OF A WATERSHED IN THE SOUTHERN APPALACHIANS

Thesis for the Degree of Ph. D.

MICHIGAN STATE UNIVERSITY

Forrest Dean Freeland, Jr.

1956

This is to certify that the

thesis entitled

THE EFFECTS OF A COMPLETE CUTTING OF FOREST VEGETATION AND SUBSEQUENT ANNUAL CUTTING OF REGROWTH UPON SOME PEDOLOGIC AND HYDROLOGIC CHARACTERISTICS OF A WATERSHED IN THE SOUTHERN APPALACHIANS

presented by

Forrest Dean Freeland, Jr.

has been accepted towards fulfillment of the requirements for

Ph.D. degree in Forestry

T. D. Stevens
Major professor

Date August 8, 1956

O-169

THE EFFECTS OF A COMPLETE CUTTING OF FOREST VEGETATION AND SUBSEQUENT ANNUAL CUTTING OF REGROWTH UPON SOME PEDOLOGIC AND HYDROLOGIC CHARACTERISTICS OF A WATERSHED IN THE SOUTHERN APPALACHIANS

by

Forrest Dean Freeland, Jr.

A THESIS

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

DOCTOR OF PHILOSOPHY

Department of Forestry

1956

ABSTRACT

This dissertation is a basic research study of watershed hydrology. The objectives of the problem were primarily to determine the effects on water yields by the removal of a deciduous forest in the superhumid region of the Southern Appalachians and the effects of this removal upon the ideal hydrologic condition of the natural forest soil.

After a four-year period of standardization of two adjacent forested watersheds on the Coweeta Hydrologic Laboratory, the forest vegetation was cut on one watershed. The slash was lopped and scattered and nothing was removed from the drainage area. No roads or skid-trails were made and maximum precaution was taken to perpetuate the former ideal condition of the forest soil. Each year thereafter all regrowth was cut and left.

In order to study the effects of treatment upon the soils an intensive soil survey of the two watersheds was made and comparable index stations over the two areas were located for sampling for the pedologic studies of treatment effects. V-notch weirs were constructed at the drainage exits of the two watersheds before the period of standardization in order to measure the streamflow characteristics. Weather stations and rain gage stations were established on and near the two watersheds to measure precipitation and other important

climatic factors. Keeping one watershed in its former natural forested state after the period of standardization furnished the control watershed approach to the hydrologic studies of the treatment effects.

The soils over the two areas possessed a high degree of uniformity. However, field and laboratory analyses indicated possible changes in the soil taking place due to treatment. The percentage of the large waterstable aggregates in the surface soil layers was found to be lower for the treated watershed. Also, laboratory tests revealed a lower degree of water stability for the large aggregates of the surface soil layers on the treated watershed. The amount of unincorporated humus lying on the soil surface was found to be much less on the treated watershed and the rate of decomposition appeared to be accelerated. A dry clod analysis, volume weight and porosity tests, a permeability test, and field capacity and moisture equivalent tests failed to reveal any trends of differences in these characteristics as yet. The soil moisture content study during the growing season did not show any large differences on the treated watershed in soil moisture from that of the control. Air temperatures and soil temperatures increased due to treatment.

The increase in water yield from the treated watershed was considerable. This increase is most pronounced in the late summer and early fall, when the increase amounts to almost one-hundred percent over non-treatment streamflow.

Minimum flows were raised but high flows were relatively unaffected. Storm peaks were raised slightly. There were no significant changes affected in storm runoff nor water quality. The groundwater depletion curve for the growing season was raised appreciably.

ACKNOWLEDGMENTS

Acknowledgment is given to the Coweeta Hydrologic Laboratory for the aid and facilities which made this study possible. The hydrologic data presented herein were computed using the records of the Coweeta Hydrologic Laboratory, a branch station of the Southeastern Forest Experiment Station, Forest Service, United States Department of Agriculture. Of particular help and guidance in the crystallization of this study were Edward A. Johnson, Research Center Leader, Dr. Jacob L. Kovner, Dr. Thomas C. Nelson, Station Silviculturist, all of the Coweeta Hydrologic Laboratory, and Dr. Charles R. Hursh, Chief of the Division of Forest Influences, Southeastern Forest Experiment Station.

Acknowledgment is given to Dr. Robert E. Dils, Associate Professor of Forestry, Dr. Terrill D. Stevens, Professor and Head of the Forestry Department, Dr. Eugene P. Whiteside, Professor of Soil Science, and Dr. William D. Baten, Professor of Mathematics, all of Michigan State University of Agriculture and Applied Science, for their kind advice and help.

VITA

Forrest Dean Freeland, Jr.

candidate for the degree of

Doctor of Philosophy

Final examination: August 8, 1956; 1:30 p.m.; Room 11, Forestry Building.

Dissertation: The Effects of a Complete Cutting of Forest Vegetation and Subsequent Annual Cutting of Regrowth upon Some Pedologic and Hydrologic Characteristics of a Watershed in the Southern Appalachians.

Outline of Studies:

Major Subject: Forestry

Minor Subjects: Soil Science, Geology

Biographical Items:

Born, June 25, 1923, Detroit, Michigan

Undergraduate Studies:

Michigan State University, 1941-1943
continued, 1946-1947
University of Michigan, 1943-1944
continued, 1947-1948

Graduate Studies:

University of Michigan, 1947-1949
Michigan State University, 1951-1954

Experience: Member, United States Marine Corps, 1943-1946; Crew Chief, Insect Control Project, Black Hills National Forest, 1948; Forest

Mensurationist and Photo Interpreter, U.S. Forest Service, 1948-1950; Forest Economist and Statistical Analyst, U.S. Forest Service, 1950-1951. Assistant Professor in Forestry, Michigan State College, 1954-1956, teaching and extension in tropical forestry, Colombia, South America.

Member: Phi Kappa Phi, Sigma Xi, Xi Sigma Pi, Sigma Pi Sigma, Seminarium Botanicum, Society of American Foresters, American Geophysical Union, Soil Science Society of America, Sociedad Dasonomica de la America Tropical, Sociedad Colombiana de la Ciencia del Suelo.

TABLE OF CONTENTS

Page

ABSTRACT ii

ACKNOWLEDGMENTS v

VITA vi

TABLE OF CONTENTS viii

PURPOSE AND SCOPE 1

REVIEW OF PAST WORK 5

DESCRIPTION OF THE AREA 24

The Coweeta Hydrologic Laboratory 24

Coweeta Watersheds 17 and 18 29

Geology and Physiography 31

Climate 35

Soils 37

Vegetation 38

Land Use History 41

HISTORY OF THE EXPERIMENT 47

Instrumentation-Installations 47

Hydrological Records 47

Meteorological Records 51

Period of Standardization, 1936-1941 52

Initial Treatment, 1941 54

Annual Regrowth Cuttings, 1941-1953 56

Page

EFFECTS OF TREATMENT ON SOME PEDOLOGIC CHARACTERISTICS 60
Experimental Technique 61
Soil Survey of the Two Watersheds 62
Soil Physical Properties 72
Mechanical Analysis 73
Aggregate Analyses 76
Aggregate Distribution 77
Dry Clod Analysis 81
Aggregate Stability 83
Unincorporated Humus Layer 85
Soil Organic Matter 88
Volume Weight 91
Porosity 93
Permeability 98
Field Capacity 100
Moisture Equivalent 104
Air-Dry Moisture Content 107
Soil Moisture Regime 110
Supplementary Observations 115
Air Temperature Observations 115
Soil Temperature Observations 117
Vegetation Observations 121

	Page
EFFECTS OF TREATMENT ON SOME HYDROLOGIC CHARACTERISTICS	126
Experimental Technique	126
Total Streamflow	126
Annual Yields	127
Monthly Yields	132
Flow Frequency	134
Storm Peaks	136
Groundwater Storage	140
Water Quality	141
Stream Turbidity	141
Stream Temperature	144
Storm Runoff	145
SUMMARY AND CONCLUSIONS	150
Pedologic Effects	150
Hydrologic Effects	155
PRACTICAL IMPLICATIONS	157
LITERATURE CITED	159
APPENDICES	164
Appendix A: Tables of Pedologic Data	165
Appendix B: Tables of Hydrologic Data and Mathematical Calculations	169

PURPOSE AND SCOPE

Various sections of the United States and numerous areas throughout the world have been confronted for many years with growing problems of water supply. Increases in both population pressure and industrial development in recent years have aggravated the situation. Increasing attention is now being focused on the need for careful consideration of the best methods for assuring the most efficient use of the water resources. The Interior and Insular Affairs Committee (23) emphasizes that the great number of commissions and survey groups that have been appointed by scientific and professional societies, by state governors, and by the President of the United States to study the Nation's water problems and to recommend measures for their solution clearly indicates the seriousness with which the public and the government have viewed the situation.

To implement a program for the highest development and best conservation of water resources a sound base of fundamental research is necessary. The Interior and Insular Affairs Committee (22) states that probably the Nation's greatest single weakness in natural resource management is its present deficiencies in scientific data concerning its water resources.

Of fundamental importance in the study of water resources is basic research into factors influencing the characteristics of streamflow, changing the quantity and quality of water yields from drainage areas, and affecting the soil properties on drainage areas. This dissertation deals with such a basic study. Streamflow characteristics and the quantity and quality of water yields from a drainage area are intimately affected by the soil conditions of that drainage area. Factors affecting the structure and stability of the soil may thereby greatly affect streamflow and water quality. Thus research into the effects on soil properties as well as into the effects on water properties is necessary in studying the true significance of the effects of a treatment upon a watershed.

The treatment applied in this problem, being a study in basic research, was not initiated to demonstrate a practical field method for increasing water yields while maintaining water quality. Generally, in view of present day economic conditions, this treatment is not recommended for large watersheds. The chief purpose and value of this treatment lies rather in the basic data it affords on the pedologic and hydrologic characteristics of watersheds.

After a standardization period of four and a half years in a natural forest condition a 33-acre watershed was clearcut in 1941. All shrubs and trees were cut but none were removed from the area. The formation of roads, skid trails and other types of soil disturbance were carefully avoided. The slash was lopped and distributed over the ground.

With the exception of the war years from 1943 to 1945, all natural regrowth on the watershed has been cut during the growing season and left each year.

This treatment was initiated to study the effect of the permanent removal of tree and shrub vegetation on the water yield of the watershed. Some basic data on the influence of vegetation could thus be obtained to aid in determining values for I + E + T in the solution of the water balance equation $P = Ro \pm \Delta S + I + E + T \pm \Delta R$ for individual drainages in the Southern Applachians. In this equation P represents precipitation, Ro represents runoff, ΔS represents groundwater storage, I represents interception, E represents evaporation, T represents transpiration, and ΔR represents retention storage in the soil.

Of fundamental importance throughout this treatment period is the fact that a minimum disturbance to the forest litter and humus layers and the surface soil, and a favorable microclimate by allowing some live cover to shade the surface were primary goals in order to maintain the forest soil in as natural, porous and stable a condition as possible.

The purpose of this thesis problem is to determine how and to what extent some of the more important pedologic and hydrologic characteristics of the watershed have been affected by the treatment and the significance of these effects. It is intended to furnish data and supply additional knowledge of the effects of the permanent removal of trees and shrubs upon water yields and upon some of the other factors of site as well. This additional knowledge can promote a better understanding of the effects of land use management and particularly forest land management upon the pedologic and hydrologic characteristics of a watershed. Such information can aid in the formulation of land use policies.

This type of study is also significant in that its findings can cast some additional light upon the influence of vegetation on the important value of interception + evaporation and transpiration in the study of the water economy of individual watersheds. This is provided by the data on the changes in streamflow characteristics and by other relative data obtained in the study.

REVIEW OF PAST WORK

The rapid increase in the pressure of population upon land the world over in the last century and the damaging effects of past mismanagement of watersheds have directed public attention more and more to watershed management problems. This concern has provided a tremendous impetus in the last fifty years to research in the hydrologic effects of land-use practices. The result has been the undertaking of numerous investigations in this country and elsewhere for the purpose of studying the influence of land-use on hydrology and soil. The literature covering these investigations is now so copious that it is not possible here to review it all. This review of past studies is an attempt to assemble the literature into a brief historical summary of the development of watershed research and a review of some of the more important and pertinent watershed research studies and their findings as they apply directly to this dissertation.

It is important to note that, numerous studies and voluminous literature to the contrary, from the standpoint of the Nation's vast forested areas less is understood about the management of water than of any other forest resource (21). Most investigations deal with some aspect of farming or grazing practices and an exhaustive study of the literature reveals that the number of investigations applying more directly to this particular study are extremely limited and even these possess various fundamental differences which tend to point up the uniqueness of this forest watershed management study. Nevertheless, a few of the agricultural investigations are reviewed here as they apply to this study both in methods used and (or) results obtained.

One of the earliest important watershed management studies in the world was the Emmenthal watershed study that was begun in 1890 in Switzerland (59). This research project dealt with the influence of forest cover on streamflow under Swiss climatic conditions and was done by the Forest Research Institute of Switzerland. The very high altitude and very different climate make the Swiss study not too applicable to this dissertation. However, the methods of research employed in this project and the problems encountered and solved have contributed much to guide subsequent watershed studies and thus influenced the original planning and procedures used in this study.

Watershed research and experimentation first began in the United States in 1909 when the United States Forest Service and the Weather Bureau cooperatively established experimental watersheds at Wagon Wheel Gap in the Rocky Mountains of Colorado (14). Since that time forest watershed research has been carried on by the Forest Service, the Tennessee Valley Authority, the United States Geological Survey, and by universities and state agricultural experiment stations. To some extent, forest land and its hydrology are included in the cropland and pasture watershed research conducted by the Soil Conservation Service (58).

The possible methods of forest hydrologic research can be grouped into three basic types of research, each possessing advantages and disadvantages over the others and each important in its own right and also contributing to the applications and results of the other two. One type is watershed laboratory studies in which entire unit watersheds under experimental control are subjected to experimental treatment after being calibrated. A second type of hydrologic research is made by confining blocks of soil, forming lysimeters, and keeping records of water added and determining losses by volumetric measure or by weighing. A third method, to escape some of the disadvantages of the lysimeter method especially when interested in forest vegetation, is plot studies in which the rainfall reaching the ground and the surface runoff are measured. Losses from the soil are determined by soil moisture sampling.

Perhaps the most important past investigation with respect to this thesis concerning the effect of changing the vegetation cover of a forested area carried through a number of years was reported by Bates and Henry (2). They reported an observable change in the water regime for a drainage area subjected to a definite change of cover type under experimental observation. Their study was made on two watersheds near Wagon

Wheel Gap, Colorado. One watershed (watershed A) was kept as a control and was not denuded. Watershed B was denuded of forest vegetation. Both of these watersheds were rather thinly forested before treatment and after denudation the aspen sprouted and rapidly restored the cover. These factors minimized differences so greatly that they concluded evapotranspiration losses were approximately equal quantities on both the treated and untreated watersheds. Other differences between the Wagon Wheel Gap study and this study include the fact that trees were skidded to roads and removed from the area and the fact that a large portion of the annual precipitation there is in the form of snow. In spite of the above mentioned difficulties and the lower total annual precipitation to work with, the Wagon Wheel Gap study did show that the cutting of forest cover increased the total annual water yield and increased the water yield from snow.

Another intensive study that is applicable in some respects to this investigation is the one begun in 1939 on watershed 13 of the Coweeta Hydrologic Laboratory. This watershed was cut similar to the initial cutting on watershed 17 but the sprouts were allowed to grow back. The increased water yield the first year after cutting was the same as on watershed 17, but, as the coppice stand grows older, the transpiration increases and there is a relative decrease in water yield each year (21, 35). After the ninth year of regrowth the forest was about thirty feet high, but the increase in annual water yield still amounted to about twenty-five percent over the pretreatment annual yields.

The United States Department of the Interior Geological Survey in cooperation with the State of New York Conservation Department began an investigation in 1932 to study the influence of reforestation on streamflow in the state forests in central New York. In 1949 Ayer reported that the submarginal land used in the study had a satisfactory initial cover of shrubs, grass, weeds and scrub brush before the reforestation was effected (1). Therefore, he found that there was practically no significant change in the relationship between runoff at a reforested area and at its control area since the project had been inaugurated.

The Coweeta Hydrologic Laboratory is also conducting other hydrologic investigations of varying importance to this dissertation (21). On one watershed only the trees and shrubs close to the stream channel were cut to study the effect of cutting riparian vegetation. About twelve percent of the total area of the watershed was cut. This treatment eliminated the diurnal fluctuation of streamflow on that watershed. It effected an increase in total annual yield of less than ten per cent. On another watershed the rhododendron and laurel understory characteristic of Southern Applachian hardwoods was cut to study the effect of cutting the ericaceous understory. The treatment effected an increase equal to 3.6 inches of runoff each year for the first two years after cutting (35).

By the third year after the cutting the increase was tapering off. Other watershed studies at Coweeta include the hydrologic effects of land use. One watershed has been subjected to steep land farming. Another watershed has been grazed by cattle to study the effects of woodland grazing. A third watershed has been subjected to mountain logging as practiced locally by private operators. Other hydrologic research projects at Coweeta include the effects of temporary defoliation by gas, the effects of forest fires, and the effects of the elimination of live vegetation by girdling and poisoning.

The United States Forest Service also conducts hydrologic studies at the San Dimas Experimental Forest under the California Forest and Range Experiment Station. Their research projects in the low rainfall chaparral and pine areas of California are necessarily devoted to watershed management studies to produce maximum yields of usable water and satisfactory regulation of flood runoff and erosion. They are also studying the effects of many factors of watershed conditions, such as vegetation, soils, geology and topography upon the disposition of rainfall. Rowe and Colman (42) reported on a study of the effects on the disposition of rainfall after removing the vegetation, trenching and maintaining a bare surface on plots in woodland chaparral, ponderosa pine and San Dimas chaparral. They found surface runoff and soil erosion were greatly increased. There was a greater carryover of soil water on the bared plots from one year to the next than was found on the annually burned or natural plots. Drying was much slower and less complete in the deeper soil layers on the bared plots and those of the bared plots with deep soil entered each rainy season with a proportionately greater carryover of water than did those with shallow soil. Denudation appeared to be more effective in reducing evaporation losses from deep than from shallow soils, and from soils protected from full insolation than from those exposed to sun and wind. They concluded that increases in usable water yield can possibly be achieved in those areas if soils are deep, by reducing interception and evapo-transpiration losses, but only if surface runoff with its resultant soil erosion can be controlled.

The Sierra Ancha Experimental Forest near Globe, Arizona, conducts watershed management investigations under the Rocky Mountain Forest and Range Experiment Station. They are studying the influences of vegetation (forest, evergreen shrub, and range) on stream flow, water uses, water losses, erosion and sediment production. Emphasis in this area is placed on range land and grazing studies. They are employing gaged watersheds, plot studies and rather unique natural lysimeters in their investigations. Rich states that the data from the studies in Arizona show relatively small differences in consumptive use of water between areas kept bare of vegetation and areas in various types of vegetation (39). This results from the fact that there are few areas in the western

United States where a sufficient supply of water is available to approach the full potential consumptive use of vegetation. Thus the differences between the consumptive uses for various vegetative covers are minimized not because the vegetation is not capable of producing significant differences but because of the usually extremely limiting factor of available moisture supply.

The Rocky Mountain Forest and Range Experiment Station also carries on hydrologic investigations at the Fraser Experimental Forest, the Manitou Experimental Forest and the Western Slope Research Center. These investigations, being conducted in the Central Rockies, are necessarily concerned with precipitation in the form of snow, the accumulation of snow, and the rate of snow melt. Wilm and Dunford (59) reported on such a study in 1948. They used twenty 5-acre plots to study the effects of timber cutting on water available for streamflow from a lodgepole pine forest. The project was begun in 1938. In sharp contrast to the climate at Coweeta, snow melt played an important part in Wilm and Dunford's study. However, they found an increase of thirty-one percent in the quantity of water available for streamflow on the cut plots over pre-treatment yields. Their experiments indicated that timber cutting in the lodgepole pine type of the Central Rocky Mountains exerts a real and immediate influence on the amount of water available for streamflow from those forested watersheds. They found that timber cutting exerted pronounced effects on all their measured components except soil moisture.

The Intermountain Forest and Range Experiment Station is studying various aspects of forest hydrology and influences in southwest Idaho, the Wasatch Mountains in northern Utah, and the Wasatch Plateau in central Utah. They are conducting research on 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. Their objective is 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. Since 1912 a study of the influence of herbaceous plant cover on surface runoff and soil erosion in relation to grazing has been conducted on two small watershed areas in the head of Ephraim Canyon, Utah. Forsling reports (12) that the results of this study show conclusively that both runoff and erosion have been increased by the removal of herbaceous vegetation through grazing, a much different method of destroying the vegetation than is used on watershed 17 at Coweeta.

The Northeastern Forest Experiment Station began a study late in 1948 to determine water behavior for a watershed covered by a dense growth of scrub oak at the Lehigh-Delaware Experimental Forest. It is planned to study the effects of converting the scrub-oak to a better forest type by forest management upon runoff and ground water on the 1,530-acre Dilldown Watershed (38). Watershed studies also were begun in 1952 on five small watersheds on the Fernow Experimental

Forest in West Virginia to study the effects of various levels of timber cutting upon water behavior.

The Tennessee Valley Authority in 1951 reported the results of watershed studies made at the White Hollow Watershed, Tennessee. The report is a study of the effects of fifteen years of watershed management, which included extensive erosion-control operations and tree planting, upon the hydrologic characteristics of a watershed. They report the following conclusions (48): (a) The improvement in forest cover which occurred resulted in a 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 fifteen-year period of observations.

In 1940 the Michigan Hydrologic Research Project was established as a cooperative study between the United States Soil Conservation Service, the Michigan Agricultural Experiment Station and Michigan State College. A main objective of the project was to determine the fundamental hydrologic relationships of typical Michigan soils under varying types of land use, with special emphasis upon the movement of water through the soil profile during the fall and winter months. Three small unit watersheds were used in the study. Two were subjected to current farming practices. The third possessed an oak-hickory forest for the first eleven years and was then subjected to a commercial clear-cut in 1951. Smith and Crabb (46) report that the watershed under forest cover yielded very little surface runoff and suffered almost no soil loss during the first eleven years, while each of the two cultivated watersheds yielded eight times as much surface runoff and lost roughly five hundred times as much soil. Data on the effects of the commercial clear-cut treatment are not yet complete.

As mentioned earlier, although primarily with cropland watershed research rather than with forest land, the Soil

Conservation Service of the Department of Agriculture has conducted some important hydrologic studies. Their first experimental watershed studies were initiated in the Muskingum Watershed Conservancy District near Coshocton, Ohio. This project is conducted primarily in the interest of conservation and land use, and erosion-control practices are tested for their effects on flood flows, surface runoff, and soil and moisture conservation (12). Dreibelbis and Post reported on a comparison of soil-water relationships among a wooded watershed, a pasture watershed and two cultivated watersheds and found the wooded watershed to have a much lower volume of surface runoff (11).

Using the plot method by extracting soil cores from representative parts of the Allegheny River watershed, Trimble, Hale and Potter studied the effect of land use and soil conditions upon the movement and storage of water in the soil (50). They studied percolation rates and storage capacities in relation to soil type and cover condition. For forest land they found grazing, drainage and humus type to be the factors having a major influence on the soil-water relations of the upper two feet of soil.

There are also numerous studies and a copious supply of literature which more or less apply to the phase of this thesis dealing with the changes in the soil moisture regimen brought about by changes in the vegetative cover due to forest land management. Schiff and Dreibelbis studied the effects of improved wheat, contour improved corn and improved permanent pasture upon storage space and moisture depletion curves for both topsoil and subsoil (43). Their study showed transpiration differences to be an important factor on runoff and thus on streamflow characteristics.

Houk ran some interesting soil moisture trend experiments in 1916 in which he compared soil moisture contents under sod to that under a bare surface (19). He measured the soil moisture content for only the top two feet of soil, where evaporation from a bare surface has most of its effect. He found the moisture content under sod was slightly higher than under a bare surface during the summer months for these top two feet. Conrad and Veihmeyer sampled soil moisture to a depth of six feet, comparing soil under grain sorghum and soil under a bare surface (7). They found that the loss of moisture by direct evaporation from the surface of the soil is practically confined to shallow depths of the soil, and that losses from deeper layers (aside from percolation when excessive amounts of water are applied) are due to transpiration from plants growing on the soil. In another agricultural experiment Weaver and Bruner studied the root habits of many crops and determined the differences in the degree of soil moisture depletion by the various crops (57). These studies and those studies reported by Weaver alone (56) showed that variations in rooting habits greatly influenced the characteristics of soil moisture depletion trends. They found that the root extent should furnish the criterion as to the depth to which soil moisture should be studied and also the maximum depth to which samples should be taken.

Hendrickson and Veihmeyer, in studying the effects of soil moisture on peach trees, demonstrated the relative unimportance of evaporational losses to soil moisture when considering transpirational losses caused by tree vegetation (15). They found that all depths were depleted at approximately the same time. In later studies by Hendrickson and Veihmeyer with prune trees (16) and still later studies with pear and apple trees (17), they observed that soil moisture curves showing the rate of extraction by trees are essentially straight lines with a pronounced change in direction when the soil moisture is reduced to about the permanent wilting percentage. Veihmeyer and Hendrickson also studied plots in a walnut orchard with trees having an extensive root system out to twenty feet from each tree (53). They found a comparatively small variation in soil moisture content whether the samples were taken eight, twelve, sixteen, or twenty feet from the tree. The curves they obtained illustrate the fact that the readily available water at a given depth was extracted about as rapidly near the tree as it was farther away and the permanent wilting percentage at twenty feet from the trunk of the tree was reached as soon as it was at eight feet. Although slightly slower than for the top six feet of the soil, they found definite downward trends in the soil moisture curves for the seventh-, eighth-, and ninth-foot levels also. Richards and Wadleigh, in summarizing the studies of Hendrickson and Veihmeyer, conclude that the pattern of moisture extraction in soils is largely a matter of active root distribution (45). They state that in addition to the extent of root penetration, consideration must also be given to root proliferation or the spacial density of root distribution.

Bauer studied the effects of chaparral upon soil moisture (3). He found that plant roots of brush and chaparral vegetation absorbed moisture from all levels down to sixty centimeters at about the same rate. He did not sample below sixty centimeters. There was very little loss of water at the location of his experiment (a northerly exposure) by direct evaporation from the soil surface, since the ten centimeter depth showed about the same moisture content near the surface as at the deeper levels. Bauer also found that on an area where the chaparral had been recently destroyed by fire, the water content at the thirty centimeter level remained above the permanent wilting percentage throughout the year. This was in great contrast to soil under normal chaparral.

Veihmeyer and Johnston studied soil moisture characteristics of chaparral and brush vegetation as affected by burning (54). Their data show that denudation will result in a reduction of soil-moisture losses, but that the amounts of water saved are appreciable only where the burned areas are not revegetated by the sprouting brush. Where grasses and herbs follow burning, there was a substantial saving of water. No portion of the soil in the unburned plots escaped depletion of its readily available moisture by the end of the growing season.

Craib observed the fluctuations of soil moisture in a forest in New Hampshire and found that soils in the open contained considerably more moisture during dry periods than the forest soils (8). During the driest periods of the year there was more than twice the actual volume of moisture in the first ninety centimeters of soil available to plants in the open than in the forest. He also found that the amount of available moisture was greatly increased by the elimination of root competition.

Korstian and Coile made a soil moisture experiment under forest vegetation in the Duke Forest, using trenched plots (25). They found that with but few exceptions the soil of the trenched plots contained significantly greater amounts of moisture than their corresponding control plots during periods of moisture stress during the growing season. Trenched plots had reduced root competition and transpiration and, therefore, had decreased retention storage opportunity.

Toumey and Kienholz ran a trenching experiment in a white pine stand in New Hampshire (49). They observed that, during the driest months of the year, soil moisture was from two to nine times as great on the trenched as on the untrenched plot. Soil moisture occasionally fell below the wilting coefficient on the untrenched plot but never fell below on the trenched plot.

In his studies of the distribution of soil moisture under isolated forest trees, Lunt found his data showed that the whole root system of a tree is involved in moisture absorption and not any one particular portion (31). Except in wet soils, the tree must extract moisture from the subsoil as well as the surface layer in order to meet its moisture needs.

These numerous studies support the statement by Kramer that it is generally agreed that transpirational losses exceed losses by evaporation where well-developed grasslands and forests occur (26). He also states that as evaporation removes water only from the surface foot of soil, the remainder of the soil moisture would remain untouched were it not for the roots of plants. Kramer concludes that, in general, considerably more water is lost from an area by transpiration than would be lost by evaporation from the same soil surface if it bore no vegetation. Lassen, Lull, and Frank further state that, since available storage space depends largely on transpiration losses, any change in the condition of vegetation that alters transpiration rates will also affect retention storage opportunity (27). They explain that the removal, killing, or partial cutting of vegetation affects transpiration because the leaf area and hence the transpiring surface is reduced. They state that there tends to be a balance between crown and root activity. Thus, killing of vegetation reduces effective root depth because the active new plants are younger and, in consequence, reduces the depth of soil from which roots extract moisture.

The above summary of the more important studies having the most direct bearing on this dissertation emphasizes three things: (1) There is a great deal of literature with more or less application to one or more phases of this study. (2) None of the past studies were conducted in the same manner and under similar climatic conditions as this problem, and as a result, direct comparisons between this and past studies are extremely limited. (3) Most of the past studies are actually land-use studies and thus differ somewhat in their fundamental intent from this type of basic study. There also exists a great abundance of other literature containing incidental conclusions and research methods which more or less pertain in some way to various phases of this dissertation.

Kittredge enumerates five possible methods that have been used in making comparisons to evaluate the effects of vegetation (24). Among these methods he describes one which involves the comparing of two forested areas as nearly identical as possible for a preliminary period to establish the relations between them either as ratios or differences. Then by removing the forest from one of the areas and comparing the ratios or differences between them after deforestation with those before, comparisons may be obtained. This is the research method by which the hydrologic phase of this study was made. The standardization period together with the use of the similar, control watershed, which is protected in a natural condition, offers a high degree of both control and reliability in comparing the hydrologic effects of treatment. In addition to climatic differences and treatment differences, few of the hydrologic studies discussed above employed this experimental design. Another of the five possible methods described by Kittredge is the simple method of the comparison of two similar areas with different vegetative cover. This is the method employed in the pedologic phase of the study.

DESCRIPTION OF THE AREA

The Coweeta Hydrologic Laboratory

The Coweeta Hydrologic Laboratory is a 5,600 acre tract located in the Nantahala Mountains about eighty miles southwest of Asheville, North Carolina, and one hundred and twenty miles northeast of Atlanta, Georgia. It can be reached by traveling eleven miles south from Franklin, North Carolina, on United States Highway 23 and then turning west on a paved road. Figure 1 gives its location with respect to highways and local towns.

The United States Forest Service chose this site in 1931 for the location of a watershed laboratory to evaluate the hydrologic principles basic to practical watershed management in the high rainfall belt of the Southern Appalachian Mountains. Hursh (21) stresses that this site in western North Carolina was selected only after careful research to find an area that would meet rigid specifications designated by hydrologists, engineers, and foresters interested in watershed research. Geology, soils, topography, rainfall distribution, and stable ownership for control of treatments were considered.

Geologically and topographically, the Coweeta Laboratory is well adapted for watershed studies. The Coweeta area is part of the older Appalachians and is in the cross-range

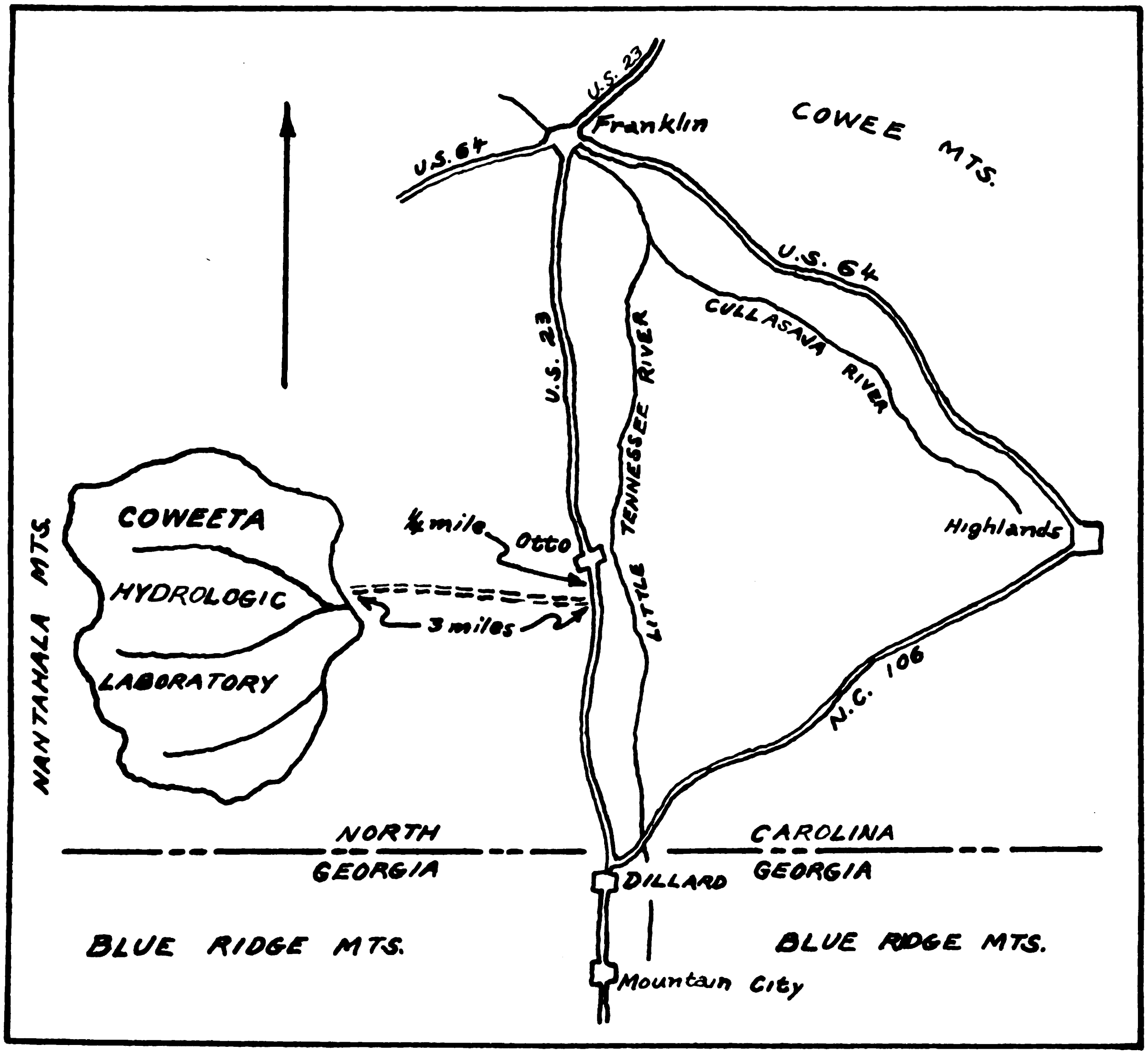


Figure 1. Location of the Coweeta Hydrologic Laboratory.

country joining the Blue Ridge and Smoky Mountains. The area is free of extensive faulting or intrusive dykes and the massive underlying rock formations are apparently watertight. There is no indication of any quantity of deep seepage escaping measurement. The Coweeta Hydrologic Laboratory lies at elevations of from 2,200 to 5,200 feet. Its mountainous terrain provides many steep slopes and sharp crested ridges forming natural, well defined boundaries for its numerous small watersheds. Thus the topography and geology of this field laboratory are well suited to the experimental study of small drainage areas that meet all requirements of independent hydrologic units. The drainage pattern of the Coweeta Hydrologic Laboratory is shown in Figure 2. The pattern of drainage for both composite and individual watersheds is dendritic. Figure 3 shows the individual drainage basins with the two watersheds concerned in this dissertation indicated in black.

The soils of Coweeta are derived from the weathering of underlying acid crystalline rock formations, which consist mainly of gneisses and schists. The soils are relatively deep and porous and thus are well adapted to hydrologic studies in vegetational changes.

The climate of the area is also ideal for hydrologic studies. It is classified as superhumid during the growing season. The Coweeta Hydrologic Laboratory, being on the southeastern side of the southern Appalachian Mountains, is

Figure 2.

DRAINAGE PATTERN
COWEETA HYDROLOGIC LABORATORY
(DRYMAN FORK EXCLUDED)

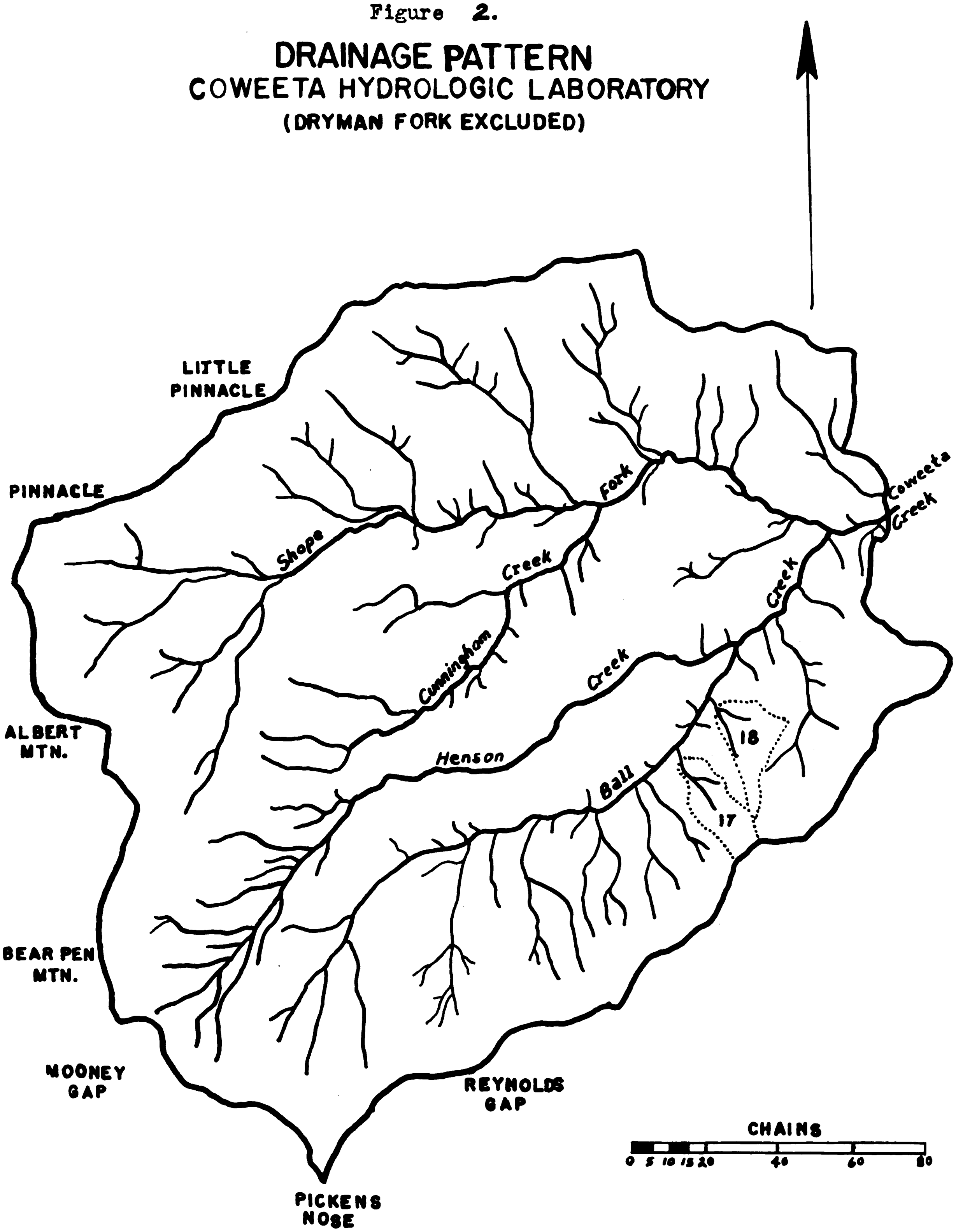
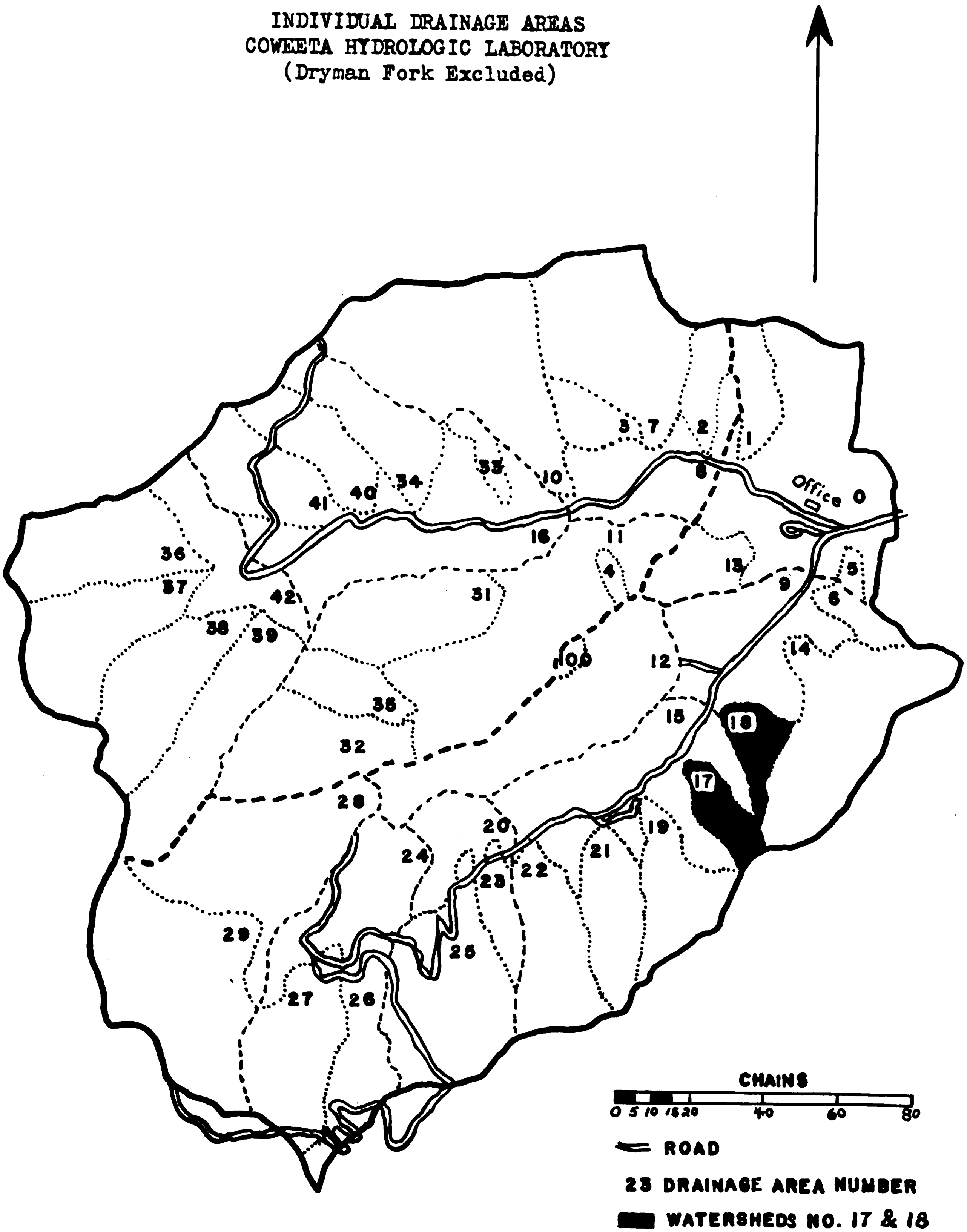


Figure 3.

INDIVIDUAL DRAINAGE AREAS
COWEETA HYDROLOGIC LABORATORY
(Dryman Fork Excluded)



so located that it presents the first orographic barrier to moisture-laden winds and tropical storms moving inland and in a westerly direction from the South Atlantic or in a northeasterly direction from the Gulf of Mexico. The weighted average annual precipitation is above seventy inches and is fairly evenly distributed throughout all the months of the year. October is the lowest month and March is the highest. Less than two percent of the mean annual precipitation occurs as snow. Because of this pattern of precipitation and the large number of storms per year, it is possible to obtain experimental results in a relatively few years, as compared with regions having less rainfall. Figure 4 shows the rainfall distribution pattern for a portion of the Southeastern United States with the Coweeta Hydrologic Laboratory located in the area of highest precipitation.

As is typical over much of the Southern Appalachian region, a dense mixed hardwood forest provides the dominant vegetative cover for Coweeta. Chestnut (*Castanea dentata*) was the major species before it was eliminated by the chestnut blight (*Endothia parasitica*). The forest is now predominantly in oak-hickory stands.

Coweeta Watersheds 17 and 18

Treated watershed 17 and control watershed 18 are located adjacent to each other in the southeastern portion of the Coweeta Hydrologic Laboratory, as is shown in Figure 3.

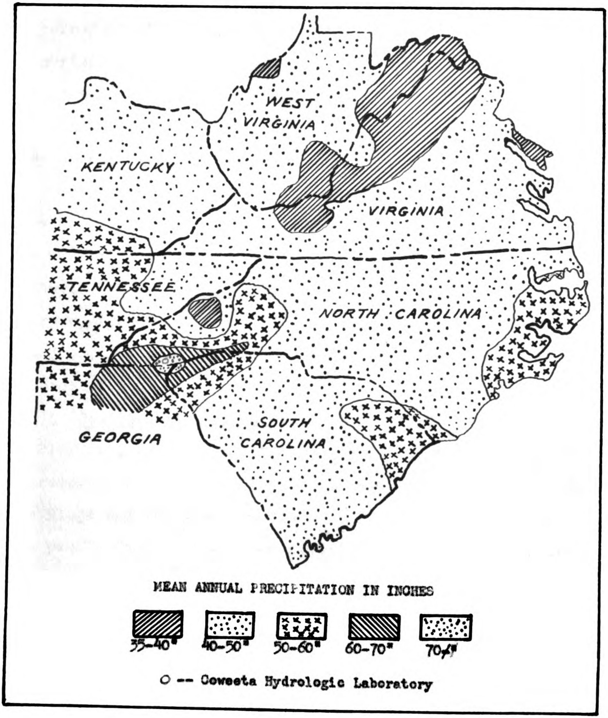


Figure 4. Distribution of mean annual precipitation in the Appalachian Region of the Southeastern United States.

The permanent stream flowing from watershed 17 is known as the Hertzler Branch and the permanent stream flowing from watershed 18 is called the Grady Branch. These two streams flow into Ball Creek, which in turn flows into Coweeta Creek. Coweeta Creek is a tributary of the Little Tennessee River.

Watershed 17 contains 33.32 acres and watershed 18 contains 30.84 acres. These closely associated watersheds both possess the same aspect or exposure, which is generally northwest. Figure 5 shows a map of the two drainage basins. Figure 6 shows an over-all view of watershed 17 during the experiment. Figure 7 shows a view of watershed 18 during the experiment.

Geology and Physiography. The two watersheds are in the Blue Ridge province of the Southern Appalachians. The watersheds form a part of the cross-range country joining the Blue Ridge and the Smoky Mountains. The area is underlain with deeply weathered Archean granite formations. Under these watersheds the formations consist of various kinds of Roan and Carolina granitic mica schists and gneisses of Archean time. The underlying massive rock formations are deeply and complexly folded and are exceedingly thick. There is no evidence of open faults or fractures. The two drainage basins show no indication of any quantity of deep seepage escaping measurement.

The topography on both watersheds is rugged with steep slopes and sharp-crested ridges. Figure 5 includes contour lines, permanent streams and intermittent streams to show the

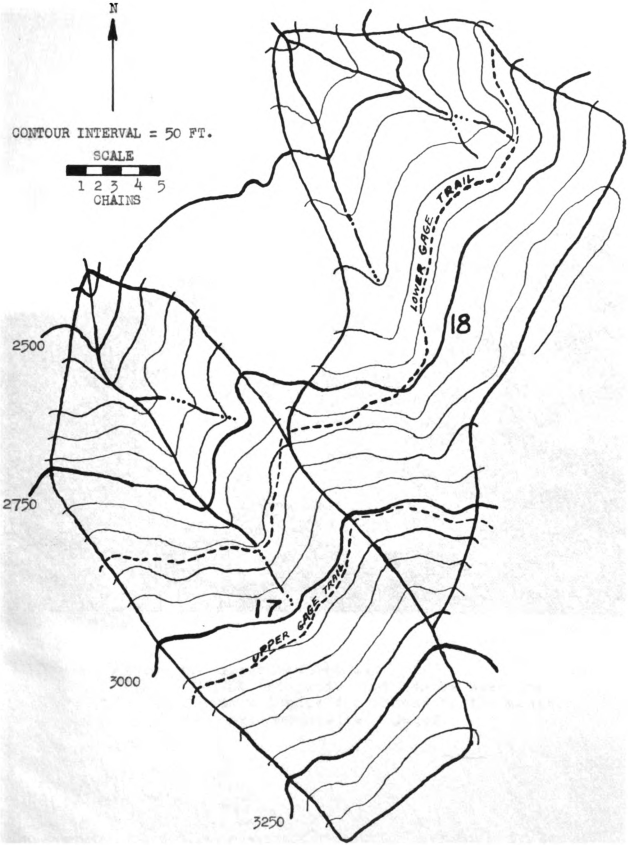


Figure 5. Watersheds 18 and 17 of the Coweeta Hydrologic Laboratory.

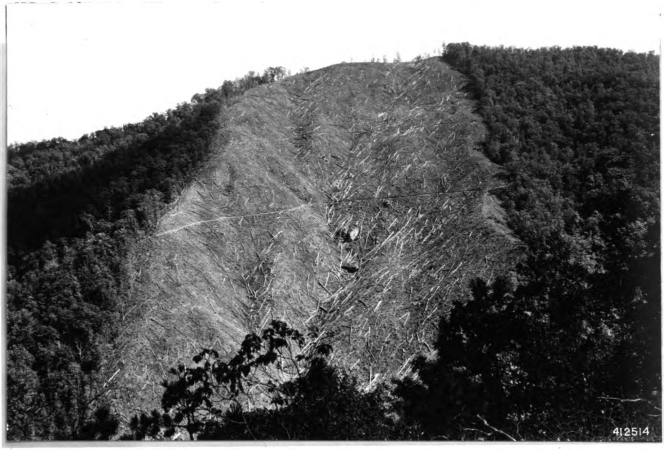


Figure 6. Watershed No. 17.
The two paths that can be seen are gage trails for access to the weather stations and rain gages.

Figure 7. Watershed No. 18.
A small portion of Watershed No. 17 appears at the right edge of the photograph.

topographic characteristics. The two watersheds are closely similar in all respects. The maximum elevation above mean sea level for watershed 17 is 3,381 feet and for 18 it is 3,258 feet. The minimum elevation for watershed 17 is 2,422 feet and for 18 it is 2,382 feet. Thus the total relief for watershed 17 is 959 feet, while the total relief for 18 is 876 feet. The mid-area contour for 17 is 2,916 feet and for 18 is 2,703 feet. The percent land slope east-west for watershed 17 is 53.0 and for watershed 18 it is the same. The land slope north-south for watershed 17 is 60.3 percent and for 18 is 51.9 percent. The average land slope for 17 is 56.7 percent and for 18 is 52.5 percent.

The drainage pattern on both watersheds is dendritic. The channel length for watershed 17 is 0.22 miles and for 18 is 0.18 miles. The channel gradient for 17 is 29.4 percent and for 18 is 18.9 percent. The stream density in miles of stream per square mile of watershed is 4.23 for watershed 17 and 3.74 for watershed 18.

Climate. Observations on the microclimate for the two watersheds will be discussed in the section on Supplementary Observations in the chapter entitled "Effects of Treatment of Some Pedologic Characteristics." Except for the changes brought about by treatment, the two watersheds are nearly identical in all factors affecting microclimate. The watersheds lie side by side on the same major cross-ridge. They have similar aspects and are situated at the same elevations.

They are about the same size and possess closely similar drainage patterns.

The macroclimate is continental; although the mountain ranges forming the western boundary of Coweeta exerts a strong modifying influence. The climate is superhumid during the growing season. The weighted average annual precipitation for watershed 17 is 74.44 and for 18 is 71.73 inches. The extremes for watershed 17 are 51.34 and 93.69, while for 18 they are 51.84 and 90.44 and occur during the same years, of course. There is a large number of storms per year and the precipitation is well distributed throughout the year. October is the dryest month with an average of 4.31 inches precipitation and March is the wettest with an average of 8.32 inches for watershed 17. The same is true for watershed 18 with an average of 4.17 inches in October and 7.91 inches in March.

The temperatures at Coweeta are moderate. The mean annual temperature recorded at weather station No. 1 at Coweeta is 55°F. The mean temperature for the growing season is 68°F. Daily maxima above 90°F. are rare. The cool summer nights are reflected in the average of 55°F. for the summer daily minima. The mean temperature of December through February is 40°F. Daily minima are rarely below 32°F. and there are frequent periods of warm weather (70°-75°F.) in winter months. There is a marked uniformity of temperature during the summer, in contrast with the fluctuations common during other seasons.

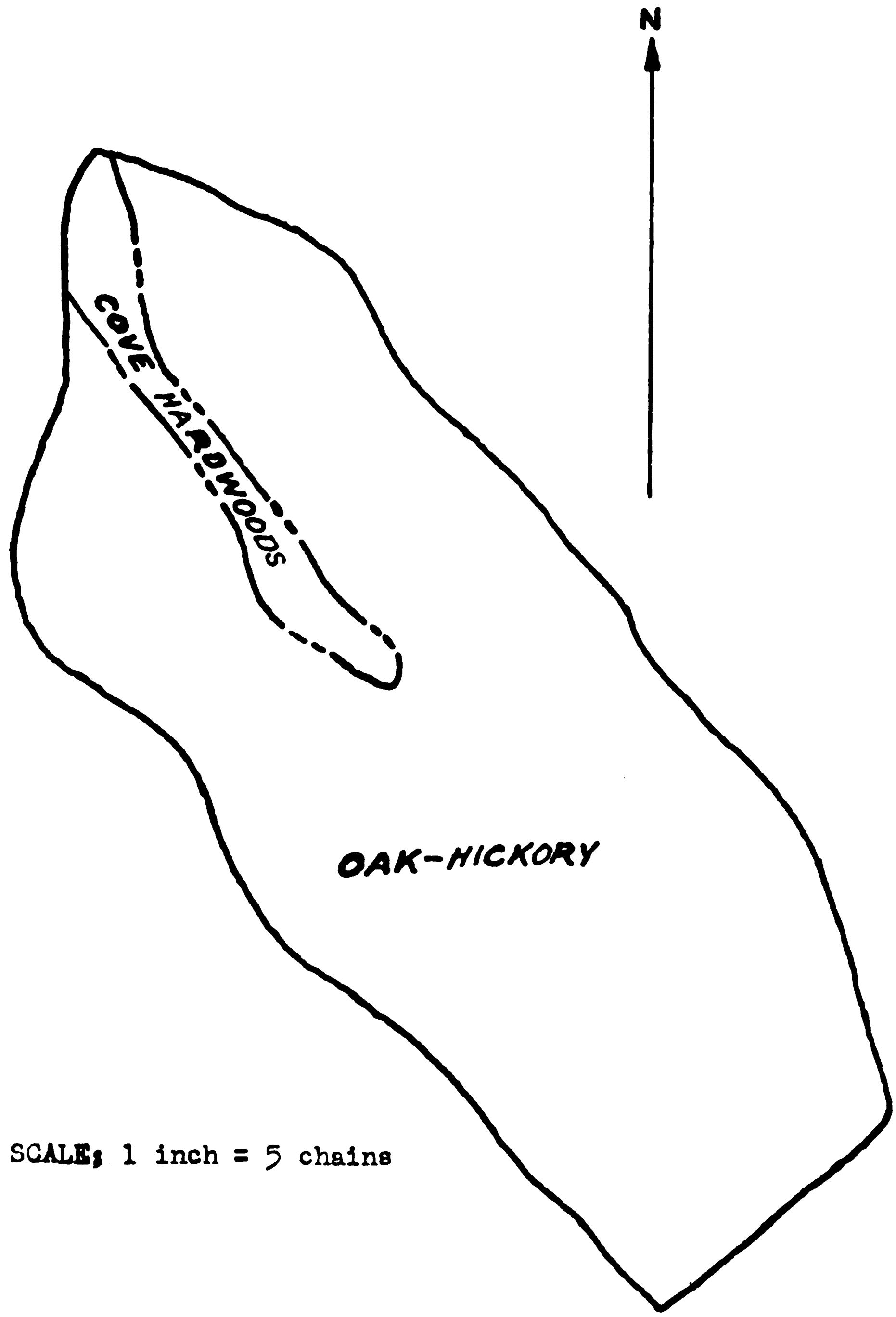
Soils. The broad grouping of soils in the Southern Appalachian Mountain region of which Coweeta is a part has been classified as the Gray-Brown Podzolic and Lithosol great soil groups. This area has never been subjected to glaciation and the soils of the watersheds have been derived from the weathering of acid crystalline gneisses and schists. This area is within the region of the Porters-Ashe association.

Devereux et al. (9) have classified the soils of both watersheds as rough stony land, within which may be found small areas of Porters loam and Porters stony loam. At the lower elevations of both watersheds there can be found Porters loam, colluvial phase near the stream channels. These colluvial fills in some cases may be twenty feet thick. On the upper slopes the soils range in depth from two to ten feet. Some rock outcrops are present, as can be seen in Figure 6, but these cover a very small area of the watersheds. There is evidence of landslides and soil creep. A large amount of angular stones and rock fragments are found throughout the young, immature soil profiles throughout both watersheds. The relatively rapid geologic erosion and the high rock content cause most of the soils on these watersheds to be classed as azonal lithosols. The characteristics of the specific soils found on these two watersheds have been studied in detail as a part of this dissertation and the results of an intensive soil survey and laboratory analyses of the soils are described in the chapter entitled "Effects of Treatment on Some Pedologic Characteristics."

The soils on these two drainage areas are much too steep for cultivation. However, elsewhere on favorable slopes Porters loam and Porters loam, colluvial phase are considered good agricultural soils in Macon County. Only a small portion of these soils is in cultivation because of the steep topography which prevails. The principal crop is corn. Cabbage, potatoes, snap beans and pumpkins are also grown. Porters loam is one of the good pasture-grass soils of western North Carolina.

Vegetation. Before the treatment was applied to watershed 17 the two watersheds were closely similar in their vegetative cover. Both supported the dense mixed hardwood forest typical of the Southern Appalachians. Chestnut was the major species before being killed out by the blight. At the time of treatment oak-hickory stands supplied the major regional forest type for the drainage basins and occupied most of the area. A small area of cove hardwoods were on both watersheds. Yellow pine-hardwoods occupied two small areas on watershed 18. Figures 8 and 9 show the areas of the regional forest types on the two watersheds. Oak-hickory stands occupied 93.3 percent of the area on watershed 17 and 91.4 percent of the area on watershed 18. Cove hardwoods covered 6.7 percent of the area on 17 and 2.3 percent of the area on 18. Yellow pine-hardwoods occupied 6.3 percent of the area on 18.

The forests of this area are three storied with large trees forming the upper layer, small trees and large shrubs



SCALE; 1 inch = 5 chains

Figure 8. The forest regional types on watershed 17.

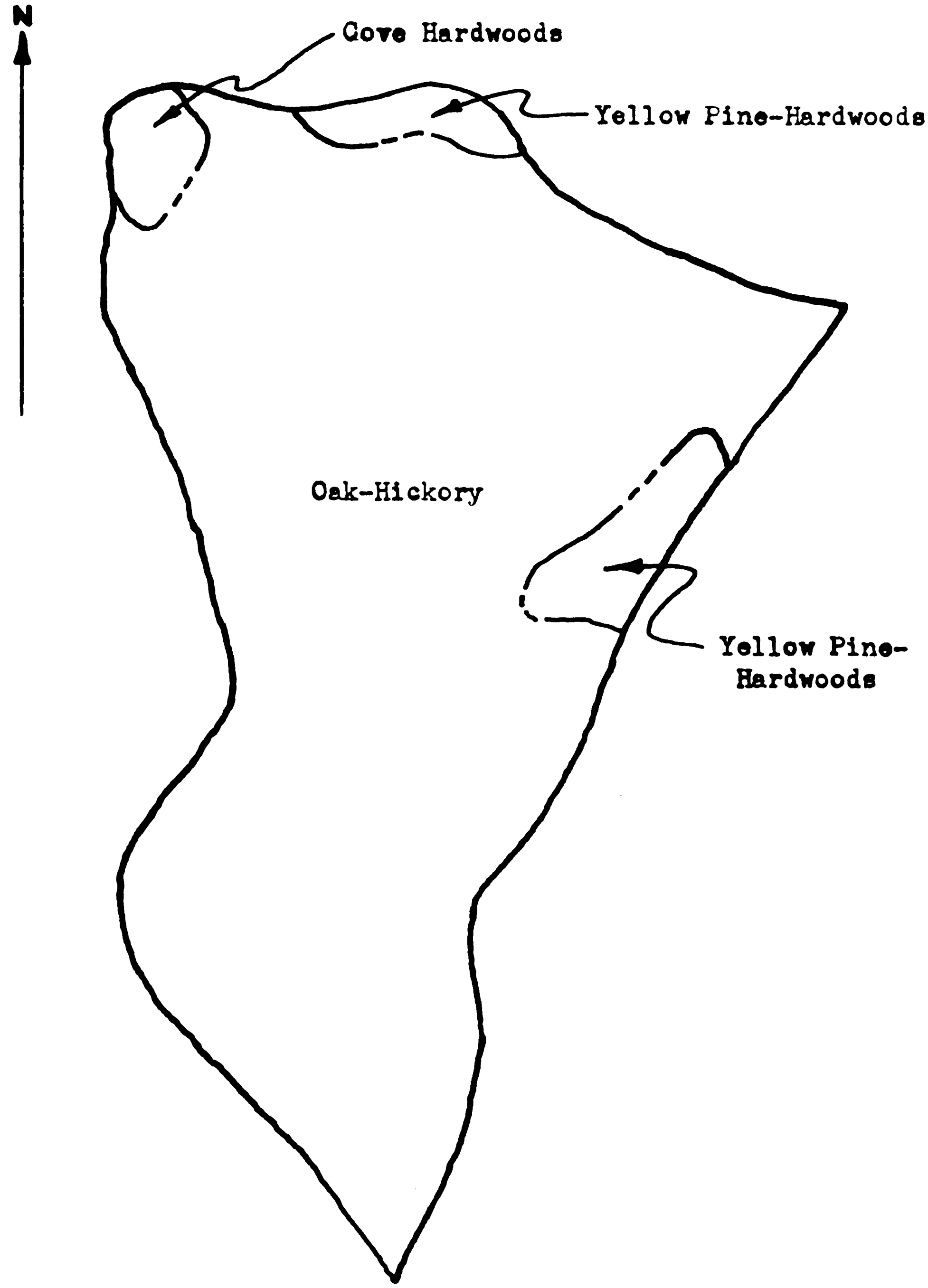


Figure 9. The regional forest type areas
on watershed 18.

the second, and herbs and shrubs the lower layer covering the ground. The second story is made up principally of laurel (_Kalmia latifolia_) and rhododendron (_Rhododendron maxima_).

Figures 10 and 11 show the distribution of forest types over the two drainage areas prior to treatment. A dense understory of laurel and rhododendron covered the major portion of both watersheds. The large area distribution of the understory composed of these two species is also shown in Figures 10 and 11.

A more detailed description of stand composition by basal area distribution and stem count within diameter classes is provided for watershed 17 because of the information supplied at the time of the original cut. The total basal area per acre for watershed 17 at the time of cut was 79.68 square feet. Deciduous trees comprised 75.82 square feet of this, 0.67 square feet were in conifers, and 3.19 square feet were in laurel and rhododendron. Table I shows the species composition of the stand by percent of basal area and Table II shows the number of stems per acre by diameter classes.

Land Use History. The Coweeta Hydrologic Laboratory is near what was the heart of the Cherokee Indian Nation. Many camp sites have been found on the area but there is no evidence of a permanent Indian settlement. The Indians used the area primarily as a range for livestock. The first white settler moved into the area in 1848. Watersheds 17 and 18 were subjected to woodland grazing and the area was burned

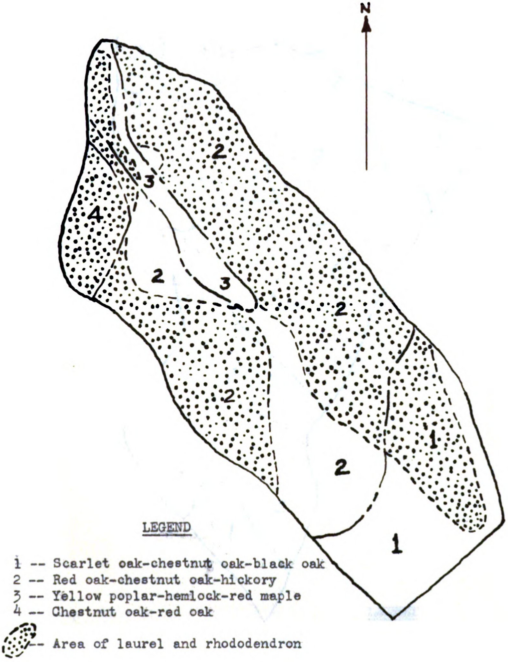
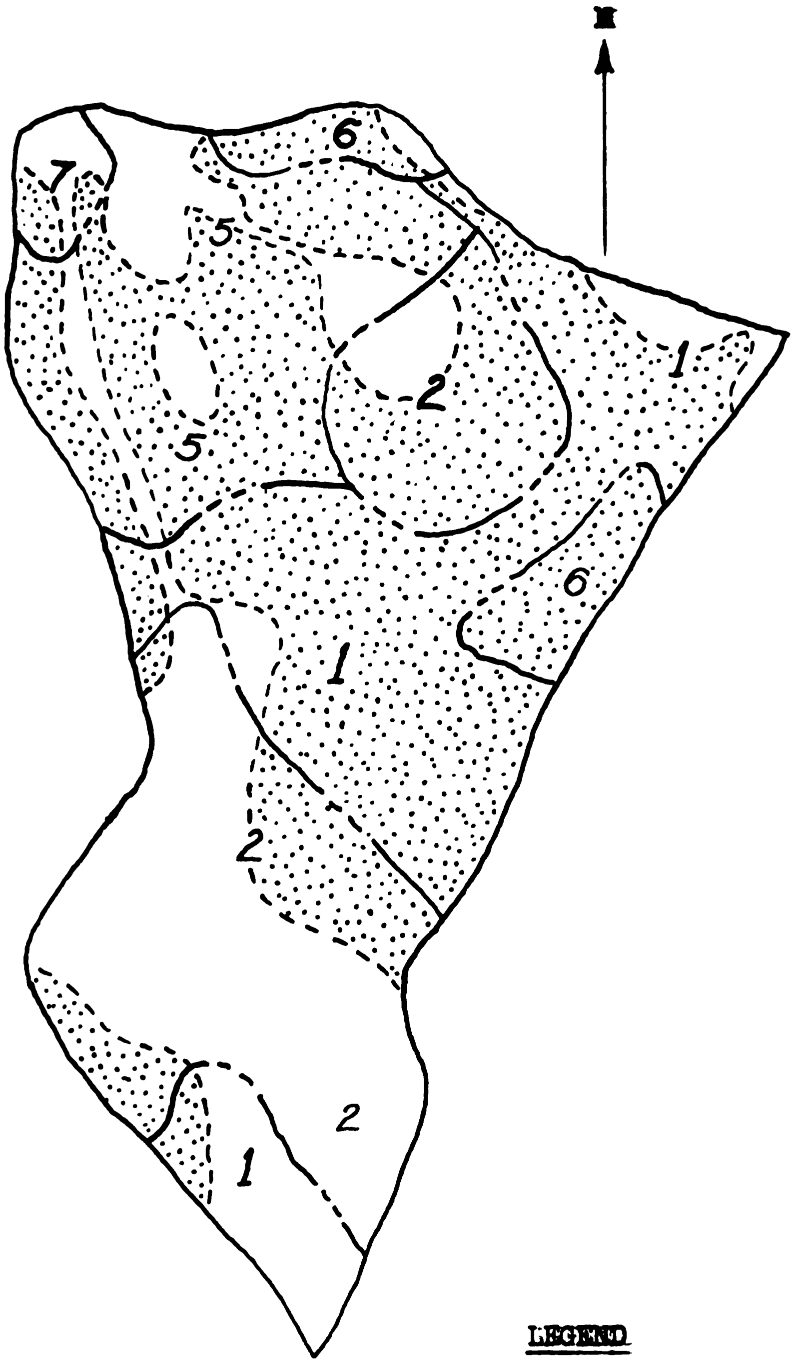


Figure 10. The distribution of forest cover types and the laurel and rhododendron understory over watershed 17.



LEGEND

1 -- Scarlet oak-chestnut oak-black oak
2 -- Red oak-chestnut oak-hickory
5 -- Scarlet oak-black oak-white oak
6 -- Pitch pine-scarlet oak-chestnut oak
7 -- Yellow poplar-red maple-white oak
 -- Area of laurel and rhododendron

Figure 11. The distribution of forest cover types over watershed 18.

TABLE I

SPECIES COMPOSITION OF THE STAND IN PERCENT OF BASAL AREA FOR WATERSHED NO. 17., COWEETA HYDROLOGIC LABORATORY

Species		Percent of Basal Area
Chestnut oak		31.44
Black oak		11.11
Eastern red oak		8.28
Hickory		8.18
Laurel		6.93
Red maple		6.22
Black gum		3.87
Rhododendron		3.42
Sourwood		2.84
Black locust		2.50
Dogwood		2.23
Live chestnut		1.74
Yellow poplar		1.17
Hemlock		0.65
Witch-hazel		0.59
Sassafras		0.57
All others	Less than	0.50

TABLE II

DISTRIBUTION OF NUMBER OF STEMS PER ACRE BY DIAMETER CLASSES FOR WATERSHED NO. 17

Diameter Class in Inches	Number of Stems per Acre	Diameter Class in Inches	Number of Stems per Acre
1	1356.52	18	1.95
2	308.80	19	1.49
3	96.04	20	1.28
4	25.30	21	0.70
5	14.33	22	0.73
6	13.29	23	0.37
7	9.45	24	0.46
8	7.26	25	0.24
9	5.76	26	0.21
10	5.58	27	0.15
11	4.21	28	0.09
12	4.02	29	0.03
13	3.14	30	0.00
14	3.60	31	0.06
15	3.17	32	0.03
16	2.71	33	0.03
17	2.50	34	0.03
		Total	1,873.60

over annually, a practice said to have been started by the Indians to favor grazing. The settlers were moved from the area in 1902 when it was purchased by a land company which subsequently sold it to operating lumber companies. Grazing and burning continued, but no land clearing was made on these watersheds for growing crops, pasture, or other purposes.

Logging in Coweeta began in 1909, with intermittent small cutting operations continuing until 1918. At this time the land was sold to the United States Forest Service with the timber rights reserved. By agreement with the Forest Service, logging continued until 1923 but no trees were cut that were smaller than fifteen inches on the stump. This resulted in only a light cut and a vigorous, second-growth forest quickly restocked the area. Watershed 18 was cut more heavily than 17 and had a higher percentage of its area in second-growth forest than did 17 at the time treatment was applied. No large fires have occurred since lumber company ownership. After Forest Service purchase, grazing use was gradually reduced and finally stopped completely with the establishment of the hydrologic laboratory.

HISTORY OF THE EXPERIMENT

Instrumentation - Installations

Hydrological Records. Because of the Coweeta Hydrologic Laboratory's ideal location for hydrologic studies on small unit watersheds, the streams coming from both watersheds flow continuously throughout the year. Therefore, a measurable base is always present with which to study effects of treatments.

After a thorough examination of watershed 17 and a study of its stream to determine the proper weir design for maximum accuracy and adequate capacity, a 90-degree V-notch weir having a capacity of 270 c.s.m. was installed. For obtaining continuous streamflow records a continuous water stage recorder was used. On June 6, 1936 the continuous recording of streamflow began. Figure 12 shows the weir installation on watershed 17 in February, 1941 during the initial cut. Figure 13 shows the same installation in August, 1953. Figure 12 shows the weir blade and Figure 13 shows the ponding basin.

After similarly considering watershed and streamflow characteristics on watershed 18, a 120-degree V-notch weir was installed and continuous streamflow recording began on June 3, 1936. Figure 14 shows the stream control for watershed 18 in September, 1937.

Figure 12. The 90-degree V-notch weir of watershed 17 in February, 1941.

Figure 13. Stream control for watershed 17 in August, 1953.

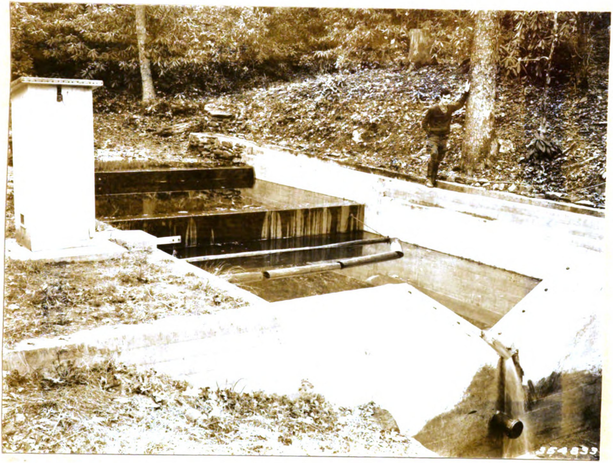


Figure 14. The 120-degree V-notch weir of watershed 18 in September, 1937.

The streamflow data are continuously recorded in head versus time readings on water level charts. These data are converted into volume discharge values, i.e., cubic feet per second (c.f.s.), cubic feet per second per square mile (c.s.m.), and area inches. The volume discharge values are summarized by days, months, hydrologic seasons and years.

The recorder charts are changed once each week and are checked by hook gage readings at the time the charts are changed. Water stage recorders are completely serviced and overhauled at least once each year.

Meteorological Records. Precipitation records for watersheds 17 and 18 are obtained from four standard rain gages, numbers 14, 39, 50, and 69. All four standard rain gages are used in measuring the amount of precipitation on watershed 18. Rain gages 50 and 69 are used in measuring the amount of precipitation on watershed 17. Continuous records have been kept since the beginning of the calibration period in 1936. The standard rain gages are read following each storm. These data are converted into area-inches of precipitation for the respective watersheds and then are summarized and tabulated by months, hydrologic seasons, hydrologic years and calendar years.

The conversion of the standard rain gage data into a weighted depth of precipitation for each watershed is done by the Horton-Theissen Means (20) method, using polygons to express the theoretical weight to be placed on each gage as is explained also by Wisler and Brater (60). The locations of the four standard rain gages and their respective polygons and weight factors are shown in Figure 15.

Meteorological station 12 is maintained on watershed 18 and station 13 on watershed 17.

Period of Standardization, 1936-1941

The period of standardization or calibration of watershed 17 prior to the application of the treatment began on June 6, 1936, when continuous streamflow records were begun. The gage type used for obtaining these measurements is a 90° V-notch weir. Employing a 120° V-notch weir, the continuous streamflow records for watershed 18 were begun on June 3, 1936.

The period of standardization officially ended with the beginning of the initial treatment, which began on watershed 17 on January 6, 1941. Therefore, the calibration period for the two watersheds spans slightly more than four and one-half years. During this period sufficient streamflow and climatic records were obtained in order to establish normal rainfall and runoff relations for the two watersheds. The length of the standardization period was ample because of the wide range of values obtained during those years and because of the normally high frequency of storms, the distribution of precipitation over the year, and the high total annual precipitation for this region. These climatic factors provide an accurate index of all possible variation extremes in a minimum length of time. In this area an average of about fifty significant storm hydrographs suitable for detailed analysis are obtained each year. Also the distribution of seasonal yield

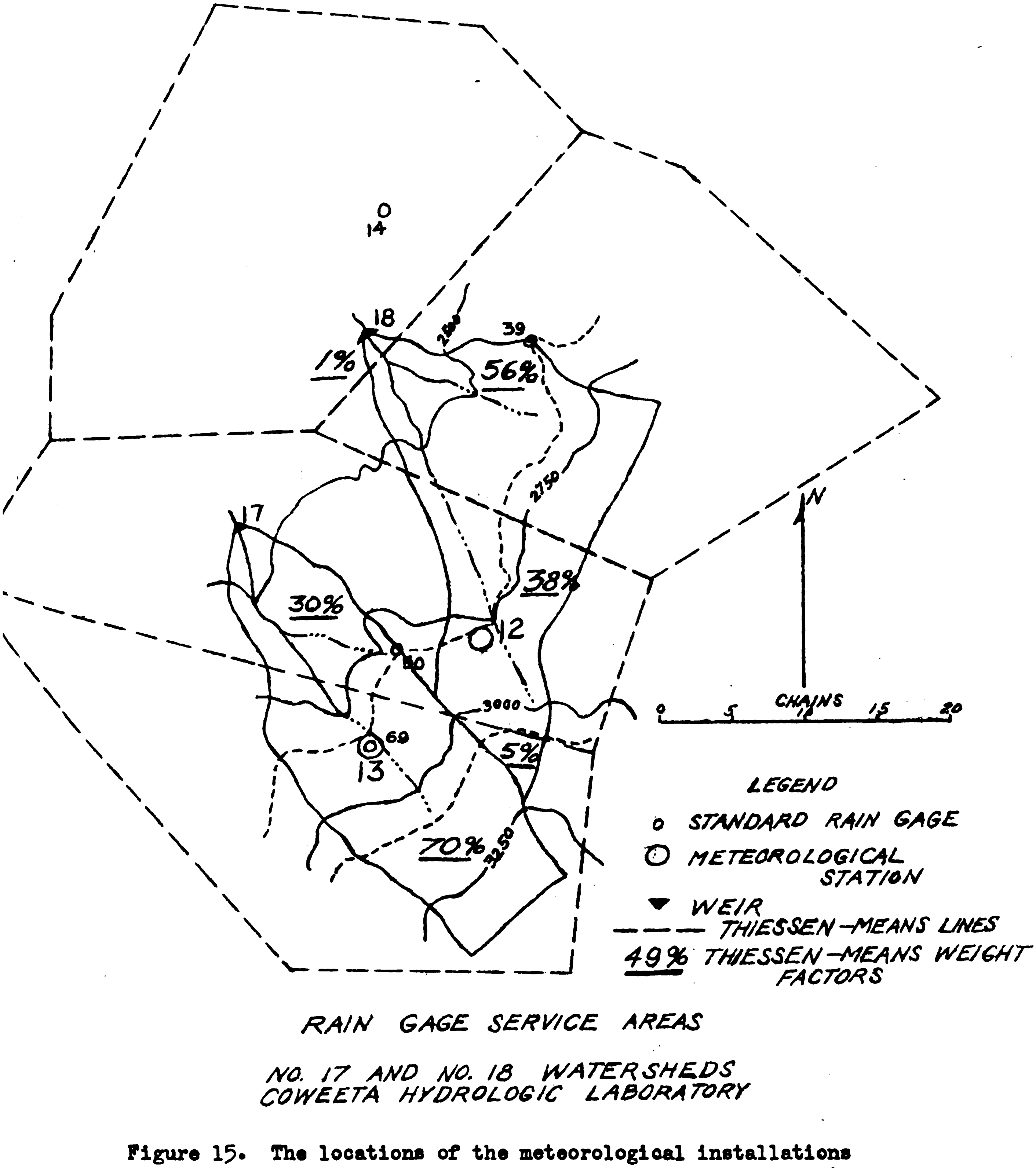


Figure 15. The locations of the meteorological installations and the Thiessen-means lines on and near watersheds 17 & 18.

by months quickly falls into a rather uniform pattern in a very few years (21).

Streamflow and meteorological data for the two watersheds during this period will be furnished in later chapters and in the appendix, where they can be conveniently compared and used in evaluating treatment effects.

Initial Treatment, 1941

On January 6, 1941, the treatment period began with the start of operations to cut all shrub and tree growth on watershed 17. This initial cutting operation was completed on March 31, 1941. This unusual type of cutting operation required 1,372 man-days of C.C.C. labor, or an average of 41.8 man-days per acre. Figure 16 shows watershed 17 in December, 1940, just before the initial cutting.

The prime objective was to reduce the sources of transpiration as much as possible but with an absolute minimum of disturbance to the soil. No material was removed from the area. The trees were left where they fell. There was no skidding or hauling and no roads were established. All slash was lopped and scattered. The large proportion of evergreen rhododendron and mountain laurel produced a good slash cover which formed a loose mulch over the area. This condition permitted a maintenance and protection of the original forest soil characteristics for as long as it was possible to do so, because it provided a source of organic matter and also

Figure 16. Watershed 17 in December, 1940, just before the initial cutting operation began.

protected the soil much as a living canopy would do. Figure 17 is of a portion of watershed 17 in March, 1941, just after the initial cutting. This figure shows the trees left where they fell and the thorough job of lopping and scattering of all slash.

To eliminate the possible effects of side influence an isolation strip fifty feet in width around the watershed boundary received identical treatment.

Annual Regrowth Cuttings, 1941-1953

Regrowth cutting operations were begun in 1941, the same year as the initial cutting. These annual cutting operations were carefully done in order to keep transpiration at a minimum and yet minimize soil disturbance. As in the initial cutting, nothing was removed and care was taken to try to preserve the original favorable forest soil condition as much as possible.

The first annual regrowth cutting began on August 4, 1941, and was completed September 3, 1941. A total of 333 man-days were required. The second annual cutting was begun on June 15, 1942. This operation was interrupted briefly during July and August but was completed on August 31, 1942.

No regrowth cutting was done on watershed 17 from September, 1942, until February, 1946, because of World War II. Regrowth of the vegetation was rapid during that period and the stocking was very dense. By the end of the 1945

Figure 17. A view of a portion of watershed 17 in March, 1941, just after the initial cutting. The trees were left where they fell and all slash was lopped and scattered.

growing season some species had attained heights of ten to twelve feet. During the growing seasons the ground surface was almost completely hidden by foliage and large amounts of litter were being added to the soil surface each year.

On February 6, 1946, regrowth cutting operations were begun again, but the progress of cutting was interrupted several times before being finally completed over the entire watershed on January 9, 1947. The following cutting began on June 24, 1947, and was completed August 22, 1947, without any interruptions to the operation. In 1948 the cutting began June 1, 1948 and was completed July 22, 1948.

The sixth annual cutting of all regrowth started on June 13, 1949, and was completed August 18, 1949. Each subsequent annual cutting after 1949 was performed during the summer months and completed in less than a month and a half. By the end of 1953 watershed 17 had received ten annual regrowth cuttings in addition to the initial cutting of the area.

During all of this period, including the war years in which it was not possible to secure the manpower for annual cutting, continuous hydrologic and meteorologic records were obtained for the two watersheds without interruption.

Figure 18 shows a cutting crew in action in July, 1952, during the ninth annual cutting of regrowth on watershed 17. Brush scythes and brush hooks, as shown in this photograph, were the tools commonly used in the more recent cuttings. The individual sprouts were observed to be of smaller size than in the early years, but more numerous.

Figure 18. The crew in operation during July, 1952, cutting the annual regrowth on watershed 17. Note the brush hooks and brush scythes being used.

EFFECTS OF TREATMENT ON SOME PEDOLOGIC CHARACTERISTICS

To determine and evaluate the long range effects upon a watershed by the treatment of completely cutting the forest vegetation and the subsequent annual cutting of all regrowth, it is of fundamental importance to study the treatment effects upon the soil. The pedologic effects are of great importance in their profound effect on the streamflow characteristics and water qualities for a watershed. The physical properties of the soil and how these properties are changed through land use determine to a large degree the manner of disposition of precipitation upon a watershed and, consequently, the character of the streamflow from that watershed.

Because of the dynamic quality of soil, the basic influence of soil upon water yields, and the sensitivity of many soil properties to changes in land use, a study of the effects of land use upon the soil is an integral part of watershed management research.

From the standpoint of the hydrologic characteristics of soil, the effects of land use and vegetation are reflected chiefly in changes in soil structure, porosity and stability. Therefore, it is these particular physical characteristics upon which is placed the emphasis of research in this dissertation. The object of this phase of the study is to determine whether or not this watershed treatment produced changes in some of the dynamic properties of the soil, what the new characteristics are, and whether or not there is any significance in the changes observed.

Experimental Technique

In certain phases of study in its unit watershed approach to research in forest hydrology, the Coweeta Hydrologic Laboratory has made use of the index station method for studies of watershed treatment effects on some of the vegetation, soil, and soil hydrology characteristics. Due to the large number of independent variables involved and the difficulties peculiar to the analysis of data on a watershed basis, the index station method has been found to have several advantages for studying such characteristics. The use of a completely random design and analysis of data would be prohibitive in time and cost in this study because of the extremely intensive sampling that would be required to control the effects of the many variables. In order to limit the otherwise large number of samples required it is first necessary to survey the area to be studied to establish the important variables and select stations best representing each important strata of variables.

A soil survey of watershed 17 and 18 was made so that a sampling design could be devised and the number and locations of the index stations could be determined. With the soil survey data the areas of the watersheds could be classified according to the knowledge obtained of the important soil physical characteristics present in various parts of the watersheds. Within each of the classified areas or strata there then could be selected representative and uniform areas for index stations. Within these representative areas of each stratum each index station could be so located as to duplicate as closely as possible all of the conditions within the same soil-site class on the other watershed. The number of replications could be determined according to the variability of the factors to be studied and the precision required, time and costs, and available facilities for laboratory analyses. Since the index stations are not randomly chosen, statistical methods used in analysis of variance to indicate significant differences are not applicable. In applying the index station approach, the locations must be carefully chosen as truly representative so as to more than offset the forfeiting of the statistical advantages of the more samples required in random sampling.

Soil Survey of the Two Watersheds

In June of 1953, compass lines were established over the two watersheds prior to the soil survey by setting out stakes at station intervals of two chains, horizontal distance, to enable accurate mapping of the large number of survey points. The compass lines were spaced two survey chains apart, horizontal distance. The soil survey of the watersheds was made in early July of 1953.

The soil survey was accomplished using soil augers, shovels, and an Abney level. The number, arrangement, thickness, texture and color of the soil horizons, the total depth of the soil profile when shallow, the topographic site, the percent of slope, the presence of rock fragments in the soil profile, and the occurrence of massive rock were noted at a total of 305 key locations, representative of their immediate surroundings and well distributed over the two watersheds. One hundred and twenty-five such representative locations were distributed over watershed 18 and 180 were distributed over watershed 17. Figures 19 and 20 show the distribution of these points over the two watersheds. The intensity of the survey can be seen by the pattern of these points.

The data obtained in the soil survey substantiated the previous soil surveys which had placed both of these watersheds into the same geologic formation and classified both areas as possessing the same soil types (9). These general characteristics of the soils, geology and physiography of the watersheds are given in the chapter on the "Description of the Area." Several zones of soils and topographic conditions were found at different locations on the watersheds. Description of the various soil profiles found were sent to the Soil Survey Office, Soil Conservation Service, United States Department of Agriculture. These data indicated that both watersheds have areas of Clifton sandy loam, Talladega sandy loam and Porters sandy loam. Each watershed was found to possess the same range of

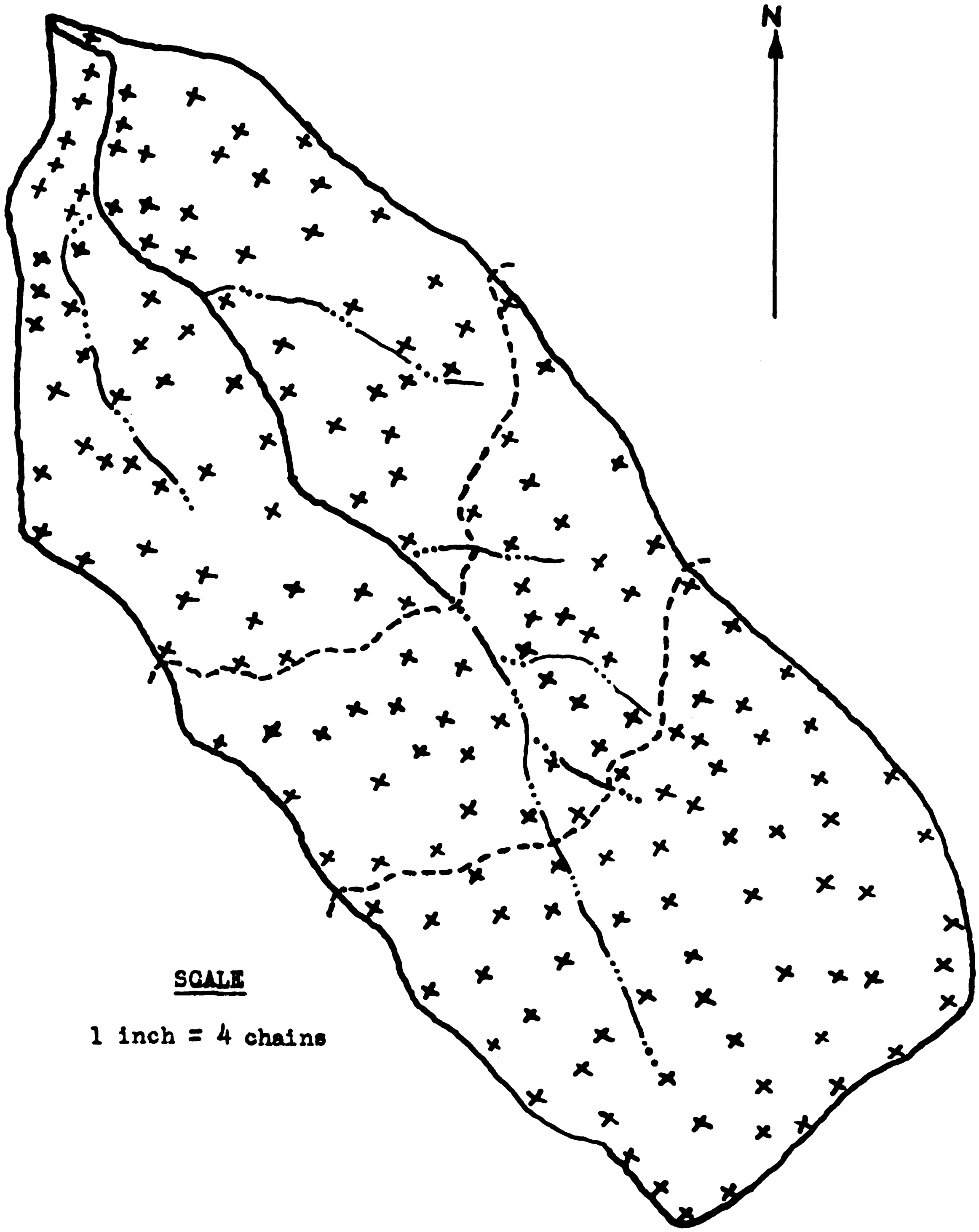


Figure 19. The distribution of soil survey location points over watershed 17.

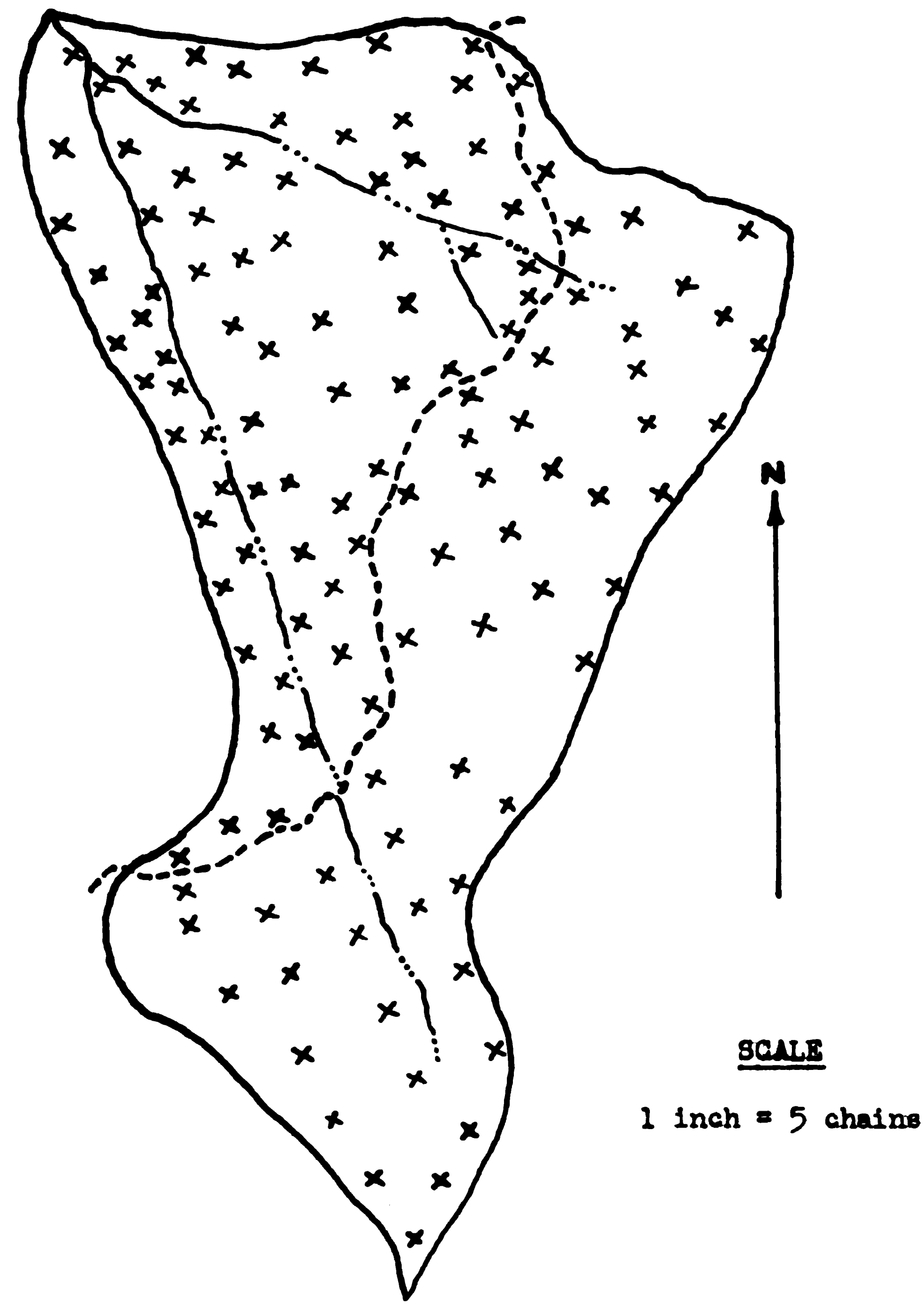


Figure 20. The distribution of soil survey location points over watershed 18.

soil and physiographic conditions as the other, although in different proportions with respect to area.

The data from the soil survey then enabled a grouping of the locations into strata of closely similar soil properties, topographic site and aspect, percent slope, and amount of in-drainage from above. With the knowledge of the above physical factors obtained in the soil survey, it was found that the locations stratified best into three basic soil-site strata. The same three soil-site strata exist on both watersheds, although in different proportions to the total area, of course. The soil physical properties were observed to be quite uniform. On the basis of the type of information desired and low variability of the soil physical properties observed, it was decided that within each stratum on each watershed three index stations would be located which best represent all the characteristics of that stratum. Table III defines these soil-site strata and lists the index stations in these strata for each watershed. Figure 21 shows the locations of these index stations on the watersheds. The three soil-site strata are as follows: Soil-site I. Deep, sandy loam to sandy clay loam soils with rock fragments in the profile, cove sites. Soil-site II. Deep to medium deep, sandy loam to sandy clay loam soils with rock fragments in the profile, middle and lower slope sites. Soil-site III. Medium deep, sandy loam to sandy clay loam soils with rock fragments in the profile, upper slope and ridge sites. Henceforth in this dissertation

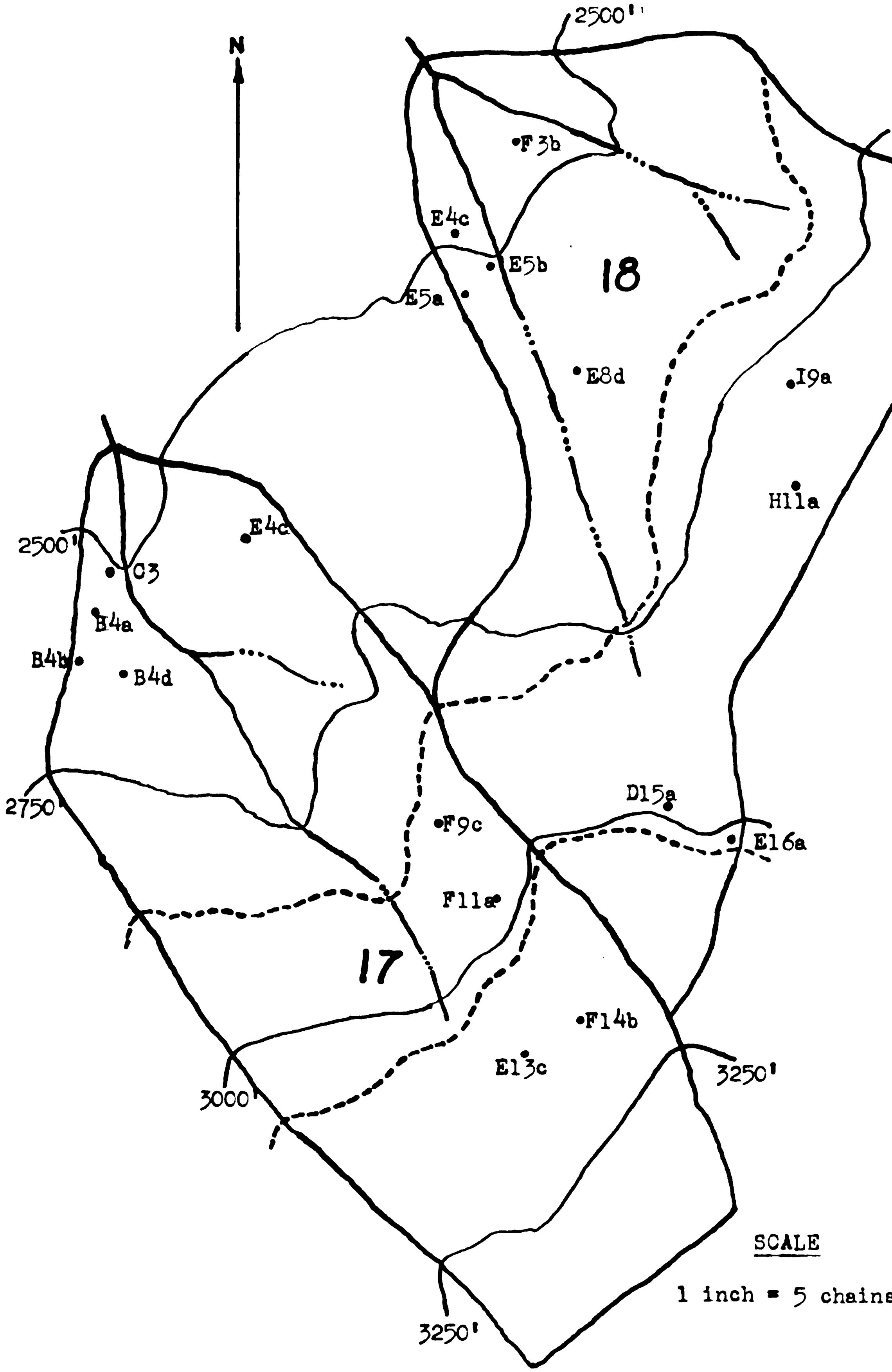


Figure 21. The locations of the soil-site index stations on watersheds 17 and 18, Coweeta Hydrologic Laboratory.

TABLE III

THE SOIL-SITE INDEX STATIONS FOR WATERSHEDS 17 AND 18

Soil-site	Watershed 17	Watershed 18
Soil-site I.	Station	Station
Deep, sandy loam to sandy clay loam soils with rock fragments in profile, cove sites.	C3 B4d F14b	F3b E5b D15a
Soil-site II.		
Deep to medium deep, sandy loam to sandy clay loam soils with rock fragments in profile, middle and lower slope sites	F9c B4a E4c	I9a E4c E8d
Soil-site III.		
Medium deep, sandy loam to sandy clay loam soils with rock fragments in profile, upper slope and ridge sites.	B4b F1la E13c	E5a E16a H1la

these three strata will be referred to as soil-site I, soil-site II, and soil-site III.

The measurements of the depth of the soil mantle over bedrock taken in this soil survey are summarized on maps of the two watersheds in Figures 22 and 23. The depth of the soil mantle was an important segment of the soil survey. As Lassen, _et al._, state, soil depth is an extremely important hydrologic characteristic because it affects, among other things, the storage capacity of the soil (27). Soil depth must be recognized as an important and often limiting factor in soil-water storage. It can be seen from Figures 22 and 23 that, over most of the two watersheds, the soils are deep.

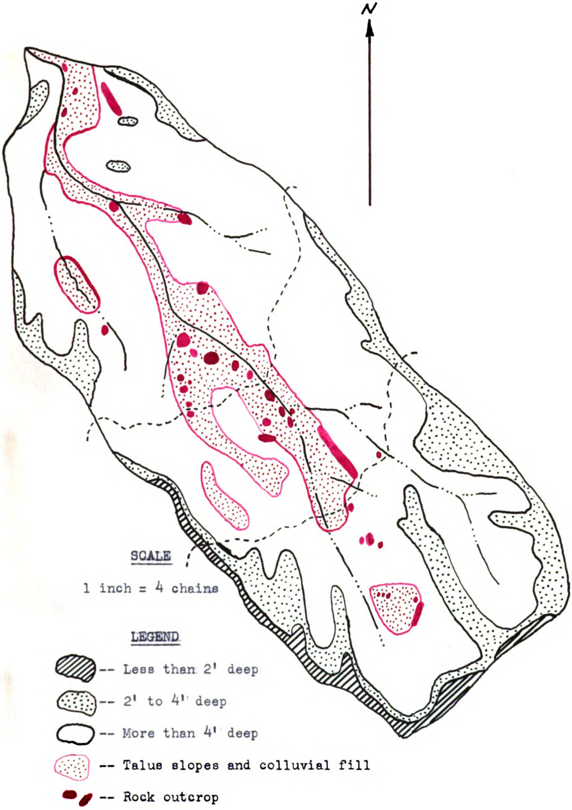


Figure 22. Depth of the soil mantle over bedrock on watershed 17, Coweeta Hydrologic Laboratory.

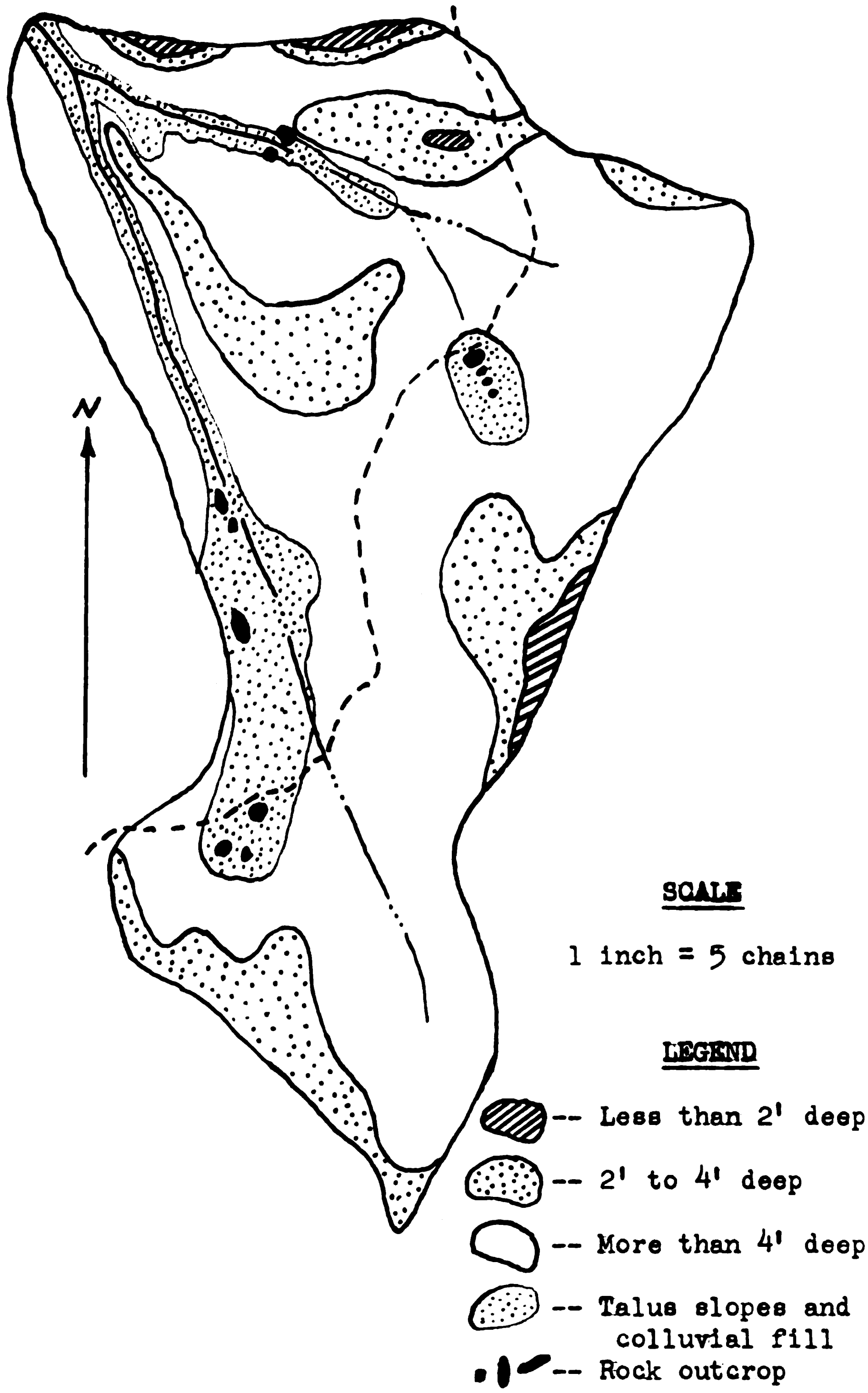


Figure 23. Depth of the soil mantle over bedrock on watershed 18, Coweeta Hydrologic Laboratory.

In the main drainages the soils are usually very deep, containing a high proportion of large rock fragments frequently extending up to the surface. A deep soil is important in evaluating the hydrologic effects of a treatment of this type. With a very shallow soil even the roots of sprout and herbaceous growth may well occupy all the available soil depth and thereby have access to the same amount of water storage facilities in the soil as would be available to trees and other plants of larger life form.

Pits were then dug at each index station for more detailed study of the soil body. The number, arrangement and thickness of the soil horizons were observed. The texture, color, reaction, and rock content of each horizon were also noted. From the data obtained in the initial soil survey it was decided to extract samples at depths of 0 to 3 inches, 3 to 6 inches, 12 to 15 inches and 30 to 33 inches for the necessary laboratory analyses. Throughout both watersheds the depths of the different horizons were constant enough so that the depth of 0 to 3 inches included the A_1 horizon. The 3 to 6 inch depth sampled the A_2 horizon without exception. The 12 to 15 inch depth consistently sampled the B horizon when such horizon existed or a poorly differentiated A_3. The 30 to 33 inch depth sampled the upper C horizon or low enough in a thick B horizon to still reflect the properties of the lower depths of the soil profile. At each index station a sack sample and a cylindrical core sample of soil was collected at each depth. The cores are three inches in height and three inches in diameter. The samples were extracted from the soil profile using a drop-hammer type core sampler designed to minimize soil disturbance as much as possible.

The soil reaction of each depth at each index station was tested with an improved Soiltex kit. The soil reaction using this method was found to vary within narrow limits even when considering all depths for all soil-sites on both watersheds. The lowest hydrogen ion concentration reading was pH5.0 and the highest was pH4.0. Thus, all soil samples were found to be strongly acid or very strongly acid. Lower soil horizons tended to be slightly more acid than upper horizons, with the A horizon usually strongly acid and the B horizon very strongly acid.

Soil color for the A_1 horizon on all soil-sites for both watersheds was found to be either dark brown, dark reddish brown or dark grayish brown, using the Munsell soil color charts. The A_2 was dark brown, reddish brown or dark yellowish brown. The B horizon was from strong brown to yellow red.

The other physical soil properties which are important in their effect upon the soil hydrologic characteristics are reported below.

Soil Physical Properties

The physical characteristics of the soil determine its hydrologic characteristics. The three basic hydrologic characteristics of the soil are infiltration rate, the percolation rate and the storage capacity and all soil physical properties that influence these are extremely important to the watershed manager because of their subsequent effect on streamflow. These basic characteristics determine the proportional disposition of precipitation on a watershed (27).

Mechanical Analysis. Soil texture, the relative proportion of the various size groups of individual particles, is of basic importance in determining the hydrologic properties of a soil. It is of further importance in this study because soil texture is one characteristic of the soil which can be changed very little by land use except through soil loss, which has not occurred under this treatment. Therefore, soil texture, in addition to supplying hydrologic information, can measure the natural variability of the soils over the two watersheds and determine if the basic soil skeleton over the two watersheds is similar. Knowing that the two watersheds were similar in all other respects before the treatment of watershed 17, differences between the watersheds in soil characteristics that could be sensitive to land use practices can be more certainly attributed to treatment effects if they are in contrast to a proven similarity of soil texture, soil color, and number and depth of soil horizons.

The size distribution of individual particles in the soil influences the water-holding capacity, the infiltration rate and percolation rate of the soil by its influence upon both the surface area of the soil particles and the size distribution and amount of soil pore space.

Soil texture at the various depths at each index station was determined by mechanical analysis in the laboratory using the Bouyoucos hydrometer method (5). Air dried sack samples were used and the soil was first prepared for analysis by mechanically crushing the larger clods and aggregates and placing the entire sample on a 12mm. and 2 mm. sieve nest. Those pebbles, rock fragments and concretions found on the 2 mm. sieve after shaking were weighed to determine the proportion of this fine gravel separate at each soil depth. A mechanical analysis was then made of the material which passed through the 2 mm. sieve. The Bouyoucos hydrometer method of mechanical soil analysis is widely used and its simplicity and rapidity make the hydrometer method a valuable tool for mechanical analysis where extreme accuracy is not necessary (4).

The results of these laboratory tests are summarized in Table IV. Examination of this table shows a close textural uniformity in the soils of the two watersheds. The soils throughout both watersheds vary only from a sandy loam to a sandy clay loam. In all cases the percentage of the sand separate is high, making it the dominant separate. The range in variation for any particular depth is low even when considering this dominant separate, sand. Even disregarding soil-site strata the maximum range is still less than ten percent. The greatest range is for the 30 to 33 inch layer, with 62.9 percent for the cove sites on watershed 17 and 72.5 percent for the ridge sites also on watershed 17. For the

TABLE IV

SUMMARY OF THE RESULTS OF A MECHANICAL ANALYSIS OF THE SOILS OF WATERSHEDS 17 AND 18

Watershed and Depth of Soil	Percent of Sample 2-12 mm. in Size	Total Percent of Sand and Coarser Fractions	Percent Distribution of Separates Less Than 2 mm. in Size			
			Sand	Silt	Coarse Clay	Fine Clay
		Soil-site I				
Watershed 18						
0-3 inch layer	14.4	79.7	76.3	12.1	1.7	9.9
3-6 inch layer	7.1	73.9	71.9	13.9	2.2	12.0
12-15 inch layer	9.0	73.8	71.2	11.3	1.9	15.6
30-33 inch layer	9.5	71.1	68.1	12.3	1.8	17.8
Watershed 17						
0-3 inch layer	16.1	78.3	74.2	15.2	1.7	8.9
3-6 inch layer	18.5	76.7	71.4	15.1	2.0	11.5
12-15 inch layer	9.5	66.6	63.1	14.3	2.1	20.5
30-33 inch layer	18.0	69.6	62.9	13.6	1.6	21.9
		Soil-site II				
Watershed 18						
0-3 inch layer	14.8	76.8	72.7	16.0	2.1	9.2
0-6 inch layer	11.5	74.3	71.0	15.8	2.3	10.9
12-15 inch layer	14.0	72.0	67.5	14.8	2.2	15.5
30-33 inch layer	11.7	72.5	68.8	13.0	1.7	16.5
Watershed 17						
0-3 inch layer	11.9	74.7	71.3	16.6	2.1	10.0
3-6 inch layer	12.3	72.5	68.7	17.4	2.4	11.5
12-15 inch layer	12.9	70.5	66.1	14.7	2.2	17.0
30-33 inch layer	13.2	71.1	66.7	13.0	1.5	18.8
		Soil-site III				
Watershed 18						
0-3 inch layer	10.4	77.0	74.4	12.6	2.0	11.0
3-6 inch layer	9.5	71.1	68.1	13.4	2.1	16.4
12-15 inch layer	7.7	67.4	64.7	13.0	1.8	20.5
30-33 inch layer	3.8	66.4	65.1	11.8	1.3	21.8
Watershed 17						
0-3 inch layer	15.9	77.7	73.5	15.2	2.1	9.2
3-6 inch layer	14.2	74.8	70.6	14.7	2.2	12.5
12-15 inch layer	14.1	74.8	70.7	13.6	1.5	14.2
30-33 inch layer	17.2	77.2	72.5	9.9	1.1	16.5

same soil-site strata and soil depth, the textural differences between the two watersheds are obviously not significant and have no practical significance from the point of view of influencing soil or watershed hydrology. The uniformity of results of the mechanical analysis on the two watersheds further substantiates the apparent original similarity before treatment. When considering just the gravel between 2 mm. and 12 mm. in diameter more variation is encountered because the percentages involved are small and also individual particles have a much greater influence on a weight basis.

Aggregate Analyses. The aggregation of primary soil particles into compound particles, or clusters of primary particles, which are separated from adjoining aggregates by surfaces of weakness, is termed soil structure (47). Soil structure, like soil texture, is of fundamental importance in determining the hydrologic properties of soils. It is also of importance in its effect on soil stability and resistance to erosion. The degree of aggregation and the relative stability of the soil aggregates can provide important clues as to whether a soil is being favorably or unfavorably affected by a particular land use. Lutz and Chandler report that as a general practice it may be stated that favorable soil structure is best maintained by healthy forest stands of species well adapted to their environment (33). They point out that living plants and unincorporated organic matter resting on the mineral soil protect the aggregates from disruption by diminishing

the violence with which rain drops strike. The removal of litter from forest stands can result in increased compactness of the soil. Decreases in soil organic matter will reduce both degree of aggregation and aggregate stability. Therefore, it is possible that this treatment of watershed 17 may eventually deteriorate the soil structure and a study of the degree and stability of the soil aggregation on the two watersheds may provide an important clue as to this possible treatment effect.

In studying the important properties of the degree and stability of the soil aggregation on the two watersheds three types of soil aggregate analyses were made in the laboratory upon the soil samples which were collected in the middle of the summer: a Yoder wet-sieve analysis, a dry clod analysis, and an aggregate stability analysis.

To measure the percentage of water-stable secondary particles in the soil the Yoder wet-sieve method of aggregate analysis was used (61). Air dried samples from each depth at each index station were tested by this dunking method. As the Yoder wet-sieve method is frequently employed without attempting to correct for the presence of primary particles, Table V summarizes the results of the Yoder wet-sieve aggregate analysis with no correction. As in Table IV, each figure in Table V represents an average of three replications. The data of Table V for every soil-site show a tendency toward a lower percentage of the hydrologically important larger-than-4 mm.

TABLE V

SUMMARY OF THE RESULTS OF THE YODER WET-SIEVE AGGREGATE ANALYSIS WITH NO CORRECTION FOR PRIMARY PARTICLES

Watershed and Depth of Soil Layer	Proportion of Soil Sample in Each Size Class in Percent					
	Larger than 4 mm.	2-4 mm.	1-2 mm.	0.5-1 mm.	0.25-0.5 mm.	0.105-0.25 mm.
			Soil-site I			
Watershed 18						
0-3 inch layer	27.43	23.29	15.13	12.53	9.27	7.36
3-6 inch layer	30.75	21.55	14.01	11.71	9.57	6.10
12-15 inch layer	9.45	15.21	12.37	16.74	20.13	16.90
30-33 inch layer	8.68	8.33	10.90	18.10	23.54	17.81
Watershed 17						
0-3 inch layer	9.61	19.06	14.25	19.77	17.91	11.09
3-6 inch layer	14.11	22.27	14.77	15.12	16.67	10.68
12-15 inch layer	9.86	12.93	14.67	21.26	21.77	11.78
30-33 inch layer	12.83	12.97	12.03	18.43	21.82	13.35
			Soil-site II			
Watershed 18						
0-3 inch layer	16.11	15.33	13.05	14.51	15.65	13.17
3-6 inch layer	21.29	18.09	14.21	13.20	12.41	11.23
12-15 inch layer	10.47	17.88	12.91	16.15	18.09	15.12
30-33 inch layer	13.54	12.19	11.20	14.32	18.90	14.81
Watershed 17						
0-3 inch layer	11.39	17.31	13.60	16.67	16.82	13.81
3-6 inch layer	12.83	16.28	11.06	15.26	17.38	15.00
12-15 inch layer	14.61	14.18	11.95	14.83	19.53	13.95
30-33 inch layer	7.34	9.70	10.95	17.52	22.77	17.49
			Soil-site III			
Watershed 18						
0-3 inch layer	18.51	17.31	12.00	12.39	13.67	14.89
3-6 inch layer	13.17	15.97	13.47	15.03	16.93	15.19
12-15 inch layer	15.71	16.53	11.15	14.17	18.52	15.49
30-33 inch layer	14.65	14.31	11.63	14.81	18.91	16.55
Watershed 17						
0-3 inch layer	14.91	12.77	10.95	16.07	20.17	12.33
3-6 inch layer	17.05	15.93	13.05	15.17	16.73	11.71
12-15 inch layer	10.55	14.99	12.04	14.45	19.77	16.14
30-33 inch layer	14.99	11.22	11.81	16.79	20.25	13.54

aggregates in the surface layer of soil for watershed 17. Lutz and Chandler noted that the amount of unincorporated organic matter resting on the mineral soil protects the surface soil aggregates and prevents surface soil compaction (33). Thus, it is possible that a watershed treatment which reduces the amount of the unincorporated humus layer may eventually adversely affect soil structure. To test this possible effect of land use upon the tendency toward soil structure deterioration indicated in Table V, a study was made of the amount of the unincorporated humus layer resting on the mineral soil of the two watersheds. The results of this study are presented in the next section. Changes in land use generally do not affect soil structure at the lower depths and it is significant to note that no such consistent trend in a lower percentage of the large aggregates on watershed 17 is shown at lower depths. This fact emphasizes the basic similarity of the soils before treatment in addition to focusing attention to the fact that, since the surface layer data do not agree with this uniformity, the surface layer of soil may have been affected by the treatment.

Table VI summarizes the results of the Yoder wet-sieve aggregate analysis with corrections made for primary particles. To correct for primary particles, the aggregates on each sieve were dispersed, using a laboratory policeman and soil dispersing machines as described by Bouyoucos (5), and then passed through the same sieve. The difference in weight before and after

TABLE VI

SUMMARY OF THE RESULTS OF THE YODER WET-SIEVE AGGREGATE ANALYSIS WITH CORRECTIONS FOR PRIMARY PARTICLES

Watershed and Depth of Soil Layer	Proportion of Soil Sample in Each Size Class in Percent					
	Larger than 4 mm.	2-4 mm.	1-2 mm.	0.5-1 mm.	0.25-0.5 mm.	0.105-0.25 mm.
			Soil-site I			
Watershed 18						
0-3 inch layer	24.51	21.17	14.29	10.59	2.98	1.27
3-6 inch layer	28.07	20.43	13.26	9.98	3.64	0.97
12-15 inch layer	7.95	13.92	11.23	14.11	11.71	8.61
30-33 inch layer	4.05	6.50	9.53	14.92	13.33	7.76
Watershed 17						
0-3 inch layer	6.94	15.90	12.95	16.74	8.04	1.66
3-6 inch layer	10.70	19.92	13.66	12.53	8.21	2.63
12-15 inch layer	5.80	11.48	13.43	18.35	12.44	2.61
30-33 inch layer	7.57	10.74	10.85	15.67	12.99	4.65
			Soil-site II			
Watershed 18						
0-3 inch layer	9.72	12.79	11.93	11.91	7.28	4.93
3-6 inch layer	18.33	16.20	13.25	10.99	5.07	4.47
12-15 inch layer	5.79	15.52	11.86	13.71	10.23	7.39
30-33 inch layer	10.36	9.58	9.97	11.48	9.79	5.85
Watershed 17						
0-3 inch layer	7.41	15.06	12.41	13.87	7.95	5.09
3-6 inch layer	10.21	14.53	9.96	12.70	9.17	6.93
12-15 inch layer	9.77	12.37	10.87	12.31	11.44	5.99
30-33 inch layer	2.93	7.50	9.58	14.35	12.61	7.49
			Soil-site III			
Watershed 18						
0-3 inch layer	15.65	14.64	10.92	9.89	5.62	6.97
3-6 inch layer	11.79	14.07	12.36	12.59	8.76	7.38
12-15 inch layer	12.19	14.54	10.17	11.77	10.84	8.03
30-33 inch layer	13.43	12.95	10.44	12.07	10.09	7.88
Watershed 17						
0-3 inch layer	6.39	10.88	9.70	13.15	11.17	3.15
3-6 inch layer	11.83	14.20	11.69	12.30	8.05	4.06
12-15 inch layer	5.45	13.29	10.68	11.29	9.61	6.15
30-33 inch layer	8.15	8.43	10.44	13.58	9.97	3.43

dispersion gave the corrected amount of aggregates of that particular size. Thus, Table VI gives a more accurate picture of the percentage aggregation into water stable, secondary particles of various sizes. The corrected results in Table VI in no way alter the trend indicated in Table V and in some cases increases the emphasis of the trend.

In soil conservation and in watershed management, aggregate stability as well as percentage aggregation is a very important characteristic of soil structure. To test the stability of the aggregates and to determine if the trend indicated in Tables V and VI was actually due to differences in the percentage of all aggregation or the water-stable aggregation only, a dry clod analysis and an aggregate stability analysis of air dried soil samples were made.

For the dry clod analysis a dry sieving of an air-dried sack sample from each depth at each index station was made. A summary of the results of this analysis is shown in Table VII. Again, there is no indication for the lower soil layers that there is any trend of differences in the percentages of large aggregates for the two watersheds. In the surface layer of soil there appears to be differences in the percentage of large aggregates for soil-site I and soil-site III, but the data from soil-site II show no such difference between the two watersheds. The results from this dry clod analysis does not indicate any constant trend in aggregate deterioration in the surface soil on watershed 17, although it does support the data

TABLE VII

SUMMARY OF THE RESULTS OF THE DRY CLOD ANALYSIS OF THE SOILS OF WATERSHEDS 17 AND 18

Soil-site and Depth of Soil Layer in Inches	Distribution of Clods in Each Size Class in Percent							
	Larger than 6mm.		2mm.-6mm. size		1mm.-2mm. size		Less than 1mm.	
	Watershed 18	Watershed 17	Watershed 18	Watershed 17	Watershed 18	Watershed 17	Watershed 18	Watershed 17
Soil-site I								
0-3 inch layer	26.32	11.57	31.59	23.11	12.58	14.18	29.51	51.14
3-6 inch layer	19.37	14.44	31.86	28.64	12.25	13.01	36.52	43.91
12-15 inch layer	15.46	20.14	23.81	23.41	12.55	12.12	48.18	44.33
30-33 inch layer	24.90	31.10	24.34	25.97	11.91	11.45	38.85	31.48
Soil-site II								
0-3 inch layer	8.42	8.62	22.64	25.83	12.46	14.67	56.48	50.88
3-6 inch layer	12.95	17.18	24.62	24.17	12.56	11.46	49.87	47.19
12-15 inch layer	18.69	22.27	25.35	23.34	11.66	11.10	44.30	43.29
30-33 inch layer	23.25	21.08	23.81	25.07	11.04	13.21	41.90	40.64
Soil-site III								
0-3 inch layer	16.26	5.63	23.03	22.00	10.61	13.47	50.10	58.90
3-6 inch layer	17.47	21.75	26.04	23.81	11.18	11.28	45.31	43.16
12-15 inch layer	25.21	18.72	24.69	22.85	9.77	11.21	40.33	47.22
30-33 inch layer	24.21	27.18	22.56	22.93	9.64	10.52	43.59	39.37

of Tables V and VI in part. This lack of consistency in the results obtained in the dry clod analysis may mean that aggregate stability is also playing an important part in showing the trend of differences in percentage aggregation found in the Yoder wet-sieve analysis.

To further study this trend in the differences in percentage distribution of the large aggregates in the surface soil layer, an aggregate stability analysis was made of samples from the 0 to 3 inch layer and the 3 to 6 inch layer from each index station. This is a test to study how much the aggregates break down. The samples consisted only of secondary particles larger than 6 mm. in diameter. No particles of smaller size classes and no separate primary particles of any size class were present in the samples. Each sample was then subjected to the Yoder wet-sieving process to determine how much the aggregates break down into smaller size classes. The results of this study are summarized in Table VIII. These data show a marked and consistent difference in aggregate stability between the two watersheds for both of the surface layers. The large appregates of the surface soil of watershed 17 are not as water-stable as those of watershed 18, when subjected to this type of laboratory test. Since differences in land use produce their greatest structural effects on the surface soil, it is logical that differences in stability are not as great in the 3 to 6 inch layer as in the 0 to 3 inch layer as is shown in Table VIII and this result substantiates prior tests

TABLE VIII

SUMMARY OF THE RESULTS OF THE AGGREGATE STABILITY ANALYSIS OF THE SOILS OF WATERSHEDS 17 AND 18

Depth of Soil Layer and Watershed	Distribution of Aggregates in Each Size Class in Percent					
	Larger than 4 mm.	2-4 mm.	1-2 mm.	0.5-1 mm.	0.25-0.5 mm.	0.105-0.25 mm.
			Soil-site I			
0-3 inch layer						
Watershed 18	93.57	2.67	0.95	0.57	0.40	0.35
Watershed 17	64.48	15.57	7.98	4.89	3.38	2.00
3-6 inch layer						
Watershed 18	82.03	9.20	2.25	1.76	1.41	1.23
Watershed 17	58.72	15.07	7.47	7.74	5.74	2.85
			Soil-site II			
0-3 inch layer						
Watershed 18	75.00	9.67	2.83	2.97	3.00	2.60
Watershed 17	49.31	23.19	0.51	5.00	4.76	3.72
3-6 inch layer						
Watershed 18	77.88	10.39	2.78	2.34	2.18	1.83
Watershed 17	53.45	19.85	7.51	6.13	5.40	4.01
			Soil-site III			
0-3 inch layer						
Watershed 18	87.95	4.03	1.61	1.31	1.31	1.29
Watershed 17	63.35	13.30	6.50	6.02	4.48	3.57
3-6 inch layer						
Watershed 18	63.67	14.28	6.48	6.17	4.77	2.68
Watershed 17	50.40	12.88	9.15	9.07	8.75	5.57

demonstrating the fact that the indicated differences may be due to treatment effects. Table XXIV of Appendix A shows the individual values for the three largest size classes in the aggregate stability analysis.

Unincorporated Humus Layer. It was stated above that the unincorporated humus layer has an important eventual effect upon the aggregate stability of the surface layer of soil. This humus layer also has a profound effect upon infiltration (60). The presence of this layer also increases the total storage capacity and decreases evaporation. The unincorporated humus layer is also an important source of organic matter to become incorporated in the mineral layers of the soil.

After the initial treatment was applied to watershed 17 there existed for several seasons an excess of loose litter and unincorporated organic matter on the mineral soil surface over the conditions previous to the original cutting. This was due to the careful lopping and scattering of all slash on the area. The subsequent annual cuttings and the natural return of organic matter to the soil surface prolonged this favorable forest floor condition. Observations in 1948 showed a very favorable comparison with watershed 18 in this respect, with the unincorporated organic layer being deeper on watershed 17 than on 18. However, the higher surface temperatures and greater surface exposure as a result of the annual cutting back of all growth were accelerating the rate of decomposition. In 1949 litter studies at the end of the growing season showed a rapid decrease in the depth of the humus layer during that year. The greatest accumulation of unincorporated organic matter was observed around the fifth cutting of regrowth and the amount appeared to be decreasing since that time.

The condition of this humus layer offers an important clue to the ultimate effect of continuing the present treatment because of the influence of this layer upon surface soil structure and stability, as well as upon evaporation and total water storage capacity. In the spring of 1954 a study was made to determine if the amount of the unincorporated humus has now decreased to a point where there is less than that on watershed 18. So that the differences in the time of the organic additions due to normal seasonal leaf fall and the annual cutting of regrowth would not mask the results, the loose and undecayed litter of the previous year as nearly as could be determined was removed from each plot as carefully as possible before the sample was taken. Thus, this study was actually made of the F and H layers as described by Lutz and Chandler (33). Each sample of this organic layer was removed from one square foot of ground, oven dried at a temperature of 90° centigrade and weighed. Three such samples were made around each index station by collecting them ten feet to the east, west and south from the index station marker. Thus, fifty-four such humus samples were collected in all for the study. The results are summarized in Table IX and the individual values are presented in Table XXV of Appendix A. The data

TABLE IX

A SUMMARY OF THE RESULTS OF A STUDY OF THE DIFFERENCE IN THE AMOUNT OF UNINCORPORATED HUMUS ON WATERSHEDS 18 AND 17

Soil-site	Average Oven Dry Weight of Humus Per Square Foot on Watershed 18 in Grams	Average Oven Dry Weight of Humus Per Square Foot on Watershed 17 in Grams
Soil-site I	210.8	104.6
Soil-site II	274.1	113.1
Soil-site III	223.7	110.8

of Table IX show a marked difference in the quantity of unincorporated humus measured by this method on the two watersheds. For all three soil-sites, watershed 18 has about twice the amount of this type of humus that watershed 17 possesses. The differences oftained are sufficiently obvious and great so as to preclude the possibility that they are entirely due to the admitted difficulties involved in sampling these humus layers. Although it is impossible to correctly sort out the previous year's litter, the method of sampling was consistent on both watersheds and did endeavor to remove the bias of the difference in the time of year when the greatest fall of organic matter occurred on the two watersheds. These data indicate a possible eventual deterioration of the favorable forest soil conditions if this treatment is continued. The humus study results also reflect the possible influence of the treatment upon the results of the aggregate analyses presented in the previous section. As an illustration of this possibility, Lunt found that the removal of forest litter was quickly detrimental to the soil structure in his studies of the relationship between the forest floor and the mineral soil (32).

Soil Organic Matter. The organic matter incorporated with the mineral portion of the soil is of great importance to the physical and hydrologic properties of a soil body. Lassen, Lull and Frank state that when organic matter is decomposed and mixed in the soil it coats the mineral particles with a gel-like, porous and highly adsorptive substance (27). This increases the surface area of the mineral particles and their related storage capacity. The retention storage capacity of the soil is thereby increased.

Soil organic matter is also important in soil structure and aggregation and other physical properties. Middleton, in discussing the importance of soil organic content, quotes the statements of soil scientists to the effect that organic matter affects the following physical properties of soils (36): "Weight, cohesion, structure, absorption, porosity, color, temperature, and tilth." In addition to these, he states that organic matter also has very important effects on soil moisture relationships.

To determine the organic matter content of the soils of these two watersheds the dry combustion method as developed by Schollenberger was employed (44). Although there is no method affording an accurate means of estimating organic matter in all types of soils, it is generally acknowledged that dry combustion is the most reliable method at present. Two-gram, air-dried samples of each of the four depths at every index station were tested for organic matter content by this method. The results of this analysis are summarized in Table X. The data in this table indicate no decrease as yet in the content of organic matter mixed in the mineral

TABLE X

SUMMARY OF THE PERCENT CONTENT OF ORGANIC MATTER IN THE SOILS OF WATERSHEDS 18 AND 17

Soil-site and Depth of Soil Layer	Percent Content of Organic Matter, Watershed 18	Percent Content of Organic Matter, Watershed 17
Soil-site I		
0-3 inch layer	5.40	7.45
3-6 inch layer	3.73	4.19
12-15 inch layer	1.19	1.41
30-33 inch layer	0.65	0.95
Soil-site II		
0-3 inch layer	6.13	7.39
3-6 inch layer	4.20	4.04
12-15 inch layer	1.31	1.64
30-33 inch layer	0.67	0.69
Soil-site III		
0-3 inch layer	4.81	5.90
3-6 inch layer	2.34	2.46
12-15 inch layer	1.23	1.16
30-33 inch layer	0.68	0.59

soil. The differences in organic matter content between the two watersheds are not great. If any trend is present, then it is at least temporarily in favor of a slightly higher percentage on watershed 17.

The fact that the organic matter content in the mineral soil of watershed 17 is at least as great as on watershed 18 at present is an interesting one and not necessarily in conflict with the results presented in the previous section on unincorporated humus. It was mentioned in the above section that the humus layer was observed to be deeper on watershed 17 than on 18 as recently as 1948 and that decomposition has been going on very rapidly since that time. This acceleration of decomposition of the surface humus layer could promote better mixing of the decomposed organic matter down through the soil through the easier transportation of the decomposition products. Such a condition must be a more or less temporary one, however, for the main source of these products, the surface humus layer, is rapidly diminishing. Thus, there is the possibility that, when a final new equilibrium is reached between the environment created by the continued treatment and the depth of the surface humus layer and the organic matter content in the mineral soil, the percent organic matter in the soil will be lower than before the initial treatment and lower than on control watershed 18. It is also possible that there exists a temporary condition of a higher incidence of dead and decaying roots in the soil of watershed 17 due to the treatment and this source of organic matter may likewise diminish as the vegetation reaches an equilibrium with the continued treatment.

Volume Weight. Lutz and Chandler have defined volume weight as the ratio between the dry weight of a given volume of undisturbed soil and the weight of an equal volume of water (33). The apparent specific gravity and bulk density are other terms sometimes used to designate volume weight.

Volume weight is an important physical soil property as it affords a measure of soil volume and weight with its included pore space. Volume weight thus reflects soil structure and compactness. Soils with low volume weight values are in a more porous condition and less compact than similar soils with higher volume weight values. When considering similar soils, a soil with a higher volume weight will generally have poorer aeration, slower infiltration of water and lower water storage capacity. Other characteristics being similar, soils possessing a high percentage of aggregation generally have a lower volume weight than those with low aggregation. It has also been found that soils with a high content of organic matter have a lower volume weight than soils with a low content of organic matter. Thus, volume weight is chiefly dependent on soil structure and organic matter content. Because of their high content of organic matter, their good structural condition, and the protection afforded by the humus layer and tree canopy, forest soils generally have lower volume weight values than similar soils in pasture or cultivation.

Volume weight also serves as a tool for the hydrologist in order to convert percent soil moisture content by weight into inches depth of water in watershed studies. This conversion is made by the following formula:

$$\text{Inches of Soil Water} = \text{Inches of Soil Depth} \times \text{volume wt.} \times \frac{\text{percent soil moisture}}{100}$$

Cylindrical core samples of soil three inches high and three inches in diameter were collected at each of the four depths at every index station for determining volume weights. The soil samples were carefully collected, avoiding rocks, using a drop-weight type core sampler designed to minimize soil disturbance as much as possible. The procedure for collecting the core samples, saturating them for obtaining the saturated weight, and oven drying them for obtaining the oven-dry weight was patterned after that described by Coile (6). The oven-dry weight of the soil core in grams was divided by the volume of the core in cubic centimeters to obtain the volume weight of the soil. The summary of the volume weight values obtained are shown in Table XI. After the series of tests, each core was examined to eliminate the possibility of the presence of large stones in the sample unduly influencing the results.

The results of this study show no definite trend of difference between the two watersheds in volume weight. For soil-site I the volume weight for the surface layer of soil is lower for watershed 17 than for 18, but the reverse is the case for the other two soil-sites. The values are quite uniform over all the soil-sites and both of the watersheds, in

TABLE XI

SUMMARY OF VOLUME WEIGHTS FOR THE SOILS OF WATERSHEDS 18 AND 17

Soil-site and Depth of Soil Layer	Volume Weight, Watershed 18	Volume Weight, Watershed 17
Soil-site I		
0-3 inch layer	1.00	0.85
3-6 inch layer	1.08	1.02
12-15 inch layer	1.15	1.30
30-33 inch layer	1.39	1.35
Soil-site II		
0-3 inch layer	0.86	0.92
3-6 inch layer	1.03	1.02
12-15 inch layer	1.15	1.12
30-33 inch layer	1.43	1.37
Soil-site III		
0-3 inch layer	0.98	0.99
3-6 inch layer	1.03	1.07
12-15 inch layer	1.26	1.30
30-33 inch layer	1.39	1.48

agreement with the similarity shown by the mechanical analysis and dry clod analysis. At present, this type of study indicates no deterioration of site with respect to volume weight of soil. It is to be noted that Table XI shows a general increase in volume weight with soil depth at all index stations.

Porosity. From the standpoints both of watershed hydrology and of soil conservation, soil porosity is a basically important physical soil property. A knowledge of the amount of pore space and its size distribution is essential for an accurate picture of the hydrologic characteristics of a soil. It is important to know total porosity and pore size distribution not only because of their effects on aeration and permeability but also because of their effect as the water storage reservoir of the soil. The total porosity determines the total water storage capacity of a soil. The proportion of various pore sizes determines the capacity of the soil to hold water against the action of various degrees of force. The non-capillary or large soil pores allows water to pass downward under the force of gravity and, therefore, determines the total detention storage capacity of the soil. The capillary pores are able to retain the water against the force of gravity and determine the total retention storage capacity. At any one time, the total capillary porosity minus that capillary porosity occupied by moisture equals the retention storage opportunity of the soil. The same relationship exists between noncapillary porosity and detention storage opportunity. However, the detention storage reservoir is ordinarily never occupied by water until the retention storage opportunity is first satisfied. Most of the water in retention storage is available for use by vegetation and for evaporation, but it is held at a sufficient force to be chiefly unavailable for streamflow. The transpirational draft of plants increases this retention storage opportunity which must first be satisfied by precipitation before water can pass down through the soil in the noncapillary pores and contribute to streamflow. It is this phenomenon that is chiefly being studied by the treatment of watershed 17. Theoretically, a treatment which reduces the depth of soil to which active roots penetrate for transpirational draft will, thus, reduce the water losses due to transpiration and limit retention storage opportunity below the depths of the shallower root systems. Precipitation can then satisfy the retention storage opportunity more quickly and a higher proportion will ultimately contribute to streamflow. This treatment of watershed 17 is basic research into how man's treatment of the vegetation can influence this relationship.

The porosity characteristics at each soil depth at every index station were determined using the 3 x 3-inch cylindrical soil cores described in the section on volume weights. The cores were saturated from below for twenty-four hours and weighed in the manner outlined by Coile (6). The cores were then placed on a pF or tension table designed after that described by Leamer and Shaw and their directions for use were followed (28). The cores first stood on the pF table under a tension of 20 cm. of water or pF 1.30 for twenty-four hours, were weighed, and then were placed on the pF table under 40 cm. tension for twenty-four hours and reweighed. This was repeated for 60 cm. tension and then the cores were oven-dried and weighed for computing volume weight as well as total porosity and the porosity at the three tensions. A summary of the results are presented in Table XII.

The percent-by-volume porosity was obtained for the pF's of 1.30, 1.60 and 1.78 to determine the pattern of pore size and also to satisfy all opinions as to which tension best measures capillary and noncapillary pore space. Nelson

TABLE XII

SUMMARY OF PERCENT-BY-VOLUME POROSITY AT VARIOUS TENSIONS FOR THE SOILS OF WATERSHEDS 18 AND 17

Watershed and Depth of Soil Layer	Total Porosity in per-cent-by Volume	Porosity Distribution in Percent-by-Volume			
		20 cm. Tension pF 1.3	40 cm. Tension pF 1.6 (Noncap-illary Porosity)	Total Above 40 cm. (capil-lary Porosity)	60 cm. Tension pF 1.8
			Soil-site I		
Watershed 18					
0-3 inch layer	60.9	20.5	24.9	36.0	27.0
3-6 inch layer	58.6	18.1	21.9	36.7	23.9
12-15 inch layer	57.7	16.4	22.7	35.0	25.4
30-33 inch layer	50.4	10.6	15.7	34.7	18.1
Watershed 17					
0-3 inch layer	62.2	24.0	28.7	33.5	31.0
3-6 inch layer	58.5	20.4	24.7	33.8	26.9
12-15 inch layer	51.1	11.6	15.9	35.2	18.3
30-33 inch layer	51.2	12.3	16.7	34.5	19.1
			Soil-site II		
Watershed 18					
0-3 inch layer	61.9	21.8	28.3	33.6	31.1
3-6 inch layer	61.1	18.6	24.8	36.3	27.9
12-15 inch layer	54.9	16.6	22.3	32.6	24.9
30-33 inch layer	49.0	14.3	18.7	30.3	21.2
Watershed 17					
0-3 inch layer	61.3	20.6	25.8	35.5	28.5
3-6 inch layer	58.3	16.6	21.8	36.5	24.8
12-15 inch layer	56.6	18.1	23.8	32.8	27.0
30-33 inch layer	51.1	12.7	17.5	33.6	20.4
			Soil-site III		
Watershed 18					
0-3 inch layer	61.3	19.0	24.5	36.8	27.5
3-6 inch layer	61.7	20.2	25.4	36.3	28.5
12-15 inch layer	53.3	15.2	19.8	33.5	22.5
30-33 inch layer	49.5	9.8	13.8	35.7	16.3
Watershed 17					
0-3 inch layer	57.4	19.3	24.7	32.7	27.2
3-6 inch layer	57.4	16.1	21.6	35.8	24.6
12-15 inch layer	52.5	16.2	22.1	30.4	25.3
30-33 inch layer	46.5	11.0	16.3	30.2	18.6

and Baver found the best correlation existed between soil samples drained under a tension of 40 cm. of water or pF 1.6 and percolation than existed at any other tension studied (37). Therefore, this tension was used for determining capillary and noncapillary pore space in Table XII.

Table XII shows very little difference between the two watersheds in soil porosity characteristics. The twelve years of continued treatment on watershed 17 before these samples were collected has as yet failed to produce enough changes in these particular soil characteristics to be strongly reflected in the summarized data of Table XII. The small range of values for these characteristics over the two watersheds and throughout the three soil-sites again demonstrates the basic physical similarity of the soils over the area. As would be expected, Table XII shows that both total porosity and the proportion of large pores decreases with increasing soil depth.

Table XII offers applications as a tool in watershed hydrology. Theoretically, capillary and noncapillary porosity should determine the retention and detention storage capacities of the soil. Thus, for the 0 to 3 inch layer of soil-site I on watershed 18, the retention storage capacity is three inches multiplied by 0.36 or is approximately 1.1 inches of water depth. This is assuming that a tension of 40 cm. of water marks the dividing point on the tension curve between capillary and noncapillary pore space. If there is 0.5 inch of water in these three surface inches then the retention storage opportunity would be 0.6 of an inch and there would have to be at least 0.6 of an inch precipitation in a storm before water would begin occupying the detention storage reservoir and thus be available for percolation to lower depths. The total storage capacity for these three inches of soil is three inches multiplied by .609 or approximately 1.8 inches. Detention storage capacity for these same three inches is approximately 0.7 inch.

Permeability. The permeability of a soil is its capacity for transmitting water under pressure and percolation is the movement of water through the interstices of the soil (34). Therefore, the percolation rate of water through a given column of soil under a constant pressure is a measure of the permeability of that soil to water. The importance of this physical characteristic in watershed hydrology is obvious. It is one of the soil characteristics which influence the disposition of rainfall into surface runoff and subsurface runoff and absorption of precipitation. Studies by Baver show that soil permeability is closely dependent upon the noncapillary porosity and varies directly with it (4).

Permeability rates were determined using the same cores employed for porosity determinations. As nearly as possible a half-inch head of water was maintained on the saturated soil core for a period of one hour. For core samples with very high permeability rates the period was reduced to a half-hour and the results doubled. The amount of water passing through the core in that period of time was measured and converted to inches per hour. The averages of the percolation or permeability rates obtained in this study are presented in Table XIII.

TABLE XIII

THE PERMEABILITY IN INCHES-PER-HOUR FOR THE SOILS OF WATERSHEDS 18 AND 17

Soil-site and Depth of Soil Layer	Permeability in Inches-per-Hour, Watershed 18	Permeability in Inches-per-Hour, Watershed 17
Soil-site I		
0-3 inch layer	56.9	103.0
3-6 inch layer	35.3	45.8
12-15 inch layer	19.2	8.3
30-33 inch layer	6.1	6.4
Soil-site II		
0-3 inch layer	53.5	45.4
3-6 inch layer	37.1	26.8
12-15 inch layer	15.7	24.2
30-33 inch layer	9.6	8.8
Soil-site III		
0-3 inch layer	40.8	45.3
3-6 inch layer	33.6	22.2
12-15 inch layer	15.3	13.9
30-33 inch layer	4.6	9.1

Table XIII shows no consistent differences between the two watersheds in soil permeability. The permeability rates were quite highly variable as they usually are in this laboratory test. The individual results obtained in this laboratory study are presented in Table XXVI of Appendix A to show their variability. The presence of a decayed root channel or a worm hole greatly influences the rate of percolation of water through the soil column in a core sample. It is of significance to note that all the surface soil permeability values are well in excess of occurring rainfall intensities. Probably, long time effects of this type of continued treatment of watershed 17 would never so drastically affect these surface layer permeability values as to reduce the rates to below possible rainfall intensities and thereby produce changes in surface runoff and streamflow characteristics on the watershed except through deterioration of soil structure. Because of the texture of the soil on the watershed and the mildness of this treatment in comparison to soil cultivation or soil compaction by grazing or road building it is believed that this treatment will never produce differences in permeability rates that would be worthwhile in noting.

Field Capacity. The maximum amount of water that any soil can retain indefinitely against the action of gravity is defined by Wisler and Brater as the field capacity of the soil (60). However, it is known that under a constant tension soils will continue to yield decreasing amounts of water over an extended period of time. A better definition for field capacity might be that given by Veihmeyer and Hendrickson as the amount of water held in the soil after the excess gravitational water has drained away and after the rate of downward movement of water has materially decreased (52). Among the most important soil factors influencing the field capacity of soils in a given region are texture, organic matter content and structure. It has been found that texture is by far the most important of these factors (33). Therefore, it would be expected that the field capacities for the soils on these two watersheds would be closely similar.

From the points of view of watershed hydrology and ground water hydrology the field capacity is a basically important soil moisture constant because it expresses the boundary between gravitational water and capillary water. Thus it is another method of expressing the retention storage capacity of the soil.

In soil moisture relationships the yield of water from a soil at various tensions or forces is best expressed by a curve. Therefore, being points on a curve, most soil moisture constants are not clearcut but include a zone. Field capacity possesses this natural variation and soil scientists do not entirely agree as to where the point should be on the curve. It is generally agreed that soils in which drainage is unobstructed attain field capacity one to five days after a prolonged rainfall or irrigation. Many soil scientists regard two to three days as sufficient time for the soil moisture content to arrive at field capacity. The drainage time required varies greatly with soil texture and structure.

To determine the field capacity for the soils of watersheds 18 and 17 soil samples were extracted using modified King soil-sampling tubes as described by Veihmeyer (51). The samples were taken from each depth at every index station and were immediately placed in air-tight cans. They were then weighed, oven-dried and weighed again. The watersheds were sampled during April, 1954, at a time when the stream hydrograph indicated that base flow was at its maximum and ground water recharge was complete. Sampling for field capacity was done after the passage of a sufficient interval of time for internal drainage after a major rain.

A summary of the results of the field capacity determinations is presented in Table XIV. Each figure for each depth is an average of the three index stations within a soil-site on each watershed. The field capacity is given both as a percentage of the oven-dry weight and as a percentage of the volume of soil. The latter value is computed by multiplying the percentage of over-dry weight by the volume weight of the soil for that depth and soil-site as given in Table XI. From the viewpoint of watershed hydrology, these percentages as based on soil volume are the more significant. It is only necessary to multiply these percentages by the inches depth of soil in question to obtain the retention storage capacity on an inch-depth basis.

Table XIV shows the soils over the two watersheds to be quite uniform with respect to the field capacity values obtained in this study. No general trend of differences can be noted. It is of particular significance to note the close correspondence between these percentage-by-volume values for

TABLE XIV

SUMMARY OF FIELD CAPACITY IN PERCENT BY WEIGHT AND BY VOLUME FOR THE SOILS OF WATERSHEDS 18 AND 17

Soil-site and Depth of the Soil Layer	Field Capacity in Percent by Weight, Watershed 18	Field Capacity in Percent by Weight, Watershed 17	Field Capacity in Percent by Volume, Watershed 18	Field Capacity in Percent by Volume, Watershed 17
Soil-site I				
0-3 inch layer	41.7	41.6	41.7	35.4
3-6 inch layer	37.8	37.4	40.8	38.1
12-15 inch layer	27.0	27.7	31.0	36.0
30-33 inch layer	23.6	23.2	32.8	31.3
Soil-site II				
0-3 inch layer	36.7	46.3	31.6	42.6
3-6 inch layer	31.3	36.6	32.2	37.3
12-15 inch layer	26.6	30.3	30.6	33.9
30-33 inch layer	22.0	24.1	31.5	33.0
Soil-site III				
0-3 inch layer	42.6	37.7	41.7	37.3
3-6 inch layer	33.8	35.0	34.8	37.4
12-15 inch layer	26.1	25.7	32.9	33.4
30-33 inch layer	24.3	24.6	33.8	36.4

field capacity and the percentage-by-volume values for capillary porosity above 40 cm. of water tension as given in Table XII. These are two different methods endeavoring to measure the same hydrologic characteristics of the soil. Both attempt to determine the volume of pores under a certain size and the retention storage capacity of the soil. Comparison of the field capacity percentages of porosity at various tensions as given in Table XII does show the best agreement with the values for 40 cm. of tension (pF 1.6) than with the other tensions. This is consistent with the findings of Nelson and Baver mentioned in the section on porosity.

Using the percent-by-volume field capacity values for the various soil layers as given in Table XIV, it is possible to compute the field capacity for the top four feet of soil in terms of inches-depth of water. For watershed 18 the inches-depth of water for field capacity in the top four feet of soil is 15.9 inches for soil-site I, 15.0 inches for soil-site II, and 16.3 inches for soil-site III. For watershed 17 it is 16.2 inches for soil-site I, 16.4 inches for soil-site II, and 17.0 inches for soil-site III.

Moisture Equivalent. Baver reports that the moisture equivalent is one of the most frequently used determinations for characterizing the moisture relations of soils (4). The moisture equivalent may be defined as the percentage of water retained by a soil when the moisture content is reduced by means of a constant centrifugal force until it is brought into a state of capillary equilibrium. Since field capacity is difficult to standardize because there are many possible techniques for measuring field capacity and it is also difficult to decide on a particular point on the continuous curve of soil moisture, the moisture equivalent has a definite advantage in being a purely arbitrary point arrived at by carefully following a specific laboratory experimental procedure.

The moisture equivalent has been found to be a good soil moisture constant for determining the dividing line between capillary water and gravitational water for many medium textured soils. Veihmeyer and Hendrickson state that many investigators have reported tests which indicate that the moisture equivalent is a close approximation of the amount of water that the soil in the field will retain against the pull of gravity (52).

To determine the moisture equivalent for the soils of watersheds 18 and 17, a thirty-gram sample from each depth at each index station was tested following the procedure used by Veihmeyer, Oserkowsky and Tester (55). The thirty-gram samples were centrifuged for thirty minutes at a speed of 2,444r.p.m., producing a force of one thousand times that of gravity. The pF value at this moisture equivalent is approximately 2.7.

A summary of the results of this laboratory analysis is presented in Table XV. The moisture equivalents are expressed both in percent by weight and percent by volume. Table XXVII of Appendix A gives the individual values in percent by weight for this study. The results given in Table XV show the soils over the two watersheds to be closely similar in the moisture equivalent values obtained. This again reflects the general uniformity in texture, which basically influences moisture equivalent as it does field capacity. It is of significance to note that these moisture equivalent percentages are lower than the percentages for field capacity. This is

TABLE XV

SUMMARY OF THE MOISTURE EQUIVALENT IN PERCENT FOR THE SOILS OF WATERSHEDS 18 AND 17

Soil-site and Depth of the Soil Layer	Moisture Equivalent in Percent by Weight, Watershed 18	Moisture Equivalent in Percent by Weight, Watershed 17	Moisture Equivalent in Percent by Volume, Watershed 18	Moisture Equivalent in Percent by Volume, Watershed 17
Soil-site I				
0-3 inch layer	21.9	22.7	21.9	19.3
3-6 inch layer	21.8	21.0	23.6	21.5
12-15 inch layer	20.4	19.4	23.4	25.2
30-33 inch layer	18.1	19.1	25.2	25.8
Soil-site II				
0-3 inch layer	20.5	23.1	17.6	21.2
3-6 inch layer	20.4	21.3	21.0	21.8
12-15 inch layer	18.3	18.9	21.1	21.2
30-33 inch layer	16.7	17.5	23.9	23.9
Soil-site III				
0-3 inch layer	21.3	21.5	20.8	21.3
3-6 inch layer	19.8	20.1	20.4	21.5
12-15 inch layer	19.7	17.3	24.8	22.5
30-33 inch layer	18.3	15.5	25.4	23.0

to be expected for sandy loam to sandy clay loam soils such as these. It has been found that for heavy clays the moisture equivalent is higher, and in sands lower, than the field capacity. The moisture equivalent percentages obtained in this study are generally even lower than percentage capillary porosity that could be obtained from Table XII by subtracting the percentage of larger pores obtained at 60 cm. water tension from the total porosity. Examination of all the results of the soil porosity study, the field capacity study, and the moisture equivalent study indicate that the porosity percentages obtained at a pF of 1.6 or 40 cm. of water tension offer a good criteria for defining the point between capillary water and gravitational water for the particular soils of these two watersheds.

It is of interest also to note in Table XV the general decrease in the moisture equivalent in percent-by-weight with the depth of the soil layer, but a general increase with depth when considering percent-by-volume. This reflects the influence of increase in soil density with depth upon percent-by-weight values and the influence of the general increase in fine clay content with depth as shown in Table IV upon the percent-by-volume figures.

The moisture equivalent percentages may be used for estimating the permanent wilting point by dividing the moisture equivalent by 1.84 (4). For another possible application, some workers have found that the hygroscopic coefficient of many soils is about 0.37 times the moisture equivalent (33).

<u>Air-Dry Moisture Content</u>. The air-dry moisture content is the amount of water in the soil when an equilibrium is established between the soil and the atmosphere. The amount of water thus held by the soil varies with the specific surface of the soil, the vapor pressure of the water molecules in the atmosphere surrounding the soil and the hysteresis effect. The vapor pressure is dependent upon the humidity and temperature of the atmosphere.

The air-dry moisture content values in this study were obtained with the soil samples reaching an equilibrium in a normal room atmosphere by drying out from a higher moisture content. It is felt that these conditions better approximate the air drying of the surface soils on the two watersheds during the hotter drying periods of the summer growing season than do the artificial conditions maintained in obtaining the hygroscopic coefficient. It is reported that the hygroscopic coefficient has been found to be hypothetical and elusive and generally unsatisfactory although widely used (33).

The air-dry moisture content is not studied here with any intention that these conditions in any way simulate the field conditions. It is presented here merely as a study of the moisture relationships of these soils over a very wide range of tensions.

In determining the air-dry moisture content, soil samples at each depth from each index station were air-dried under normal room conditions for three months, weighed, oven-dried at 110° C for twenty-four hours and weighed again. A summary of the results of this study are presented in Table XVI as percentages both by weight and by volume.

Table XVI shows no significant differences nor trends of differences between the soils of the two watersheds in respect to the air-dry moisture content. As would be expected, the air-dry moisture percentages obtained by the method used in this study are considerably below the percentages that would

TABLE XVI

SUMMARY OF THE PERCENT AIR-DRY MOISTURE CONTENT FOR THE SOILS OF WATERSHEDS 18 AND 17

Soil-site and Depth of the Soil Layer	Percent Air-Dry Moisture Content by Weight, Watershed 18	Percent Air-Dry Moisture Content by Weight, Watershed 17	Percent Air-Dry Moisture Content by Volume, Watershed 18	Percent Air-dry Moisture Content by Volume, Watershed 17
Soil-site I				
0-3 inch layer	1.6	1.3	1.6	1.1
3-6 inch layer	1.4	1.2	1.5	1.2
12-15 inch layer	1.3	1.1	1.5	1.4
30-33 inch layer	1.2	1.0	1.6	1.4
Soil-site II				
0-3 inch layer	1.4	1.7	1.2	1.6
3-6 inch layer	1.4	1.5	1.4	1.6
12-15 inch layer	1.2	1.2	1.3	1.3
30-33 inch layer	1.3	1.2	1.8	1.7
Soil-site III				
0-3 inch layer	1.4	1.5	1.4	1.5
3-6 inch layer	1.1	1.2	1.1	1.2
12-15 inch layer	1.1	1.0	1.4	1.3
30-33 inch layer	1.1	1.0	1.5	1.5

be obtained for the hygroscopic coefficient. An example of this can be shown by estimating the hygroscopic coefficient by multiplying a moisture equivalent value in Table XV by 0.37. Doing this for the 0 to 3 inch layer in soil-site I on watershed 18 gives a value of 8.1 percent-by-volume for the hygroscopic coefficient as compared to a value of 1.6 in Table XVI.

As was noted for the moisture equivalent percentages, there is a general decrease in air-dry moisture content percentages-by-weight with depth. This is at least partially due to the increase in soil density with depth because no such trend is shown when using percent-by-volume.

Using the percent-by-volume air-dry moisture content values for the various soil layers as given in Table XVI, the air-dry moisture content in terms of inches-depth of water in the top four feet of soil on watershed 18 is 0.74 inch for soil-site I, 0.74 inch for soil-site II, and 0.68 inch for soil-site III. For watershed 17 these values are 0.66 inch for soil-site I, 0.74 inch for soil-site II, and 0.67 inch for soil-site III. Rounding these values to the nearest tenth inch gives 0.7 inch depth of water at air-dry moisture content for the top four feet of soil on all soil-sites for both watersheds.

Soil Moisture Regime

Soil moisture is one of the more dynamic soil characteristics and is often one of the more sensitive soil characteristics to changes in land use. Soil moisture is the major source of water for transpiration and evaporation and is therefore of major importance in watershed management. Soil moisture content also influences streamflow in quantity, quality and timing. If soil moisture is low and there exists a large retention storage opportunity, a minor rain may have no influence on water yield from a watershed. If the soil moisture content is high and there is no retention storage opportunity then such a minor rain may noticeably contribute to the water yield from the drainage area. Thus, a knowledge of the trends in the soil moisture content, together with the information on the total porosity, retention storage capacity and detention storage capacity, can increase the knowledge of the hydrologic effects of land use and aid in the study of the balanced water cycle on watersheds (29). The soil, with its definite storage capacity, serves as a regulating reservoir for water. The amount of water in this reservoir antecedent to a given storm is a determining factor as to the rate and amount of runoff from that storm. Therefore, soil moisture conditions are important to the forecaster of streamflow.

To study soil moisture changes periodic soil moisture sampling was done at all index stations on each watershed during the period of maximum evaporation and transpiration in the hydrologic year. Percent soil moisture by weight was obtained gravimetrically using modified King tubes to extract the soil samples (51). At each index station soil samples were obtained from the 0 to 3 inch, 3 to 6 inch, 6 to 12 inch, 1 to 2 feet, 2 to 3 feet, 3 to 4 feet depths and, wherever possible, every foot layer down to eight feet depth. Using the volume weight values as shown in Table XI, these percentages were converted into inches depth of water.

The sampling for this study was begun in April of 1954 after a major storm at the end of the dormant season, when stream hydrographs for both watersheds indicated the soils to be at field capacity. At this point the two watersheds are at the same soil moisture content, with retention storage opportunity essentially at zero and the stored ground water at a maximum for the hydrologic year. With the soil texture and structure so similar over the two watersheds, field capacity for all practical purposes amounts to the same moisture content on both watersheds. Thus the sampling was begun at the divide between accretion and depletion of the total watershed storage, at the time when the two watersheds were at a par, and was then carried through the period of soil moisture depletion during the time of maximum evaporation and transpiration. This is the hydrologic period to be most affected by the treatment applied to watershed 17. Sampling was begun April 12, 1954, and continued until August 26, 1954.

The results of this study are summarized in total inches depth of water for the entire soil profile down to a depth of four feet in Table XVII. Due to natural variation and the influence of the presence of small rock fragments in the samples, the results for individual soil layers were more obscured than when totalling them for the entire profile. However, although much more obscure, each depth generally showed the same trend as indicated in Table XVII. Table XVII shows a lower content of soil moisture for the top four feet of soil on watershed 18 than on 17 through the entire growing season of maximum evaporation and transpiration. This may be partly due to a possible reduction in rainfall interception

TABLE XVII

A SUMMARY OF THE SOIL MOISTURE REGIME IN INCHES-DEPTH OF WATER IN THE TOP FOUR FEET OF SOIL DURING THE GROWING SEASON OF 1954 FOR WATERSHEDS 18 AND 17

Soil-site and Watershed	Inches-Depth of Water in the Top 4 Feet of Soil									
	Apr. 12-13	Apr. 30 & May 1	May 5-6	May 12	May 27	June 10	June 28	July 19	Aug. 12	Aug. 26
Soil-site I										
Watershed 18	15.4	14.8	14.8	14.5	13.5	14.4	12.4	11.4	14.1	11.4
Watershed 17	15.9	15.7	14.8	13.7	14.2	14.0	12.6	11.9	14.5	12.8
Soil-site II										
Watershed 18	14.4	12.5	13.1	12.9	12.5	12.5	12.0	11.5	11.7	10.5
Watershed 17	15.1	15.5	15.6	14.8	13.3	14.3	12.1	10.7	12.5	11.4
Soil-site III										
Watershed 18	16.1	14.8	14.3	14.7	13.4	13.6	11.4	11.8	12.8	11.0
Watershed 17	15.3	16.7	14.8	14.6	12.0	15.6	12.4	13.0	12.6	12.2
Average of all Soil-sites										
Watershed 18	15.3	14.0	14.1	14.0	13.1	13.5	11.9	11.6	12.9	11.0
Watershed 17	15.4	16.0	15.1	14.3	13.2	14.6	12.3	11.8	13.2	12.1

as well as reduced transpiration on watershed 17. These differences between the two watersheds are extremely slight in view of the variability in the individual values except that their consistency throughout the growing season when grouping all samples for each watershed does show a trend of higher moisture content on watershed 17.

To determine if there were any pronounced treatment effects that might be different for the soil moisture content of the soil surface, the results for the top six inches of soil are totalled and summarized in Table XVIII. Though more obscure,

TABLE XVIII

A SUMMARY OF THE SOIL MOISTURE REGIME IN INCHES-DEPTH OF WATER IN THE TOP SIX INCHES OF SOIL DURING THE GROWING SEASON OF 1954 FOR WATERSHEDS 18 AND 17

Soil-site and Watershed	Inches-Depth of Water in the Top 6 Inches of Soil									
	Apr. 12-13	Apr. 30 & May 1	May 5-6	May 12	May 27	June 10	June 28	July 19	Aug. 12	Aug. 26
Soil-site I										
Watershed 18	2.9	2.8	2.6	2.4	2.4	2.4	1.6	2.1	2.2	1.6
Watershed 17	2.2	2.5	2.2	1.9	1.7	1.8	1.1	1.5	2.1	1.4
Soil-site II										
Watershed 18	2.0	1.8	1.6	1.8	1.6	1.7	1.1	1.6	1.5	1.1
Watershed 17	2.4	2.7	2.5	2.4	2.0	2.2	1.6	1.5	2.2	1.6
Soil-site III										
Watershed 18	2.2	2.3	2.2	2.3	2.0	1.9	1.2	1.6	1.6	1.4
Watershed 17	2.4	2.6	2.2	2.1	1.6	1.9	1.3	1.7	1.6	1.5
Average of all Soil-sites										
Watershed 18	2.4	2.3	2.1	2.2	2.0	2.0	1.3	1.7	1.8	1.4
Watershed 17	2.3	2.6	2.3	2.1	1.8	2.0	1.3	1.6	2.0	1.5

In general the same slight trend of higher soil moisture content on watershed 17 than on watershed 18 is indicated for the top six inches as is shown in Table XVII for the entire top four feet. Apparently the surface soil evaporation has not been greatly affected by the treatment as yet and also the sprout growth of watershed 17 still draws water from lower depths rather than concentrating its demands on the surface six inches of soil. None of the individual layers indicate a concentration of water demands. Richards and Wadleigh, in summarizing the results of many studies, state that the pattern of moisture extraction in soils is largely a matter of active root distribution and this pattern can be used as an indication of the probable root distribution in the soil profile (40). On the basis of this information, no changes in the distribution of active roots due to treatment is indicated and the general lessening of transpirational demand on the soil profile as a whole in this particular treatment, if it exists at all, is not great. If the treatment is continued indefinitely to the point where the sprout growth from original trees loses its dominance to an herbaceous cover of different rooting characteristics, then this pattern of moisture extraction may change. This has not yet taken place.

Supplementary Observations

For a complete picture of the pedologic and hydrologic effects of a watershed treatment of this type, especially when considering long-time effects, any supplemental information available on microclimatic changes and vegetation changes due to treatment can be valuable in indicating future permanent trends. Of course, it was not possible to make complete studies of such supplementary effects in this study for they could comprise a dissertation in themselves.

Air Temperature Observations. It is well known that a forest canopy influences air temperature, especially the daily maximum air temperature (24). The daily maximum air temperature is lowered while the daily minimum is usually slightly raised due to the forest canopy's insulating effect. The usual net effect of a forest cover upon air temperature is to reduce the mean temperature because of the more pronounced effect of lowering the maximum. Air temperature close to the surface of the soil can be very important pedologically and hydrologically through its influence on the rate of decomposition of organic matter, the rate of evaporation from the surface of the soil, and plant growth. Air temperature through its influence on soil temperature may greatly influence the microbiological activity within the surface layer of the soil.

To study the effect of the treatment of watershed 17 upon the air temperature, daily maximum and minimum air temperatures at four and one-half feet above ground were recorded at weather station 12 on watershed 18 and weather station 13 on watershed 17 for two years from June, 1941, through August, 1943. The locations of these stations are shown in Figure 15. The two stations are very similarly located on the two watersheds. They are at almost the same elevation and each possesses the same exposure and they are located in the same position with respect to the major drainage on each watershed. Further indication of their very close similarity in every respect except the treatment is found in their very close air temperature values during the winter months of December through

April when the treatment effects are at a minimum with the absence of the tree leaf canopy on watershed 18.

The results of this study are summarized in Table XIX. Note how very similar the temperatures are at the two stations during the winter months when the influence of the treatment is at a minimum, showing the similarity between the two locations.

The data of Table XIX indicate a treatment effect of a greatly increased daily maximum air temperature and a slightly decreased daily minimum during the summer growing season as a result of cutting the forest vegetation. The net result is to raise the mean air temperature during the summer months and, to a lesser extent, raise the mean annual air temperature.

Soil Temperature Observations. Soil temperature is now regarded as a physical characteristic of the soil and as such is one of the more dynamic properties of the soil body. Because of the close relationship between soil temperature and the temperature of the air directly above it, it is appropriate to discuss soil temperature observations with air temperature observations.

Soil temperature is important because of its influence upon the chemical reactions in the soil, the temperature of the roots of growing plants, the microbiological factors of the soil, the soil moisture movement, and the moisture retention in the soil (41). Thus soil temperature influences

TABLE XIX

A SUMMARY OF THE MONTHLY MEANS OF DAILY MAXIMUM AND MINIMUM AIR TEMPERATURES AT FOUR AND A HALF FEET ABOVE THE GROUND ON WATERSHEDS 18 AND 17

Year and Month	Watershed 18, Station 12			Watershed 17, Station 13			Difference, 17-18		
	Max. °F	Min. °F	Mean °F	Max. °F	Min. °F	Mean °F	Max. °F	Min. °F	Mean °F
1941									
June	76.8	60.1	68.4	81.7	59.4	70.6	+4.9	-0.7	+2.2
July	76.0	62.5	69.2	82.2	62.1	72.2	+6.2	-0.4	+3.0
Aug.	77.3	62.7	70.0	83.1	60.1	71.6	+5.8	-2.6	+1.6
Sept.	71.5	57.5	64.5	76.7	57.0	66.8	+5.2	-0.5	+2.3
Oct.	65.8	52.8	59.3	70.1	52.1	61.1	+4.3	-0.7	+1.8
Nov.	53.0	35.2	44.1	55.8	35.3	45.4	+2.8	+0.1	+1.4
Dec.	50.8	31.9	41.4	49.5	32.6	41.0	-1.3	+0.7	-0.4
1942									
Jan.	43.5	26.5	35.0	45.5	26.6	36.0	+2.0	+0.1	+1.0
Feb.	41.3	24.0	32.6	40.8	24.9	32.8	-0.5	+0.9	+0.2
Mar.	54.9	37.8	46.4	54.8	36.5	45.6	-0.1	+1.3	-0.8
Apr.	71.3	45.1	58.2	71.8	45.8	58.8	+0.5	+0.7	+0.6
May	69.8	52.3	61.0	72.6	51.6	62.2	+2.8	-0.7	+1.2
June	74.6	60.8	67.7	80.9	61.1	71.0	+6.3	+0.3	+3.3
July	76.4	62.6	69.5	81.8	62.2	72.0	+5.4	-0.4	+2.5
Aug.	73.1	60.0	66.6	78.1	59.1	68.6	+5.0	-0.9	+2.0
Sept.	68.4	55.1	61.8	74.2	54.0	64.1	+5.8	-1.1	+2.3
Oct.	61.0	46.2	53.6	63.4	46.1	54.8	+2.4	-0.1	+1.2
Nov.	55.0	40.2	47.6	56.3	40.1	48.2	+1.3	-0.1	+0.6
Dec.	42.7	30.4	36.6	42.5	28.9	35.7	-0.2	-1.5	-0.9
1943									
Jan.	47.9	33.0	40.4	48.4	32.4	40.4	+0.5	-0.6	-0.0
Feb.	-	-	-	48.0	28.2	38.1	-	-	-
Mar.	51.6	34.8	43.2	51.0	33.0	42.0	-0.6	-1.8	-1.2
Apr.	62.6	42.4	52.5	63.2	43.4	53.3	+0.6	+1.0	+0.8
May	73.0	56.3	64.6	74.5	54.9	64.7	+1.5	-1.4	+0.1
June	76.0	64.2	70.1	83.0	62.3	72.6	+7.0	-1.9	+2.5
July	74.0	63.6	68.8	81.3	61.9	71.6	+7.3	-1.7	+2.8
Aug.	72.9	65.0	69.0	82.2	62.3	72.2	+9.3	-2.7	+3.2

the other physical properties and the chemical properties of the soil.

To study the effect of the treatment of watershed 17 upon soil temperature, daily temperatures were recorded for the soil surface, six inches depth, twelve inches depth and eighteen inches depth at the same weather station locations as for the air temperature measurements on the two watersheds. These temperatures were recorded from June, 1941, through July, 1942, during the first year that air temperatures were recorded. A summary of the monthly mean temperatures for each soil depth on the two watersheds is given in Table XX.

The soil temperature data of Table XX reflect the influence of the increased air temperature due to treatment as shown in Table XIX. During the summer months when the treatment effect is greatest, the soil temperatures down to eighteen inches depth were consistently greater at the weather station on watershed 17 than at the weather station on watershed 18. In December and January, because of the lack of the insulating effect of the forest, the surface soil temperatures were slightly lower on watershed 17 but not sufficiently lower for a long enough period to bring the temperature on watershed 17 at eighteen inches depth below that on watershed 18. The data of Table XX also show the natural temperature lag at increasing soil depths with the change of seasons. The data indicate that the treatment applied to watershed 17 has increased temperatures above the ground, at the soil surface

TABLE XX

THE MONTHLY MEANS OF DAILY SOIL TEMPERATURES AT VARIOUS DEPTHS FOR WATERSHEDS 18 AND 17

Year and Month	Watershed	Soil Temperature in Degrees Fahrenheit			
		Soil Surface	6 inch Depth	12 inch Depth	18 inch Depth
1941					
June	18	67.6	62.2	61.1	61.3
	17	74.8	64.5	62.0	60.8
July	18	69.7	65.4	64.4	64.4
	17	77.4	66.3	65.3	64.6
August	18	67.6	68.4	67.4	66.6
	17	70.1	70.4	69.6	68.0
September	18	62.6	63.9	63.9	63.2
	17	67.3	64.7	64.7	64.7
October	18	58.3	59.6	59.4	59.3
	17	57.5	58.8	59.1	61.0
November	18	43.5	47.3	47.7	48.6
	17	43.1	46.3	49.9	48.6
December	18	39.1	42.2	43.0	43.7
	17	36.3	41.8	42.0	44.3
1942					
January	18	34.6	35.8	37.3	37.9
	17	32.7	35.3	36.0	38.0
February	18	33.0	35.9	36.4	37.3
	17	33.9	35.4	36.0	38.6
March	18	40.9	39.4	39.8	40.1
	17	-	40.1	40.9	40.9
April	18	51.3	-	-	-
	17	54.9	49.5	50.2	46.6
May	18	57.0	57.3	56.8	-
	17	57.5	58.2	59.2	-
June	18	64.2	63.8	63.0	-
	17	67.3	65.4	66.2	-
July	18	-	66.6	66.3	66.4
	17	-	69.3	69.5	68.2

and within the soil profile. The maximum temperatures have been markedly increased, the minimum temperatures were slightly lowered and the mean annual temperatures were raised.

Vegetation Observations. Climate, vegetation and soil are closely interrelated and interdependent. The change in the microclimate on watershed 17 will ultimately produce changes in the vegetative cover which in turn will affect the soil. Changes in vegetation due to treatment can supply information as to the changes already produced in the microclimate and to the ultimate changes to be expected in the soil.

No attempt was made to cruise watershed 17 to measure the proportions of the various plant species now growing on it for that would again necessitate a major study in itself. But it can be helpful in the complete picture of the treatment effects if it is noted even in a general way how the vegetation is responding to treatment.

As was described in the section on vegetation in the earlier chapter on the description of the area, the vegetation on the two watersheds was quite similar before the treatment of watershed 17.

Of course, the most apparent and direct effect upon the vegetation due to treatment was the immediate change in the dominant life form from the life form of deciduous trees to the life form of deciduous shrub growth. This new shrub life form was comprised mostly of sprout growth from the stumps of the former dominant trees. The continuous application of the treatment will never allow the tree life form to again dominate the area.

The removal of the dominant tree life form and the high shrub life form of the laurel and rhododendron as well, together with the resulting change in the microclimate and total environment, sets the stage for the dominance of a new life form, the invasion of new plant species and a reapportionment of the numbers of individuals and importance of the existing species.

After the initial treatment it was observed that sprouting from the freshly cut stumps was vigorous and quickly dominated the area. During the first few seasons there was little chance for invasion by other plant species. During the wartime years of 1943-45 there was no cutting of the regrowth and sprouts of tree species were in complete dominance. An index to the changes in the size and woodiness of the dominant life forms with subsequent annual cuttings is supplied by the tools required each year by the laborers to cut back the regrowth. Until 1947 axes and brush hooks were used. By 1948 sprout growth and other shrub growth were small and succulent enough to almost eliminate the need for axes. In 1948 and 1949 brush hooks were chiefly used. In 1950 it became possible to use scythes over some of the area. Each subsequent year since 1950 scythes were used more and brush hooks less.

By the summer of 1949 it was observed that herbaceous species, low briars, and vines were invading the area.

Blackberry bushes and broomsedge have become increasingly dominant each year since that time. The blackberry bushes are especially abundant in the drainages and on the more level moist sites. The broomsedge is abundant on the slopes on the east side of the lower portions of the watershed.

Figure 24 shows the vegetation of watershed 17 in March, 1941, just prior to treatment. The dominance of the tree life form is apparent and there is also an abundance of large shrubby growth consisting of laurel, rhododendron and small trees. Figure 25 shows the vegetation of watershed 17 in April, 1952, eleven years after the initial cutting and just prior to the ninth annual cutting of regrowth. This figure shows the low shrub life form that is now dominant on watershed 17. Small sprouts of red maple and tulip poplar can be seen and are typical of the persistent sprout growth over the area. Bracken fern can also be seen in Figure 25 and is now a very prevalent species over much of the watershed. Blackberry bushes are the most abundant plants in the photograph and they are now dominant over many sections of watershed 17. It is of interest to note the advanced stage of decay of the log felled during the initial treatment. Most such logs over the watershed are now decaying and disappearing very rapidly.

Figure 24. A view of the vegetation on watershed 17 in March, 1941, just prior to the initial cutting.

Figure 25. A view of the vegetation on watershed 17 in April, 1952, after the initial cutting and eight subsequent annual cuttings.

EFFECTS OF TREATMENT ON SOME HYDROLOGIC CHARACTERISTICS

Various kinds and intensities of forest management may have important effects upon the hydrologic characteristics of a watershed. This treatment of cutting forest vegetation and subsequent annual cutting of regrowth was designed as a basic research study into the effects of the change in vegetative cover upon the hydrologic characteristics of a watershed. This treatment is an effort to determine the maximum effect on streamflow yields by cutting all forest vegetation yet minimizing soil disturbance as much as possible.

Experimental Technique

The method of experimentation employed in this study involved the comparison of two forested watersheds as nearly identical as possible for a preliminary period to establish the relations between them. Then the forest from one of the drainage areas was removed so that the treatment effects could be measured by comparing the ratios or differences between them after deforestation with those before. This experimental technique gives the before and after comparisons a degree of control.

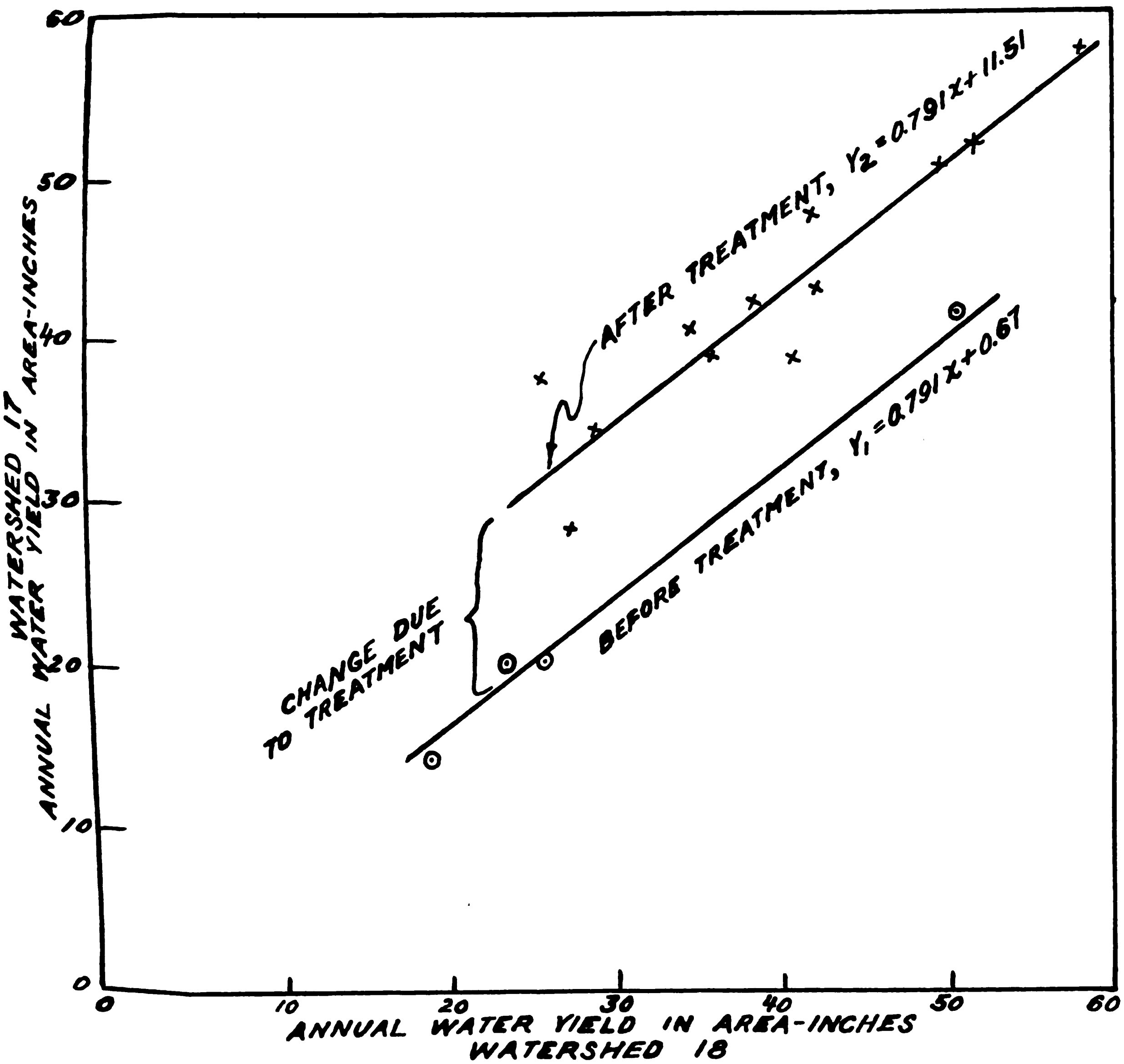
Total Streamflow

Streamflow to the forest hydrologist represents the most important hydrologic tool in studying the runoff characteristics of a watershed. Of course, it is streamflow which supplies us with our major source of water and it is also streamflow characteristics which fundamentally affect floods. To study the hydrologic effects of the treatment in this experiment considerable emphasis must be given to the effects on various streamflow characteristics. Among these characteristics total annual yields and total monthly yields furnish valuable measurements of treatment effects.

Annual Yields. Total annual yield of streamflow serves as a measure of the actual increase or decrease in water yield from a drainage area due to treatment. The sharp-crested, notched weirs that are used on the two watersheds as the stream-gaging controls are described above in the section on instrumentation-installations and photographs of the two installations are shown in Figures 12 and 13. Likewise, the instrumentation for measuring precipitation and the keeping of records of these two factors are described above in the same section. Tables XXVIII and XXIX of Appendix B show the summary of weighted monthly precipitation on the two watersheds from July, 1936, to November, 1952. A summary of water yield from 1937 through 1951 is shown for the two watersheds in Tables XXX and XXXI of Appendix B. Note that in all these tables the runoff is presented in terms of area-inches so as to enable easy comparison of the two watersheds as well as for comparison with the measurements of precipitation. Table XXXII of Appendix B shows the monthly runoff for the two watersheds after treatment from April, 1941, to May, 1953, and the monthly increase in area-inches of flow from watershed 17 for that period.

To compare the total annual yields in streamflow from watershed 17 before and after treatment, the control watershed approach using the data from watershed 18 offers a reliable means of measuring the treatment effect. One statistical method currently in use for this type of comparison is the system of pooled regressions for computing the estimated total annual streamflow from watershed 17 for each year after treatment based on its relationship with watershed 18 before treatment and also on the yields from watershed 18 each year since the treatment. These estimated values are then the most accurately computed yields obtainable at the present time for watershed 17 since 1941 if the treatment had not been applied. The change in water yield due to treatment is then computed by subtracting this estimated non-treatment yield from the actual yield for that year. These computations for the pooled regressions and the changes between treatment and non-treatment streamflows are shown in Figures 32 and 33 in Appendix B. The yearly totals are all based upon the hydrologic year of the region of the Southern Appalachian Mountains. This hydrologic year runs from May 1 to April 30.

Figure 26 shows the pooled regression equations before treatment and after treatment in graphical form with the actual annual yields plotted also to show their low deviation from



LEGEND

⊙ -- Actual yields before treatment
✕ -- Actual yields after treatment

Figure 26. The increase in streamflow from watershed 17 after treatment by comparing its relationship to watershed 18 before and after treatment.

the regression lines. Table XXI gives the actual annual yield for watershed 17, the estimated yield if treatment had not been applied, and the increase of the actual over the estimated for the years since the treatment was begun. Figure 27 shows this increase in annual yield due to treatment in a bar graph form.

TABLE XXI

THE INCREASE IN ANNUAL STREAMFLOW OF WATERSHED 17 OVER ESTIMATED NON-TREATMENT FLOWS

Hydrologic Year, May 1 to April 30	Actual Annual Yield in Area-Inches	Estimated Non-Treatment Yield in Area-Inches	Increase Due to Treatment in Area-Inches
1941-42	37.72	20.78	16.94
1942-43	47.73	33.63	14.10
1943-44	43.07	33.86	9.21
1944-45	27.92	22.13	5.79
1945-46	38.62	32.67	5.95
1946-47	40.67	27.93	12.74
1947-48	42.24	30.85	11.39
1948-49	52.07	41.44	10.63
1949-50	57.75	46.59	11.16
1950-51	39.33	28.86	10.47
1951-52	50.65	39.89	10.76
1952-53	34.43	23.41	11.02

These data on total annual streamflow in area inches per hydrologic year show a decided increase in annual yield on watershed 17 due to treatment. This increase is consistent throughout the duration of the treatment and is apparent even during the World War II years when annual cutting was interrupted. Including those war years, the average annual increase in streamflow is 10.84 area-inches. This increase appears to have stabilized during the last six years from 1947 to 1953 at

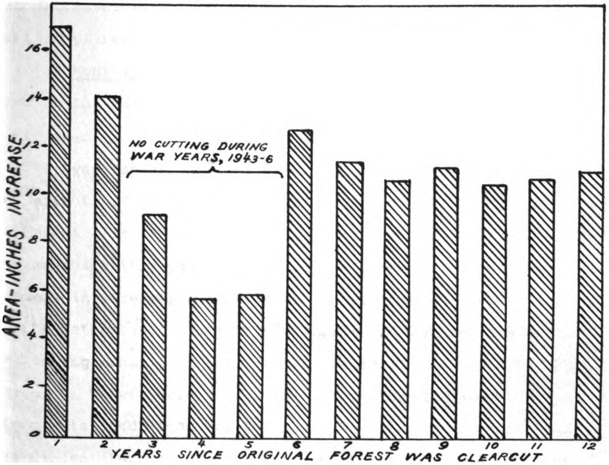


Figure 27. The increase in annual water yields on watershed 17 due to treatment.

around 10.90 area-inches. The greatest single year increase was noted in the first year after the initial cut. The smallest increases were recorded during the war years when annual cutting of regrowth was interrupted.

Monthly Yields. Because of the variations in streamflow as the various hydrologic seasons progress during a hydrologic year, a breakdown of total streamflow into the months of the hydrologic year offers another important analysis of the effects of treatment upon total streamflow. There are different climatic and biologic factors at work during different months of the year and their interplay causes monthly changes in streamflow and the other hydrologic characteristics of the watershed. Hoover (18) computed linear regressions for predicting monthly runoff from watershed 17 and estimated the change in water-yield as a result of treatment by months, using watershed 18 as the control. He found the correlation-coefficient for monthly runoff from the two watersheds to be +0.99 and the standard error for predicting monthly runoff from watershed 17 using watershed 18 as a control was 0.15 inch. Table XXII shows the average actual and estimated monthly streamflow for watershed 17 and the average increase in monthly streamflow over the estimated non-treatment values. These estimated values were computed by applying the method described by Hoover to the additional data recorded since his original calculations (18). The individual monthly values are given in Table XXXII of Appendix B.

TABLE XXII

THE INCREASE IN AVERAGE MONTHLY STREAMFLOW OF WATERSHED 17 OVER ESTIMATED NON-TREATMENT FLOWS

Month of Hydrologic Year	Actual Monthly Yield in Area-Inches	Estimated Non-treatment yield in Area-Inches	Increase Due to Treatment in Area-Inches	Percent Increase Over Non-Treatment Yields
May	3.52	3.15	0.37	12
June	2.42	1.95	0.47	24
July	2.55	1.63	0.92	55
August	2.22	1.24	0.98	79
September	2.26	1.16	1.10	95
October	1.67	0.87	0.80	92
November	2.47	1.40	1.07	76
December	3.79	2.46	1.33	59
January	5.26	3.82	1.44	38
February	5.45	4.58	0.87	19
March	6.31	5.90	0.41	7
April	4.58	4.33	0.25	6

Table XXII shows the pronounced increase in monthly streamflow from watershed 17 due to treatment. Logically, this increase is greatest in the summer and early fall, when the effects of water loss from forest transpiration during the growing season would otherwise have reduced streamflow to a lower minimum. This effect is best illustrated on a percentage basis as is shown in the last column of Table XXII. It is significant that the greatest monthly increases due to treatment occur at the time of the lowest rate of streamflow during the year. Thus the increase comes at a time when it is most needed. The percent column of Table XXII also shows how well the hydrologic year is delimited. During the hydrologic seasons of ground water recharge, the high precipitation in this region of the Southern Appalachians restored streamflow for the watershed when forested to very close to the streamflow for the watershed when deforested. April represents the month of maximum ground water recharge, and this month shows the lowest increase in streamflow due to treatment. May marks the beginning of the hydrologic season of maximum evaporation and transpiration, and the increase in streamflow due to treatment begins to rise for this month. The beginning of the hydrologic season of soil moisture recharge is also well marked by the first drop in the percentage increase in October. This season ends after December when the drop in percent between December and January is the greatest and there is a sharp rise in streamflow. Figure 28 presents the data of Table XXII in graphical form.

Flow Frequency

Another useful hydrologic characteristic for the hydrologist and watershed manager is the computation of the percent of time that the streamflow exceeds certain mean daily flows. These values are plotted on probability paper and a curve is constructed. Of course, the probability of not exceeding certain mean daily flows decreases as the values for mean daily flow are increased.

A study was made of the changes in streamflow frequency on watershed 17 due to treatment by Lieberman and Hoover (30). The results of their study are presented in graphical form in

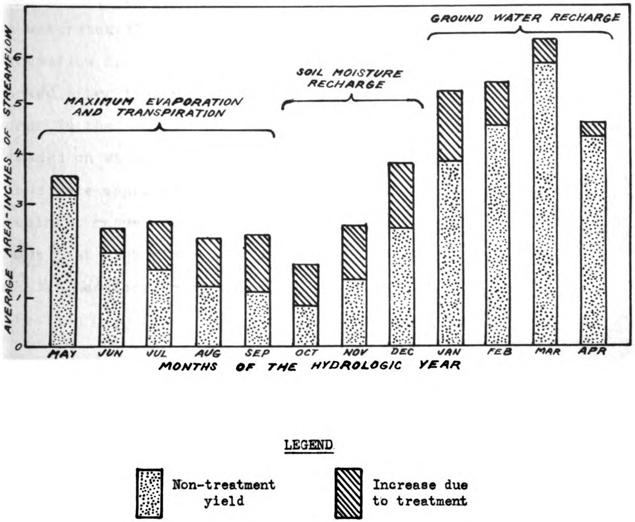


Figure 28. The increase in monthly streamflow on watershed 17 due to treatment.

Figure 29. The graphs of Figure 29 show that the streamflow frequency relationships did not change at all for control watershed 18 for the period before the treatment was initiated on watershed 17 and the period after. However, the change in streamflow frequency relationships on watershed 17 is quite marked after treatment. This shows that minimum flows, which occur in the late summer and early autumn, were markedly increased on watershed 17 due to treatment. Although minimum flows were appreciably raised, the convergence of the after treatment curve with the before treatment curve at higher flows shows that high flows were not greatly affected by the treatment. Therefore, minimum flows were increased without greatly affecting high flows nor increasing the flood danger.

Storm Peaks

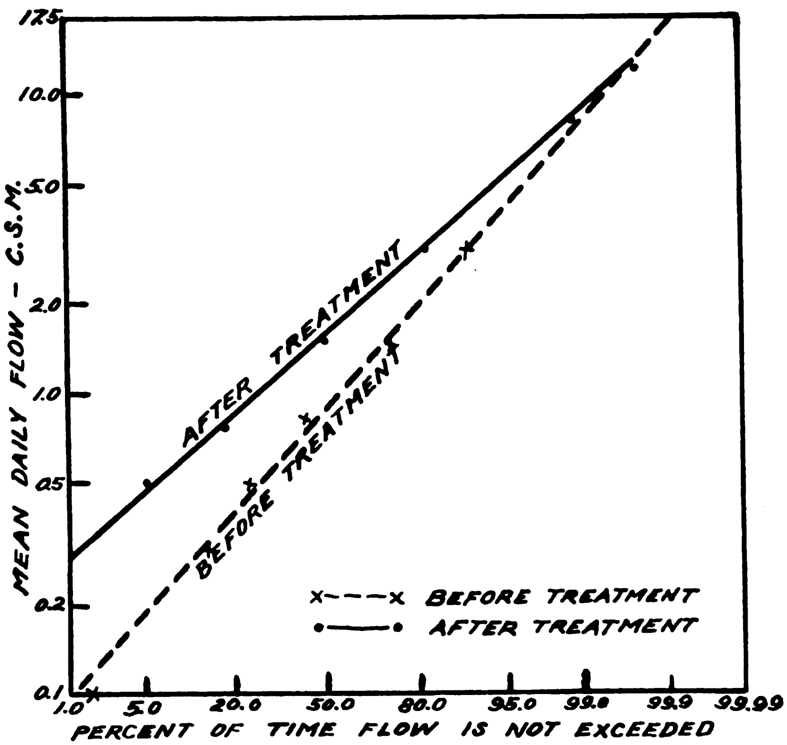
The increase or decrease in the maximum peak discharges of storm peaks in streamflow is an important hydrologic characteristic. This characteristic can indicate a greater or lesser tendency of a stream to produce floods. This characteristic can be extremely sensitive to poor land-use and can increase manifold under watershed mismanagement (10).

To study the changes in this sensitive characteristic of storm peaks the control watershed approach was used in which regression lines between control watershed 18 and treated watershed 17 were computed for the maximum peak discharges for before and after treatment. These computations are shown

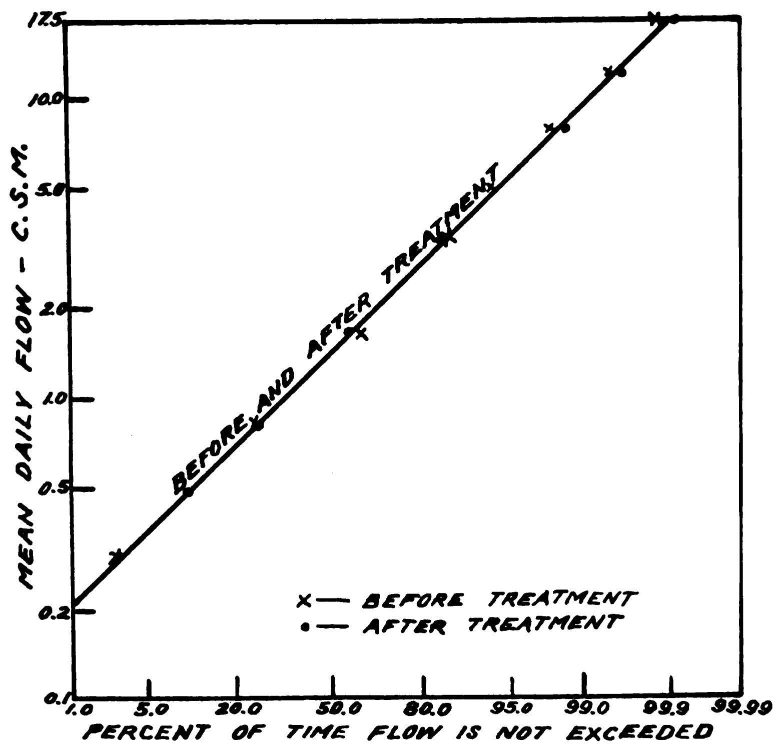
FIGURE 29.

BEFORE AND AFTER TREATMENT FLOW FREQUENCY CURVES FOR TREATED WATERSHED 17 AND CONTROL WATERSHED 18.

TREATED WATERSHED 17.

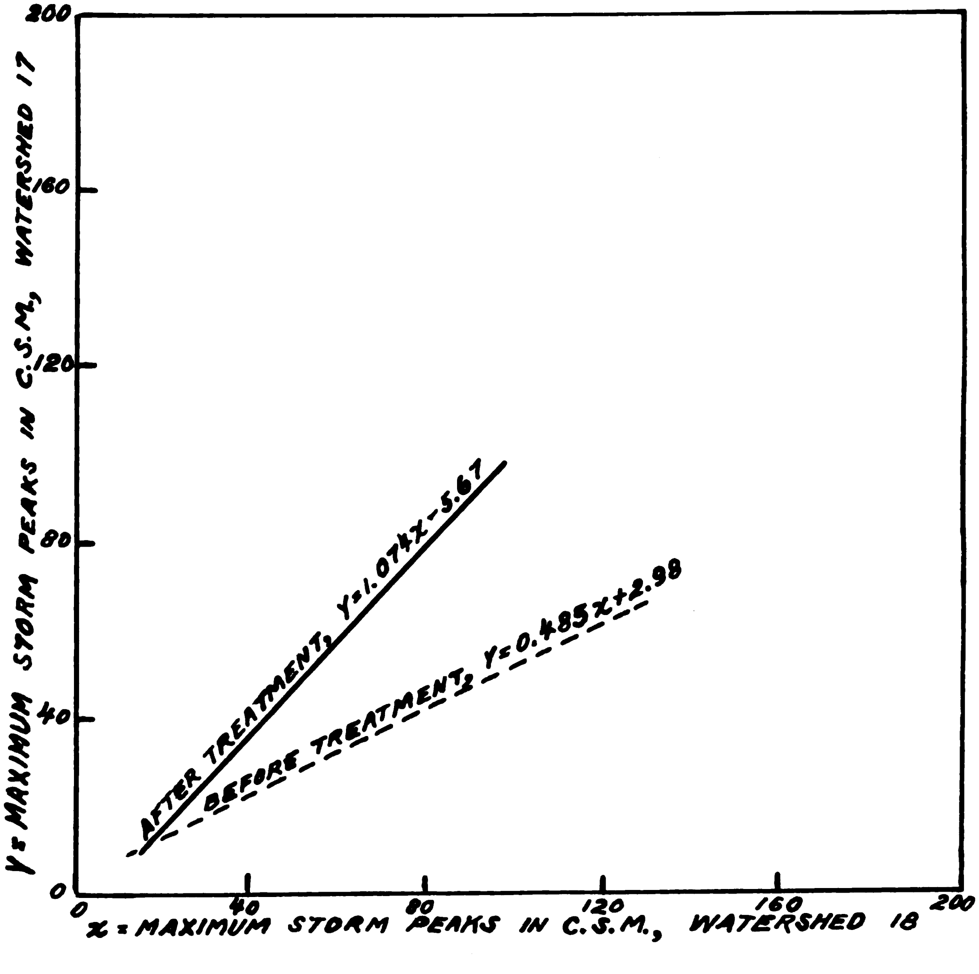


CONTROL WATERSHED 18.



in Figure 34 of Appendix B. The results of this study are shown graphically in Figure 30.

Figure 30 shows that there has been an increase in the magnitude of storm peaks on watershed 17 due to treatment. Due to the hydrologic changes brought about on watershed 17 a change in this particularly sensitive characteristic is to be expected. However, it is interesting to note that this treatment has brought the magnitude of storm peaks up to a point that is no higher for the most part than for watershed 18, a drainage area still in natural forest and in a state of ideal hydrologic condition from the standpoint of streamflow regulation. The maximum peak discharge recorded on watershed 17 was 89 c.s.m. Using this extreme peak and referring to the after treatment regression line it can be seen that the same peak would also be produced on forested watershed 18. The average maximum storm peak for watershed 17 after treatment is 25.14 c.s.m., which is still below the average storm peak of 28.68 c.s.m. for control watershed 18. Therefore, the changes produced in the magnitude of storm peaks cannot be considered as significant in terms of effects of differences in land management for these magnitudes still lie in the range for forested watersheds and are far below the magnitudes characteristic of mountain logging, mountain grazing and mountain farming (10,21). For many storms, the increased storm peak discharge can be accounted for by the higher initial baseflow of the stream. In a later section it will be



Note: Maximum range of storm peaks during period of study is 15 to 124 c.s.m. for watershed 18 and 15 to 89 c.s.m. for watershed 17.

Figure 30. Maximum storm-peak relationship between control watershed 18 and treated watershed 17.

shown that no overland flow has yet taken place on treated watershed 17. Thus, runoff is still controlled by groundwater conditions.

Groundwater Storage

The monthly groundwater storage during the growing season is another hydrologic characteristic which can serve as a measure of the vegetation treatment effects. Situated in a superhumid climate in the Southern Appalachian region, the groundwater storage on watershed 17 reaches a maximum during the hydrologic season of groundwater recharge in the latter part of March. In this superhumid climate the soil moisture is quantitatively constant from year to year at that time so that the influence of the treatment is then at a minimum. Furthermore, the time of this groundwater storage maximum was the same before treatment as after.

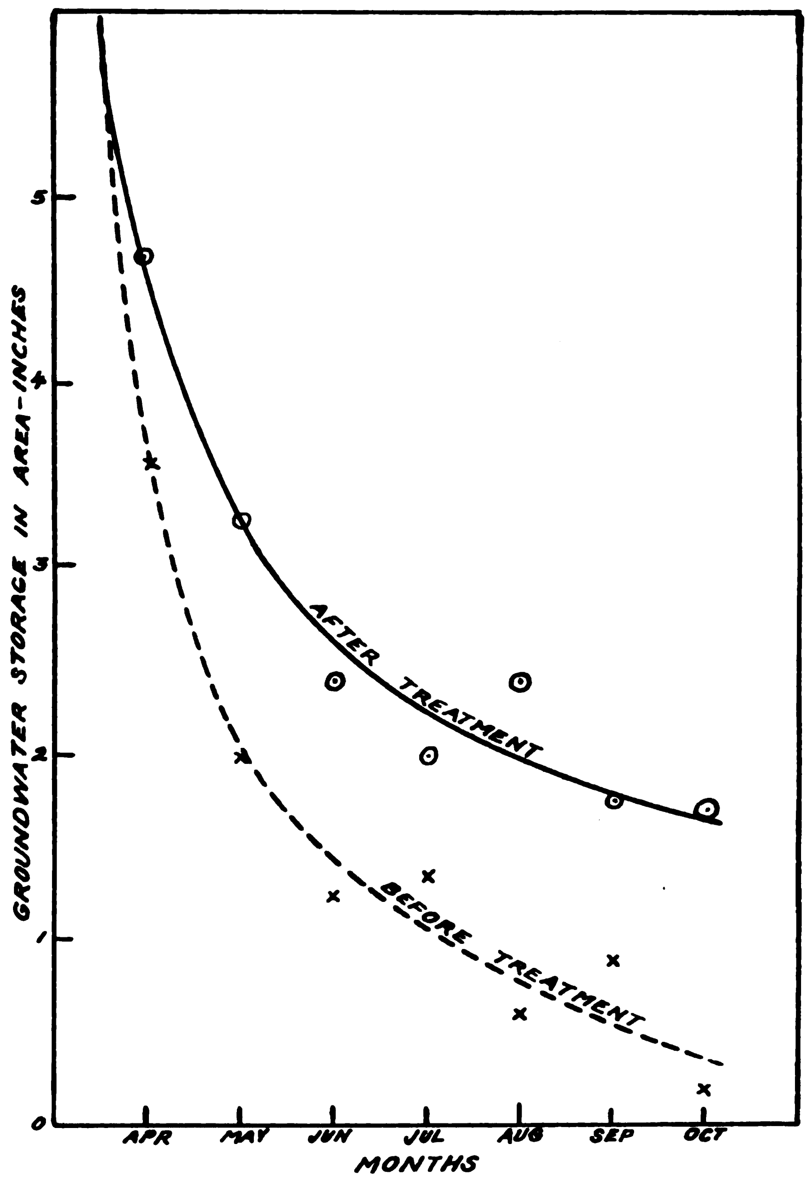
The groundwater depletion during the growing season, starting with maximum storage during March, was studied for possible treatment effects. The groundwater storage in area-inches was calculated for each month from April through October and averages were computed for the period before treatment and the period after initial treatment. The computations for the regressions of the groundwater storage relations between control watershed 18 and treated watershed 17 are shown in Figure 35 of Appendix B. The average monthly groundwater storage in inches for the before and after periods for watershed 17 are shown in Figure 31. Only the growing season was studied in order to show the change in the depletion curve due to treatment.

The graph of the results of the study in Figure 31 shows that there has been a marked change in the groundwater depletion curve for watershed 17 during the growing season. With less loss to transpiration during the growing season soil moisture remains at higher levels. Summer rains, therefore, satisfy the retention storage opportunity more quickly and more water becomes available to the groundwater reservoir than was the case before treatment. This contributes to the increase in streamflow during the late summer low flows.

Water Quality

For some purposes water quality can be as important a hydrologic characteristic as water quantity. Certain industries use water as a cooling agent to regulate temperature. Stream temperature and turbidity greatly influence stream flora and fauna. Many uses of water require that it be pure and potable. Turbidity, pollution, taste, and high temperature can all affect the value of water. Of the above water quality factors, water turbidity and water temperature are the only factors that could possibly be affected by this particular land use treatment.

Stream Turbidity. The important characteristic of stream turbidity has been checked and observed periodically



LEGEND

--- Before treatment, from 1936 to 1940
—— After treatment, from 1946 to 1951

Figure 31. Change in the depletion curve of groundwater storage on watershed 17 due to treatment.

by the station staff since the initiation of the treatment on watershed 17. No overland stormflow has ever been observed on watershed 17 and there has been no shuffling of the litter material or the forming of litter dams by the passage of water over the soil surface. This is in agreement with the high permeability rates obtained in the permeability study discussed in the preceding chapter. No turbidity save that of harmless organic matter has ever been observed passing through the weir of watershed 17 during peak flows. This is in sharp contrast to the turbidities caused by other forms of mountain land use, such as farming, grazing and logging (10, 21).

Although no turbidity due to mineral soil content has been observed coming from watershed 17, because of the greater possibility of this taking place as the treatment is continued a turbidity study was made from August, 1953, until April, 1954. Aliquots were collected once each week at approximately the same time of day on the same day of the week. The samples were taken of the water passing over the weir blade for both the control watershed 18 and the treated watershed 17. Turbidities were measured using an electrophotometer and were converted to parts per million by means of an electrophotometer turbidity conversion table. The individual values obtained in this study are given in Table XXXIII of Appendix B.

The results of this study show a very close similarity between the two watersheds in this characteristic. Control watershed 18 had an average turbidity of 1.89 ppm. during the period of study and treated watershed 17 averaged 1.91 ppm. Therefore, the results of this study show no differences between the two watersheds in the commonly sensitive land-use hydrologic characteristic of stream turbidity.

Stream Temperature. It is possible to influence the important water quality characteristic of stream temperature by cutting down all vegetation shading the stream channel and thus expose the stream and the stream bed to the direct rays of the sun. In instances where this has been done for many miles over a slow moving stream, stream temperatures have been raised appreciably. Watershed 17 possesses a perennially flowing stream of only 0.2 mile in length with a mean slope of 28.4 percent in a northwesterly direction. With this short, steep channel, swift stream and angle of slope away from the direction of the sun's rays, a pronounced change in stream temperature due to treatment cannot be expected. The volume of flow, combined with the above factors of shortness of channel and swiftness of current, also permits little chance of raising instantaneous maximum stream temperatures more often above 66°F. than was the case before treatment. Sixty-six degrees Fahrenheit is now considered by fisheries men in that region as an important maximum temperature in trout production and a treatment of this type on watersheds with longer stream channels and less gradient would be more sensitive in terms of affecting instantaneous stream temperatures.

A study was made during the calendar year of 1947, measuring maximum and minimum stream temperatures on control watershed 18 and treated watershed 17. Table XXXIV of Appendix B lists the average monthly maximum and minimum stream temperatures for these two watersheds. For the entire year control watershed 18 had an average maximum temperature of 55.5°F. and an average minimum of 47.9°F. Treated watershed 17 had an average maximum of 55.8°F. and an average minimum of 48.3°F. Thus, the treated watershed had an average maximum 0.3° and an average minimum 0.4° higher than the stream temperatures of the control watershed. The average monthly differences seem to be somewhat more apparent during the winter months than during the growing season. This is difficult to explain unless the shading effect of the evergreen rhododendron, which grows dense along stream channels of watershed 18, is important during the winter period of low air temperatures. In any case, the differences in stream temperatures between the two watersheds are very slight and may well be due to chance or to factors other than treatment since treatment effects upon stream temperature could not be great when considering the shortness and steepness of the northwesterly sloping channel.

Storm Runoff

Analyses of stream hydrographs offer another sensitive criterion for the evaluation of the effects of different land-management practices upon the hydrologic characteristics of a watershed. Certain forms of land use profoundly affect in various ways the component of stormflow in the stream hydrograph. It is essential, therefore, that stormflow be separated from groundwater flow for a more accurate study of the sensitive stormflow segment of the hydrograph.

To separate stormflow from groundwater flow there are several recognized and acceptable methods in use. The important criterion is that one of these systems be used consistently throughout. To study the changes in stormflow on watershed 17 a groundwater depletion curve for the hydrologic year was prepared by the station staff as described by Wisler and Brater (60). This curve was converted to read directly in gage height over the weir and adjusted to the time scale of the original field charts. A transparency of the curve was then made in order to employ it as an overlay on the original charts. Stormflow was represented by the area between this curve and the gage height on the charts. This was done for the before treatment period from 1937 through 1940 and the after treatment period from 1941 through 1942. This first year after treatment produced the greatest increase in total water yield and, therefore, it provides a good basis for studying the sensitive characteristic of total stormflow.

The results of this study are summarized in Table XXIII, which gives the average seasonal and average annual stormflow and groundwater flow in area-inches before and

TABLE XXIII

THE AVERAGE SEASONAL AND AVERAGE ANNUAL GROUNDWATER FLOW AND STORMFLOW FROM WATERSHED 17 BEFORE AND AFTER TREATMENT

Period and Season	Total Runoff in Area-Inches	Groundwater Flow in Area-Inches	Stormflow in Area-Inches
Before Treatment, 1937-1940			
Dormant season[1]	18.81	16.75	2.06
Growing season[2]	9.09	8.36	0.73
Water year[3]	27.90	25.11	2.79
After Treatment, 1941-1942			
Dormant season	17.95	16.68	1.26
Growing season	14.58	13.60	0.98
Water year	32.53	30.28	2.24

[1]The dormant season consists of the last half of the water year from November 1 to April 30.

[2]The growing season is the first half of the water year from May 1 to October 31.

[3]The water year is here considered from November 1 to October 31.

after the treatment of watershed 17. The values obtained for the individual years are given in Table XXXV of Appendix B. Table XXIII shows that stormflow, a hydrologic characteristic that is sensitive to land abuse, changed very little after the initiation of the treatment on watershed 17, during the year in which the increase in total yield was the greatest. The increases in water yield from the cutting of all forest vegetation are almost entirely in the form of groundwater flow, and this during the growing season. This finding is corroborated by the study showing no changes in water quality and by the fact that no overland stormflow has been observed and the surface litter material has not been disturbed or formed into litter dams. There appears in the data a slight increase in stormflow during the growing season. This increase is negligible and cannot be considered significant. The treatment applied to watershed 17 in 1941 exposed a stream, which had been completely covered by a forest canopy before treatment, so that rains afterward fell directly into the stream channel. This may account for the slight change in maximum flows during storm periods. However, with the other characteristics of the watershed being held sufficiently constant by protection, the data show no worthwhile changes to date in streamflow save in the increase in total yields during the late summer low flows.

In a further study into the distribution of storm runoff in individual storms, unit hydrographs for watershed 17 were studied by the station staff for the changes in the distribution of storm runoff before and after treatment. Each unit hydrograph constructed was a composite of three comparable storms. The two composite unit hydrographs reflected the above mentioned exposure of the stream channel to direct channel precipitation but showed no worthwhile changes in storm runoff distribution after treatment. Channel precipitation decreased the time of concentration very little and all other characteristics remained the same. This negligible effect is again explained by the still very favorable condition of the soil, the absence of overland flow and the absence of any change in the short stream channel except the removal of the forest canopy. In comparison with the spectacular effects of land abuse upon storm runoff with many forms of land management, a change in storm runoff characteristics which fails to increase stormflow and storm peaks beyond those of the control watershed, which is still in ideal natural forest condition, cannot be considered significant in a watershed management sense.

SUMMARY AND CONCLUSIONS

In this nation and in many regions of the world the growth of population and the development of industry have placed increasing demands upon the limited water supply. For the protection and maximum development of the water resources it has become imperative to launch a comprehensive program of scientific research into groundwater supplies, watershed management, and water conservation. As a part of this over-all program complete cutting of forest vegetation and the subsequent annual cutting of regrowth on watershed 17 of the Coweeta Hydrologic Laboratory comprise a scientific study designed as basic research into watershed management and water conservation. The drastic treatment had as its principle objective the study of its effect on water yields from a watershed. The studies into some of the pedologic and hydrologic effects of this treatment showed the following results.

Pedologic Effects

The close similarity in the soils of the treated watershed and the control watershed of this experiment enables a comparison to be made of some pedologic characteristics on the two watersheds in an effort to determine the effects of treatment upon the soils of watershed 17. An intensive soil survey and a mechanical analysis of the soils on the two watersheds reveals a general physical uniformity of the soils over the two watersheds. Texturally, the soils of the two watersheds possess low variability. Sand is the dominant textural separate and the soils throughout the two watersheds vary only from a sandy loam to a sandy clay loam. Similar geology, land use history, and vegetation before treatment also attest to the similarity of the soils of the two watersheds before treatment.

To ascertain the possibility that the treatment of watershed 17 was affecting soil structure, tests of percentage aggregation of water-stable aggregates, aggregate stability analyses and dry clod analyses were made. Results showed no differences between the two watersheds in the structural characteristics measured for the lower soil layers. This substantiates the hypothesis of soil uniformity over the two watersheds. A treatment of this kind on the vegetative cover would not be expected to appreciably affect the structure of the lower soil layers. However, the percentage aggregation of the large water-stable aggregates in the surface soil layers was found to be higher for control watershed 18 than for treated watershed 17. The dry clod analyses did not reflect this trend but the aggregate stability analyses also showed a higher degree of stability for the large aggregates in the surface layers of soil for control watershed 18 than for treated watershed 17. The dry clod analysis serves to emphasize the original structural uniformity of the soils of the two watersheds while the tests involving the stability of these structural units show a possible trend of deterioration in the surface soil layers. That this trend is most pronounced in the top soil layer provides further indication of treatment effects, because differences in land use produce their greatest structural effects at the soil surface. The amount of unincorporated humus lying on the soil surface was found to be much less on the treated watershed. The decrease in this layer may be the direct cause for the trend shown in the deterioration of the stability of the surface soil structure. During the early years of the treatment this humus layer was augmented by the cuttings of the original vegetation and it has only been during the few later years that accelerated oxidation and decomposition decreased this layer on treated watershed 17 to a point much less than on the control watershed. The study of the amount of incorporated organic matter in the mineral soil does not yet reflect these differences. This may possibly be due to a temporary lag because of the accelerated decomposition of the formerly thick humus layer and the resultant better mixing of these decomposition products in the mineral soil layers. Dead and decaying roots of the trees cut in the initial treatment may also be temporarily contributing organic matter in these mineral soil horizons.

In agreement with the textural uniformity of the soils of the two watersheds and the similarity in dry clod analyses where aggregate stability was not concerned, the volume weight

ses
ase
chro
the
a
wit
are
Tut
ses,
wat
be
ses w
fo
la
eal
soi
atersh
nger
nd det
sual
ract
serva
eler
getat
deal
tter

values obtained for the soils of the two watersheds as yet revealed no trend of differences. Soil porosity studies at various tensions using a tension table and soil permeability tests also show no trends of differences in these soil physical characteristics between the two watersheds. Soil permeabilities rates for the surface layers were found to be well above any high intensity of rainfall that could possibly occur. Studies of the field capacity values, moisture equivalent values, and air-dry moisture contents for the soils of the two watersheds also showed the soils of the two watersheds to be closely similar physically. Thus, no trends of differences were shown as yet except that of lower aggregate stability for the surface layers, lower percentage aggregation of the large, water-stable aggregates for the surface layers, and a decidedly lower amount of the unincorporated humus layer for the soils of treated watershed 17 than for the soils of control watershed 18. If the treatment were continued for a much longer period of time, this disappearance of the humus layer and deterioration of structural stability could result in a gradual deterioration of some of the other soil physical characteristics as well. Air temperature and soil temperature observations indicate an increase in temperatures, which could accelerate the decomposition of organic matter. Observed vegetational changes also indicate a trend away from the ideal hydrologic conditions of a natural forest soil and litter layer. The dominant life form has been changed from

a deciduous forest to a deciduous low shrub growth which is being perpetuated through continued treatment. A gradual invasion and establishment of new shrub and grass species is being observed. Broomsedge and blackberry bushes are expanding their areas of dominance.

A study of the soil moisture regime during the growing season shows a high variability in soil moisture content from sample to sample, but for the total profile, where this influence of individual variability is minimized by the assemblage of the greatest number of samples, a trend of higher soil moisture content on the treated watershed than on the control watershed is indicated throughout the growing season. There appeared to be no trend of difference in surface soil evaporation and no concentration of soil moisture demands by plant roots was revealed for any particular soil layer. Apparently, this form of treatment has neither greatly affected the vertical distribution of the active plant roots nor has greatly reduced the transpirational draft throughout the soil profile. As new shrubs and grasses establish their dominance, a concentration of active roots in the shallower horizons may eventually occur. At present, this treatment is permitting tree stumps to continue competing as an active part of the plant community and their root systems are therefore still partially active in the deeper horizons. It is suffice to note that the treatment of watershed 17 is reflected in only a slight trend of higher soil moisture content during the growing season.

Hydrologic Effects

The treatment of watershed 17 caused a marked increase in total annual water yield. This increase due to treatment amounted to nearly seventeen area inches during the first year of treatment and is now stabilizing itself at about eleven area inches per year during the last six years of record from 1947 to 1953. In terms of monthly yields this increase is greatest during the period of low flows at the end of the growing season. During September and October the increase over pre-treatment water yields is almost one hundred percent. Communities with limited storage facilities, industries consuming water and farmers using small streams for irrigation are often more interested in this limiting factor of minimum streamflow during the season of low flows than in the periods of high flows when the supply may be in excess of demand. Thus, this treatment increases water yields right at the critical period in the hydrologic year when such increases are most needed.

An analysis of the change in flow frequency due to treatment shows that minimum flows were raised but the effect decreases as increasingly higher flows are considered. High flows were relatively unaffected by the treatment. The study of storm peaks shows that their magnitude was somewhat raised by the treatment but that these storm peak volumes are still no greater than those from the forested watershed. This is in contrast to the spectacular storm peaks that may be produced in other forms of mountain land use, such as mountain farming, mountain grazing and mountain logging.

The depletion curve of ground water storage during the growing season was markedly raised by the treatment of watershed 17. This is in agreement with the increase in base flows discussed above since ground water is the contributor of base flow. The study showing no changes in stream turbidity strengthens the observations that there has never been overland flow on the treated watershed and there has been no observed shuffling of the litter material by water running over the soil surface. Thus, the increases in water yields are in consequence of a higher groundwater storage supply. Stream temperatures were not affected by the treatment because of the shortness, steepness and northerly exposure of the stream channel. An analysis of storm runoff also showed no appreciable changes due to treatment. This is in agreement with the facts that no overland runoff and no other changes of the stream channel or the watershed, except the exposure of the channel to direct rainfall, were produced by the treatment, if the groundwater flow is eliminated from the hydrograph. Exposure of the channel slightly shortened the time of concentration but not to an extent that is significant when considering the changes that can be produced by other forms of mountain land use.

PRACTICAL IMPLICATIONS

The treatment of the complete cutting of forest vegetation and subsequent annual cutting of all regrowth, together with no removal of the cuttings from the watershed and the maximum protection of the soil, was a pure research study in watershed management. The project was not designed with the thought that such a form of land use would ever be recommended in exactly this manner as a practical form of watershed management.

The chief practical contributions of this study are the indirect, theoretical contributions to our knowledge of the hydrologic behavior of watersheds and the possible hydrologic and pedologic effects of various types of land management upon our watersheds. This treatment indicates how much water yields may be increased by the complete cutting of a natural forest in the Southern Appalachians, how much the other streamflow characteristics may be controlled, and whether or not the desirable original forest soil conditions can be maintained indefinitely.

This basic research treatment did produce an appreciable increase in total annual water yield and in minimum flows from a watershed in the Southern Appalachians but it took place in a superhumid region and every effort was made not to disturb the soil surface and to preserve the soil stability. Continuation of the higher annual water yield and higher minimum flows would necessitate continuation of the treatment of cutting down all regrowth each year. Considering these factors, such a treatment cannot be recommended on the basis of these findings as a practical emergency method of supplying an increase to minimum streamflows that might be economically worthwhile in areas outside of this superhumid region of the Southern Appalachians. The amount and seasonal pattern of precipitation, the topography and character of the soil, the type of vegetation, the cost and facilities for conducting such a thorough and careful treatment, the streamflow characteristics, and the value of the possible increase in critical low flows for some emergency period must all be taken into consideration. At least one of these factors and usually several would combine in an unfavorable manner so as to make such a treatment economically unfeasible.

LITERATURE CITED

1. Ayer, G. R. 1949. A progress report on an investigation of the influence of reforestation on stream-flow in State Forests in Central New York. U.S. Dept. Int. Geol. Surv. in cooperation with State of New York Conservation Dept. 185 pp.

2. Bates, C. G. and A. J. Henry. 1928. Forest and stream flow experiment at Wagon Wheel Gap, Colorado, Monthly Weather Review (Supplement No. 30). U.S. Dept. Agr. Weather Bureau, W.B. No. 946. 79 pp.

3. Bauer, H. L. 1936. Moisture relations in the chaparral of the Santa Monica Mountains, California. Ecol. Monographs 6: 409-454.

4. Baver, L. D. 1948. Soil physics, 2nd ed. John Wiley and Sons, Inc., New York. 398 pp.

5. Bouyoucos, G. J. 1936. Directions for making mechanical analyses of soils by the hydrometer method. Soil Science 42: 225-229.

6. Coile, T. S. 1936. Soil samplers. Soil Science 42: 139-142.

7. Conrad, J. P. and F. J. Veihmeyer. 1929. Root development and soil moisture. Hilgardia IV : 113-134.

8. Craib, I. J. 1929. Some aspects of soil moisture in the forest. Yale Univ. School of Forestry Bull. 25.

9. Devereux, R. E., F. E. Goldston and W. A. Davis. 1929. Soil survey of Macon County, North Carolina, U.S. Dept. Agr., Bur. Chem. and Soils, No. 16, Series 1929. 21 pp.

10. Dils, R. E. 1953. Influence of forest cutting and mountain farming on some vegetation, surface soil and surface runoff characteristics. U.S. Forest Serv., Southeastern Forest Expt. Sta., Station Paper No. 24. 55 pp.

11. Dreibelbis, F. R. and A. F. Post. 1941. An inventory of soil water relationships on woodland, pasture and cultivated soils. Soil Sci. Soc. Am. Proc. 6: 462-473.

12. Forest Service and Soil Conservation Service. 1940. Influences of vegetation and watershed treatments on run-off, silting, and stream flow: A progress report. U.S. Dept. Agr. Misc. Publ. 397. 80 pp.

13. Forsling, C. L. 1931. A study of the influence of herbaceous plant cover on surface runoff and soil erosion in relation to grazing on the Wasatch Plateau in Utah. U.S. Dept. Agr. Tech. Bull. No. 220. 71 pp.

14. Harper, V. L. 1953. Watershed management. Unasylva Vol. VII (3): 105-114.

15. Hendrickson, A. H. and F. J. Veihmeyer. 1929. Irrigation experiments with peaches in California. Calif. Agr. Expt. Sta. Bull. 479.

16. ________ and ________. 1934. Irrigation experiments with prunes. Calif. Agr. Expt. Sta. Bull. 573.

1 . ________ and ________. 1942. Irrigation experiments with pears and apples. Calif. Agr. Expt. Sta. Bull. 667.

18. Hoover, M. D. 1944. Effect of removal of forest vegetation upon wateryields. Trans. Am. Geophys. Union Vol. 25 : 969-977.

19. Houk, I. E. 1921. Rainfall and runoff in the Miami Valley. Miami Cons. Dist. Tech. Report, Part VIII : 1-234.

20. Hursh, C. R. 1940. Outline for compiling precipitation and runoff data for small drainage areas. U.S. Forest Serv., Applachian Forest Expt. Sta. Tech. Note 34. 59 pp.

21. ________. 1951. Research in forest-streamflow relations. Unasylva Vol. V (1) : 2-9.

22. Interior and Insular Affairs Committee. 1953. II, The physical basis of water supply and its principal uses. The Physical and Economic Foundation of Natural Resources. House of Representatives, U.S. Congress. U.S. Govt. Printing Office. 93 pp.

23. ________. 1953. III, Ground-water regions of the United States-their storage facilities. The Physical and Economic Foundation of Natural Resources. House of Representatives, U.S. Congress. U.S. Govt. Printing Office. 78 pp.

24. Kittredge, J. 1948. Forest influences. McGraw-Hill Book Co., Inc., New York. 394 pp.

25. Korstian, C. F. and T. S. Coile. 1938. Plant competition in forest stands. Duke Univ. School of Forestry Bull. 3.

26. Kramer, P. J. 1949. Plant and soil water relationships. McGraw-Hill Book Co., Inc., New York.

27. Lassen, L., H. W. Lull and B. Frank. 1952. Some plant-soil-water relations in watershed management. U.S. Dept. Agr. Circular No. 910. 64 pp.

28. Leamer, R. W. and B. Shaw. 1941. A simple apparatus for measuring noncapillary porosity on an extensive scale. Jour. Am. Soc. Agron. 33: 1003-1008.

29. Lieberman, J. A. and P. W. Fletcher. 1947. Further studies of the balanced water cycle on experimental watersheds. Trans. Am. Geophys. Union Vol. 28, No. 3 : 421-424.

30. ________ and M. D. Hoover. 1951. Stream-flow frequency changes on Coweeta experimental watersheds. Trans. Am. Geophys. Union Vol. 32 : 73-76.

31. Lunt, H. A. 1934. Distribution of soil moisture under isolated forest trees. Jour. Agr. Res. 49 (8) : 695-703.

32. ________. 1937. The effect of forest litter removal upon the structure of the mineral soil. Jour. Forestry 35 : 33-36.

33. Lutz, H. J. and R. F. Chandler, Jr. 1951. Forest soils. John Wiley and Sons, Inc., New York. 514 pp.

34. Meinzer, O. E. 1923. Outline of ground-water hydrology with definitions. U.S. Dept. of Interior Water-Supply Paper 494. 71 pp.

35. Merrick, E. and E. A. Johnson. 1952. Mountain water. Reprint from American Forests : Oct. 1952. 5 pp.

36. Middleton, H. E. 1952. Chap. 1. Soil as a physical system. Shaw, B. F., Editor. Vol. II, Soil Physical Conditions and Plant Growth. Academic Press, Inc., New York. 491 pp.

37. Nelson, W. L. and L. D. Baver. 1940. Movement of water through soils in relation to the nature of the pores. Soil Science Soc. Am. Proc. 5 : 69-76.

38. Northeastern Forest Experiment Station. 1953. Annual report - 1952. U.S. Dept. Agr., Forest Service, Upper Darby, Penn. 71 pp.

39. Rich, L. R. 1952. Forest and range vegetation. Consumptive Use of Water: A Symposium. Trans. Amer. Soc. Civ. Eng. 117: 974-987.

40. Richards, L. A. and C. H. Wadleigh. 1952. Chap. 3. Soil water and plant growth. Shaw, B. T., Editor. Vol. II, Soil Physical Conditions and Plant Growth. Academic Press, Inc., New York. 491 pp.

41. Richards, S. J., R. M. Hagan and T. M. McCalla. 1952. Chap. 5. Soil temperature and plant growth. Shaw, B. T., Editor. Vol. II, Soil Physical Conditions and Plant Growth. Academic Press, Inc., New York. 491 pp.

42. Rowe, P. B. and E. A. Colman. 1951. Disposition of rainfall in two mountain areas of California. U.S. Dept. Agr. Tech. Bull. No. 1048. 84 pp.

43. Schiff, L. and F. R. Dreibelbis. 1949. Infiltration, soil moisture, and land-use relationships with reference to surface runoff. Trans. Am. Geophys. Union 30 : 75-88.

44. Schollenberger, C. J. 1945. Determination of soil organic matter. Soil Science 59 : 53-56.

45. Shaw, B. T., et al. 1952. Soil physical conditions and plant growth; Agronomy II. Academic Press, Inc., New York. 491 pp.

46. Smith, J. L. and G. A. Crabb. 1952. Progress report on the wooded watershed of the Michigan Hydrologic Research Station. Michigan Agr. Expt. Sta. Quarterly Bull. 34, No. 4 : 383-394.

47. Soil Survey Staff, Bur. of Plant Industry, Soils, and Agr. Eng. 1951. Soil survey manual. U.S. Dept. Agr. Handbook No. 18. 503 pp.

48. Tennessee Valley Authority. 1951. Effect of 15 years of forest cover improvement upon hydrologic characteristics of White Hollow Watershed. T.V.A. Div. Water Control Planning, Hydraulic Data Branch, Report 0-5163. 74 pp.

49. Toumey, J. W. and R. Kienholz. 1931. Trenched plots under forest canopies. Yale Univ. School of Forestry Bull. 30.

50. Trimble, G. R., Jr., C. E. Hale and H. S. Potter. 1951. Effect of soil and over conditions on soil-water relationships. N.E. For. Expt. Sta. Paper No. 39.

51. Veihmeyer, F. J. 1929. An improved soil-sampling tube. Soil Science 27: 147-152.

52. ________ and A. H. Hendrickson. 1931. The moisture equivalent as a measure of the field capacity of soils. Soil Science 32 : 181-193.

53. ________ and ________. 1938. Soil moisture as an indication of root distribution in deciduous orchards. Plant Physiol. 13: 169-177.

54. ________ and C. N. Johnston. 1944. Soil-moisture records from burned and unburned plots in certain grazing areas of California. Trans. Am. Geophys. Union 25, Part I : 72-88.

55. ________, J. Oserkowsky and K. B. Tester. 1927. Some factors affecting the moisture equivalent of soils. Proc. and Papers of the First International Cong. of Soil Sci., Part II, Comm. I : 512-534.

56. Weaver, J. E. 1926. Root development of field crops. McGraw-Hill Book Co., Inc., New York.

57. ________ and W. E. Bruner. 1927. Root development of vegetable crops. McGraw-Hill Book Co., Inc., New York.

58. Wilm, H. G. 1953. Research problems in forest and range influences in the United States. A paper presented at the Congress of International Union of Forest Research Organizations, Rome.

59. ________ and E. G. Dunford. 1948. Effect of timber cutting on water available for stream flow from a lodgepole pine forest. U.S. Dept. Agr. Tech. Bull. 968. 43 pp.

60. Wisler, C. O. and E. F. Brater. 1951. Hydrology. John Wiley and Sons, Inc., New York. 419 pp.

61. Yoder, R. E. 1936. A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. Jour. Am. Soc. Agron. 28: 337-351.

APPENDICES

APPENDIX A

TABLES OF PEDOLOGIC DATA

TABLE XXIV

RESULTS FOR THE THREE LARGEST SIZE CLASSES IN THE AGGREGATE STABILITY ANALYSIS OF THE SOILS OF WATERSHEDS 18 AND 17

Soil-site and Depth of Soil Layer	Distribution of Aggregates in Percent					
	Larger than 4 mm.		2-4 mm. size class		1-2 mm. size class	
	Watershed 18	Watershed 17	Watershed 18	Watershed 17	Watershed 18	Watershed 17
Soil-site I						
0-3 inch layer	91.36	93.56	3.44	2.03	1.44	1.53
	96.72	74.40	0.80	12.23	0.44	4.30
	92.44	25.48	3.76	32.44	0.96	18.12
3-6 inch layer	67.60	88.74	17.44	5.47	3.68	1.64
	90.12	66.66	3.68	18.62	1.80	5.28
	88.36	20.76	6.48	21.12	1.28	15.48
Soil-site II						
0-3 inch layer	41.08	37.72	25.20	24.20	6.60	10.52
	96.52	36.99	0.84	34.33	0.24	14.07
	87.40	73.21	2.96	11.04	1.64	3.94
3-6 inch layer	90.04	66.88	3.20	8.84	2.04	5.48
	55.68	66.64	25.20	20.00	4.32	4.68
	87.91	26.84	2.77	30.72	1.99	12.36
Soil-site III						
0-3 inch layer	91.28	81.74	3.36	8.57	1.48	3.11
	85.40	76.52	6.64	10.16	1.72	4.08
	87.16	31.80	2.08	21.16	1.64	12.32
3-6 inch layer	87.64	92.92	5.68	2.12	1.60	1.20
	65.00	32.88	16.64	22.52	7.36	13.44
	38.36	25.40	20.52	14.00	10.48	12.80

TABLE XXV

THE AMOUNT OF UNINCORPORATED HUMUS
FOUND ON WATERSHEDS 18 AND 17

Soil-site and Watershed	Index Station	Oven Dry Weight in Grams per Square Foot		
		Sample 1	Sample 2	Sample 3
Soil-site I				
Watershed 18	F3b	525.9	94.6	105.3
	E5b	195.6	231.9	130.5
	D15a	151.8	221.4	240.5
Watershed 17	C3	132.8	223.5	87.5
	B4d	96.5	70.3	102.1
	F14b	50.6	81.1	96.9
Soil-site II				
Watershed 18	I9a	197.2	217.0	215.1
	E4c	533.0	129.6	410.5
	E8d	420.9	179.9	164.1
Watershed 17	F9c	76.2	409.3	48.6
	B4a	61.0	91.4	80.9
	E4c	80.1	131.0	39.3
Soil-site III				
Watershed 18	E5a	261.5	225.0	165.3
	E16a	121.2	175.5	259.3
	H11a	182.0	426.3	196.8
Watershed 17	B4b	116.5	230.4	68.1
	F11a	151.8	143.9	146.1
	E13c	36.4	46.1	58.0

TABLE XXVI

THE PERMEABILITY IN INCHES-PER-HOUR FOR THE SOILS OF WATERSHEDS 18 AND 17

Watershed	Permeability in Inches-per-Hour			
	0-3 inch layer	3-6 inch layer	12-15 inch layer	30-33 inch layer
		Soil-site I		
Watershed 18	32.4	30.0	14.8	9.2
	62.5	21.2	23.0	4.8
	75.8	54.6	19.8	4.4
Watershed 17	119.0	47.9	4.9	3.9
	136.3	53.4	15.9	4.4
	53.7	36.0	4.2	10.9
		Soil-site II		
Watershed 18	74.0	59.8	14.9	10.6
	47.9	9.0	16.1	1.2
	38.7	42.5	16.1	17.0
Watershed 17	23.4	27.8	20.3	4.5
	27.9	12.3	38.0	3.2
	85.0	40.4	14.4	18.6
		Soil-site III		
Watershed 18	24.6	18.8	13.8	5.6
	35.1	23.7	17.2	2.9
	62.7	58.3	14.9	5.2
Watershed 17	64.6	19.3	18.1	5.6
	35.4	26.4	9.5	12.0
	35.9	21.0	14.2	9.6

TABLE XXVII

THE MOISTURE EQUIVALENT IN PERCENT BY WEIGHT FOR THE SOILS OF WATERSHEDS 18 AND 17

Watershed	Moisture Equivalent in Percent by Weight			
	0-3 inch layer	3-6 inch layer	12-15 inch layer	30-33 inch layer
		Soil-site I		
Watershed 18	23.02	21.86	20.96	18.51
	20.32	20.45	19.06	17.79
	22.34	23.19	21.08	18.05
Watershed 17	19.83	18.93	17.82	18.97
	2[illegible].22	21.00	19.84	19.48
	25.08	23.20	20.60	18.83
		Soil-site II		
Watershed 18	21.16	21.24	19.23	18.89
	18.74	19.44	19.00	18.91
	21.61	20.61	16.71	12.29
Watershed 17	24.13	20.55	19.29	18.44
	20.87	20.53	18.79	16.21
	24.28	22.93	18.56	17.74
		Soil-site III		
Watershed 18	19.50	18.79	18.88	17.92
	23.31	21.80	21.42	21.48
	20.97	18.91	18.73	15.45
Watershed 17	21.78	21.72	19.80	14.97
	22.32	20.62	18.31	20.40
	20.37	17.91	13.86	11.16

APPENDIX B

TABLES OF HYDROLOGIC DATA AND MATHEMATICAL CALCULATIONS

TABLE XXVIII

A SUMMARY OF WEIGHTED MONTHLY PRECIPITATION IN INCHES FOR WATERSHED 18

Year	Weighted Precipitation in Inches											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1936							7.40	6.79	8.93	5.08	2.04	12.32
1937	12.60	6.43	3.10	7.89	2.30	5.61	3.97	4.77	2.87	9.30	2.93	6.86
1938	4.95	2.84	8.97	6.22	6.43	6.94	11.99	3.80	3.53	0.16	11.67	3.33
1939	8.07	16.45	8.20	5.42	3.67	3.44	6.17	6.66	1.15	0.91	0.85	4.07
1940	3.39	7.56	5.62	7.74	2.21	7.46	4.34	14.06	0.92	1.92	5.73	5.18
1941	3.61	1.62	5.45	3.50	1.38	3.24	10.54	3.22	3.43	2.83	4.61	8.41
1942	5.30	6.90	9.81	1.00	9.84	3.34	9.84	4.09	6.39	3.58	2.65	13.04
1943	7.05	5.16	9.39	6.03	4.16	6.48	11.75	5.06	5.32	2.71	2.46	4.41
1944	4.56	12.19	12.49	6.75	4.63	1.45	3.89	6.52	7.64	1.15	5.94	7.50
1945	2.60	8.36	5.78	8.45	3.24	3.06	3.54	3.68	8.42	5.15	4.87	8.56
1946	12.72	8.03	11.06	4.83	8.44	3.18	4.96	3.54	4.84	4.46	4.22	5.01
1947	12.33	2.84	5.57	5.83	4.09	5.02	3.72	6.33	3.22	7.87	6.68	4.31
1948	5.83	8.87	11.54	2.42	4.57	4.35	9.59	8.16	3.97	1.17	19.15	7.41
1949	9.58	6.81	6.64	8.09	6.02	10.37	8.58	8.91	5.44	10.24	2.56	7.20
1950	5.97	8.17	7.32	5.40	4.95	4.87	7.49	10.79	6.08	6.11	2.07	5.78
1951	3.98	5.35	7.77	5.48	0.97	11.10	7.36	1.53	5.76	4.94	4.20	12.66
1952	7.06	5.09	15.60	4.75	3.43	5.02	1.89	5.61	3.53	1.31		

APPENDIX B

TABLES OF HYDROLOGIC DATA AND MATHEMATICAL CALCULATIONS

TABLE XXVIII

A SUMMARY OF WEIGHTED MONTHLY PRECIPITATION IN INCHES FOR WATERSHED 18

Year	Weighted Precipitation in Inches											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1936							7.40	6.79	8.93	5.08	2.04	12.32
1937	12.60	6.43	3.10	7.89	2.30	5.61	3.97	4.77	2.87	9.30	2.93	6.86
1938	4.95	2.84	8.97	6.22	6.43	6.94	11.99	3.80	3.53	0.16	11.67	3.33
1939	8.07	16.45	8.20	5.42	3.67	3.44	6.17	6.66	1.15	0.91	0.85	4.07
1940	3.39	7.56	5.62	7.74	2.21	7.46	4.34	14.06	0.92	1.92	5.73	5.18
1941	3.61	1.62	5.45	3.50	1.38	3.24	10.54	3.22	3.43	2.83	4.61	8.41
1942	5.30	6.90	9.81	1.00	9.84	3.34	9.84	4.09	6.39	3.58	2.65	13.04
1943	7.05	5.16	9.39	6.03	4.16	6.48	11.75	5.06	5.32	2.71	2.46	4.41
1944	4.56	12.19	12.49	6.75	4.63	1.45	3.89	6.52	7.64	1.15	5.94	7.50
1945	2.60	8.36	5.78	8.45	3.24	3.06	3.54	3.68	8.42	5.15	4.87	8.56
1946	12.72	8.03	11.06	4.83	8.44	3.18	4.96	3.54	4.84	4.46	4.22	5.01
1947	12.33	2.84	5.57	5.83	4.09	5.02	3.72	6.33	3.22	7.87	6.68	4.31
1948	5.83	8.87	11.54	2.42	4.57	4.35	9.59	8.16	3.97	1.17	19.15	7.41
1949	9.58	6.81	6.64	8.09	6.02	10.37	8.58	8.91	5.44	10.24	2.56	7.20
1950	5.97	8.17	7.32	5.40	4.95	4.87	7.49	10.79	6.08	6.11	2.07	5.78
1951	3.98	5.35	7.77	5.48	0.97	11.10	7.36	1.53	5.76	4.94	4.20	12.66
1952	7.06	5.09	15.60	4.75	3.43	5.02	1.89	5.61	3.53	1.31		

TABLE XXIX

A SUMMARY OF WEIGHTED MONTHLY PRECIPITATION IN INCHES FOR WATERSHED 17

Year	Weighted Precipitation in Inches											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1936						2.77	7.46	7.12	9.04	5.17	2.06	12.18
1937	12.87	6.54	3.10	7.97	2.32	5.70	4.05	4.83	2.93	9.53	3.07	6.07
1938	4.83	2.92	9.04	6.28	6.50	6.99	11.96	3.59	3.84	0.15	11.77	3.45
1939	8.24	16.76	8.67	5.54	3.89	3.48	5.90	6.96	1.19	0.90	0.88	4.30
1940	4.03	7.84	6.13	7.70	2.03	7.82	4.53	14.30	0.96	1.94	6.34	5.65
1941	3.87	1.60	5.43	3.47	1.32	3.19	10.80	2.92	3.48	3.27	3.88	8.11
1942	5.26	6.91	9.75	1.00	10.03	3.23	9.89	4.15	6.26	3.57	2.97	13.88
1943	7.30	5.89	10.23	6.19	4.61	6.89	12.16	5.24	5.54	2.92	2.63	4.79
1944	4.93	13.29	13.87	7.48	5.09	1.66	4.23	7.10	8.43	1.15	6.55	8.34
1945	2.81	9.24	6.10	9.20	3.53	3.12	3.81	3.72	9.31	5.41	5.38	8.66
1946	13.67	8.68	11.79	5.03	9.87	3.17	4.91	3.09	5.42	4.70	4.90	5.51
1947	13.41	3.19	5.98	6.01	4.37	5.29	4.22	6.34	3.49	7.94	6.93	4.71
1948	6.39	9.57	12.31	2.54	4.84	4.49	9.92	8.28	4.21	1.26	19.41	7.86
1949	10.38	7.39	6.86	8.21	6.24	10.44	8.56	8.90	5.55	10.48	2.70	7.98
1950	6.87	8.79	7.58	2.59	5.01	5.06	7.55	10.70	5.97	6.20	2.21	5.84
1951	4.34	5.70	8.03	5.66	0.95	11.28	6.86	1.42	6.09	5.28	4.52	13.34
1952	8.12	5.32	15.95	4.88	3.71	4.95	1.82	5.82	3.51	1.33		

TABLE XXX

A SUMMARY OF THE PRECIPITATION AND WATER YIELD FOR SIX MONTH PERIODS ON WATERSHED 18

Water Year	Six Months Ending Oct. 31				Six months Ending April 30			
	Precipitation, Inches	Runoff			Precipitation, Inches	Runoff		
		Area Inches	c.s.m.	Percent of Precip.		Area Inches	c.s.m.	Percent of Precip.
1936-37					44.38	29.35	4.36	66.1
1937-38	28.82	9.[illegible]	1.42	33.7	32.[illegible]	16.04	2.38	48.9
1938-39	32.85	15.20	2.22	40.3	53.14	35.41	5.26	66.6
1939-40	22.00	9.68	1.41	44.0	29.23	9.24	1.36	31.6
1940-41	30.91	11.87	1.73	38.4	25.09	11.55	1.72	46.0
1941-42	24.64	6.29	0.92	25.5	36.03	19.15	2.84	53.2
1942-43	37.08	12.55	1.83	33.8	43.32	29.12	4.33	67.2
1943-44	35.48	15.55	2.27	43.8	42.86	26.41	3.90	61.6
1944-45	25.28	10.72	1.57	42.4	38.63	16.41	2.44	42.5
1945-46	27.09	9.85	1.44	36.4	50.07	30.60	4.55	61.1
1946-47	29.42	13.83	2.02	47.0	35.80	20.63	3.07	57.6
1947-48	30.24	10.05	1.47	33.2	39.65	28.11	4.15	70.9
1948-49	31.81	12.87	1.88	40.5	57.68	38.67	5.74	67.0
1949-50	49.56	26.72	3.90	53.9	33.62	31.32	4.65	93.3
1950-51	40.29	14.97	2.19	37.2	30.43	20.68	3.07	68.0

TABLE XXXI

A SUMMARY OF THE PRECIPITATION AND WATER YIELD
FOR SIX MONTH PERIODS ON WATERSHED 17

Water Year	Six Months Ending Oct. 31				Six months Ending April 30			
		Runoff				Runoff		
	Precipitation, Inches	Area Inches	c.s.m.	Percent of Precip.	Precipitation, Inches	Area Inches	c.s.m.	Percent of Precip.
1936-37					44.72	25.30	3.76	56.6
1937-38	29.36	7.04	1.03	24.0	32.21	13.34	1.98	41.4
1938-39	33.03	12.08	1.76	36.6	54.43	29.65	4.41	54.5
1939-40	22.32	7.23	1.06	32.4	30.88	6.93	1.02	22.4
1940-41	31.58	10.01	1.46	31.7	26.36	10.32	1.53	39.2
1941-42	24.98	12.13	1.77	48.6	34.91	25.59	3.80	73.3
1942-43	37.13	17.02	2.49	45.8	46.46	30.70	4.56	66.1
1943-44	37.36	17.24	2.52	46.2	46.99	25.84	3.82	55.0
1944-45	27.66	9.36	1.37	33.8	42.24	18.56	2.76	43.9
1945-46	28.90	9.73	1.42	33.7	53.21	33.99	5.05	63.9
1946-47	31.16	14.72	2.15	47.2	39.00	20.85	3.10	53.5
1947-48	31.65	11.56	1.69	36.5	42.45	30.68	4.53	72.3
1948-49	33.00	15.35	2.24	46.5	60.11	36.72	5.45	61.1
1949-50	50.17	27.70	4.05	55.2	36.51	30.14	4.45	82.6
1950-51	40.49	19.60	2.86	48.4	31.78	19.72	2.93	62.0

TABLE XXXII

THE MONTHLY RUNOFF FOR WATERSHEDS 18 AND 17 AND THE INCREASE IN RUNOFF FOR 17 AFTER TREATMENT

Water Year, Watershed & Increase* on Wtsd.17	Runoff in Area-Inches											
	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
1941-42												
Wtsd. 18	1.74	1.08	1.65	0.83	0.54	0.45	0.59	1.58	2.06	4.29	6.73	3.89
Wtsd. 17	1.86	1.36	4.08	2.19	1.45	1.18	1.81	3.86	4.36	5.21	6.73	3.63
Increase	0.54	0.61	2.84	1.66	1.17	0.92	1.43	2.60	2.67	1.54	0.89	0.43
1942-43												
Wtsd. 18	4.10	2.44	2.09	1.48	1.31	1.14	1.10	4.73	5.79	6.30	6.09	5.10
Wtsd. 17	4.23	2.87	2.61	2.58	2.46	2.28	1.80	5.82	6.75	6.27	5.58	4.48
Increase	0.85	0.95	0.98	1.48	1.51	1.41	0.96	1.76	1.77	0.83	0.33	0.24
1943-44												
Wtsd. 18	3.76	2.35	3.61	2.78	1.78	1.27	1.14	1.14	2.17	4.87	9.17	7.92
Wtsd. 17	3.38	2.24	4.42	3.51	2.22	1.46	1.33	1.27	2.52	4.86	8.79	7.07
Increase	0.30	0.39	1.47	1.28	0.86	0.49	0.47	0.41	0.75	0.69	0.80	0.19
1944-45												
Wtsd. 18	4.47	2.16	1.34	1.08	0.98	0.69	0.85	1.30	2.28	3.28	4.06	4.64
Wtsd. 17	3.68	1.85	1.16	0.91	0.94	0.82	1.10	1.68	3.38	3.58	4.26	4.56
Increase	-.02	0.16	0.19	0.16	0.28	0.41	0.50	0.68	1.51	0.82	0.81	0.60
1945-46												
Wtsd. 18	4.04	1.97	1.23	0.93	0.99	0.69	0.83	2.05	7.67	7.28	7.65	5.12
Wtsd. 17	4.11	1.89	1.13	0.78	1.03	0.79	1.10	2.68	0.63	7.83	7.65	5.10
Increase	0.78	0.37	0.25	0.16	0.36	0.38	0.52	1.02	2.97	1.52	1.01	0.71
1946-47												
Wtsd. 18	5.62	3.01	2.09	1.20	0.99	0.92	0.96	1.21	5.86	3.59	4.07	4.94
Wtsd. 17	6.19	3.23	1.99	1.23	1.05	1.03	1.17	1.55	6.85	3.51	3.34	4.43
Increase	1.48	0.80	0.36	0.38	0.38	0.42	0.47	0.63	1.80	0.48	-.12	0.20

1947-48												
Wtsd. 18	3.50	2.17	1.41	1.14	0.79	1.04	1.80	2.14	2.66	6.91	7.86	6.73
Wtsd. 17	3.04	2.06	1.64	1.55	1.24	2.03	4.05	3.61	3.08	7.08	6.90	5.96
Increase	0.18	0.36	0.60	0.75	0.75	1.32	2.61	1.87	0.87	1.10	0.08	0.14
1948-49												
Wtsd. 18	3.36	1.71	2.20	3.02	1.52	1.06	5.49	6.37	8.64	6.99	5.30	5.88
Wtsd. 17	2.64	1.46	3.06	4.89	2.01	1.29	6.77	6.88	7.86	5.97	4.26	4.98
Increase	-.10	0.16	1.34	2.45	0.88	0.56	2.05	1.38	0.34	-.08	-.29	-.09
1949-50												
Wtsd. 18	5.89	5.48	4.69	3.55	3.79	3.31	4.08	4.36	5.23	5.56	7.65	4.46
Wtsd. 17	5.01	5.28	4.72	3.71	5.01	3.97	4.74	4.25	5.18	5.26	6.74	3.88
Increase	0.07	0.70	0.82	0.81	1.90	1.28	1.27	0.53	0.69	0.48	0.10	0.08
1950-51												
Wtsd. 18	2.98	2.24	1.69	1.57	4.05	2.44	1.85	3.24	2.69	3.18	4.54	5.17
Wtsd. 17	2.39	2.18	1.99	2.42	7.43	3.19	2.13	3.34	2.57	2.92	4.16	4.61
Increase	-.01	0.42	0.71	1.33	4.04	1.26	0.64	0.62	0.34	0.25	0.28	0.17
1951-52												
Wtsd. 18	3.26	2.85	2.25	1.31	1.15	0.98	1.52	5.97	5.27	5.59	13.15	6.28
Wtsd. 17	2.73	2.62	2.48	1.77	1.43	1.35	2.54	8.08	5.59	5.35	11.61	5.10
Increase	0.08	0.33	0.71	0.82	0.62	0.69	1.34	2.93	1.07	0.54	0.09	-.32
1952-53												
Wtsd. 18	3.38	2.08	0.91	0.91	0.69	0.53	0.72	1.23	3.27	6.18	5.61	3.24
Wtsd. 17	3.02	2.00	1.33	1.09	0.89	0.69	1.06	3.49	5.29	7.61	5.74	3.22
Increase	0.27	0.38	0.73	0.49	0.48	0.42	0.58	1.55	2.54	2.28	0.91	0.50

* The following regression equations were used to compute the monthly increase on watershed 17:

Dormant Season $Ro = 0.888\ P - 0.155$

Growing Season $Ro = 0.872\ P - 0.195$

File No.

POOLED REGRESSIONS OF ANNUAL YIELDS

Computed by F. D. FREELAND, Jr.
Checked by

Before

Water Year	Water Yield 18 in X	17 in Y		Σx^2	xy	Σy^2
37-38	25.76	20.38	Σx^2	4130.87	3380.03	2769.31
38-39	50.60	41.72	$n\bar{x}^2$	3523.02	2866.25	2331.92
39-40	18.92	14.16	diff	607.85	513.78	437.39
40-41	23.43	20.32				
Total	118.71	96.58				
Mean	29.68	24.15				

$B = \frac{SP_{xy}}{SS_{xy}} \quad \frac{513.78}{607.85} = 0.84524$

$A = \bar{y} - B(\bar{x})$: $A = 24.15 - .84524 \times 29.68$
$A = -0.94$

$y = Bx - A$: $Y = 0.8452X - 0.94$

After

Water Year	X	Y			
41-42	25.43	37.72	19739.99	21,026.82	22,609.32
42-43	41.67	47.23	18629.11	20,181.11	21862.40
43-44	41.96	43.07	1110.88	845.71	746.92
44-45	27.13	27.92			
45-46	40.45	38.62			
46-47	34.46	40.67			
47-48	38.15	42.04			
48-49	51.54	52.07			
49-50	58.05	57.75			
50-51	35.64	39.33			
51-52	49.58	50.65			
52-53	28.75	34.43			
Total	472.81	512.20			
Mean	39.40	42.68			

$B = \frac{SP_{xy}}{SS_{xy}} \quad \frac{845.71}{1110.88} = 0.7613$

$A = 42.68 - 0.7613 \times 39.40$
$A = 12.68$

$Y = 0.7613X + 12.68$

Sheet of sheets

TABLE XXXII

THE MONTHLY RUNOFF FOR WATERSHEDS 18 AND 17 AND THE INCREASE IN RUNOFF FOR 17 AFTER TREATMENT

Water Year, Watershed & Increase* on Wtsd. 17	Runoff in Area-Inches											
	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
1941-42												
Wtsd. 18	1.74	1.08	1.65	0.83	0.54	0.45	0.59	1.58	2.06	4.29	6.73	3.89
Wtsd. 17	1.86	1.36	4.08	2.19	1.45	1.18	1.81	3.86	4.36	5.21	6.73	3.63
Increase	0.54	0.61	2.84	1.66	1.17	0.92	1.43	2.60	2.67	1.54	0.89	0.43
1942-43												
Wtsd. 18	4.10	2.44	2.09	1.48	1.31	1.14	1.10	4.73	5.79	6.30	6.09	5.10
Wtsd. 17	4.23	2.87	2.61	2.58	2.46	2.28	1.80	5.82	6.75	6.27	5.58	4.48
Increase	0.85	0.95	0.98	1.48	1.51	1.41	0.96	1.76	1.77	0.83	0.33	0.24
1943-44												
Wtsd. 18	3.76	2.35	3.61	2.78	1.78	1.27	1.14	1.14	2.17	4.87	9.17	7.92
Wtsd. 17	3.38	2.24	4.42	3.51	2.22	1.46	1.33	1.27	2.52	4.86	8.79	7.07
Increase	0.30	0.39	1.47	1.28	0.86	0.49	0.47	0.41	0.75	0.69	0.80	0.19
1944-45												
Wtsd. 18	4.47	2.16	1.34	1.08	0.98	0.69	0.85	1.30	2.28	3.28	4.06	4.64
Wtsd. 17	3.68	1.85	1.16	0.91	0.94	0.82	1.10	1.68	3.38	3.58	4.26	4.56
Increase	-.02	0.16	0.19	0.16	0.28	0.41	0.50	0.68	1.51	0.82	0.81	0.60
1945-46												
Wtsd. 18	4.04	1.97	1.23	0.93	0.99	0.69	0.83	2.05	7.67	7.28	7.65	5.12
Wtsd. 17	4.11	1.89	1.13	0.78	1.03	0.79	1.10	2.68	0.63	7.83	7.65	5.10
Increase	0.78	0.37	0.25	0.16	0.36	0.38	0.52	1.02	2.97	1.52	1.01	0.71
1946-47												
Wtsd. 18	5.62	3.01	2.09	1.20	0.99	0.92	0.96	1.21	5.86	3.59	4.07	4.94
Wtsd. 17	6.19	3.23	1.99	1.23	1.05	1.03	1.17	1.55	6.85	3.51	3.34	4.43
Increase	1.48	0.80	0.36	0.38	0.38	0.42	0.47	0.63	1.80	0.48	-.12	0.20

1947-48												
Wtsd. 18	3.50	2.17	1.41	1.14	0.79	1.04	1.80	2.14	2.66	6.91	7.86	6.73
Wtsd. 17	3.04	2.06	1.64	1.55	1.24	2.03	4.05	3.61	3.08	7.08	6.90	5.96
Increase	0.18	0.36	0.60	0.75	0.75	1.32	2.61	1.87	0.87	1.10	0.08	0.14
1948-49												
Wtsd. 18	3.36	1.71	2.20	3.02	1.52	1.06	5.49	6.37	8.64	6.99	5.30	5.88
Wtsd. 17	2.64	1.46	3.06	4.89	2.01	1.29	6.77	6.88	7.86	5.97	4.26	4.98
Increase	-.10	0.16	1.34	2.45	0.88	0.56	2.05	1.38	0.34	-.08	-.29	-.09
1949-50												
Wtsd. 18	5.89	5.48	4.69	3.55	3.79	3.31	4.08	4.36	5.23	5.56	7.65	4.46
Wtsd. 17	5.01	5.28	4.72	3.71	5.01	3.97	4.74	4.25	5.18	5.26	6.74	3.88
Increase	0.07	0.70	0.82	0.81	1.90	1.28	1.27	0.53	0.69	0.48	0.10	0.08
1950-51												
Wtsd. 18	2.98	2.24	1.69	1.57	4.05	2.44	1.85	3.24	2.69	3.18	4.54	5.17
Wtsd. 17	2.39	2.18	1.99	2.42	7.43	3.19	2.13	3.34	2.57	2.92	4.16	4.61
Increase	-.01	0.42	0.71	1.33	4.04	1.26	0.64	0.62	0.34	0.25	0.28	0.17
1951-52												
Wtsd. 18	3.26	2.85	2.25	1.31	1.15	0.98	1.52	5.97	5.27	5.59	13.15	6.28
Wtsd. 17	2.73	2.62	2.48	1.77	1.43	1.35	2.54	8.08	5.59	5.35	11.61	5.10
Increase	0.08	0.33	0.71	0.82	0.62	0.69	1.34	2.93	1.07	0.54	0.09	-.32
1952-53												
Wtsd. 18	3.38	2.08	0.91	0.91	0.69	0.53	0.72	1.23	3.27	6.18	5.61	3.24
Wtsd. 17	3.02	2.00	1.33	1.09	0.89	0.69	1.06	3.49	5.29	7.61	5.74	3.22
Increase	0.27	0.38	0.73	0.49	0.48	0.42	0.58	1.55	2.54	2.28	0.91	0.50

* The following regression equations were used to compute the monthly increase on watershed 17:

Dormant Season Ro = 0.888 P - 0.155
Growing Season Ro = 0.872 P - 0.195

FIGURE 32.

POOLED REGRESSIONS OF ANNUAL YIELDS

~~Coweeta Hydrologic~~ Laboratory
United States Forest Service

Computed by F. D. FREELAND, Jr.
Checked by

File No.

Before

Water Year	Water Yield 18 in X	17 in Y		Σx^2	xy	Σy^2
37-38	25.76	20.38	Σx^2	4130.87	3380.03	2769.31
38-39	50.60	41.72	$n\bar{x}^2$	3523.02	2866.25	2331.92
39-40	18.92	14.16	diff	607.85	513.78	437.39
40-41	23.43	20.32				
Total	118.71	96.58				
Mean	29.68	24.15				

$B = \frac{SP_{xy}}{SS_{xy}}$ $\frac{513.78}{607.85} = 0.84524$

$A = \bar{y} - B(\bar{x})$: $A = 24.15 - .84524 \times 29.68$

$A = -0.94$

$y = B.x - A$: $Y = 0.8452X - 0.94$

After

Water Year	X	Y	Σx^2	xy	Σy^2
41-42	25.43	37.72	19739.99	21,026.82	22,609.32
42-43	41.67	47.73	18629.11	20,181.11	21862.40
43-44	41.96	43.07	1110.88	845.71	746.92
44-45	27.13	27.92			
45 46	41.45	38.62			
46 47	34.46	40.67			
47 48	38.15	42.04			
48 49	51.54	52.07			
49 50	58.05	57.75			
50 51	35.64	39.33			
51 52	49.58	50.65			
52 53	28.75	34.43			
53 Total	472.81	512.20			
Mean	39.40	42.68			

$B = \frac{SP_{xy}}{SS_{xy}}$ $\frac{845.71}{1110.88} = 0.7613$

$A = 42.68 - 0.7613 \times 39.40$

$A = 12.68$

$Y = 0.7613X + 12.68$

Sheet of sheets

POOLED REGRESSIONS OF ANNUAL YIELDS

Coweeta Hydrologic Laboratory
United States Forest Service

Computed by F. D. FREELAND, JR.
Checked by ____________

File No. ____________

Pooled.

Σx^2	Σxy
607.85	513.78
1110.88	845.71
1718.73	1359.49

$$B = \frac{SP_{xy}}{SS_{xx}} = \frac{1359.49}{1718.73} = 0.7910$$

Before Period

$$Y_1 = 0.7910(X - 29.68) + 24.15$$

$$\text{or } Y_1 = 0.7910X + 24.15 - 0.791(29.68)$$

After Period

$$Y_2 = 0.7910(X - 39.40) + 42.68$$

$$\text{or } Y_2 = 0.7910X + 42.68 - 0.7910(39.40)$$

Before $Y_1 = 0.7910X + 0.67$

After $Y_2 = 0.7910X + 11.51$

$$Y_2 - Y_1 = \begin{matrix} 42.68 \\ -24.15 \end{matrix} + \begin{matrix} 23.48 \\ -31.17 \end{matrix} = 10.84 \text{ inches}$$

$$\text{or } (42.68 - 24.15) + (23.48 - 31.17) = 10.84 \text{ inches}$$

$$Y_2 - Y_1 = 11.51 - 0.67 = 10.84 \text{ inches}$$

FIGURE 33.

Coweeta Hydrologic Laboratory
United States Forest Service

COMPUTATION OF INCREASE OVER PRETREATMENT FLOWS

Computed by F.D. FREELAND, JR.
Checked by ______

File No. ______

Water Year May 1	Water Year Apr. 30	18 X	17 Act Y	17 Est Y	Increase Over Pretreatment Flows in Area-Inches Act - Est.
41	42	25.43	37.72	20.78	16.94
42	43	4167	47.73	33.63	14.10
43	44	41.96	43.07	33.86	9.21
44	45	27.13	2792	22.13	5.79
45	46	40.45	38.62	32.67	5.95
46	47	3446	40.67	2793	12.74
47	48	38.15	42.24	30.85	11.39
48	49	51.54	52.07	41.44	10.63
49	50	58.05	57.75	46.59	11.16
50	51	35.64	39.33	28.86	10.47
51	52	49.58	50.65	39.89	10.76
52	53	28.75	34.43	23.41	11.02
53	Total	472.81	512.20		
	Mean	39.40	42.68		

$Y = 0.7910X + 0.67$

Sheet ____ of ____ sheets

FIGURE 31.

STORM PEAKS

(CONTROL WATERSHED APPROACH)

Coweeta Hydrologic Laboratory
United States Forest Service

File No. ____

Computed by F. D. FREELAND, JR.
Checked by ____

July 1936 August 1940

Storm Peaks 18	17				
csm	csm	ΣX^2	Σxy	Σy^2	
X	y	33615.72	17,188.49	9,494.83	Σx^2
		22,239.79	12,812.12	7,380.93	$n\bar{x}^2$
683.4	393.7	11,375.93	4,376.37	2,113.90	diff.
n=21	n=21				
32.54	18.75				

$B = \frac{SP_{xy}}{SS_{xx}} = \frac{4376.37}{11,375.93} = 0.4847$

$A = \bar{Y} - B(\bar{X})$

$A = 18.75 - .04847(32.54)$

$A = 4.298$

$Y = 0.4847X + 2.98$ $Y = Bx + A$

Nov 1946 - Apr. 1951

717.1	628.4	25,765.49	23,606.26	22,848.98
n=25	n=25	20,569.30	18,025.03	15,795.46
28.68	25.14	5,196.19	5,581.23	7,053.52

$B = \frac{SP_{xy}}{SS_{xx}} = \frac{5,581.23}{5,196.19} = 1.0741$

$A = 25.14 - 1.0741(28.68)$

$A = -5.67$

$Y = 1.0741X - 5.67$

Range of Flows

46-51 WS18 15 to 78 csm WS17 15 to 89 c.s.m.

36-40 WS18 15 to 124 csm WS17 15 to 48 csm

Sheet ___ of ___ sheets

INCREASES IN GROUND WATER STORAGE

Coweeta Hydrologic Laboratory
United States Forest Service

File No. ______

Computed by F. D. FREELAND, JR.
Checked by ______

36 to Dec 40

Groundwater Storage				
18	17	ΣX^2	ΣXy	Σx^2
in	in	1237 145	590 208	$n\bar{x}^2$
X	y	793815	343 161	
		443 330	247 047	diff.
20280	8799 Total			
n: 52	52			
390	169 Mean			

$B = \frac{SP_{xy}}{SS_{xx}} = \frac{247047}{443.330} = 0.5572$

$A = 1.69 - .5572(390)$, $A = \bar{y} - B(\bar{x})$

$A = -.483$

$Y = .5572X - .483$, $Y = BX + A$

Nov 46 - Apr 1 51

		ΣX^2	
34445	20927	2428 206	1449 575
n: 65	65	1825 850	1109 131
530	322	602356	340 444

$B = \frac{SP_{xy}}{SS_{xx}} = \frac{340444}{602.356} = 0.5652$

$A = 3.22 - 0.5652(5.30)$

$A = +0.22$

$Y = .5652X + 0.22$

Watershed 18 Average Monthly Groundwater Storage

Period	Mar	April	May	June	July	Aug	Sept	Oct.
1936-1939	7.65	7.32	4.48	3.11	3.26	1.95	2.46	1.23
1947-1951	9.01	7.88	5.38	3.85	3.20	3.82	2.78	2.68

Estimated Ground Water Storage WS 17 *

Period	Mar	April	May	June	July	Aug	Sept	Oct.
1936-1939	3.80	3.60	2.00	1.25	1.35	0.60	0.90	0.20
1947 1951	5.30	4.70	3.25	2.40	2.00	2.40	1.75	1.70

* FIGURES ROUNDED TO NEAREST 0.05

Sheet ___ of ___ sheets

Cowea
Labo
St

Date

8/25
(N

9/8
9/15
9/22
9/29
10/6
10/13
10/20
10/27
11/
11/10
11/17
11/2
12/1
12/1
12/
12/29
1/5
1/1
1/19
1/2
2/2
(

2/9
2/15
2/2
3/
3/2
3/
4/5
4/1
4/2

Coweeta Hydrologic Laboratory, United States Forest Service

TABLE XXXIII

WATER QUALITY

TURBIDITY

Computed by:
F. D. Freeland, Jr.
Checked by:
May 11, 1954

Computed from Electrophotometer Readings

Date	Watershed 17			Watershed 18		
	Time	Electro	ppm	Time	Electro	ppm
8/25/53	1325	0.2	0.4	1350	0.7	1.5
{No comparative record on other watershed						
9/8/53	1350	2.0	5.0	1400	1.0	2.3
9/15/53	1335	1.3	2.9	1400	1.5	3.5
9/22/53	1415	1.2	2.7	1400	1.0	2.3
9/29/53	1420	0.6	1.2	1445	0.6	1.2
10/6/53	1410	1.0	2.3	1440	2.1	5.3
10/13/53	1350	0.2	0.1	1420	2.0	5.0
10/20/53	1315	2.4	6.2	1340	1.2	2.7
10/27/53	1315	1.3	2.9	1330	2.7	7.3
11/3/53	1305	2.0	5.0	1330	1.2	2.7
11/10/53	1305	0.0	0.0	1330	0.0	0.0
11/17/53	1320	0.0	0.0	1335	0.0	0.0
11/24/53	1325	0.0	0.0	1345	0.0	0.0
12/1/53	1350	0.0	0.0	1410	0.0	0.0
12/15/53	1400	0.0	0.0	1410	0.0	0.0
12/22/53	1325	0.0	0.0	1345	0.5	1.0
12/29/53	1330	0.0	0.0	1350	0.0	0.0
1/5/54	1350	0.2	0.4	1410	0.0	0.0
1/12/54	1400	0.2	0.4	1420	0.0	0.0
1/19/54	1350	1.0	2.3	1405	1.6	3.8
1/26/54	1315	0.0	0.0	1335	0.0	0.0
2/2/54	1405	0.0	0.0	1430	0.0	0.0
{No comparative record on other watershed						
2/9/54	1340	0.5	1.0	1400	0.0	0.0
2/16/54	1310	1.0	2.3	1325	0.0	0.0
2/23/54	1350	1.5	3.5	1400	1.0	2.3
3/2/54	1315	0.5	1.0	1340	0.0	0.0
3/23/54	1350	0.5	1.0	1320	1.0	2.3
3/30/54	1320	0.0	0.0	1345	1.0	2.3
4/6/54	1320	3.0	8.4	1335	2.0	5.0
4/13/54	1325	2.5	6.6	1340	2.9	8.0
4/21/54	1320	1.5	3.5	1340	0.0	0.0
				{No comparative record on other watershed		
Totals			59.1			58.5
Averages		ppm	1.91		ppm	1.89

TABLE XXXIV

COMPARISON OF AVERAGE MONTHLY MAXIMUM AND MINIMUM STREAM TEMPERATURES FOR WATERSHEDS 18 AND 17 FOR CALENDAR YEAR 1947

Month of Year 1947	Maximum Temperatures, °F.			Minimum Temperatures, °F.		
	Water-shed 18	Water shed 17	Differ-ence 17-18	Water-shed 18	Water-shed 17	Differ-ence 17-18
January	49.8	51.0	+1.2	40.0	40.7	+0.7
February	43.5	44.2	+0.7	34.5	36.0	+1.5
March	46.2	46.5	+0.3	37.2	37.8	+0.6
April	54.2	54.2	0.0	45.0	44.5	-0.5
May	57.6	57.8	+0.2	50.0	49.2	-0.8
June	62.5	62.5	+0.3	54.2	53.8	-0.4
July	62.8	64.2	+1.4	56.5	57.2	+0.7
August	65.4	65.7	+0.3	61.2	60.0	-1.2
September	65.8	65.0	-0.8	60.5	60.0	-0.5
October	59.5	58.6	-0.9	51.0	52.2	+1.2
November	52.3	52.2	-0.1	45.5	46.5	+1.0
December	46.8	48.0	+1.2	40.2	42.5	+2.3
Average	55.5	55.8	+0.3	47.9	48.3	+0.4

TABLE XXXV

THE SEASONAL AND ANNUAL GROUNDWATER FLOW AND STORMFLOW FROM WATERSHED 17 BEFORE AND AFTER TREATMENT

Year	Season	Precipitation in Inches	Total Runoff in Inches	Groundwater in Inches	Stormflow in Inches
1937	Dormant[1]	44.72	25.30	22.93	2.37
	Growing[2]	29.36	7.04	6.48	0.56
	Water year[3]	74.08	32.34	29.41	2.93
1938	Dormant	32.21	13.34	12.23	1.11
	Growing	33.03	12.08	11.12	0.96
	Water year	65.24	25.42	23.35	2.07
1939	Dormant	54.43	29.65	26.08	3.57
	Growing	22.32	7.23	6.94	0.29
	Water year	76.75	36.88	33.02	3.86
1940	Dormant	30.88	6.93	5.75	1.18
	Growing	31.58	10.01	8.90	1.11
	Water year	62.46	16.94	14.65	2.29
1941	Dormant	26.36	10.32	9.57	0.75
	Growing	24.98	12.13	11.57	0.56
	Water year	51.34	22.45	21.14	1.31
1942	Dormant	34.91	25.59	23.80	1.79
	Growing	37.13	17.02	15.63	1.39
	Water year	72.04	42.61	39.43	3.18

[1] The dormant season consists of the last half of the water year from November 1 to April 30.

[2] The growing season is the first half of the water year from May 1 to October 31.

[3] The water year is here considered from November 1 to October 31.