SOME EFFECTS OF VEGETAL COVER UPON THE HYDROLOGY OF WATERSHEDS AT EAST LANSING, MICHIGAN

Thesis for the Degree of Ph. D.

MICHIGAN STATE COLLEGE

James Le Roy Smith

1954

This is to certify that the

thesis entitled

" SOME EFFECTS OF VEGETAL COVER UPON THE HYDROLOGY OF WATERSHEDS AT EAST LANSING, MICHIGAN."

presented by

James LeRoy Smith

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Forestry

T. D. Stevens
Major professor

Date July 30, 1954

O-169

SOME EFFECTS OF VEGETAL COVER UPON THE HYDROLOGY OF WATERSHEDS AT EAST LANSING, MICHIGAN

By

JAMES LEROY SMITH

A THESIS

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

DOCTOR OF PHILOSOPHY

Department of Forestry

1954

THESIS

ACKNOWLEDGEMENTS

All of the hydrologic data used herein was taken from the records of the Michigan Hydrologic Research Station at East Lansing, Michigan. This station is a cooperative project between the Michigan Agricultural Experiment Station and the Soil and Water Conservation Research Branch of the Agricultural Research Service, United States Department of Agriculture.

The writer wishes to express his appreciation to Mr. George A. Crabb, Supervisor of the station for his assistance and constructive criticism .

Acknowledgement is made to Dr. T.D. Stevens, Head of the Forestry Department and Chairman of the writer's graduate committee, for guidance, criticism, and encouragement in this study. Acknowledgement is also made to Dr. Leo Katz, Professor of Mathematics, for assistance in outlining statistical procedures.

The writer wishes to also express appreciation to his wife, Waunda Bowen Smith, for assistance in the preperation of this manuscript.

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candidate for the degree of

DOCTOR OF PHILOSOPHY

Final Examination: Friday, July 30, 9:00 a.m., Forestry Building

Dissertation: Some Effects of Vegetal Cover Upon the Hydrology of Watersheds at East Lansing, Michigan.

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AN ABSTRACT

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Year 1954

Approved Robert E. Dils

JAMES LEROY SMITH ABSTRACT

Two small watersheds at East Lansing, Michigan were compared on the basis of 11 years records. One watershed was forested, the other cultivated. The watersheds were compared as to differences in soil moisture, physical soil differences, soil losses and surface run-off. A further comparison was made between the wooded watershed while forested, and for the first year after a commercial clear cut.

Soil moisture at the wooded watershed was found to be consistently higher than that found at the cultivated watershed. This was due to the higher absorptive qualities of the wooded watershed soils. Both Retention and detention storage were higher for the wooded watershed soils. Organic content was higher, volume weights lower and saturation point higher for the wooded soils.

The cultivated watershed lost a large amount of winter precipitation to surface run-off, while the wooded losses were insignificant. Cultivated losses were due to rain and snow melt on frozen soil. The wooded soils were seldom observed in a frozen state, while the cultivated soils were frozen for most of the first three months of the year.

As a result of the clear cut on the wooded watershed, soil moisture for the first year following the cut was higher than usual. This high moisture content of the soil was due to lessened use of water caused by removal of most of the vegetation on the area. This high moisture was the cause of a run-off in August 1952. This was the second run-off in August for the period of study--12 years.

The first run-off was caused by an abnormal rainfall for the entire year. The 1952 run-off occured in spite of a rainfall of 10 inches less than that registered for the year of the first run-off.

The cultivated watershed lost over 50,000 pounds of soil per acre in an eleven year period. In the same time, wooded watershed erosion losses were only 62.0 pounds of soil per acre. The cultivated watershed lost 13 percent of yearly precipitation to run-off, the wooded lost only 1.7 percent.

Storms for the eleven year period were classified as to intensity class. High intensity storms were found to occur during the period from May to September. Low intensity storms were found to occur during the winter months. High intensity storms were found to be statistically significant in producing run-off on the cultivated, but not the wooded watershed.

Soil and air temperatures on the wooded watershed for year preceeding the cut and the year following the cut showed a change due to vegetation removal. Air temperatures at 2.5 feet elevation above the forest floor were more nearly equal to those at 4.5 feet elevation in a field outside the forest, after the cut. Winter minimum temperatures were lower after the cut than before. Summer maximum temperatures were higher after the cut than before.

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HISTORY OF THE PROJECT

A cooperative hydrologic study between the Michigan Agricultural Experiment Station and the Soil Conservation Service of the United States Department of Agriculture was established at East Lansing, Michigan in 1940. The primary purpose of this study was the determination of the effect of land use on the hydrology of farm lands under varying types of snow cover and frozen soil. The two primary objectives were: (1) The determination of the manner in which freezing and thawing of soils with varying types of land use contributes to run-off, erosion, and flood flow under northern conditions, and (2) to determine the basic hydrologic relationships of typical Michigan soils under different types of land use-- particularly under freezing and thawing conditions such as are encountered in the East Lansing area.

Under the guidance of Mr. Walter U. Garstka, the first supervisor of the station, three watersheds in the East Lansing area were selected as sites for future hydrologic installations. The original plans called for the establishment of only two watersheds, both under cultivated crops. However, the Forestry Department of Michigan State College prevailed upon the governing committee to include a forested watershed along with the two cultivated watersheds.

Three watersheds, as nearly alike as was possible to find, were selected. Two of these watersheds lie side by side on lands belonging to Michigan State College and are located approximately two miles south of the campus. These two watersheds are planted to a five year rotation of corn, oats and a mixture of alfalfa and brome grass for three years. Tillage and other farm practices, including the use of winter cover crops to control erosion, are the same as generally followed in this locality. The third watershed is located on lands of the Rose Lake Wild-Life Experiment Station, ten miles north-east of East Lansing. This woodlot was covered by a good stand of pole size oak-hickory. During the winter of 1951-52, this watershed was clear-cut to a 4.5 inch diameter limit, in order to determine the effect of this type logging operation upon the hydrology of the watershed.

IMPORTANCE OF THE STUDY

As population pressures increase, and with the continued industrial development of the Michigan area, the once seemingly inexhaustable resource of usable water is being rapidly depleated to the point that it threatens to hamper the continued development of the area. When one adds to this the increased demand for supplemental irrigation water for farms and orchards; the new use of water for such purposes as sprinkling muck farmlands to prevent frost damage by early frosts and the increased demands made on lakes and streams for recreation, this resource assumes a new importance.

The southern and central portion of Michigan has an average annual precipitation of 31.43 inches. Of this amount, 20 inches comes during a growing season of 158 days. From the standpoint of farming, this means the farmer must depend upon at least five inches of water stored in the soil reservoir from winter precipitation in order to produce a crop of corn (15).

In the year 1946, yearly precipitation was only 21.65 inches at the cultivated watersheds and 23.88 inches at the wooded watershed. The cultivated watershed dealt with in this study, watershed B, was covered by a second year growth of alfalfa-brome during the entire year. This crop yielded one cutting during the year as compared with the normal of two cuttings per year. With a total precipitation of only 21.65 inches, watershed B lost 3.31 inches to surface run-off. Expressed in terms of corn yield this lack of precipitation caused a decrease in yield. The sister watershed to B had a yield of 37.6 bushels dry weight of corn per acre, as opposed to the yield of 84.8 bushels per acre in 1950, a year with a total precipitation of 38.59 inches and a water loss of 5.43 inches to run-off. In 1951, the yield of corn for this watershed was 52.0 bushels per acre, with a total precipitation of 30.82 inches and a water loss of 2.00 inches. Doubtless, a sizable portion of the increased yields for 1950 and 1951 can be attributed to the greater amount of water available for plant use.

As a result of the unreliability of rainfall, there is a growing awareness of the advisability of developing methods of holding water in the soil for later use. There is also a growing trend toward supplemental irrigation, with its attendant demands upon streams, lakes and ground water storage. Thus, methods of trapping winter precipitation, and methods of holding it in the soil until needed are receiving much attention. This is of importance to the entire population as well as the farmer, for unless this water is temporarily detained in the soil and distributed slowly to the streams, disastrous floods occur during periods of heavy snow melt and heavy rainfalls. In addition to this, lake levels and river levels drop during the dry summer months unless sustained by inflow from the soil reservoir.

One of the important sources of income for Michigan is the tourist trade. No small percent of the resort dollar is spent either directly or indirectly on fishing. An excess of run-off water, with the silting in of streams, lakes and reservoirs, the result of uncontrolled run-off, is one of the surest ways to lose this important source of revenue.

The concept of land management for the production of water of the purity needed for human consumption, for fish production, for industrial use, is a new one for the nation and for Michigan. However, as artesian water levels continue to drop, as flood threats increase and as droughts increase in frequency, there comes a growing awareness that this is a problem that must be met. The only foreseeable answer in the minds of the men in the field is the fullest use of this concept of land management for the production and control of water.

It is the expressed purpose of this study to attempt to add a little to the knowledge of the reaction of lands under various types of vegetal cover to the precipitation encountered in the southern and central portions of the lower peninsula of Michigan.

PAST WORK

The management of natural watersheds to insure favorable conditions of streamflow first attained some degree of national recognition approximately sixty years ago. At that time, the national Congress set aside the Federal Forest Reserves in the west. This action came about as the result of reports that destruction of the plant cover had induced violent floods. Since that time, the Congress has authorised a large number of programs designed to strengthen and broaden this work (21).

During this sixty year span, the published literature on various phases of the work has become voluminous. The writer will, therefore, not attempt to review the literature in the entire field, but will attempt to cite various projects that have been carried on in the past or that are being currently carried on that are pertinent to this study.

When the Forest Reserves were transferred to the Department of Agriculture and became the present system of National Forests, authority was given to enlarge the system to include aid to states and private land owners, and to do research on matters pertaining to forest and range problems. These problems included watershed management (38).

At a later date, authorization was given the Department of Agriculture to give financial and technical aid for soil and water conservation practices carried out on the farm. The Taylor Grazing Act was another effort designed to provide better protection through management of the Public Domain. During the depression years, the Civilian Conservation Corps Act authorised an extensive program of land improvement, much of which was directed toward flood and erosion control measures.

In 1936, the Omnibus Flood Control Act gave the Secretary of Agriculture the authority needed to make surveys, and to authorize measures for the prevention of erosion on lands where floods had caused damage.

As an example of the seriousness with which the problem of soil and water conservation is viewed, the following list of stations conducting this type work is presented.

WATERSHED RESEARCH CENTERS IN THE UNITED STATES
(As of January 1, 1950)

U.S. DEPARTMENT OF AGRICULTURE

U.S. Forest Service (primarily in forest, brush, or range areas).
- Sierra Ancha, Globe, Arizona.
- San Dimas (Southern California), Glendora, California.
- Continental Divide, Fraser, Colorado. (Bureau of Reclamation, Department of the Interior, co-operating on snow-cover relations phase).
- Front Range, Woodland Park, Colorado.
- Western Slope, Delta, Colorado.
- Coweeta Hydrologic Laboratory (southern Appalachian Mountains), Dillard, Georgia.
- Boise Basin, Boise, Idaho.
- Delaware Basin, Bethlehem, Pennsylvania.
- Central Piedmont, Union, South Carolina.
- Great Basin, Ephraim, Utah.
- Wasatch, Farmington, Utah.
- Tallahatchie, Oxford, Mississippi.
- Mountain State, Elkins, West Virginia.

Soil Conservation Service (in agricultural areas).
- Watkinsville, Georgia
- Edwardsville, Illinois
- Lafayette, Indiana
- Iowa City, Iowa
- Boonsboro, Maryland
- College Park, Maryland
- East Lansing, Michigan
- Hastings, Nebraska
- Ithaca, New York
- Coshocton, Ohio
- Guthrie, Oklahoma
- Waco, Texas

Blacksburg, Virginia.
Chatham, Virginia
Staunton, Virginia

LaCrosse, Wisconsin
Fennimore, Wisconsin

DEPARTMENT OF THE ARMY AND DEPARTMENT OF COMMERCE

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

U. S. DEPARTMENT OF THE INTERIOR

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

TENNESSEE VALLEY AUTHORITY

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

The Soil Conservation Service established one of its first experimental watershed projects in the vicinity of Coshocton, Ohio. Studies on watershed management are being carried out on 44 watersheds under various covers. One of the studies carried out at Coschocton in 1941 by Dreibelbis and Post (17) was a comparison between a wooded, two cultivated and a pastured watershed. On the cultivated watersheds, 15 percent of the precipitation was lost to surface run-off, while 1.4 percent appeared as run-off on the pastured area and only 0.2 percent on the wooded area.

These results are substantiated by the findings of Smith and Crabb(29) at East Lansing, Michigan. At East Lansing, two small cultivated and one small wooded watershed were compared on the basis of eleven years records. The results showed a loss to surface run-off of 14.5 percent and 13.4 percent for the two cultivated watersheds and a loss of only 1.7 percent for the wooded watershed.

A watershed study near Zanesville, Ohio showed, according to Borst and Woodburn (7), a loss of annual precipitation to surface run-off of 0.34 percent while under wooded cover.

Two Soil Conservation Service watershed projects located in the Piedmont regions of the south, Watkinsville, Georgia and Statesville, North Carolina, are engaged in studying the effects of vegetation upon run-off and soil loss. Studies at Statesville are centered on both cultivated and wooded watersheds. To date, these studies indicate decreasing soil losses in the order given: fallow, continuous cotton, cotton and corn rotated with winter cover crops, grass, woods burned annually and unburned wooded areas. The same order is followed as regards surface run-off with the exception of burned woods, which yields more to run-off than grassed areas. Unburned woods allowed only 0.7 percent of the annual precipitation to become surface run-off.

A published progress report on the experimental watershed for the Brazos Drainage Basin near Waco, Texas (36), indicated results from fallow, cultivated, and wooded watersheds to be similiar to those reported from Statesville, North Carolina. In the Brazos project, plots in wooded cover yielded 0.12 percent of annual precipitation as run-off, with a loss to run-off of 30 percent from fallow plots and 10 percent from continuously cropped cotton land.

The Coweeta Hydrologic Laboratory, a unit of the Southeastern

Forest Experiment Station of the United States Forest Service, located near Dillard, Georgia, is engaged in a large number of hydrologic studies. Amoung the studies pertinent to this project are those which include the determination of the effects upon water yield and quality of the following: (a) permanent, complete removal of all major vegetation, (b) temporary, complete removal of all major vegetation, (c) woodland grazing and (d) mountain farming, following a standardizing period under wooded cover. These investigations have been carried on long enough to provide the following results. Results are listed in the same order as above(a) water yields to streams were increased by 17 area inches per year. This increased yield appeared as sub-surface flow rather than surface run-off (35), (b) temporary, complete removal of major vegetation increases water yields by 17 area inches, become progressively less as cover increases (35), (c) woodland grazing brings about a drastic increase in run-off and soil loss (18), and mountain farming after a period under wooded cover results in a change in surface run-off from 2.66 percent to 4.50 percent of annual precipitation (11).

The Sierra Ancha Experimental Forest near Globe, Arizona is engaged in experimental research designed to show the influence of wooded cover, evergreen shrub cover, and range cover upon erosion, surface run-off, stream flow and water uses by plants involved. This station utilizes so-called "natural lysimeters", watersheds and plots in its studies. Studies at this station indicate that ungrazed range lands where the cover is good, produced higher water yields, less overland flow and less erosion than overgrazed, poorly covered range lands (34).

The Northeastern Forest Experiment Station's Lehigh - Delaware Experimental Forest is the site of a watershed management research project designed to show the influence of scrub-oak on surface run-off. Future plans for this area include the gradual conversion of the stand to a better forest type, and evaluating this change from a hydrologic standpoint.

Trimble, Hale and Potter (32), found in a study of the Allegheny River watershed that the movement and storage of water in the soil are affected by grazing, drainage conditions, and humus type. The greater the humus depth, the greater the retentive capacity of the soil. In open lands, soils are most affected by vegetative cover and by drainage condition. The lowest percolation rates were observed in land devoted to row crops. This land also had the lowest detention storage capacities. The highest rates were found in forested lands, followed by good pasture, close-growing crops and hay.

Ramser reported as early as 1927 (26), that forest cover exerted a decided influence in reducing surface run-off rates from a watershed, unless the storm in question had been preceded by high antecedent rainfall (indicating high soil moisture), in which case the influence is slight.

In 1951, the Tennessee Valley Authority published results from a 15 year study on the White Hollow watershed, located near Norris, Tennessee. Results of this study indicate the improvement in forest cover resulted in greater soil protection without decrease in water yield. There was no seasonal shift in run-off pattern as a result of cover improvement.

One of the results of this study showed that as cover improved there was no change in evapo-transpiration plus other losses, indicating that evaporation and transpiration were working to offset one another. As cover increased, peak discharges during the summer became progressively smaller. Time distribution charts show that the better cover produced a prolonging of the flow of surface runoff, giving a more sustained flow and less flashy flow. There was also a material reduction in soil loss as cover improved(31).

As this summary of past work of a nature similiar to the present study indicates, the literature pertaining to hydrologic research is voluminous, and the results of many research projects point to the indisputable fact that vegetal cover exerts a modifying effect upon surface run-off, silt loss and other related factors.

There are few cases on record where watersheds have been instrumented to operate on a round the year basis in a belt of alternate freezing and thawing conditions. It is the purpose of this study to attempt to evaluate the different factors which acting together produce the end result--- a lessening or increasing of soil loss and surface run-off.

CLIMATE OF THE EAST LANSING AREA

The atmospheric climate of the area under discussion alternates between continental and semi-marine, with changing meteorologic conditions (37). The semi-marine type of climate is primarily occasioned by the influence of the Great Lakes, which surround the Lower Penninsula of the state on three sides. This lake influence is controlled by the force and direction of the winds. During periods of slight wind movement over the area, the climate follows the continental pattern, with sharp variations in temperatures, ranging from hot summers to severely cold winters. These extremes vary sharply and are quickly modified by a strong wind from over the lakes.

The area has a fifty year average annual January temperature of 22.9 degrees Fahrenheit and an average July temperature of 71.1 degrees. The average date of the last killing frost in the spring is May 5, and the average date of the first killing frost in the fall is October 10. Average annual precipitation amounts to 31.43 inches, of which 20 inches falls during the frost free season. The remaining precipitation may occur as rain, snow or sleet. The normal annual amount of insolation received in the area is 102,602 Langleys (39).

As stated above, wind direction and velocity plays an important role in shaping the climate of the area. The daily hourly wind velocities of the area are at their maximum during the period from November to the first of April. During this time, velocities average 8.5 miles per hour, but may reach velocities as high as 20 miles per hour, expressed as a daily hourly velocity. The period from July to August has the least wind movement of the year, with an average daily hourly velocity of 5.5 miles per hour. The April to July interval is one of declining velocities, while the period from August 31 to November 1 is a period of higher velocities (3).

Baten and Eichmeier (3) report the humidity for the East Lansing area, based on a thirty nine year daily average, to be rather high. The greatest relative humidities for the area occur during the fall and winter months. During the months of September, October, the latter part of December and all of January, the average relative humidity at 7:30 A.M. is reported to be approximately 88 percent. The month of November shows an average of 85 percent, while the latter part of April, May, June, and July, show the lowest readings. These range from 75 to 80 percent relative humidity for the seven-thirty readings for the above months. The 1:30 P.M. readings for the 39 year average are lower, but still significantly higher than for much of the nation. High readings for the one-thirty period occur during December and January and range from 65 to 85 percent. Low readings occur during the summer months, with the low coming during July and registering 45 percent.

INSTRUMENTATION

As has been previously stated, this project was designed to operate during the winter months as well as the frost free period. In order to gather the large amount of data needed for a comprehensive analysis of the hydrologic factors operating under northern conditions, the project had to be heavily instrumented. The factors considered important for this study and thus the determinants for selecting instruments were:

1. Precipitation
    a. Amount
    b. Intensity
2. Water Losses
    a. Run-off
        (1) Amount and rate
        (2) Evaporation and transpiration
        (3) Infiltration
3. Erosion Losses
4. Soil Moisture
5. Temperature
    a. Soil temperature at several depths
    b. Air temperature
6. Wind Movement
    a. Total amount
    b. Direction and velocity
7. Solar Radiation

Since the station was designed as a one-man station, as many of the instruments as possible were designed to operate either by use of electrical power or clocks. The project was initiated during a time of national emergency, and war restrictions made it impossible to construct a power line to the wooded watershed. As a consequence, this watershed has not been instrumented in such detail as has the cultivated.

Description of the Instruments

Precipitation. Precipitation is measured by the standard U.S. Weather Bureau type, non-recording rain gage. In addition, it is also measured by a nine-inch weighing type recording rain gage, to provide intensity values. A standard rain gage, equipped with Nipher shield is also used to check the reliability of rainfall measurements under conditions of high wind. These instruments are placed in two locations. One instrument grouping is located adjacent to the wooded watershed; the other adjacent to the cultivated watersheds.

Water losses. Surface run-off is measured below each watershed by means of a float type water stage recorder and a 3-H flume. A concrete approach section leads from each watershed outlet to the measuring flume. In order to prevent freezing of the water in the flume during periods of alternately freezing and thawing weather, strip heaters were installed under and along the edges of the flumes at the cultivated watersheds. An electric heater was suspended in the still well of these two flumes in such manner as to permit free float action. These heaters are adequate to keep the still well from freezing, but will not thaw ice once it has formed.

Each run-off recorder is equipped with an adjustable float stop in such a way that the float never drops lower in the still well than its zero point of buoyancy. The float stop adjustment can be read to the nearest 0.001 foot.

Evaporation. Evaporation losses from a free water surface are determined by means of a black pan evaporimeter, at a height of four feet.

Fig. 1. Instrument enclosure adjacent to the wooded watershed. Instruments from left to right are: recording rain gage, Nipher shielded rain gage, shelter housing hygrothermograph and thermometers and standard raingage.

This instrument is unique and not in general use elsewhere. The unit measures evaporation during the frost free season and sublimation of ice during the winter. It consists of a shallow black pan mounted on a Fergusson nine inch, weighing type, recording gage. When water evaporates from this pan, it is replaced, maintaining a uniform level. The evaporimeter is located adjacent to a standard raingage, so that any accretion to the evaporimeter by rainfall can be accounted for. In 1951 a standard Weather Bureau evaporation pan was installed near the evaporimeter. Results of a comparison of water losses to evaporation between the two types of evaperimeters show that the Weather Bureau pan averaged only 89 percent of the losses of the black pan evaporimeter. Crabb (10) accounts for this difference by one or both of two inherent differences existing between the two types of instruments. There is, first of all, a four foot difference in elevation between the exposed water surfaces, and secondly, the evaporimeter pan is blackened for maximum heat absorption, while the Weather Bureau pan has a galvanised finish.

<u>Infiltration</u>. Infiltration rates have been determined by means of hydrograph analysis of individual storms, and by means of tests utilizing the double ring type infiltrometer.

<u>Erosion losses</u>. Soil losses are determined for each watershed after each run-off producing storm. Run-off water from a watershed enters a concrete silt box after passing through the flume. Since the silt boxes are not large enough to hold the total quantity of run-off yielded by some storms, the outlet end of the box is equipped with a weir over which

run-off water flows after reaching a depth of two feet in the box. In the side of each silt box, a Ramser divisor was installed, thus capturing an aliquot sample of the excess run-off being discharged over the weir. This sample is caught in a catchment tank and total soil loss for any storm may be determined by analyzing for dry weight per cubic foot the catchment in the auxiliary tank, multiplying by the total volume of run-off which passed over the weir and adding that to the dry weight of the soil caught in the silt box.

Soil moisture. A method of measuring soil moisture was needed which was accurate, rapid, and which did not require the taking of soil samples. The Bouyoucos electrical resistance method (8), making use of the gypsum block principle, was selected. This method utilizes variations in the electrical resistance of porous blocks buried in the soil. The resistance of such units is directly related to the moisture content and temperature of the blocks. Since the wooded watershed was located some ten miles from the college and could not be serviced every day, soil samples were taken twice monthly for moisture determination. Soil moisture at the wooded watershed was sampled at depths of 0-6 inches, 12-18 inches, and 30-36 inches. Moisture was sampled at the cultivated watershed at 12 depths, ranging from one inch to 60 inches.

Soil temperature. At the wooded watershed a three-pen soil thermograph is used for recording soil temperatures. This instrument simultaneously records the temperature at the one inch, six inch soil depths, and at a point six inches above the surface of the soil. Soil temperatures at the cultivated watershed are taken by means of

thermocouples and resistance thermometers. The thermocouple temperatures are read and recorded manually each day at 8:00 A.M. The resistance thermometers are commected to a recorder which automatically records, at 15 minute intervals, soil temperatures at each of 14 different locations, and air temperature three inches above the soil.

Fig. 2. Three-pen soil thermograph at the wooded watershed. Top pen records air temperature, middle pen records soil one inch temperature and bottom pen records six inch soil temperature. Maximum-minimum thermometers are above thermograph clock.

Air temperature. Air temperatures are measured at the watersheds by means of standard Weather Bureau maximum-minimum thermometer sets, supplemented by mercurial current thermometeters, hygro-thermographs and resistance thermometers. The hygro-thermographs simultaneously record air temperature and relative humidity by means of a bourdon-tube thermal unit and moisture sensitive hair element.

DESIGN OF THE PROBLEM

An evaluation of the effects of vegetal cover upon the hydrology of an area must of necessity encompass several different subjects, some of which at first glance may seem to have little relation to the others. However, when one views each in relation to the effect it has upon the production of run-off from an area, it becomes apparent that many factors work together to contribute the set of circumstances which permit water to become run-off rather than enter the soil.

Of primary importance in this study, is an evaluation of the vegetal cover found upon these watersheds at the time of the study. Of equal importance with vegetal cover, is the soil found upon these watersheds. To a large degree, the soil characteristics which affect the hydrology of soil are a direct result of man's manipulation of the vegetation upon the soil affected.

Another factor vitally affecting the hydrology of a watershed in the central Michigan area, is the temperature of the soils affected. If one soil freezes rapidly while another remains in an unfrozen state, the frozen soil is far more likely to yield precipitation to surface run-off than the unfrozen soil. Lassen, Lull and Frank (20) state that in regions subject to freezing and thawing action, infiltration and permeability may be affected by the formation of frost. The type of frost formed depends upon the type, condition, or treatment of the vegetal cover as reflected in soil compaction and the reduction of organic matter.

Baver (4) points out that frost penetration is deeper and its disapearance slower under bare ground than under grass cover, since grass acts as an insulating layer to the soil. He states that there is ample evidence that soils in forests with a good surface litter freeze only to a rather shallow depth during the coldest winter.

Soil moisture is another factor which has a vital bearing upon whether a watershed will hold precipitation falling upon it, or whether this watershed will discharge a portion of the precipitation in the form of surface run-off.

The intensity with which rain drops fall upon soil has been shown by many investigators to be of paramount importance in determining whether run-off will result from any given storm. The portion of the storm in which the highest intensities occur is of equal importance with the intensity rate.

It is easy to perceive from brief discussion that any comparative analysis between the wooded watershed and the cultivated watershed will of necessity cover a wide field and will consist of many seemingly disconnected topics.

The writer has attempted to separate these diverse factors into separate chapters, first drawing conclusions between the cover types based on the differences between individual factors, such as soil moisture, frozen or unfrozen soil conditions and storm intensity differences, to name a few. Statistical analyses have been made wherever practical, and here again, the comparisons between the types of cover are held to differences attributable to changes in one factor. In the hydrologic summary section of the study the writer has attempted to point out the end result obtained by the working together of all these factors.

The writer has also attempted to point out some factors which have affected the soil temperature and soil moisture of the wooded watershed during the first year following the clear-cutting operation of 1951-52. It is realized that many years of research are preferred to one year when dealing with hydrologic data. However, the writer felt justified in utilizing a single year's data in a study of the kind attempted here. In an experiment where tree cover is removed and allowed to come back in naturally, the area is not in a static condition. Each of the first few years after the cut covers a period of rapid change in the revegetation of the area. An average of conditions existing during the first 10 years following the cut would perhaps be those present during the fifth year and would not reflect conditions existing during the first year. As an example, the first year following the cut on the watershed there was little undergrowth and almost no grass cover. The second year saw an invasion of herbaceous cover and grasses and the third brought a heavy growth of shrubs and grasses. The shielding effect from the sun's rays under heavy vegetal growth is quite different from that experienced under conditions of sparse cover. Likewise, transpirational-evaporational requirements of the two conditions will be different.

DESCRIPTION OF THE WATERSHEDS

Physical Aspect

The wooded watershed. The wooded watershed of the Michigan Hydrologic Research Station is located some ten miles north-east of the campus of Michigan State College. It is situated on lands belonging to the Rose Lake Wildlife Experiment Station.

The watershed in question has an area of 1.65 acres and is roughly oval in shape. The aspect of the watershed is to the north, as is the case with all the station's watersheds. The weighted average slope of the watershed is 6.1 percent. At it's steepest, the watershed slopes a distance of 17 vertical feet from west to east in a matter of some 150 feet. From north to south the slope amounts to 17 vertical feet in 335 feet.

The wooded watershed from the begining of the study in 1941 until December 1951 was covered by a good, well stocked oak-hickory stand averaging 70-80 feet in height for the dominants, with an average diameter of 12 inches.

Soils of the wooded watershed are derived from glacial till, and have been mapped by Soil Conservation Service personel as Conover loam, Conover silt loam, Miami loam, Hillsdale sandy loam and Hillsdale sandy loam-Metea sandy loam complex. All of these soils with the exception of Metea are derived from non-stratified parent material. The Metea is a two-storied soil.

Fig. 3: View from north to south along the steep west slope of the wooded watershed. Summer 1952.

Fig. 4: Cultivated Watershed B, showing corn in the seedling stage.

Cultivated watershed B. The cultivated watershed used in this study is located two miles south of the campus of Michigan State College. It is one of a pair which lie side by side.

The watershed has been planted to a rotation of corn, oats and alfalfa-brome since its inception in 1941.

Physiographically, the soils of this watershed are classed as consisting of undulating and rolling till. The soils are members of the Gray Brown Podzolic region. Locally they are known as Spinks fine sandy loam, Spinks loamy fine sand and Tuscola fine sandy loam.

The aspect of the watershed is to the north. It has an average weighted slope of 6.5 percent.

A comparison of the slope class distributions for the wooded and cultivated watersheds is given below.

TABLE I

COMPARISON OF SLOPE CLASS DISTRIBUTION

Slope class in percent	Percent of watershed in slope class	
	Wooded	Cultivated
2-3	17	3
3-4	3	17
4-6	30	29
6-8	34	29
8-10	6	10
10-12	5	12
12-14	5	0
Weighted average	6.1	6.5

Vegetation

The wooded watershed. An extensive vegetative survey of the watershed was made during the summer of 1951. This survey included a cruise of all stems one inch in diameter and up. The results of this cruise are shown in table 2. There were 749 cubic feet of timber in the 4.5 to 9.5 inch diameter class, and a total of 9,010 board feet, International one-fourth inch log rule, on the entire watershed. This breaks down to 4,914 board feet per acre of timber 10 inches in diameter and larger. Species wise, 74.7 percent of the timber was composed of *Quercus velutina* and *Quercus rubra*. Basal area is 105.076 per acre. As shown in table 4, when the basal area is broken down into one inch diameter classes, 93.4 percent is shown to be in the 4.5 inch diameter class and above. Sixty two and a half percent of the basal area is in the 9.5 through the 14.5 inch class.

Basal area by species for the watershed is tabulated in table 5. This table shows that 88 percent of the basal area is in *Quercus velutina* and *Quercus rubra*.

A lesser vegetation survey on nine plots, measuring 15 feet square, was carried out at the same time as the cruise. Species were identified and the proportion of the plot surface covered by each species was determined. The results of this survey are given in table 6.

A crown cover map of the wooded watershed, showing the projection of all crowns of stems one inch in diameter and larger is presented in the appendix. In addition to the crown projection, all stem locations, species of tree and stem diameter are shown on the map.

TABLE II

CUBIC AND BOARD FOOT VOLUMES, WOODED WATERSHED 1951

Diameter at breast height in inches	Cubic and Board Foot Volumes by species[1]					
	Quercus velutina	Quercus rubra	Carya ovalis	Carya ovata	Quercus alba	Acer rubrum
5	1		15	30	10	
6	2		20	12	10	
7	24		48	28	36	
8	42		60	54	42	
9	72	9	54	81	99	
10	444		72	204	216	
11	458	208	397	396	214	
12	722	74	74	166		
13	1346	336	134	90	33	
14	1131	315	183			
15	524	206				
16	240					106
17		206				
18	184	233				
Total board feet	5047	1678	463	856	860	106

1. Diameter classes 5-9 inches are given in cubic feet. Classes 10-18 inches are given in board feet.

TABLE III

SPECIES COMPOSITION BY PERCENT OF CRUISE

Species	Percent of Total
Quercus velutina	56.1
Quercus rubra	18.6
Carya ovalis	5.1
Carya ovata	9.5
Quercus alba	9.6
Acer rubrum	1.1

Fig.5: View along northern boundary, showing average stand spacing

Fig. 6. Density of one and two inch stems on the forest floor under the largest canopy opening; located in the depression in the center of the watershed.

Fig. 7. Vegetation in front of approach section. Lesser vegetation is largely mayapple.

TABLE IV

BASAL AREA BY ONE INCH DIAMETER CLASSES, WOODED WATERSHED

Diameter class Inches	Basal Area[1]	Percent 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

1. Basal area for entire watershed area of 1.65 acres.

TABLE V

BASAL AREA BY SPECIES, WOODED WATERSHED

Species	Basal Area per acre
Quercus velutina	32.818
Quercus rubra	20.515
Ulmus thomasi	.227
Fraxinus americana	.013
Crataegus spp.	.167
Hamamelis virginiana	.017
Prunus virginiana	.812
Carya ovalis	10.607
Carya ovata	17.369
Acer rubrum	1.259
Cornus racemosa	.026
Prunus serotina	4.359
Quercus alba	16.821
Total	105.076

Lesser vegetation was very dense under the few openings that existed in the canopy. There were few such openings, however, and most of the forest floor was simply covered by a dense mat of leaves. As shown in table 6, when nine test quadrats measuring 15 feet square were mapped for lesser vegetation, 46 percent of the area had no lesser vegetation. The largest constituent of the lesser vegetation was sedge (Carex pennsylvanica), which covered 25 percent of the test area.

TABLE VI

LESSER VEGETATION ON TEST QUADRATS BY SPECIES AND PERCENT OF AREA COVERED, WOODED WATERSHED AUGUST, 1951 [1]

Specie	Percent
No lesser vegetation	46.161
Carex pennsylvanica Lam.	25.138
Prunus virginiana L.	5.608
Galium boreale L.	3.721
Prunus serotina Ehrh.	3.678
Hamamelis virginiana L.	3.373
Aster macrophyllus L.	1.632
Salsola pestifer Nels.	1.448
Quercus velutina Lam.	1.440
Solidago bicolor var. ovalis Farw.	1.005
Amphicarpa bracteata L.	.821
Rosa carolina L.	.795
Ulmus thomasi Sarg.	.634
Vaccinium angustifolium Ait.	.481
Cornus racemosa Lam.	.376
Alnus rugosa Ehrh.	.371
Quercus alba L.	.332
Galium circaezans Mich.	.307
Rubus spp. (Tourn) L.	.307
Podophyllum peltatum L.	.238
Helianthus divaricatas L.	.202
Carya ovata Mill.	.186
Thalictrum dioicum L.	.181
Crataegus spp. L.	.087
Carya ovalis Sarg.	.074
Osmorhiza longistylis Torr.	.053
Antennaria plantaginifolia L.	.028
Prenanthes alba L.	.020
Quercus boreaalis Mich. [2]	.012
Circaea latifolia L.	.012
Desmodium nudiflorum L.	.005
Fraxinus americana L.	.005

1. All scientific names from Gray's Manual of Botany, Ed.8, edited by M.L. Fernold, American Company, New York, 1632 pp., 1950.

2. Given as Quercus rubra L. in Check List of Native and Naturalized Trees, Forest Service, U.S. Department of Agriculture, Agricultural Handbook No. 41, 1953.

Cultivated watershed B. Thevegetative cover on the cultivated watershed for the period 1941 to 1953 is presented in diary form. This watershed has been under a rotation of corn, oats and alfalfa-brome.

Crop diary for cultivated watershed B for the period 1941-1953.

1941	April 4-5	Soil bare
	June 6	Corn cultivated
	June 13	Corn 6-10 inches tall
	June 19-20	Corn cultivated
	September 30	Rye seeded
	October 7	Rye washed out
		Soil bare during winter of 1941-42
1942	April 15	Oats seeded
	May 12	Oats 6-12 inches tall
	May 29	Oats 10-14 inches tall
	June 11	Oats 24-30 inches tall
	July 18	Oats harvested
		Yield of 59.9 bushels per acre plus 1450 pounds air dry litter per acre. Alfalfa-brome planted.
1943	February 10	Dead growth of alfalfa brome
	October 20	Yield of alfalfa-brome for year of 3,634 pounds of hay per acre.
1944		Alfalfa-brome and clovers for entire year. Used as a sheep pasture.
1945		Alfalfa-brome and clovers for entire year. Used as a sheep pasture.
1946	July 5	Alfalfa mowed
	July 6	Hay raked
1947	April 19	Plowed
	June 3	Double disked both ways
	June 4	Spring tooth harrowed both ways and planted to corn
	June 24-25	Cultivated corn
	September 11	Drilled rye in corn
	October 5	Harvested corn. Yield of 56.7 bushels per acre

1948	May 5	Plowed and culti-packed
	May 25	Planted corn
	June 15	Cultivated corn
	July 9	Cultivated corn
	September 25	Corn cut for ensilage. Yield of 5,497 pounds green corn per acre, and 13,630 pounds of ensilage per acre. Rye drilled in stubble.
1949	April 13	Plowed
	April 14	Drilled oats, brome and alfalfa
	August 15	Oats harvested
1950	June 22	Hay cut
	August 23	Hay cut
	October 30	Alfalfa 6-8 inches tall, thin growth. Yield of first cut was 2,254 pounds per acre air dry weight. Yield of second cut was 2,783 pounds per acre, air dry weight.
1951	April 20	Alfalfa-brome 2-4 inches tall
	May 4	Alfalfa-brome 4-6 inches tall
	May 16	Alfalfa-brome 12-16 inches tall
	June 19	Hay cut. Yield of 5,704 pounds per acre.
	August 30	Hay cut. Yield of 2,536 pounds per acre.
	November 3	Medium growth in field
1952	May 9	Plowed
	May 14	Planted corn
	October 16	Corn picked, yield of 61.5 bushels per acre.
1953	May 8	Plowed
	May 16	Planted corn
	June 1	Cultivated corn
	October 12	Harvested corn
	October 13	Stubble disked, rye seeded.

DIFFERENCES BETWEEN AND WITHIN THE WATERSHEDS DUE TO VEGETATION

Soils

Various investigators have shown that soil characteristics exert a very powerful influence upon the hydrology of an area. Soil in the eyes of the watershed manager is simply a reservoir in which to store water. There are two regions of storage in this soil reservoir. They are the groundwater reservoir and the portion of the soil profile lying between the water table and the surface.

The groundwater reservoir is of importance in the central Michigan area as the source of our springs and artesian wells. Recharge water for this zone must come from precipitation entering the reservoir at an outcropping of some aquifer material such as porous sandstone or limestone, or it must percolate downward through the soil into this porous structure at some point where it is not capped by an impervious material. This artesian water finds its way by graitational flow to a zone of outlet, usually many miles from the inlet area. Fletcher (13) states that if the avenues for recharging this artesian aquifer are destroyed by some abusive land management, the water table will drop. He further states that it would be in the best interests of both flood control and increased water yield for forest soil profiles in humid regions to be handled in such manner that they would transmit maximum amounts of water through the soil profile to the groundwater profile.

A soil must be considered as a dynamic, changing organism. It is continually changing in color, structure and even in depth. These changes come about as the direct result of such agencies as freezing and thawing, burrowing of animals, shrinking and expanding under the influence of wetting and drying cycles, moving under the influence of flowing water or moving ice, and changing structure, color and depth with the addition or depletion of organic matter.

Lassen, Lull and Frank (20), speak of the soil as a series of seives. In this likeness, if water is poured on a household seive, if flows out very rapidly. However, if several seives are placed one upon the other, and water is poured through, it goes through less rapidly than before. More water may also be retained on the meshes than before. Also, the larger the meshes, the faster the water will flow through them. Soil like a seive is composed of many pores, or openings. The greater the size of the pores and the shallower the soil, the faster the water will percolate through a soil.

Soil pores are divided into two groups (17). These groups are distinguished primarily by forces which control the movement and storage of water through and in the soil profile. The first of these groups makes up what is known as detention storage. It is the storage space available in the large pores, the non-capillary pores of the soil. The second group, making up the retention storage is composed of the small, or capillary pores.

Water in the large soil pores, non-capillary pores, is said to be in detention storage. This water moves downward through the chain of pores by the pull of gravity. The large pores may transmit water laterally down a slope as well as vertically. Hursh and Hoover (17) point out that the factors influencing water storage opportunities in

the detention storage are volume, size, size distribution and shape of the large pores, as well as their continuity. In addition, the volume of the pore space available at any given time is of importance. The large pores will drain within a period of from a few to 48 hours after saturation in all but the heaviest soils. This rate of drain is, of course, tied in very closely with the continuity of the pores. If there is a layer of less permeable soil underlying a layer of highly porous surface soil, once the surface layer porosity is filled to capacity, this layer can only discharge water to the layers below it at the rate imposed by the less permeabile sub-soil.

The second group of pores, the small, capillary pores make up the soil's retention storage. This water is held in the small pores against the pull of gravity. Water in retention storage is subject to the pull of evaporation and to transpirational draft. Some of this water in the retention storage is completely unavailable to evaporative or transpirational draft. It adhere so tightly to the soil particles that plants wilt before it becomes available. The portion of soil water in retention storage that the hydrologist is chiefly interested in is that portion lying between pF 1.78 (field capacity) and pF 4.2 (permanent wilting point) (13). Retention storage is influenced by the same factors that influence detention storage. However, it is influenced more by soil moisture, in that it takes longer for retention storage to be depleted than for detention.

Of importance in retention storage is the size of the particles making up the soil. Water is held in films around the particles.

This water must be held against the pull of gravity. The point at which the holding forces refuse to release water in response to gravitational pull is known as the field capacity of the soil. More simply stated, it is the point at which all gravitational water has been drained.

Adsorption of moisture is a surface phenomenon, and the total adsorbed on a particle at any adsorptive force is directly proportional to the surface area of the particle. As can be seen, the surface area of the soil particles is an important factor to consider in determining the storage capacity of a soil. Of importance and related to the above, is the rule that the surface area of a unit volume of soil particles will increase as the number of particles increase (20).

Retention storage capacities of various textural classes of soils are given below (1):

Textural class	Retention storage capacity (inches depth of water per foot depth of soil)
Fine sand	0.5
Sandy loam	1.7
Silt loam	2.5
Loam	3.3
Clay	4.5

One of the important factors affecting retention storage is the amount of organic matter present in the soil. Organic matter serves a two fold purpose. It increases the storage capacity of the soil and increases the total volume of the soil. Organic matter being very absorptive may take on 4.4 times its own weight in water (19).

When organic matter is decomposed and mixed in the soil, it surrounds the soil particles with a very absorptive, gel-like coating. This has the effect of increasing the surface area of the particle, as well as the storage capacity of the soil profile.

Mechanical analysis. A mechanical analysis, the results of which are shown in table 7, was made in order to determine the size distribution of the individual particles which go into making up the soil. The relative amounts of each of the different sized particles which go into a soil determines the texture of a soil. From a hydrologic standpoint, other things being equal, texture influences the amount of surface area of the soil particles, which in turn affects the water holding capacity of a soil. Retention storage is greater in silts and clays than in sands. A high percentage of sand may indicate the presence of a large number of non-capillary pores, increasing detention storage.

The soils were prepared for the mechanical analysis by breaking the large clods and shaking the soil on a 2 millimeter seive, the samples passing through the seive were then subjected to the Bouy-oucos Hydrometer Method of mechanical analysis (9).

In general, the clay and silt content of the soils from the cultivated watershed were less than the clay and silt content for soils from the same depths at the wooded watershed. This is especially true of the first three inches of the Spinks loamy fine sand. The specific gravity of eroded material from this watershed during the first five years of the study consistently ran in the neighborhood of 1.18 . This indicates that the humus matter in the soil was among the first victims of erosion.

TABLE VII

SUMMARY OF RESULTS OF MECHANICAL ANALYSIS

Depth, Soil type and Watershed	Mechanical Composition in percent Sand	Silt	Clay
0-3 inch layer			
Wooded watershed			
Miami loam	45.3	38.1	15.7
Conover loam	65.2	16.8	18.0
Hillsdale sandy loam-Metea sandy loam complex	63.9	28.5	7.4
Conover silt loam	30.3	59.7	10.0
Cultivated watershed			
Spinks loamy fine sand	78.7	17.4	3.9
Spinks fine sandy loam	61.6	27.5	10.9
4-7 inch layer			
Wooded watershed			
Miami loam	47.3	35.0	17.5
Conover loam	67.7	15.3	17.0
Hillsdale sandy loam - Metea sandy loam complex	61.0	29.2	9.9
Hillsdale sandy loam	60.6	30.1	10.3
Conover silt loam	31.3	51.3	17.4
Cultivated watershed			
Spinks loamy fine sand	62.3	28.9	8.8
Spinks fine sandy loam	66.4	24.5	9.1
12-15 inch layer			
Wooded watershed			
Miami loam	40.0	31.0	28.0
Conover loam	72.8	14.3	12.9
Hillsdale sandy loam - Metea sandy loam complex	50.0	26.2	24.8
Hillsdale sandy loam	57.1	26.1	16.8
Conover silt loam	32.0	52.3	15.7
Cultivated watershed			
Spinks loamy fine sand	56.6	33.9	9.5
Spinks fine sandy loam	68.8	20.4	10.8

All soil values used in this study were replicated three times.

The fine sandy soils at the cultivated watershed fall into the third grouping of Atterberg's system of particle size seperation (2). This group consists of particles from 0.2 to 0.02 millimeters in size. Baver (4) states that the lower range of these sands do not have the normal properties of sands and can be coagulated to form better structure. These sands are on the dividing line between dry, unproductive sands, and moist productive soils.

Soil organic matter. Soil organic matter has a very decided influence upon a soils water holding capacity. High organic matter content may increase both the detention and the retention storage. Organic matter for the soils on the two watersheds was measured in this study. Organic matter content was determined by the dry combustion method (28). Organic matter is determined by measuring the amount of carbon dioxide evolved in the combustion of soil and converting it into percent of organic matter present in the sample before the burning.

As shown in table VIII, organic matter content in the wooded soils is high, while that of the cultivated soils is low. This is reflected in the greater retentivity, as well as the greater detention storage present in the wooded soils. The effect of the high organic matter content is further shown in the lower volume weights for the wooded soils. Organic matter content for the wooded soils drops sharply from the first three inches to the next, while the decline for the cultivated soils is less abrupt. This is due to the mixing effect of plowing.

<u>Volume weight</u>. Volume weight is the ratio between the dry weight of a given mass of undisturbed soil and its volume, and is found by dividing the oven dry weight of the soil in grams by the volume of the core in cubic centimeters.

Volume weight is dependent upon structure and organic matter content. Usually, compact soils with low pore volume possess a high volume weight. Porous soils, however, may do the same. Soils with high organic matter content have low volume weights. Soils with low volume weights usually show good soil-water relations. Those with high volume weights usually have a low infiltration rate and low detention storage.

Volume weights for the wooded soils are in general much lower than those for corresponding depths at the cultivated watershed. This is due primarily to the effect of the much higher organic matter present in the wooded soils.

TABLE IX

ORGANIC CONTENT AND VOLUME WEIGHTS

Soils and Watershed	Depth in Inches					
	Organic Matter in Percent			Volume Weights		
	0-3	4-7	12-15	0-3	4-7	12-15
Wooded watershed						
Miami loam	18.2	6.4	.1	.79	1.01	1.51
Conover loam	8.8	3.4	.2	1.00	1.27	1.05
Hillsdale sandy loam - Metea sandy loam	15.0	6.3	.7	.87	1.09	1.43
Hillsdale sandy loam	19.3	5.6	.9	.76	1.01	1.35
Conover silt loam	5.3	1.5		1.36	1.68	1.60
Cultivated watershed						
Spinks loamy fine sand	1.8	1.7	.5	1.45	1.44	1.60
Spinks fine sandy loam	1.9	1.4	.2	1.40	1.41	1.61

Porosity. The most important single criterion for judging the hydrology of a soil is perhaps the pore space distribution of that soil.

Soil porosity is divided into two classes, capillary and non-capillary. In making porosity determinations for this study, 3x3 inch soil cores were saturated, weighed and placed on a tension table. There they were subjected to tensions of 10, 20, 40, and 60 centimeters. The division point of 60 centimeters was used as the line between capillary and non-capillary porosity. After being removed from the tension table, the cores were oven dried at 105 degrees Centigrade to determine capillary volume and volume weights.

Average values obtained for the various soils for capillary, non-capillary and total porosity are given in table X.

In general, the wooded soils had a considerably higher total porosity than their cultivated counterparts.

Even more important than total porosity are the percentages of capillary and non-capillary pore space distribution. All the surface layers of the wooded watershed soils have much greater non-capillary pore space than the cultivated, and most of the 4-7 inch layer in the wooded soils also has higher non-capillary pore space values. The Miami loam, which makes up approximately half the area of the wooded watershed, has a very low non-capillary pore space at the 12-15 inch level, indicating poor detention storage, as well as poor permeability. The Conover silt loam has poor detention storage space in the area from 4-15 inches deep. This is, again, an indication of poor permeability. This means that water will move through these layers at a low rate of speed.

TABLE X

TOTAL, CAPILLARY, AND NON-CAPILLARY PORE SPACE DISTRIBUTION OF SOILS FROM THE WOODED AND CULTIVATED WATERSHEDS

Soil and Watershed	Depth in Inches	Pore Space Distribution in Percent		
		Total	Capillary	Non-capillary
Wooded watershed				
Miami loam	0-3	53.29	37.10	16.19
	4-7	49.50	34.90	14.60
	12-15	38.78	35.19	3.59
Conover loam	0-3	48.08	35.2[illegible]	12.87
	4-7	34.45	25.25	9.20
	12-15	40.62	30.86	9.76
Hillsdale sandy loam-Metea sandy loam	0-3	50.42	33.02	17.40
	4-7	46.25	32.38	13.86
	12-15	43.80	34.62	10.18
Hillsdale sandy loam	0-3	54.09	38.01	16.09
	4-7	48.05	37.38	10.67
	12-15	38.30	28.65	9.65
Conover silt loam	0-3	51.65	38.38	13.27
	4-7	32.05	26.38	5.67
	12-15	35.30	25.65	9.65
Cultivated watershed				
Spinks loamy fine sand	0-3	45.09	34.54	10.56
	4-7	45.09	36.53	8.56
	12-15	39.43	30.35	6.08
Spinks fine sandy loam	0-3	40-94	29.20	11.74
	4-7	40.00	34.10	5.90
	12-15	37.63	30.63	7.00

The low non-capillary porosity of the Conover silt loam is particularly important since this soil occurs in the central basin of the watershed. Any water flowing over the Conover silt loam has little opportunity to infiltrate, but must continue to flow down slope as surface run-off. In addition to surface run-off, water draining down slope from the large pores in the Miami loam will come to the surface over the Conover silt loam and will become surface run-off unless the Conover can absorb it. With the very low detention storage it possesses, there is little likelihood of its absorbing large quantities.

The cultivated soils had relatively low detention storage space in the two lower layers. In addition, the cultivated soils had a lower retention storage than the wooded soils.

Permeability. Permeability of the soil is the rate at which water moves through the soil column. It differs from infiltration, in that infiltration is the rate at which water enters the soil. These two form the most important of criteria for judging the hydrology of a soil. If a soil has a high permeability rate and a low infiltration rate, caused perhaps by the sealing of the surface pores as a result of the beating action of raindrops, the high permeability will be little used. Likewise, if the surface has a high infiltration rate and a lower layer possesses a low permeability rate, then the soil will only be able to absorb water at the surface, once the surface becomes saturated, at a rate equal to the permeability rate of the dense layer below it.

Permeability rates for the study were determined in inches per hour by determining the time required for known quantities of water to pass through saturated 3 x 3 inch cores of soil.

The permeability rates listed in Table XI are probably very near the true field conditions for the cultivated soils. The rates for the wooded watershed are probably low, since the effects of hydraulic channels made by rodents, worms and decaying roots could not be measured by use of 3 x 3 inch cores of soil.

TABLE XI

PERMEABILITY RATES

Soil and Watershed	Depth in Inches Rates in Inches per Hour		
	0-3	4-7	12-15
Wooded watershed			
Miami loam	70.96	25.70	0.05
Conover Loam	15.36	3.62	2.00
Hillsdale sandy loam - Metea sandy loam complex	38.30	21.00	5.15
Hillsdale sandy loam	45.18	19.35	2.01
Conover silt loam	14.34	.08	1.04
Cultivated watershed			
Spinks loamy fine sand	17.01	11.36	.64
Spinks fine sandy loam	15.64	7.06	.80

Permeability values for the wooded soils are considerably higher than those of the cultivated, with one notable exception. The 12-15 inch layer of the Miami loam has a rate of only 0.05 inches per hour. It is felt that this rate is a true reflection of the permeability for this layer. Infiltration tests on the sub-soil of the Miami, and infiltration rates obtained by hydrograph analysis show a constant rate of 0.04 inch per hour after the soil becomes saturated. In view of the foregoing and in view of the fact that the Miami loam covers half of the watershed, it is valid to assume that practically all the surface run-off for the watershed comes from the Miami loam and the Conover silt loam. When the Miami loam becomes saturated, it begins discharging water downslope onto the Conover silt loam, since the clay layer below the Miami has such a low rate of permeability. As the concentration of water builds up on the surface of the Conover silt loam, which has a very low rate of permeability itself, it finally overcomes the resistance of brush dams and begins to run off the watershed. The writer observed a run-off on the watershed on March 24, 1954 which clearly supports the above. The watershed yielded run-off as the result of a rain which placed 1.68 inches of water on the watershed in a period of ten hours. Soil moisture at the begining of the rain was near field capacity. At the time of first observation, seven hours after the begining of run-off, the entire central basin of the watershed was covered in standing water to a depth of from two to four inches. The Conover Silt loam covers practically all of the basin. At this time, water was observed trickling out of the Miami at the base of the slope lying to the west of the center basin. The period of the next observation was some 30 hours after run-off began. All run-off had ceased at this time, but some puddles of water were still standing on the surface of the Conover.

Permeability rates for the cultivated soils show the 12-15 inch layer to be the critical one. Rates of 0.64 and 0.80 inch per hour were obtained in the laboratory. Previous preliminary analysis of storms occuring on the cultivated watershed have shown that once enough precipitation has fallen to saturate the soil, an intensity greater than 0.80 inch per hour would cause run-off.

Infiltration. Results of a Double Ring infiltration test on the Miami loam of the wooded watershed indicated the infiltration rate over a period of seven hours for the surface soil was 7.5 inches per hour. Before saturation the rate amounted to 12.4 inches per hour. Subsoil at a depth of 13 inches gave a rate of only 0.04 inch per hour.

As stated in the previous section, when the Miami becomes saturated it discharges water down slope. Under this thesis, the rate of 7.5 inches per hour sustained infiltration is not so much a measure of how fast water is moving downward into the soil, but it is a measure of how fast this water is being discharged downslope.

Infiltration tests have not been run on the cultivated soils. Analysis of hydrographs of run-off from the cultivated watershed indicate that initial rates vary drastically, depending upon the extent of cover. Sustained rates of infiltration seem to approximate the 0.80 inch per hour that was noted in the permeability test.

Soil Moisture

In order to determine the saturation point and field capacity, as well as the manner in which the soils lose moisture, soil cores were drained at various tensions on the tension table. The results of the study are given in table XII. All soils of the wooded watershed are accounted for in this table. Only one of the two cultivated soils is listed, since both gave almost identical results.

TABLE XII

SOIL MOISTURE IN PERCENT FOR VARIOUS TENSIONS FOR SOILS FROM THE CULTIVATED AND WOODED WATERSHED

Soil. Tension in Centimeters	Depth in Inches			
	0-3	4-7	12-15	30-33
Wooded Watershed				
Miami loam				
Saturation	67.0	35.5	28.3	16.0
10.0	55.0	24.5	23.0	15.0
20.0	52.0	23.5	22.1	15.0
40.0	48.0	23.0	20.5	14.5
60.0	45.5	21.5	19.0	14.0
Conover loam				
Saturation	36.5	25.3	27.2	16.0
10.0	34.0	23.5	24.0	14.5
20.0	32.5	22.1	23.5	14.0
40.0	32.0	19.5	21.8	14.0
60.0	31.0	17.5	20.9	13.0
Hillsdale sandy loam - Metea sandy loam complex				
Saturation	41.0	29.1	22.5	24.0
10.0	33.9	24.5	22.0	23.1
20.0	33.2	23.5	22.0	23.0
40.0	30.5	21.1	19.0	19.2
60.0	28.2	17.1	16.5	16.8
Hillsdale sandy loam				
Saturation	65.0	45.0	28.0	32.0
10.0	57.0	39.0	26.0	31.5
20.0	55.0	36.0	25.5	31.0
40.0	50.5	34.0	23.0	30.5
60.0	49.0	33.0	20.3	29.0
Conover silt loam				
Saturation	35.0	19.0	25.6	30.0
10.0	34.0	18.0	19.4	28.7
20.0	32.0	18.0	18.1	28.0
40.0	31.5	17.0	16.9	25.2
60.0	31.0	16.0	15.0	17.0

TABLE XII (CONTINUED)

Soil. Tension in Centimeters	Depth in Inches			
	0-3	4-7	12-15	30-33
Cultivated watershed				
Spinks loamy fine sand				
Saturation	24.0	23.0	22.0	24.7
10.0	23.3	20.4	21.0	24.3
20.0	22.0	19.2	20.8	23.0
40.0	19.5	18.8	15.9	21.5
60.0	17.9	17.8	15.6	19.0

With the exception of the Conover loam and the Conover silt loam, all wooded watershed soils have a far greater detention storage,(that water stored between saturation and 60.0 centimeters tension), than do the cultivated watershed soils. This is particularly true of the first three inches, and to a lesser extent, the 4-7 inch layer. This greater detention storage is doubtless due to the high percent of organic matter found in the surface layer of the wooded soils. There exists a striking difference between the two groups of soils in relation to the amount of retention storage also. In the surface layers, the wooded soils are able to hold against the pull of gravity a far greater amount of water than the cultivated soils. However, there seems to be no difference in retention storage below the 12 inch layer between the soils of the two watersheds. This depth is out of the zone of influence of the organic matter.

<u>Soil moisture comparisons between the watersheds</u>. Soil moisture readings were made at two week intervals at the wooded watershed. The method of measurement used was gravimetric sampling. Soil moisture at the

Fig. 8. Double ring infiltrometer in use at the wooded watershed.

cultivated watershed was taken daily at 8:00 A.M. by means of the electrical resistance method.

Soil moisture prior to a storm is of great importance in determining whether or not surface run-off will result from a storm. The amount of soil moisture stored in a soil profile is also important in determining whether enough water will be available for plant growth.

An examination of Figures 9, 10 and 11 show graphically the diffcrence between the two watersheds from a water storage standpoint. These charts are based on bi-monthly readings for a six year period.

Figure 9 shows the moisture relationship between the two watersheds for the 0-6 inch depth. The cultivated watershed, on a bi-monthly reading, never approached field capacity. The wooded watershed remained near field capacity during the months of March and April. As the transpirational draft became greater, soil moisture rapidly decreased until it was near the wilting point for a short time in August. It then began to rise and continued this trend until it reached a near saturated condition in the spring.

The cultivated watershed follows the same trend, but the fluctuations are not so great as those of the wooded. The soil at the 0-6 inch level at the cultivated watershed remains near the permanent wilting point for a longer period of time than that of the wooded.

Figure 10 indicates the same trend as Figure 11 with the exception that the peaks and troughs at the 30-36 inch level occur some two weeks later those of the 12-18 inch level.

Soil moisture changes due to clear - cutting the wooded watershed. As has been previously stated, the wooded watershed was clear-cut during the winter of 1951-52.

The yearly soil moisture regime for the three depths tested, 0-6, 12-18, and 30-36 inches was plotted on Figures 9, 10 and 11 in order to show the effect that removal of cover had on the soil moisture of these layers. The soil moisture for the cultivated watershed was also plotted for these layers for the year 1952, in order to have a further comparison between cover types.

In order to more clearly present the effect upon water storage of such a cut, Table XIII has been prepared, showing the average precipitation for the six year period covered in Figures 9, 10 and 11. Monthly precipitation for 1952 is also presented.

TABLE XIII

PRECIPITATION MEASURED AT THE WOODED WATERSHED

Months	1945-1951 Average in Inches	1952 in Inches
January	2.10	2.01
February	1.58	1.54
March	2.53	2.09
April	2.65	3.58
May	4.21	4.09
June	3.64	1.15
July	2.54	2.79
August	3.12	4.35
September	3.34	1.68
October	2.72	0.51
November	2.31	3.47
December	2.06	1.73
Total	32.71	28.99

The year 1952 had a deficit of 3.72 inches when compared with the average of the six previous years. It should be noted that the soil moisture for the year for the 0-6 inch layer, as portrayed in Figure 9, began the year at the minimum point for the previous six years. It rose rapidly, and continued high for the remainder of the year. Only twice did it cross the six year average line, and then for only a short time. The 1952 soil moisture line for the same depth was erratic, but in general was much nearer the average line than its wooded counterpart.

In comparing the 1952 soil moisture with the six year average, as is shown in Figures 9, 10 and 11, the deeper the layer in question, the higher the moisture content in 1952, as related to that of the average. This reflects the influence of evaporation and the transpiration of shallow rooted plants. The lack of deeper rooted plants enables the lower soil levels to maintain a high soil moisture content. The cut raised the soil moisture content of all the depths, it's influence being greatest on the lower levels.

A comparison of the years 1951 (under wooded cover) and 1952 (cut-over), affords another means of showing the effect of vegetation removal upon soil moisture.

Figure 12 presents the normal picture of the average soil moisture year under wooded cover. It should be noted that a typical summer drought period prevails from July to October. This condition of low soil moisture exists in every year since the station began soil moisture measurements. It exists for all three soil depths tested. It should be noted that this condition does not exist in the case of the 1952 soil moisture.

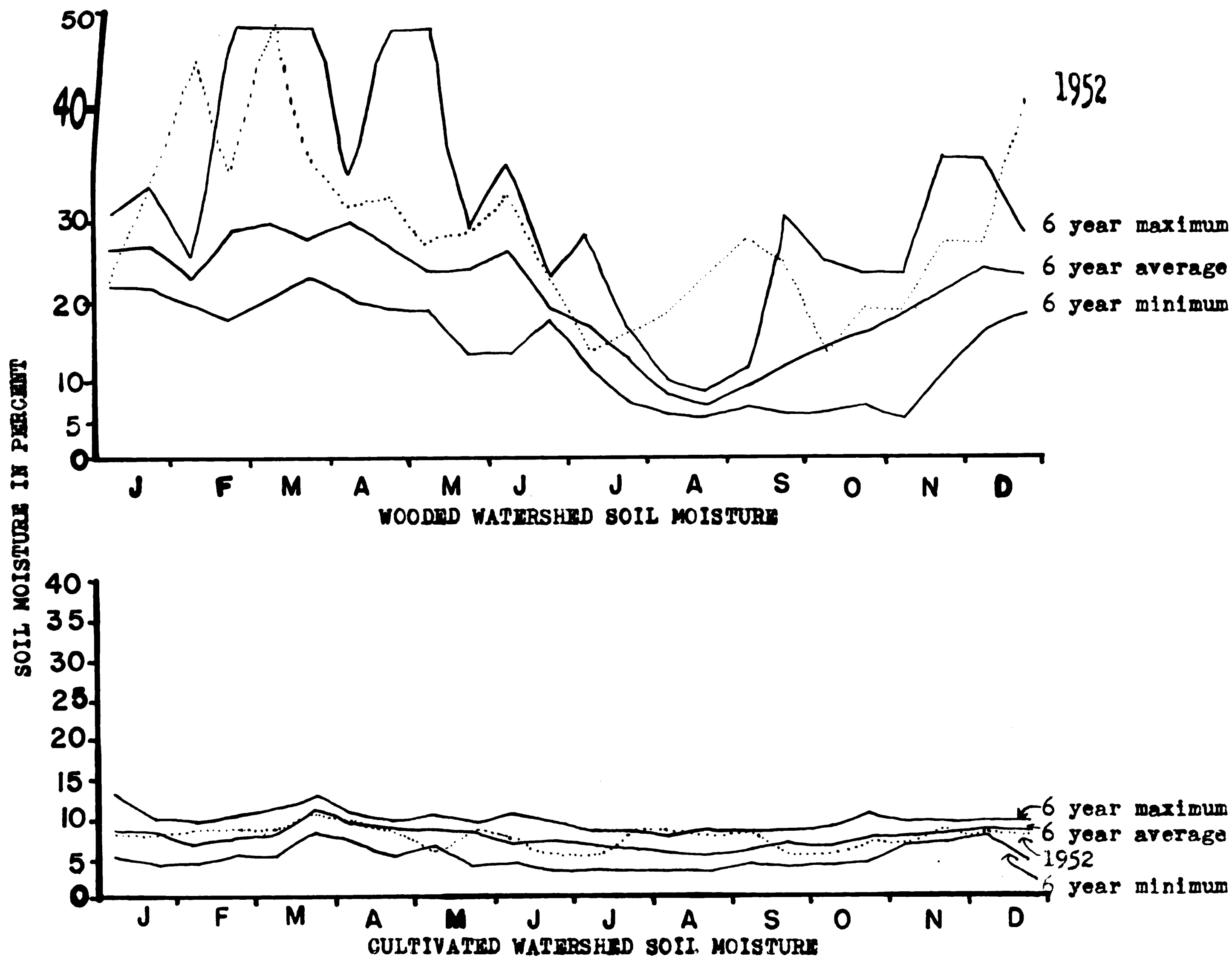
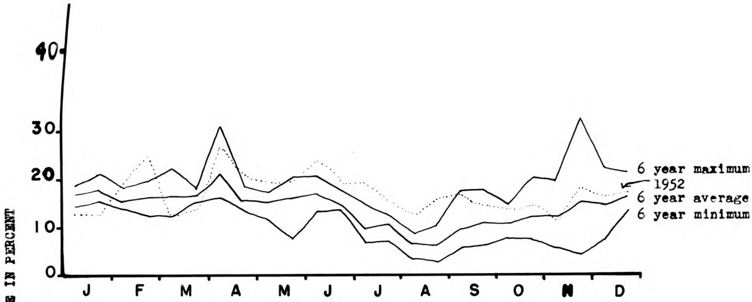
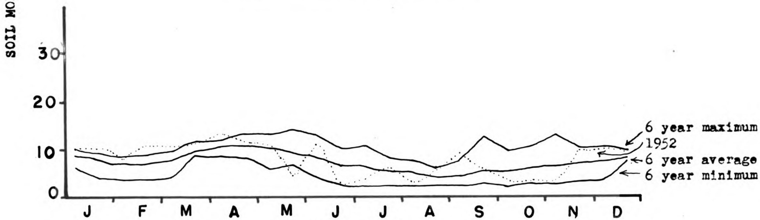


Fig. 9. Six year bi-monthly maximum, minimum, and average, and 1952 soil moisture for 0 - 6 inch depth at the wooded and cultivated watersheds.



WOODED WATERSHED SOIL MOISTURE



CULTIVATED WATERSHED SOIL MOISTURE

Fig. 10. Six year bi-monthly maximum, minimum, and average, and 1952 soil moisture for 12 - 18-inch depth at the wooded and cultivated watersheds.

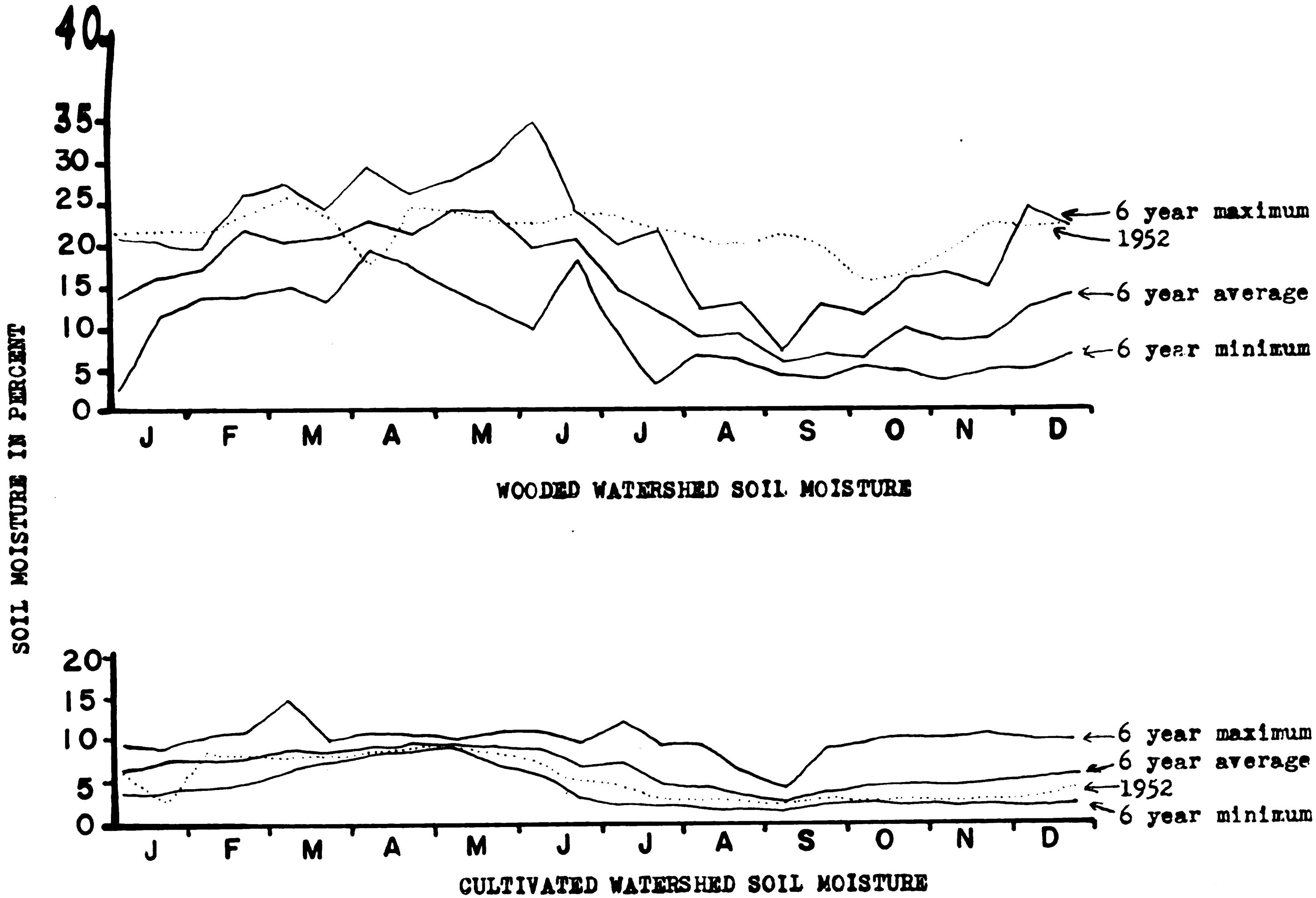


Fig. 11. Six year bi-monthly maximum, minimum, and average, and 1952 soil moisture for 30 -36 inch depth at the wooded and cultivated watersheds.

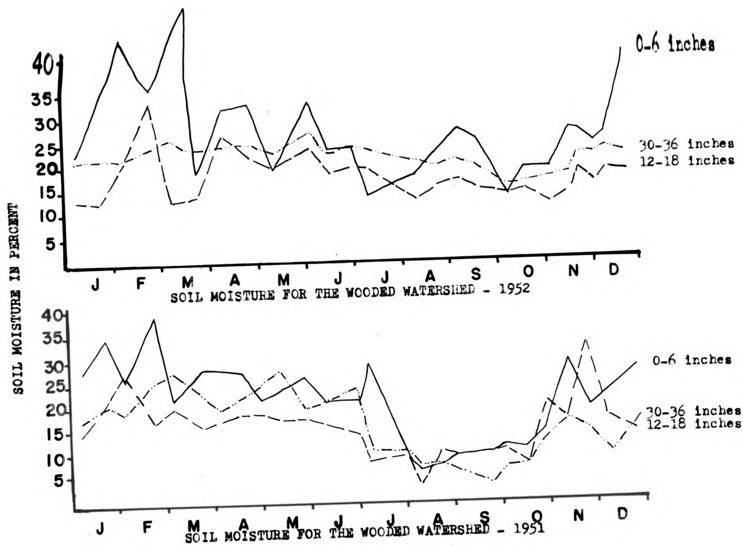


Fig. 12. Wooded watershed soil moisture for 1951 and 1952.

Fig. 13. Wooded watershed immediately after the cut, showing debris left on the ground. View is to the north. Instrument house for the run-off gaging station is located at the extreme left.

Fig. 14. Wooded watershed in August 1953, two growing seasons after the cut.

There were slight, short duration drops in the 0-6 and 12-18 inch levels, but not to the extent that existed previously. The 30-36 inch level continued unseasonably high.

As a further help in making the evaluation, the following table is presented. It should be noted that the total precipitation for 1951 is almost identical with the average for the previous six years. It should also be noted that the August precipitation is quite high in favor of 1952. The June precipitation is much greater for 1951, however. It should also be noted that the year 1952 showed a deficit of almost four inches for the entire year when compared with 1951, yet it ended the year with soil moisture values as high as those of 1951.

TABLE XIV

PRECIPITATION BY MONTHS FOR 1951 AND 1952

Month	Precipitation in Inches		Month	Precipitation in Inches	
	1951	1952		1951	1952
January	2.85	2.01	July	1.41	2.79
February	1.56	1.54	August	2.54	4.35
March	1.76	2.09	September	2.72	1.68
April	3.80	3.58	October	4.21	.51
May	3.09	4.09	November	2.97	3.47
June	3.17	1.15	December	2.66	1.73
			Total	32.74	28.99

Hydrologically the increased soil moisture caused by less use of moisture due to the reduction of vegetation, is of importance. It will be shown in a later chapter that the period from July to September is one of thunderstorm activity, with high precipitation intensities and high total precipitation per rainstorm. It seems logical to assume that the higher soil moisture caused by cutting will leave less storage space in the soil and will thus aid in producing some surface run-off in the event one of the high precipitation intensity storms should occur.

All storms occuring on the wooded watershed which yielded 0.25 inch rain or over for the period 1945-1951 were analyzed by means of a two way table and using Chi Square to determine significance. These storms were divided into those producing run-off and those producing no run-off. These were further divided into two groups, those which fell on soil having a percent moisture at or above field capacity, and those falling on soil below field capacity. There were 12 run-off producing storms on the wooded watershed during this time. Of the 12, only two fell on soil which had a moisture content below field capacity. The Chi Square test showed that high soil moisture was highly significant in aiding to produce run-off.

Neal (23) noted that the soil moisture content at the begining of a rain had a greater effect upon the rate of infiltration during the first 20 minutes than any other factor. The rate of infiltration varied approximately inversely as the square root of the soil moisture content at the begining of the rain.

A Chi Square analysis similiar to the one made at the wooded watershed was made for the cultivated watershed. In this analysis, however, the soil moisture conditions preceeding the storms were divided at 9.5 percent soil moisture. It is realized that this is well below field capacity for these soils, but examination of the data indicated this to be a critical point. When storms falling during the frost-free period of the year were analyzed, it was found that an antecedent soil moisture of 9.5 or over in the first six inches of the profile, proved to be highly significant in aiding to produce run-off.

The effect of cutting on the first years surface run-off. An attempt was made to determine the effect, if any, the cutting of the timber growth would have on surface run-off for the first year following the cut. As shown in Figures 3 and 4, there was very little lesser vegetation on the forest floor before the cut was made. Figure 13 shows the condition of the forest floor following the cut. After the cut was made there was an interim period of one year before any appreciable amount of vegetation came up to cover the area and begin using the additional soil moisture made available by the lack of transpiration of the former vegetation. Figure 14 shows that by the end of two years there was a large amount of vegetation on the area. However, the first year's cover consisted of the scattered small stems left on the area and a few small patches of grass and shrubs.

With less water usage than formerly, the soil moisture was unusually high at all levels tested. There were only two run-offs during 1952. One of these occured in April, a month of high soil moisture in any year at the wooded watershed. This storm, occuring on April 12, 13, and 14, dumped 2.13 inches of rain on the watershed with the highest intensity only 0.6 inch per hour. Run-off amounted to 0.05 inch. This storm was compared with the storm of December 20-22, 1949. The December storm was as nearly like the April 1952 storm as could be found in the records. The major differences were that the December storm yielded 2.51 inches of precipitation, compared to 2.13 for the

April storm. The December storm had higher intensities than the April storm also. In every instance, the December storm was more conducive to producing run-off, yet it did not, while the smaller April 1952 storm did produce run-off.

The second run-off of 1952, while yielding less surface run-off than the April one, was more spectacular in pointing out the effect the increased soil moisture has on run-off. The August 16, 1952 rain yielded 1.80 inches of precipitation in four hours. Intensities reached a peak of 2.76 inches per hour for a period of five minutes during this storm. The surface run-off for the storm amounted to .0028 inch and run-off lasted for three hours, the major portion coming during the first 40 minutes following the peak intensity.

The wooded watershed has yielded surface run-off on only one other occasion during the history of the project in the month of August. August, as shown in Figures 9, 10 and 11, is a month of high transpiration, and soil moisture is at a low during this month.

On August 31, 1945 a rain of 1.49 inches, lasting for a period of 3 hours and 41 minutes fell on the wooded watershed. This rain caused a trace of run-off which lasted for a period of 52 minutes. Both of these August storms were of high intensity types. Intensities for the 1945 storm reached a peak intensity of 3.00, 4.00 and 2.40 inches per hour for periods of 2, 3, and 2 minutes respectively. The storms were of the same pattern. Both started with a high intensity burst of rain, followed by low intensities before the highest intensities in the middle of the storm.

It appears from the above description that these two storms are sufficiently alike that it can be safely said that the difference in run-off produced was due to some factor not inherent in the storms themselves. As soil moisture measurements were not begun until 17 days after the 1945 storm, the antecedent soil moisture measurements can not be compared. The measurements for the rest of 1945 are given in table XV and do help in analyzing the situation.

TABLE XV

SOIL MOISTURE IN PERCENT FOR PART OF 1945 FOR THE WOODED WATERSHED

Month	Depth in Inches					
	1945			1952		
	0-6	12-18	30-36	0-6	12-18	30-36
September	11.6	8.6	5.9	24.9	15.6	19.7
October	18.1	16.5	10.0	17.0	13.8	16.3
November	21.0	13.3	9.4	23.7	14.6	19.4
December	19.1	15.7	13.2	33.2	16.8	21.2

Precipitation for the years 1945 and 1952 are given in table XVI. Precipitation for 1945 amounted to nearly ten inches more than that received in 1952. Rainfall for the four months preceeding the 1945 storm amounted to 18.76 inches. Rainfall for the four months preceeding the 1952 storm amounted to only 12.38 inches. The month of August for the two years had almost the same amount of rain, as did the month of July for both years. In the months of May and June, the precipitation for 1945 was over twice that of 1952. It should also be noted that September 1945 received 6.18 inches rain while the same month in 1952 received only 1.68 inches. However, as is shown in table XV, soil moisture at the wooded watershed was much greater in 1952 than in 1945. This is true for all three depths tested. It follows from the above the reason for the low moisture content of the soil in 1945 was the heavy use of water by the vegetation, and the high soil moisture of 1952 was due to the low use of water due to the absence of vegetation. It then follows that the high soil moisture present in 1952 was conducive to allowing run-off as a result of a rain of the magnitude of the August 16, 1952 storm. This was the only storm of such magnitude during the July to September period. It seems reasonable to assume that if as much precipitation had fallen in 1952 as fell in 1945, soil moisture would have been even higher than it was, and more than 0.05 inch of run-off would have resulted from a storm such as the August 16 one.

TABLE XVI

INCHES PRECIPITATION AT THE WOODED WATERSHED FOR TWO YEARS

Month	Precipitation in Inches 1945	1952
January	0.41	2.01
February	1.17	1.54
March	2.19	2.09
April	3.60	3.58
May	7.21	4.09
June	4.00	1.15
July	2.60	2.79
August	4.95	4.35
September	6.18	1.68
October	3.27	0.51
November	1.51	3.47
December	1.33	1.73
Total	38.42	28.99

<u>The effect of frozen soil on surface run-off.</u> Conditions of frozen soil have not occured so frequently at the wooded watershed as at the cultivated. The cultivated is usually in a frozen state from December to April. The wooded watershed while freezing at times, only remains in a frozen state for a short time, and the frozen layer seldom extends beyond six inches. This portion of the study will be concerned with the freezing of the soil at the cultivated watershd, it's effect upon run-off, and the comparison of run-off from the two watersheds during the period of freezing temperatures.

Table XVII is a compilation of precipitation, run-off, soil moisture for unfrozen soil and a tabulation of all frozen layers in the soil profile. The table covers the period from December 1, 1946 to the middle of April, 1947.

An examination of Table XVII shows that as soil moisture froze to a depth of six inches, run-off occured on two days, as a result of snow melt. There was little run-off for the month as a whole. On January 10, a short period of warm weather caused snow melt, and again run-off occured. On January 14, a rain of .08 inch caused a partial thawing of the frozen soil, and again run-off occured as the result of melting snow. This continued until January 26, when warm weather again forced a partial thaw. At this time, all run-off ceased, with the mean air temperature going as high as 44 degrees Fahrenheit. All snow melt occuring during this time was absorbed by the partially thawed soil. On February 4, temperatured dropped drastically to daily means of 6 and 8 degrees Fahrenheit. In response to this, the soil again reached a state of hard freezing to a depth of 12 inches.

TABLE XVII

PERCENT MOISTURE, FROZEN SOIL[1], PRECIPITATION[2] AND RUN-OFF FOR WATERSHED B, WINTER 1946-1947

Date	Depth of Observation in Inches												Run-off	Precipitation	
	1	3	6	9	12	18	24	30	36	42	48	60		Type	Amount
1946 December															
1	8.5	8.5	8.0	10.0	10.0	7.5	4.5	2.0	2.0	2.0	1.5	3.2		S	.01
2	8.5	8.0	8.0	10.0	1C.0	7.5	4.5	2.0	2.0	2.0	1.5	3.5			
3	f	f	7.5	10.0	10.0	7.5	4.5	2.0	2.0	2.0	1.5	3.5			
4	f	f	8.0	1C.0	10.0	7.5	4.5	2.0	2.0	2.0	1.5	3.5			
5	*	*	7.5	10.0	9.5	7.5	4.5	2.0	2.0	2.0	1.5	3.5			
6	*	8.5	8.0	10.0	10.0	7.5	4.5	2.0	2.0	2.0	1.5	3.5		R	T
7	9.0	9.5	8.0	10.0	10.0	7.5	4.5	2.0	2.0	2.0	1.5	3.5			
8	9.5	10.0	8.0	10.0	10.0	7.5	4.5	2.0	2.0	2.0	1.5	3.5			
9	9.0	9.5	8.0	10.5	10.0	7.5	4.5	2.0	2.5	2.0	1.5	3.5		R	.01
10	9.0	9.5	8.0	10.0	10.0	7.5	4.5	2.0	2.0	2.0	1.5	3.5		R	.14
11	9.0	9.0	7.5	10.0	10.0	8.0	4.5	2.0	2.0	2.0	1.5	3.5			
12	8.0	10.0	8.0	10.0	10.0	8.0	5.0	2.0	2.0	2.0	1.5	3.5		R&S	1.51
13	8.5	10.0	8.0	10.5	10.5	8.5	5.0	2.0	2.0	2.0	1.5	3.5			
14	F	F	8.0	10.5	10.5	8.5	5.0	2.0	2.0	2.0	1.5	3.5			
15	F	F	8.0	10.5	10.5	8.5	5.0	2.0	2.0	2.0	1.5	3.5			
16	F	F	8.0	10.5	10.0	8.0	5.5	2.0	2.5	2.5	1.5	3.5		R&S	.07
17	F	F	8.0	10.5	10.0	8.0	5.5	2.0	2.5	2.0	1.5	3.5		S	.01
18	F	F	8.0	10.0	10.0	8.0	5.5	2.0	2.0	2.0	1.5	3.5		S	T
19	F	F	*	10.0	10.0	8.0	5.5	2.0	2.5	2.0	1.5	3.5		S	T
20	F	F	f	10.0	10.0	8.0	6.0	2.5	2.5	2.0	1.5	3.5		S	T
21	F	F	*	10.0	10.0	8.0	6.0	2.5	2.0	2.0	1.5	3.5		S	.14
22	F	F	*	10.0	10.0	8.0	6.0	2.5	2.0	2.0	1.5	3.5			
23	F	F	*	10.0	10.0	8.0	6.0	2.5	2.0	2.0	1.5	4.0			
24	F	F	*	10.0	10.0	8.0	6.0	3.0	2.0	2.0	1.5	4.0			
25	F	F	F	10.0	10.0	8.0	6.5	3.0	2.0	2.0	1.5	4.0			

TABLE XVII (CONTINUED)

Date	Depth of Observation in Inches												Run-off	Precipitation	
	1	3	6	9	12	18	24	30	36	42	48	60		Type	Amount
December (Continued)															
26	F	F	F	10.0	10.0	8.0	6.5	3.0	2.0	2.0	1.5	4.0			
27	F	F	F	10.0	10.0	8.0	6.5	3.0	2.0	2.0	1.5	4.0	.0188	R	.13
28	f	f	f	10.5	10.0	8.5	7.0	3.5	2.0	2.0	1.5	4.0	.0005	R	.02
29	F	f	*	10.0	10.0	8.0	7.0	4.0	2.5	2.0	1.2	4.0		R	.43
30	F	F	*	10.0	10.0	8.0	7.0	4.5	2.0	2.0	1.5	4.0			
31	F	F	f	10.0	10.0	8.0	7.0	5.0	2.0	2.0	1.5	4.0			
December Total													.0193		2.47
January 1947															
1	F	F	F	10.5	10.0	8.0	7.0	5.5	2.5	2.5	1.5	4.0			
2	F	F	F	10.0	10.0	8.5	7.0	6.0	2.5	3.0	1.5	4.0		S	.45
3	F	F	f	10.0	10.0	8.5	7.0	6.5	2.5	3.5	1.5	4.0		S	.02
4	F	F	F	10.0	10.0	8.0	7.5	6.5	3.0	4.0	1.5	4.0			
5	F	F	F	10.0	10.0	8.0	7.0	6.5	3.0	4.0	1.5	4.0		S	T
6	F	F	F	10.5	10.0	8.5	7.5	7.0	3.5	4.5	1.5	4.0			
7	F	F	f	10.5	10.0	8.0	7.5	7.0	3.5	5.0	2.0	4.0			
8	F	F	f	10.0	10.0	8.5	7.5	7.0	3.5	5.5	2.0	4.0		S	T
9	F	F	F	10.0	10.0	8.0	7.5	7.0	3.5	6.0	2.0	4.0		S	T
10	F	F	F	10.5	10.0	8.5	7.5	7.5	3.5	6.5	2.0	4.0		S	.01
11	F	F	f	10.5	10.0	8.5	7.5	8.0	4.0	7.0	2.5	4.0	.0023		
12	f	F	f	10.5	10.5	8.5	7.5	7.5	4.0	8.0	2.5	4.0	.0102		
13	F	F	F	10.5	10.0	8.0	7.5	8.0	4.0	8.0	3.5	4.0		S	T
14	f	f	f	10.5	10.5	8.0	7.5	7.5	4.5	8.0	5.0	4.0	.6141	R	.08
15	F	F	f	10.5	10.0	8.5	8.0	8.0	4.5	8.5	6.5	4.0	.0272		
16	F	F	f	10.5	10.0	8.5	7.5	8.5	4.5	9.0	7.0	4.0	.0030	S	.01
17	F	F	F	10.5	10.0	8.5	7.5	8.5	4.5	9.0	7.0	4.0			
18	F	F	F	11.0	10.0	8.5	7.5	8.0	5.0	9.0	7.0	4.0	.0081		

TABLE XVII (CONTINUED)

Date	Depth of Observation in Inches 1	3	6	9	12	18	24	30	36	42	48	60	Run-off	Precipitation Type	Amount
January 1947 (Continued)															
19	F	F	F	10.5	10.0	8.5	7.5	8.5	5.0	8.5	7.5	4.0	.0301		
20	f	f	f	11.0	10.0	8.5	8.0	8.5	5.5	9.0	7.5	4.0	.2394		
21	F	F	F	11.5	10.5	8.5	7.5	8.5	5.5	9.5	8.0	4.0	.0006	R&S	.45
22	F	F	F	*	10.0	8.5	7.5	8.5	6.0	9.0	8.0	4.0		S	T
23	F	F	F	f	10.5	8.5	7.5	8.5	6.0	9.0	8.0	4.0			
24	F	F	F	F	10.0	8.5	7.5	8.5	6.5	9.5	8.0	4.5	.2485	S	T
25	F	F	f	*	10.5	8.5	8.0	8.5	6.5	9.0	8.5	4.5	.1482	S	T
26	f	f	f	*	10.0	8.5	8.0	8.5	6.5	9.0	8.0	4.5	.0786	R	.01
27	*	*	f	8.0	10.0	8.0	7.5	8.5	7.0	9.0	8.0	4.5	.0096	R	.01
28	*	*	*	9.5	11.0	8.5	8.0	8.5	7.5	9.5	8.0	5.0			
29	f	*	*	10.5	10.5	8.5	7.5	8.5	7.0	9.0	8.0	5.5		S	.67
30	f	f	*	11.0	10.5	8.5	7.5	9.0	7.5	9.5	8.5	5.5		S	1.09
31	f	*	*	11.0	10.5	8.5	8.0	9.0	7.5	9.5	8.5	5.5		S	.03
Total for January													1.4199		2.83
February 1947															
1	F	F	*	11.0	10.5	8.5	8.0	8.5	7.5	9.5	8.5	6.0		S	.02
2	F	F	f	11.0	10.5	8.0	8.0	8.5	7.5	9.0	8.0	6.0		S	T
3	F	F	F	11.0	10.5	8.5	8.0	8.5	8.0	9.0	8.5	6.5		S	T
4	F	F	F	11.0	10.5	8.5	7.5	8.5	8.0	9.0	8.5	7.0		S	T
5	F	F	F	9.5	10.5	8.5	7.5	8.5	8.0	9.0	8.5	7.5		S	T
6	F	F	F	f	10.0	8.0	7.5	8.0	8.0	9.0	8.0	8.0		S	.02
7	F	F	F	F	9.5	8.0	7.5	8.0	8.0	9.0	8.0	8.0		S	.02
8	F	F	F	F	8.5	8.5	8.0	8.5	8.5	9.5	8.5	8.0		S	.01
9	F	F	F	F	f	8.5	7.5	8.5	8.5	9.0	8.0	8.0			
10	F	F	F	F	F	8.5	7.5	8.5	8.0	9.0	8.0	8.5			

TABLE XVII (CONTINUED)

Date	Depth of Observation in Inches												Run-off	Precipitation	
	1	3	6	9	12	18	24	30	36	42	48	60		Type	Amount
February 1947 (Continued)															
11	F	F	F	F	F	8.5	7.5	8.5	8.0	9.0	8.5	8.5			
12	F	F	F	F	F	8.0	7.5	8.5	8.5	9.0	8.5	8.5			
13	F	F	F	F	F	8.0	7.5	8.0	8.5	9.0	8.0	8.5			
14	F	F	F	F	F	8.0	7.5	8.0	8.5	9.0	8.0	8.5	.0016		
15	F	F	F	F	f	8.0	7.5	8.0	8.0	9.0	8.0	8.5	.0293	S	.01
16	f	f	F	f	f	8.0	7.5	8.0	8.5	8.5	8.0	8.5	.0221	S	.04
17	F	F	f	f	*	8.0	7.5	8.0	8.5	9.0	8.0	9.0	.0065	S	T
18	F	F	f	f	*	8.0	7.5	8.5	8.5	9.0	8.5	9.0		S	T
19	F	F	F	f	*	8.5	8.0	8.5	8.5	8.5	9.0	9.5			
20	F	F	F	F	F	8.5	7.5	8.5	8.5	9.0	8.5	9.0			
21	F	F	F	F	F	8.0	7.5	8.0	8.5	9.0	8.5	9.5		S	.01
22	F	F	F	F	F	8.0	7.5	8.0	8.5	9.0	8.0	9.0			
23	F	F	F	F	F	8.0	8.0	8.0	8.5	9.0	7.5	8.5		S	.02
24	F	F	F	F	F	8.0	7.5	8.0	8.5	9.0	8.0	9.0		S	.02
25	F	F	F	F	F	8.0	7.5	8.0	9.0	9.0	8.0	9.0			
26	F	F	F	F	F	8.0	7.5	8.5	8.5	9.0	8.5	9.0		S	T
27	F	F	F	F	F	7.5	7.5	8.0	9.0	9.0	6.5	9.5			
28	F	F	F	F	F	7.5	7.5	8.0	8.5	9.0	8.5	9.5			
February Total													.0595		.17
March 1947															
1	F	F	F	F	F	7.0	7.5	8.0	8.5	9.0	8.0	9.0		S	.03
2	F	F	F	F	F	*	7.5	8.0	8.5	9.0	8.0	8.5		S	.08
3	F	F	F	F	F	f	7.5	8.0	8.5	9.0	8.0	9.0			
4	F	F	F	F	F	F	7.5	8.0	8.5	9.0	8.0	9.5			
5	F	F	F	F	F	F	7.5	8.0	8.5	9.0	8.0	9.5			

TABLE XVII (CONTINUED)

Date	Depth of Observation in Inches												Run-off	Precipitation	
	1	3	6	9	12	18	24	30	36	42	48	60		Type	Amount
March 1947 (Continued)															
6	F	F	F	F	F	F	7.5	8.0	8.5	9.0	8.5	9.5			
7	F	F	F	F	F	F	7.5	8.0	8.0	8.5	8.5	9.5			
8	F	F	F	F	F	F	7.5	8.0	8.5	9.0	8.5	9.5			
9	F	F	F	F	F	F	7.5	8.0	8.5	9.0	8.0	9.5			
10	F	F	F	F	F	F	7.5	8.5	8.5	9.0	8.5	9.5	.0247		
11	F	F	F	F	F	F	7.5	8.0	8.5	9.0	8.5	9.5	.2367		
12	F	F	F	F	F	F	7.5	8.0	8.5	8.5	8.5	9.5	.4614		
13	F	F	F	F	F	f	7.5	8.0	9.0	9.0	8.5	9.5	.4467	R	.21
14	f	f	F	F	F	f	7.5	8.0	9.0	9.0	8.5	9.5	.2257	R	T
15	F	F	F	F	F	f	7.0	8.0	8.5	9.0	8.0	9.0	.0290	T	T
16	F	F	F	F	F	f	7.0	7.5	8.5	8.5	7.5	9.0		R	T
17	F	F	F	F	F	f	7.5	8.0	8.5	9.0	8.0	9.0		R	T
18	F	F	F	F	F	F	7.5	8.0	8.5	9.0	8.0	9.0	.0959		
19	F	F	F	F	F	F	7.0	8.0	8.5	9.0	8.0	9.5			
20	F	F	F	F	F	F	7.5	8.0	8.5	9.0	8.5	9.0			
21	F	F	F	F	F	F	7.5	8.0	8.5	9.0	8.5	9.0			
21	F	F	F	F	F	F	7.5	8.0	8.5	9.0	8.0	9.0		S	.01
22	F	F	F	F	F	f	7.5	8.0	8.5	9.0	8.0	9.5			
23	f	f	F	F	F	f	7.5	8.0	8.5	9.0	8.0	9.5		R	.24
24	14.0	13.5	f	f	F	f	7.0	7.5	8.5	9.0	7.5	9.0		R&S	.58
25	Record incomplete for this date													S	.04
26	11.5	12.5	f	f	f	*	7.5	8.0	8.5	9.0	7.5	9.0		S	T
27	10.5	12.0	*	f	f	*	7.0	7.5	8.0	9.0	8.0	9.0		S	T
28	f	11.5	*	*	f	*	7.0	7.5	8.5	9.0	7.5	9.0		S	.01
29	*	12.0	*	*	f	*	7.0	7.5	8.0	8.5	7.5	9.0		S	.12
30	f	9.5	*	*	f	*	7.0	7.5	8.0	8.5	7.5	9.0			
31	f	9.5	*	*	*	5.5	7.0	7.5	8.5	8.5	7.5	9.0		S	.01
March Total													1.5201		1.33

TABLE XVII (CONTINUED)

Date	Depth of Observation in Inches												Run-off	Precipitation	
	1	3	6	9	12	18	24	30	36	42	48	60		Type	Amount
April 1947															
1	*	11.0	*	*	*	6.0	7.5	7.5	8.0	8.5	7.5	9.0		S	.02
2	14.5	13.0	*	*	*	6.5	7.0	7.5	8.0	8.5	7.5	9.0		R	.97
3	12.0	12.5	7.5	*	*	7.0	7.5	7.5	8.0	8.5	7.5	9.0			
4	12.0	13.0	9.0	7.5	*	7.5	7.5	7.5	8.0	9.0	8.0	9.0		R	.20
5	12.0	13.0	12.5	8.5	8.0	7.5	8.0	7.5	9.0	9.0	8.0	9.0	.5407	R	2.57
6	11.0	12.5	11.5	10.0	10.5	8.0	8.0	7.5	9.0	9.0	8.0	9.0			
7	11.0	12.0	11.5	11.0	12.0	8.0	8.0	8.5	9.0	9.0	8.0	9.0			

1. * indicates frozen soil, with resistance block readings less than 10,000 ohms.
   f indicates frozen soil, with resistance block readings from 10,00 to 50,000 ohms.
   F indicates frozen soil, with resistance block readings over 50,000 ohms.
2. S refers to snow.
   R refers to rain.

TABLE XVII (CONTINUED)

Date	Depth of Observation in Inches												Run-off	Precipitation	
	1	3	6	9	12	18	24	30	36	42	48	60		Type	Amount
April 1947															
1	*	11.0	*	*	*	6.0	7.5	7.5	8.0	8.5	7.5	9.0		S	.02
2	14.5	13.0	*	*	*	6.5	7.0	7.5	8.0	8.5	7.5	9.0		R	.97
3	12.0	12.5	7.5	*	*	7.0	7.5	7.5	8.0	8.5	7.5	9.0			
4	12.0	13.0	9.0	7.5	*	7.5	7.5	7.5	8.0	9.0	8.0	9.0		R	.20
5	12.0	13.0	12.5	8.5	8.0	7.5	8.0	7.5	9.0	9.0	8.0	9.0	.5407	R	2.57
6	11.0	12.5	11.5	10.0	10.5	8.0	8.0	7.5	9.0	9.0	8.0	9.0			
7	11.0	12.0	11.5	11.0	12.0	8.0	8.0	8.5	9.0	9.0	8.0	9.0			

1. * indicates frozen soil, with resistance block readings less than 10,000 ohms.
   f indicates frozen soil, with resistance block readings from 10,00 to 50,000 ohms.
   F indicates frozen soil, with resistance block readings over 50,000 ohms.
2. S refers to snow.
   R refers to rain.

On February 14 accumulated snow began melting and contributing to surface run-off over frozen soil. This was caused by temperatures high enough to melt snow, but not high enough to affect the frozen soil under the snow blanket.

February 16 affords an exapmle of normal ice release from the soil in this area, with thawing taking place from both the top and bottom. The coldest layer is generally between the two extremes.

During the month of March, rising temperatures on the 10th. to the 14 th. caused snow melt, aided by some rain. The greater part of the rain and snow melt ran off the watershed. The high temperatures of March 24 and 25, together with the rains of these days, completely eliminated the ice from the top three inches. The colder weather which followed re-froze the surface one inch. The other layers continued to thaw, until all ice vanished from the soil on April 4.

A close appraisal of the table points out the fact that one of the most serious problems facing the hydrologist in this area is the determination of means by which snow melt during the winter months may be channeled down into the soil, rather than run-off over a frozen surface. As shown earlier in this study, soil moisture field capacity at the cultivated watershed is considerably lower than that of the wooded water-shed. However, the cultivated soils can not take advantage of the storage capacity they have, due to poor infiltration durimg the months when the soil is frozen.

Under the conditions of soil freezing outlined in Table XVII, during the month of January, the watershed lost an amount of water equal to half the precipitation falling during the month. In February, with the soil frozen to a 12 inch depth, one third the precipitation was lost to run-off. In March, with the soil frozen to 18 inches, more snow melt and rain water were lost to run-off than fell during the month. This indicates that some of the previous month's snow ran-off during March.

Table XVIII is a summary of the precipitation and run-off for the two watersheds for the period December 1946 to April 5, 1947. It very clearly shows that while the cultivated watershed was losing large quantities of it's precipitation to run-off, the wooded only had one run-off for the winter. This run-off occured on April 5, at the same time the cultivated had a run-off. The wooded watershed run-off occured as the result of snow melt and rain occuring on saturated soil.

TABLE XVIII

SUMMARY OF PRECIPITATION AND RUN-OFF, WINTER 1946-1947

Month	Cultivated Watershed B		Wooded Watershed	
	Precipitation in Inches	Run-off in Inches	Precipitation in Inches	Run-off in Inches
December	2.47	0.0193	2.83	0.00
January	2.83	1.4199	3.24	0.00
February	0.17	0.0595	0.71	0.00
March	1.33	1.5207	1.84	0.00
April 5, 1947	2.57	0.5407	2.25	0.7397

Table XIX is a compilation of snow depths, density and soil moisture for the two watersheds for the period mentioned above. It should be noted that while the cultivated watershed was in a frozen state from the middle of December to the first of April, the wooded

watershed was not observed in a frozen condition all winter. It is interesting to note that the snow survey of February 17 to March 17 showed the snow at the cultivated watershed to be in such a frozen state that no snow survey was possible. The snow at the wooded watershed was not in this condition.

Snow depths at the wooded watershed were greater in every instance than at the cultivated. This deeper snow blanket will have a tempering effect upon soil temperatures, hindering any sudden changes.

TABLE XIX

COMPARATIVE SNOW DEPTHS, DENSITY AND SOIL MOISTURE, WINTER 1946-47

Date	Cultivated Watershed			Wooded Watershed		
	Snow Depth in Inches	Density in Per-cent	Soil Moisture in Per-cent	Snow Depth in Inches	Density in Per-cent	Soil Moisture in Per-cent
12-16-1946	No snow		Frozen	No snow		18.5
12-23-46	1.62	14.81	Frozen	2.33	9.01	
12-30-46	2.73	14.81	Frozen	2.95	13.22	29.8
1 - 6-47	6.09	13.79	Frozen	6.95	15.97	29.8
1 -13-47	3.68	17.12	Frozen	4.73	20.08	
1 -20-47	.31	70.97	Frozen	2.88	28.13	27.3
1 -27-47	Trace		Frozen	Trace		26.9
2 - 3-47	4.94	37.65	Frozen	7.08	31.07	21.9
2 - 11-47	7.61	30.22	Frozen	9.18	26.69	
2 - 17-47	To much ice to make survey		Frozen	7.47	27.80	17.6
2 -24-47	To much ice		Frozen	8.63	27.46	
3 - 3-47	To much ice		Frozen	10.02	24.65	20.2
3 -10-47	To much ice		Frozen	7.93	32.28	
3 -17-47	To much ice		Frozen	5.96	33.72	22.1
3 -24-47	No snow		14.0	No snow		
3 -31-47	Trace of snow		Frozen	4.72	25.00	35.5
4 - 5-47	Snow gone		12.0	Snow gone		Saturated

An examination of soil temperatures for the winter of 1946-47 showed that one inch soil temperatures at the wooded watershed frequently reached 28 degrees Fahrenheit several times without freezing. Soil temperatures of 32 degrees indicated freezing at the cultivated watershed, if these temperatures remained for any appreciable length of time.

Little is known about the freezing point for various soils. This is a flexible point, depending upon the salts in solution in the soil moisture, the quantity of soil moisture, organic content and duration of freezing.

The problem of freezing temperatures has not been completely evaluated. The problem of freezing temperatures, the point at which various soils freeze, means of preventing freezing in soils, and methods of inducing infiltration during periods of freezing temperatures is of vital importance in the hydrology of an area such as Lansing. The entire question of the influence of frost on infiltration rates is yet to be completely evaluated. The type of frost appears to be a factor. There appear to be two types, concrete and honeycombed (24). It is believed the concrete type may reduce infiltration rates drastically, much more so than the honeycombed type, due to the greater density of the concrete type. Root material, organic matter, air space and temperatures slightly below freezing seem to favor the development of the honeycomb type, while compact soil, high soil moisture content, low volumes of air space and low temperatures seem to favor the development of the concrete type of frost.

Surface run-off summary for the months of January, February, and March. Tables XX and XXI show the percent of run-off occuring during the first three months of the year, the months of heavy soil freezing. It clearly indicates this period to be the most important one in the year from the standpoint of surface run-off. The one year which was the exception to the rule, 1941, was a year with relatively warm winter temperatures and little soil freezing. As may be seen in Table XX, the three month precipitation was smallest in 1951.

The cultivated watershed received, on the basis of an eleven year average, 18.36 percent of it's yearly precipitation during the first three months. It lost, to surface run-off, during this time, 78.35 percent of the total amount lost to surface run-off. The wooded watershed indicated another trend, with 18.45 percent of the yearly precipitation coming during the test period. It lost 39.42 percent of it's contribution to run-off during the first three months. The similiarity between the watersheds ended here. The wooded received an average of 32.77 inches precipitation per year to 31.55 inches for the cultivated. In nine out of the eleven years in the test period, the wooded watershed received more precipitation than the cultivated. The cultivated lost to surface run-off an average of 4.23 inches per year, with 3.77 inches being lost during the three month period. The wooded watershed lost a yearly average of 0.5423 inch to run-off, with 0.2138 inch of this coming during the first three month period.

A statistical analysis of all rain producing storms occuring over the cultivated watershed during the period 1945 to 1951 was made. This analysis was carried out to determine the effect of cover in

TABLE XX

HYDROLOGIC SUMMARY FOR THE MONTHS OF JANUARY, FEBRUARY AND MARCH -CULTIVATED WATERSHED

Year	Yearly Precipitation in Inches	Yearly Run-off in Inches	3 Months Run-off in Inches	Percent of Total Precipitation in Three months	Percent of Total Run-off in Three Months
1941	28.47	2.15	0.00	10.01	0.00
1942	34.03	7.71	6.46	16.30	83.78
1943	33.06	2.13	1.86	15.84	87.32
1944	22.83	3.83	3.79	24.17	98.95
1945	37.48	1.73	1.05	11.41	60.69
1946	21.65	3.31	3.29	23.97	99.39
1947	37.59	6.83	4.15	11.51	60.76
1948	28.55	6.89	6.01	23.77	87.22
1949	34.43	5.92	5.24	23.99	88.51
1950	38.59	4.41	4.20	23.71	95.23
1951	30.82	1.65	1.65	17.35	100.00
Average	31.55	4.23	3.77	18.36	78.35

TABLE XXI

HYDROLOGIC SUMMARY FOR THE MONTHS OF JANUARY, FEBRUARY AND MARCH - WOODED WATERSHED

Year	Yearly Precipitation in Inches	Yearly Run-off in Inches	Three Month Run-off in Inches	Percent of Total Precipitation in Three Months	Percent of Total Run-off in Three Months
1941	27.64	0.0038	0.0038	9.97	100.00
1942	37.11	0.7907	0.7907	18.10	100.00
1943	34.99	1.7569	0.2841	15.71	16.17
1944	25.63	0.5989	0.0176	23.01	2.93
1945	38.42	0.0806	0.0000	11.45	0.00
1946	23.88	0.0726	0.0726	24.20	100.00
1947	38.73	0.7397	0.0000	11.61	0.00
1948	29.57	1.3130	0.8842	23.63	67.34
1949	32.46	0.0114	0.114	24.11	100.00
1950	39.33	0.5972	0.2875	23.75	48.14
1951	32.74	Trace	Trace	17.37	100.00
Average	32.77	0.5423	0.2138	18.45	39.42

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1943	34.99	1.7569	0.2841	15.71	16.17
1944	25.63	0.5989	0.0176	23.01	2.93
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1947	38.73	0.7397	0.0000	11.61	0.00
1948	29.57	1.3130	0.8842	23.63	67.34
1949	32.46	0.0114	0.114	24.11	100.00
1950	39.33	0.5972	0.2875	23.75	48.14
1951	32.74	Trace	Trace	17.37	100.00
Average	32.77	0.5423	0.2138	18.45	39.42

preventing run-off during periods when the soil was frozen. The analysis was carried out by means of two way tables and Chi Square by the method of expected numbers. It contrasted the effect of open cultivated crop residue interspersed with rye against the cover afforded by a winter cover of alfalfa-brome. The results of the analysis indicated that within the limits tested, cover did not have any significant effect in preventing the begining of surface run-off when the soil was frozen. Another analysis was made to determine the effect of cover upon the size of run-off. This study indicated that the alfalfa-brome was significantly better than corn stubble and rye in preventing the run-offs from becoming large. Put in other words, run-offs under alfalfa-brome were significantly smaller than those under corn stubble and rye.

A statistical analysis was not made of the wooded watershed for this portion of the study, since cover was the same for eleven years, and it was not felt that the one years data following the cut was sufficient basis for a statistical analysis. No analysis was made between the watersheds on the basis of cover, since the size of the rainstorms, as well as their intensities were not always the same. The differences between the hydrologic summaries of run-off for the watersheds were so great that a statistical analysis was not needed to prove significance.

Soil temperature variations caused by clear-cutting the wooded watershed. It is of importance, from a hydrologic standpoint to know the effect upon soil temperatures of a clear-cutting operation such as was carried out on the wooded watershed. If, for example, winter soil temperatures drop several degrees lower under denuded conditions than under weeded, and this temperature drop leads to soil freezing where none existed before, or if it leads to a concrete type frost, where honeycomb would have resulted before the cut, the risk is run of incurring serious run-off by such a cut.

In order to partially determine the effect such a cut would have upon soil temperatures, a statistical analysis was made on two years data, one year preceeding the cut, and the first year following the cut. It is realized that a long period of study is to be desired for such a study. However, in view of the fact that the first year following the cut is so different from any other in relation to vegetation, the writer felt justified in making the analysis. Since the differences exhibited by the two years in question was so small, a graphic presentation of the differences was made.

The daily records from a hygrothermograph at an elevation of 4.5 feet above the surface of the ground, located in an open field adjacent to the watershed, and one inch soil temperatures taken from a three-pen soil thermograph located on the watershed were used. The daily ranges of temperatures for each day in the two years were taken from the charts in question. Each daily soil temperature range was subtracted from the 4.5 feet elevation air temperature range for the same day. The differences were then submitted to Fishers "t" test in order to determine significance between the summed differences of the two years. As shown in Table XXII, the difference obtained was barely sufficient to give significance at the one percent level. Since the difference between the means for the two years was

only 1.4 degrees, and since the results were barely significant, the accumulated differences between ranges of degrees Fahrenheit between maximum and minimum temperatures for the one inch soil depth and the air temperature at the 4.5 feet elevation, were plotted as monthly totals. As shown in both figure 14 and Table XXII, the differences that do exist between the two years are slight. The effect of this slight change was impossible to measure with the one years data available. Data taken over the next ten years should furnish the answer to the question.

TABLE XXII

SOME VALUES USED IN CALCULATING "t" FOR ONE INCH SOIL TEMPERATURE DIFFERENCES FOR TWO YEARS

Date	ΣX Difference between Ranges in Degrees Fahrenheit	ΣX^2	N Number of Observations	$\bar{X}$ of Differences between Ranges in Degrees F.	"t" Obtained	"t" Needed for Significance
1951	5207	95111	359	14.5	2.687	2.590 at the 1% level
1952	4715	77227	359	13.1		

Air temperature changes caused by clear-cutting the wooded watershed. Since air temperatures near the surface of the soil are instrumental in melting snow and in determining soil temperature, any variations in the temperature of the air near the surface of the soil that is caused by the clear-cutting of a watershed is of importance.

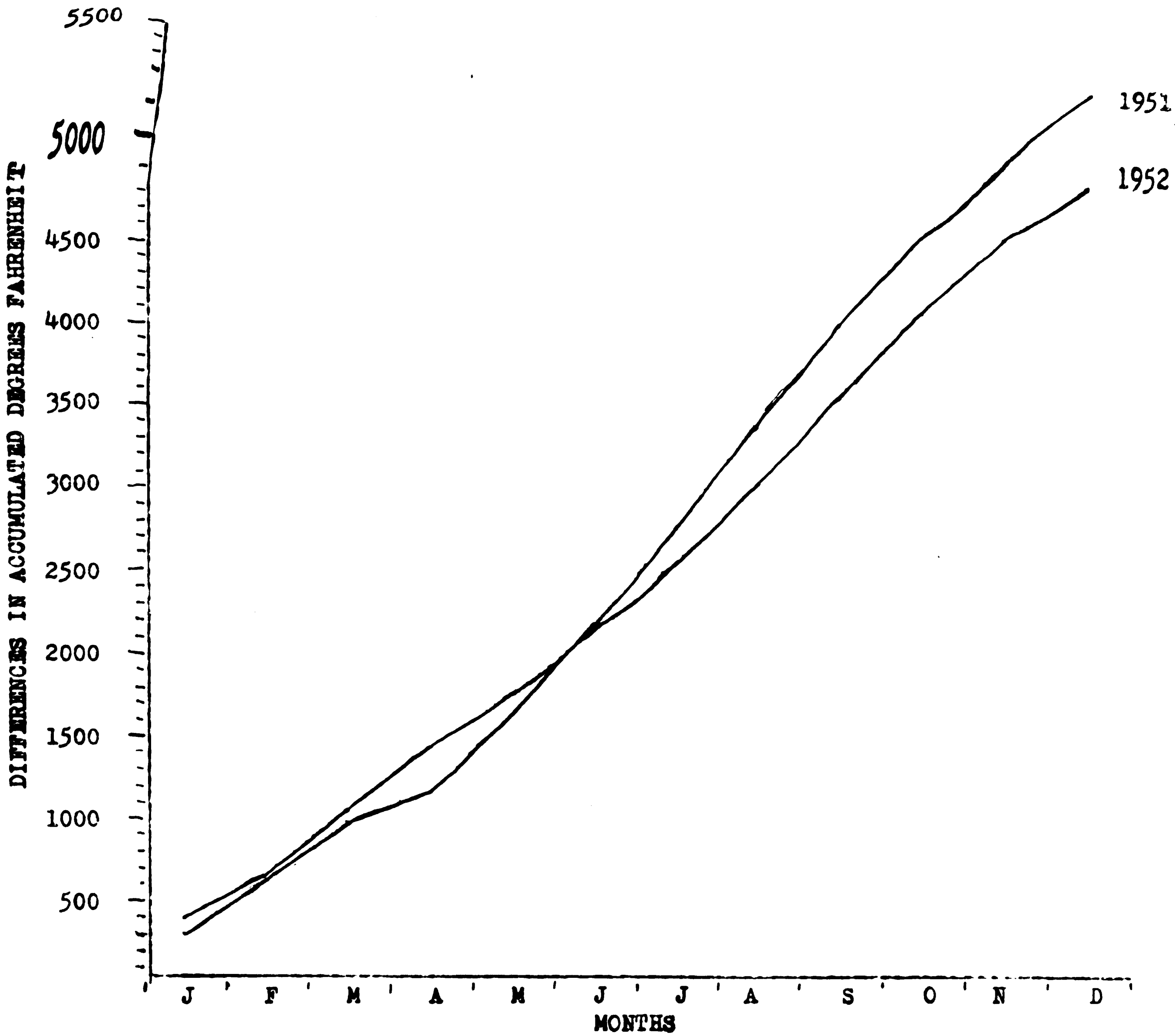

Fig. 14: Accumulated differences in ranges of degrees Fahrenheit between daily maximum and minimum temperatures for one inch soil depth and air temperature at a 4.5 feet elevation, plotted as monthly totals.

The differences between ranges of degrees between maximum and minimum monthly averages, made up from weekly readings, for two elevations are plotted in FIGURE 15. These differences are for the years 1951 and 1952, and were taken from the readings of maximum-minimum thermometer sets located in standard Weather Bureau houses at elevations of 4.5 and 2.5 feet. The 4.5 feet station is located in an open field adjacent to the wooded watershed, while the 2.5 feet station is located on the watershed.

The plotted values were obtained by subtracting for the year 1951, the monthly average minimum from the monthly average maximum for 4.5 feet. The monthly average minimum for 2.5 feet was then subtracted from it's maximum. These two operations yielded two ranges. Range one was then subtracted from range two, and the difference plotted for the respective year. The same operation was performed for each year. The resulting chart is a graphical presentation of the differences in atmospheric fluctuation between the two elevations while the watershed was under wooded cover and after the area was clear-cut.

An examination of the chart indicates that the daily fluctuations of temperatures between the two elevations were greater before than after the cut. Fluctuations were greatest during the summer months, before the cut, but there were definite differences during the winter as well.

Table XXIII is a presentation of average maximum, minimum weekly temperatures expressed as monthly means for 1951 and 1952 for the two above mentioned elevations.

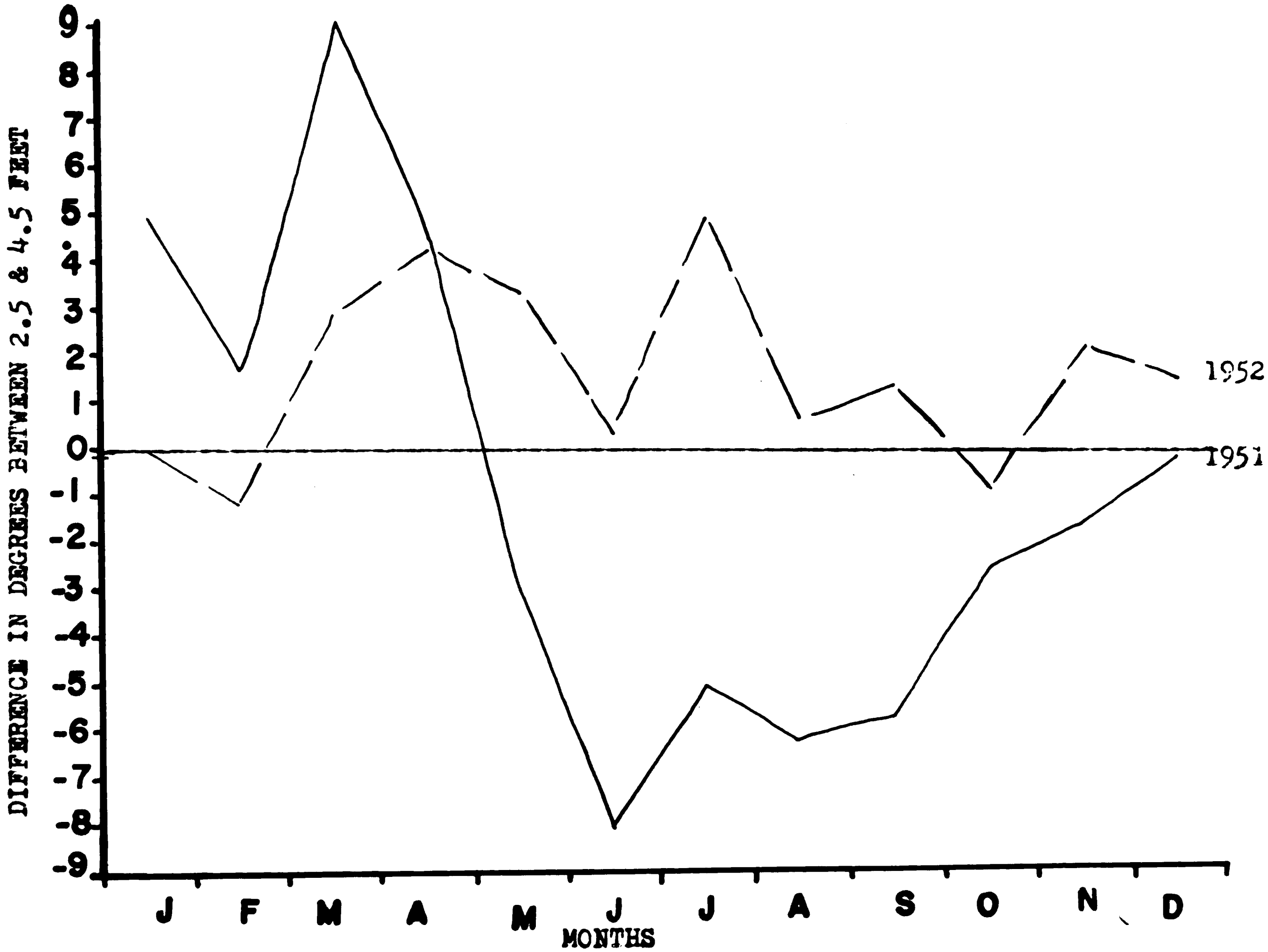

Fig. 15. Differences in ranges of degrees between maximum and minimum monthly averages for 4.5 and 2.5 feet elevations for two years.

Figures 16 and 17 are made up from the values in Table XXIII. They show that under wooded cover the 2.5 feet elevation has higher maximums during the winter than does the 4.5 feet elevation in the open field. The shielding effect of the trees in cutting down on wind movement would tend to make the woods warmer than the outside. In 1952, after the cut, temperatures tended to be more nearly equal. During the summer, maximums were considerably less under wooded cover than outside the forest. After the cut, the 2.5 feet elevation maximums within the cut over area were some warmer than those at 4.5 feet outside. Figure 17 is a graphical presentation of the temperature comparisons for 1952. Changes in the minimums are less than those for the maximums, but some differences do exist. The greatest difference exists in the months between February and May. Minimums under wooded cover were higher than they were after the stand was cut.

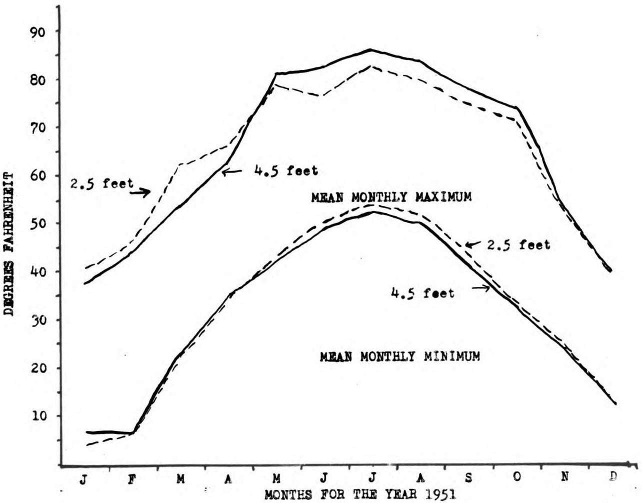

Fig. 16. Comparison of the mean monthly maximum and mean monthly minimum for two heights; one located on the wooded watershed at an elevation of 2.5 feet, and the other located in an open field adjacent to the watershed at an elevation of 4.5 feet.

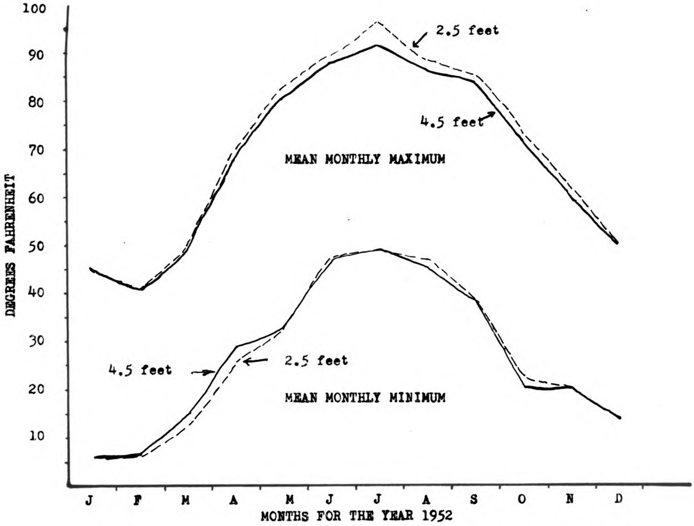

Fig. 17. Comparison of the mean monthly maximum and mean monthly minimum for two heights; one located on the watershed at 2.5 feet elevation, and the other located in an open field adjacent to the wooded watershed at an elevation of 4.5 feet.

TABLE XXIII

AVERAGE MAXIMUM AND MINIMUM WEEKLY AIR TEMPERATURES EXPRESSED AS THE MONTHLY MEAN, 1951[1]- 1952

Month	1951				1952			
	4.5 feet open field		2.5 feet Forest		4.5 feet open field		2.5 feet Forest	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
January	37.2	2.0	40.5	-.5	45.3	6.7	44.7	6.0
February	44.0	2.2	45.4	2.0	40.1	6.7	40.8	6.2
March	53.6	18.4	62.2	18.0	48.8	14.9	49.3	12.6
April	62.5	30.7	65.9	29.9	67.9	28.7	69.1	25.7
May	80.6	37.8	78.4	38.6	80.0	32.9	82.4	32.0
June	82.7	44.2	76.2	45.8	87.9	46.4	89.0	47.2
July	86.0	47.2	82.2	48.5	91.1	48.6	96.0	48.6
August	83.7	44.7	79.4	46.6	86.0	45.0	88.0	46.4
September	77.6	35.8	74.1	38.0	83.7	37.7	85.0	37.7
October	73.9	26.8	71.9	27.3	71.6	19.8	72.8	21.8
November	52.7	18.2	52.6	19.7	60.0	20.0	61.7	19.5
December	39.8	6.7	39.6	6.7	49.5	13.7	50.0	13.7

1. Values for 1951 are for the months of January through October. November and December values are from 1950. The watershed was in the process of being cut during these months, and the disturbed condition would have given erroneous readings for a forested area.

PATTERNS AND CLASSES OF RAINFALL AND THEIR EFFECT UPON SURFACE RUN-OFF

The data used in this phase of the study, as is true of most of the data used in the entire study, was obtained from the files of the Michigan Hydrologic Research Station, and cover the years 1941 to 1951 unless otherwise stated.

No storm was considered in this study which yielded less than 0.25 inch of rain, since anything less than this amount was not considered significant in producing run-off under frost free conditions. No storm producing snow was considered, since neither pattern or class of snow fall has any effect upon run-off.

The Establishment of Classes

For purposes of this study, precipitation class may be defined as the intensity with which the major block of precipitation falls during a storm.

The classes of rainfall used in this study are essentually those presented by Schiff (27), with minor modifications by the writer to bring these groupings into line with the climatic conditions prevailing in the Lansing area. Each rain storm of 0.25 inch or larger was placed in one of the below listed classes.

Class 1: Uniform intensities up to and including 0,25 inch per hour, a deviation of one and one-half times the mean rate permitted for the maximum intensity within a storm.

Class 2: Combination of intensities up to and including 0.50 inch per hour, with a deviation of one and one-half times the mean rate permitted for the maximum intensity within a storm.

Class 3: Combination of intensities up to and including 0.50 inche per hour, with not more than 15 percent of the amount falling at intensities in excess of 0.50 inch per hour.

Class 4: A combination of intensities below and above 0.50 inch per hour, up to and including 1.00 inch per hour with more than 15 percent of the amount falling at intensities below 0.50 inch per hour and more than 15 percent of the amount falling at intensities in excess of 0.50 inch per hour, and less than 15 percent of the amount falling at intensities in excess of 1.00 inch per hour.

Class 5: A combination of intensities below 0.50 inch per hour and over 1.00 inch per hour. It may include intensities between 0.50 inch and 1.00 inch per hour, with more than 15 percent of the amount falling at intensities below 0.50 inch per hour and more than 15 percent of the amount falling at intensities in excess of 1.00 inch per hour, and more than 15 percent may fall at intensities between 0.50 and 1.00 inch per hour.

Class 6: Uniform and combination of intensities of 0.50 inch per hour and over, with not more than 15 percent of the amount falling at intensities below 0.50 inch per hour.

Precipitation Pattern Establishment

Precipitation pattern may be defined as the position, with reference to time, in which the highest intensities within a storm are grouped.

The first four pattern designations and definitions used are those of Horner and Jens (16). Schiff (27) first used the last two designated patterns. The definitions used are those published by Schiff (27).

Pattern designations and definitions.

Advanced: A storm having it's highest intensities, 15 percent or more of the total rainfall, near the begining of the storm.

Intermediate: The highest intensities occur near the center of the storm. These intensities must equal 15 per cent of total amount of rainfall.

Delayed: The highest intensities, 15 per cent or more of total rainfall, occurs near the end of the storm.

Uniform: No distinct grouping of high intensities which make up 15 percent of total rainfall. Individual intensities may deviate one and one- hald the mean rate of intensities for the period.

Interrupted: A storm having high initial and final intensities seperated by a period of lower intensities. The period of lower intensities must equal at least 15 percent of the total rainfall.

Sporadic: This type storm does not contain enough percentages of the total rainfall in any single portion which would permit giving the storm another name.

Discussion of results. Two of the most important causal factors in the ultimate disposition of rainfall as surface run-off are, (1), the intensity and the duration of the intensities with which the rain falls, and (2), the order in which the high intensities occur. Rainfall excess, the difference between rainfall and infiltration, is affected by both the above.

Just as soil conditions before a storm have a great influence upon rainfall disposition, so does changing conditions during a storm. There is a drop in the rate of infiltration, brought about by the sealing of the surface of the soil through the action of raindrop impact washing fine particles of soil into soil pores and plugging them. (6). With increased intensity, there is usually an increase in size of drops (22) (5).

Figure 18 shows the distribution of precipitation classes by months. Class one storms reach a minimum in August and become more frequent to either side. This class would reach a maximum in the winter months if one considered snow storms along with rain storms.

Class two storms are fairly consistent in number for each month in the year. Class three storms occur in groups of two or three months.

Class four storms are scarce during the winter months, and never very numerous .

Class five storms are almost non-existent during the winter months. This class reaches it's maximum in the period May through September.

Class six storms are only frequent during the summer months. If class five and six storms are combined, it may be seen that the high intensity storms of these two classes begin appearing in May, and for

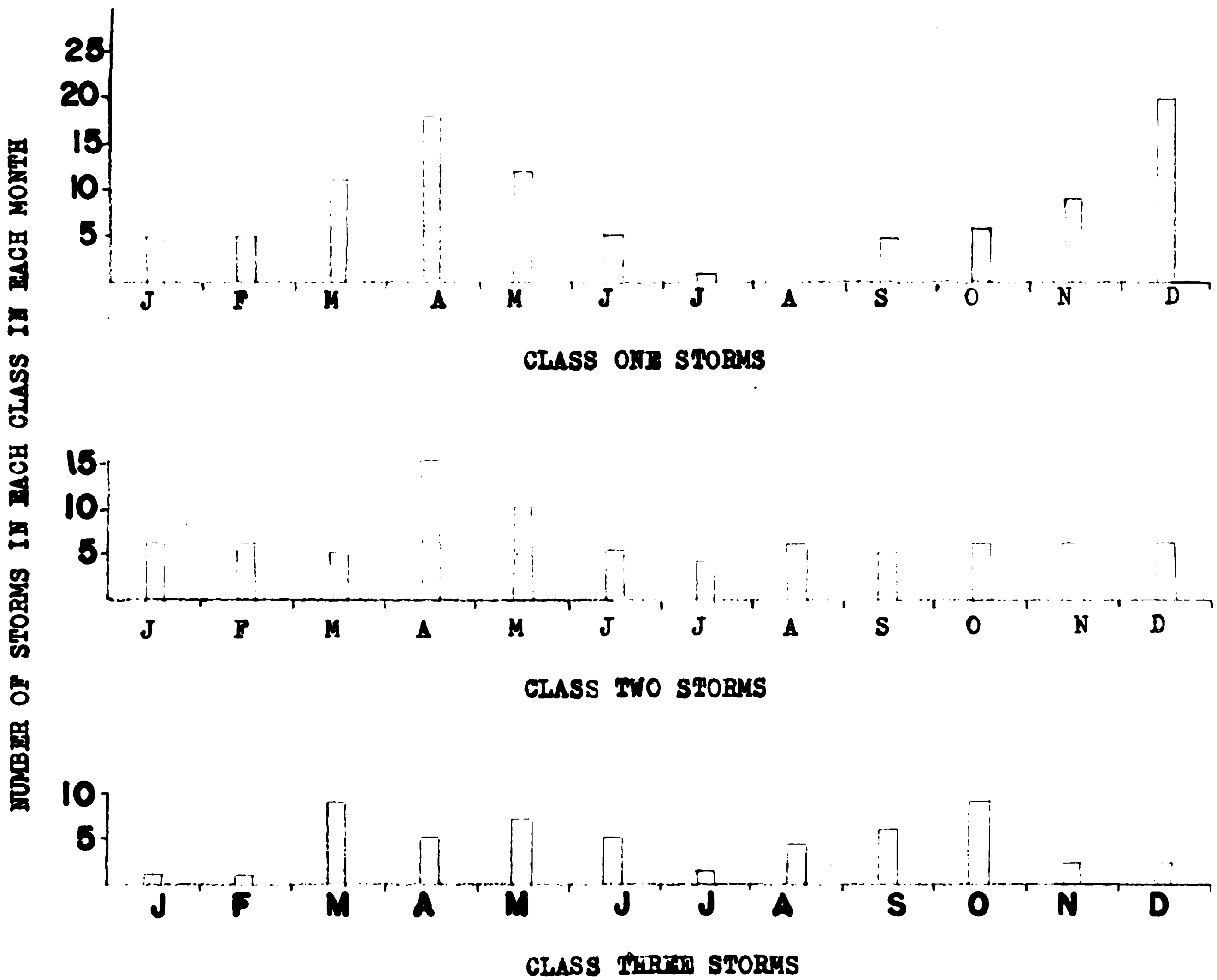

Fig. 18: Distribution of classes in each month during the period 1941-51

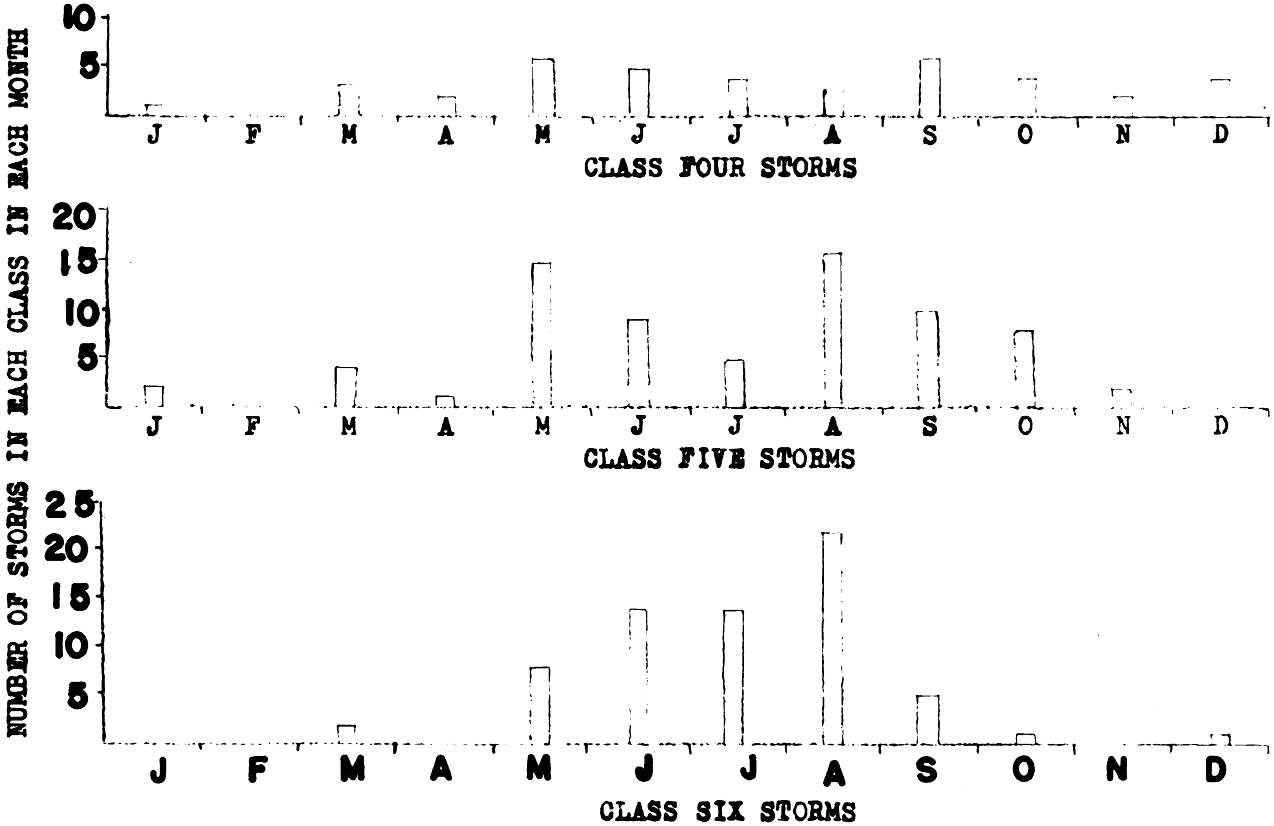

Fig. 18 (Cont.). Distribution of classes in each month during the period 1941-51.

all practical purposes end in October.

TABLE XXIV

NUMBER OF RAIN STORMS BY CLASSES, 1941 - 1951

Year	Classes of Rainfall						Total
	1	2	3	4	5	6	
1941	6	9	2	3	10	2	32
1942	4	13	5	5	7	8	42
1943	7	8	3	3	3	6	30
1944	15	3	3	3	0	2	26
1945	2	3	4	4	18	6	37
1946	2	3	2	0	6	8	21
1947	10	9	5	2	4	7	37
1948	7	9	1	2	5	3	27
1949	14	9	5	5	1	9	43
1950	5	8	11	7	6	9	46
1951	20	6	8	3	2	2	41
Total	92	80	49	37	62	62	382

Table XXIV is a listing of the number of storms falling into the various classes for each year during the period under study.

Distribution of patterns by months is shown in Table XXV.

All storms in class one are by definition uniform. Class two storms are predominantly uniform, although there is a sprinkling of all patterns in the spring of the year. Class three appears predominantly as a uniform pattern, although the months of April and May have numerous advanced and intermediate patterns. Class four occurs as an intermediate pattern during May, June and July. From August to November the advanced becomes most numerous. Class five storms occur largely during the summer months and are distributed between the advanced,

TABLE XXV

DISTRIBUTION OF PATTERNS[1] BY MONTHS FOR CLASSES 1-6, 1941-1951

Month	Class 1	Class 2						Class 3						Class 4					
	U	A	U	I	D	T	S	A	U	I	D	T	S	A	U	I	D	T	S
January	6		4	2					1					1					
February	5		4	1	1					1									
March	9		1	1	1		1	1	3	2	2	2			1	1	1		
April	18	1	8	3	1		2	2	1	2							1		1
May	9	2	3	2	1	1	1	2	1	1	1	1		1	1	4			
June	5	1	1	2			1	1	3	1						4		1	
July	1		4						1							2	1	1	
August		1	4				1			1	2			2		2			
September	5	2	3					1	1	2	1			2		1	1		1
October	6		1	2			3	1	5	2	1			1		1	1		1
November	9		4	1			1		2					2		1			
December	19		2		1	1	2		2										

1. Pattern designations as follows:
A----Advanced I-----Intermediate T-----Interrupted
U----Uniform D----Delayed S----Sporadic

TABLE XXV (CONTINUED)

Month	Class 5						Class 6					
	A	U	I	D	T	S	A	U	I	D	T	S
January	1		1									
February												
March			1	1				1		1		
April			1									
May	6		4	2	3		3	3			1	
June	5		1	1	2		7	2	2	2	1	
July	3	2					8	2		1	2	1
August	4	3	1	1			6	11				
September	4	5	1				2	2	1	1		
October	1		1	2		3						1
November			2									
December								1				

intermediate, delayed and interrupted patterns with little grouping. Class six is found largely from May to September and is distributed between advanced and uniform patterns.

Table XXVI is a compilation of 382 storms, with the number of storms in each class and pattern, and the distribution of some of the storms in selected months for each class. For example, there were 80 storms in class two. Of these, 47, or 58.75 percent occured during the period from January to June. Of these, six were of the advanced type and 21 were uniform in pattern. Twelve storms were intermediate, four storms were delayed, one interrupted and three were sporadic.

Of the total number of 80 storms, 15 occured during July, August, and September. Of these, three were advanced and 12 were uniform in pattern. Eighteen storms of this class occured duringOctober, November and December.

The 382 storms listed in Table XXVI are only those storms which produced 0.25 inch or more of rain. The Lansing area receives much of it's precipitation in rains of less than 0.25 inch. Table XXVII lists the total number of storms by months which occured during the frost free period of the years 1941-51. In addition, these are broken down into the number in each month which yielded above and below 0.25 inch rain, as well as the percent of the total rainfall contributed by each group.

During the period of April to December, 1941 to 1951, there occured a total of 957 rainstorms on the cultivated watershed. Of these, 662 had a total precipitation of less than 0.25 inch, with only 295 having a total of over 0.25 inch. Twenty two and six tenths percent of

TABLE XXVI

CLASS, DISTRIBUTION, PATTERN AND TOTAL RAINFALL[1] FOR 382 STORMS, 1941 - 1951

Storm Class	Total Number of Storms	Number of Storms in Selected Months: Months	Number	Percent	Number of Storms in Each Pattern: Number	Percent	Pattern[2]	Number of Storms in Ranges of Total Rainfall: 0.25 to 0.50	0.51 to 0.75	0.76 to 1.00	1.01 to 1.25	1.26 to 1.50	1.51 to 1.75	1.76 to 2.00	2.01 to 2.25	2.76 to 3.00
1	92	Jan, Feb, Mar, Apr, May, June	53	57.61	53	57.61	U	38	7	5	2	1				
		Sept, Oct, Nov, Dec.	39	42.4	39	42.4	U	27	10	1	1	—				
					Sub-total Number			65	17	6	3	1				
							Percent	70.65	18.47	6.52	3.26	1.09				
2	80	Jan, Feb, Mar, Apr, May, June	47	58.75	6	7.50	A	3	1	2						
					21	26.25	U	14	4	2		1				
					12	15.00	I	3	5	2			1			1
					4	5.00	D	1	1	2						
					1	1.25	T			1						
					3	3.75	S	2		1						
		July, Aug, Sept.	15	18.75	3	3.75	A	2	1							
					12	15.00	U	6	5	1						
		Oct, Nov, Dec.	18	22.50	8	10.00	U	6	2							
					3	3.75	I	1	2							
					1	1.25	D				1					
					6	7.50	S	2	1	1		1		1		
					Sub-total Number			40	22	12	1	2	1	1		1
							Percent	50.0	27.5	15.0	1.25	2.50	1.25	1.25		1.25

TABLE XXVI (CONTINUED)

Storm Class	Total Number of Storms	Number of Storms in Selected Months: Months	Number	Percent	Number of Storms in Each Pattern: Number	Percent	Pattern	Number of Storms in Ranges of Total Rainfall: 0.25 to 0.50	0.51 to 0.75	0.76 to 1.00	1.01 to 1.25	1.26 to 1.50	1.51 to 1.75	2.01 to 2.25	2.26 to 2.50	2.51 to 2.75
3	49	Jan,Feb,	6	12.24	5	10.20	U	2	1	2						
		Nov,Dec.			1	2.04	I	1								
		Mar,Apr,	39	79.59	8	16.33	A	7		1						
		May,June,			14	28.57	U	8	2	3	1					
		Sept,Oct.			8	16.33	I	1	3		2	2				
					6	12.24	D	4				1	1			
					2	4.08	I		1				1			
					1	2.04	S							1		
		July, Aug,	4	8.16	1	2.04	U		1							
					1	2.04	I	1								
					2	4.08	D	1	1							
					Percent			51.02	18.37	12.24	6.12	6.12	4.08	2.04		
				Sub-total Number				25	9	6	3	3	2	1		
4	32	Jan,Feb,	18	48.65	8	21.62	A	5		2	1					
		Mar,Apr,			1	2.70	U	1								
		Sept,Oct,			3	8.11	I	1	1			1				
		Nov,Dec.			3	8.11	D		2				1			
					3	8.11	S	1	1		1					

TABLE XXVI (CONTINUED)

Storm Class	Total Number of Storms	Number of Storms in Selected Months: Months	Number	Percent	Number of Storms in Each Pattern: Number	Percent	Pattern	Number of Storms in Ranges of Total Rainfall: 0.25 to 0.50	0.51 to 0.75	0.76 to 1.00	1.01 to 1.25	1.26 to 1.50	1.51 to 1.75	1.75 to 2.00	2.01 to 2.25	2.26 to 2.50	2.76 to 3.00
4 (Cont.)		May, June July, Aug.	19	51.35	3	8.11	A		2		1						
					1	2.70	U				1						
					12	32.43	I	1	5	4			1			1	
					1	2.70	D			1							
					2	5.41	T	1	1								
					Sub-total Number			10	12	7	4		3			1	
					Percent			27.03	32.43	18.92	10.81		8.11			2.70	
5	62	Jan, Feb, Dec.	3	4.84	2	3.84	A	1	1								
					1	1.61	I		1								
		Mar, Apr, Nov.	6	9.68	4	6.45	I	1	2	1							
					1	1.61	D	1									
					1	1.61	S									1	
		July	5	8.06	3	4.84	A	1	2								
					2	3.22	I		1		1						
		May, June, Aug, Sept, Oct.	48	77.42	18	29.03	A	5	5	6	1				1		
					13	20.97	I	1	7		2	1		1			1
					6	9.68	D	1	2	1		1		1			
					7	11.29	I	1		1	1	2	1	1			
					4	6.45	S	1			1	1	1				
					Sub-total Number			13	21	9	6	5	2	3	1	1	1
					Percent			21.00	33.87	14.52	9.68	8.06	3.23	4.84	1.61	1.61	1.61

TABLE XXVI (CONTINUED)

Storm Class	Total Number of Storms	Number of Storms in Selected Months: Months	Num- ber	Per- cent	Number of Storms in Each Pattern: Num- ber	Per- cent	Pat- tern	Number of Storms in Ranges of Total Rain-fall: 0.25 to 0.50	0.51 to 0.75	0.76 to 1.00	1.01 to 1.25	1.26 to 1.50	1.51 to 1.75	1.76 to 2.00	2.01 to 2.25	2.26 to 2.50	2.51 to 2.75	2.76 to 3.00	3.01 and over
6	62	Jan, Feb, Mar, Apr, Oct, Nov, Dec.	3	4.84	1	1.61	U				1								
					1	1.61	D			1									
					1	1.61	S				1								
		May, June July, Aug, Sept.	59	95.16	25	40.32	A	9	7	4	2	1	1	1					
					10	25.81	U	6	6	2	1								1
					3	4.84	I	2											
					5	8.06	D	5											
					8	12.90	T	4	1		2	1							
					2	3.22	S	1	1										
					Sub-total Number			27	15	7	7	2	2	1					1
					Percent			45.55	24.19	11.29	11.29	3.22	3.22	1.61					1.6
Total	382							180	96	47	24	13	10	5	2	2		2	1
Percent	100							47.1	25.1	12.3	6.3	3.4	2.6	1.3	.5	.5		.5	.26

1. Total rain-fall in inches.
2. Pattern designations: A---Advanced, U---Uniform, I---Intermediate, D---Delayed, I---Interrupted, S---Sporadic.

the total precipitation fell in rains of 0.25 inch or less.

As stated earlier, rainfall intensities are of the utmost importance in determining whether a soil is able to soak up all the rain falling on it. If the intensity exceeds the infiltration rate, the precipitation excess has no recourse except to run-off (41).

As soil moisture increases and approaches the saturation point, the infiltration rate becomes less importantand the permeability of the least permeable soil layer becomes important and becomes the limiting factor in determining how fast water may move into and through the soil profile (4).

In order to more clearly illustrate the part rainfall intensities play in contributing to run-off, and to illustrate the peak sizes of rainfall experienced in a typical year, Figure 19 has been presented. This chart illustrates peak intensities experienced at East Lansing for the entire year of 1942. Peak intensities are given for periods of two and five minutes. It should be noted that the rise and decline of intensity peaks follow the same trends as those noted earlier under the rainfall class study. The highest intensity noted for two minutes was 6.00 inches per hour. Intensities have reached 9.00 inches per hour at this station for periods up to one minute. It should be noted that this is well within the range of infiltration values for both watersheds under ideal conditions. However, due to other factors, such as surface sealing under raindrop impact on bare soil, frozen soil, high soil moisture, and others, both watersheds have yielded some run-off as the result of most storms with intensity rates over 6.00 inches per hour for two minutes or longer.

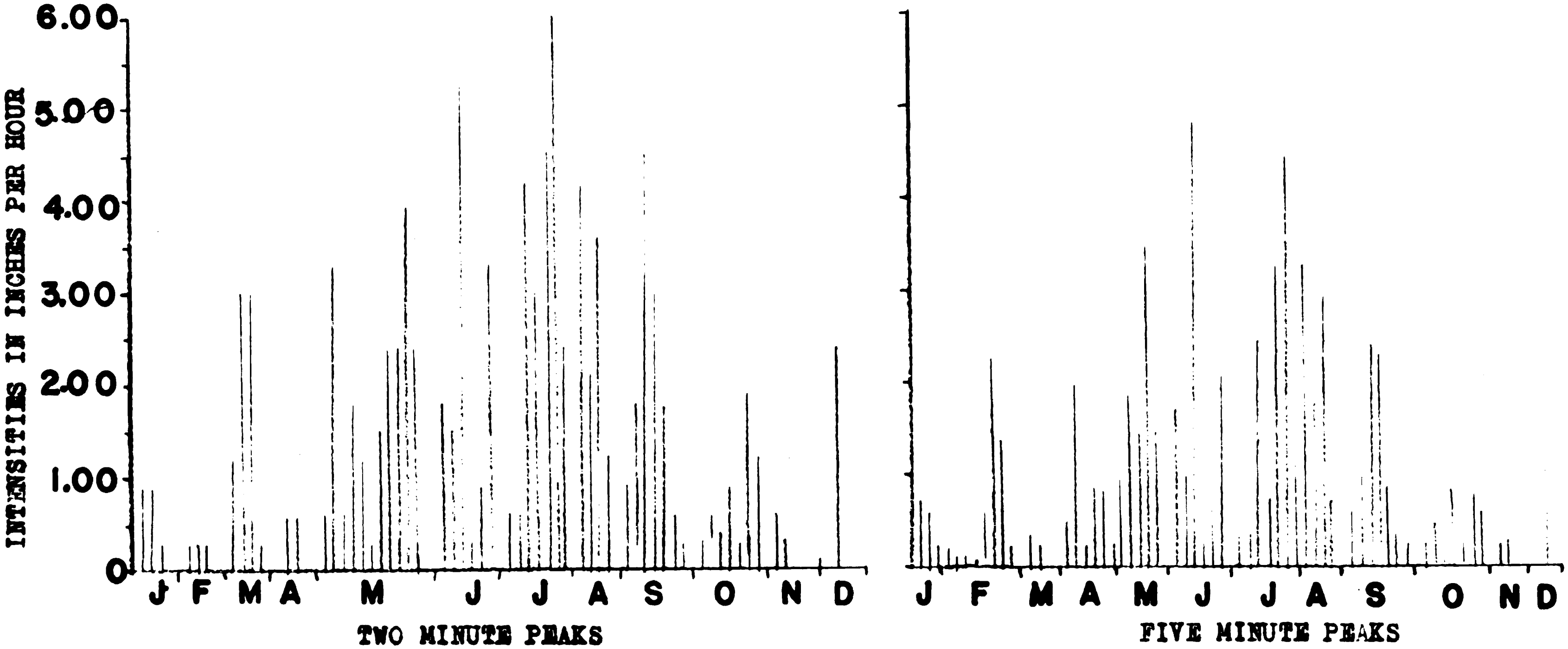

Fig. 19. Peak intensities for periods of two and five minutes experienced at East Lansing, Michigan for the year 1942.

Statistical analyses. Statistical analyses, using the Chi Square test for independence in 2 x 2 tables, were made to determine if the quantity of rainfall was significant in producing rainfall on the wooded watershed. In this study, all rainfalls over 0.25 inch were divided into those under 1.00 inch total and those over 1.00 inch. These were further subdivided into storms producing run-off and those producing no run-off. Rainfalls of 1.00 inch and greater proved to be significant in aiding to produce run-off.

A similiar analysis was run on those storms occuring over the wooded watershed to determine if the precipitation class (intensity) was significant in aiding to produce run-off. The two highest classes, five and six, did not prove to be significantly different from those of lesser intensity. It is felt that this is true for the conditions at the wooded watershed. Several factors contribute to this seemingly contradictory statement. The heavy vegetal cover and leaf mat break the impact of the raindrops, and the beating effect of the higher intensities is not felt in the woods. Infiltration under wooded cover is so great that infiltration capacity is never lower than rain intensity until soil moisture reaches a relatively high level. When soil moisture approaches saturation the permeability of the least permeabile layer becomes the limiting factor, and this is so low that any number two storm could contribute more water than the soil could discharge through it's layers. Perhaps the most important factor lies in the simple fact that the lower intensities occur during the winter and spring months when soil moisture is at it's highest. This is the period of greatest number of run-offs.

Due to the larger number of storms which produced run-off at the cultivated watershed, it was possible to make two analyses of the effect of total amounts of rainfall in any given storm. The effect of total rainfall upon producing run-off was tested by means of Chi Square and 2 x 2 tables, and storms of 1.00 inch and greater proved to be highly significant at the one percent level. A similiar test was made of all storms producing run-off during the frost free periods of the years 1941 to 1951. The purpose of this study was to determine if the larger rains tended to produce larger run-offs. On the basis of the small number of storms available for the study, larger storms, with the exception of the very large, did not prove to be significantly different from the smaller ones.

The same type analysis was made to determine if storms of intensity classes five and six were significantly different from the lower ones in producing run-off on the cultivated watershed. The two higher classes proved to be highly significant in this respect.

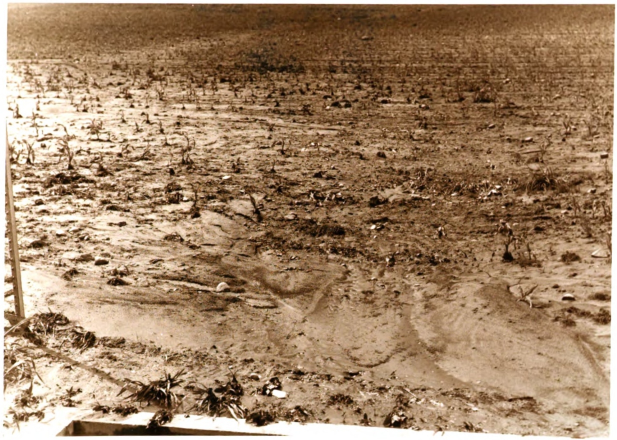

Fig. 20. View of the cultivated watershed following run-off occasioned by high intensity storm occuring on bare soil.

PRECIPITATION, RUN-OFF AND SOIL LOSS SUMMARY FOR THE PERIOD 1941-51

The monthly and yearly values for precipitation, run-off and soil less for the cultivated and wooded watersheds are shown in Table XXIX and Table XXX. Table XXIX shows the hydrologic summary for precipitation, soil loss and run-off.

The wooded watershed has received more precipitation for the period than the cultivated. It has received more precipitation in all but two of the eleven years. The total eleven year precipitation for the cultivated watershed was 347.51 inches, of which 46.57 inches was lost to surface run-off. The wooded watershed received 360.50 inches precipitation, with a loss of only 5.96 inches. The difference in soil loss is even more striking. The cultivated watershed lost 56,235.5 pounds of soil per acre, while the wooded watershed lost only 62 pounds of soil per acre for the period.

It is important to know both the total run-off amounts for the year as well as the months in wich these run-off's occur. Table XXX is a compilation of average precipitation, run-off and soil loss by months, for the entire period. These figures become more useful if the number of years each month contributed to run-off is known. This information is given in Table XXXI.

Tables XXX and XXXI show that on the basis of an eleven year average, winter water losses are very high. When the first three months are examined, it is seen that this is a consistently high water loss period. Run-off has occured in seven months out of the eleven for the

TABLE XXIX

PRECIPITATION, RUN-OFF, SOIL LOSS SUMMARY, 1941-1951

Year	Cultivated Watershed "B"			Wooded Watershed		
	Precipitation in Inches	Run-off in Inches	Soil Loss Pounds per Acre	Precipitation in Inches	Run-off in Inches	Soil Loss Pounds per Acre
1941	28.47	2.1500	26972.0	27.64	.0038	
1942	34.03	7.7092	2028.9	37.11	.7907	
1943	33.06	2.1291		34.99	1.7569	
1944	22.83	3.8353		25.63	.5989	
1945	37.48	1.7309		38.42	.0806	
1946	21.65	3.3059		23.88	.0726	
1947	37.59	6.8297	24649.7	38.73	.7397	
1948	28.56	6.8853	527.4	29.57	1.3130	27.2
1949	34.43	5.9296	1172.9	32.46	.0114	
1950	38.59	4.4102	685.8	39.33	.5972	34.8
1951	30.82	1.6547	198.8	32.74		
Total	347.51	46.5699	56235.5	360.50	5.9648	62.0
Percent of precipitation lost to surface run-off	13.4				1.7	

TABLE XXXI

NUMBER OF YEARS EACH MONTH CONTRIBUTED AT LEAST ONCE TO SURFACE RUN-OFF AND SOIL LOSS FOR THE PERIOD 1941 - 1951

Month	Cultivated Watershed		Wooded watershed	
	Run-off	Soil loss	Run-off	Soil loss
January	7	3	1	
February	10	4	3	
March	10	5	6	2
April	4	1	2	1
May	3	3	3	
June	4	4	3	1
July	2	1		
August	5	4		
September	2	1		
October	1	1		
November	1			
December	5	1		

TABLE XXX

AVERAGE PRECIPITATION, SURFACE RUN-OFF, AND SOIL LOSS BY MONTHS FOR THE WOODED AND CULTIVATED WATERSHED, 1941-1951

Month	Cultivated Watershed			Wooded Watershed		
	Precipitation in Inches	Run-off in Inches	Soil Loss in Pounds per Acre	Precipitation in Inches	Run-off in Inches	Soil Loss in Pounds per Acre
January	1.89	.8191	50.03	2.10	.0010	
February	1.34	1.3110	96.83	1.58	.0270	
March	2.32	1.6874	198.22	2.53	.1856	3.47
April	2.67	.1499	1.31	2.65	.0831	1.50
May	4.49	.0752	64.24	4.21	.0877	
June	3.88	.2365	1588.13	3.64	.1573	.65
July	2.45	.0081	.05	2.45		
August	2.81	.0312	8.10	3.12		
September	3.14	.0988	2236.36	3.34		
October	2.58	.0719	867.27	2.72		
November	2.09	.0063		2.31		
December	1.89	.1094	1.73	2.06		
Total	31.55	4.6048	5112.27	32.71	.5417	5.62

month of January, and in ten of the eleven for both February and March.

Run-off is most likely to occur in the month of March at the wooded watershed also. Run-off occured in six of the eleven years recorded at the wooded watershed.

Water Losses as Influenced by Cover on the Cultivated Watershed

Water losses are broken down by cover types and season in Table XXXII. The monthly grouping was arranged as follows. The first period consists of the months of January, February, March and April. This is the period of snow accumulations, frozen soil and the spring thaw. This is the period of high water loss. The second period consists of the months from May through August. It has been taken as the growing season, marked by heavy plant use of water, high intensities and low water loss. Soil loss during this period is high. The months of September to December are usually marked by low soil moisture, and relatively good cover over the soil surface. Soil and water losses during this period are usually caused by large storms. Frost conditions enter the picture in December, but seldom have any effect upon run-off. Snow accumulation during December is usually light and may be carried over into the next year.

During the first period, the precipitation is low, compared with that received during the growing season. For the twelve year period under study, precipitation amounted to an average of 8.22 inches for the four month period. Of this amount, 48.9 percent was lost to surface run-off.

An inspection of soil moisture charts shows the first four months to be the season of moisture recharge. The highest soil moisture of the year is recorded during this time. During this season, transpiration, and evaporation are at a minimum. If the water can be held on the soil until it has a chance to infiltrate it will be a valuable source of moisture for the drier months of the summer.

Cultivated watershed B, with it's average loss of 4.00 inches to surface run-off during the first four months of the year presents one of the most important conservation problems in Michigan. Harold and Dreibelbis (15) state that 25.0 inches of water is needed to produce a corn crop in the vicinity of Coschocton, Ohio. With a loss of 4.00 inches of water during the first four months of the year out of a total of only 31.55 inches in an average year, the margin for producing a corn crop safely is slight. If the winter run-off could be stored in the soil for use later on, it would constitute insurance against drought losses.

A basic problem, the solution of which is pressing, is the determination of methods of increasing infiltration during the frost season.

It has been generally felt that cover exerted a great influence over whether run-off would occur from a storm. In order to determine the effects of heavy cover (alfalfa-brome), as opposed to lighter cover, (corn and rye), Tables XXXII and XXXIII have been prepared. These tables show the comparative precipitation, run-off and soil loss for the cultivated watershed for years when the watershed was planted to various crops.

A close study of Table XXXII shows that during the first four months of the year, based on a total of 12 years, watershed B had 98.79 inches of precipitation and lost 40.55 inches to run-off. When broken down into cover types, the watershed was planted to rye, following a corn crop for three winters. Under this cover, the watershed received 25.31 inches of precipitation and lost 17.71 inches to run-off. This was a loss of 31.08 percent. Percentage wise, the loss to run-off under sod was less than half that under rye. This fact is further substantuated by the results of the Chi Square test. This test, utilising all storms occuring on the watershed during periods when the soil was not frozen, showed sod to be significantly superior to corn and rye in preventing run-off.

The period during the middle of the year received the largest amount of rainfall, more than one and one-half times as much as that received during either of the other two periods. This is also the period of high rainfall intensity. These high intensity rains are accompanied by high intensity run-offs. Out of a total of 374.58 inches precipitation for the 12 years, 161.75 inches fell during this period. Of this amount, only 3.82 inches were lost to run-off.

There is a definite indication that sod decreases run-off during the summer months. Sod lost only 0.38 inch to run-off over a six year period, while clean tilled crops lost 3.44 inches during the same time span. There was almost the same amount of precipitation for each period.

The great differences between run-off for the two covers may be explained by referring to FIGURE 18. It will be noted that during these months storms of class five and six predominate. These high

TABLE XXXII

WATER LOSSES BY MONTHS AND COVER TYPES, WATERSHED B - 1941-1952

Period by Months	Rye cover in Corn Stalks, 3 Years			Oats, Alfalfa-brome			Sod		
	Precipitation in Inches	Percent Run-off	Inches Run-off	Precipitation in Inches	Percent Run-off	Inches Run-off	Precipitation in Inches	Percent Run-off	Inches Run-off
Three years							Nine years		
January	5.90	42.88	2.53				16.54	19.29	3.19
February	4.70	131.06	6.16				11.34	64.55	7.32
March	10.00	90.20	9.02				17.68	59.39	10.50
April	4.71						27.92	6.55	1.83
Sub-total	25.31	69.97	17.71				73.48	31.08	22.84
		Four years			Two years			Six years	
May	19.13	0.20	0.04	7.46	8.18	0.61	27.52	0.62	0.17
June	12.93	10.98	1.42	11.11	10.53	1.17	19.96		
July	7.53			6.88	0.15	0.01	14.81	0.57	0.14
August	11.00	1.27	0.14	5.29	0.95	0.05	18.13	0.77	0.14
Sub-total	50.59	3.16	1.60	30.74	5.99	1.84	80.42	0.47	0.38
		Four Years						Eight Years	
September	11.61	- 9.13	1.06				24.81	0.08	0.02
October	10.79	7.32	0.79				18.24		
November	10.08	0.59	0.06				16.57		
December	6.41	7.49	0.48				15.53	4.57	0.71
Sub-total	38.89	6.15	2.39				75.15	0.97	0.73

intensity storms falling on poorly protected soil cause a rapid sealing of the surface layer of the soil and a corresponding decrease in infiltration and a high rate and large amount of run-off.

Water losses for May were negligible under all crops. June losses under corn were high, while sod showed no losses at all. July and August losses were negligible. The few run-offs that did occur came as the result of unusually heavy storms.

The last four month period had a slightly smaller loss than the preceeding period. The losses in September under rye cover were due to two storms in 1947. The water loss for October occured as a result of two storms in 1941. November had negligible losses, and the run-offs that did occur all came in 1941. The December loss occured as a result of frozen soil conditions. The run-offs from the entire four-month period was the result of unusual storms with frequent occurances.

An examination of Table XXXIII shows a large difference between cover types in soil loss. There is a large difference during the winter months, and throughout the summer and fall months losses become less under sod, while becoming increasingly larger under clean tilled crops.

Erosion between the watersheds becomes even more striking. The cultivated watershed lost to erosion 31,938.73 pounds of soil per acre, during the period 1941 to 1951, while the wooded watershed lost only 62 pounds of soil per acre.

TABLE XXXIII

SOIL LOSS BY MONTHS AND COVER TYPES, WATERSHED B, 1941 -52

Months	Rye in Corn Soil Loss per acre in pounds	Oats, Alfalfa Soil Loss per Acre in pounds	Sod Cover Soil Loss per acre in pounds
	(Three years)		(Nine years)
January	348.0		202.39
February	582.5		498.04
March	2000.5		247.96
April			14.50
Total	2932.0		962.89
	(Four years)	(Two years)	(Six years)
May	23.4	683.3	
June	17401.2	68.3	
July		.6	
August	81.7	1.3	6.1
Total	17506.3	735.5	6.1
	(Four years)		(Eight years)
September	24619.1		
October	9540.0		
November			
December			1.9
Total	34159.1		1.9

Recommendations

Sod was effective in decreasing the amount of water lost to surface run-Off, particularly during the winter and spring months. This is the critical period of water loss for the cultivated water-shed. It is obviously impractical to keep all cultivatable land in sod. Therefore, a method of cultivation is needed which will provide winter cover for the soil and will add organic matter to the soil, and yet allow the land to be used for clean cultivated crops during the growing season.

Tyson and Crabb (33) report that Stubble Mulch Tillage reduced damage to the soil from the impact of rain drops, decreased run-off and erosion, and increased infiltration of water. Personel of the Michigan Hydrologic Research Station are considering further research in this field.

Run-off Producing Storms on the Wooded Watershed

During the period 1941-1951, surface run-off has occured at the wooded watershed only 26 times. The writer felt the only way to properly evaluate the causal factors for these few run-offs would be to deal directly with the storms in question, rather than by group analysis alone.

Pertinent data for each storm and run-off is given in Table XXXIV. An examination of this table will show that all but two of these storms fell on soil having an antecedent soil moisture at or above field capacity. Two storms fell on soil whose moisture content at the begining of the storm was below field capacity, but both of these storms were of unusual size. One storm contributed 2.99 inches of rain in 20 hours, while the other contributed 3.13 inches of rain in 10 hours. One storm fell on soil which was frozen for the surface few inches. In addition, this rain fell on an accumulation of snow and melted it.

In terms of duration of rainfall, the run-off producing storms break down as follows:

Number of Storms	Hours of Duration
5	0 - 5
9	5.5 - 10
8	10.5 - 20
3	20.5 - 25
1	48

The wooded watershed yielded run-off as the result of two sets of circumstances. These were: (1) small rains of low intensity and low and high total volume and long duration on frozen or saturated soil. The Miami soil, which comprises half the area of the watershed, has a clay layer at a depth of from seven to twelve inches which has an infiltration rate of only 0.04 inches per hour. When the soil above

TABLE XXXIV

ALL RUN-OFF PRODUCING STORMS ON THE WOODED WATERSHED, 1941-51

Date	Precipitation in Inches	Surface Run-Off	Soil Moisture[1]	Precipitation Intensity Class	Duration in Hours	
					Precipitation	Run-off
March 9, 1942	1.88	.1419	Above FC	1	21	25
March 16, 1942	1.61	.4263	Above FC	4	6	18
March 17, 1942	.70	.2276	Above FC	2	7	9
February 6, 1943	.46	Trace	Above FC	3	12	8
February 22, 1943	.15	Trace	Frozen	1	6	3
February 23, 1943	.04	.0336	Above FC	1	2	9
March 10, 1943	.78	Trace	Above FC	4	15	14
March 15, 1943	1.27	.2505	Above FC	3	7	14
May 11, 1943	1.51	.3030	Above FC	1	16	20
June 2&3, 1943	1.79	1.1698	Above FC	6	1	3
March 16, 1944	.36	.0159	Above FC	1	5	25
May 21, 1944	2.47	.5813	Above FC	6	2	1
May 15, 1945	2.12	.0806	Above FC	4	25	15
August 31, 1945	1.49	Trace	Above FC	6	3	4
March 6, 1946	.32	.0726	Above FC	2	14	10
April 5, 1947	2.24	.7397	Above FC	6	5	29
March 19, 1948	3.13	.8842	Below FC	6	10	30
May 10, 1948	2.99	.4288	Below FC	5	19	48
January 18, 1949	1.50	.0114	Above FC	4	4	8
February 14, 1950	.99	.0170	Above FC	2	25	10
February 28, 1950	.52	.1748	Above FC	2	10	13
March 25, 1950	.40	.0133	Above FC	6	8	10
March 26, 1950	.25	.0811	Above FC	5	8	6
April 24, 1950	.97	.1098	Above FC	3	19	8
April 25, 1950	.95	.0652	Above FC	3	12	7
June 2, 1950	2.62	.1329	Above FC	6	9	12

1. FC---Field capacity

layer is saturated, any rain in excess of 0.04 inch per hour will cause run-off. (2) Some of the run-off producing storms have been high intensity storms with large total precipitation. The high intensities have usually occured in the middle or at the end of the storm, after the earlier portion of the storm had satisfied much of the soil moisture requirements of the soil.

SUMMARY

Basically there are two regions of a watershed affected by vegetal cover. One is concerned with differences within the soil itself, and is concerned with such factors as the effect of humus upon freezing and the freezing point of the soil. It is also concerned with the soil moisture retentive capacity, and the increased percolation of water through the soil due to the addition of organic matter, root channels and animal borings within the soil as well as the improved structure that comes with the addition of organic matter. The surface of the soil is the second region affected. The better the surface is protected by vegetal cover, the less risk is run of raindrop splash sealing the surface pores. The heavy transpiration of water by plants during the growing season also provides storage space for winter precipitation and the large amount of debris on the surface acts as a sponge in absorbing and holding large quantities of water, as well as slowing down surface run-off by providing barriers. This action gives the soil a chance to infiltrate the water during any break in the high rainfall intensity.

<u>Soils</u>. The basic difference between the two watersheds is primarily one of organic matter content of the soils of the watersheds. There are differences due to clay and silt contents, but organic matter differences overshadow the others.

Infiltration rates at both watersheds are basically good. However, those at the cultivated are subject to splash erosion. The Miami soil at the wooded watershed has a limiting layer of clay at a depth

seven to twelve inches with infiltration and percolation rates of only 0.04 inch per hour. Since this soil makes up almost half the area of the watershed, when the soil above this layer becomes saturated, almost any rain will cause surface run-off. The cultivated soils do not have this limiting clay layer, but they also do not have the retentive storage capacity of the wooded soils.

Soil Moisture. Soil moisture at the wooded watershed is almost always higher than that of the cultivated. The retentive capacity of the wooded soils is much greater and this storage is utilized to a greater extent than that at the cultivated.

Soil moisture at the woods reaches a low near the permanent wilting point in late summer and then begins a gradual climb to saturation, or near saturation in March or April. Moisture remains high until June, when it begins a rapid decline under heavy transpirational use by plants.

It appears, on the basis of one years records, that a cutting such as was administered to the timber of the wooded watershed, tends to increase the soil moisture, particularly in the 12-18 and 30-36 inch levels. The increase is noticeable at the 0-6 inch depth, but not to the extent that prevails at the lower levels. Hydrologically, this increased water provides less storage space for winter precipitation, as well as the high intensity and high total rainfall storms of the summer. Theoretically, run-offs could be occasioned by smaller rains than previously. This theory seems to be substantuated by the run-off of August 16, 1952. This storm occasioned run-off in August, a month in which run-off has occured once before in eleven years.

The previous run-off came as the result of unusually heavy rains and high soil moisture occasioned by a yearly rainfall of over 38 inches. The 1952 run-off occured although the yearly precipitation was only slightly over 28 inches, and the yearly precipitation from January to August was much lower than was the case in the previous storm.

Cultivated soil moisture was almost always considerably below the wooded. During long periods of summer drought conditions, the watershed soil moisture approaches and often goes below the permanent wilting point for considerable lengths of time. Any practice that will aid in storing more water in the soil will provide additional water fer plant growth during these dreughty conditians. Stubble mulch tillage studies have shown this form of addition of organic matter to the soil increases the storage of water.

Effect of frozen soil upon surface run-off. Soil moisture at the cultivated watershed usually reached a frozen state in December and remained in this condition until April. During this time, in the typical year chosen for the study, the watershed lost 3.0188 inches to run-off, while receiving only 5.13 inches precipitation. This loss all came as the result of rain and melting snow on a frozen soil.

The wooded watershed soil was not observed in a frozen state during the winter under discussion. The only run-off for the year came as the result of a rain of both high intensity and large total amount falling on a saturated soil. In line with the unfrozen soil of the wooded watershed, the snow surveys for the winter showed snow depths under wooded cover to be deeper than those on the cultivated watershed.

Soil and air temperatures. Soil temperatures changed significantly at the wooded watershed as a result of cutting the vegetation on the wooded watershed.

Maximum and minimum monthly averages of air temperatures in the open were compared with those in the watershed. The station on the watershed showed less fluctuation and closer uniformity of temperature with the station in the open after the cut.

Patterns and classes of rainfall. Class one, two and three storms were the most numerous during the winter months when they are practically the only classes to appear. High intensity classes reach a maximum during the period May to September.

Class five and six storms were found to be of the advanced and uniform patterns in the majority of cases. These storms occur during the summer months.

It was found that 69.2 percent of the storms occuring in the East Lansing area had a total precipitation of less than 0.25 inch precipitation. These storms made up 22.6 percent of the total rainfall.

Rainfalls of 1.00 inch and over were found to be significant in producing water from both watersheds, when the storms of this size were contrasted to those of smaller size.

Precipitation classes did not prove to be significantly different in producing run-off on the wooded watershed. Classes five and six did prove to be significantly different from lower classes in this respect at the cultivated watershed.

Precipitation, run-off and soil loss summary. The wooded watershed received 360.5 inches precipitation, with a loss of only 5.96 inches run-off and a soil loss of only 62 pounds over an 11 year period.

During the same period, the cultivated watershed received 347.51 inches precipitation and lost 46.57 inches to surface run-off, and had a soil loss of 56,235.5 pounds of soil per acre.

January, February and March were the months of high water loss at the cultivated watershed. The majority of run-offs for the wooded watershed occured in March. Run-off occured in 7 out of 11 years for January at the cultivated, and 10 out of 11 for the months of February and March. Run-off occured during March at least once each March for six years out of eleven.

Effect of cover in reducing soil and water loss at the cultivated watershed. When planted to sod, the watershed lost 31.08 percent of precipitation. When planted to rye, it lost 69.97 percent of the precipitation received. These were winter losses. Summer losses for sod were only 0.47 percent of precipitation, while losses under corn amounted to 3.16 percent. During the fall months, losses under sod amounted to 0.97 percent of precipitation, while that of corn-rye amounted to 6.15 percent.

Run-off producing storms on the wooded watershed. There were 26 instances of run-off from the wooded watershed during the 11 year study period. Of these, 23 were the direct result of precipitation falling on saturated soil, or soil so near saturation that the precipitation raised the moisture content above saturation. Two storms fell on soil having soil moisture below field capacity. Both of these were of large total amounts and high intensities. One storm fell on frozen soil, melting an accumulation of snow.

CONCLUSIONS

1. Soil moisture under wooded cover is considerably higher than under cultivated conditions. This is due to organic matter content. Practices such as stubble mulch tillage will increase stored water, and will also cut down on run-off losses.

2. The cultivated watershed remains in a frozen state during most of the winter. Water losses for this period are higher than for any other period of the year. The wooded watershed, while freezing during some winters, does not freeze to the depths, not for the same length of time as the cultivated. Water losses from the wooded watershed as the result of run-off over frozen soil are very small.

4. As a result of cutting the timber on the watershed, there appeared to be an increased soil moisture content for all depths tested. This in turn appeared to be directly responsible for a run-off in the month of August. That was the second run-off in twelve years of records. The first run-off was caused by unusually high rainfall for the entire year. The run-off in 1952 came during a droughty year, when rainfall was approximately 4.00 inches less than normal.

5. Winter rainstorms are almost exclusively storms of low intensity. Storms of high intensity occur during the months of May to September. Most run-offs occur as the result of melting snow, or rain falling on frozen soil. The heaviest intensity classes are significant in producing run-off on the cultivated watershed, but not the wooded.

6. Rainfalls of 1.00 inch or over proved to be significant in producing run-off, when tested against those of smaller size.

7. The loss of water to surface run-off by the wooded watershed was much less than that of the cultivated watershed.

8. Causes of run-off from the wooded watershed have been, in decreasing order of importance, (1) precipitation or melting snow on saturated soil, (2) high intensity and high total precipitation storms, and (3) rain or melting snow on frozen soil.

IMPLICATIONS OF THE STUDY

The entire state of Michigan has become a heavily used resort area. One of the most important drawing cards for the resort centers is the sport fishing afforded by the streams and lakes of the state. This sport fishing is most important in the less heavily populated northern portions of the state. This area was once covered by timber. With the coming of the white man, the timber was cut, fire ravaged the area, and settlers cultivated the soil. Rivers and streams, which once furnished a habitat for trout and other game fish, rapidly silted in. As a result, the game fish disappeared from many of the streams. Biologists of Michigan State College are attempting to find methods of controlling this form of pollution, and attempting to return these streams to a condition which will encourage their use by game fish. In this work, yardsticks for determining rates of erosion from watersheds under different covers are needed.

It is of importance for the research specialist in soil conservation to know the basic causes of run-off and erosion from the soils of his locality. It is also of importance for him to have at hand all the information that relates to the causal factors of erosion and run-off, such as precipitation intensity classes and patterns that may be expected to occur at various seasons of the year. Knowing these, the technician is in a position to design cultural practices, and choose cover crops which will provide maximum protection for the soil.

Highway engineers have depended to a large extent upon formulae for the determination of bridge and culvert size. These formulae have proved to be an unsatisfactory tool. There has come an awareness in these circles that the only way to effectively and accurately design a structure which will discharge the maximum amounts of run-off water and yet not have a safety factor so great that the cost is burdensome, is to accurately know the amounts of water which will be discharged through these structures. A formula will not give this amount with the certainty needed. Therefore, when a formula is used, the engineer must add a safety factor, which in turn increases the cost of the structure. It is hoped this study will supply part of the answers to the problem, for only by knowing the drainage characteristics of different watersheds under various cover types, and only with the gathering and assimilation of this data from many watersheds over the area, can the engineer design and build bridges and culverts which are designed to carry the proper amounts of water, instead of one of such size that it will carry a run-off from a storm of such magnitude that it will occur perhaps once in 100 years instead of the once in 25 years the engineer was striving for.

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APPENDIX

CROWN COVER MAP OF THE WOODED WATERSHED
MICHIGAN HYDROLOGIC RESEARCH PROJECT
AFTER COMPLETION OF COMMERCIAL CLEAR CUT

(MICHIGAN AGRICULTURAL EXPERIMENT STATION
MICHIGAN STATE COLLEGE DEPARTMENT OF FORESTRY
ROSE LAKE WILDLIFE EXPERIMENT STATION
U.S.D.A. SOIL CONSERVATION SERVICE
COOPERATORS)

MAPPED IN 1952 BY : J. L. SMITH
DRAWN BY : J. L. SMITH

WATERSHED AREA = 1.65 ACRES

LEGEND

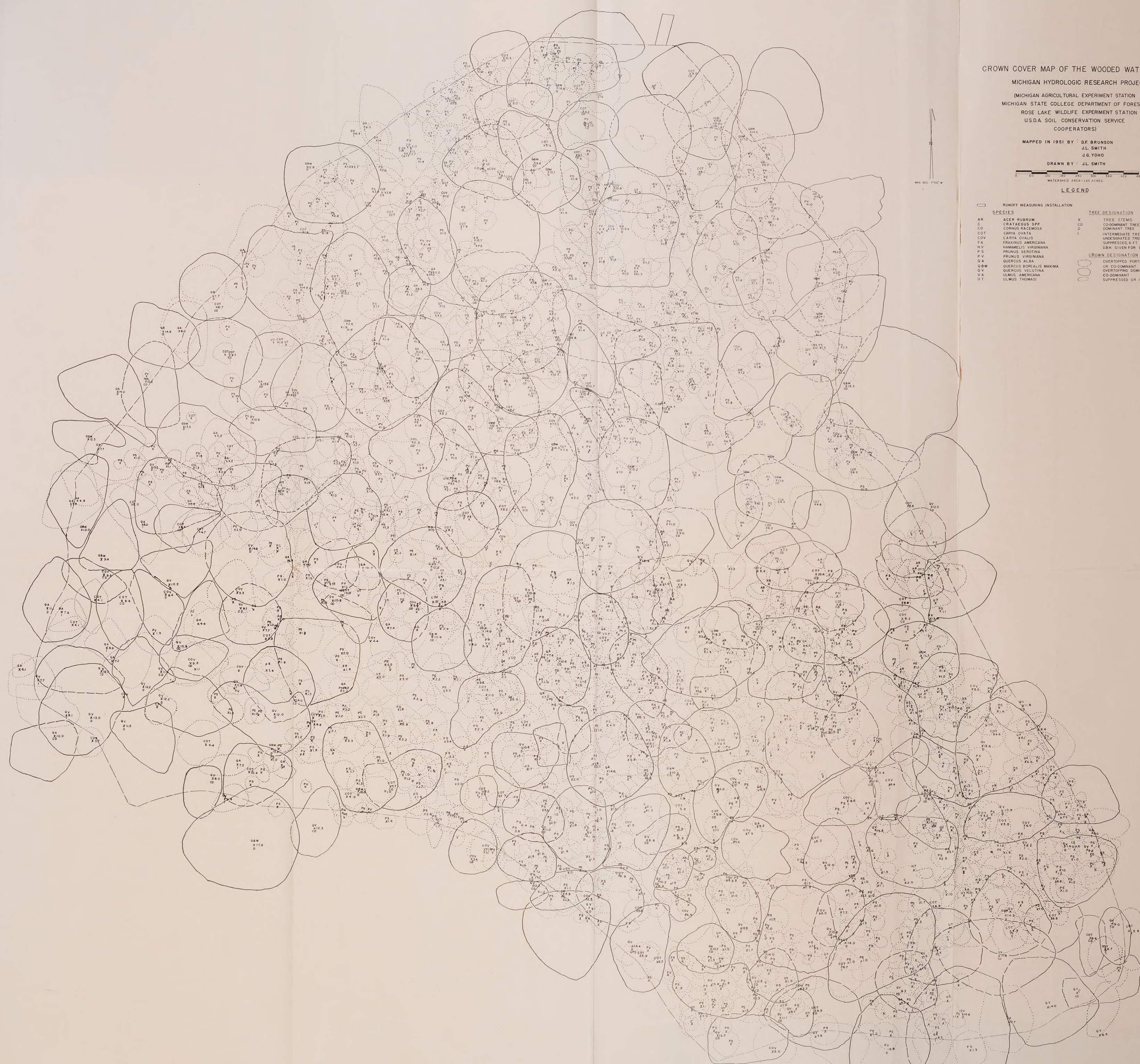
RUNOFF MEASURING INSTALLATION
X TREE STEM

SPECIES

AR	ACER RUBRUM
C	CRATAEGUS SPP.
CO	CORNUS RACEMOSA
COT	CARYA OVATA
COV	CARYA OVALIS
FA	FRAXINUS AMERICANA
HV	HAMAMELIS VIRGINIANA
PS	PRUNUS SEROTINA
PV	PRUNUS VIRGINIANA
QA	QUERCUS ALBA
QBM	QUERCUS BOREALIS MAXIMA
QV	QUERCUS VELUTINA
UA	ULMUS AMERICANA
UT	ULMUS THOMASI

CROWNS

FORMER DOMINANT - CODOMINANT
FORMER SUPPRESSED - INTERMEDIATE
B BROKEN



CROWN COVER MAP OF THE WOODED WATERSHED

MICHIGAN HYDROLOGIC RESEARCH PROJECT

(MICHIGAN AGRICULTURAL EXPERIMENT STATION
MICHIGAN STATE COLLEGE DEPARTMENT OF FORESTRY
ROSE LAKE WILDLIFE EXPERIMENT STATION
U.S.D.A. SOIL CONSERVATION SERVICE
COOPERATORS)

MAPPED IN 1951 BY : D.F. BRUNSON
J.L. SMITH
J.G. YOHO

DRAWN BY : J.L. SMITH

0 60 120 180 240 300 360 420 480
WATERSHED AREA = 1.65 ACRES

LEGEND

RUNOFF MEASURING INSTALLATION

SPECIES

AR	ACER RUBRUM
C	CRATAEGUS SPP.
CO	CORNUS RACEMOSA
COT	CARYA OVATA
COV	CARYA OVALIS
FA	FRAXINUS AMERICANA
HV	HAMAMELIS VIRGINIANA
PS	PRUNUS SEROTINA
PV	PRUNUS VIRGINIANA
QA	QUERCUS ALBA
QBM	QUERCUS BOREALIS MAXIMA
QV	QUERCUS VELUTINA
UA	ULMUS AMERICANA
UT	ULMUS THOMASI

TREE DESIGNATION

X	TREE STEMS
CD	CO-DOMINANT TREE
D	DOMINANT TREE
I	INTERMEDIATE TREE

UNDESIGNATED TREES ARE SUPPRESSED, 6 FT. HIGH & OVER
D.B.H. GIVEN FOR 1 INCH & OVER

CROWN DESIGNATION

OVERTOPPED PORTION OF DOMINANT OR CO-DOMINANT
OVERTOPPING DOMINANT OR CO-DOMINANT
SUPPRESSED OR INTERMEDIATE