SOME EFFECTS OF A COMMERCIAL-TYPE CLEARCUT ON SOIL AND WATER RELATIONS ON A SMALL WOODED WATERSHED

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This is to certify that the

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SOME EFFECTS OF A COMMERCIAL-TYPE CLEARCUT ON SOIL AND WATER RELATIONS ON A SMALL WOODED WATERSHED

By

GEORGE BERNARD COLTHARP

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

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AN ABSTRACT

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ABSTRACT

Because of the increased interest manifest in the water resources of southern lower Michigan it is highly desirable to ascertain the water yield contributions of areas under various types of land use and vegetative cover. The purpose of this study was to determine and evaluate the effects of a commercial-type clearcut on soil and water relations on a small wooded watershed representative of the farm woodlot-type.

A small wooded watershed, located within the Rose Lake Wildlife Experiment Station approximately ten miles northeast of East Lansing, Michigan, was established during 1941. The watershed, supporting a well stocked stand of the oak-hickory type, was calibrated hydrologically for an eleven year period. During the fall and winter of 1951 the forest cover on the watershed was subjected to a commercial-type clearcut operation, removing all trees larger than 5.5 inches d.b.h. Hydrologic data were obtained after treatment through 1957.

Detailed soil sampling for soil physical property determinations was accomplished on the watershed during 1953, 1957, and on the adjacent uncut area during 1957. Gravimetric soil moisture sampling was initiated during the latter part of 1945 and continued on a bi-weekly basis through 1952. Weekly soil moisture samples were obtained from March through September of 1957.

These soil and hydrologic data were obtained in an effort to determine and evaluate the effects of the vegetative treatment on the soil reservoir and the water yield of the watershed.

The results of the study do not indicate any pronounced changes in soil texture, bulk density, porosity, and permeability as a result of treatment. There was an apparent increase in soil organic matter and a decrease in unincorporated organic matter.

Soil moisture showed a very definite and statistically significant increase during the growing season of 1952 as a result of treatment. During 1957 soil moisture values were intermediate between the high values of 1952 and the mean pre-treatment values. Computed evapotranspiration values were lower during the 1952 growing season than during the pre-treatment period or during 1957.

Mean soil and air temperatures were generally increased as a result of treatment.

Average monthly and annual runoff, maximum rates of runoff, and average volume per runoff decreased slightly during the post-treatment period. The average infiltration rate for the watershed, as determined by hydrograph analysis, increased slightly after treatment. A hydrologic summary for the entire period of study indicated no significant change in the established hydrologic characteristics of the watershed.

The commercial-type clearcut has apparently not had any deleterious effects on the soils of the watershed nor on the water resources of the area.

TABLE OF CONTENTS

Chapter		Page

Chapter | Page

LIST OF TABLES

Table		Page

LIST OF FIGURES

Figure		Page

CHAPTER I

INTRODUCTION

Many heavily industrialized and urbanized areas, such as southern lower Michigan, are taxing existing water resources. The future developement, as well as the present existance, of such areas depends upon the maintenance of adequate water supplies.

Because of the increased interest manifested in the water resources of southern lower Michigan it is highly desirable to ascertain the water yield contributions of areas under various types of land use and vegetative cover. Watershed management experiments, in various parts of the country, have indicated that the type of vegetative cover on an area markedly affects the water yield from that area. Many of the watershed experiments concerned with vegetative cover, especially forest cover, have envolved the determination of hydrologic response to drastic vegetative treatment. Colman (1953) states "There is a great need for studies which do not deal with extreme conditions, but rather with problems associated with land use practices and the treatment of vegetation over a wide intermediate range." The determination of pedologic and hydrologic effects of cutting practices on farm woodlots in southern lower Michigan represents a study of the type suggested by Colman. The most common type of timber harvest cut on the 1.4 million acres of farm woodlots in southern lower Michigan[1] is the commercial-type clearcut.

The purpose of this study is to determine and evaluate the effects of a commercial-type clearcut on soil and water relations on a small wooded watershed representative of the farm woodlot-type. A small wooded watershed, 1.65 acres in size, was calibrated hydrologically for an eleven year period, then subjected to a commercial-type clearcut treatment. Soil physical properties were determined under treated and untreated conditions in order to evaluate treatment effects on the soil reservoir. Soil moisture regime was studied before and after treatment in order to detect any changes in soil water relations as a result of the vegetative treatment. Runoff and erosion were also measured under treated and untreated conditions in order to evaluate the effects of treatment on water yield and water quality.

Although limited to one small watershed, it is felt that the results of this study may permit a better understanding of the contributions of the farm woodlot areas to the water resources of southern lower Michigan.

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[1]Unpublished data from the files of Dr. Lee M. James, Professor of Forestry, Michigan State University.

CHAPTER II

REVIEW OF LITERATURE

Within the past fifty years research in the hydrologic and pedologic effects of various land-use practices has received ever-increasing attention. This may be attributed to the awareness among land managers and research workers of the intimate relation between land use and hydrology. As a result of this tremendous impetus the literature has become so voluminous that no attempt will be made to review it all. Instead, only representative studies will be cited, which provide a particularly pertinent background to the concepts and conduct of the present study.

Early studies, prior to 1900, were confined almost exclusively to the relation of forest to streamflow. The majority of these early studies were conducted in European countries and consisted of observing the flow of rivers and attempting to correllate the flow with the amount of deforestation (Wex, 1873; Berghaus, 1837). Two exceptions may be noted. Lowdermilk reports a systematic watershed study made in 1851 by Belgrand, a French engineer, in an attempt to determine the effects of varying degrees of forest cover on streamflow.[1] The Emmenthal study instigated by the Swiss

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[1]W. C. Lowdermilk, (no date), Forest and agricultural influences in streamflow and erosion control; Summary review of literature up to 1930, U. S. Soil Conservation Service, (mimeo.).

Central Experiment Station in 1890 was a carefully planned and executed watershed experiment to evaluate the effects of forest vegetation on stream flow in the Swiss Alps (Burger, 1929a, 1929b, 1945). Here also, watersheds with varying degrees of forest cover were used.

Most of the early work was thoroughly summarized in 1927 by Zon. It should be re-iterated, that this early work consisted primarily of evaluating the influence of varying degrees of forest cover on stream flow. The varying amounts of forest cover were obtained by using separate watersheds with different degrees of forest cover, not by treating the vegetation on the same watershed, i. e. cutting or planting to increase or decrease the cover. Therefore, these early studies are not particularly pertinent to the present study but contributed much to guide subsequent watershed studies which pertain in some ways to the present study.

There are several possible methods of performing forest hydrologic research, with each method possessing certain advantages and disadvantages over the others. Zon (op. cit.) recognized two of these methods and the third may be said to be a combination of the first two. The first type involves the study of stream flow from experimental watersheds or the hydrometric method. A second type involves the determination of the amounts of water available for stream flow by a synthesis of individually measured factors, or the physical method. The third type of research is a combination of the first two, i.e. the individual factors which determine the disposition of precipitation on a watershed are measured, as well as stream flow from the watershed, which is the net result of the interaction of the individually measured factors.

The early studies, as summarized by Zon, were essentially of the hydrometric type, due primarily to the fact that stream flow was the most obvious and easily measured result of the various land use practices on a watershed. Later studies, after 1920, tended to emphasize the physical methods of research in order to explain why certain types of land use affected stream flow as they did. Still later research, up to the present day, utilizes the third method, i.e. the combined hydrometric and physical methods in an attempt to tie together those phases of the hydrologic cycle which function on a watershed basis.

Forest watershed research began in this country shortly after the turn of the century with the inauguration of the Wagon Wheel Gap Experiment (Harper, 1953). Since that time the tempo of research has increased until today watershed studies are being conducted by the United States Departments of Agriculture (Forest Service and Agricultural Research Service), Interior (Geological Survey), Army (Corps of Engineers), and Commerce (Weather Bureau). Also the Tennessee

Valley Authority and the various departments and services in cooperation with state agricultural experiment stations and universities. Frank and Netboy (1950) listed forty watershed research centers operated by the various government agencies as of January 1, 1940.

The earliest research in the United States concerned with the effects of forest vegetation on watershed hydrology was conducted near Wagon Wheel Gap, Colorado. This study, a cooperative effort by the U. S. Forest Service and the U. S. Weather Bureau, was initiated in 1909 to investigate the water regime of a watershed subjected to a definite change of cover type. Two contiguous watersheds were selected, completely covered with forest vegetation and similar as to topography and size. These watersheds were studied (calibrated) as to meteorological conditions and stream flow for a period of eight years. At the conclusion of this calibration period the timber was cut from one of the watersheds and records were obtained for an additional seven years in both the forested and denuded state. Bates and Henry (1928) reported that cutting the forest cover increased the total annual water yield, increased water yield from snow, and produced increased erosion. It was further indicated that the results were not too conclusive due to porous soils, thin original forest cover, and prolific sprouting of aspen which quickly restored a vegetative cover to the treated watershed.

Another early study involving vegetation manipulation on a watershed was reported by Hoyt and Troxell (1934). The vegetation, principally chaparral type, was removed from the watersheds by fire and cutting. Results reported indicated that total annual yield of water increased and that erosion increased considerably.

In 1934 the U. S. Forest Service established the 4700-acre Coweeta Hydrologic Laboratory in western North Carolina to determine how forests and forestry practices affect water yields, water quality, and stream flow behavior in the southern Appalachians (Dils, 1957). From 1934 to 1940 the various experimental watersheds were calibrated as to water yield, water quality, and distribution of stormflow from undisturbed forested watersheds. Following the six year calibration period some of the watersheds were subjected to the following treatments: (a) clearcut and subsequent removal of annual sprout growth, (b) clearcut and natural revegetation, (c) commercial logging with prevailing practices and equipment, (d) removal of riparian vegetation, (e) woodland grazing, (f) removal of ericaceous understory vegetation, (g) and clearing and mountain farming.

Dils (1953) summarizes the results of these investigations:

> (a) cutting all trees on a steep, heavily forested watershed and annually cutting back the sprouts (with no removal of wood products and no disturbance to soil) increases water yields by 17 area inches annually; (b) similar cutting, but with sprouts allowed to grow back, increases water yield approximately 17 inches and this increase becomes progressively less as the coppice stand grows older; (c) cutting streambank vegetation tends to eliminate diurnal fluctuations in stream flow; (d) local logging practices, particularly poorly located and constructed logging roads, effect a marked increase in erosion and turbidity; (e) woodland grazing brings about a marked increase in overland storm runoff and erosion and shows that the cattle grazed on the watershed fail to thrive.....; (f) the removal of an understory of laurel and rhododendron effects an increase in water yield of approximately 3 area inches per year; .....

As a result of clearing and mountain farming, frequencies and intensities of flood flows were increased and erosion rates increased approximately twenty times.

Hoover (1944) found that in treatments (a) and (b) above the removal of the vegetation increased stream flow by an amount equal to the estimated transpiration.

The above mentioned studies conducted at the Coweeta Hydrologic Laboratory bear an important relation to the present study in that they involve definite changes in the vegetative cover of calibrated watersheds. This, however, is as far as the comparison may be extended due to the different degrees of forest removal and soil disturbance which exist between the present study and the aforementioned studies.

In contrast to studies involving denudation of the vegetative cover of a watershed several studies have been undertaken to determine the effects of reforestation and change of cover type on water regime.

A study was started in 1932 by the Geological Survey of the United States Department of Interior in cooperation with the New York State Conservation Commission to determine the influence of reforestation on stream flow from state forests in Central New York. Submarginal lands were purchased and planted to coniferous tree species. Ayer (1949) reported that up to 1949 no significant changes in runoff had been affected.

Storey (1951) reports a cooperative study between the Northeastern Forest Experiment Station of the United States Forest Service and the Pennsylvania Department of Forests and Waters was initiated in 1948 in the Lehigh-Delaware Experimental Forest to determine water behavior for a watershed covered by scrub-oak. After a period of calibration, the 1500-acre Dilldown watershed is to be converted from scrub-oak cover to a better forest type by forest management and protection. An attempt will be made to evaluate the effects of this change in vegetative cover on runoff and ground water.

A most recent account of the effects of reforestation on water regime is that furnished by the Tennessee Valley Authority in 1951 (Smallshaw and Ackerman, 1951). The 1715-acre White Hollow Watershed was set aside for watershed studies in 1936. After acquisition, intensive watershed management work was undertaken, including extensive erosion-control operations and tree planting. Results obtained during the first fifteen years of the study are summarized as follows: (a) No change in seasonal or annual quantities of stream flow were detected. (b) Quantity of stream flow varied from season to season and year to year, but were associated with corresponding variations in rainfall. Apparently, since the start of treatment the changes in watershed vegetation had neither increased nor decreased evaporative water losses. (c) No significant changes were detected in the volumes of flow associated with storms. (d) There were, however, significant changes in peak flow rates measured during comparable storms. These decreased progressively from the start to the end of the study. (e) More prolonged high flows after storms compensated for the reduced volumes of water released during peak periods, so that no change in total volume of storm discharge was evident. Apparently, a progressive improvement in water yield characteristics has been achieved. How much of this improvement was due to the check dams and other structures and how much to conversion of the area to forest has not been evaluated.

A similar study in western Tennessee has been reported (Fry, 1952; Tennessee Valley Authority, 1955). An 88-acre watershed was calibrated as to stream flow and sediment yield from 1941 to 1945. Between 1946 and 1948 check dams and various soil conservation practices were instituted, as well as the planting of over 100,000 loblolly pine trees. Results indicate a reduction in surface runoff and an increase in subsurface flow. Again, it is debatable whether the check dams and other soil conservation practices or reforestation produced the desirable results.

There have been numerous studies concerning the influence of forest cover in controlling runoff. One of the earlier studies was that initiated in 1917 near Jackson, Tennessee. Six small watersheds, varying in size from 1.25 to 112 acres, were used. None of the watersheds were completely forested and the amount of forest cover ranged from none to fifty-five per cent. Ramser (1927) concluded that timber has a definite influence in reducing the rate of surface runoff from a watershed, but that the effect of timber is slight when the maximum rate of runoff occurs after considerable rain has already fallen.

An analysis of soil and water relationships on four small watersheds of approximately two acres in size was made at Coshocton, Ohio by Dreibelbis and Post (1941). A comparison between wooded, pasture, and two cultivated watersheds on similar soils showed a much lower volume of surface runoff from the wooded area. Annual runoff from the wooded watershed (an ungrazed stand of mixed second-growth hardwoods) amounted to only .11 inch compared with .60 inch for pasture, and 6.22 inches for the cultivated. This amounted to .2, 1.4, and 15 per cent respectively of the total annual precipitation. The total annual percolation amounted to 13.01 inches for the woods, 12.52 inches for the pasture, and from 5.49 to 2.12 inches for the cultivated areas.

Comparisons of surface runoff from depleted and abandoned agricultural land with that from wooded areas have been obtained in the Applachian region (U. S. D. A. Miscellaneous Publication 397, 1940). Records of runoff from eight small watersheds in the Bent Creek Experimental Forest near Ashville, North Carolina represent different types of forest and other vegetal cover. Average maximum flow for any forested watersheds amounted to eighty-four cubic feet per second per square mile, whereas flows of 403 and 785 cubic feet per second were recorded for abandoned agricultural land and pasture respectively. The average peak flow from the pastured areas was 18.7 times greater, and the abandoned farm land 9.2 times greater than the average of all forested lands.

From studies on upland loessial soils of northern Mississippi, McGinnis (1935) reported the effects of certain vegetated soils to absorb large quantities of moisture, thus preventing surface runoff. Over a two year period, runoff from oak forest was 1.03 inches and from barren abandoned fields 61.70 inches from a total of 130 inches of rainfall. The soil losses were ninety-one pounds per acre and 319,000 pounds per acre respectively for oak and bare areas. In short, surface runoff from the abandoned agricultural land was 108 times greater than from forest land and the amount of soil lost was over 900 times greater.

A study near Zanesville, Ohio (Borst, et al., 1945) compared the runoff and erosion from three small watersheds ranging in size from 2.2 to 3.6 acres. One of the watersheds was covered with a second-growth hardwood forest, another with a permanent pasture cover, and the third was cropped successively to corn, wheat, and meadow in a three year rotation. The wooded watershed lost as runoff 3.2 per cent of the rain received, the pasture lost 13.8 per cent, and the cropped watershed lost 20.6 per cent. Soil loss was negligible under both wooded and pasture cover, but averaged seventeen tons per acre per year under cultivation.

Copley, et al., (1946) reports a similar study near Statesville, North Carolina which showed that the best control over surface runoff and erosion was provided by forest and grass cover.

Smith and Crabb (1953) also pointed out the beneficial effects of forest cover on controlling surface runoff at East Lansing, Michigan. Two small cultivated watersheds and one wooded watershed were compared on the basis of eleven years of record as to total annual surface runoff. The wooded watershed yielded only 1.7 per cent of the total annual precipitation as runoff, while the cultivated watersheds yielded 14.5 per cent and 13.4 per cent.

A study near La Crosse, Wisconsin (Hays, *et al.*, 1949) indicates the part which cleared pastures and grazed and ungrazed woodlots play in relation to runoff and erosion on steep slopes. Three small watersheds were used: (a) a pasture recently cleared of timber; (b) a watershed covered with typical hardwood forest that was being pastured; (c) a typical undisturbed woodlot. During the growing season of 1935 a succession of high intensity storms offered good opportunity to test the effectiveness of the different types of vegetative cover and land use on runoff and erosion. The recently cleared pasture yielded three per cent of the total storm precipitation as runoff, the grazed woodlot nine per cent, and the undisturbed woodlot only 0.15 per cent. Soil loss was 600 and 1600 pounds per acre for the cleared pasture and grazed woodlot respectively and only seventeen pounds per acre for the undisturbed woodlot.

A number of experiments have been made in the United States and Europe on the general influence of forest cover upon soil moisture regime. Those studies concerned with the effect of vegetation manipulation on the soil moisture regime of an area are particularly pertinent to portions of this study.

Halden (1926) has summarized the more significant early European soil moisture investigations. The results generally agree with those obtained in this country in that forest stands tend to lower the ground-water table and dry out the soil. An exception to this is noted in a study reported by Axley and Thomas (1948). Soil moisture on small watersheds in Maryland during the summer growing season was found to be less under pasture vegetation and became progressively higher under grain and grass seeding, hay, corn, and woods. The authors consider the protective effect of vegetative cover in reducing evaporation as being the most important factor in controlling soil moisture. Perhaps this would hold true for the surface foot of soil, but not for greater depths.

Several investigations have been made to determine the pattern of soil moisture extraction by individual trees. Lunt (1934) found that the lowest moisture content was usually immediately beneath the crown, close to the trunk, at two depths - the surface and between the second and fourth feet. The greatest moisture content occurred at the one foot level.

There has been some question as to the rate of available soil moisture depletion by forest vegetation. Veihmeyer and Hendrickson (1955) experimenting with pine, oak, and manzanita on a watershed area and apricot and prune trees under cultivation have shown that the rate of moisture extraction from the soil is not influenced by the amount of water in the soil so long as the latter is above the permanent wilting percentage.

Fletcher and McDermott (1957), studying soil moisture depletion by forest cover in the Ozarks of Missouri, reported that the soil moisture depletion curves for the forest suggests that after the soil surface has been dried by evaporation, transpiration removes soil moisture at a uniform rate until supplies are virtually exhausted.

Lassen, et al., (1951) indicate that soil moisture is reduced uniformly throughout the profile inhabited by the tree roots. They further state:

> .....that the rate of moisture extraction is a function of moisture content; the greater the content, the more rapidly is water removed. .....it is evident that the rate at which roots extract moisture decreases as soil moisture content is decreased, ...

A study in northern Wisconsin by Thames, et al., (1955) compared soil moisture regimen between forested and nonforested (hay crop) areas on Spencer silt loam. Less available soil moisture was found in the surface one to two feet of forested site due to depletion by trees.

Hoover, et al., (1953) reported that in a study on soil moisture under a young pine plantation in South Carolina that water was withdrawn most rapidly from the zone where it was most readily available, regardless of depth, despite the greater concentration of roots in the surface layer.

Craib (1929), in a study in New Hampshire, has shown that soils in the open contain considerably more moisture during dry periods than forest soils. The soils in the open contained more than twice the volume of available moisture in the upper thirty-five inches than under the forest. By elimination of root competition the amount of available soil moisture was greatly increased.

Several investigators (Korstian and Coile, 1938; Toumey and Kienholz, 1931), using trenched plots under forest vegetation, have found that the elimination of root competition, which reduced transpiration, greatly increased soil moisture and consequently reduced retention storage.

Zahner (1955) has studied the influence of different forest types on soil moisture depletion in Arkansas. He measured the depletion of soil water by even-aged stands of upland oaks and loblolly-shortleaf pine under similar site and stand conditions. The data indicated little difference between rate of loss for the two stands for corresponding depths. In both stands, layers below three feet lost water at about half the rate of the upper layers.

The effects of various degrees of forest cuttings on soil moisture regimen has received considerable interest among investigators. Moyle and Zahner (1954) studied soil moisture depletion in Arkansas during the summer of 1953 under six different forest conditions. Three forested sites were left undisturbed; an all-aged loblolly and shortleaf pine stand with hardwood understory; a non-commercial all-aged hardwood type; an even-aged young hardwood type. Three others were variously treated to remove vegetation: bare area; timber stand improvement in 1951 in all-aged hardwood; timber stand improvement in all-aged hardwood in 1953. On the undisturbed pine and hardwood stands with seventy to 100 square feet of basal area water was removed from the soil rapidly with the onset of hot dry weather. On plots where large cull hardwoods were deadened, but not felled, and on bare areas, soil moisture remained relatively high throughout the summer. Soil moisture depletion was greater where all vegetation had been removed than where only culls had been deadened, but only in the surface layers. Below the effective zone of evaporation soil moisture remained at a constant high level.

A study was made in the lodgepole pine type at Frazer, Colorado on the effects of various levels of cutting on components of the hydrologic cycle. Wilm (1943) reports "Soil moisture deficiencies in the season of 1941 were strongly affected by the cutting treatments, with the greatest deficiencies on the uncut plots and the smalles on the clear-cut areas." The following values indicate the extent of influence exerted by the various treatments:

	Reserve Stand (bd.ft./acre)				
	Uncut: 11890	6000	4000	2000	0
Autumn Soil Moisture (inches)	2.67	3.07	3.29	3.12	4.21

Wilm and Dunford (1948) in a later report on the above mentioned study concluded:

> .....the effect of timber cutting on autumn deficits in soil moisture may not result primarily from variations in the sum of transpiration and evaporation from the soil, but more probably depends upon the amounts of net rainfall which reach the soil to replace these losses. After a dry summer season, therefore, the autumn deficits should be much alike under all cutting treatments. After a wet season, on the other hand, when substantially more rain has reached the soil in cut-over stands than in uncut areas, autumn deficits should be more directly and strongly associated with the density of the remaining forest.

The authors indicate in the above statement that interception is apparently more influential in affecting soil moisture fluctuations than is evapotranspiration.

Goodell (1952), in another study at Frazer, Colorado, reports that on plots thinned from an average of 89.3 square feet of basal area to an average of 39.7 square feet of basal area the soil moisture in the zero to eighteen inch and eighteen to forty-eight inch depths showed no increase over untreated plots the first year after cutting or after four years.

Croft and Monninger (1953) studied the effects of aspen removal on soil water in Utah. The removal of aspen trees, leaving the herbaceous understory and litter undisturbed, reduced evapotranspiration losses and increased the amount of water available for stream flow about four inches without seriously increasing overland flow or soil erosion during summer rains. Removal of remaining herbaceous cover further reduced evapotranspiration losses and increased the amount of water available to streams by an additional four inches, but resulted in undesirable increases in runoff and soil loss from summer rains.

An investigation of the effects on soil moisture of removing sprouting and non-sprouting vegetation was made by Veihmeyer and Johnson (1944). Working with chaparral and woodland-grass vegetation in California they found that burning plots which had supported non-sprouting vegetation reduced soil moisture loss in contrast to the moisture loss of similar unburned plots. On plots supporting mainly sprouting type vegetation no significant differences in soil moisture was noted.

Soil moisture regime was studied on a pair of Coweeta watersheds in forested and clearcut conditions. All vegetation was cut, lopped, and left on the clearcut watershed with minimum disturbance of litter. Subsequent sprouting was cut back annually. Freeland (1956) reports that soil moisture increased only slightly due to the cutting treatment. In an attempt to explain this lack of a pronounced soil moisture change Freeland states:

> .....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.

Several studies have indicated the effects of various degrees of cutting on soil physical properties. Wilm and Dunford (1948) summarized these effects seven years after cutting: (a) soil stability was hardly affected, i.e. no perceptible erosion or surface runoff; (b) surface aspect of the soil did not change except for the addition of quantities of logging debris; (c) original forest litter remained on the ground except in skid trails.

Hulisashile (1945) reports investigations on the effects of cutting upon soil properties in mountain areas of the Transcaucasus and eastern Georgia in the U.S.S.R. He studied total, capillary, and non-capillary porosity of brown forest soils and measurements indicate that the degree of cutting definitely affects physical properties of the soil. Partial cuts were found not to be effective until the canopy is reduced to three-tenths of original coverage.

Hursh (1944), working in South Carolina, found that clearing of forest land and subsequent erosion drastically effects soil porosity and water storage capacity. An undisturbed forest soil had a total of 3.78 area inches of storage available in the upper thirty-six inches of soil while the same soil type which had been cleared, farmed, and abandoned had only 1.38 area inches of storage available. The available storage was determined in terms of macro-pore space.

Blow (1955), working in upland oak forest in eastern Tennessee, reported some effects of cutting on litter accumulation. A heavy selection saw timber cut on an area changed the vegetation from mixed hardwood to pure yellow poplar. As a result, litter was reduced from 8.9 tons per acre to 4.2 tons per acre after five years. The author suggested that since yellow poplar litter decomposes more rapidly than oak litter this would account for some of the reduction in total litter accumulation.

Trimble and Tripp (1949) observed some effects of cutting on forest soils in lodgepole pine forests of the northern Rocky Mountains. The authors found that the condition of the underlying soil, and the humus depth, were apparently directly correlated with the intensity of cutting. Observations in stands which had been cut in a number of ways indicate the effect on the forest floor seemed to be the result of two things: (a) mechanical ground disturbance resulting in erosion and humus destruction; and (b) opening up of the stand so that increased sunlight, higher temperatures, and increased air movement acted to oxidize the humus. On areas which had been clearcut for some time the humus had generally disappeared and the soil was more compacted than under uncut areas.

Forest cover has been found to exert considerable influence on the nature and extent of soil freezing. Post and Dreibelbis (1942) studied soil freezing at Coshocton, Ohio for several years and found that forest soils did not contain concrete (impermeable) frost at any time. Kienholz (1940) found that frozen soil in northwestern Connecticut was about twice as deep in a plowed field as in a forest of either white pine or red maple and it lasted longer in the field than either forest area.

Belotelkin (1941) observed depth of soil freezing in northern New Hampshire in an open field, a hardwood area, a spruce swamp, and a spruce flat. The swamp exhibited the greatest freezing depth, the spruce flat and the open area had intermediate depths, and the hardwood forest had the least depth.

MacKinney (1929) investigated soil freezing in two adjacent plots within a pine plantation in Connecticut. On one plot the forest floor was undisturbed; on the other all litter and humus had been removed. As a result of the soil denudation ice was formed in the bare plot one month earlier than in the undisturbed plot and was considerably deeper.

Lassen and Munns (1947) reported on soil freezing studies conducted by the Forest Service in New York, New England, and Ohio. They concluded:

> Frost penetration into soils under hardwood forest has so far been found to be less than in soils under other types of forest cover. As hardwoods are usually found on better soils and these are usually rich in organic matter, it is assumed that organic content is the governing factor rather than forest type.

CHAPTER III

DESCRIPTION OF THE PROJECT AND STUDY AREA

The Michigan Hydrologic Research Project

The Michigan Hydrologic Research Project was established at East Lansing, Michigan early in 1940 as a cooperative project between the Soil Conservation Service of the United States Department of Agriculture and the Michigan Agricultural Experiment Station. The project is presently administered by the Soil and Water Conservation Branch of the Agricultural Research Service of the United States Department of Agriculture and the Michigan Agricultural Experiment Station. The primary purpose of this undertaking was to study the effects of land use on the hydrology of farm lands under varying types of snow cover and frozen soil. The objectives of this project were: 1) To determine the manner in which freezing and thawing of soils on watersheds with varying types of land use contributes to runoff, erosion, and flood flow under northern winter conditions, and 2) 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.

It was realized that to successfully develop a project of this type it would be necessary to collect a variety of data from numerous sources in order to properly evaluate the climatic and hydrologic factors affecting the work. The following items were considered to be of major importance:

1. Precipitation
    a. Amount and intensity
2. Water losses
    a. Runoff: Amount and rate
    b. Infiltration: Rate
    c. Evaporation: Total and rate
    d. Transpiration: Total and rate
3. Erosion losses
4. Soil moisture
5. Temperature
    a. Air
    b. Soil
6. Solar radiation
7. Wind movement
    a. Velocity and direction
    b. Total wind movement

Three small watersheds in the East Lansing area were selected as sites for the future hydrologic installations. Two of the watersheds, contiguously situated, are located on lands of Michigan State University approximately two miles south of the campus. These two watersheds were to be handled under approved, prevailing farming practices. The watersheds

were to be subjected to rotations of corn, oats, and a mixture of alfalfa and brome grass.

The third watershed is located approximately ten miles northeast of East Lansing on lands of the Rose Lake Wildlife Experiment Station of the Michigan Department of Conservation. This watershed was under wooded cover, typical of farm woodlots in southern lower Michigan. It is with this watershed that this study is concerned, hence a more detailed description follows in the next section.

The three watersheds were selected to be as nearly alike in every respect as probable to find in nature, with the exception of vegetative cover.

The Wooded Watershed

Location

The study area is located in southeastern Clinton County of southern lower Michigan. The wooded watershed is situated approximately ten miles northeast of East Lansing on Clinton County Road 454, between the villages of Bath and Perry (see Fig. 1). The watershed is a part of the drainage basin of the Looking Glass River which, in turn, is a part of the Grand River drainage basin which empties into Lake Michigan.

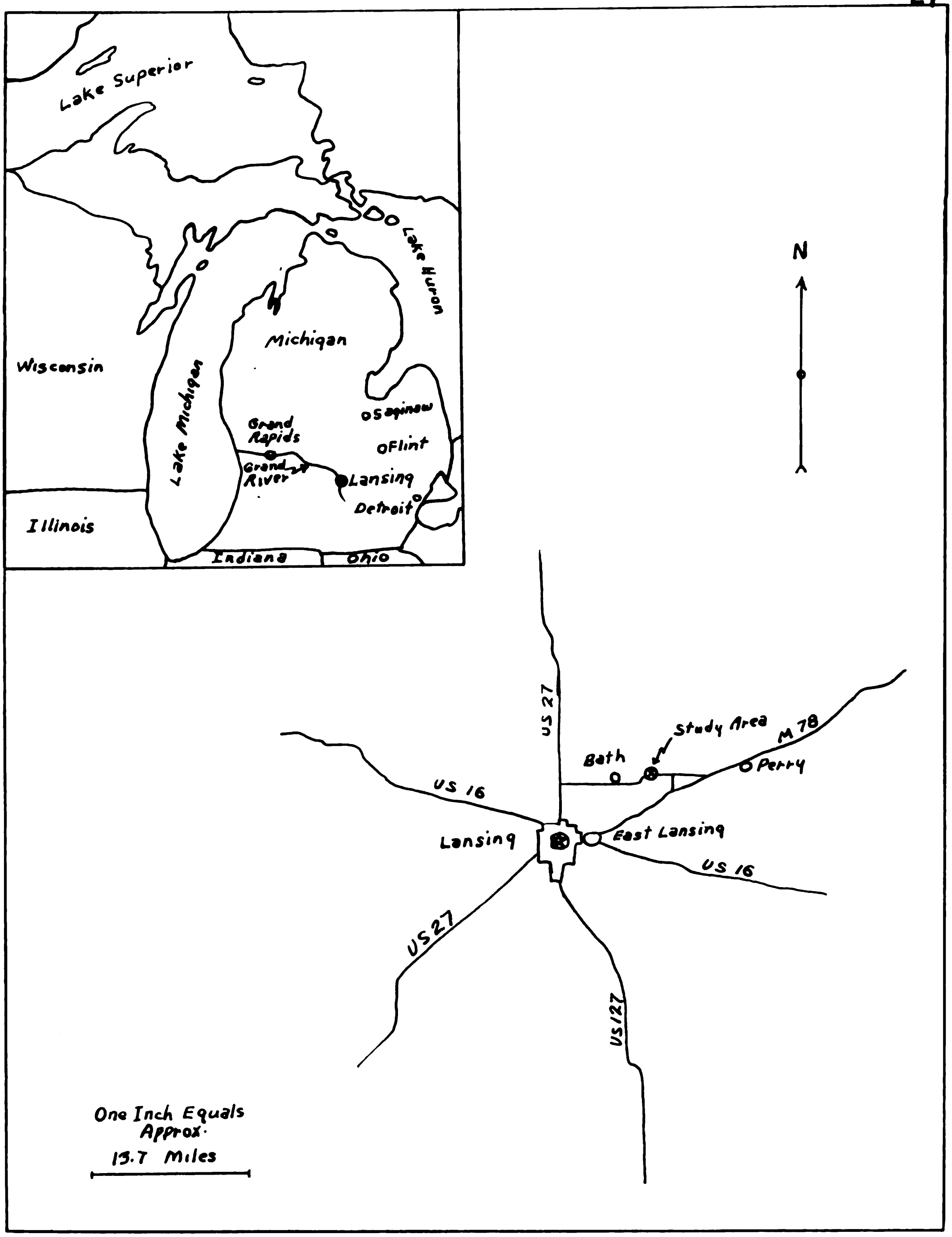

Fig. 1.-Location of the wooded watershed, with reference to the Lansing area and to the state.

<u>Geology and Physiography</u>

The watershed is located within the northern portion of the Central Lowland Physiographic Province of the Interior Plains Division. The area is situated within the Michigan Basin, which is underlain with sedimentary bedrock formed during the Pennsylvanian Period of the Paleozoic Era. The bedrock, which consists of shales, limestones, and sandstones, exhibits little or no weathering due to the scouring action of the glaciers which covered this area as recently as ten thousand years ago. The glacial drift is characterized by a great variety of igneous, metamorphic, and sedimentary rocks and varies in depth from a few feet to more than two hundred feet.

The surface geologic formations were deposited during the last stages of the glacial period, hence the land surface is comparitively young. The configuration features are almost entirely constructional since streams have not had time to develop complete dendritic systems. The general area has been described (Veatch, 1953) as having an undulating and rolling topography, with local relief generally not more than fifty to seventy-five feet. The slopes are short and rarely steep; there are shallow sags and short draws, with basin depressions and swampy valleys.

The watershed has an area of 1.65 acres and is roughly triangular in shape (Fig. 2). The aspect is to the north.

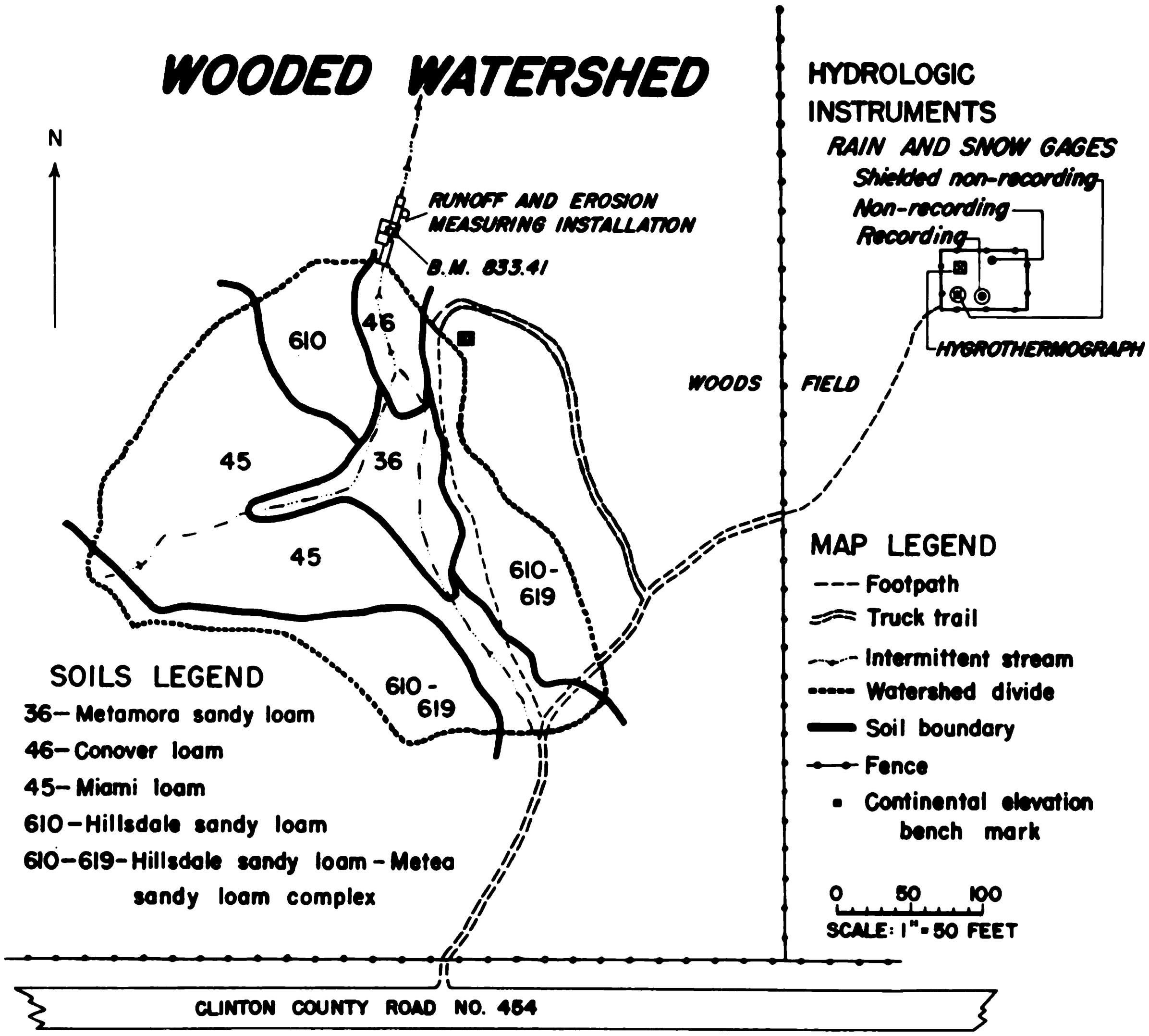

Fig. 2.-Map of the wooded watershed showing soil types and hydrologic and meteorologic installations. (After the Michigan Hydrologic Research Station)

The weighted average slope is 6.1 per cent, with the maximum slope not exceeding fourteen per cent (Fig. 3). The maximum relief is sixteen feet. The elevation of the outlet of the watershed is 833.41 feet above sea level.

Two intermittent streams drain the watershed, dividing it roughly into thirds (Fig. 2). Each of the intermittent streams have a length of approximately 340 feet from source to outlet of the watershed with average channel slopes of 3.5 per cent and 2.9 per cent respectively for the western-most channel and eastern-most channel. The channels of these intermittent streams are not well defined.

Climate

The climate of the area alternates between continental and semimarine with changing meteorological conditions (Wills, 1941). The marine type is due to the influence of the Great Lakes, which, in turn, is governed by the force and direction of the wind. When there is little or no wind, the weather becomes continental in character, which means pronounced fluctuations in temperature - hot weather in the summer and severe cold in the winter. Likewise, a strong wind from the Lakes may immediately transform the weather into a semimarine type.

Precipitation is well distributed throughout the year, with no conspicuous variations noted in the seasonal march. The average annual precipitation for the East Lansing area

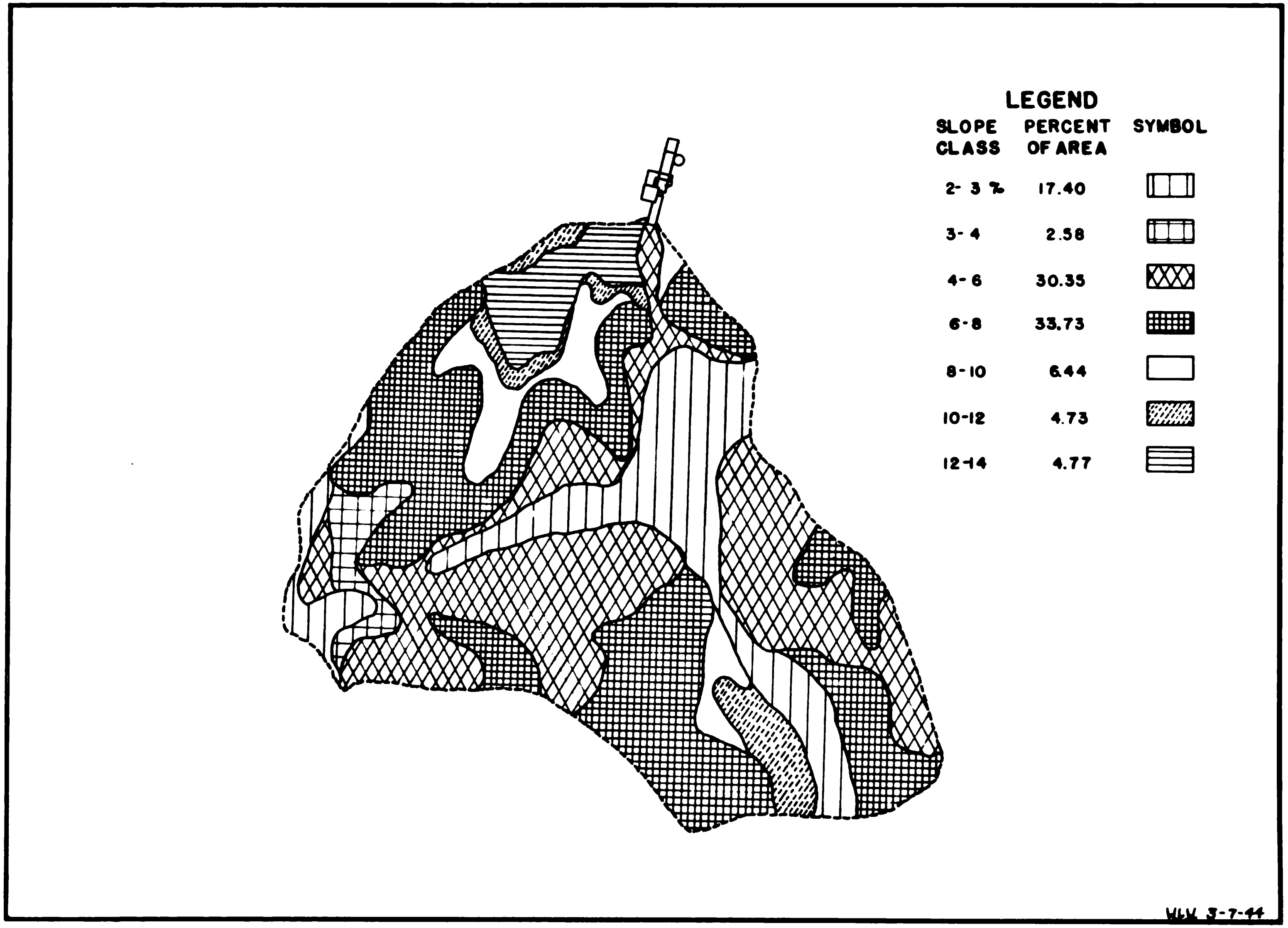

Fig. 3.-Slope class distribution on the wooded watershed. (Michigan Hydrologic Research Station)

is 31.08 inches.[1] Figure 4 illustrates the seasonal distribution of precipitation. The wettest month of the year is May with an average of 3.75 inches, while the driest month is February with 1.81 inches. The precipitation averages 17.96 inches during the growing season of April through September. Precipitation received during the months of October through March is primarily in the form of snow with a total annual fall of 49.2 inches (Baten and Eichmeier, 1951).

The area has a mean annual temperature of 46.9°F, with a mean winter temperature of 24.2°F and a mean summer temperature of 68.6°F. Temperature extremes that have been recorded are 102°F and -26°F.[2] The average date of the last spring frost is May 5 and of the first fall frost is October 10. The growing season averages 158 days.

Evaporation values, as determined from a standard U. S. Weather Bureau Class A Evaporation Pan, are relatively low. Average evaporation for the months of May through October is 6.31 inches. Solar radiation, which seems to be highly correlated with evaporation, is well below the mean values for the

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[1]Precipitation values are based on thirty year normals furnished the Michigan Hydrologic Research Project by Mr. A. H. Eichmeier, U. S. Weather Bureau, East Lansing, Michigan.

[2]Temperature data from <u>Climate and Man</u>, 1941, U. S. Department of Agriculture, <u>Agricultural Yearbook</u>. All other hydrologic and meteorologic data, unless otherwise cited, are from the files of the Michigan Hydrologic Research Project.

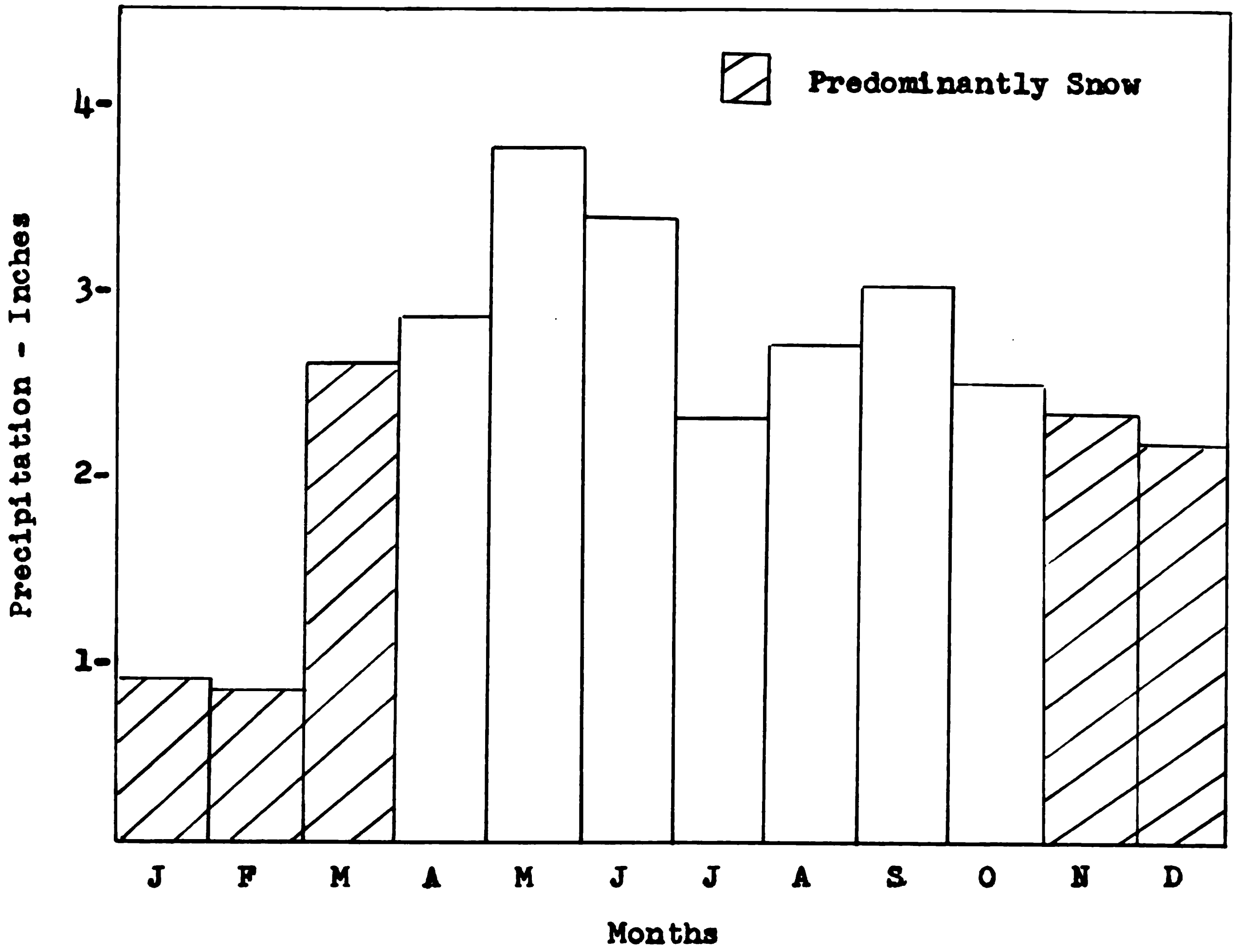

Fig. 4.—Monthly distribution of precipitation. (Based on precipitation normals furnished the Michigan Hydrologic Research Station by Mr. A. H. Eichmeier, U. S. Weather Bureau)

United States (Crabb, 1950). The average annual amount of solar radiation for the East Lansing area is 102,602 Langleys (gram-calories per square centimeter).

Wind movement, which is important in this area because of its ameliorating influence on weather, is greatest during the period from November to April and least from May to October. The prevailing wind direction is from the southwest.

Soils

The soils of the wooded watershed belong to the Gray-Brown Podzolic Great Soil Group. These soils are derived from medium to heavy textured calcareous drift of the late Wisconsin glacial period (Leverett and Schneider, 1917). The drift covering is sufficiently thick (at least eighty feet) in this area to completely mask any direct influence of the underlying bedrock on the soils. The drift consists of transported residue of weathered material and rock fragments of shales, limestones, and sandstones with some crystalline rock material from distant sources included.

The Rose Lake area falls within the Fox-Plainfield-Hillsdale-Bellefontaine Soil Association as mapped by Veatch (1953). Johnsgard, et al., (1942) mapped the area immediately around and including the watershed as Hillsdale sandy loam, rolling phase.

More specifically, the soils within the watershed were mapped in 1940 as Miami loam, Hillsdale sandy loam, Hillsdale sandy loam - Metea sandy loam complex, Conover loam, Conover silt loam.[3] Intensive soil sampling during 1957 by the writer indicated that the soil formerly mapped as Conover silt loam was sandy loam in texture and has been reclassified as Metamora sandy loam (Fig. 2).

The soils may be subdivided into two groups on the basis of drainage: 1) Well-drained soils, and 2) imperfectly drained soils. The well-drained group includes the Miami loam, Hillsdale sandy loam, and Hillsdale sandy loam - Metea sandy loam complex. The imperfectly drained group includes the Conover loam and the Metamora sandy loam. The physical properties of these soils are discussed in detail in Chapter VI.

<u>Vegetation</u>

The forest vegetation of this area is representative of the northern portion of the central hardwood region. Prior to cutting (winter of 1951 - 1952) the watershed supported a well-stocked stand of second growth oak-hickory (Fig. 5). The timber had been "high graded" at various times since settlement of the area in the mid-1800's.

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[3]The soils of the watershed were mapped by Mr. Leo R. Jones, Soil Conservation Service, U. S. Department of Agriculture.

a

b

Fig. 5.-Vegetation on the wooded watershed, May, 1951. (a) view is towards the south from the approach section of the runoff station. Note the density of reproduction in the center of the photo. (b) view is towards the west across the center of the watershed.

An intensive vegetative inventory was made on the watershed during the summer of 1951 (Smith, 1954). The inventory included a cruise of all stems one inch in diameter and larger. A crown map was also made showing the projection of all crowns of stems one inch in diameter and larger (Fig. 6a). Table 1 gives the basal area for the watershed by species.

TABLE 1

BASAL AREA BY SPECIES[a]

Species	Basal area per acre
Quercus velutina	32.818
Quercus rubra	20.515
Quercus alba	16.821
Carya ovata	17.369
Carya ovalis	10.607
Prunus serotina	4.359
Acer rubra	1.259
Prunus virginiana	.812
Ulmus thomasi	.227
Crataegus spp.	.167
Cornus racemosa	.026
Hamamelis virginiana	.017
Fraxinus americana	.013

[a]From Smith, 1954.

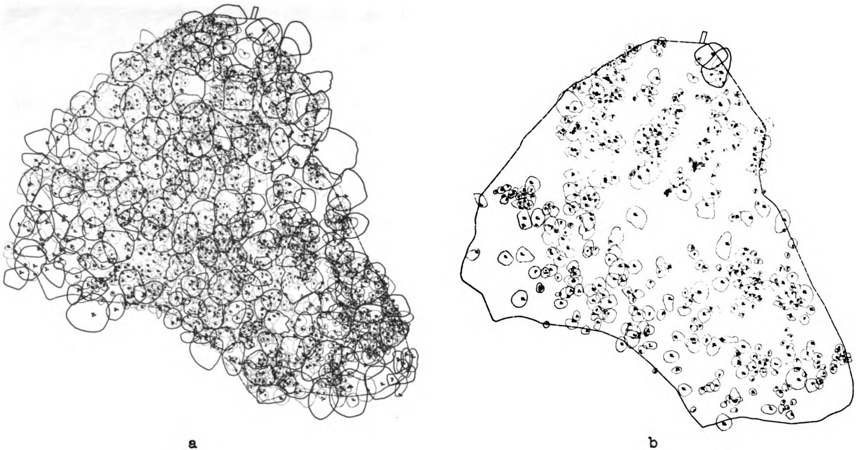

Fig. 6.-Crown cover maps of the wooded watershed. (a) made during the summer of 1951, prior to commercial-type clearcut. (b) made during the summer of 1952, after the commercial-type clearcut treatment. (Smith and Crabb, 1953)

This tabulation indicates the oaks (*Quercus velutina* Lam., *Quercus rubra* L., *Quercus alba* L.) contained 66.8 per cent of the basal area, and the hickories (*Carya ovalis* Sarg., *Carya ovata* Mill.) contained 26.6 per cent, for a combined total of 93.4 per cent of the stand, hence the designation of the forest type as oak-hickory was well justified. Basal area by one inch diameter classes is given in Table 2.

There was a total of 8,912 board feet (International one-fourth inch log rule) on the watershed in the 10- to 18-inch diameter class (Smith and Crabb, 1953). This amounted to 5,570 board feet per acre. The largest volume of saw timber was in black oak (*Quercus velutina* Lam.). In the 5- to 9- inch class there were 454 cubic feet per acre. Of a total of 2,008 stems on the watershed in the 1- to 19-inch category, 83.9 per cent were less than five inches in diameter.

A lesser vegetation survey made on nine fifteen feet square quadrats indicated that 46.2 per cent of the area had no lesser vegetation (Smith, *op. cit*.). Dense concentrations of lesser vegetation were noted in the few openings in the stand (Fig. 5).

The status of the watershed vegetation after cutting is given in Chapter IV.

TABLE 2

BASAL AREA BY ONE INCH DIAMETER CLASSES[a]

Diameter class (inches)	Basal area (square feet)	Per cent of total
1	3.845	2.2
2	3.849	2.2
3	2.158	1.2
4	1.749	1.0
5	5.397	3.1
6	6.749	3.9
7	7.096	4.1
8	15.954	9.2
9	9.670	5.7
10	16.053	9.3
11	18.894	10.9
12	17.128	9.9
13	16.335	9.5
14	22.368	12.9
15	10.660	6.1
16	5.395	3.1
17	4.675	2.7
18	3.517	2.0
19	1.887	1.0

[a]From Smith, 1954.

CHAPTER IV

HISTORY OF THE WOODED WATERSHED STUDY

The Michigan Hydrologic Research Project was formally established January 1, 1940. The project was originally set up to study watershed conditions under the influence of agricultural cropping practices prevailing in this area. However, it was decided during the summer of 1940 to include a watershed under forested conditions to contrast the effects of various kinds of cover conditions on the hydrology of small agricultural watersheds. An agreement was formulated between the Michigan Department of Conservation, the Michigan Agricultural Experiment Station, and the Soil Conservation Service of the U. S. Department of Agriculture to utilize lands of the Rose Lake Wildlife Experiment Station for the purpose of studying watershed conditions under a forest cover. The small wooded watershed north of Clinton County Road 454 was selected as the site for the watershed study. Surveying, mapping, construction of installations, and instrumentation of the study area were effected during the latter half of 1940 and January of 1941.

Instrumentation

<u>Precipitation</u>

In order to study the hydrology of an area it is necessary to know how much precipitation is received on the area. Precipitation received on the watershed during the months of April through October occurs primarily as rainfall. During the months of November through March precipitation occurs primarily as snow. Precipitation records have been taken since February, 1941 at the watershed.

The total amount of precipitation was measured with a standard U. S. Weather Bureau type, eight inch non-recording rain gage. A nine inch weighing-type (Ferguson) recording rain gage was used to determine precipitation intensity. As a supplemental measurement, a standard non-recording rain gage equipped with a Nipher shield was used to determine the reliability of rain and snow measurements under conditions of high wind.

Precipitation was measured as soon as possible after each storm, to prevent undue losses from the gages by evaporation. Also, as the recording rain gage used a twelve hour chart with a clock that ran for one week it was necessary to change the chart as soon as possible after precipitation in order to prevent confusion as to the timing of the precipitation. For winter snow measurements the catchment funnels were removed from all three gages to allow easy access of the snow. An anti-freeze solution was added to the precipitation catchment pail of the recording gage to reduce the snow catch to its liquid content. The water content of the snow caught in the standard gages (shielded and non-shielded) was obtained by melting the snow catch per gage on a small kerosene stove. In addition to the snow measurements obtained in the precipitation gages a snow survey was made on the watershed after each snowfall. As the depth of snow on the ground seldom exceeds ten inches in this area it was impractical to use a snow tube in the conventional manner, viz., obtaining a representative core of snow in the tube, then weighing the tube and snow core on a specially calibrated scale to get water content. Consequently, a special method was used, employing a snow tube of the conventional type. It has been determined that the cross-sectional area of the snow tube is approximately 1/28 the cross-sectional area of a standard eight inch rain gage. Hence by getting twenty-eight snow cores at random from the watershed area a representative sample of snow depth and water content was obtained which was equivalent in cross-sectional area to a catch obtained in a standard gage. The snow was melted and measured as in the case of the catch in the standard gages.

All precipitation data were recorded as inches depth of water and inches per hour. In the case of snow, average depth of snowfall and average snow density were also recorded.

The data were tabulated by days, months, and years. A summary of precipitation received on the area for the period of study, 1941 - 1957 is included in Chapter VI.

Temperature

Air temperature and relative humidity were recorded by means of a hygrothermograph located in a standard Weather Bureau instrument shelter 4.5 feet above ground (Fig. 7). The air temperature and relative humidity fluctuations were recorded on a weekly, clock operated chart. Maximum and minimum air temperatures were determined by means of a U-Type maximum - minimum thermometer. Air temperatures were tabulated as maximum and minimum values per week as well as average weekly temperature.

Soil temperatures were obtained at depths of one inch and six inches below the soil surface by means of a recording three-pen thermograph. The third pen of the thermograph recorded air temperature six inches above the soil surface. The soil and air temperatures were tabulated as weekly maximum and minimum, and average weekly temperature per location.

Runoff

Runoff was measured by means of a float-type portable water stage recorder used in conjunction with a metal 3-H type flume. A reinforced concrete approach section at the outlet of the watershed delivers the water to the flume in an orderly manner. The runoff recorder was equipped with an

Fig. 7.-Meteorological station at the wooded watershed. The objects are, from left to right, instrument shelter housing hygrothermograph and maximum-minimum thermometers, Niepher-shielded standard rain gage, standard 8-inch non-recording rain gage, 9-inch weighing-type recording rain gage. (Michigan Hydrologic Research Station)

adjustable float stop so that the float never dropped below the zero point of bouyancy. The float stop was equipped with a vernier and could be read to the nearest 0.001 foot. Figure 8 pictures the runoff measuring installations.

Runoff data were recorded as cubic feet per second (c.f.s.), and area inches per hour. Runoff data for the period of study, 1941 - 1957, are summarized in Chapter VI.

Erosion

As runoff water passed through the measuring flume it flowed into a reinforced concrete silt box. This silt box would hold runoff water to a depth of two feet, with the remainder flowing over a weir plate at the lower end. A Ramser divisor, located on the side of the silt box at the level of the weir plate, obtained an aliquot sample of all runoff flowing over the weir plate (Fig. 8). Total soil loss was obtained by determining soil loss per cubic foot caught in the divisor, multiplying by the total volume of runoff passing over the weir plate and adding that to the total soil loss obtained in the silt box. Soil loss was computed in terms of pounds per acre.

Soil Moisture

Soil moisture sampling was initiated on the watershed during September of 1945. Bi-weekly gravimetric sampling, with a Veihmeyer tube, in the Metamora sandy loam furnished a measure of soil moisture for the watershed. Bouyoucos

Fig. 8.-Runoff measuring installations at the wooded watershed. (1) catchment tank for Ramser divisor, (2) Ramser divisor, (3) 3-H type flume, (4) silt box, (5) shelter house containing water stage recorder. (Michigan Hydrologic Research Station)

moisture blocks were installed in the same soil type during the summer of 1953 and weekly readings of soil moisture at various depths were recorded. The blocks were removed during the summer of 1957 and new blocks were installed. Weekly gravimetric sampling was initiated during March of 1957 and continued through September of 1957. During this period of gravimetric sampling all five soil types on the watershed were sampled.

A more detailed description of the soil moisture sampling procedure is given in Chapter V.

Calibration Period, 1941 - 1951

In watershed studies, such as this, it is desirable to accumulate data on the various meteorologic and hydrologic factors under a diversity of conditions as might normally be encountered on a particular area. This standardization or calibration period varies according to climatic and physiographic factors. Statistical methods have been developed which enable the calculation of the desired calibration period for a particular set of conditions (Kovener and Evans, 1954). However, no such calculations were available at the beginning of this study, thus an arbitrary length of calibration period was decided on.

The instrumentation of the watershed was completed by February 1, 1941 and meteorological and hydrological records were commenced from that date. Pre-treatment data were accumulated through November of 1951.

Treatment, 1951

By the summer of 1951 the watershed had undergone an eleven year period of standardization and it was felt that in that period a representative cross-section of storms had been experienced on the area. Consequently the Hydrologic Project Committee recommended that the forest canopy be altered in order to observe changes, if any, in runoff, erosion, and silting. As a result of this recommendation the "Joint Working Plan of the Michigan Agricultural Experiment Station and the Soil Conservation Service," which formed the working basis for the Michigan Hydrologic Research Project, was amended November 26, 1951 to include the following treatment:[1]

1. The present forest cover at the wooded watershed to be altered so as to give additional data on the effects of watershed management on soil and water losses. This alteration to be accomplished by commercially clearcutting in the same manner as is common in southern Michigan woodlots. In addition, an isolation strip 50 feet wide around the watershed will be treated similarly to eliminate edge effect.

2. Commercial clearcutting will take all trees down to the 5- inch diameter class. Trees 10 inches and

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[1]From the files of the Michigan Hydrologic Research Station.

larger in diameter will be cut into sawlogs. Material in the 6-inch to 9-inch diameter classes will be cut into cordwood. Cruise data indicates a volume of 8,000 board feet in the watershed. Cutting an isolation strip will increase this volume to approximately 12,000 board feet. All material will be cut and decked outside the cutting area, and will become the property of the Rose Lake Wildlife Experiment Station. The expense of cutting and decking operations will be borne by the Forestry Department. Tops will be left in the area unless the Rose Lake Wildlife Experiment Station desires to utilize them for fuelwood or brushpiles for game cover.

3. Clearcutting operations will commence about November 27, 1951, and continue until the project is completed.

4. This cultural treatment will not change the use of the area by the Game Division, Michigan Conservation Department.

5. This cultural treatment will not change the present instrumentation of the watershed, nor the studies now underway thereon.

This treatment was carried out, as proposed, by the end of the year 1951. The trees were felled, bucked, and tractor skidded to a landing off the watershed area. There was no attempt to minimize soil disturbance on the area. Approximately 1600 stems, less than five inches in diameter, remained on the watershed, with many of these damaged by the logging operation (Fig. 9).

As the entire treatment operation required only a minimum amount of time, approximately one month, only a few data were collected during this transitory period. Likewise, as this period of the year is more or less dormant, from a hydrologic standpoint, the entire 1951 year was included in the pre-treatment period.

a

b

Fig. 9.-Stand condition on the watershed immediately after logging. (a) View from the northwest towards the southeast. (b) View from south to north. (Michigan Hydrologic Research Station)

Post Treatment Period, 1952 - 1957

After the initial cutting treatment, during the fall and winter of 1951, no further treatment was effected on the area. The first year after treatment, 1952, was the only year the watershed was affected by the full impact of the treatment. With each subsequent year the regrowth of vegetation became more dense, hence the effect of the treatment was progressively ameliorated. Figure 10 illustrates the regrowth of vegetation during the 1952 season, while Figure 11 indicates vegetative cover during 1957. The vegetative cover was very dense during the 1957 growing season, with nearly 100 per cent crown coverage for the watershed. The vegetation type varied from grass cover on one small area to bramble to sapling stage of cherry, elm, oak, and hickory, with a few pole-sized trees of the same species. There were profuse growths of blackberry and wild grape on scattered areas.

Fig. 10.-Vegetative cover, summer of 1952. View from east to west across the center of the watershed. (Michigan Hydrologic Research Station)

Fig. 11.-Vegetative cover on the watershed, summer of 1957. In the foreground is the concrete approach section leading to the 3-H flume. (Michigan Hydrologic Research Station)

Fig. 12.-Vegetative cover on the adjacent uncut area, summer of 1957. (Michigan Hydrologic Research Station)

CHAPTER V

METHODS OF STUDY

Research related to the hydrologic effects of vegetation treatment has generally followed one or more of the following methods or techniques: Measurement of water yield and sediment from small watersheds on which the vegetation or land use has been altered or on groups of watersheds which are similar except for vegetative cover or land use; measurement of sample plots upon which vegetation can be manipulated; area sampling of hydrologic conditions on land areas which have undergone vegetation changes. Each method has considerable merit, as well as disadvantages: The first approach has the disadvantage that only the end results of treatment are measured, i.e. run-off. The second approach deals only with the various components which affect water yield from an area, but do not in themselves measure the end result. The third approach permits a relative measure of the effects of vegetation and land use treatments but does not attain any degree of specific delineation of cause or effect of treatment. Ideally, a combination of the first and second approaches would furnish the maximum amount of useful information, as the individual components affecting water yield on the watershed would be measured, as well as the end result of the interaction of these components, i.e. runoff.

In order to determine and evaluate some of the effects of a commercial-type clearcut on soil and water relations on a small watershed it was considered desirable to use a method of study approaching a combination of the first and second methods mentioned above. Consequently the methods of study have been separated into parts: The determination of some effects of treatment on soil physical properties; and the determination of some effects of treatment on water yield and quality.

Determination of Treatment Effects on Soil Physical Properties

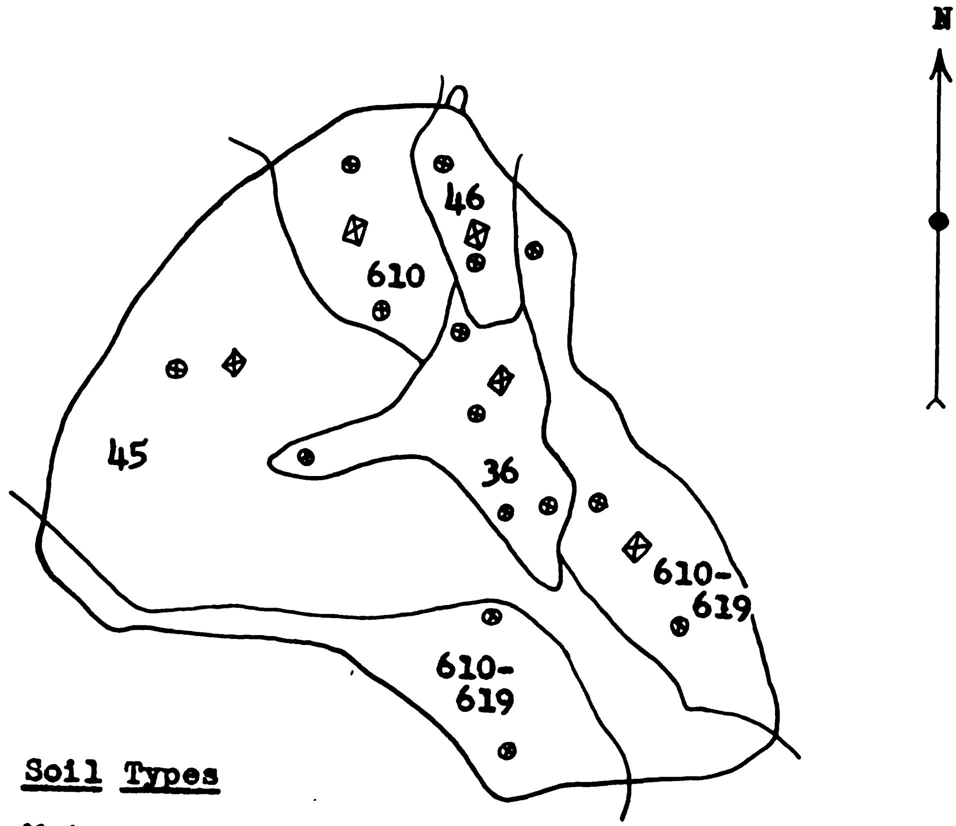
Soil may be regarded as a product of its environment and as such it is not a static body but is dynamic and may be expected to change with modification of its environment. Since vegetation is a component of the environment of an area any drastic changes in the vegetative cover may promote changes in the physical constitution of the solum. This portion of the dissertation is concerned with the determination of effects of vegetation treatment on soil physical properties.

The basic procedure employed in this study was to determine the physical characteristics of the soils on the watershed during the last year of study, 1957, and contrast these values with soils of the same type on untreated areas immediately adjacent to the treated watershed area. Also these values were to be contrasted with values obtained in

1953, one year after treatment, by Smith (1954)on the watershed area. The basic approach should have included determination of soil physical properties prior to vegetative treatment and subsequent determinations of these properties at prescribed intervals. This, however, was not the case, hence the procedure described above was employed.

Soil Physical Properties

The physical properties determined in this study were soil texture, permeability, porosity, bulk density, moisture equilibrium points (field capacity and permanent wilting point), and loss on ignition. The above physical properties were determined from soil samples extracted from the various soil types represented on the watershed and the immediately surrounding area. Figure 13 indicates the location of the soil sampling pits on the watershed. The basic soil samples consisted of soil cores, three inches in diameter by three inches high, extracted in aluminum cylinders by means of a core sampler similar to that originally described by Lutz (1940), (Fig. 14). The sampling procedure generally followed that described by Hoover, et al., (1954). Only one soil sampling pit was excavated within each soil type on the watershed because of the limited area occupied by each soil type and to prevent, as much as possible, any overall disturbance to the watershed. The depths sampled were 0 - 6 inches, 12 - 18 inches, 30 - 36 inches, and 42 - 48 inches. The sampling



<u>Soil</u> <u>Types</u>

36 Metamora sandy loam

46 Conover loam

45 Miami loam

610 Hillsdale sandy loam

610 - 619 Hillsdale sandy loam-

Metea sandy loam

⊗ Soil Moisture
Sampling Station

⊠ Soil Physical
Property Sampling
Pit

Fig. 13.-Location of soil moisture sampling stations and soil physical property sampling pits.

a

b

Fig. 14.-Soil core sampler in use. Note the use of one pint cardboard containers for transporting soil cores to the laboratory. (Michigan Hydrologic Research Station)

depths, down through thirty-six inches, were selected to coincide with the soil moisture sampling depths originally selected in 1945. The greatest depth, 42 - 48 inches, was selected to coincide with the additional depth of soil moisture sampling in 1957. The writer felt that physical changes in the soil, associated with vegetation or land use changes, are not usually effected below a depth of six inches (except with cultivation), hence physical property determinations on the soils of the untreated area were confined to the upper six inches of the profile.

Three cores were obtained from each sampling depth in order to reduce, somewhat, the natural variability of the soils and also to have at least one or two cores for each depth in the event that a core had to be discarded because of large root channels or rocks. The soil cores were placed in one-pint cylindrical cardboard containers to prevent drying and to protect the relatively undisturbed structure during transit to the laboratory. The soils were sampled when the moisture was at field capacity or slightly below. Past investigations indicate that at this moisture content structural cracks and cleavages are closed and there is sufficient moisture in the soil to lubricate the sample, hence a relatively undisturbed sample may be obtained.

Bulk samples were obtained, in addition to the soil cores, for use in determining loss on ignition, permanent wilting percentage, and soil texture.

Soil texture. The texture of the soil indicates the relative proportion of sand, silt, and clay separates which constitute the soil body. A mechanical analysis, using the Bouyoucos hydrometer method, was employed in the laboratory to determine the soil textures (Forest Soils Committee of the Douglas Fir Region, 1953). The relative proportions of sand, silt, and clay were expressed as percentages of total separates less than 2 mm. in size.

Permeability. Permeability, as expressed by percolation rates (inches per hour), was determined in the laboratory on the 3 X 3 -inch soil cores with a permeability apparatus described by Hoover, *et al.*, *op. cit.* Figure 15 illustrates the permeability apparatus.

Porosity. A tension table, similar to that originally described by Leamer and Shaw (1941), was used for pore space determinations. The previously described 3 X 3 -inch soil cores were subjected to tensions of 20 cm., 40 cm., and 60 cm. Total porosity, capillary porosity, and non-capillary porosity values were determined following procedures outlined by Hoover, *et al.*, *op. cit.* The delineation between capillary and non-capillary porosity was attained by considering the 60 cm. tension value as representing the force with which capillary water is held. Thus, the porosity values obtained at 60 cm. of tension represented capillary porosity. Porosity values were expressed as per cent of soil volume.

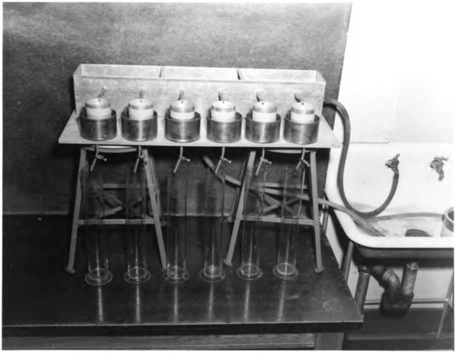


Fig. 15.-Permeability apparatus used for determining percolation rates of soil cores.

Bulk density. The bulk density of each core sample was obtained after the permeability and porosity values were determined. The oven-dry weight of the soil core in grams was divided by the volume of the core in cubic centimeters to obtain the bulk density values.

After completing the bulk density determinations all soil cores were examined for large stones and roots which would tend to exaggerate the permeability, porosity, and bulk density values. Any such cores found were discarded.

Field capacity. Various methods have been advanced for the determination of soil moisture content at the moisture equilibrium point known as field capacity. The reason for the variety of methods apparently rests on the lack of agreement as to the tension value most representative of the attraction of the soil particles for water at the so called field capacity condition. If the moisture held in the pore space at 60 cm. of tension represents capillary moisture, and that is the assumption made in this study as indicated in the above section on porosity, then the moisture content at this tension level should indicate approximate field capacity.

Permanent Wilting Percentage. The use of fifteen atmospheres of tension as representative of the attraction of soil for water at the permanent wilting percentage has gained rather widespread acceptance among researchers (Baver, 1956), hence this tension value was used in this study. The pressure-membrane apparatus, as described by Richards (1947), was used to determine the moisture content at permanent wilting point. A plastic sausage casing-type membrane was used in the apparatus. Rubber rings were used to retain the soil samples within the apparatus. The soils were sieved through a 2 mm. screen before being tested. Moisture contents at the permanent wilting point were expressed as per cent moisture on an oven-dry basis and on a volume basis.

<u>Loss on ignition</u>. The values obtained from loss on ignition represent an approximation of total soil organic matter (Forest Soils Committee of the Douglas Fir Region, 1953). For sandy soils loss on ignition values are probably the most accurate indication of soil organic matter content. In clay soils, however, water intimately associated with the soil particles may be driven off, giving inaccurate values for organic matter content. Therefore, all values representing total soil organic matter, as determined in this dissertation, are presented as loss on ignition. Ten gram samples of oven-dry soil, ground to pass through a 60 mesh screen, were ignited in a muffle furnace at 600°C for four hours. The results obtained were expressed as per cent loss on ignition.

Soil Moisture Regime

Soil moisture values were determined gravimetrically for depths of 0 - 6 inches, 12 - 18 inches, and 30 - 36 inches. The soil moisture sampling area was located within the Metamora sandy loam soil type (see Fig. 2, Chap. III). The sampling depths, as well as the soil type to be sampled, were decided by personnel of the Michigan Hydrologic Research Station in 1945. The soil moisture values were obtained on a bi-weekly basis from September, 1945 through December, 1952. In order to ascertain the degree of soil moisture variation between soil types on the watershed, weekly soil moisture samples were obtained from the five soil types during the period of March through September, 1957. The depths sampled were the same as the three previously mentioned plus an additional depth of 42 - 48 inches. Fifteen soil moisture sampling stations were established on the watershed early in 1957, with three sample stations within each soil type. However, with subsequent revision of soil type boundaries, some soil types contained only two sample stations while others contained four (Fig. 13). The soil moisture samples were obtained with a Veihmeyer tube (Veihmeyer, 1929), and placed in air-tight aluminum sample cans (Fig. 16). The moisture samples were weighed to the nearest one-tenth of a gram. The samples were oven-dried at a temperature of 105°C for a twenty-four hour period (Lull and Reinhart, 1955). Soil

Fig. 16.-Gravimetric soil moisture sampling by means of a Veihmeyer tube. Note wooden trough used to hold the soil cores. (Michigan Hydrologic Research Station)

moisture values were determined as per cent moisture on an oven-dried weight basis. The values were also expressed as per cent moisture on a volume basis by multiplying per cent moisture on an oven-dried weight basis by the bulk density value for the appropriate soil and depth. In order to account for the intervening depths between the depths actually sampled, for determining total profile moisture content (0 - 48 inches), arbitrary depths, based on the writer's observations of the profiles, were assigned as follows:

Depth Sampled (inches)	Representative Depth (inches)
0 - 6	0 - 6
12 - 18	7 - 25
30 - 36	26 - 36
42 - 48	37 - 48

There were no usable soil moisture values obtained during the years 1953 - 1956. Plaster-of-paris soil moisture blocks, developed by Bouyoucos and Mick (1940), were installed in the Metamora sandy loam soil during the summer of 1953. The blocks failed to give satisfactory results, perhaps because of the wet site, and were never calibrated, thus the results obtained were of no use to this study. These soil moisture blocks were removed during the summer of 1957 and the more recently developed nylon-type moisture blocks (Bouyoucos, 1952) were installed in the same area. As gravimetric samples were obtained during the 1957 growing season no data were used from the moisture blocks in this study.

Evapotranspiration

Evapotranspiration values were computed for periods when soil moisture was at or below field capacity, in order to reduce as much as possible incorporation of percolation losses in the computed values. When soil moisture depletion occurred, evapotranspiration equaled the difference between any two consecutive soil moisture values plus precipitation received during the period. When soil moisture accretion occurred, the amount of evapotranspiration equaled the precipitation minus the amount of soil moisture increase. Evapotranspiration values were computed from mean monthly soil moisture values and monthly precipitation, and expressed as mean daily and monthly values for the period of June through September.

Soil Temperature Regime

Soil temperatures were determined at depths of one inch and six inches below the surface by means of a three-pen soil thermograph. A third temperature element was located six inches above the soil surface. Figure 2 indicates the location of the three-pen thermograph, which was on the Hillsdale sandy loam - Metea sandy loam complex. The temperature records used in this study include the years

1946 through 1951 (pre-treatment period) and 1952 through 1957 (post-treatment period). Average weekly and monthly temperatures from each of the three locations or depths were compared with average weekly and monthly air temperatures at 4.5 feet above ground (hygrothermograph at meteorological station) to determine effects of treatment on soil and surface air temperatures.

Unincorporated Organic Matter

A measure of the amount of unincorporated organic matter, i.e. all organic matter down to mineral soil, on the treated watershed area and the surrounding untreated area was obtained during November of 1957. All unincorporated organic matter, excluding limbs and large twigs, was collected from within one foot square sample plots. Samples were obtained from within each soil type on the watershed and corresponding soil types on the untreated area immediately adjacent to the watershed. The samples were oven-dried at 100°C for twenty-four hours and the oven-dry weight recorded. The weight of unincorporated organic matter on each soil type was expressed as tons per acre.

Determination of Treatment Effects on Water Yield and Quality

Runoff or water yield from the watershed represents the net results of the interaction of the various vegetative and pedologic factors affecting the disposition of precipitation on the watershed. By studying the runoff behavior of the watershed before and after vegetative treatment the over-all hydrologic effect of treatment may be ascertained. The quality of water (silt content) running off from the water-shed serves as an indication of the effectiveness of the vegetative cover in protecting the soil from raindrop impact and the scouring action of surface runoff. Therefore, a comparison of erosion amounts before and after treatment may indicate whether the treatment reduced the effectiveness of the vegetative cover.

Runoff

Runoff records were available for the entire period of study, 1941 - 1957. Runoff characteristics, i.e. average annual runoff, average monthly runoff, average runoff per storm, average maximum rates of runoff per hour and twenty-four hours, average rate per storm, and frequency of runoff were determined for the pre-treatment period and contrasted with post-treatment runoff characteristics. All runoff data were analyzed in consideration of precipitation received on the area.

Infiltration

The average infiltration rate, in inches per hour, (r_{av}) for the watershed (includes interception losses) was determined for storms occuring during the frost-free season. Hydrograph analysis, as described by Foster (1948), was employed to determine the average infiltration rate. Infiltration rates for storms occuring before treatment were contrasted with rates for storms after treatment, in an attempt to detect effects of vegetative treatment.

Erosion

The silt content of all runoff water was determined for the entire period of study, 1941 - 1957. Pre-treatment amounts, expressed as pounds per acre, were contrasted to post-treatment amounts in order to ascertain any degree of change which might be attributable to treatment effect.

CHAPTER VI

RESULTS AND DISCUSSION

The results of this study of some effects of a commercial-type clearcut on soil and water relations on a small wooded watershed are presented in two parts. The first part is devoted to the presentation and discussion of the results of the soil studies. The second part is devoted to the results of the hydrologic aspects of the study.

Soil Studies

The soil is the fundamental water regulating agent on a watershed. The physical characteristics of the soil determines its hydrologic characteristics, i.e. infiltration, percolation, and storage capacity. These characteristics in turn determine the disposition of precipitation in terms of surface runoff, subsurface flow, and water storage within the soil mantle.

Soil Physical Properties

Because physical properties of soils are rather sensitive to vegetation and land use changes it is of fundamental importance in watershed management research to ascertain the effects of these changes or treatments on the soil physical properties in order to evaluate any changes in water regime of an area. The study of runoff and erosion from a treated watershed indicates the nature of the treatment on water regime, but in order to determine the reasons why the treatment causes certain changes in water regime it is necessary to first determine what changes are effected in the soil reservoir.

Soil texture. Soil texture refers to the relative proportions of sand, silt, and clay separates in the soil. As the number and size distribution of soil particles in a unit volume determines soil texture, texture determines the amount of surface area, and in turn, the water holding capacity of the soil. For a given volume of soil, the smaller the size of primary particles the greater the water holding capacity. The American Society of Civil Engineers (1949) indicates that clay can hold nine times as much water as fine sand against the force of gravity. The retention storage capacity, in terms of inches depth of water per foot depth of soil, of sandy loam is given as 1.7 inches, loam 3.3 inches, and clay 4.5 inches. From the above discussion it is apparent that soil texture has a definite hydrologic function.

Since it is generally recognized that the texture of the soil can be altered very little by vegetative treatment (Lutz and Chandler, 1949), the purpose for the determination of soil texture in this study was to furnish a check on the previously established textural classifications as well as provide textural information for additional depths of soils not previously sampled.

Soil texture data, as determined by means of mechanical analyses, are given for the various soil types and depths in Table 3. Textural data obtained by Smith (1954) are given in Table 4 as a comparison. The results of the mechanical analyses in both tables are rather comparable, with one notable exception. Smith's data list a soil type as Conover silt loam, while in the present study this soil type is listed as Metamora sandy loam. This constitutes a considerable discrepancy as to textural designation and the only plausible explanation offered is that the classification as silt loam is a result of the vagaries of sampling. The writer sampled the soil type in question intensively during the summer of 1957 and failed to detect any occurrence of a silt loam texture. The soil type would have formally been classified as Conover sandy loam but is now being mapped as Metamora sandy loam.[1]

The soils of the watershed exhibited a certain degree of similarity of texture in that all soils at all depths were classified as being loamy in nature, varying from sandy loam to clay loam. Loam soils are generally recognized as exhibiting favorable hydrologic properties as well as being more

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[1]The affirmation of this soil type was made in consultation with Mr. Ivan Schneider of the Soil Science Department at Michigan State University.

TABLE 3

SUMMARY OF RESULTS OF MECHANICAL ANALYSIS, 1957

Soil type and depth	Distribution of separates < 2 mm. sand	silt	clay	Texture
	- Per cent -			
Metamora sandy loam				
0 - 6 inch depth	67.4	22.2	10.4	sandy loam
12 - 18 inch depth	70.0	18.0	12.0	sandy loam
30 - 36 inch depth	63.2	25.8	11.0	sandy loam
42 - 48 inch depth	50.0	39.8	10.2	loam
Conover loam				
0 - 6 inch depth	41.2	39.6	19.2	loam
12 - 18 inch depth	37.2	32.6	30.2	clay loam
30 - 36 inch depth	9.2	56.4	34.4	silty clay loam
42 - 48 inch depth	51.2	37.8	11.0	loam
Miami loam				
0 - 6 inch depth	37.2	45.2	17.6	loam
12 - 18 inch depth	40.4	31.6	28.0	clay loam
30 - 36 inch depth	67.2	14.6	18.2	sandy loam
42 - 48 inch depth	71.4	12.4	16.2	sandy loam
Hillsdale sandy loam-Metea sandy loam				
0 - 6 inch depth	62.2	28.6	9.2	sandy loam
12 - 18 inch depth	67.2	25.6	7.2	sandy loam
30 - 36 inch depth	55.0	24.2	20.8	sandy clay loam
42 - 48 inch depth	75.0	13.4	11.6	sandy loam
Hillsdale sandy loam				
0 - 6 inch depth	60.0	28.2	11.2	sandy loam
12 - 18 inch depth	58.8	23.6	17.6	sandy loam
30 - 36 inch depth	51.8	23.6	24.6	sandy clay loam
42 - 48 inch depth	68.8	18.6	12.6	sandy loam

TABLE 4

SUMMARY OF RESULTS OF MECHANICAL ANALYSIS, 1953
(FROM SMITH, 1954)

Soil type and depth	Distribution of separates < 2 mm.		
	sand	silt	clay
	- Per cent -		
Conover silt loam			
0 - 3 inch depth	30.3	59.7	10.0
4 - 7 inch depth	31.3	51.3	17.4
12 - 15 inch depth	32.0	52.3	15.7
Conover loam			
0 - 3 inch depth	65.2	16.8	18.0
4 - 7 inch depth	67.7	15.3	17.0
12 - 15 inch depth	72.8	14.3	12.9
Miami loam			
0 - 3 inch depth	45.3	38.1	15.7
4 - 7 inch depth	47.3	35.0	17.5
12 - 15 inch depth	40.0	31.0	28.0
Hillsdale sandy loam-Metea sandy loam complex			
0 - 3 inch depth	63.9	28.5	7.4
4 - 7 inch depth	61.0	29.2	9.9
12 - 15 inch depth	50.0	26.2	24.8
Hillsdale sandy loam			
0 - 3 inch depth	-	-	-
4 - 7 inch depth	60.6	30.1	10.3
12 - 15 inch depth	57.1	26.1	16.8

favorable for forest growth than either coarse sands or fine clays. The part of this chapter devoted to hydrologic studies indicates the generally favorable hydrologic characteristics of these soils.

Bulk density. The bulk density of a soil may be defined as the ratio between the dry weight of a given volume of undisturbed soil and the weight of an equal volume of water (Lutz and Chandler, 1947). Volume weight and apparent density are terms frequently used in place of bulk density.

One of the most important factors influencing bulk density is soil structure. Very compact soils, with low pore volume, have high bulk density values. In contrast, loose, porous soils have low bulk densities. Consequently, since the bulk density of soils is greatly affected by soil structure, the measurement of bulk density should give a relative indication of the structural condition of a soil, providing, of course, that soil texture is also considered. Organic matter is another factor which influences soil bulk density. With other factors being equal, soils with a high content of organic matter have lower bulk densities than soils with a low organic matter content. With other factors being the same, a soil with a low bulk density would have a greater percolation rate, better aeration, and greater detention storage than a soil with high bulk density. It can be seen, therefore, that for a given soil if the bulk density values increase after vegetative treatment a deleterious hydrologic effect would likely be the result.

Bulk density values have been obtained by soil type for various depths on the watershed the second year after treatment, 1953, (Smith, 1954), the sixth year after treatment, 1957, and on the adjacent untreated area during 1957. These bulk density values have been summarized and are presented in Table 5. The results of the study indicate considerable variation between values obtained during 1953 and 1957 in the upper six inches of the profile. The 1953 values are consistantly lower than the 1957 values in the upper six inches, while the values for the 12 - 18 inch depth are of similar magnitude for these two years. Because the location of sample plots used in 1953 are unknown it is rather difficult to directly compare data for the two sampling years. The apparently lower bulk density values obtained during 1953 may be attributed to a thorough mixing of mineral soil and unincorporated organic matter in areas disturbed by skidding. The data indicate very little compaction attributable to logging. The values for the upper six inches obtained on the watershed during 1957 were consistantly lower than the values obtained on the adjacent area during the same year. Loss on ignition values, which are presented in a following section, indicate higher relative organic matter content in the upper six inches of the watershed soils than

TABLE 5

SUMMARY OF BULK DENSITY VALUES

Soil type and depth	Treated watershed 1953[a]	Treated watershed 1957	Untreated area 1957
Metamora sandy loam			
0 - 3 inch depth	1.36	1.30	-
3 - 6 inch depth	1.68	1.56	-
12 - 18 inch depth	1.60	1.59	-
30 - 36 inch depth	-	1.62	-
42 - 48 inch depth	-	1.63	-
Conover loam			
0 - 3 inch depth	1.00	.88	1.11
3 - 6 inch depth	1.27	1.20	1.47
12 - 18 inch depth	1.05	1.53	-
30 - 36 inch depth	-	1.41	-
42 - 48 inch depth	-	1.48	-
Miami loam			
0 - 3 inch depth	.70	1.10	1.18
3 - 6 inch depth	1.01	1.21	1.30
12 - 18 inch depth	1.51	1.39	-
30 - 36 inch depth	-	1.64	-
42 - 48 inch depth	-	1.62	-
Hillsdale sandy loam-Metea sandy loam complex			
0 - 3 inch depth	.87	.97	1.22
3 - 6 inch depth	1.09	1.29	1.42
12 - 18 inch depth	1.43	1.40	-
30 - 36 inch depth	-	1.67	-
42 - 48 inch depth	-	1.55	-
Hillsdale sandy loam			
0 - 3 inch depth	.76	1.15	1.19
3 - 6 inch depth	1.01	1.33	1.63
12 - 18 inch depth	1.35	1.77	-
30 - 36 inch depth	-	1.70	-
42 - 48 inch depth	-	1.57	-

[a]From Smith, 1954.

TABLE 5

SUMMARY OF BULK DENSITY VALUES

Soil type and depth	Treated watershed 1953[a]	Treated watershed 1957	Untreated area 1957
Metamora sandy loam			
0 - 3 inch depth	1.36	1.30	-
3 - 6 inch depth	1.68	1.56	-
12 - 18 inch depth	1.60	1.59	-
30 - 36 inch depth	-	1.62	-
42 - 48 inch depth	-	1.63	-
Conover loam			
0 - 3 inch depth	1.00	.88	1.11
3 - 6 inch depth	1.27	1.20	1.47
12 - 18 inch depth	1.05	1.53	-
30 - 36 inch depth	-	1.41	-
42 - 48 inch depth	-	1.48	-
Miami loam			
0 - 3 inch depth	.70	1.10	1.18
3 - 6 inch depth	1.01	1.21	1.30
12 - 18 inch depth	1.51	1.39	-
30 - 36 inch depth	-	1.64	-
42 - 48 inch depth	-	1.62	-
Hillsdale sandy loam-Metea sandy loam complex			
0 - 3 inch depth	.87	.97	1.22
3 - 6 inch depth	1.09	1.29	1.42
12 - 18 inch depth	1.43	1.40	-
30 - 36 inch depth	-	1.67	-
42 - 48 inch depth	-	1.55	-
Hillsdale sandy loam			
0 - 3 inch depth	.76	1.15	1.19
3 - 6 inch depth	1.01	1.33	1.63
12 - 18 inch depth	1.35	1.77	-
30 - 36 inch depth	-	1.70	-
42 - 48 inch depth	-	1.57	-

[a]From Smith, 1954.

in the soils on the adjacent untreated area. This higher organic matter content may be a contributing factor to the lower bulk density values on the watershed.

As indicated in Table 5 the watershed soils were rather compact below thirty inches and in some instances below twelve inches. The bulk density averages 1.6 for the 30 - 48 inch depths, which is quite high for soils of medium texture. This degree of compactness exhibited by the soils probably offers sufficient resistance to prevent free access to tree roots. The writer observed very few roots below thirty inches depth when obtaining soil samples. Veihmeyer and Hendrickson (1948) have shown that roots do not readily penetrate sands with bulk densities greater than 1.75 and clays with bulk densities greater than 1.46 to 1. 63. From a hydrologic standpoint, restriction of the majority of tree roots to the upper thirty inches of soil would reduce the retention storage opportunity of the soil.

Porosity. Baver (1956) has defined soil porosity as the percentage of soil volume which is not occupied by solid particles. Soil porosity is one of the more important physical properties of soils, as considered from the standpoint of hydrology and watershed management. Hursh and Hoover (1941) state "Two most essential soil profile characteristics pertinent to hydrologic studies are functions of porosity. They are storage opportunity and the transmission rate of water." Since the soil acts as the reservoir of the watershed, soil porosity serves as an indicator of total storage space for water in the reservoir. The relative distribution of pore sizes, i.e. capillary and non-capillary, is of more practical significance than total porosity. A soil with a high percentage of capillary pore space will have a high retention capacity and a low percolation rate. Such soils would also be less likely to be droughty. A soil, on the other hand, which contained a large proportion of non-capillary pore space would have a low retention capacity, relatively high percolation rate, and would tend to be droughty.

Soil pore space constitutes two types of water storage space, retention and detention storage. Retention storage refers to the water held by the soil particles against the force of gravity, or capillary storage. This water moves so slowly as to be considered for all practical purposes as being in storage. Water in retention storage is available for use by vegetation and evaporation, but is unavailable for streamflow. Non-capillary or large pores provide another form of storage. Water moves downward through these pores under the influence of gravity and is only temporarily detained, hence the use of the term detention storage. This water is available for streamflow or to replenish the ground water supply.

It is apparent that the storage space provided by soil pore volume is of utmost importance from a hydrologic standpoint and any change in the type and amount of pore space by vegetative treatment would be of great importance. Lassen, et al., (1951) state "The effects of land use and vegetation on the soil are reflected principally in the resulting changes in the number, shape, and size of its pores."

A summary of total, capillary, and non-capillary porosity values is given in Table 6. Porosity values at various tensions are also given in Table 7. The results of the study indicate a rather favorable total pore volume in the upper six inches of soil for all soils examined. However, capillary porosity accounts for approximately seventy per cent of the total porosity while more ideally constituted soils would contain fifty per cent capillary porosity and fifty per cent non-capillary porosity. Below twelve inches depth the total pore volume drops considerably, i.e. less than forty per cent. At these lower depths capillary porosity accounts for an even higher percentage of the total pore volume. At a depth of 30 - 36 inches in the Hillsdale sandy loam the capillary porosity accounts for eight-nine per cent of the total porosity. These low porosity values are reflected in the bulk density values in the preceding section and the percolation rates in the following section on permeability. Comparison of porosity values obtained during 1953 and 1957 on the

TABLE 6

SUMMARY OF TOTAL, CAPILLARY, AND NON-CAPILLARY PORE SPACE

Soil type and depth	Per cent porosity: Capillary (60 cm. tension)			Non-capillary (60 cm. tension)			Total		
	Ta 1953	Tb 1957	Uc 1957	T 1953	T 1957	U 1957	T 1953	T 1957	U 1957
Miami loam									
0 - 3 inch depth	37.10	35.73	28.57	16.90	12.70	20.44	53.29	48.43	49.01
3 - 6 inch depth	34.90	33.47	27.94	14.60	12.20	14.79	49.50	45.10	42.73
12 - 18 inch depth	35.19	31.49	-	3.59	11.88	-	38.78	43.37	-
30 - 36 inch depth	-	28.56	-	-	6.35	-	-	34.91	-
42 - 48 inch depth	-	24.38	-	-	9.47	-	-	33.85	-
Hillsdale sandy loam									
0 - 3 inch depth	38.01	37.93	27.08	16.09	12.10	19.13	54.09	50.03	46.21
3 - 6 inch depth	37.38	30.72	24.46	10.67	13.78	11.97	48.05	44.50	36.43
12 - 18 inch depth	28.65	27.50	-	9.65	5.61	-	38.30	33.11	-
30 - 36 inch depth	-	33.04	-	-	4.07	-	-	37.11	-
42 - 48 inch depth	-	23.95	-	-	11.42	-	-	35.37	-
Hillsdale sandy loam-Metea sandy loam com.									
0 - 3 inch depth	33.02	29.93	27.45	17.40	24.61	20.46	50.42	54.54	47.91
3 - 6 inch depth	32.38	29.07	23.22	13.86	16.72	16.58	46.25	45.79	39.80
12 - 18 inch depth	34.62	24.81	-	10.18	12.54	-	43.80	37.35	-
30 - 36 inch depth	-	24.57	-	-	8.60	-	-	33.17	-
42 - 48 inch depth	-	32.85	-	-	7.80	-	-	40.65	-

TABLE 6 (continued)

Soil type and depth	Per cent porosity: Capillary (60 cm. tension)			Non-capillary (60 cm. tension)			Total		
	T 1953	T 1957	U 1957	T 1953	T 1957	U 1957	T 1953	T 1957	U 1957
Metamora sandy loam									
0 - 3 inch depth	38.38	33.43	-	13.27	13.23	-	51.65	46.66	-
3 - 6 inch depth	26.38	27.18	-	5.67	10.14	-	32.05	37.32	-
12 - 18 inch depth	25.65	24.42	-	9.65	11.22	-	35.30	35.64	-
30 - 36 inch depth	-	30.96	-	-	6.23	-	-	37.19	-
42 - 48 inch depth	-	32.57	-	-	5.85	-	-	38.42	-
Conover loam									
0 - 3 inch depth	35.21	43.45	36.83	12.87	16.92	13.44	48.08	60.37	49.27
3 - 6 inch depth	25.25	39.77	32.66	9.20	10.58	8.46	34.45	50.35	41.12
12 - 18 inch depth	30.86	33.49	-	9.76	9.16	-	40.62	42.62	-
30 - 36 inch depth	-	37.95	-	-	9.55	-	-	47.50	-
42 - 48 inch depth	-	34.61	-	-	9.99	-	-	44.60	-

[a]Treated watershed, 1953. Smith, 1954.

[b]Treated watershed, 1957.

[c]Untreated area adjacent to the watershed, 1957.

TABLE 7

SUMMARY OF POROSITY VALUES AT VARIOUS TENSIONS

Soil type and depth	Per cent porosity at various tensions							
	saturation		20 cm.		40 cm.		60 cm.	
	T[a] 1957	U[b] 1957	T 1957	U 1957	T 1957	U 1957	T 1957	U 1957
Miami loam								
0 - 3 inch depth	48.43	49.01	38.78	34.19	36.79	30.45	35.73	28.57
3 - 6 inch depth	45.44	42.73	36.20	33.73	33.19	29.78	32.65	27.94
12 - 18 inch depth	43.37	-	33.94	-	32.32	-	31.49	-
30 - 36 inch depth	34.91	-	30.82	-	29.61	-	28.56	-
42 - 48 inch depth	33.85	-	29.53	-	26.23	-	24.38	-
Hillsdale sandy loam								
0 - 3 inch depth	50.03	46.21	42.99	33.24	40.13	29.44	37.93	27.08
3 - 6 inch depth	44.50	36.43	36.71	31.34	32.80	27.39	30.72	24.46
12 - 18 inch depth	33.11	-	29.57	-	28.37	-	27.50	-
30 - 36 inch depth	37.11	-	34.82	-	33.90	-	33.04	-
42 - 48 inch depth	35.37	-	29.71	-	25.77	-	23.95	-
Hillsdale sandy loam-Metea sandy loam complex								
0 - 3 inch depth	54.54	47.91	39.97	33.84	33.73	29.58	29.93	27.45
3 - 6 inch depth	45.79	39.80	38.85	29.35	33.35	25.32	29.07	23.22
12 - 18 inch depth	36.35	-	32.72	-	28.08	-	24.81	-
30 - 36 inch depth	33.17	-	29.27	-	26.72	-	24.57	-
42 - 48 inch depth	40.65	-	35.84	-	34.09	-	32.85	-

TABLE 7 (continued)

Soil type and depth	Per cent porosity at various tensions							
	saturation		20 cm.		40 cm.		60 cm.	
	T 1957	U 1957	T 1957	U 1957	T 1957	U 1957	T 1957	U 1957
Metamora sandy loam								
0 - 3 inch depth	46.66	-	39.51	-	36.22	-	33.43	-
3 - 6 inch depth	37.32	-	33.13	-	30.01	-	27.18	-
12 - 18 inch depth	35.64	-	29.69	-	26.36	-	24.42	-
30 - 36 inch depth	37.19	-	33.74	-	32.44	-	30.96	-
42 - 48 inch depth	38.42	-	35.11	-	33.73	-	32.57	-
Conover loam								
0 - 3 inch depth	60.37	49.47	47.97	39.48	44.91	37.84	43.45	36.83
3 - 6 inch depth	50.35	41.12	43.94	34.53	41.23	33.35	39.77	32.66
12 - 18 inch depth	42.65	-	36.05	-	34.28	-	33.49	-
30 - 36 inch depth	47.50	-	41.31	-	39.12	-	37.95	-
42 - 48 inch depth	44.60	-	38.18	-	35.50	-	34.61	-

[a]Represents the treated watershed during 1957.

[b]Represents the untreated adjacent area during 1957.

watershed and 1957 on the adjacent area does not indicate any definite trend in soil pore volume, which may be attributable to the vegetative treatment. It is interesting to note that the porosity values for the upper six inches of the soil profile on the watershed during 1953 and 1957 were consistantly higher than those porosity values obtained during 1957 on the adjacent untreated area.

Figures 17a. and b. illustrate graphically the relative distribution of capillary and non-capillary pore volume by depth of the various soils of the watershed in 1957. Several of the soils, namely Miami loam, Hillsdale sandy loam, and Metamora sandy loam possess very limited non-capillary porosity within the 30 - 36 inch depth, indicating impeded water movement through this zone. This is of particular importance with Metamora sandy loam since it occupies the intermittant drainage areas and the low central basin of the watershed (Fig. 2, Chapter III). Subsurface flow from the higher lying soils tends to concentrate within the Metamora sandy loam and because of the impeded drainage there is a tendency for a perched water table to develop. This condition was observed frequently during May, June, and July of 1957, when the water table was within three to six inches of the soil surface.

Permeability. Dawson (1954) defines permeability as "the property of a material which permits the passage of

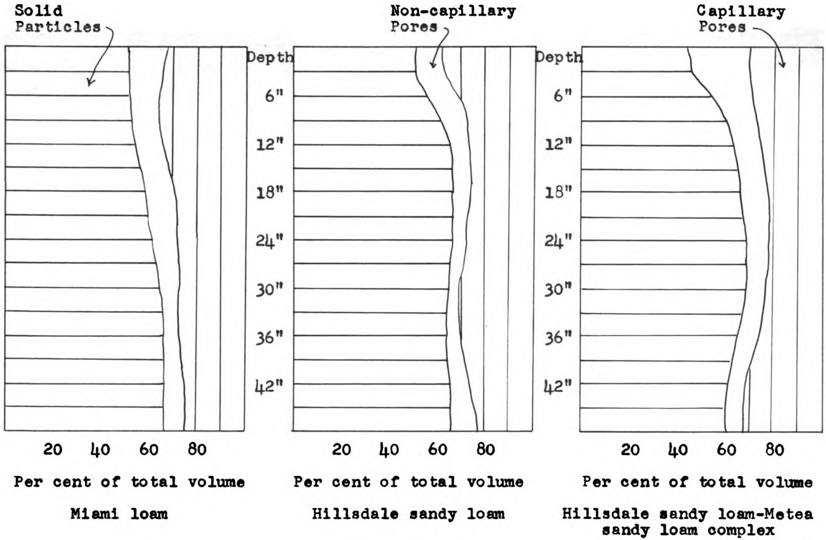


Fig. 17a.-Pore-space relationships in the Miami loam, Hillsdale sandy loam, and Hillsdale sandy loam-Metea sandy loam complex, 1957.

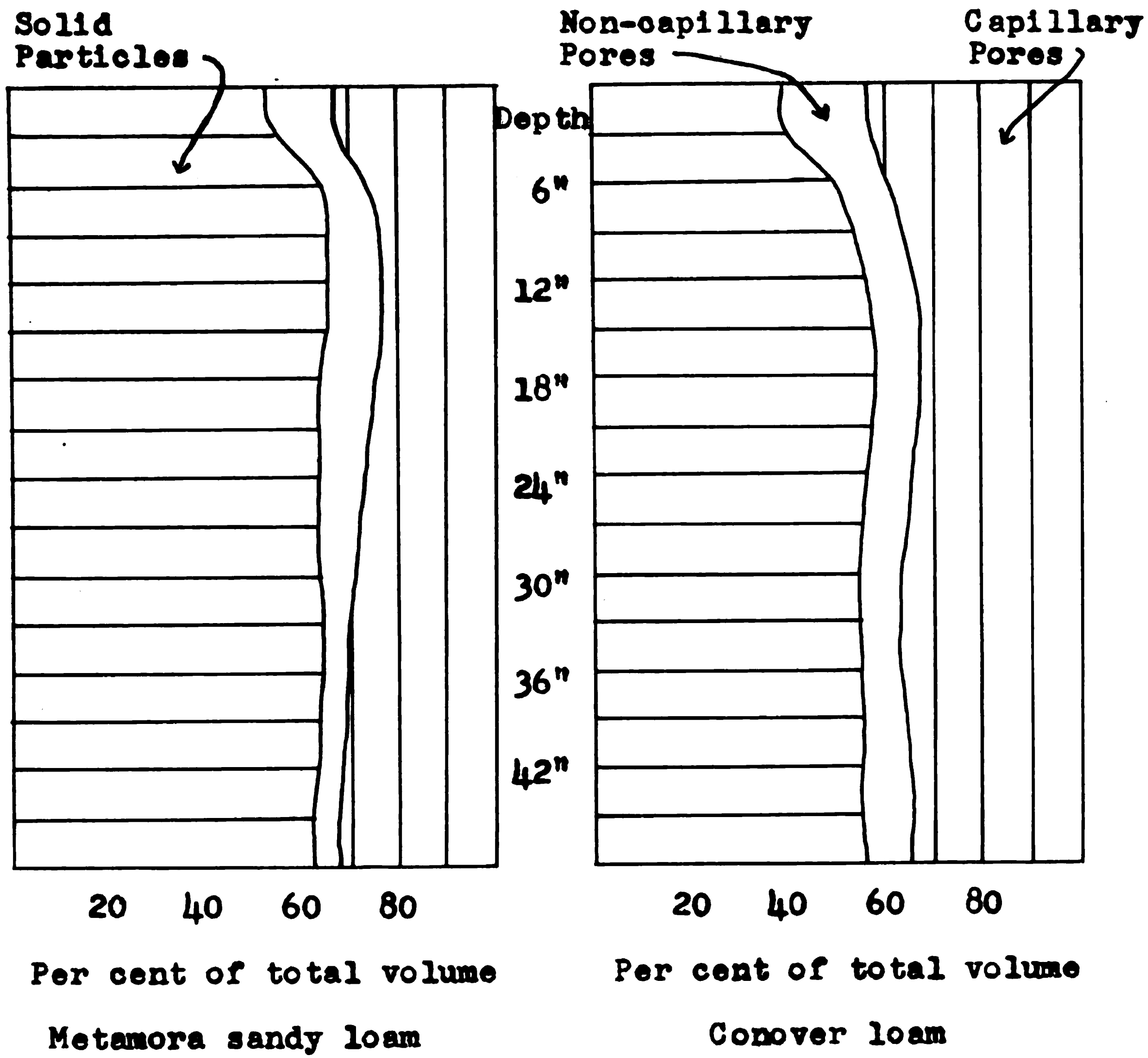


Fig. 17b.-Pore-space relationships in the Metamora sandy loam and Conover loam, 1957.

fluids through its pores." Permeability of a soil refers to the relative ease with which water moves through the non-capillary pore space in the profile. The rate at which water moves through a saturated soil is termed the percolation rate. Percolation differs from infiltration in that infiltration is the entry of surface water into the surface of the soil, while percolation is the movement of water through the soil. Infiltration proceeds independently of percolation phenomena until the soil becomes saturated, then the percolation rate of the least permeable layer of the soil profile determines the minimum infiltration (f_c). Soil permeability affects the disposition of precipitation into surface, subsurface, and base flow, and the utilization of storage space. From a hydrologic standpoint, it can be seen that soil permeability is of fundamental importance in watershed research.

Percolation rates were determined for the soils on the watershed and for the adjacent untreated area during 1957 and are summarized in Table 8. The study does not indicate any pronounced trend in percolation rates as a result of the vegetative treatment. In comparing the percolation rates of the treated and untreated areas for the 0 - 6 inch depths considerable variation is noted between the two areas. The greater variation appears to be in the 0 - 3 inch depth, while there are several percolation values for the 3 - 6 inch depth which are quite similar. All of the watershed soils, as well

TABLE 8

SUMMARY OF PERCOLATION RATES IN INCHES PER HOUR

Soil type	Depth of sampling - in inches				
	0-3	3-6	12-18	30-36	42-48
Miami loam	5.72	3.47	1.46	.26	.30
Hillsdale sandy loam	5.92	7.64	.20	.21	.98
Hillsdale sandy loam-Metea sandy loam complex	25.80	3.70	1.66	1.17	.75
Metamora sandy loam	2.33	.81	.88	.23	.27
Conover loam	30.99	10.60	4.47	2.31	1.73
Untreated area					
Miami loam	27.81	1.64	-	-	-
Hillsdale sandy loam	12.98	1.03	-	-	-
Hillsdale sandy loam-Metea sandy loam complex	9.78	3.70	-	-	-
Conover loam	18.62	10.07	-	-	-

as the soils of the adjacent area, have rather rapid percolation rates for the 0 - 6 inch depth. A notable exception is that of Metamora sandy loam which has a low percolation rate (.81 inches per hour) for the 3 - 6 inch depth. Several of the watershed soils, Miami loam, Hillsdale sandy loam, and Metamora sandy loam have limiting percolation rates ranging between .2 and .3 of an inch per hour in the 30 - 36 inch depths. This limiting percolation rate tends to promote subsurface flow downslope in the Miami loam and Hillsdale sandy loam. With the Metamora sandy loam, however, there is little opportunity for any degree of subsurface flow because of low transmisability rate below the three inch depth, as indicated by the percolation rate at this depth. Thus, water concentrates on and within this soil type. The Conover loam, which occupies the area immediately before the runoff approach section (Fig. 2, Chapter III), has the most favorable water drainage properties of any of the watershed soils. The minimum percolation rate for this soil type is 1.73 inches per hour, at the 42 - 48 inch depth. It is within this soil type that most of the water concentrated on and within the Metamora sandy loam is percolated to the underlying water table, thus reducing to a minimum runoff from the watershed. The Hillsdale sandy loam - Metea sandy loam complex exhibits rather rapid percolation rates throughout the profile and it is unlikely that this soil type contributes to surface runoff.

Field capacity. Veihmeyer and Hendrickson (1931) have defined field capacity as ".....the amount of water held in the soil after the excess gravitational water has drained away." Field capacity represents the maximum amount of water which can be held in the capillary pore space of a soil. From a hydrologic viewpoint, field capacity represents an important soil moisture equilibrium point. When a soil is at field capacity, retention storage is satisfied and any additional moisture received by the soil will go into detention storage and eventually into streamflow, ground water, or evapotranspiration. Dreibelbis (1944) states "The amount of water in the profile in excess of the field capacity is usually held but a relatively short time. It is, however, very important from the viewpoint of flood control because much of this water is likely to contribute to storm-runoff." Since soils normally drain to field capacity and plants permanently wilt at the wilting percentage, it may be seen that the amount of water available to plants is represented by the difference between these two equilibrium values. This difference also represents total retention storage for a particular soil. The difference between field capacity and saturation represents the total detention storage in a soil.

A summary of field capacity values (moisture content in per cent by volume) for the watershed soils for various depths is given in Table 9. The determination of field capacity values in this study was not for purposes of determining effects of vegetative treatment, as such, but to be used as a tool in the computation of available soil moisture and also to be used in interpreting soil moisture measurements.

<u>Permanent wilting percentage</u>. Baver (1956) defines the permanent wilting percentage as ".....that moisture content at which soil cannot supply water at a sufficient rate

TABLE 9

SUMMARY OF SOIL MOISTURE EQUILIBRIUM POINTS

Soil type and depth	Per cent moisture - volume basis	
	Field capacity[a]	Wilting point[b]
Miami loam		
0 - 3 inch depth	37.76	6.98
3 - 6 inch depth	33.05	8.43
12 - 18 inch depth	31.64	14.36
30 - 36 inch depth	28.65	11.79
42 - 48 inch depth	24.58	9.96
Hillsdale sandy loam		
0 - 3 inch depth	37.72	7.04
3 - 6 inch depth	30.87	5.04
12 - 18 inch depth	27.56	10.53
30 - 36 inch depth	33.03	16.66
42 - 48 inch depth	23.86	8.20
Hillsdale sandy loam-Metea sandy loam complex		
0 - 3 inch depth	30.14	8.86
3 - 6 inch depth	29.13	6.53
12 - 18 inch depth	24.85	3.50
30 - 36 inch depth	24.65	15.05
42 - 48 inch depth	32.86	8.00
Metamora sandy loam		
0 - 3 inch depth	33.68	4.51
3 - 6 inch depth	27.22	2.91
12 - 18 inch depth	24.42	5.24
30 - 36 inch depth	30.94	5.14
42 - 48 inch depth	32.58	4.63
Conover loam		
0 - 3 inch depth	43.05	19.79
3 - 6 inch depth	39.73	16.90
12 - 18 inch depth	33.45	21.42
30 - 36 inch depth	37.94	19.54
42 - 48 inch depth	34.69	17.95

[a]Moisture held in the soil at 60 cm. of tension.

[b]Moisture held in the soil at 15 atmos. of tension.

to maintain turgor, and the plant permanently wilts." Veihmeyer and Hendrickson (1945) have shown that the permanent wilting percentage is not a unique value, but a small range of soil moisture contents within which permanent wilting takes place. This range need not exceed one per cent for fine-textured soils or .5 per cent for coarse-textured soils. The permanent wilting percentage represents the lower limits of retention storage and, also, the lower limit of available moisture. As mentioned above, the difference between the moisture content at field capacity and permanent wilting percentage represents the amount of available water in the soil. It also indicates total retention storage. The permanent wilting percentage is affected by such factors as soil texture, structure, and organic matter content.

Permanent wilting percentage values (per cent moisture by volume) are summarized for the watershed soils in Table 9. As with the field capacity data, no attempt is made to attribute treatment effects to these soil moisture equilibrium points but they are used in determining available soil moisture, as indicated in the section on soil moisture regime.

<u>Loss on ignition</u>. Although loss on ignition represents only an estimation of total soil organic matter, when comparing similar soils the relative difference in organic matter constitutes a valid comparison. Physical properties of soils, such as structure, porosity, bulk density, permeability, and

moisture equilibrium points are modified or affected by organic matter. Soil organic matter is particularly important in its influence on the formation and maintenance of soil aggregation. It is generally recognized that organic matter increases the water holding capacity of the soil, though it does not necessarily increase the amount of available soil moisture (Baver, 1956). Since the primary source of soil organic matter is the vegetative cover of an area, particularly the trees, any change in the vegetative density or cover type should be reflected in the relative amounts of soil organic matter.

Loss on ignition values for the watershed soils and the adjacent area are summarized for 1957 in Table 10. As would be expected, the relative organic matter contents decrease with increasing soil depth. The watershed soils have an average loss on ignition value for the 0 - 6 inch depth of 5.57 per cent, while the soils on the adjacent untreated area have an average of 3.72 per cent. This indicates that the watershed soils averaged 49.73 per cent more loss on ignition than the soils of the adjacent area or, in other words, the soils of the treated area contained relatively greater amounts of organic matter in the 0 - 6 inch depth than the soils of the untreated area. This apparent increase in organic matter may be the result of a change in litter type as affected by the vegetative treatment. Prior to treatment the predominant

TABLE 10

RELATIVE SOIL ORGANIC MATTER CONTENT

Soil type and depth	Loss on ignition watershed 1957	Loss on ignition adjacent 1957	Organic matter 1953[a]
		- Per cent -	
Miami loam			
0 - 3 inch depth	5.81	5.10	18.3
3 - 6 inch depth	4.59	2.40	6.4
12 - 18 inch depth	3.09	-	.1
30 - 36 inch depth	1.87	-	-
42 - 48 inch depth	1.67	-	-
Hillsdale sandy loam			
0 - 3 inch depth	5.97	4.37	19.3
3 - 6 inch depth	3.12	1.69	5.6
12 - 18 inch depth	2.29	-	.9
30 - 36 inch depth	2.52	-	-
42 - 48 inch depth	2.38	-	-
Hillsdale sandy loam-Metea sandy loam complex			
0 - 3 inch depth	7.58	4.18	15.0
3 - 6 inch depth	3.42	1.99	6.3
12 - 18 inch depth	.90	-	.7
30 - 36 inch depth	1.72	-	-
42 - 48 inch depth	1.34	-	-
Metamora sandy loam			
0 - 3 inch depth	3.68	-	5.3
3 - 6 inch depth	1.60	-	1.5
12 - 18 inch depth	1.75	-	-
30 - 36 inch depth	1.47	-	-
42 - 48 inch depth	1.77	-	-
Conover loam			
0 - 3 inch depth	13.66	6.86	8.8
3 - 6 inch depth	6.49	3.17	3.4
12 - 18 inch depth	3.93	-	.2
30 - 36 inch depth	3.60	-	-
42 - 48 inch depth	3.96	-	-

[a]Determined by means of the dry-combustion method for organic matter determination (Smith, 1954).

litter type was oak and hickory, while after treatment a more herbaceous type of vegetation prevailed on the watershed. As generally recognized, oak and hickory leaves are more resistant to decomposition than leaves of herbaceous vegetation, hence with a more rapid rate of decomposition more organic matter is incorporated into the soil. Dils (1953) in a study in the southern Appalachians found that organic matter content was greater under coppice type forest than under undisturbed forest.

Unincorporated Organic Matter

The term unincorporated organic matter, as used in this study, refers to the litter layer (L), fermentation layer (F), and the humus layer (H) as described by Lutz and Chandler (1947). The amount of unincorporated organic matter present on the surface of a particular soil exerts certain fundamental and important influences. First of all, the unincorporated organic matter is the primary source of soil organic matter. Secondly, unincorporated organic matter protects the soil surface from raindrop impact, thus preventing the destruction of soil structure and the attendent decrease in infiltration rate. An important hydrologic function of unincorporated organic matter is its ability to absorb large quantities of precipitation. According to Trimble and Lull (1956) the field capacity of humus ranges between 100 and 200 per cent of its oven-dry weight, while minimum field-moisture contents range between twenty and forty per cent. Blow (1955) studying litter under upland oak forests in eastern Tennessee found that moisture content at saturation ranged between 200 and 250 per cent, while field capacity was approximately 135 per cent. Blow also stated that litter intercepted approximately one inch of precipitation per year, but considered this negligible compared to the reduction in evaporation provided by the litter. It is quite evident that the role of unincorporated organic matter in watershed hydrology is an important one.

A summary of relative amounts of total unincorporated organic matter found on the watershed and adjacent untreated area during 1957 is given in Table 11. The study indicates that the average amount of unincorporated organic matter on the untreated adjacent area (5.80 tons per acre) was 58.07 per cent more than that on the treated watershed (3.53 tons per acre). This additional amount found on the untreated area is not necessarily an indication of greater annual accumulations, but may be indicative of a more rapid rate of organic matter decomposition on the treated area. A more rapid rate of decomposition of unincorporated organic matter due to treatment, if this is the case, may be the result of higher soil and air temperatures on the treated area and lower resistance to decomposition of herbaceous foliage. The hypothesis of more rapid decomposition is substantiated by

TABLE 11

TOTAL UNINCORPORATED ORGANIC MATTER

Soil type	Watershed 1957	Adjacent area 1957
	- Tons per acre -	
Miami loam	3.48	6.32
Hillsdale sandy loam	4.57	5.88
Hillsdale sandy loam-Metea sandy loam complex	3.48	4.68
Metamora sandy loam	1.74	-
Conover loam	4.36	6.32
Average	3.53	5.80

the 49.73 per cent increase in soil organic matter (loss on ignition values) in the 0 - 6 inch depth on the treated area, contrasted to the untreated adjacent area.

The amounts of unincorporated organic matter on the various soil types of the watershed are rather uniform, with the exception of the Metamora sandy loam. A portion of this soil type supports a grass cover which would contribute less organic material to the soil surface than a herbaceous or forest cover, hence the smaller amount listed for this type.

Numerous studies have shown that reduction or removal of unincorporated organic matter (particularly litter) usually results in the destruction of surface soil structure, increased surface runoff, and increased erosion. These deleterious effects have been noted regardless of whether the vegetative cover was disturbed or not. The apparent reason, in the writer's opinion, for the lack of significant treatment effect on soil physical properties in this study is that the unincorporated organic matter layer was not sufficiently disturbed during the logging to expose the mineral soil. Also, the lopped logging slash left on the watershed area provided additional protection.

Soil Moisture Regime

The amount of moisture in the soil at any particular time is a function of the amount of precipitation received and the type and condition of vegetative cover on the soil. Soil moisture, therefore, may be considered a dynamic physical property of the soil mass. Under relatively static conditions of vegetative cover, i.e. the type of vegetative cover remains the same over a period of years, soil moisture exhibits certain seasonal variations which are governed by seasonal precipitation and seasonal stages of vegetative development. This trend of seasonal soil moisture variation may be determined for a particular area by measuring soil moisture throughout the seasons of the year over a period of years. What happens to the established trend of seasonal soil moisture variation when the vegetative cover of an area is changed?

Since the portion of the soil in which soil moisture is affected by vegetation is limited to the zone of active rooting, it is this zone in which changes in soil moisture is to be expected as a result of vegetation manipulation. Soil moisture occurs in the soil primarily in the capillary and non-capillary pore spaces. The moisture in the non-capillary pore spaces is subject to gravitational drainage and is retained a relatively short time (two to three days) provided no restricting soil layers are present to prevent percolation to greater depths. On the other hand, moisture in the capillary pore space is, for all practical purposes, not affected by gravitational force. This capillary moisture is removed by evaporation (only within the surface foot of soil) and transpiration. As soils normally drain to field capacity (maximum capillary moisture) and plants wilt at the permanent wilting percentage, the amount of moisture in the soil between these two moisture equilibrium points represents water available to plants. Therefore, it is within this range of soil moisture, i.e. available moisture, that vegetation exerts its most pronounced influence. This does not mean that evaporation and transpiration do not effect removal of gravitational soil moisture but it is difficult to determine the amount to be attributed to these losses.

The trends of seasonal soil moisture variation prior to treatment, the first year after treatment and six years after treatment are presented graphically for the 0 - 6 inch, 12 - 18 inch, and 30 - 36 inch depths in Figures 18 a, b, and c. Monthly precipitation is also graphically represented on these figures. The trend of soil moisture for the various depths prior to treatment generally exhibits the influence of precipitation and vegetation throughout the year. Late fall, winter, and spring are characterized as periods of moisture storage in the soil, primarily because of minimum transpiration demands of vegetation during this period. The period of June, July, and August is one of soil moisture depletion, as a result of increased evapotranspiration demands. September marks the beginning of a period of soil moisture accretion which extends into December. Since the soil moisture values for the pre-treatment period represent average monthly values for a six year period the graphical representation of these values appears as a rather smooth curve. In contrast, the monthly values for the individual post-treatment years (1952 and 1957) appear extremely variable, particularly for the 0 - 6 inch depth. It may be noted, however, that soil moisture during the first post-treatment year was consistantly greater at all depths than the average for the pre-treatment period. This difference, as would be expected, is most pronounced during the growing season, reflecting the effect of vegetation removal. The soil moisture values for 1957 (sixth post-treatment year) tend to occupy an intermediate position, i.e. greater than the pre-treatment average and less than the first post-treatment year. This tendency of the 1957 year to occupy the medium position perhaps indicates a return of soil moisture values to the pre-treatment condition owing to the re-establishment of vegetative cover.

The soil moisture values represented by Figures 18 a, b, and c, are for total soil moisture and do not reflect merely evapotranspiration losses, but also percolation losses as well. Figure 19 illustrates graphically inches of available soil moisture in the upper three feet of soil. The soil moisture fluctuations exhibited in this graph are directly attributable to precipitation and evapotranspiration. Available moisture remained at a high level throughout the first post-treatment year while that of the sixth year after treatment occupied the middle position. This was especially apparent during the period of high transpirational draft, i.e. June through September.

The comparison of soil moisture values of individual years with averaged values for a period of years does not indicate whether the variation exhibited by the individual years is significantly greater than the variation which may have occurred for a particular year within the averaged period. In order to provide a more valid comparison of pre-treatment and post-treatment soil moisture values an analysis of variance (Snedecor, 1953) was used to detect statistical signifi-

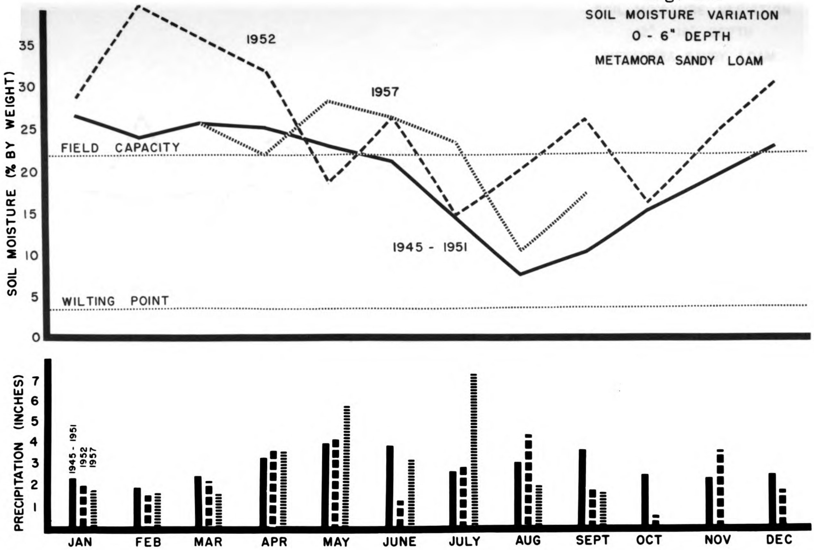


Fig. 18a
SOIL MOISTURE VARIATION
0 - 6" DEPTH
METAMORA SANDY LOAM

Fig. 18b
SOIL MOISTURE VARIATION
12" - 18" DEPTH
METAMORA SANDY LOAM

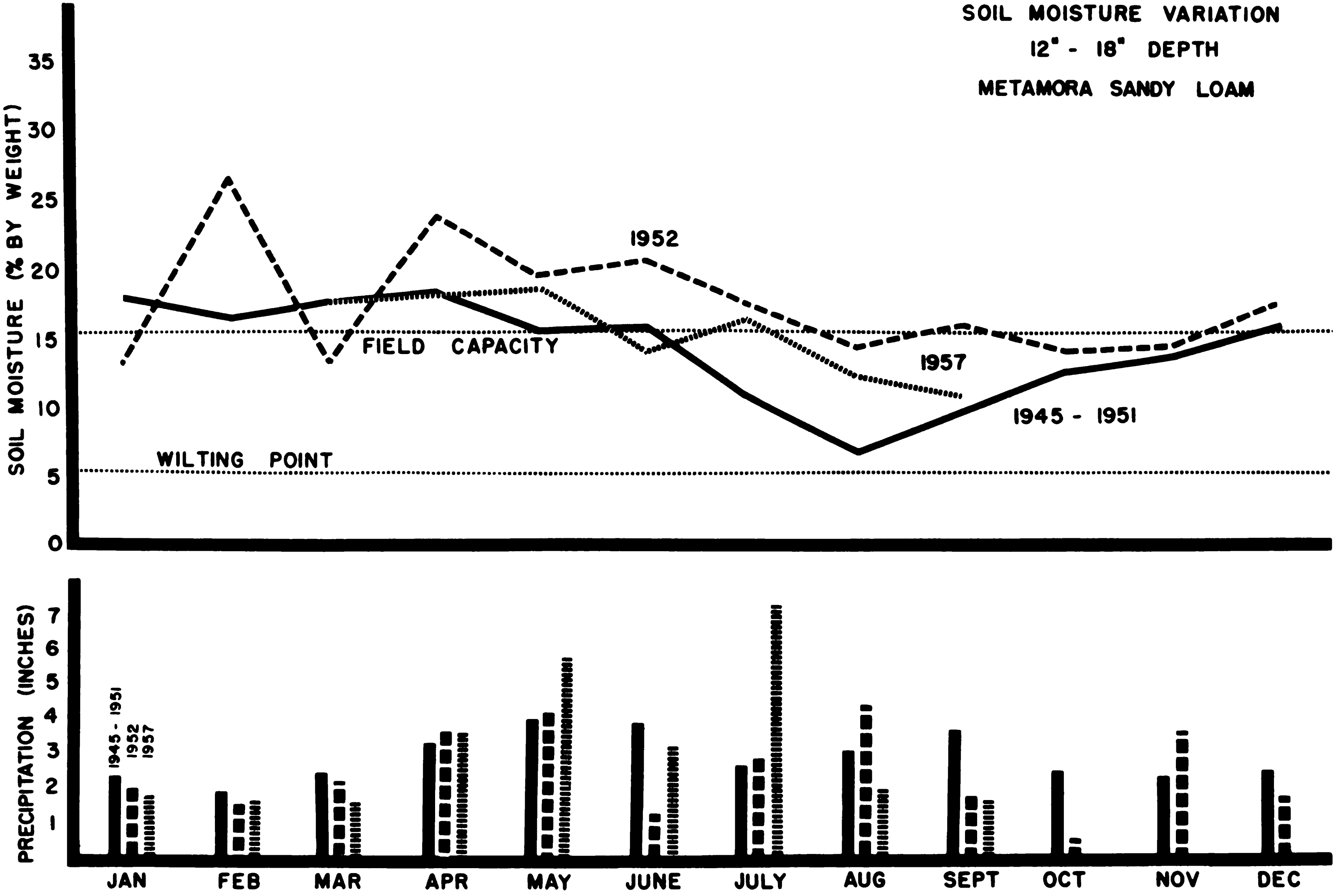
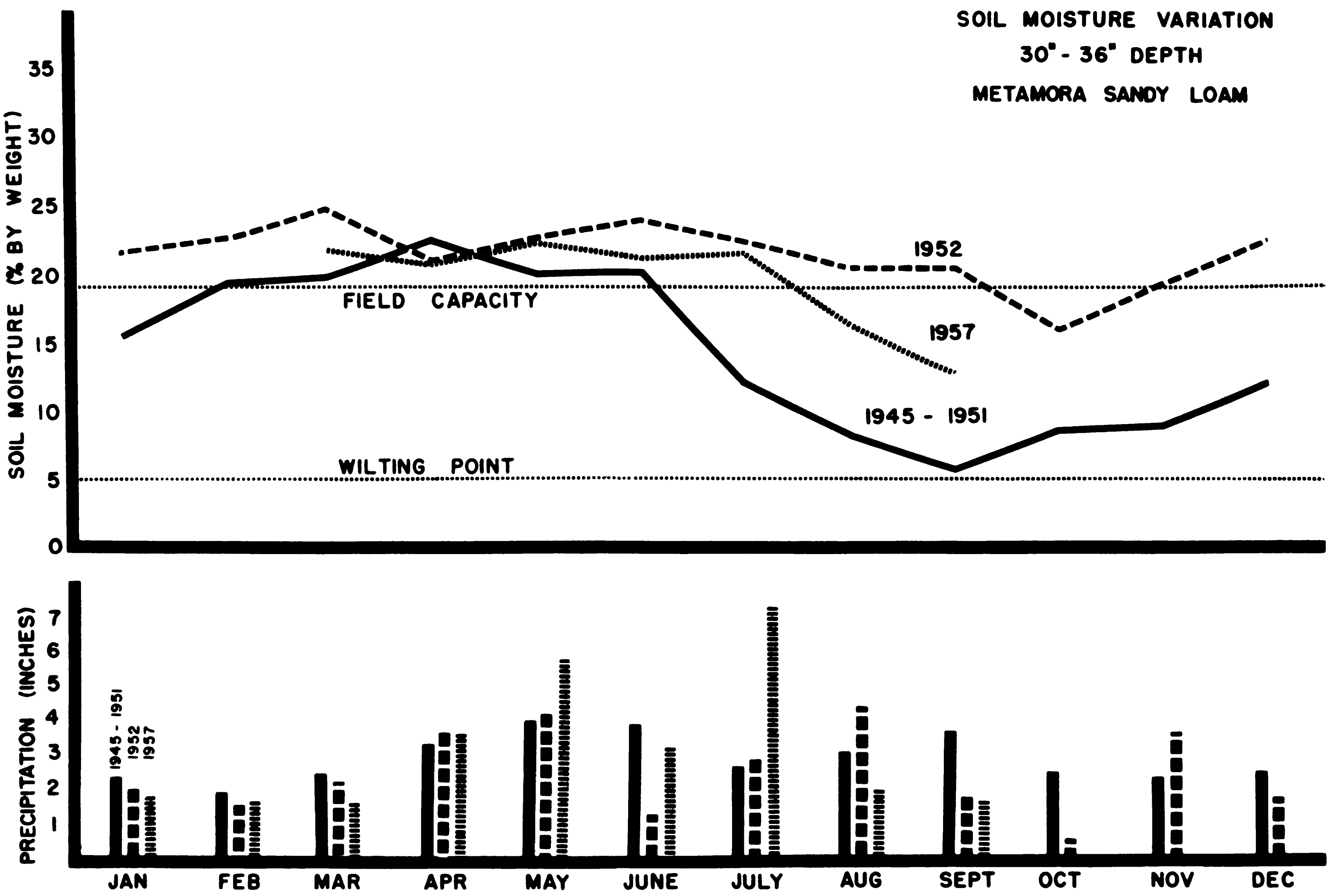


Fig. 18c


SOIL MOISTURE VARIATION
30" - 36" DEPTH
METAMORA SANDY LOAM
SOIL MOISTURE (% BY WEIGHT)
35
30
25
20
15
10
5
0
1952
1957
1945 - 1951
FIELD CAPACITY
WILTING POINT
PRECIPITATION (INCHES)
7
6
5
4
3
2
1
1945 - 1951
1952
1957
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC

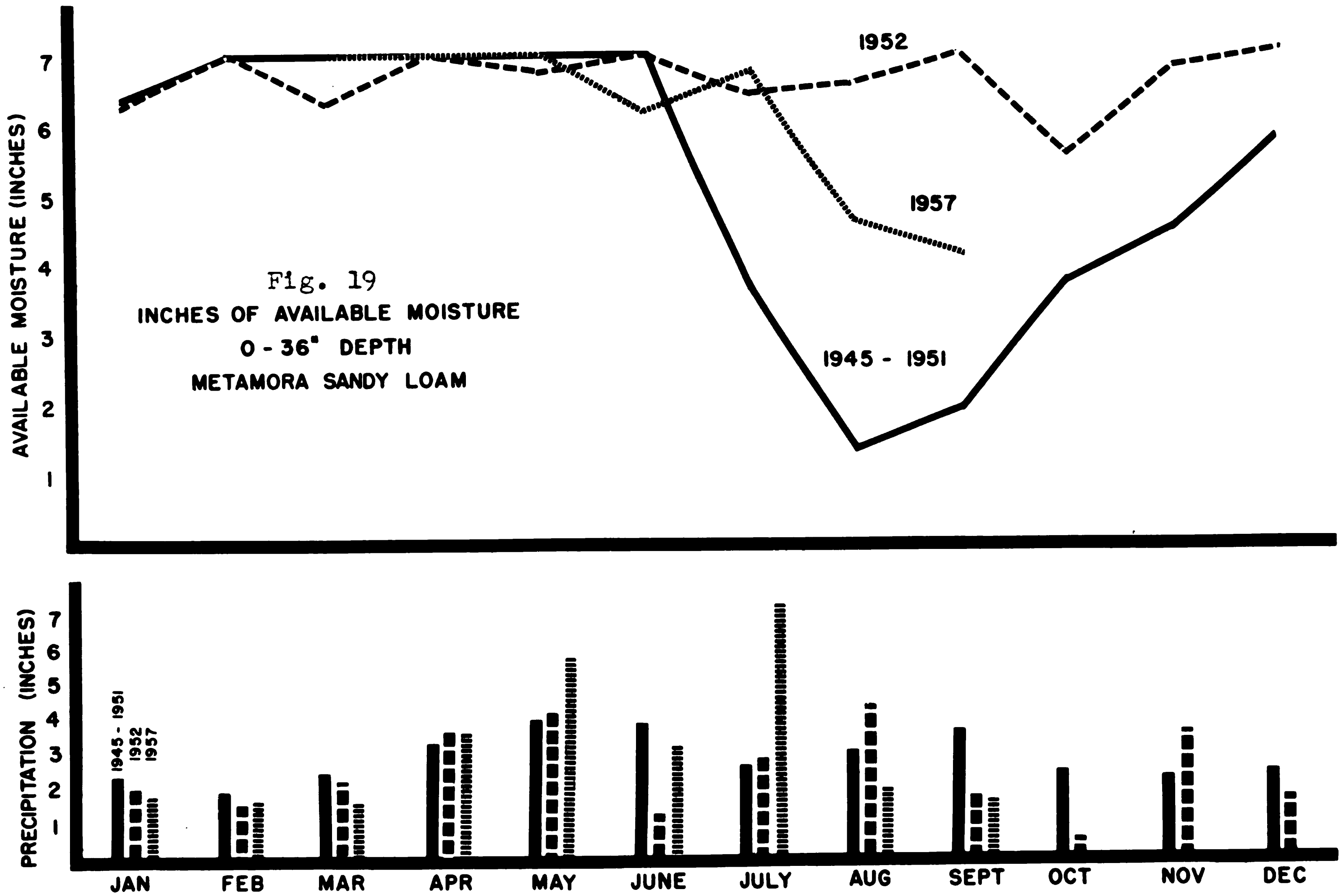


Fig. 19
INCHES OF AVAILABLE MOISTURE
0 - 36" DEPTH
METAMORA SANDY LOAM

cance between mean monthly values of soil moisture during the growing season (actually March through September) for the individual years. Table 12a summarizes the average monthly soil moisture values in inches of available water for 0 - 36 inches depth, for the years 1946 - 1952 and 1957. The analysis of variance indicated a highly significant (one per cent level) difference between monthly soil moisture means for the individual years, Table 12b. To determine which years were significantly different the mean soil moisture values for the individual years were subjected to a "studentized range" test (Duncan, 1955). The results of this analysis, Table 12c, indicate that 1952 soil moisture values were significantly different (five per cent level) from all other years except 1947 and 1957. The two years, i.e. 1947 and 1957, both received more precipitation than the year 1952 (Table 14a), which perhaps explains the lack of significant difference.

As a further attempt to ascertain the effect of vegetative treatment on soil moisture content of the 0 - 36 inch depth the average monthly soil moisture for the period of maximum transpirational draft, i.e. July, August, and September, for the individual years of the study were analyzed statistically. Table 13a summarizes the soil moisture data for this period. The analysis of variance indicated a highly significant difference (one per cent level) between the individual years, Table 13b. To determine which years were

TABLE 12

a

AVERAGE MONTHLY SOIL MOISTURE, DURING THE GROWING SEASON, METAMORA SANDY LOAM, 0 - 36 INCH DEPTH, 1946 - 1952 AND 1957

	1946	1947	1948	1949	1950	1951	1952	1957
	- inches of available water -							
March	7.02	6.71	7.06	6.86	7.06	7.06	6.34	7.06
April	7.00	7.06	7.06	7.06	7.06	7.06	7.06	7.04
May	7.06	7.06	7.06	7.06	6.32	7.06	6.82	7.06
June	6.74	7.06	6.33	6.04	7.06	6.90	7.06	6.26
July	2.09	5.39	3.65	2.83	5.11	3.36	6.49	6.84
August	.88	2.66	1.29	.95	2.42	1.28	6.62	4.62
September	1.56	5.06	1.17	.63	2.95	1.81	7.06	4.17
Average	4.62	5.86	4.80	4.49	5.43	4.93	6.78	6.15

b

ANALYSIS OF VARIANCE

Source of variation	Degrees of freedom	Sums of squares	Mean squares	F
Total	55	273.25		
Years	7	33.75	4.68	3.60**
Months	6	185.93	30.99	
Error	42	54.57	1.30	

**Significant at the one per cent level.

TABLE 12 (continued)

c

STUDENTIZED RANGE TEST

	1946	1947	1948	1949	1950	1951	1952	1957
1946	-	NS[a]	NS	NS	NS	NS	S[b]	S
1947		-	NS	S	NS	NS	NS	NS
1948			-	NS	NS	NS	S	NS
1949				-	NS	NS	S	S
1950					-	NS	S	NS
1951						-	S	NS
1952							-	NS
1957								-

[a]Not significant at the five per cent level.

[b]Significant at the five per cent level.

significantly different the monthly soil moisture means for the individual years were subjected to the "studentized range" test. The results of this test, Table 13c, indicate 1952 soil moisture values were significantly different from all other years at the five per cent level and significantly different from all except 1957 at the one per cent level.

On the basis of the statistical analyses it appears that the vegetative treatment significantly increased soil

TABLE 13

a

AVERAGE MONTHLY SOIL MOISTURE DURING THE PERIOD OF MAXIMUM TRANSPIRATIONAL DRAFT, 0 - 36 INCH DEPTH, METAMORA SANDY LOAM, 1946 - 1952 AND 1957

	1946	1947	1948	1949	1950	1951	1952	1957
			- Inches of available water -					
July	2.09	5.39	3.65	2.83	5.11	3.36	6.49	6.84
August	.88	2.66	1.29	.95	2.42	1.28	6.62	4.62
September	1.56	5.06	1.17	.63	2.95	1.81	7.06	4.17
Average	1.51	4.37	2.04	1.47	3.49	2.15	6.72	5.21

b

ANALYSIS OF VARIANCE

Source of variation	Degrees of freedom	Sums of squares	Mean squares	F
Total	23	100.53		
Years	7	77.95	11.14	21.42**
Months	2	15.36	7.68	
Error	14	7.22	.52	

**Significant at the one per cent level.

c

STUDENTIZED RANGE

- five per cent level -

	1946	1947	1948	1949	1950	1951	1952	1957
1946		S[a]	NS[b]	NS	S	NS	S	S
1947	S		S	S	NS	S	S	NS
1948	NS	S		NS	S	NS	S	S
1949	NS	S	NS		S	NS	S	S
1950	S	NS	NS	S		S	S	S
1951	NS	S	NS	NS	NS		S	S
1952	S	S	S	S	S	S		S
1957	S	NS	S	S	NS	S	NS	

- one per cent level -

[a]Significant

[b]Non-significant

moisture during 1952. However, soil moisture during 1957 seemed to be approaching pre-treatment conditions.

As mentioned previously, the amount of precipitation affects the amount of moisture in the soil. To determine whether average monthly precipitation for the growing season for the individual years of study was significantly different an analysis of variance was employed. Table 14a presents monthly precipitation during the months of March through September for the years 1946 through 1952 and 1957. The

TABLE 14

a

AVERAGE MONTHLY PRECIPITATION DURING THE GROWING SEASON
1946 - 1952 AND 1957

	1946	1947	1948	1949	1950	1951	1952	1957
				- Inches -				
March	2.19	1.84	4.08	2.28	2.06	1.76	2.09	1.62
April	.70	5.78	2.11	2.05	4.61	3.80	3.58	3.46
May	3.96	4.23	4.28	2.16	2.22	3.09	4.09	5.66
June	3.66	3.31	3.98	3.43	4.94	3.17	1.15	3.15
July	.18	2.81	2.75	3.77	4.75	1.41	2.79	7.22
August	1.16	5.33	1.33	2.06	3.40	2.54	4.35	1.87
September	1.71	5.66	2.14	2.62	3.94	2.72	1.68	1.60
Average	1.94	4.14	2.95	2.62	3.70	2.64	2.82	3.51

b

ANALYSIS OF VARIANCE

Source of variation	Degrees of freedom	Sums of squares	Mean squares	F
Total	55	112.14		
Years	7	24.29	3.47	1.91
Months	6	11.39	1.90	
Error	42	76.46	1.82	

average monthly precipitation was not significantly different for the individual years of study (Table 14b). Of the two primary factors affecting available soil moisture i.e. precipitation and vegetation, precipitation did not prove significantly different for the period of study. It therefore appears that significant soil moisture increases can be attributed to vegetative treatment. The increases in soil moisture noted in this study cannot be attributed entirely to evapotranspiration reduction, but also to reduced interception losses.

Soil moisture sampling, prior to 1957, was restricted to the Metamora sandy loam soil type. To establish the relationship between soil moisture on the sampled soil to that of the other types on the watershed a correlation analysis was run on the data in Table 15. This table summarizes average monthly available soil moisture in the 0 - 36 inch depth for the five soil types on the watershed. Table 16 presents the results of the correlation analysis. It appears that soil moisture in the Metamora sandy loam varies as the soil moisture varies in the other watershed soils. Thus, soil moisture in the Metamora sandy loam serves as an "indicator" of soil moisture in the other soil types on the watershed and as such gives a relative measure of over-all soil moisture for the watershed.

TABLE 15

AVERAGE MONTHLY SOIL MOISTURE DURING THE GROWING SEASON
0 - 36 INCH DEPTH, BY SOIL TYPE, 1957

Month	Soil type				
	Miami loam	Hillsdale sandy loam	Hillsdale sandy loam-Metea sandy loam complex	Metamora sandy loam	Conover loam
	- inches of available water -				
March	6.03	5.22	6.04	7.06	4.96
April	4.64	5.44	5.38	7.06	5.43
May	4.82	5.41	6.11	7.06	5.25
June	3.77	4.22	4.88	6.73	4.92
July	3.47	4.29	4.45	6.92	4.73
August	1.21	.86	2.41	4.34	2.65
September	.91	1.23	2.61	4.29	3.15
Average	3.55	3.81	4.55	6.21	4.44

TABLE 16

CORRELATION BETWEEN SOIL MOISTURE CONTENTS OF WATERSHED SOILS

Soil types compared	Correlation coefficient
Metamora sandy loam and Miami loam	.94**
Metamora sandy loam and Hillsdale sandy loam	.98**
Metamora sandy loam and Hillsdale sandy loam-Metea sandy loam complex	.94**
Metamora sandy loam and Conover loam	.95**

**Significant at the one per cent level.

Evapotranspiration

Evapotranspiration refers to the removal of water from the soil by evaporation (usually the surface foot) and transpiration (throughout the depth of effective rooting). Evapotranspiration constitutes the major depleting agent of available soil moisture. The importance of evapotranspiration to hydrologic research is immediately apparent. By removing available soil moisture, retention storage is created and this in turn affects detention storage, because retention storage must be satisfied before water can go into detention storage. This concept is important in flood control efforts. On the other hand, reduction of transpiration losses by vegetative manipulation would tend to increase water yield from an area (Lull, 1953). Hoover (1944), in a study in the southern Applachians, reported that cutting all forest vegetation increased water yield by an amount equal to the estimated transpiration.

Computed evapotranspiration values for Metamora sandy loam are presented in Table 17. Average daily evapotranspiration for the period of June through September was lower during 1952 than during any other year of the study. Also total monthly evapotranspiration was lower for the same period. To determine whether the average daily evapotranspiration values were significantly different for the individual years of the study the data were subjected to an analysis of variance. The analysis indicated a significant difference (five per cent level) between years (Table 18a). To determine which years differed significantly, the data were analyzed by means of the "studentized range" procedure. The results, Table 18b, indicate that average daily evapotranspiration during 1952 was significantly less (five per cent level) than for 1947, 1949, and 1950. Only one other significant difference was detected, that being between 1946 and 1950. The above analyses indicate that 1952 evapotranspiration values were lowered, presumably because of vegetative treatment. Apparently vegetative recovery was nearly to pre-treatment status by 1957, as evapotranspiration values were not significantly different from pre-treatment years.

TABLE 17

AVERAGE DAILY AND MONTHLY EVAPOTRANSPIRATION DURING JUNE - SEPTEMBER, 1946 - 1952 AND 1957

Year	Inches per day				Average
	June	July	August	September	
1946	.13	.16	.08	.03	.10
1947	.11	.14	.26	.10	.13
1948	.16	.17	.12	.07	.13
1949	.15	.22	.13	.10	.15
1950	.14	.22	.20	.11	.17
1951	.11	.16	.15	.07	.12
Average	.14	.18	.16	.08	.14
1952	.05	.11	.14	.04	.08
1957	.12	.19	.14	.05	.12
	Inches per month				
1946	3.98	4.83	2.37	1.03	3.05
1947	3.31	4.48	8.06	3.26	4.78
1948	4.71	5.43	3.69	2.26	4.02
1949	4.45	6.98	3.94	2.94	4.58
1950	4.20	6.70	6.09	3.41	5.10
1951	3.33	4.95	4.62	2.19	3.77
Average	4.13	5.56	4.79	2.51	4.22
1952	1.39	3.36	4.22	1.24	2.55
1957	3.48	6.03	4.45	1.65	3.90

TABLE 18

a

ANALYSIS OF VARIANCE OF AVERAGE DAILY EVAPOTRANSPIRATION VALUES

Source of variation	Degrees of freedom	Sums of squares	Mean squares	F
Total	31	.0913		
Years	7	.0213	.0030	2.73*
Months	3	.0459	.0153	
Error	21	.0241	.0011	

b

STUDENTIZED RANGE ANALYSIS

	1946	1947	1948	1949	1950	1951	1952	1957
1946	-	NS[a]	NS	NS	S[b]	NS	NS	NS
1947		-	NS	NS	NS	NS	S	NS
1948			-	NS	NS	NS	NS	NS
1949				-	NS	NS	S	NS
1950					-	NS	S	NS
1951						-	NS	NS
1952							-	NS
1957								-

[a]Not significant at the five per cent level.

[b]Significant at the five per cent level.

In a study reported by Lull and Axley (1958) in New Jersey, evapotranspiration values were computed, in a manner similar to that used in the present study, for various cover types, including a thirty-two year old stand of black and red oak. Average daily evapotranspiration, as computed by Lull and Axley, during June and July was .13 inches per day (0 - 5 foot depth), while the average daily rate for the same period in this study, prior to treatment, was .16 inches per day (0 - 3 foot depth). The greater evapotranspiration rates reported in the present study are, perhaps, attributable to the age of the pre-treatment stand which was approximately twice the age of the stand reported on by Lull and Axley.

Soil Temperature Regime

Soil temperature is one of the more dynamic physical properties of the soil. According to Baver (1956), "Soil temperature is one of the more important factors that control microbiological activity involved in the production of plants." It is well recognized that the rate of organic matter decomposition increases with temperature. The role of frozen soil in hydrologic studies is also recognized. Soils containing concrete-type frost are, for all practicable purposes, impermeable to precipitation, thus promoting maximum surface run-off.

The temperature of the soil depends primarily upon the amount of radiant energy received from the sun. The vegetation of an area exerts a major effect on soil temperature by intercepting a considerable portion of the sun's radiant energy. The principle effect of forest vegetation on soil temperature is that of amelioration, i.e. reduces maximums and increases minimums. Consequently, the alteration of the vegetative cover of an area should considerably affect soil temperatures. Because air temperature immediately above the soil surface (six inches) is so intimately connected with soil temperature it is appropriate to discuss soil and air temperature trends together.

Mean monthly soil and air temperatures for the period 1946 through 1956 are listed in Table 19. Average pre-treatment soil and air temperatures generally exhibit recognized trends. Soil temperatures were higher than air temperatures from September through February. Soil temperatures were lower than air temperatures from March through August. The most apparent effect of hardwood forest on soil temperatures is exerted during the growing season, when the foliage intercepts considerable radiant energy. The reduction of the forest canopy resulted primarily in increased maximum soil and air temperatures (six inch air and one inch soil) during the summer months. Table 20 indicates the effect of vegetative treatment on air temperature six inches above the soil surface. Air temperature at six inches equaled or exceeded 90°F only twice prior to treatment, while after treatment

TABLE 19

MEAN MONTHLY SOIL AND AIR TEMPERATURES, 1946 - 1956

Year	Height or depth	J	F	M	A	M	J	J	A	S	O	N	D	Av.
		Degrees Fahrenheit												
1946	4.5'a	21.3	23.9	42.1	46.8	54.6	69.1	67.2	63.7	61.6	55.0	38.7	29.6	47.8
	6"b	20.2	26.5	43.8	48.1	59.4	65.0	68.4	63.8	62.6	54.8	38.1	29.9	48.4
	1"c	33.5	31.0	42.4	46.6	53.9	61.3	65.0	62.9	60.5	54.7	44.6	35.3	49.3
	6"d	35.4	33.2	40.1	44.6	50.1	58.6	64.6	62.6	60.8	54.9	48.6	40.0	49.5
1947	4.5'	22.5	19.4	27.7	44.7	53.4	65.5	65.3	73.0	50.3	55.6	35.3	25.6	44.9
	6"	20.0	16.9	26.8	44.2	58.4	64.5	66.4	75.0	57.5	54.3	34.0	21.2	44.9
	1"	30.0	29.8	30.0	42.7	53.3	58.2	61.3	67.3	60.3	55.6	44.2	35.0	47.3
	6"	33.7	31.1	30.8	38.9	49.9	57.3	61.6	70.0	62.0	56.9	46.9	36.7	48.0
1948	4.5'	14.1	20.6	30.2	50.0	56.3	62.2	66.8	65.7	63.0	47.0	42.5	28.2	45.6
	6"	12.7	18.5	29.6	51.7	59.5	63.6	67.9	69.1	64.3	47.2	42.0	25.4	46.0
	1"	29.6	26.7	32.7	46.9	54.1	58.6	64.0	62.9	61.0	49.6	44.8	34.0	47.1
	6"	31.8	28.9	31.7	44.4	51.8	56.5	63.5	63.5	62.1	52.6	48.0	37.2	47.7
1949	4.5'	27.3	25.1	33.7	48.0	56.5	66.6	70.5	68.3	56.5	48.9	30.8	31.1	46.9
	6"	24.2	22.4	34.5	50.4	59.5	67.5	72.5	72.6	58.7	49.2	26.6	21.7	46.6
	1"	32.1	29.7	34.7	44.6	53.5	61.2	66.8	67.1	57.4	53.4	39.5	34.0	47.9
	6"	33.3	31.7	33.2	43.6	53.4	59.6	67.1	66.2	58.3	56.7	45.0	36.8	48.7
1950	4.5'	30.2	19.8	31.9	40.4	56.8	62.9	65.5	64.3	58.4	52.8	35.5	21.7	45.0
	6"	25.9	19.3	28.2	37.6	50.3	57.7	63.1	62.5	54.9	49.1	30.2	19.6	41.5
	1"	32.6	26.8	30.6	41.0	54.5	59.7	62.0	62.1	57.7	52.6	40.8	30.5	45.9
	6"	34.4	30.0	30.6	38.2	50.8	58.6	61.4	61.8	59.3	55.3	44.6	34.1	46.6
1951	4.5'	25.4	18.5	35.4	46.6	58.2	62.9	65.5	63.8	55.8	52.1	32.6	24.3	45.1
	6"	24.0	17.1	38.6	48.9	59.6	62.6	65.9	64.3	56.6	57.7	31.6	25.5	46.0
	1"	27.8	26.7	33.4	43.5	57.1	57.2	61.3	60.3	55.1	50.6	35.4	30.6	44.9
	6"	30.7	29.5	33.0	41.6	50.7	57.1	61.6	62.0	56.4	51.8	38.2	34.6	45.6

TABLE 19 (continued)

Year	Height or depth	J	F	M	A	M	J	J	A	S	O	N	D	Av.
						Degrees Fahrenheit								
1952	4.5'	29.5	23.5	34.4	47.5	56.3	67.8	69.8	64.8	61.2	45.7	40.0	31.6	47.7
	6"	24.5	25.3	32.7	47.2	61.2	75.7	76.5	73.2	69.4	48.9	36.6	28.2	49.9
	1"	31.7	29.3	33.5	46.8	58.4	68.6	70.0	65.2	59.8	47.8	41.2	35.3	49.0
	6"	27.3	23.3	25.5	38.8	51.1	64.9	67.3	62.8	57.4	42.8	36.5	29.8	44.0
1953	4.5'	24.7	31.8	40.6	48.8	60.6	63.7	64.2	62.6	56.0	50.6	40.2	29.8	47.8
	6"	22.2	28.0	41.5	49.6	69.8	73.3	80.1	79.8	72.1	63.6	39.4	31.2	54.2
	1"	30.0	27.6	37.1	46.8	59.8	63.5	64.3	64.5	59.5	53.8	43.8	37.1	49.0
	6"	25.8	25.4	30.2	38.1	52.3	58.2	61.3	61.5	57.4	48.4	38.6	30.7	44.0
1954	4.5'	20.6	27.8	32.0	49.1	51.7	67.2	65.2	64.6	61.7	48.9	38.3	28.0	46.3
	6"	19.1	25.1	30.3	50.2	50.5	59.7	58.0	56.6	52.7	42.8	27.0	23.0	41.2
	1"	31.2	34.6	37.3	53.3	60.0	69.9	70.3	69.7	67.5	61.0	49.5	33.0	53.1
	6"	30.3	31.0	33.1	47.3	54.8	66.7	68.1	68.2	65.6	57.7	43.0	35.0	50.1
1955	4.5'	-	-	-	51.9	56.8	65.1	73.8	71.1	63.5	53.2	34.8	24.1	-
	6"	-	-	-	41.1	47.8	71.4	60.7	61.3	53.1	42.2	20.3	9.0	-
	1"	-	-	-	54.8	60.2	65.7	72.6	73.3	67.1	60.5	49.4	38.6	-
	6"	-	-	-	49.4	56.7	63.8	70.9	72.1	65.3	57.1	42.9	33.7	-
1956	4.5'	20.6	23.9	28.0	46.2	53.6	69.1	66.2	-	58.1	53.7	39.1	27.9	-
	6"	4.7	7.4	11.6	-	-	72.3	70.6	-	59.9	57.3	33.1	19.6	-
	1"	33.7	33.5	33.9	47.1	56.6	62.4	63.8	-	57.2	53.6	43.5	34.9	-
	6"	30.4	29.8	30.7	40.5	54.1	60.8	62.9	-	57.1	53.0	45.0	37.1	-

[a]Air temperature at 4.5 feet above the soil surface.
[b]Air temperature at six inches above the soil surface.
[c]Soil temperature one inch below the soil surface.
[d]Soil temperature six inches below the soil surface.

TABLE 20

FREQUENCY OF AIR TEMPERATURE AT 4.5 FEET AND SIX INCHES EQUALING OR EXCEEDING PRESCRIBED TEMPERATURES

Year	Number of times air temperature at 4.5 feet ⩾ 90 F		Number of times air temperature at six inches ⩾ 100 F
1946	8		0
1947	5		0
1948	5		1
1949	8		1
1950	0		0
1951	2	Pre-treatment	0
1952	10	Post-treatment	16
1953	3		14
1954	4		0
1955	10		0
1956	2		0

this temperature was equaled or exceeded thirty times.

Figure 20a, b, c, d, and e, illustrates graphically the soil and air temperature trends for the pre-treatment period and for 1952, 1953, 1954, and 1956. Average soil temperatures during the pre-treatment period were higher during the winter and lower during the summer than air temperatures. During 1952, the first post-treatment year, air

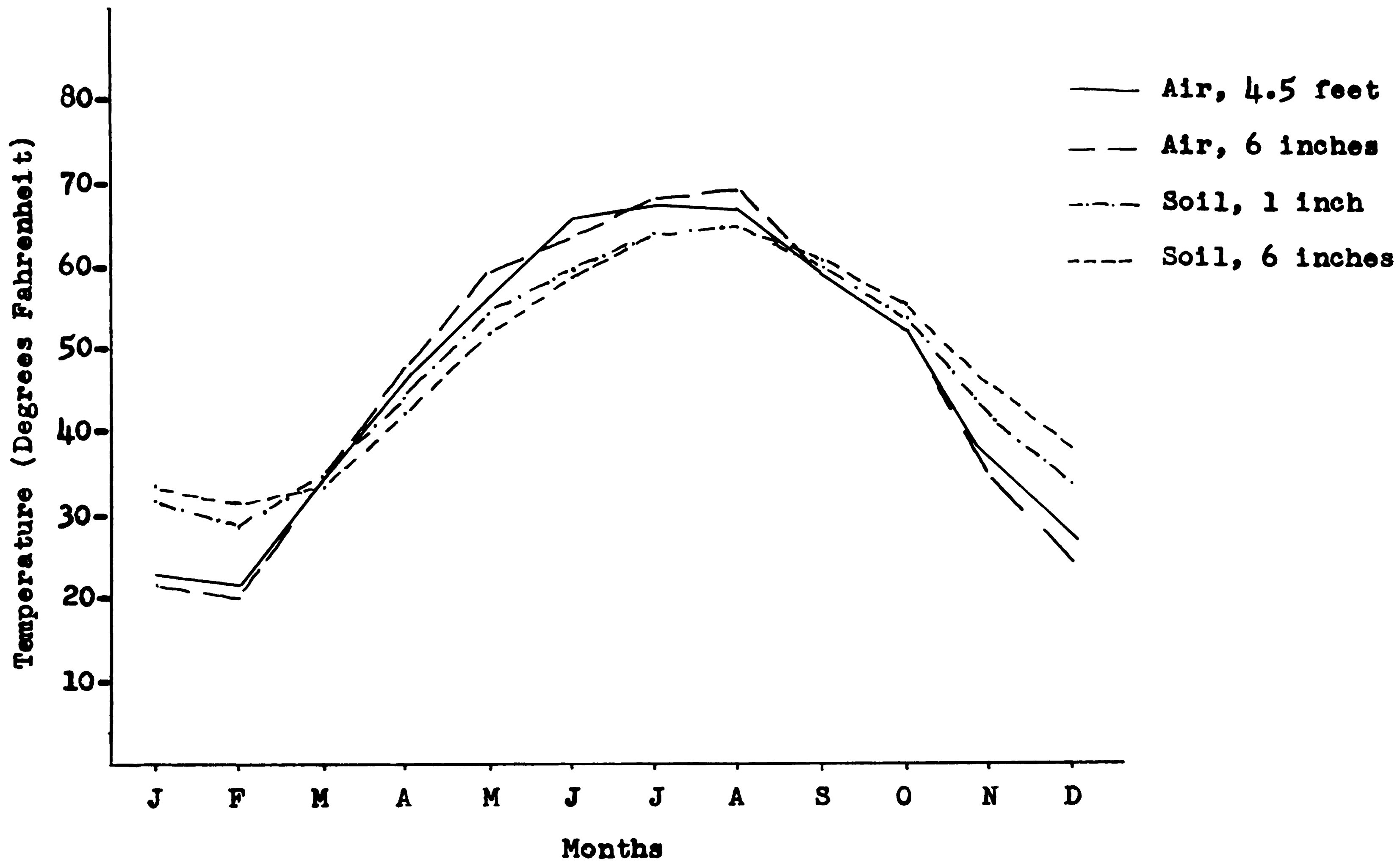


Fig. 20a.-Average monthly soil and air temperatures, pre-treatment period, 1946 - 1951.

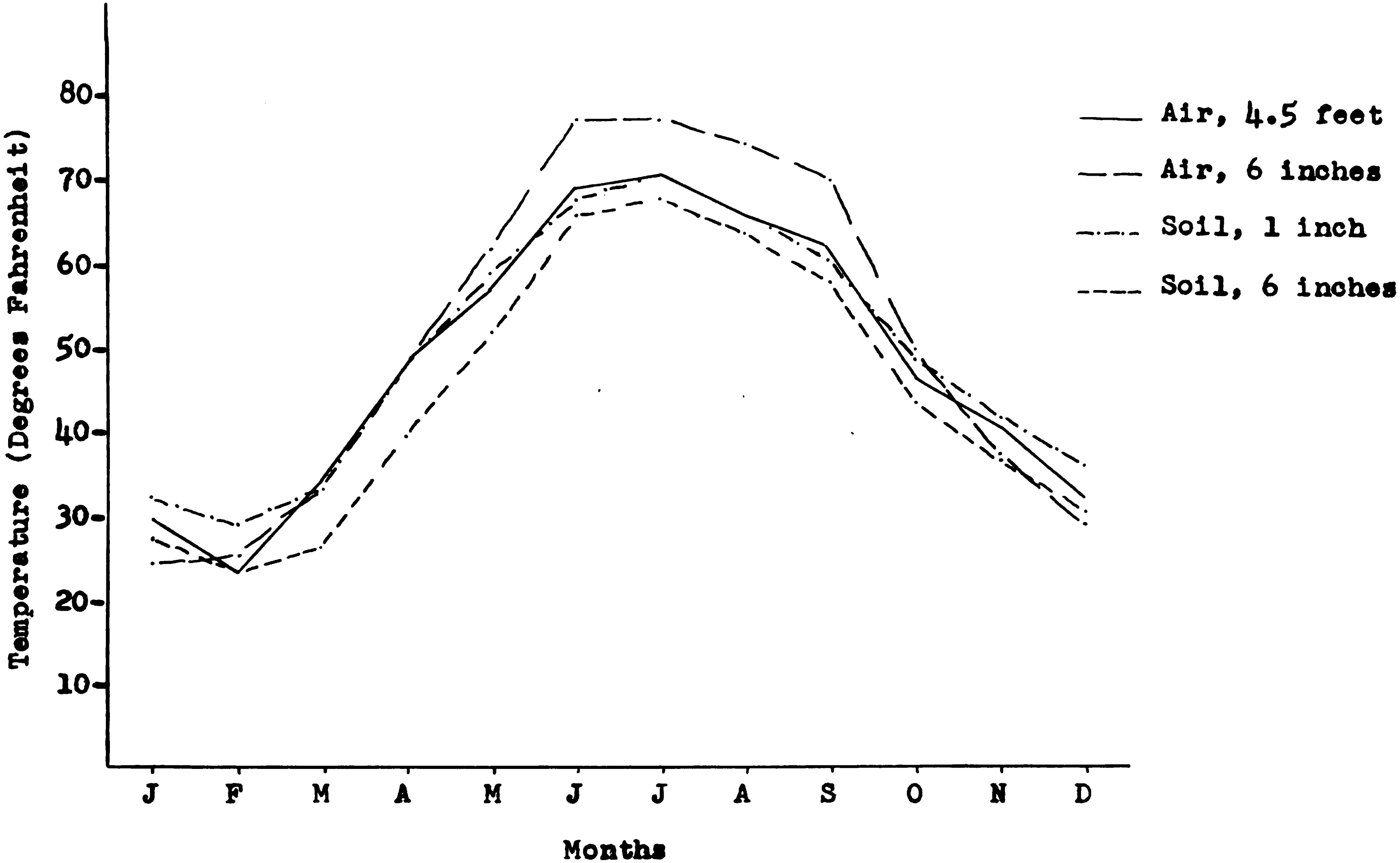


Fig. 20b.-Average monthly soil and air temperatures, 1952.

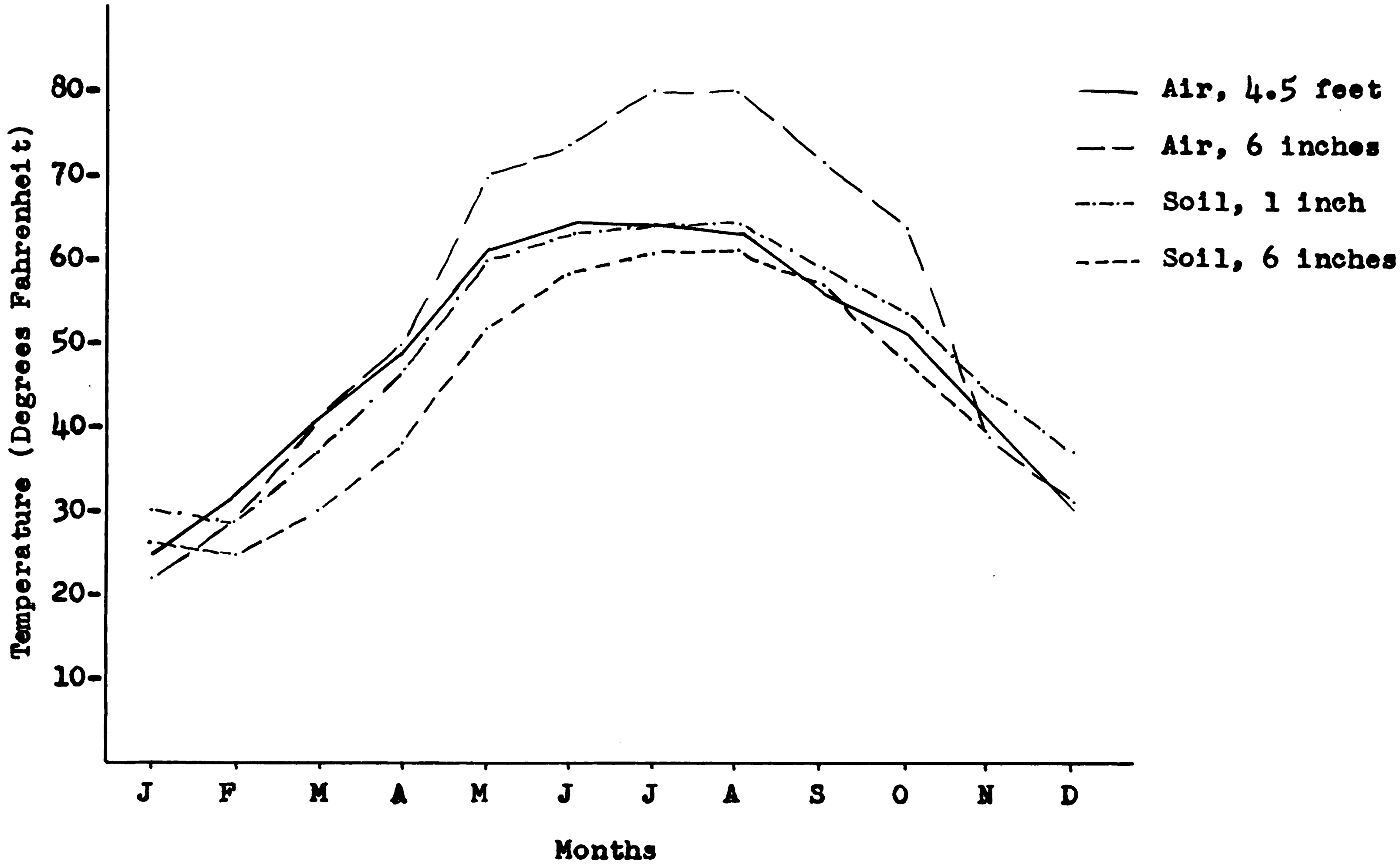


Fig. 20c.-Average monthly soil and air temperatures, 1953.

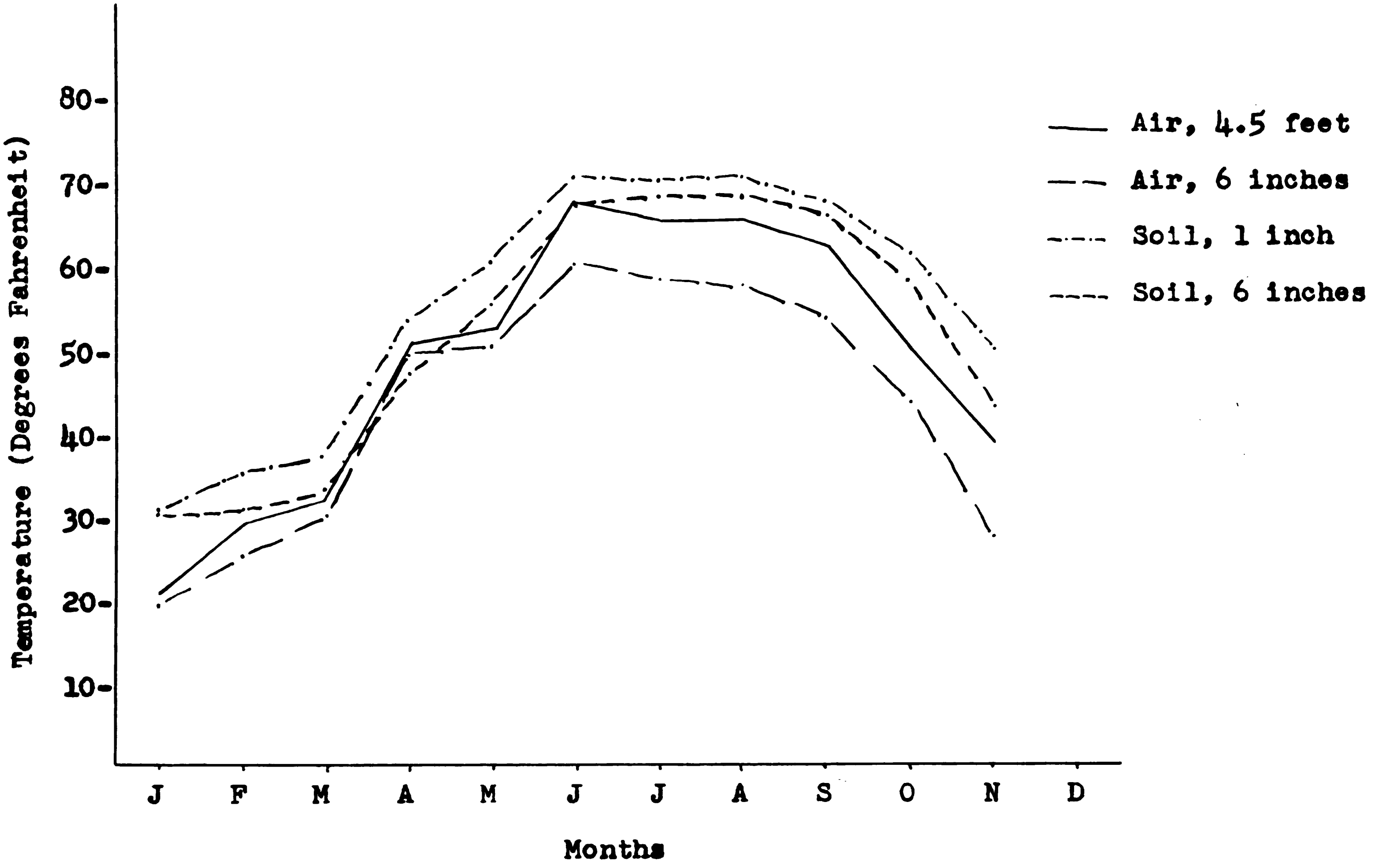


Fig. 20d.-Average monthly soil and air temperatures, 1954.

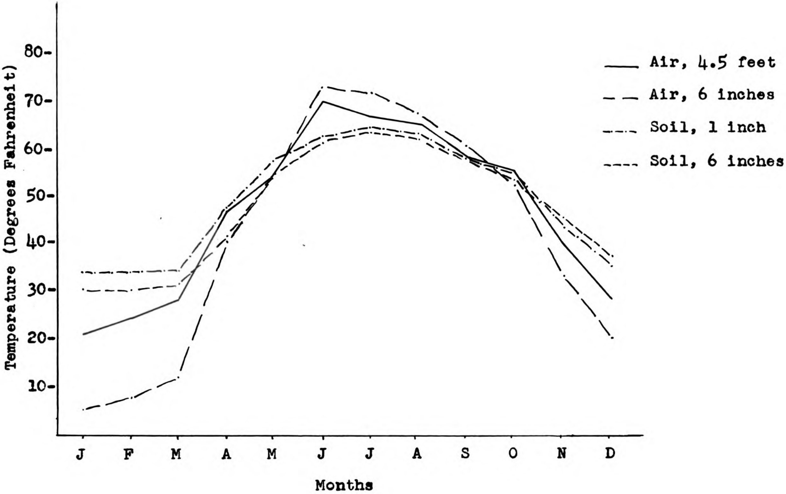


Fig. 20e.-Average monthly soil and air temperatures, 1956.

temperature at six inches was considerably greater than all other temperatures from April through October. The six inch soil temperatures, on the other hand, were consistantly lower than all other temperatures throughout the year. Soil temperature at one inch was higher than air temperature at 4.5 feet during winter and was approximately equal to air temperature throughout the warmer months. The year 1953 exhibited a trend similar to 1952, with six inch air temperature exceeding other temperatures by an even greater margin. This may be the result of increased ingrowth of lesser vegetation, with a consequent reduction in air circulation at the six inch height. During 1954 soil temperatures generally exceeded air temperatures throughout the year. This represented a complete reversal of temperature trends for the two preceeding years. By 1956, soil and air temperatures had returned to a pattern similar to pre-treatment, i.e. soil temperatures were warmer during the winter and cooler during the summer than air temperatures.

In general, minimum soil and air temperatures were not reduced, as a result of treatment, with the same magnitude as maximums were increased. Perhaps the overall result of the increased maximum temperatures was manifested in the increased oxidation of organic matter, as indicated by the reduction in total unincorporated organic matter and increased soil organic matter.

Hydrologic Studies

The watershed, as a natural unit, reflects the interactions of soil, water, and vegetation by providing a common end product, runoff, which enables the net effects of these interactions to be measured and evaluated. Runoff is a recognized criterion of watershed conditions and also of the effectiveness of watershed management. One of the basic premises of watershed management is that the amount and rate of streamflow expresses the natural and cultural characteristics and conditions of the watershed which produces it. The quality of runoff, which in this study refers to silt content, is also indicative of the effectiveness of the vegetative cover in protecting the soil from erosion.

This aspect of the study is concerned, therefore, with detecting any variations in runoff behavior as a result of the vegetative treatment applied to the watershed.

Runoff

The term "runoff", as used in this study, refers to water leaving the watershed as surface flow, measured at the gaging station. As indicated above, runoff represents the net result of the interaction of the various factors affecting the disposition of precipitation on a watershed. Under relatively static conditions of vegetative cover and land use certain runoff patterns are established in conjunction with precipitation patterns. When, however, the vegetative cover or type of land use on a watershed is altered the relative degree of interaction of factors affecting the disposition of precipitation is frequently disrupted. The result is often manifested as changes in the runoff patterns of a watershed, such as changes in the average annual runoff, average monthly runoff, frequency of runoff, and rates of runoff.

In order to attain any degree of validity in comparing runoff behavior before and after treatment runoff values must be compared with precipitation received on the watershed. Monthly and annual precipitation and runoff values for the years 1941 through 1957 are given in Table 21. Average annual precipitation during the pre-treatment period was 32.64 inches and average annual runoff for the same period amounted to 0.54 inches. There appears to be very little correlation between annual precipitation and annual runoff. During the post-treatment period average annual precipitation was 30.37 inches while average annual runoff was 0.19 inches. The use of average annual runoff for the post-treatment period does not represent runoff under static clearcut conditions, but under a changing, increasing vegetative cover. The proportion of runoff to precipitation was less for the post-treatment period than for the pre-treatment period. Annual pre-treatment runoff constituted 1.65 per cent of annual precipitation, while for the post-treatment period annual runoff was only 0.62 per cent of annual precipitation. While the average

TABLE 21

MONTHLY AND ANNUAL PRECIPITATION AND RUNOFF, 1941 - 1957

Year		Month												Year
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1941	P[a]	-[c]	-	1.20	1.87	2.37	2.60	0.60	3.36	2.51	7.10	2.74	1.43	25.78
	Q[b]			T	0	0	0	0	0	0	0	0	0	T
1942	P	2.07	.64	4.95	.60	4.60	3.60	4.72	2.99	3.16	3.36	3.40	3.02	37.11
	Q	0	0	.79	0	0	0	0	0	0	0	0	0	.79
1943	P	2.20	1.47	2.68	2.55	6.52	5.37	2.53	4.01	3.47	1.88	1.90	.41	34.99
	Q	0	.03	.25	0	.30	1.17	0	0	0	0	0	0	1.75
1944	P	1.22	1.94	2.65	1.51	5.70	1.99	.93	3.28	2.66	.62	2.00	1.13	25.63
	Q	0	0	.02	0	.58	0	T	T	0	0	0	0	.60
1945	P	.41	1.17	2.19	3.60	7.21	2.60	4.95	6.18	3.27	4.00	1.51	1.33	38.42
	Q	0	0	0	0	.08	0	0	T	0	0	0	0	.08
1946	P	1.62	1.94	2.19	.70	3.96	3.66	.18	1.16	1.71	2.15	1.78	2.83	23.88
	Q	0	0	.07	0	0	0	0	0	0	0	0	0	.07
1947	P	3.24	.71	1.84	5.78	4.23	3.31	2.81	5.33	5.66	3.08	1.79	1.32	39.10
	Q	0	0	0	.74	0	0	0	0	0	0	0	0	.74
1948	P	1.19	2.14	4.08	2.11	4.28	3.98	2.75	1.33	2.14	.64	2.61	2.32	29.57
	Q	0	0	.88	0	.43	0	0	0	0	0	0	0	1.31
1949	P	3.25	2.40	2.28	2.05	2.16	3.43	3.77	2.06	2.62	1.97	1.68	4.69	32.46
	Q	.01	0	0	0	0	0	T	T	0	0	0	0	.01

TABLE 21 (continued)

Year		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1950	P	3.53	3.10	2.06	4.61	2.22	4.94	4.75	3.40	3.94	1.69	3.12	1.97	39.33
	Q	0	.02	.27	.18	0	.13	0	0	0	0	0	0	.60
1951	P	2.85	1.56	1.76	3.80	3.09	3.17	1.41	2.54	2.72	4.21	2.97	2.66	32.74
	Q	T	0	0	0	0	0	0	0	0	0	0	0	T
Av.	P	2.16	1.72	2.53	2.65	4.21	3.64	2.46	3.13	3.34	2.72	2.32	2.10	32.64
	Q	0	0	.21	.08	.13	.12	0	0	0	0	0	0	.54
1952	P	2.01	1.54	2.09	3.58	4.09	1.15	2.79	4.35	1.68	.51	3.55	1.73	29.07
	Q	0	0	0	.05	0	0	0	0	0	0	0	0	.05
1953	P	1.84	.84	2.25	2.64	2.30	2.87	2.63	2.94	1.07	1.77	1.04	1.89	24.08
	Q	.02	0	0	0	0	0	0	0	0	0	0	0	.02
1954	P	1.67	4.23	3.13	2.90	1.54	4.29	1.94	1.77	2.06	6.40	2.74	2.52	35.19
	Q	0	0	.14	0	0	0	0	0	0	0	0	0	.14
1955	P	1.16	1.80	2.18	1.38	2.41	.50	4.11	3.64	1.49	3.64	3.68	.65	26.64
	Q	0	0	.10	0	0	0	0	0	0	0	0	0	.10
1956	P	.76	2.43	1.82	4.23	5.93	2.97	3.23	4.88	.89	.36	1.37	1.56	30.43
	Q	0	0	0	.31	.45	0	0	0	0	0	0	0	.76
1957	P	1.76	1.58	1.62	3.46	5.66	3.15	7.22	1.87	1.60	4.06	2.70	2.25	36.83
	Q	0	0	0	0	.09	0	.01	0	0	0	0	0	.10

TABLE 21 (continued)

Year		Month												Year
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Av.	P	1.53	2.07	2.18	3.03	3.65	2.49	3.65	3.24	1.46	2.79	2.51	1.77	30.37
	Q	0	0	.04	.06	.09	0	0	0	0	0	0	0	.19

[a]Precipitation.

[b]Runoff.

[c]Official precipitation and runoff records did not start until March, 1941.

annual post-treatment precipitation amounted to ninety-three per cent of that of the pre-treatment period, average annual post-treatment runoff amounted to only thirty-five per cent of pre-treatment runoff. From a consideration of average annual precipitation and runoff before and after treatment the study indicates there was less annual runoff after treatment than before.

Over the period of study, runoff occurred predominantly during the months of March, April, May, and June both before and after treatment. During the period of study, 1941 through 1957, a total of forty-four runoffs occurred, with thirty-three of these occurring within this four month period. On examination of the soil moisture graphs presented in the section on soil studies, it is apparent that this four month period represents a period of maximum soil moisture storage with very little storage space for additional moisture. Consequently, when additional moisture was received as snowmelt and/or rainfall the available storage was quickly satisfied and the remainder of the water went into runoff. Since this March through June period represents very little vegetative activity and the bulk of the annual runoff, the effects of removing the vegetative cover on runoff was minimized. No measurable amounts of runoff were recorded during the period of July through December prior to treatment. However, during August 1952 a runoff of 0.0028 inches was recorded. Again,

on examination of the soil moisture values for 1952 it is seen that the established pre-treatment period of soil moisture depletion during July and August did not occur during 1952, thus providing a minimum of storage opportunity for additional precipitation. This minimum of water storage opportunity, together with above normal precipitation during August produced this small runoff noted. Thus, it appears that this runoff may be attributable to vegetative treatment.

The frequency of occurrence of runoff, presented in Table 22, does not indicate any particular trend attributable to the effect of clearcutting the watershed. There was an increase in the frequency of runoffs during April and May of 1956, and during July of 1957. This increased frequency of runoff occurred five and six years, respectively, after treatment and after a dense vegetative cover had been established on the watershed. An above normal amount of precipitation during these two periods is perhaps the reason for the increased frequency of runoff. The amount of precipitation recorded during July 1957 exceeded any amount previously recorded for July during the period of study.

Precipitation and runoff for individual storms causing runoff during the period of study are given in Table 23. The average amount of precipitation and runoff per storm during the pre-treatment period (from January through April) was 1.43 inches and 0.2177 inches respectively. For the post-

TABLE 22

FREQUENCY OF RUNOFF, 1941 - 1957

Years	Months												Total
	J	F	M	A	M	J	J	A	S	O	N	D	
1941	-	-	1	-	-	-	-	-	-	-	-	-	1
1942	-	-	2	-	-	-	-	-	-	-	-	-	2
1943	-	1	1	-	1	1	-	-	-	-	-	-	4
1944	-	-	2	-	1	-	-	-	-	-	-	-	3
1945	-	-	-	-	1	-	-	-	-	-	-	-	1
1946	-	-	1	-	-	-	-	-	-	-	-	-	1
1947	-	-	-	1	-	-	-	-	-	-	-	-	1
1948	-	-	1	-	1	-	-	-	-	-	-	-	2
1949	1	-	-	-	-	-	1	1	-	-	-	-	3
1950	-	1	2	2	-	1	-	-	-	-	-	-	6
1951	1	-	-	-	-	-	-	-	-	-	-	-	1
Treatment													
1952	-	-	-	1	-	-	-	1	-	-	-	-	2
1953	1	-	-	-	-	-	-	-	-	-	-	-	1
1954	-	-	1	-	-	-	-	-	-	-	-	-	1
1955	-	-	1	-	-	-	-	-	-	-	-	-	1
1956	-	-	-	4	3	-	-	-	-	-	-	-	7
1957	-	-	-	-	1	-	3	-	-	-	-	-	4
Total	3	2	12	8	8	2	4	2					41

treatment period the average amount of precipitation per storm was 1.83 inches and the average amount of runoff was 0.1049 inches (also for the interval of January through April). Runoff for this portion of the year includes snowmelt as well as rainfall. Average precipitation and runoff per storm during May through August for the pre-treatment period was 2.36 inches and 0.4494 inches respectively. For the post-treatment period (also for the interval of May through August)

TABLE 23

PRECIPITATION AND RUNOFF FOR INDIVIDUAL STORMS, 1941 - 1957

Date	Precipitation	Runoff
	- inches -	
3 - 13 - 41	.93	.0038
3 - 9 - 42	1.84	.1368
3 - 18 - 42	2.31	.6539
2 - 23 - 43	.15	.0336
3 - 15 - 43	1.01	.2505
5 - 11 - 43*	1.68	.3030
6 - 2 - 43*	2.75	1.1698
3 - 15 - 44	.52	.0159
3 - 16 - 44	.15	.0017
5 - 22 - 44*	2.47	.5813
5 - 15 - 45*	2.12	.0806
3 - 6 - 46	.93	.0726
4 - 6 - 47	2.95	.7397
3 - 19 - 48	2.69	.8842
5 - 10 - 48*	2.42	.4288
1 - 18 - 49	1.50	.0114
7 - 5 - 49*	.53	T
8 - 16 - 49*	1.08	T
2 - 14 - 50	1.77	.0170
3 - 1 - 50	.58	.1748
3 - 28 - 50	1.12	.0957
4 - 4 - 50	1.65	.1098
4 - 25 - 50	2.17	.0652
6 - 3 - 50	2.73	.1329
1 - 20 - 51	.34	T
	Treatment	
4 - 14 - 52	1.80	.0511
7 - 16 - 52	1.80	.0028
1 - 24 - 53	.74	.0209
3 - 25 - 54	1.55	.1441
3 - 4 - 55	.53	.1025
4 - 2 - 56	.40	T
4 - 27 - 56	2.13	.0536
4 - 29 - 56	3.20	.2575
5 - 6 - 56*	1.11	.0960
5 - 10 - 56*	1.86	.2391
5 - 13 - 56*	1.21	.1200
5 - 19 - 57*	1.77	.0921
7 - 4 - 57*	.19	.0010
7 - 8 - 57*	2.19	.0042
7 - 11 - 57*	2.70	.0008

*Precipitation entirely in the form of rain.

average precipitation and runoff per storm was 1.60 inches and 0.0695 inches respectively. In each instance, i.e. for the January through April period and the May through August period, runoff amounted to a smaller percentage of precipitation after treatment than before treatment.

Maximum rates of discharge are often indicative of effects of vegetative treatment. Table 24 lists the maximum rates of discharge experienced per year for the period of study. Ranked in order of decreasing magnitude, the five maximum rates of discharge for the period of study occurred during the pre-treatment period. Average annual maximum rate of discharge was also greater during the pre-treatment period. The average maximum volume of runoff per twenty-four hour period prior to treatment was 0.420 inches, whereas after treatment the average maximum twenty-four hour runoff was 0.135 inches. The average maximum runoff volume for a one hour period before treatment was 0.147 inches as contrasted to 0.045 inches after treatment. The results of the study indicate rates of runoff during the post-treatment period were less than during the pre-treatment period.

Infiltration

Infiltration refers to the entry of water into the surface of the soil and as such is entirely a surface soil phenomena. After the water enters the soil surface the subsequent movement of the water through the soil profile is a

TABLE 24

MAXIMUM RATE OF RUNOFF PER YEAR, 1941 - 1957

Date	Runoff Inches per hour
3 - 3 - 41	.003
3 - 16 - 42	.070
6 - 2 - 43	.440
5 - 21 - 44	.240
5 - 14 - 45	.020
3 - 5 - 46	.010
4 - 5 - 47	.100
3 - 19 - 48	.210
1 - 18 - 49	.003
6 - 2 - 50	.020
1 - 20 - 51	T
4 - 12 - 52	.010
1 - 19 - 53	-*
3 - 25 - 54	.040
3 - 3 - 55	.020
5 - 13 - 56	.050
5 - 18 - 57	.009

*Record lost.

function of soil permeability. Prior to the soil profile becoming saturated, the infiltration rate is the prime factor affecting the disposition of precipitation into surface runoff or subsurface movement. Only when the rate of precipitation exceeds the infiltration rate can surface runoff occur.

Average infiltration rates determined for the entire watershed by analyses of hydrographs for storms occurring during the growing season, before and after treatment, are summarized in Table 25. The study indicates that the average infiltration rate (f_{av}) per storm after treatment was greater than prior to treatment. Perhaps this slight increase in infiltration rate may be attributable to the decreased depth of unincorporated organic matter, as indicated in the section on unincorporated organic matter. Hursh and Hoover (1941) found from an infiltration study of an undisturbed forest soil profile, that approximately 2.5 per cent of artificial precipitation applied ran off as surface runoff because of the shingle effect of hardwood litter.

Erosion

The amount of soil removed from a watershed by surface runoff is indicative of the condition of vegetative cover and land use. A certain amount of erosion is taking place constantly on any given area and is referred to as normal or geologic erosion. The intensity of normal erosion is governed primarily by such factors as topography, geology, soils,

TABLE 25

AVERAGE INFILTRATION RATE PER STORM DURING THE GROWING SEASON, 1941 - 1957

Date	Average infiltration rate (inches per hour)
Pre-treatment	
5 - 11 - 43	.138
6 - 2 - 43	.232
5 - 14 - 45	.170
5 - 10 - 48	.442
6 - 2 - 50	.226
Average	.241
Post-treatment	
5 - 6 - 56	.152
5 - 9 - 56	.123
5 - 13 - 56	.160
5 - 18 - 57	.094
7 - 4 - 57	.398
7 - 8 - 57	.534
7 - 11 - 57	.504
Average	.266

climate, and vegetative cover. The disturbance of vegetative cover, with the attendant disturbance of litter, frequently accelerates the rate of erosion for a particular area.

The total erosion from the watershed for the period of study was 74.7 pounds per acre, with 62.0 pounds per acre (over eighty per cent of the total) eroded prior to treatment (Table 26). Nominal amounts of erosion were noted during 1952 and 1953, the first and second years after treatment. Apparently the treatment had no significant effect on erosion from the watershed. No increase in erosion could be expected since the amount and rate of runoff decreased slightly after treatment.

Hydrologic Summary

Precipitation, runoff, and erosion values are summarized in Table 26. The data are presented graphically in Figure 21. The hydrologic data obtained in this study do not indicate any pronounced effects of vegetative treatment on the hydrology of the watershed. Only on one occasion was runoff thought to be attributable to the effects of treatment, i.e. during August, 1952. The results of this study are contrary to opinion put forth by Smith and Crabb (1953) in reference to anticipated treatment effects on the wooded watershed. Smith and Crabb stated:

> In light of this tentative and preliminary analysis of similar storms under different cover conditions, it is anticipated that the removal of a timbered cover will have a profound effect upon the absorption of precipitation by a watershed. Runoff will be probably occasioned by storms having smaller intensities and totals of precipitation, and erosion losses will be consequently greater.

It appears that lack of treatment effect on runoff and erosion may be the result of insufficient disturbance of

TABLE 26

HYDROLOGIC SUMMARY, 1941 - 1957

Year	Yearly totals Precip. (inches)	Yearly totals Runoff (inches)	Yearly totals Erosion (lbs./acre)	Cumulative totals Precip. (inches)	Cumulative totals Runoff (inches)	Cumulative totals Erosion (lbs./acre)
1941	27.64	.0038		27.64	.0038	
1942	37.11	.7907		64.75	.7945	
1943	34.99	1.7569		99.74	2.5514	
1944	25.63	.5989		125.37	3.1503	
1945	38.42	.0806		163.79	3.2309	
1946	23.88	.0726		187.67	3.3035	
1947	38.73	.7397		226.40	4.0432	
1948	29.57	1.3130	27.2	255.97	5.3562	27.2
1949	32.46	.0114		288.43	5.3676	27.2
1950	39.33	.5972	34.8	327.76	5.9648	62.0
1951	32.74	0		360.50	5.9648	62.0
			Treatment			
1952	29.07	.0539	6.2	389.57	6.0187	68.2
1953	24.08	.0209	4.3	413.65	6.0396	72.5

TABLE 26 (continued)

Year	Yearly totals: Precip. (inches)	Yearly totals: Runoff (inches)	Yearly totals: Erosion (lbs./acre)	Cumulative totals: Precip. (inches)	Cumulative totals: Runoff (inches)	Cumulative totals: Erosion (lbs./acre)
1954	35.19	.1441		448.84	6.1837	72.5
1955	26.64	.1025		475.48	6.2862	72.5
1956	30.43	.7662	2.2	505.91	7.0524	74.7
1957	36.83	.0981		542.74	7.1505	74.7

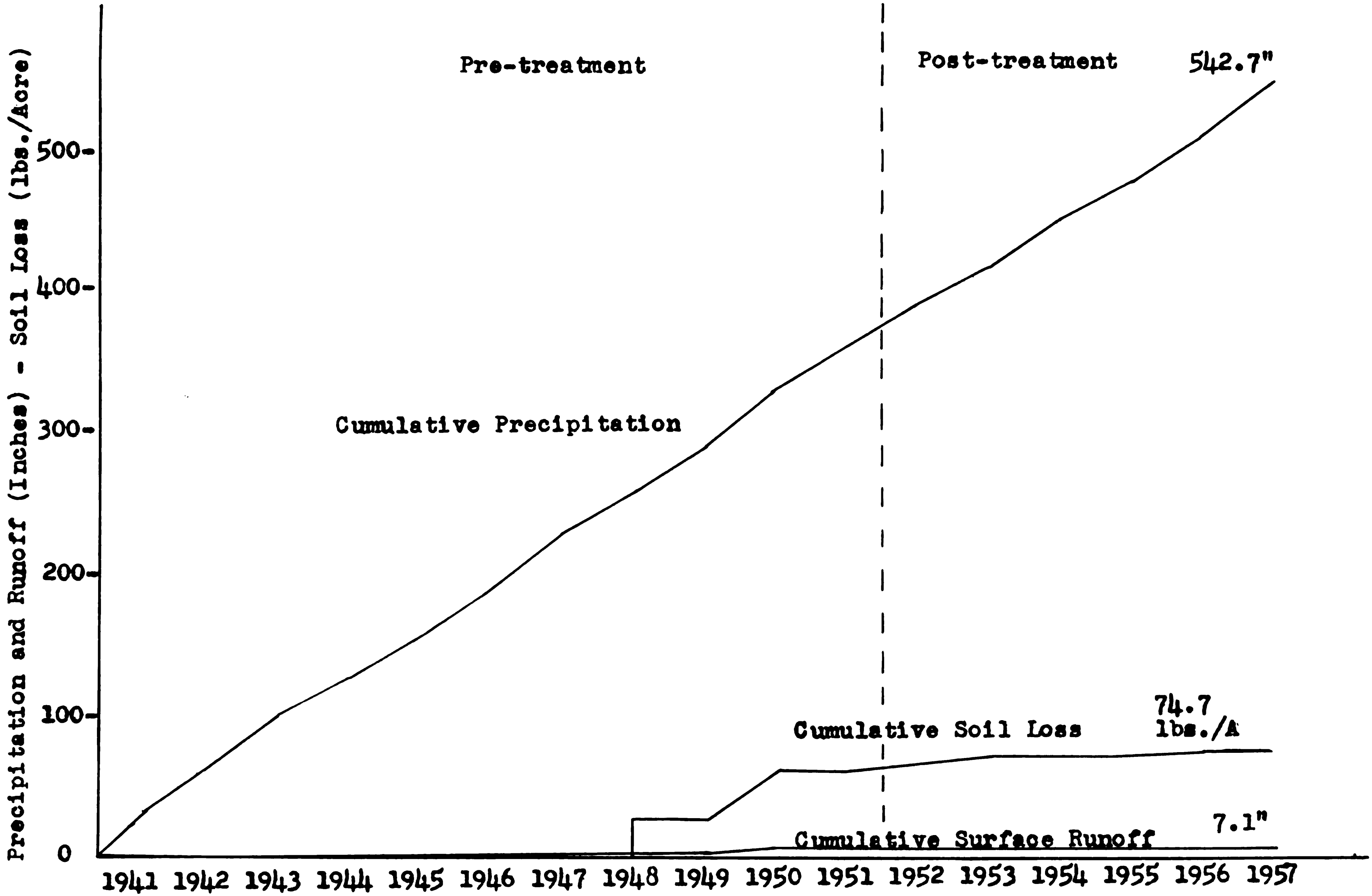


Fig. 21.-Hydrologic summary for the wooded watershed, 1941 - 1957.

unincorporated organic matter on the soil surface. Lowdermilk, *op. cit.*, summarizes this point quite clearly:

> No significant differences can be expected in experiments when the absorption conditions of the soil surface are not changed, even though the forest is cut off. Such differentials as would arise under these circumstances are referable to differentials in the interception and transpiration of different types and ages of vegetation.
>
> The chief condition, then, which is necessary to produce differences in the regimen of run-off and erosion, is found to be complete removal not only of the mantle of vegetation but particularly of the natural layer of litter.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Because of the increased interest manifested in the water resources of southern lower Michigan it is highly desirable to ascertain the water yield contributions of areas under various types of land use and vegetative cover. There are approximately 1.4 million acres of farm woodlots in southern lower Michigan on which the commercial-type clearcut is the most common type of timber harvest. The purpose of this study is to determine and evaluate the effects of this type of harvest cut on soil and water relations on a small wooded watershed representative of the farm woodlot-type.

The Study

A small wooded watershed, located on state-owned lands in southeastern Clinton County, was established during 1941. The watershed, supporting a well stocked stand of the oak-hickory type, was calibrated hydrologically for an eleven year period. During the latter part of 1951 and the early part of 1952 the forest cover was subjected to a commercial-type clearcut operation, removing all trees larger than 5.5 inches d.b.h. Hydrologic data were also obtained through 1957.

Detailed soil sampling for soil physical property determinations was undertaken on the watershed during 1953, 1957 and on the adjacent uncut area during 1957. Gravimetric soil moisture sampling was initiated during the latter part of 1945 and continued on a bi-weekly basis through 1952. Weekly soil moisture samples were obtained from March through September of 1957.

These pedologic and hydrologic data were obtained in an effort to determine and evaluate the effects of the vegetative treatment on the soil reservoir and the water yield of the watershed.

Findings of the Study

Soils

The texture of the surface soils on the study area ranged from sandy loam to loam, while the subsurface textures ranged from sandy loam to silty clay loam. As a result of this study a soil formerly classified as Conover silt loam was tentatively reclassified as Metamora sandy loam. No changes in soil texture were noted as a result of the vegetative treatment.

Bulk density values for the upper six inches of soils on the watershed were slightly lower during 1953 than during 1957. The watershed soils exhibited consistantly lower bulk density values than the similar soils on the adjacent uncut area during 1957. There is no indication of a pronounced change in soil bulk density as a result of treatment. Porosity values were found to be generally favorable for water storage and movement in the surface soils. There is no indication of change in total porosity or relative proportions of capillary and non-capillary porosity as a result of treatment. Percolation rates were found to be adequate for water drainage within the upper foot of all soils, but were definitely restricting below twelve inches in most soils. Again, there is no indication of a change in percolation rates as a result of treatment. Loss on ignition values, which are indicative of relative soil organic matter, were higher in the soils of the treated area than in the soils of the untreated area. The results seem to indicate that the treatment has increased relative organic matter content of the watershed soils, perhaps as a consequence of a change in litter type and a more rapid rate of oxidation of unincorporated organic matter resulting from higher air and soil temperatures. The amount of unincorporated organic matter on the surface also appears to have been affected by vegetative treatment. The untreated adjacent area contained more than fifty per cent more unincorporated organic matter than the treated watershed area. This reduction of unincorporated organic matter appears to be related to the increased soil organic matter content in the watershed soils. The physical properties of the soils do not appear to have been impaired by the vegetative treatment applied to the watershed.

A study of soil moisture regime before and after treatment indicated a very definite and statistically significant increase in soil moisture during the growing season of 1952 as a result of treatment. This increase was noted for the entire profile, to the depth sampled (0 - 36 inches), as well as for the individual depths sampled. Available soil moisture remained at a very high level throughout the 1952 growing season. However, during the 1957 growing season soil moisture values were intermediate between the extremely high values of 1952 and the average pre-treatment values, indicating a re-establishment of the vegetative cover towards pre-treatment conditions.

Evapotranspiration values, computed from soil moisture data, were lower during the 1952 growing season than during the pre-treatment period or during 1957. The 1957 evapotranspiration values fell within the range of the pre-treatment period values, indicating the dense regrowth on the area consumes nearly as much soil moisture as the original forest cover.

Mean soil and air temperatures were generally increased as a result of vegetative treatment. Maximum temperatures were greatly increased, perhaps resulting in increased rates of decomposition of unincorporated organic matter.

Hydrology

Average annual runoff, expressed as a percentage of average annual precipitation, was found to be less after treatment than before treatment. Likewise, average monthly runoff values were lower after treatment than before. Since the majority of the annual runoff occurs during the spring when snowmelt and saturated soil are prevalent, the opening up of the stand to increased solar radiation and wind movement may have enabled a more rapid rate of sublimation of snow and increased soil moisture evaporation. This reduction in runoff potential may have resulted in the slight decrease in runoff noted in the study. Maximum rates of runoff were also lower after treatment, as well as average volume per runoff. The frequency of runoffs was apparently not affected by the vegetative treatment. The average infiltration rate per storm during the growing season, as determined by hydrograph analysis, was found to be greater after treatment.

A hydrologic summary for the entire period of study indicated no significant change in the overall hydrologic characteristics of the watershed. However, there is an important, though not obvious, implication of the study with respect to the water resources of the area. With no apparent increase in runoff from the watershed and higher levels of soil moisture during the first year after treatment there were probably increased contributions to the ground water supply of the area.

In conclusion, it may be said that though the commercial-type clearcut is not particularly desirable from the standpoint of forest management it does not appear to have had any deleterious effects on the soils of the watershed nor on the water resources of the area.

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