April 23, 1965

To the Graduate Council:

I am submitting herewith a thesis written by Lalit Kumar Sinha entitled "Effects of Depth and Gradient on Soil Moisture Storage in a Small Agricultural Watershed." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.

C. H. Shelton
Major Professor

We have read this thesis and recommend its acceptance:

John J. McDonn
W L Powers
John D Sewell

Accepted for the Council:

Hilton A. Smith
Dean of the Graduate School

# EFFECTS OF DEPTH AND GRADIENT ON SOIL MOISTURE STORAGE IN A SMALL AGRICULTURAL WATERSHED

---

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

---

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

---

by

Lalit Kumar Sinha

June 1965

ACKNOWLEDGMENT

The author wishes to express his sincere appreciation to:

Professor Curtis H. Shelton, major professor, for his guidance and unreserved help in conducting this research.

Dr. John J. McDow, Head, Agricultural Engineering Department, for providing financial assistance for this study and for serving on the graduate committee.

Dr. John I. Sewell for his help and suggestions while serving on the graduate committee.

Dr. William L. Parks for his help and suggestions while serving on the graduate committee.

Dr. C. C. Thigpen, Head, Department of Statistics, for his help and suggestions in doing the statistical analyses.

Mr. A. L. Kennedy for his help in field work. Miss Geneva Boshears, Miss Cora McCann, and other staff members for their help.

Mr. John Ray and Mr. Earl McDow of the Computing Center.

Mrs. J. J. Knapka for the final typing of this thesis.



618246

TABLE OF CONTENTS


| CHAPTER | | PAGE |
|---|---|---|
| I. | THE PROBLEM | 1 |
| | Introduction | 1 |
| | Statement of the Problem | 2 |
| | Objectives | 3 |
| II. | WATER YIELD CONCEPT | 4 |
| III. | LITERATURE REVIEW | 7 |
| IV. | EXPERIMENTAL PROCEDURE | 15 |
| | Selection of Site | 15 |
| | Installation of Equipment | 16 |
| | Soil Moisture Access Tubes | 16 |
| | Infiltrometers | 18 |
| | Runoff plots | 18 |
| | Runoff collectors | 19 |
| | Rainfall simulators | 22 |
| | Data Collection | 25 |
| | Soil Moisture | 25 |
| | Soil Properties | 25 |
| | Infiltration Data | 26 |
| | Data Analysis | 27 |
| | Data Compilation | 27 |
| | Statistical Analysis | 28 |

CHAPTER PAGE

V. RESULTS AND DISCUSSION. . . . . 31

VI. SUMMARY AND CONCLUSIONS . . . . . 56

BIBLIOGRAPHY. . . . . 60

APPENDIX. . . . . 64

LIST OF TABLES


| TABLE | | PAGE |
|---|---|---|
| I. | Analysis of Variance of Soil Moisture Storage. . . . . | 32 |
| II. | Effect of Depth and Slope on Soil Moisture Storage (Inches). | 33 |
| III. | Soil Particle Size Distribution (Per Cent) . . . . . | 40 |
| IV. | Mathematical Relationships Between Soil Moisture, Depth, and Slope. . . . . | 42 |
| V. | Average Infiltration Rates (iph) as a Function of Time and Slope at Two Specified Rainfall Intensities. . . . . | 43 |
| VI. | Account of Water on the Runoff Plots Immediately after Operation of the Rainfall Simulators . . . . . | 48 |
| VII. | Percolation Rates of Water Through Undisturbed Cores of Topsoil. . . . . | 50 |
| VIII. | Mathematical Relationships Between Infiltration Rate and Slope, Rainfall Intensity, and Antecedent Moisture at Selected Depths. . . . . | 51 |
| IX. | Levels of Statistical Significance of Selected Factors on Infiltration Rates . . . . . | 53 |
| X. | Effect of Antecedent Moisture on Infiltration Rate . . . . . | 54 |
| XI. | The Exact Slope (Per Cent) at Which the Access Tubes Are Located on Each Site . . . . . | 66 |
| XII. | Specifications of the Nozzles Used in the Rainfall Simulators . . . . . | 67 |
| XIII. | The Equivalent Per Cent Moisture by Volume of the Neutron Counts . . . . . | 68 |

TABLE PAGE

XIV. Soil Moisture Data (Inches). . . . . 72

XV. Infiltrometer Data . . . . . 74

LIST OF FIGURES


| FIGURE | | PAGE |
|---|---|---|
| 1. | Disposition of Precipitation | 5 |
| 2. | Lay-out of Soil Moisture Access Tubes. | 17 |
| 3. | Details of Boundary Walls for Runoff Plot. | 20 |
| 4. | Details of Runoff Collector. | 21 |
| 5. | Details of Rainfall Simulator. | 23 |
| 6. | Details of Support Post. | 24 |
| 7. | Effect of Depth on Average Soil Moisture Storage at Four Selected Slopes (Site A) | 35 |
| 8. | Effect of Depth on Average Soil Moisture Storage at Four Selected Slopes (Site B) | 36 |
| 9. | Effect of Depth on Average Soil Moisture Storage at Four Selected Slopes (Site C) | 37 |
| 10. | Effect of Slope on Soil Moisture Storage | 38 |
| 11. | Average Infiltration Rates on Four Selected Slopes at 2.06 iph Rainfall Intensity (Site A). | 44 |
| 12. | Average Infiltration Rates on Four Selected Slopes at 3.83 iph Rainfall Intensity (Site A). | 45 |
| 13. | Topographic Map of the Watershed Showing Location of the Sites. | 65 |

# CHAPTER I

# THE PROBLEM

## I. INTRODUCTION

Water supply has always exerted a major influence on the development of the economy of any community, state or nation. It has been observed through history that people frequently built homes, settlements and cities adjacent to waterways, though the divides between watersheds were often steep and heavily forested, and travel across them was difficult. As time advanced population increased, communication improved, and people started moving farther away from the streams or waterways. Recently the United States population and industrial and agricultural development have reached a stage of growth where local water supplies are failing to meet the demand (29,30). Individuals and organizations have frequently been enjoined from withdrawing water from upstream channels, because such withdrawals would have seriously impaired the activities of downstream water users. To improve public water supply is, therefore, the problem on which research is required. Consequently, efforts are being made to study the full life history of the waters of the earth, and in particular the factors affecting water yield of the watersheds.

Several aspects of water yield of a watershed are of concern to those engaged in the development of water supplies. These aspects are

total quantity, fluctuations in quantity, and quality. Climate over a watershed, and watershed characteristics are such that conditions varying from droughts to floods exist. Probably little can be done about the climate, consequently interest has centered on the effects of watershed characteristics upon water yield. Soil within the watershed is among the dominant factors causing variations in water yield. Hursh and Fletcher (15) state that an analogy of the storage function of the soil profile to the storage in an artificial reservoir is justifiable. Parks and Longwell (25) state that soil moisture is Tennessee's greatest water reservoir. Moisture storage in the soil profile, however, is not static; it is dynamic. The dynamic moisture conditions in the soil profile affect watershed hydrology to a considerable extent. Thus, a knowledge of moisture storage in the soil profile of a watershed is necessary.

## II. STATEMENT OF THE PROBLEM

The purpose of this study was to investigate the influence of watershed characteristics such as land slopes and soil depths on moisture storage in the zone of aeration (soil moisture storage).

Availability of information on soil moisture storage would be of considerable help in determining land-water relationships. This information would be of general value in designing hydraulic structures within the watershed, as well as in efficient land-use planning. These in turn may modify the demand for water by the public for different purposes.

# III. OBJECTIVES

The objectives of this research were:

1. To study the effects of depth and gradient on moisture storage in the soil profile.
2. To develop mathematical relationships between observed soil moisture and degree of slope, depth, and infiltration capacity of the soil.

# CHAPTER II

## WATER YIELD CONCEPT

The terms runoff and water yield have generally been used interchangeably or synonymously in the literature. Runoff is that portion of precipitation that makes its way toward stream channels as surface or subsurface flow. The term water yield is generally considered to include that portion of precipitation which can reasonably be expected to be captured on the watershed for later use. Thus, it is apparent that runoff does not constitute the total water yield of a watershed. An analysis of the disposition of precipitation is presented below to illustrate the concept underlying water yield of a watershed.

Precipitation (P), as it reaches the ground, is disposed of in various ways (Figure 1). Much of the precipitation during the first part of a storm is stored on the vegetal cover as interception and in surface puddles as depression storage. As precipitation continues, the soil surface becomes covered with a thin film of water, known as surface detention, and overland flow ($Q_o$) begins downslope toward an established surface channel. The part of storm precipitation (interception, depression storage, evaporation during the storm) which does not appear either as infiltration (I) or as overland flow during or immediately following the storm is surface storage ($S_o$). The water in surface storage eventually moves into the soil as infiltration or is lost as evapotranspiration (ET).

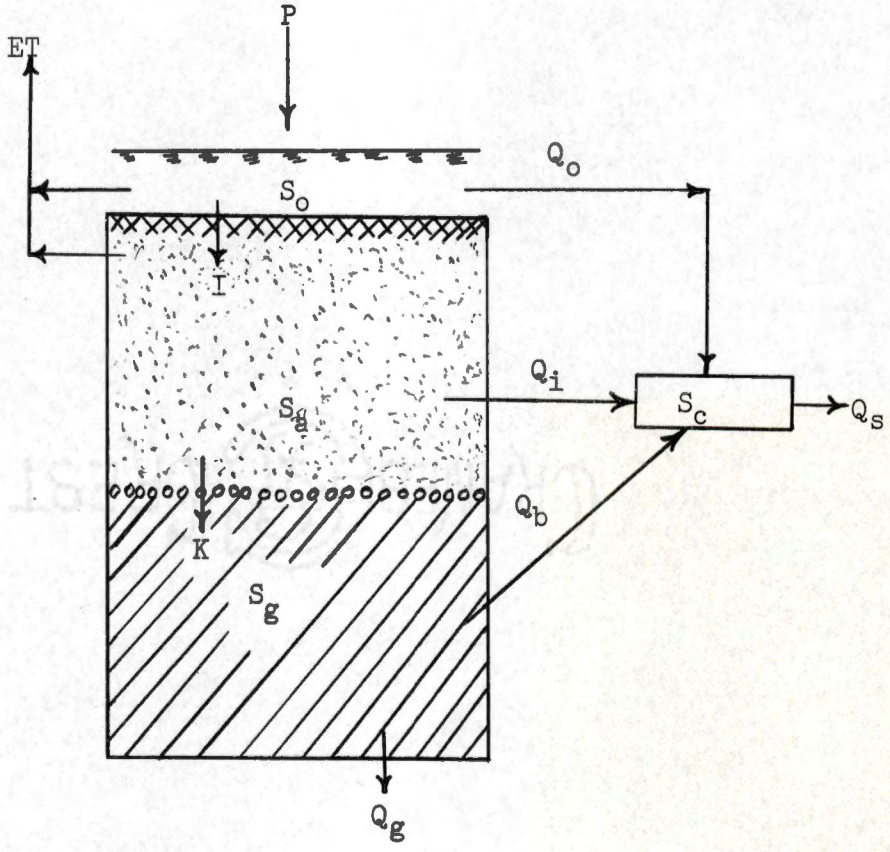



Figure 1. Disposition of precipitation.

P = Precipitation
ET = Evapotranspiration
$S_o$ = Surface storage
$S_a$ = Storage in the zone of aeration
$S_g$ = Groundwater storage
$S_c$ = Channel storage
I = Infiltration
K = Percolation

$Q_o$ = Overland flow
$Q_i$ = Interflow
$Q_b$ = Base flow
$Q_g$ = Deep percolated groundwater
$Q_s$ = Streamflow
ooo = Groundwater table
xxxx = Land surface

Water entering the soil is stored in the zone of aeration ($S_a$) as soil moisture. The thickness of the zone of aeration varies from practically zero in swamplands to several hundred feet in arid regions with substantial relief. Soil moisture continually contributes to groundwater storage ($S_g$), and channel storage ($S_c$) through percolation (K) and interflow ($Q_i$). The rate of contribution is basically governed by soil characteristics and amount of moisture present in the zone of aeration. A part of the soil moisture is lost by evapotranspiration from the top layers. Groundwater storage contributes to groundwater ($Q_g$) and channel storage through deep percolation and base flow ($Q_b$). The water in channel storage ($S_c$) contributes to streamflow ($Q_s$).

Based on the general concept of water yield as previously mentioned the total water yield may be expressed by the following equation:

$$T = Q_s + S_a + S_g$$

where

$T$ = total water yield

$Q_s$ = streamflow

$S_a$ = storage in the zone of aeration (soil moisture)

$S_g$ = groundwater storage

# CHAPTER III

## LITERATURE REVIEW

According to the water yield concept presented in Chapter II, the storage of moisture in the soil profile is a part of the total water yield. It was considered necessary, therefore, to review the literature on water yield, as well as that pertaining to soil moisture storage and infiltration.

Previous research workers involved in studies related to water yield have quite frequently expressed it in terms of runoff from the watersheds. Nixon and Schwab (24) developed a simple rational approach for estimating water yield (long term total volume of runoff per unit area). Their rational equation is as follows:

$$Y = CLSKM$$

where

Y = rating of watershed according to its relative ability to produce water yield,

C = climate factor,

L = land-use factor,

S = slope factor,

K = soil factor, and

M = land management and conservation practices factor.

Nixon and Schwab compared the water yield estimated from physical characteristics with the measured yield for each of five watersheds.

The estimated median yield from watersheds of 525 to 9,850 acres was within about 12 per cent of the measured yield. They found that the assumption, influence of one characteristic on water yield was independent of other characteristics, was not necessarily valid. They further stated that watershed geology and size, for example, are other important characteristics to be included in estimating water yield, especially under certain conditions.

Harrold (11) presented methods of analyzing and reporting data on minimum water yields from small agricultural watersheds of sizes ranging from 29 to 17,540 acres near Coshocton, Ohio. Of all the various regressions attempted, the relation of log precipitation (logP) to runoff (Q) gave the best fit to his data. He found that, at the lower end of the relationship, a uniform reduction of precipitation resulted in greater reduction of runoff. Harrold further indicated that the runoff values decreased as the drainage areas decreased.

Based on the infiltration concept, Betson (4) presented the stepwise development of a hydrologic equation to better understand the storm runoff process in watersheds. In fitting the equation to various sets of data, he found that storm runoff frequently occurred from a small but consistent part of the watershed area. This was found to be true on small test watersheds in pasture cover, and it appeared to be true also for larger watersheds with complex land-use patterns.

Several workers (2,12,32) computed runoff from small plots in watershed erosion studies. Hendrickson et al. (12) made a runoff study on the Southern Piedmont Soil Conservation Field Station located near

Watkinsville, Georgia. The study included 15 years (1940 through 1954) of records for 16 plots. The plots were 70 feet long, had 7 per cent slope, and were in continuous cotton. It was concluded from this study that on an average, 10.8 inches of runoff occurred out of 48.85 inches total annual rainfall.

An erosion study conducted by Barnett (2) indicated that the amount of runoff expected was correlated with the intensity and duration of rainfall. From 79 storms over an 8-year period, Smith et al. (32) studied the relationship between the maximum rate of runoff and 5, 15, and 30-minutes maximum rainfall intensities, and antecedent soil moisture. Runoff was from an 8.03 acre watershed of 6.7 per cent slope in up-and-down hill cultivation. A multiple correlation coefficient of 0.73 was obtained with a standard error of 0.66. The estimating equation obtained was:

$$X_1 = -1.11 + 0.29 X_2 - 0.15 X_3 + 0.85 X_4 + 0.73 X_5$$

where

$X_1$ = maximum rate of runoff in inches per hour (iph)

$X_2$ = 5-minute rainfall intensity (iph)

$X_3$ = 15-minute rainfall intensity (iph)

$X_4$ = 30-minute rainfall intensity (iph)

$X_5$ = antecedent rainfall index.

The study indicated that the 30-minute rainfall intensity had the greatest effect on the maximum rate of runoff.

To better understand watershed hydrology, recent attempts have been made to obtain an estimate of total soil moisture storage capacity

of the watershed. Reinhart (26) stated that a reliable estimate of soil moisture storage might be difficult to obtain, particularly in a forested watershed due to the variations in, and difficulties of measuring soil depth, root depth, texture, bulk density, stone content, and moisture content. He suggested a method for approximating storage from stream-flow and precipitation records. Precipitation minus runoff--in selected dry periods when ample precipitation followed a dry spell--provided the estimate of soil moisture storage capacity. The method illustrated utilized data from the Fernow experimental forest in West Virginia and was applied to two other watersheds in the northeast.

Dreibelbis (7) reported, from a study of soil moisture distribution in 8-foot profiles on four watersheds, that the zone of major hydrologic activity was in the upper 12 inches of soil and particularly in 0- to 7-inch A horizon. He attributed the variations in soil moisture distribution at different sites on the watershed to soil profile characteristics, and emphasized the factor of soil heterogeneity in watershed hydrology.

Hewlett (13) considered the difficulties in separating soil texture and depth effects from topographic and gravitational influences on natural slopes. In order to make an initial study of storage and movement of moisture on slopes, he constructed a soil model which was 18 inches deep, 24 inches wide, and 24 feet long, on a 40 per cent slope under a forest canopy. The sandy loam sub-soil excavated from a natural profile was mixed and carefully tamped into the structure to reproduce as closely as possible its original bulk density. A free water surface

was maintained at a fixed level within the soil by an outlet pipe at the base. For soil moisture measurement with a neutron meter, access tubes were installed at 4, 8, 12, 16, and 20 feet (slope distance) from the water table. Water was sprayed onto the entire soil column not to simulate actual rain but to obtain a soil profile fully charged under sustained rainfall. Soil moisture measurements indicated that a moisture gradient had developed after 15 hours, with 8 per cent more moisture at the 4-foot slope distance than at the 20-foot distance from the water table. When the rate of loss from the top began to level off, the net rate of loss in the two tubes nearest the water table increased, reflecting a reduced supply from upslope. After 48 hours, the relative rate of water loss was fairly constant at all points, but a definite gradient remained upslope. The pattern indicated that upslope moisture was continually recharging the downslope storage, which in turn fed the groundwater table.

Bianchi and Haskell (5) measured soil moisture at one-foot intervals prior to, during, and after the period of ponding in two soil profiles each 20 feet deep. In a foot-by-foot analysis of the changes in moisture storage after the passage of the wet front, they found that although measurable increases occurred, these increases were negligible as compared to the total depth of water stored above the front. They further reported that the position of the wetting front was approximately a linear function of time, and the vertical flow of water was limited to the surface few feet.

Edlefsen and Bodman (10) studied the vertical movement of water in an undisturbed deep soil of alluvial origin from which losses by evapotranspiration were prevented. They found that the downward flow under the influence of gravity rapidly decreased with time.

From moisture measurements in a 20-foot profile of sandy soil, Nixon and Lawless (23) calculated the movement of water through the soil. Approximately 11.2 inches of previously stored soil moisture passed downward during a 6-month dry season. An increase in soil moisture with depth has been reported by several workers (5,15,20,27,28).

Krimgold and Beenhouwer (19) stated that in any study of soil moisture regime, an estimate of infiltration capacity of the soil must be made. Instrumentation that can be used for infiltration studies in the field or in the laboratory have been grouped into two main classes. One class is that in which infiltration is determined as the difference between water applied and runoff. Such a device is based upon the simulation of natural conditions. The equipment used is essentially a small water supply system which irrigates a known and controlled area. Bertrand and Parr (3) have indicated the use of such equipment. They installed a rainfall simulator above a 1/3000 acre (3.81 feet x 3.81 feet) runoff plot. The rainfall simulator consisted of one full-cone, medium-angle, center-jet type mozzle. The second class of instrumentation for filtration studies is that in which infiltration is assumed to be identical to the water applied and no runoff is allowed. Kohnke (18) states that, theoretically, a device for studying infiltration should provide for an essentially vertical penetration of water into

the soil. Such a device should not impede lateral movement of water within the soil, and it should not create an air pressure in the soil greater than that which would occur under natural conditions. Any device which would attain the above considerations would provide the best estimation of the infiltration capacity of the soil under study.

Duley and Kelly (9) studied infiltration by sprinkling water with fan-shaped nozzles on 1/200 acre (6.6 feet x 33 feet) plots. They found that the rate of water intake at the beginning of application was often very high, resulting in a large total intake during the first part of each period of application. This rate decreased rapidly at first, finally reaching an approximately constant infiltration rate. These findings were similar to those of Bodman and Colman (6), and Horton (14). Duley and Kelly further reported that the amount of total intake and the infiltration rate decreased with increasing slope (2, 4, 6, and 10 per cent). This change in infiltration rate was, however, very small and very gradual with changes in slope above 2 per cent. That the degree of slope had slight effect on infiltration rate was in agreement with an earlier investigation reported by Duley and Hays (8). Duley and Kelly found no significant differences in infiltration rates due to rainfall intensities. This was similar to the findings of Neal (22).

Bodman and Colman (6) attributed the decrease in infiltration rate with time to decrease in moisture potential gradient resulting from a vertical lengthening of the transmitting zone with increased depth of penetration of the soil moisture. Horton (14) reported that infiltration capacity becomes essentially constant in the time ranging from 1-1/2 to 2 hours.

Neal (22) constructed a soil tank (2 feet x 3.63 feet x 12 feet) to study infiltration in the laboratory. He found that the infiltration rate was not affected by slope (1 to 16 per cent inclusive), and that it varied inversely with antecedent moisture.

The data of Musgrave and Free (21) concerning the relative infiltration capacity for eight of the soil profiles in Georgia indicated that, for a given intensity and duration of rainfall, marked differences in runoff may be expected.

# CHAPTER IV

## EXPERIMENTAL PROCEDURE

The experimental procedure developed to perform this research was divided into the following four steps:

I. Selection of Site

II. Installation of Equipment

III. Data Collection

IV. Data Analysis

## I. SELECTION OF SITE

A 55-acre watershed located on the University of Tennessee-Atomic Energy Commission Laboratory Farm near Oak Ridge was selected for this study. The watershed is under permanent pasture of ladino clover and orchardgrass. It is essentially bowl shaped with an average slope of 12 to 15 per cent, and the dominant soil series is Fullerton. A topographic map of the watershed, showing location of sites used in this study, is presented in Figure 13 in the Appendix.

The experiment was designed to utilize the split-plot technique. The design consisted of three sites with four slopes as main treatments within each site and six depths as subtreatments at each slope. Accordingly, three sites, each 40 feet wide and 300 feet long, were selected to be representative of the watershed conditions. The three sites were identified as A, B, and C. Within each site, the four slopes

were termed as flat (0-2 per cent), moderate (2-8 per cent), moderately steep (8-16 per cent), and steep (16-24 per cent). Starting from the watershed divide, the slopes were arranged within each site as flat, moderate, moderately steep, and steep. The distance between any two successive slopes was 100 feet.

## II. INSTALLATION OF EQUIPMENT

### Soil Moisture Access Tubes

The point slope at 100-foot intervals along the centerline across the length of each site was determined. These points gave the positions of the central access tubes at each of the four slopes. On each of the four slopes, an additional access tube was located at a distance of 20 feet on each side of the central access tube. The top row of access tubes at each site was so located that the slope at those points could be considered as zero. The 12 access tubes at each site were identified by subscripts 1 through 12 along with the letter designated for site's identification (e.g., $A_1$ . . . $A_{12}$, $B_1$ . . . $B_{12}$, and $C_1$ . . . $C_{12}$). The exact slope at which each access tube was located on each site is shown in Table XI in the Appendix. A lay-out of the access tubes within any site is presented in Figure 2.

Using a 2-inch bucket auger, holes for the access tubes were dug to a depth of 5-1/2 feet. A size 10-1/2 rubber stopper was inserted into the lower end of each access tube to prevent water from entering the tube. The 6-foot long access tube, cut from 2-inch aluminum irrigation pipe, was positioned so that 1/2-foot extended above the surface

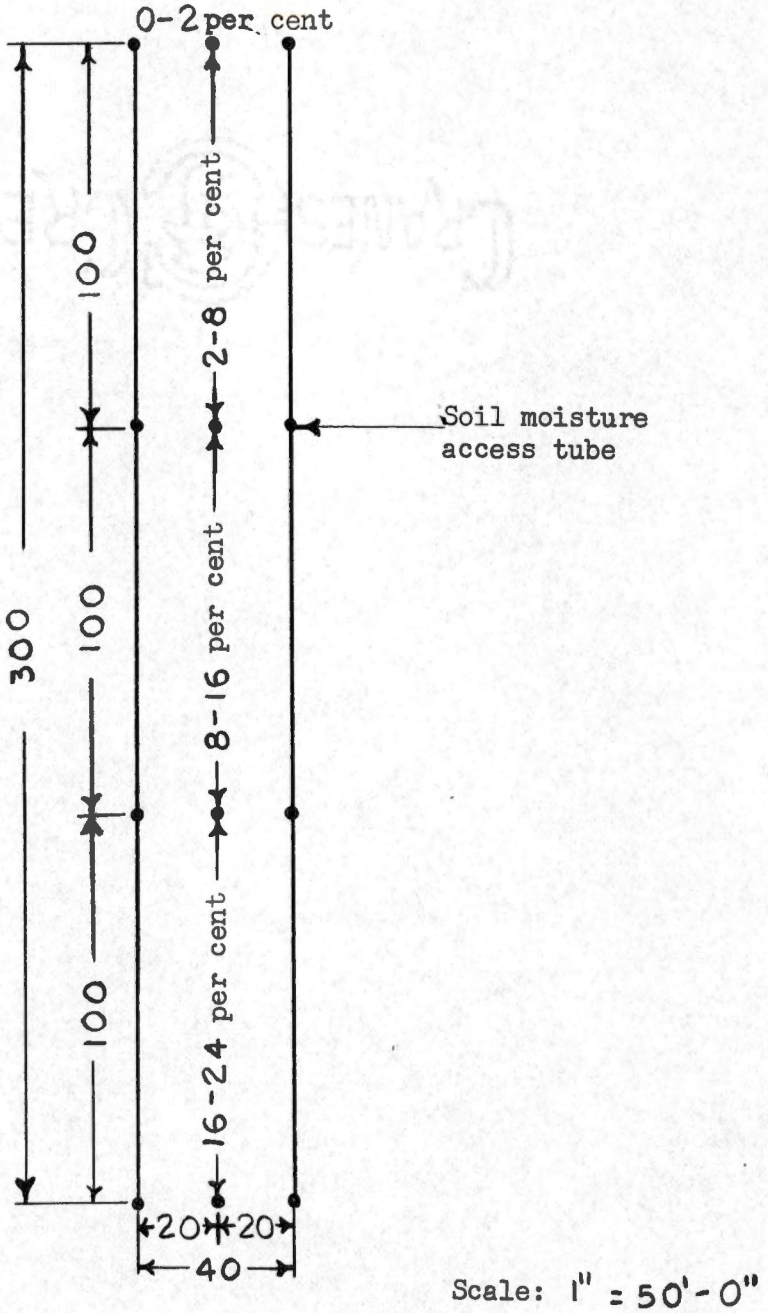



Figure 2. Lay-out of soil moisture access tubes.

NOTE: All dimensions are in feet.

of the ground. The soil was packed and mounded around each tube at the surface to prevent excessive movement of water along the exterior wall of the tube. The top end of each tube was then closed with a stopper and covered with a can to prevent water from entering the tube.

Infiltrometers

To determine the infiltration characteristics of the soil, infiltrometers were devised. The major components of the infiltrometers were as follows:

1. Runoff plots
2. Runoff collectors
3. Rainfall simulators

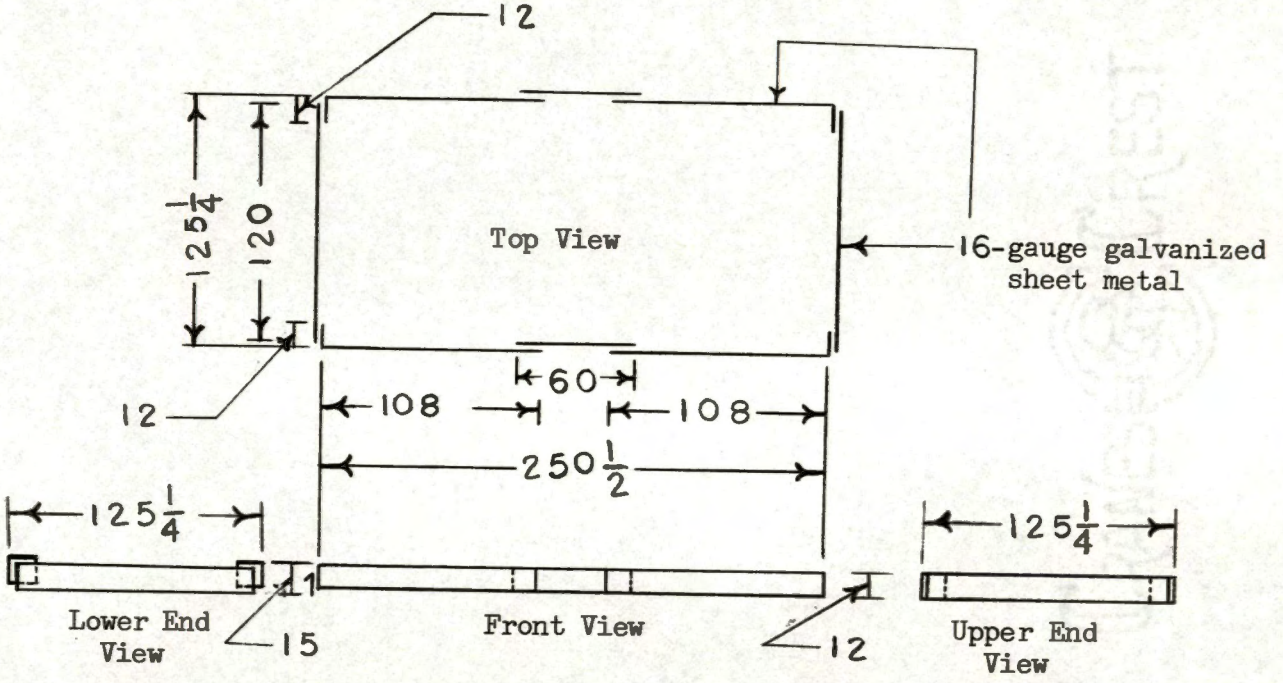
Details of design, construction, and installation of the major components of the infiltrometers are given below.

Runoff plots. A 1/200 acre (125-1/4 inches x 250-1/2 inches) runoff plot was installed around one access tube on each slope at site A. The runoff plot was so located that the access tube was in the center. The boundaries of the runoff plots were defined by 12-inch strips of 16-gauge galvanized sheet metal cut from stock size of 4 feet x 10 feet. The metal strips were installed with approximately 3 inches above the ground surface and 9 inches below the surface. Corners of the runoff plots were obtained by forming right angles on four of the strips at a distance of one-foot from one end. This provided an overlap of one-foot at each corner of the upper end wall, and an opening of 101-1/4 inch at the lower end of the plots. The strips at the lower end of the plots

were bent approximately an inch at a 45 degree angle across the length to facilitate the flow of runoff into the collector. Each of these strips was installed so that its top edge was level and as even with the ground surface as practicable. Details of construction for boundary walls of the runoff plots are shown in Figure 3.

A small tractor-mounted back-hoe was used to dig trenches approximately 10 inches deep and 12 inches wide along the boundary lines of each runoff plot. To provide space for the collector, the trenches dug at the lower end of the plots were about 12 inches deep and 36 inches wide. The sides of the plots were scraped smooth to provide a close fit for the boundary walls. After the boundary walls were set in place, the soil was back-filled in the trenches and tamped. In some instances there were small spaces between the inside of the boundary walls and the soil. Loose soil was filled in the spaces and lightly tamped. Occasionally, water was poured around the boundary walls to assist in restoring the soil to its original bulk density as closely as possible.

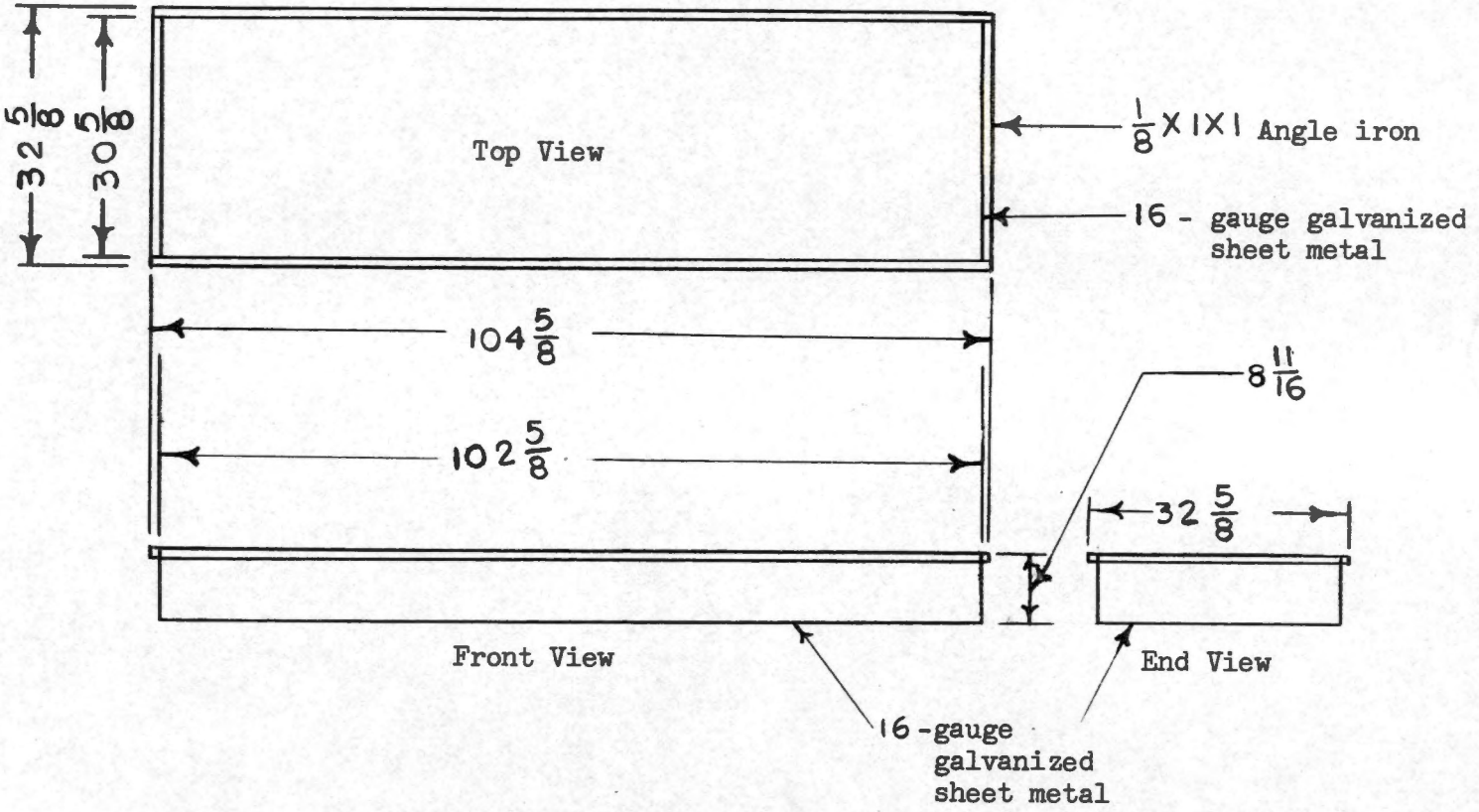
Runoff collectors. Each of the runoff collectors, 8-11/16 inches deep, 30-5/8 inches wide, and 102-5/8 inches long, was constructed from one piece of sheet metal of stock size (4 feet x 10 feet). A 1-1/2-inch outlet was provided at the bottom of each collector to facilitate draining the water whenever the collector became filled during a test run. To simplify computations of runoff volume, the area of the collectors was one-tenth that of the runoff plots. Details of construction for the collectors are shown in Figure 4.




Scale: 1" = 8' - 0"

Figure 3. Details of boundary walls for runoff plot.

NOTE: All dimensions are in inches.




Scale: 1" = 2' - 0"

Figure 4. Details of runoff collector.

NOTE: All dimensions are in inches.

The trenches at the lower end of the runoff plots were made smooth and level at the bottom. To maintain a level condition, angle iron bases were constructed and placed in a level position at the bottom of the trenches. The collectors were then placed on the bases such that the discharge from the plots could be collected without loss.

Rainfall simulators. Two rainfall simulators, each consisting of three rows of pipes and 15 nozzles, were constructed. The nozzles selected were Delavan, WSSM 10 and WSSM 20. In order to accurately regulate the flow, a low pressure gauge was installed in each row of the rainfall simulators. Detailed drawings and dimensions of the rainfall simulators are shown in Figure 5. Complete specifications for the nozzles used are given in Table XII in the Appendix.

To support the rainfall simulators at an 8-foot height above the runoff plots, 2-1/2-inch galvanized iron pipes were placed in the ground approximately one-foot away from each corner. Details of supports are shown in Figure 6. In order to prevent the rainfall simulators from sagging, support frames were constructed from 2-inch x 2-inch lumber and placed beneath the simulators at the middle of the plots across the width.

The source of water supply for the rainfall simulators was the Oak Ridge water supply line passing near the watershed. Connections for the rainfall simulators were provided by installing a tee in the main line adjacent to each plot. A connection was made to the main line at each plot with a piece of 1-1/2-inch plastic pipe, approximately 20 feet long.

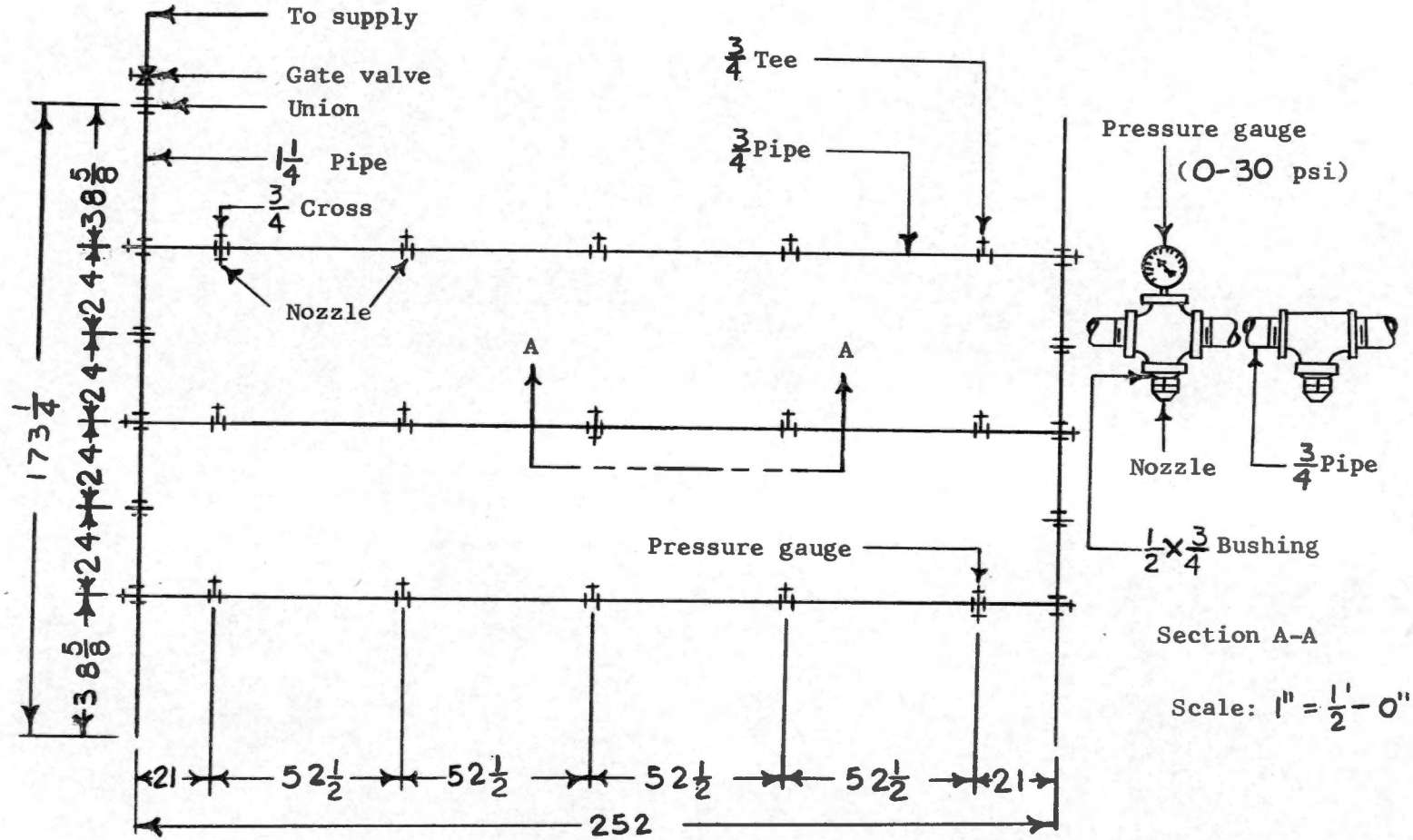



Figure 5. Details of rainfall simulator.

NOTE: All dimensions are in inches. All pipes and fittings are galvanized.

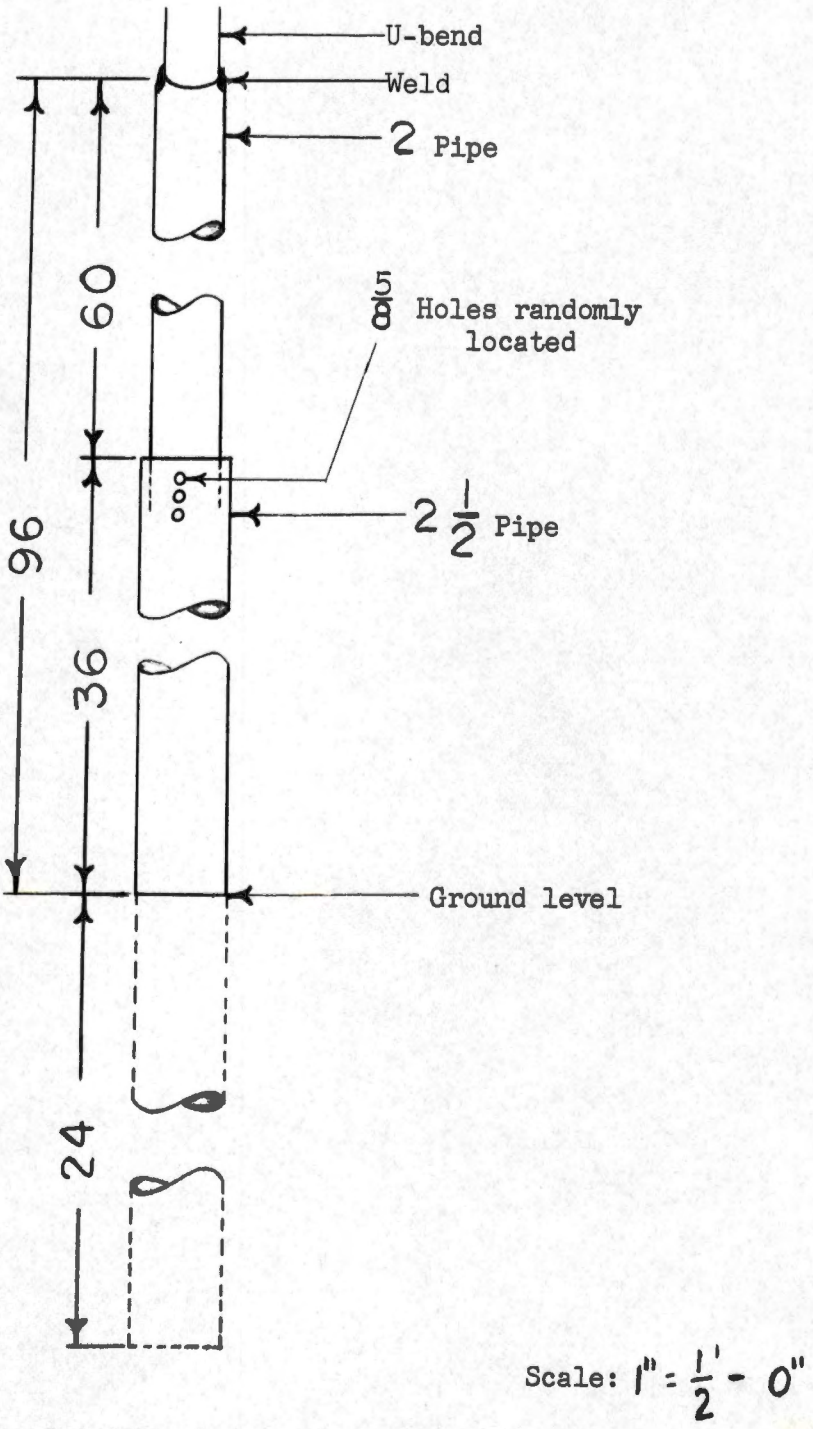



Figure 6. Details of support post.

NOTE: All demensions are in inches.

A valve was installed at the inlet of the rainfall simulators to regulate flow and pressure. It was found that, for the nozzles used, desirable rainfall characteristics were obtained with an operating pressure of 5 pounds per square inch (psi).

## III. DATA COLLECTION

### Soil Moisture

The neutron equipment used for soil moisture measurement was manufactured by Nuclear Chicago Corporation, Des Plaines, Illinois. The equipment consisted of a model 2800 scaler, a model P-19 sub-surface moisture probe, and a model P-21 surface moisture probe. The collection of soil moisture data was started on September 10, 1964 and ended on December 15, 1964. Efforts were made to take soil moisture measurements on the same day every week unless some unavoidable circumstances (weather condition, availability of neutron equipment, etc.) occurred. Neutron counts were taken at the surface and at depths of 6, 12, 24, 36, 48, and 60 inches.

### Soil Properties

As the holes were dug for soil moisture access tubes, composite soil samples were collected from the central hole at each slope on each site at depths of 0-9, 9-21, 21-39, and 39-66 inches. To determine particle size distribution, a mechanical analysis of each composite soil sample collected was made by the hydrometer method.

To determine percolation rate of water through the topsoil, cores from the top 6 inches depth were taken on the three sites by using a 4-inch core sampler. The cores were trimmed, and transferred to standard 4-inch diameter constant-head permeameters. The space between the soil core and wall of the permeameter was sealed with paraffin. Applying a constant head of 20 inches of water, percolation rates through the cores were determined in the laboratory. The formula used to compute the percolation rates was:

$$K = QL/Ah$$

where

K = percolation rate in inches per day

Q = discharge in cubic inches per day

L = length of core in inches

A = cross-sectional area of the sample in square inches

h = head of water in inches

Infiltration Data

The collection of infiltration data was started on October 20, 1964 and ended on November 18, 1964. Water was applied to the four runoff plots once each week by operating the rainfall simulators within two consecutive days. The distribution and the average rate of water application in each run was determined by randomly placing six cans in each runoff plot for a known period of time. The depth of water collected in each can was measured and recorded. The actual average intensities for all the runs of the rainfall simulators

with the number 10 and 20 nozzles were 2.06 and 3.83 iph, respectively.

The volume of runoff (inches) in the collectors was determined at time intervals of 5, 15, 30, 60, 90, 120, 150, and 180 minutes for 2.06 iph. With 3.83 iph the determination of runoff volume was limited to a maximum period of 150 minutes. When a collector became full during a test run, the rainfall simulator was stopped and water was drained from the collector.

Measurements of antecedent moisture at selected depths were made just before starting the rainfall simulators. Immediately after each test run, soil moisture measurements were taken at the same selected depths to give an estimate of the changes in the moisture conditions.

## IV. DATA ANALYSIS

### Data Compilation

Neutron counts obtained were converted into equivalent per cent moisture by volume using Table XIII presented in the Appendix. The per cent moisture by volume was converted into inches of water by multiplying this factor by appropriate soil profile depths in inches. The depths of water in each foot of the soil profile to a depth of 5 feet were computed. Experiences of previous workers with the particular neutron equipment used in this research indicated that the surface counts gave a close estimate of the moisture content of the top 9 inches of soil. The neutron counts at any depth up to 66 inches gave a close estimate of the moisture content 3 inches above and below the depth

of measurement. Therefore, the depth of water in the first foot of soil was determined by using the counts at the surface and at the 6-inch depth. In the second, third, fourth, and fifth foot depth zones, the average of the counts at depths of 12 and 24, 24 and 36, 36 and 48, and 48 and 60 inches, respectively, were used. On sites B and C, soil moisture observations from the three access tubes at each slope were averaged. On site A, soil moisture observations of the three access tubes were averaged until starting the operation of the rainfall simulator. After starting the operation of the rainfall simulator on site A, soil moisture observations from the remaining two access tubes at each slope were averaged. Thus, the average soil moisture observations on each site at each slope were available for five depths. The computed soil moisture data were compiled as presented in Table XIV in the Appendix.

The infiltration rate, at any time interval, was computed as the difference between the amount of water applied and the surface runoff. Infiltration data are presented in Table XV in the Appendix.

Statistical Analysis

A considerable variation in observed soil moisture among the three sites indicated a need to test the significance of sites on soil moisture. To determine the statistical significance of sites (S), depths (D), slopes (G), and dates of observation (T) on observed soil moisture, the procedure adapted was a four-way analysis of variance. Since soil moisture observation data for 5 depths on 4 slopes at 3 sites

were available for 11 different dates, the four-way analysis of variance was essentially a 3 x 4 x 5 x 11 factorial. The 3 x 4 x 5 x 11 factorial means that the four factors, sites, slopes, depths, and dates, were at 3, 4, 5, and 11 levels, respectively. Assumptions in this analysis were that sites and dates were random, and that depths and slopes were fixed. Techniques used in this analysis of variance were simply the extension of the procedures followed in the two- or three-way analysis of variance for factorial designs. A complete discussion of the procedure of two- or three-way analysis of variance is given by Johnson and Jackson (16).

All data were punched on IBM cards. All of the statistical analyses were done on the IBM 1620 Electronic Digital Computer at the University of Tennessee Computing Center.

The program used for the analysis of soil moisture data was a standardized program written in the ALGOL language. This program was adapted from a FORTRAN four-way analysis of variance program. The accuracy of the ALGOL program was checked against that of the original FORTRAN program. The ALGOL program gave almost identical results with those obtained from the FORTRAN program for the same set of data.

The estimates of more than one factor affecting soil moisture storage were available. Therefore, the multiple regression analysis was an appropriate statistical technique for measuring the relationship between selected factors expressed as independent variables and soil moisture storage.

The multiple regression techniques used in this thesis, in general, followed the procedures of multiple regression analysis

discussed by several authors (1,17,33). The multiple regression equation was of the form $\hat{Y} = a + b_1x_1 + b_2x_2 + \ldots + b_nx_n$.

The program used on the computer for multiple regression analysis was known as STRAP. Details about the STRAP program are given by Sinha (31). In developing the equations showing the relationships between observed soil moisture and depths and slopes, regression models tried were:

1. A linear function of slopes and depths and their linear x linear cross product term.
2. A logarithmic function of slopes and depths (ln D and ln G), their linear terms, and linear x linear cross product term.

Using the highest $R^2$ (multiple correlation coefficient) value as the criterion, the regression model selected was number 2 shown above. A value of one was assigned to the flat slope (0-2 per cent) for use with the logarithmic function in the regression model.

# CHAPTER V

## RESULTS AND DISCUSSION

The sources of variation included in the analysis of variance of soil moisture data were sites (S), depths (D), slopes (G), and dates of observation (T) as main effects; S·D, S·G, S·T, D·G, D·T, and G·T as their first order interaction terms; and S·D·G, S·D·T, S·G·T, and D·G·T as their second order interaction terms. The analysis of variance is shown in Table I.

The main effects S and D, the first order interaction term S·D, and the second order interaction term S·D·G were each highly significant. The main effect G and the first order interaction term D·G were each significant at a probability level equal to or less than 0.10. The highly significant effect of sites on soil moisture storage was probably an indication that the assumption of watershed homogeneity was not necessarily valid.

Since the main effect T was not significant at a probability level equal to or less than 0.10, soil moisture observations taken on 11 different dates were averaged for each depth at each slope[1] within each site (Table II). These average values of soil moisture storage increased with an increase in depth on all slopes at all sites. This increase in soil moisture with an increase in depth on all slopes was

---

[1]Hereafter the term "slope" means the average slope of the three sites.

TABLE I

ANALYSIS OF VARIANCE OF SOIL MOISTURE STORAGE

| Sources of Variation | Sum of Squares | Degrees of Freedom | Mean Square | F |
|---|---|---|---|---|
| Total | 986.76 | 659 | | |
| S | 721.93 | 2 | 360.96 | 75.17** |
| D | 77.05 | 4 | 19.26 | 60.19** |
| G | 3.07 | 3 | 1.02 | 3.19+ |
| T | 1.11 | 10 | 0.11 | 1.57 |
| S·D | 35.72 | 8 | 4.47 | 4.56** |
| S·G | 4.26 | 6 | 0.71 | 0.72 |
| S·T | 1.17 | 20 | 0.06 | 0.46 |
| D·G | 3.85 | 12 | 0.32 | 1.60+ |
| D·T | 2.68 | 40 | 0.07 | 0.70 |
| G·T | 30.80 | 30 | 1.03 | 1.05 |
| S·D·G | 23.56 | 24 | 0.93 | 4.90** |
| S·D·T | 10.53 | 80 | 0.13 | 0.65 |
| S·G·T | 10.51 | 60 | 0.18 | 0.90 |
| D·G·T | 12.06 | 120 | 0.10 | 0.50 |
| Residual | 48.49 | 240 | 0.20 | |

**In this and future tables, the double asterisk will indicate a probability level equal to or less than 0.01. Hereafter the term "highly significant" will be used to express this.

+In this and future tables, the single plus sign will indicate a probability level equal to or less than 0.10.

TABLE II

EFFECT OF DEPTH AND SLOPE ON SOIL MOISTURE STORAGE (INCHES)

| Slope | Depth (Feet) 1 | 2 | 3 | 4 | 5 | Σ |
|---|---|---|---|---|---|---|
| | | | Site A | | | |
| Flat | 2.50 | 4.04 | 4.81 | 4.94 | 5.00 | 21.29 |
| Moderate | 2.52 | 3.82 | 4.67 | 5.24 | 5.68 | 21.94 |
| Moderately Steep | 2.54 | 4.09 | 4.59 | 4.80 | 4.95 | 20.97 |
| Steep | 2.41 | 3.20 | 4.33 | 5.23 | 5.40 | 20.56 |
| | | | Site B | | | |
| Flat | 2.25 | 3.51 | 4.51 | 5.09 | 5.38 | 20.74 |
| Moderate | 2.11 | 2.96 | 4.06 | 4.92 | 5.06 | 19.11 |
| Moderately Steep | 2.17 | 3.35 | 4.32 | 4.72 | 5.35 | 20.14 |
| Steep | 1.95 | 3.21 | 4.01 | 4.62 | 4.93 | 18.74 |
| | | | Site C | | | |
| Flat | 2.81 | 4.93 | 5.46 | 5.60 | 5.22 | 24.02 |
| Moderate | 2.35 | 4.51 | 5.60 | 5.88 | 6.07 | 24.40 |
| Moderately Steep | 2.21 | 3.85 | 4.93 | 5.53 | 5.76 | 22.28 |
| Steep | 2.17 | 3.41 | 4.30 | 4.98 | 5.24 | 20.10 |

probably due to a downward percolation of water within the soil profile. An increase in soil moisture storage with increasing depth is in agreement with the findings of other workers (5,15,20,27,28). A graphical representation of the relationship between average soil moisture storage and depth is presented for sites A, B, and C in Figures 7, 8, and 9, respectively.

Data shown in Table II also show the effect of slope on soil moisture storage.[2] With the exception of moderate slopes, the soil moisture storage decreased with increase in slope, on each of the three sites. On moderate slopes, the soil moisture storage was a little higher than that on the flat slopes of sites A and C. On site B, the soil moisture storage on the moderate slope was less than that on the moderately steep slope. The highest soil moisture storage on sites A, B, and C was 21.94, 20.74, and 24.40 inches, respectively. The lowest soil moisture storage on sites A, B, and C was 20.56, 18.74, and 20.10 inches, respectively. Thus, the amount of water stored in the soil to a depth of 5 feet varied from 18.74 to 24.40 inches. With the exception of the steep slope, soil moisture storage on all slopes at the three sites was in order of magnitude as C > A > B. The soil moisture storage on the steep slope at site C was less than that on the steep slope at site A. A graphical representation of the relationship between soil moisture storage and slope is presented in Figure 10.

---

[2]Hereafter the term "soil moisture storage" means the average total soil moisture storage up to a depth of 5 feet.

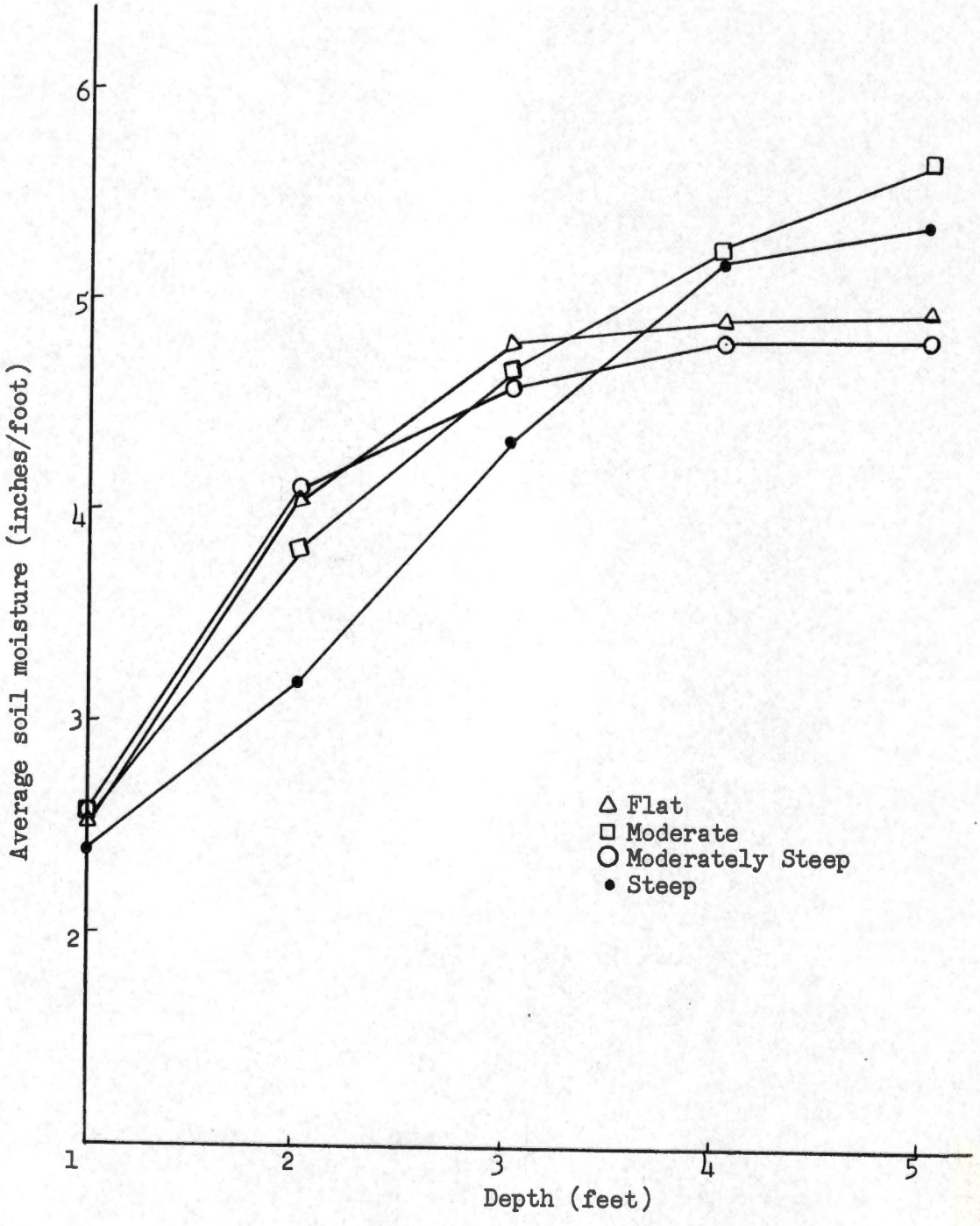



Figure 7. Effect of depth on average soil moisture storage at four selected slopes (Site A).

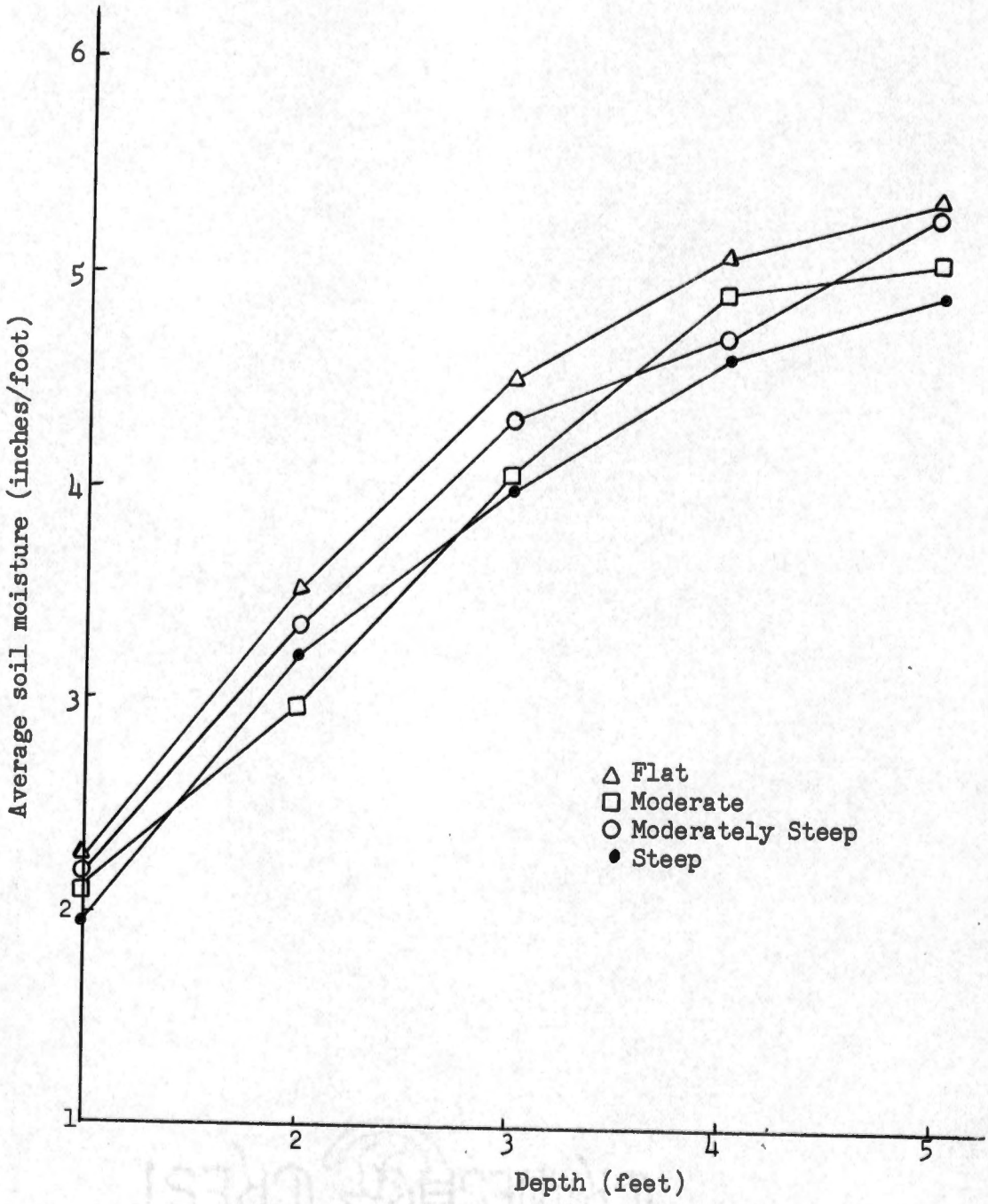



Figure 8. Effect of depth on average soil moisture storage at four selected slopes (Site B).

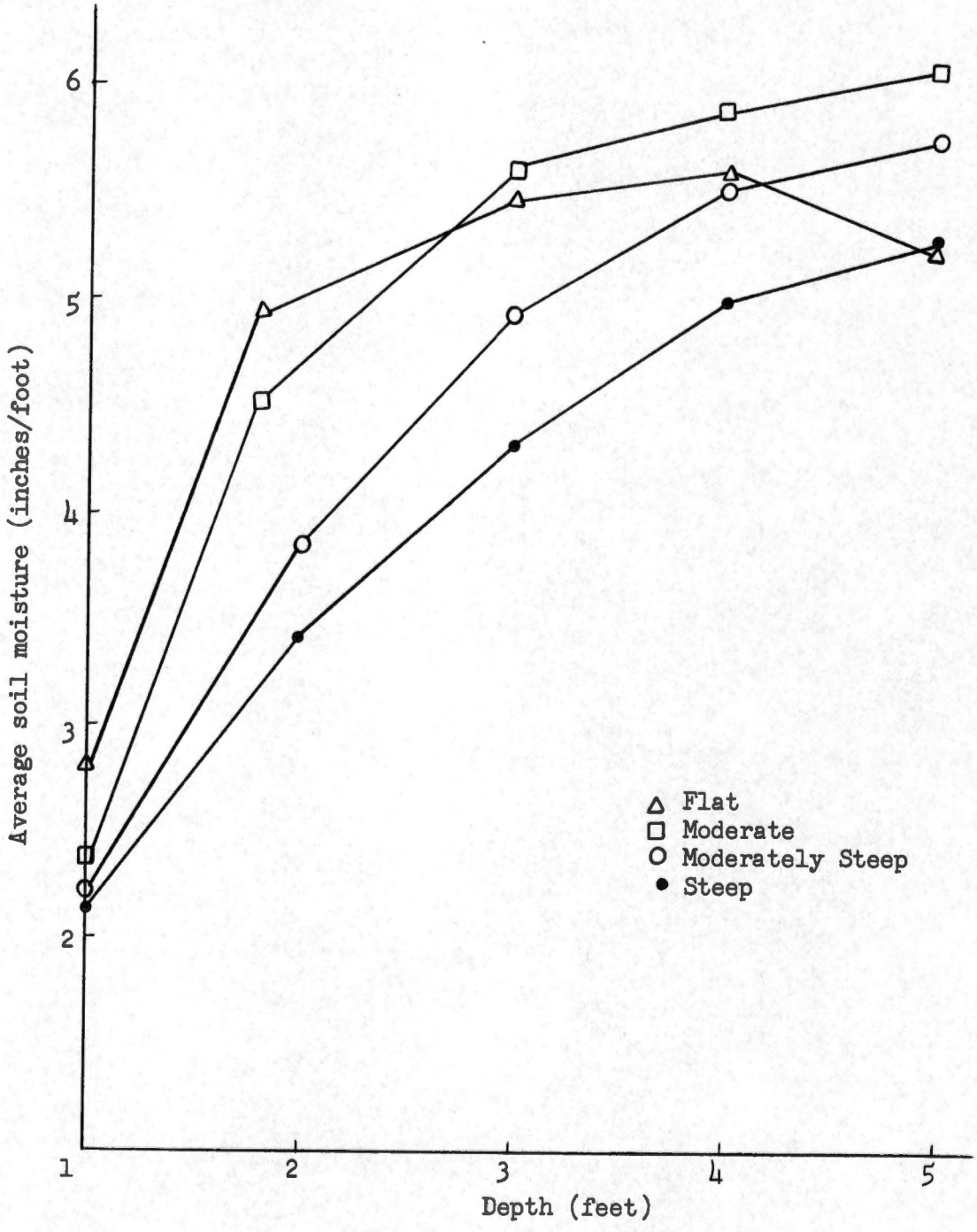



Figure 9. Effect of depth on average soil moisture storage at four selected slopes (Site C).

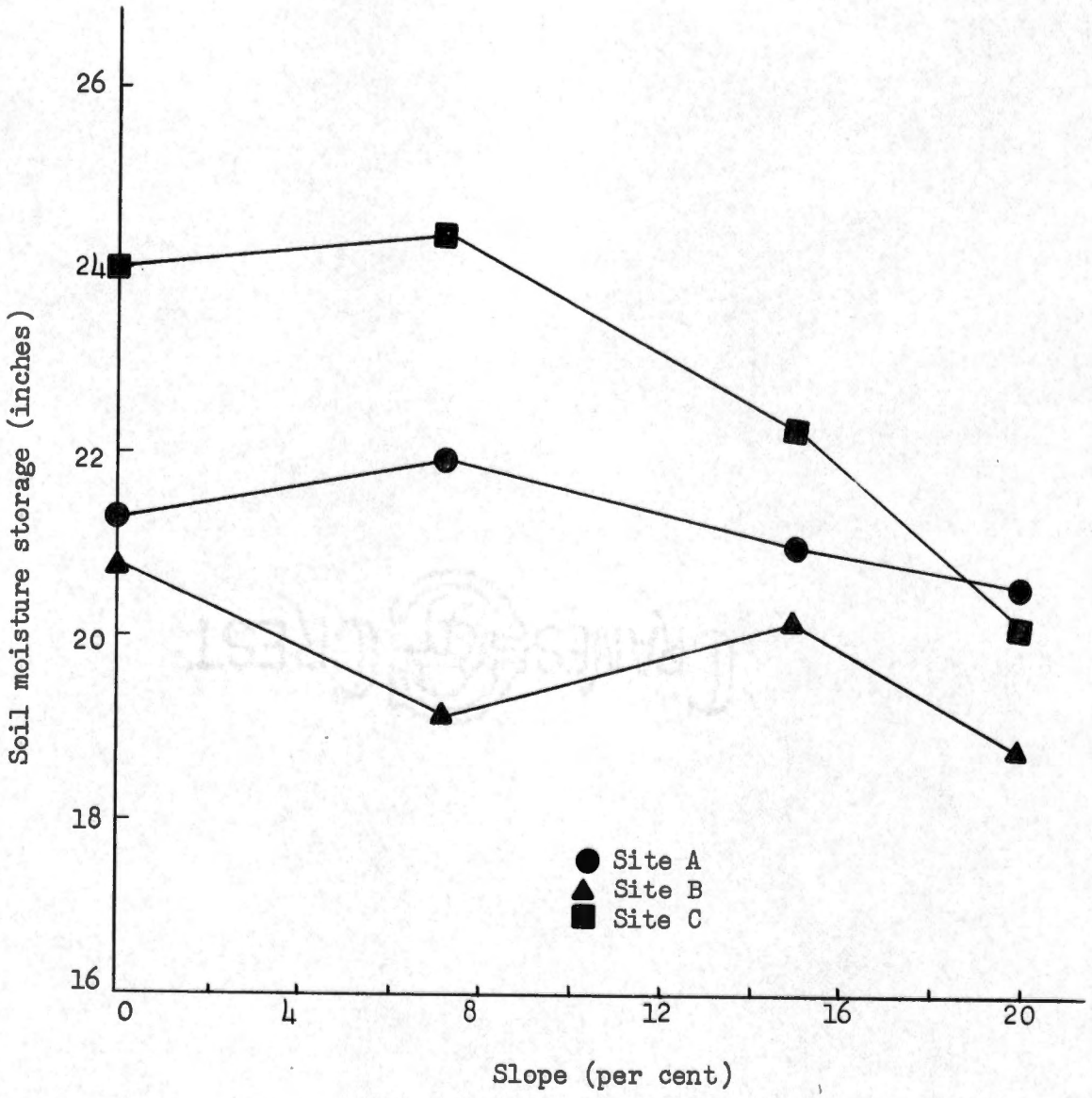



Figure 10. Effect of slope on soil moisture storage.

The per cent distribution of sand, silt, and clay at different depths on each slope at each site is presented in Table III. A comparison of the distribution of average clay content (Table III) and soil moisture storage among sites (Table II) reflects a similar pattern to that above; C > A > B on flat, moderate, and moderately steep slopes, and A > C > B on steep slopes. Within each of sites A and B, the distribution of average clay content and soil moisture storage exhibited a similar pattern on all slopes. There was no similarity between the distribution pattern of average clay content and that of soil moisture storage on flat and moderate slopes within site C. An analysis of the distribution of clay content with profile depths on flat and moderate slopes, however, somewhat helps to explain the situation on site C. A high clay content on the flat slope of site C begins after the 9-inch depth and continues to the 5-foot depth, whereas on moderate slope a high clay content starts beyond the 21-inch depth. One interpretation of this could be that a relatively high clay content beyond a 9-inch depth on flat slope retarded the downward percolation of water and thereby favored losses due to evapotranspiration from top soil layers. A relatively low clay content on the moderate slope in the 0- to 21-inch depth favored the downward percolation of water and thereby retarded losses due to evapotranspiration. The validity of this statement may be justified by the foot-by-foot distribution of observed soil moisture storage on flat and moderate slopes at site C (Table II). It seems, therefore, that one of the probable factors causing variations in soil moisture storage among and within sites was the amount and distribution

TABLE III

SOIL PARTICLE SIZE DISTRIBUTION (PER CENT)

| Slope | Depth (in.) | Site A | | | Site B | | | Site C | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Sand | Silt | Clay | Sand | Silt | Clay | Sand | Silt | Clay |
| Flat | 0-9 | 43 | 47 | 10 | 40 | 48 | 12 | 30 | 45 | 25 |
| | 9-21 | 27 | 48 | 25 | 37 | 47 | 16 | 24 | 19 | 57 |
| | 21-39 | 25 | 29 | 46 | 27 | 31 | 42 | 37 | 10 | 53 |
| | 39-66 | 29 | 19 | 52 | 27 | 12 | 61 | 30 | 16 | 54 |
| | Av. | 31.00 | 35.75 | 33.25 | 32.75 | 34.50 | 32.75 | 30.25 | 22.50 | 47.25 |
| Moderate | 0-9 | 42 | 48 | 10 | 47 | 44 | 9 | 37 | 54 | 11 |
| | 9-21 | 31 | 34 | 35 | 41 | 45 | 14 | 36 | 48 | 30 |
| | 21-39 | 37 | 28 | 45 | 46 | 29 | 25 | 26 | 22 | 52 |
| | 39-66 | 26 | 20 | 54 | 38 | 22 | 40 | 18 | 21 | 61 |
| | Av. | 31.50 | 32.50 | 36.00 | 43.00 | 35.00 | 22.00 | 25.75 | 36.25 | 38.00 |
| Moderately Steep | 0-9 | 41 | 46 | 13 | 50 | 41 | 9 | 35 | 54 | 11 |
| | 9-21 | 36 | 38 | 26 | 46 | 43 | 19 | 27 | 49 | 24 |
| | 21-39 | 31 | 42 | 27 | 40 | 26 | 34 | 30 | 35 | 35 |
| | 39-66 | 27 | 35 | 38 | 40 | 22 | 38 | 24 | 31 | 45 |
| | Av. | 33.75 | 40.25 | 26.00 | 44.00 | 31.00 | 25.00 | 29.00 | 42.24 | 28.75 |
| Steep | 0-9 | 47 | 37 | 16 | 47 | 45 | 8 | 32 | 60 | 8 |
| | 9-21 | 52 | 29 | 19 | 43 | 35 | 22 | 28 | 56 | 16 |
| | 21-39 | 52 | 20 | 28 | 45 | 31 | 24 | 35 | 43 | 22 |
| | 39-66 | 47 | 19 | 34 | 40 | 32 | 28 | 28 | 26 | 46 |
| | Av. | 49.50 | 26.25 | 24.25 | 43.75 | 35.75 | 20.50 | 30.75 | 46.25 | 23.00 |

of clay. This seems to support the view of Dreibelbis (7), who attributed the variations in soil moisture distribution in 8-foot profiles at different sites on a watershed to soil profile characteristics and emphasized the factor of soil heterogeneity in watershed hydrology.

No uniform trend of variation was observed, at all depths, in the average soil moisture storage with slope on any of the three sites (Table II and Figures 7, 8, 9). This is in agreement with the views of Hewlett (13) in his field studies of soil moisture storage and movement on slopes.

Values for the correlation coefficients ($R_1^2$) between observed soil moisture storage and ln D are shown in Table IV. The $R_2^2$ values are the correlation coefficients for the general regression equation on each of the three sites. On sites A, B, and C the $R_1^2$ values were 0.83, 0.88, and 0.80, respectively. The $R_2^2$ values on sites A, B, and C were 0.85, 0.89, and 0.90, respectively. Comparison of $R_1^2$ and $R_2^2$ values on any site indicate that the ln D was most dominant among the selected factors in explaining per cent variation in soil moisture storage.

The average infiltration rates, as a function of time and slope at two specified rain intensities,[3] are presented in Table V. A graphical representation of the relationship between average infiltration rates and time for 2.06 and 3.83 iph rain is presented in Figures 11 and 12, respectively. Table V and Figures 11 and 12 indicate that the

---

[3]Hereafter the term "rain intensity" means the average rain intensity (iph) of all the 10 runs of the rainfall simulators.

TABLE IV

MATHEMATICAL RELATIONSHIPS BETWEEN SOIL MOISTURE, DEPTH, AND SLOPE

| Site | Regression Equation | $R_1^2$ | $R_2^2$ |
|---|---|---|---|
| A | $\hat{Y} = 2.55 + 1.77 \ln D$ | 0.83 | |
| | $\hat{Y} = 2.89 - 0.05 G - 0.28 D + 0.01 G \cdot D + 0.19 \ln G + 2.32 \ln D$ | | 0.85 |
| B | $\hat{Y} = 2.07 + 1.95 \ln D$ | 0.88 | |
| | $\hat{Y} = 2.14 + 0.01 G + 0.10 D - 0.002 G \cdot D - 0.13 \ln G + 1.78 \ln D$ | | 0.89 |
| C | $\hat{Y} = 2.57 + 2.05 \ln D$ | 0.80 | |
| | $\hat{Y} = 3.61 - 0.13 G - 0.76 D + 0.01 G \cdot D + 0.42 \ln G + 3.62 \ln D$ | | 0.90 |

$\hat{Y}$ = Depth of water in inches per foot.

G = Slope in per cent.

D = Depth of soil zone in feet.

ln = Natural logarithm.

TABLE V

AVERAGE INFILTRATION RATES (iph) AS A FUNCTION OF TIME AND SLOPE
AT TWO SPECIFIED RAINFALL INTENSITIES

| Rainfall Intensity (iph) | Slope | Time Interval (min.) 5 | 15 | 30 | 60 | 90 | 120 | 150 | 180 |
|---|---|---|---|---|---|---|---|---|---|
| 2.06 | Flat | 2.06 | 2.02 | 1.92 | 1.73 | 1.62 | 1.56 | 1.52 | 1.44 |
| | Moderate | 1.86 | 1.19 | 0.84 | 0.69 | 0.55 | 0.52 | 0.48 | 0.47 |
| | Moderately Steep | 2.06 | 1.92 | 1.84 | 1.78 | 1.73 | 1.67 | 1.63 | 1.62 |
| | Steep | 1.98 | 1.83 | 1.70 | 1.56 | 1.45 | 1.39 | 1.32 | 1.28 |
| 3.83 | Flat | 3.75 | 3.42 | 3.00 | 2.70 | 2.55 | 2.47 | 2.41 | |
| | Moderate | 3.35 | 2.62 | 2.09 | 1.85 | 1.70 | 1.59 | 1.50 | |
| | Moderately Steep | 3.71 | 3.27 | 3.08 | 2.83 | 2.67 | 2.60 | 2.47 | |
| | Steep | 3.59 | 2.88 | 2.70 | 2.37 | 2.21 | 2.10 | 2.10 | |

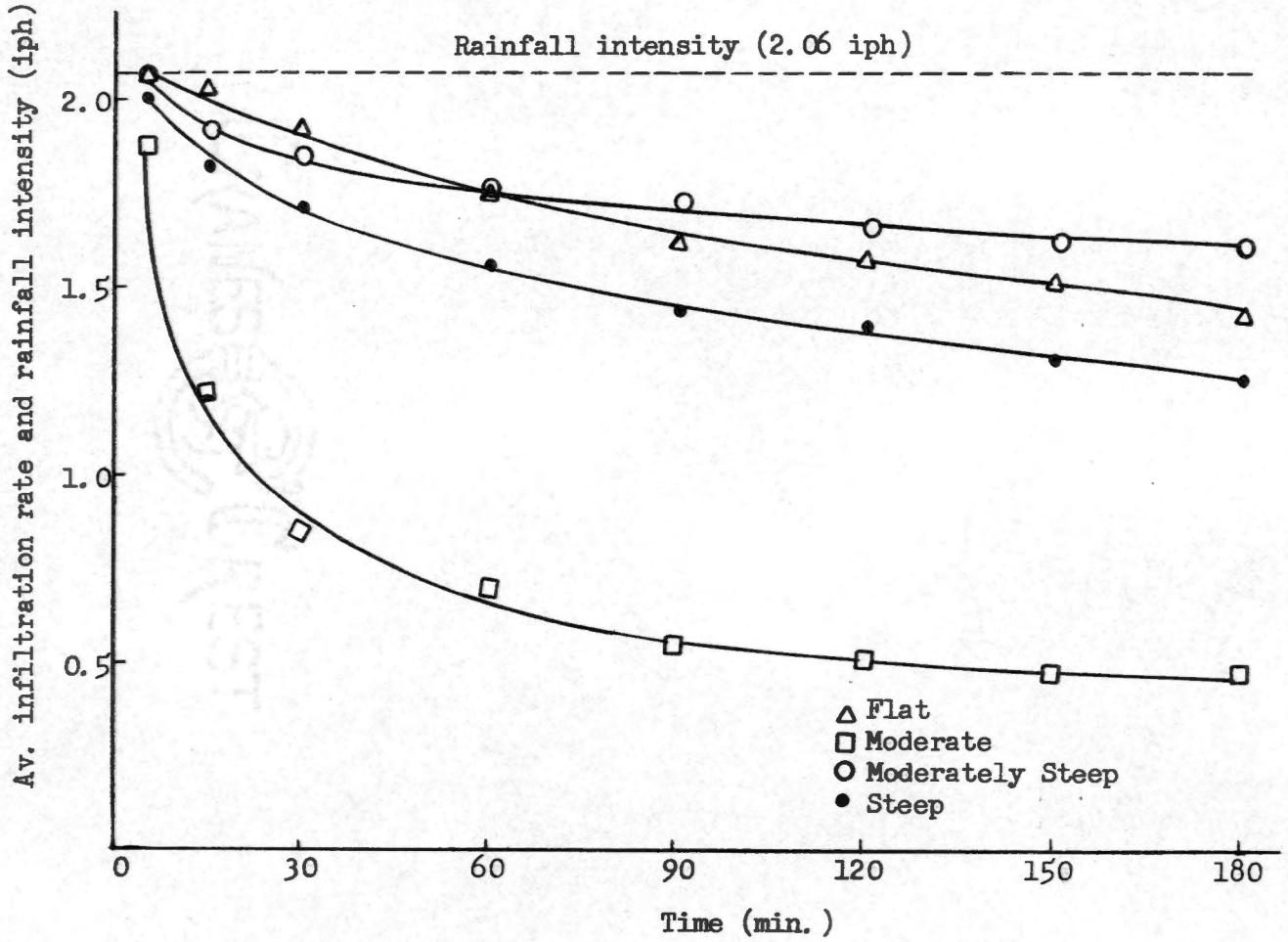



Figure 11. Average infiltration rates on four selected slopes at 2.06 iph rainfall intensity (Site A).

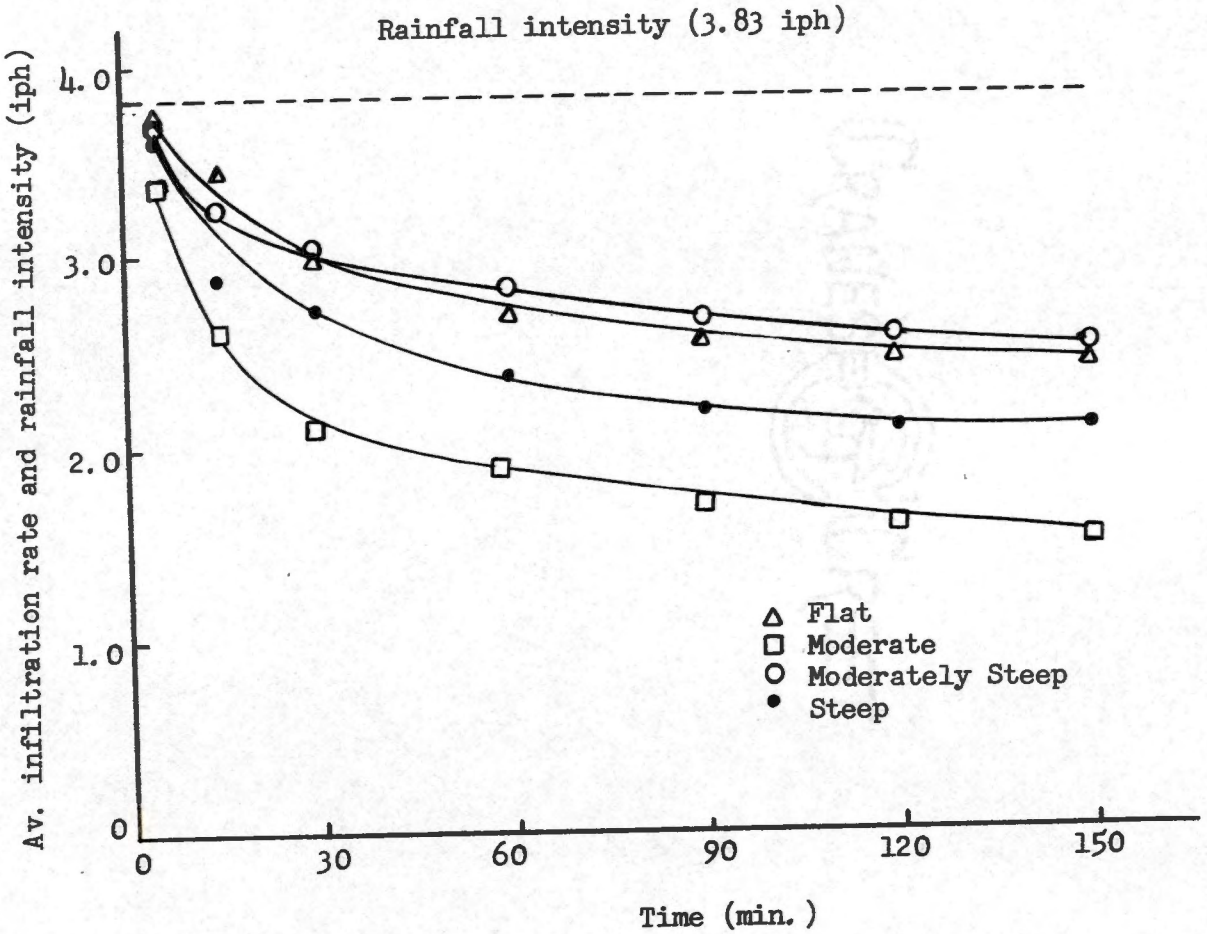



Figure 12. Average infiltration rates on four selected slopes at 3.83 iph rainfall intensity (Site A).

average infiltration rate decreased, reaching an asymptotic rate, with increase in time on all slopes. This is in agreement with that reported by Horton (14).

At both the rain intensities, the average infiltration rates were lowest on moderate slopes (Table V and Figures 11 and 12). While operating the rainfall simulators, a high runoff producing area was observed on the lower half of the runoff plot on moderate slope. Bare surface, distinct formation of small channels, and sudden increase in slope were probably the reasons for the lower half of the runoff plot producing high runoff. Results of mechanical analysis of soil presented in Table III show that, on site A, there was relatively high clay and low silt content below 9 inches of depth on moderate slope as compared with that on all other slopes. Therefore, it seems that the probable factors causing the lowest infiltration rates on moderate slope were the high runoff producing area on the lower half of the runoff plot, and the distribution of clay and silt contents in the soil profile.

The average infiltration rates were highest on moderately steep slopes after 50 and 30 minutes time at 2.06 and 3.83 iph rain, respectively. The highest infiltration rates on moderately steep slope may be attributed to the highest average silt and low average clay contents in the soil profile (Table III).

The average infiltration rates with 3.83 iph rain were higher as compared to that with 2.06 iph rain on all slopes (Table V). With 2.06 iph rain, the average infiltration rates on flat, moderate, moderately steep, and steep slopes were 1.52, 0.48, 1.63, and 1.32 iph, respectively,

at 150-minute time interval. With 3.83 iph rain, the average infiltration rates on flat, moderate, moderately steep, and steep slopes were 2.41, 1.50, 2.47, and 2.10 iph, respectively, at 150-minute time interval. In general, these values of infiltration rates seem to be somewhat high. This was probably because infiltration at any time interval was computed as the difference between amount of water applied and runoff captured. Another reason for higher values of the infiltration rates may be the cherty nature of the soil.

An account of water on the runoff plots immediately after each run of the rainfall simulators is presented in Table VI. Unaccountable water varied from -3.49 inches on flat slope (October 23, 1964) with 2.06 iph rain to +4.68 inches on moderately steep slope (October 27, 1964) with 3.83 iph rain. A negative algebraic sign associated with high values of unaccountable water on flat slope (October 23, November 10, 18) was probably due to the contact of free water with the outer wall of the access tube at lower depths. A negative sign associated with the lower values (0.04, 0.15, and 0.71 inch) of unaccountable water was probably due to experimental error. The positive algebraic sign with the unaccountable water was probably due to the following:

1. Some water probably percolated beyond a depth of 5 feet.
2. The computed average rate of water application may not have been the actual rate applied.
3. Some water probably seeped beneath the boundary wall at the lower end of the runoff plot. Thus, it could neither percolate downward within the plot nor be captured as runoff.

TABLE VI

ACCOUNT OF WATER ON THE RUNOFF PLOTS IMMEDIATELY AFTER OPERATION OF THE RAINFALL SIMULATORS

| Year | Month | Day | Slope | W (in.) | RO (in.) | △M (in.) | RO+△M (in.) | Unaccountable Water W-(RO+△M) (in.) |
|---|---|---|---|---|---|---|---|---|
| 1964 | Oct. | 23 | Flat | 6.18 | .74 | 8.93 | 9.67 | -3.49 |
| | Nov. | 10 | Flat | 6.18 | 2.97 | 6.40 | 9.37 | -3.19 |
| | Oct. | 28 | Moderate | 6.18 | 4.56 | 1.08 | 5.64 | .54 |
| | Nov. | 4 | Moderate | 5.15 | 4.04 | .82 | 4.86 | .29 |
| | | 18 | Moderate | 6.18 | 4.81 | 1.52 | 6.33 | - .15 |
| | Oct. | 20 | Mod. Steep | 6.18 | .57 | 4.79 | 5.36 | .82 |
| | Nov. | 11 | Mod. Steep | 6.18 | 2.11 | 2.18 | 4.29 | 1.89 |
| | Oct. | 27 | Steep | 6.18 | 1.64 | 3.59 | 5.23 | .95 |
| | Nov. | 3 | Steep | 6.18 | 1.18 | 3.52 | 4.70 | 1.48 |
| | | 17 | Steep | 6.18 | 3.42 | 1.75 | 5.17 | 1.01 |
| | Oct. | 28 | Flat | 11.49 | 4.05 | 5.88 | 9.93 | 1.56 |
| | Nov. | 4 | Flat | 9.58 | 2.77 | 7.51 | 10.28 | - .70 |
| | | 18 | Flat | 9.58 | 4.50 | 6.57 | 11.07 | -1.49 |
| | Oct. | 23 | Moderate | 9.58 | 3.79 | 1.97 | 5.76 | 3.82 |
| | Nov. | 10 | Moderate | 9.58 | 7.84 | .86 | 8.70 | .88 |
| | Oct. | 27 | Mod. Steep | 9.58 | 1.85 | 3.05 | 4.90 | 4.68 |
| | Nov. | 3 | Mod. Steep | 9.58 | 3.00 | 2.78 | 5.78 | 3.80 |
| | | 17 | Mod. Steep | 9.58 | 6.17 | 2.12 | 8.29 | 1.29 |
| | Oct. | 20 | Steep | 9.58 | 2.38 | 4.48 | 6.86 | 2.72 |
| | Nov. | 11 | Steep | 9.58 | 6.27 | 3.34 | 9.61 | - .03 |

W = Total amount of water applied.

RO = Total runoff collected.

△M = Total change in soil moisture content to a depth of 5 feet on runoff plots immediately after each run.

Therefore, the seemingly high infiltration rates obtained through the use of such infiltrometers are reasonable.

The percolation rates of water through undisturbed soil cores, obtained from the top 6-inch depth, are presented in Table VII. Very high percolation rates, 32.12 inches per day with core number 6 and 25.22 inches per day with core number 9, were probably a reflection of a very poor seal of paraffin between the permeameter wall and the core. The percolation rates through samples number 1 through 4 on site A are somewhat high but are fairly uniform. Thus, a high percolation rate of water through the top 6 inches of soil on site A may be one of the reasons contributing to a high value of the infiltration rate.

Using the multiple regression technique, equations defining relationships between observed infiltration rates[4] and slopes, rain intensities, and antecedent moisture at five depths were developed (Table VIII). The $R_3^2$ values are the correlation coefficients between infiltration rates and rain intensities. The $R_4^2$ values are the correlation coefficients between infiltration rates and slopes, rain intensities, and antecedent moisture. A comparison of $R_3^2$ and $R_4^2$ values indicated that rain intensity was most dominant among the selected factors in explaining the per cent variations in infiltration rates.

The $R_3^2$ value decreased from 0.95 at the 5-minute time interval to 0.35 at the 120-minute time interval. This was probably because rain

---

[4]Hereafter the term "infiltration rate" means the infiltration rate (iph) at selected time intervals.

TABLE VII

PERCOLATION RATES OF WATER THROUGH UNDISTURBED CORES OF TOPSOIL

| Core No. | Site | Average Discharge per Min. (cc) | K in./day |
|---|---|---|---|
| 1 | A | 7.22 | 10.17 |
| 2 | A | 6.28 | 8.85 |
| 3 | A | 5.78 | 8.14 |
| 4 | A | 7.13 | 10.04 |
| 5 | B | 6.25 | 8.81 |
| 6 | B | 22.88 | 32.12 |
| 7 | B | 2.93 | 4.13 |
| 8 | C | 9.40 | 13.72 |
| 9 | C | 17.90 | 25.22 |

NOTE: The values of h, L, and d used in computing the values of K were as follows:

Head of water, h = 20 inches

Length of core samples, L = 4 inches

Diameter of the permeameter, d = 4 inches.

TABLE VIII

MATHEMATICAL RELATIONSHIPS BETWEEN INFILTRATION RATE AND SLOPE, RAINFALL INTENSITY, AND ANTECEDENT MOISTURE AT SELECTED DEPTHS

| Regression Equations | $R_3^2$ | $R_4^2$ |
|---|---|---|
| $f_5 = 0.06 + 0.93\ X_2$ | 0.95 | |
| $f_5 = 0.92 + 0.02\ X_1 + 0.93\ X_2 + 0.13\ X_3 - 0.50\ X_4 + 1.00\ X_5 - 1.54\ X_6 + 0.66\ X_7$ | | 0.98 |
| $f_{15} = 0.04 + 0.80\ X_2$ | 0.63 | |
| $f_{15} = 2.31 + 0.06\ X_1 + 0.82\ X_2 - 0.18\ X_3 - 0.84\ X_4 + 2.13\ X_5 - 3.56\ X_6 + 1.67\ X_7$ | | 0.80 |
| $f_{30} = 0.03 + 0.72\ X_2$ | 0.54 | |
| $f_{30} = -0.17 + 0.11\ X_1 + 0.74\ X_2 - 0.46\ X_3 - 0.76\ X_4 + 2.68\ X_5 - 3.79\ X_6 + 1.90\ X_7$ | | 0.78 |
| $f_{60} = 0.02 + 0.65\ X_2$ | 0.45 | |
| $f_{60} = 1.34 + 0.09\ X_1 + 0.67\ X_2 - 0.48\ X_3 - 0.80\ X_4 + 2.60\ X_5 - 3.84\ X_6 + 1.81\ X_7$ | | 0.75 |
| $f_{90} = 0.01 + 0.61\ X_2$ | 0.40 | |
| $f_{90} = 2.27 + 0.08\ X_1 + 0.63\ X_2 - 0.48\ X_3 - 0.84\ X_4 + 2.50\ X_5 - 3.80\ X_6 + 1.73\ X_7$ | | 0.72 |
| $f_{120} = 0.09 + 0.55\ X_2$ | 0.35 | |
| $f_{120} = 2.38 + 0.04\ X_1 + 0.55\ X_2 - 0.69\ X_3 + 0.17\ X_4 + 1.19\ X_5 - 2.22\ X_6 + 0.84\ X_7$ | | 0.67 |
| $f_{150} = -0.02 + 0.57\ X_2$ | 0.38 | |
| $f_{150} = 2.57 + 0.08\ X_1 + 0.59\ X_2 - 0.49\ X_3 - 0.92\ X_4 + 2.52\ X_5 - 3.82\ X_6 + 1.75\ X_7$ | | 0.72 |

NOTE: Key to the symbols used in this and future tables is as follows:
$X_1$ = Slope in per cent
$X_2$ = Rainfall intensity in iph
$X_3$ = Antecedent moisture in inches for 0-12 inch depth
$X_4$ = Antecedent moisture in inches for 12-24 inch depth
$X_5$ = Antecedent moisture in inches for 24-36 inch depth
$X_6$ = Antecedent moisture in inches for 36-48 inch depth
$X_7$ = Antecedent moisture in inches for 48-60 inch depth
$f_p$ = Infiltration rate (iph) at any time interval p minutes.

intensity may be correlated with other factors affecting infiltration rate with increase in time. Therefore, the decrease in $R_4^2$ value from 0.98 at 5-minute time to 0.67 at 120-minute time may be related to the decrease in $R_3^2$ value.

The levels of statistical significance, obtained from multiple regression analysis, of selected factors (slopes, rain intensities, and antecedent moisture at five depths) on infiltration rates are presented in Table IX. The effect of rain intensity was highly significant at all time intervals. Therefore, it seems that rain intensities may cause marked differences in infiltration rates. This is in agreement with that reported by Musgrave (21).

The effect of antecedent moisture in the 0-12 inch depth was significant at 15, 30, 60, and 120-minute time intervals and highly significant at 90 and 150-minute time intervals (Table IX). The effect of slope was significant for the 5-minute time interval. The effect of antecedent moisture in the 36-48-inch depth was significant at the probability level equal to or less than 0.10 for the 5-minute time interval.

To illustrate the overall effect of antecedent moisture on infiltration, partial regression coefficients (b values) of antecedent moisture for five depths as shown in general regression equations (Table VIII) are separately presented in Table X. The overall effect of antecedent moisture on infiltration rate was then determined by summing the b values, $b_3$ through $b_7$. The sum of b values was highest (-0.25) at the 5-minute time interval, and was lowest (-0.96) at the 150-minute

TABLE IX

LEVELS OF STATISTICAL SIGNIFICANCE OF SELECTED FACTORS ON INFILTRATION RATES

| Infiltration Rate (iph) at Selected Time Interval (min.) | Slope (per cent) $X_1$ | Rainfall Intensity (iph) $X_2$ | Antecedent Moisture (in.) at Five Depths (in.) 0-12 $X_3$ | 12-24 $X_4$ | 24-36 $X_5$ | 36-48 $X_6$ | 48-60 $X_7$ |
|---|---|---|---|---|---|---|---|
| $f_5$ | * | ** | N. S. | N. S. | N. S. | + | N. S. |
| $f_{15}$ | N. S. | ** | * | N. S. | N. S. | N. S. | N. S. |
| $f_{30}$ | N. S. | ** | * | N. S. | N. S. | N. S. | N. S. |
| $f_{60}$ | N. S. | ** | * | N. S. | N. S. | N. S. | N. S. |
| $f_{90}$ | N. S. | ** | ** | N. S. | N. S. | N. S. | N. S. |
| $f_{120}$ | N. S. | ** | * | N. S. | N. S. | N. S. | N. S. |
| $f_{150}$ | N. S. | ** | ** | N. S. | N. S. | N. S. | N. S. |

*The single asterisk indicates a probability level equal to or less than 0.05. Hereafter, this will be expressed by the term "significant."

N. S. The abbreviation N. S. means not significant.

TABLE X

EFFECT OF ANTECEDENT MOISTURE ON INFILTRATION RATE

| Infiltration Rate (iph) at Selected Time Interval (min.) | b Values of Antecedent Moisture at Five Different Depths | | | | | $\sum_{n=3}^{7} b_n$ |
|---|---|---|---|---|---|---|
| | $b_3$ | $b_4$ | $b_5$ | $b_6$ | $b_7$ | |
| $f_5$ | 0.13 | -0.50 | 1.00 | -1.54 | 0.66 | -0.25 |
| $f_{15}$ | -0.18 | -0.84 | 2.13 | -3.56 | 1.67 | -0.78 |
| $f_{30}$ | -0.46 | -0.76 | 2.68 | -3.79 | 1.90 | -0.43 |
| $f_{60}$ | -0.48 | -0.80 | 2.60 | -3.84 | 1.81 | -0.71 |
| $f_{90}$ | -0.48 | -0.84 | 2.50 | -3.80 | 1.73 | -0.89 |
| $f_{120}$ | -0.69 | 0.17 | 1.19 | -2.22 | 0.84 | -0.71 |
| $f_{150}$ | -0.49 | -0.92 | 2.52 | -3.82 | 1.75 | -0.96 |

$b_3$ = Partial regression coefficient for antecedent moisture at 0-12 inch depth.

$b_4$ = Partial regression coefficient for antecedent moisture at 12-24 inch depth.

$b_5$ = Partial regression coefficient for antecedent moisture at 24-36 inch depth.

$b_6$ = Partial regression coefficient for antecedent moisture at 36-48 inch depth.

$b_7$ = Partial regression coefficient for antecedent moisture at 48-60 inch depth.

time interval. The negative algebraic sign associated with the sum of b values indicates a decreasing effect of antecedent moisture on infiltration rates. This decreasing effect of antecedent moisture on infiltration rate is in agreement with that reported by Neal (22). A decrease in the sum of b values with time indicates that the effect of antecedent moisture on infiltration rate is more pronounced with increase in time. This may be explained by the fact that water was applied to the runoff plots at a constant rate.

Since the three sites (A, B, and C) were significantly different from each other at a probability level equal to or less than 0.01, the values of infiltration rates obtained from site A could not be applied to sites B and C. Therefore, an equation defining relationships between observed soil moisture and depth, slope, and infiltration rate (I) was developed for site A only. The equation is as follows:

$$\hat{Y} = 49.60 - 0.05\ G - 0.29\ D + 0.005\ G \cdot D + 0.19 \ln G + 2.32 \ln D - 27.91\ I$$

where $\hat{Y}$ is the depth of water in inches per foot. The $R^2$ value of 0.85 in the above equation is the same as that of $R_2^2$ value on site A (Table IV). Therefore, it seems that infiltration rate made almost no contribution in explaining per cent variation in soil moisture storage. This is probably because the soil moisture content at any depth is related to infiltration rates, percolation rates, and soil texture.

# CHAPTER VI

## SUMMARY AND CONCLUSIONS

A 55-acre watershed located on the University of Tennessee-Atomic Energy Commission Laboratory Farm near Oak Ridge was selected as the site for this research. The length of the period for which the research was conducted was September 10 through December 15, 1964. The objectives of this research were:

1. To study the effects of depth and gradient on moisture storage in the soil profile.
2. To develop mathematical relationships between observed soil moisture and degree of slope, depth, and infiltration capacity of the soil.

The experimental design included three sites, each 40 feet wide and 300 feet long. The three sites were selected so that four slopes, flat (0-2 per cent), moderate (2-8 per cent), moderately steep (8-16 per cent), and steep (16-24 per cent) occurred sequentially at 100-foot intervals along the length of each site. Three soil moisture access tubes, each 5-1/2 feet deep, were located on each slope in each site at distances of 20 feet across the width. On one of the sites, a 1/200 acre (125-1/4 inches x 250-1/2 inches) runoff plot was installed around one soil moisture access tube on each of the four slopes. Rainfall simulators were used to apply water to the runoff plots at average intensities of 2.06 and 3.83 iph.

The main effects included in the analysis of variance of soil moisture data were site (S), depth (D), slope (G), and date of observation (T). The main effects S and D, the first order interaction term S·D, and the second order interaction term S·D·G were each highly significant. A regression model, using logarithmic functions of depth and slope (ln D and ln G), their linear terms, and their linear x linear cross product term, was selected to best express the relationship between observed soil moisture and depth and slope. The multiple regression equation was of the form $\hat{Y} = a + b_1x_1 + b_2x_2 + \ldots + b_nx_n$. The $R_1^2$ (multiple correlation coefficient between observed soil moisture and ln D) values on sites A, B, and C were 0.83, 0.88, and 0.80, respectively. The $R_2^2$ values are the multiple correlation coefficients between observed soil moisture and ln D and ln G, their linear terms, and their linear x linear cross product term. These $R_2^2$ values on sites A, B, and C were 0.85, 0.89, and 0.90, respectively. The highest soil moisture storage on sites A, B, and C was 21.94, 20.74, and 24.40 inches, respectively. The lowest soil moisture storage on sites A, B, and C was 20.56, 18.74, and 20.10 inches, respectively. Thus, the amount of water stored in the soil to a depth of 5 feet varied from 18.74 to 24.40 inches.

In the multiple regression analysis of the infiltration data, the effect of rain intensities was highly significant. The effect of antecedent moisture varied from significant at the 0.05 level of probability to highly significant at the 0.01 level of probability. With 3.83 iph simulated rainfall, infiltration rates at 150-minute time interval on flat, moderate, moderately steep, and steep slopes were 2.41, 1.50,

2.47, and 2.10 iph, respectively. With 2.06 iph simulated rainfall, the average infiltration rates at 150-minute time interval were 1.52, 0.48, 1.63, and 1.32 iph, respectively.

Unaccountable water on the runoff plots, after each operation of the rainfall simulator, varied from -3.49 inches on flat slope with 2.06 iph rain to +4.68 inches on moderately steep slope with 3.83 iph rain. Since the study was conducted for a relatively short period, and the number of observations was limited, no definite conclusions can be drawn. Analysis of the results, however, indicates the following trends:

1. The assumption that the watershed condition was homogeneous was probably not valid. One of the probable factors causing soil moisture storage variations among and within sites was the amount and distribution of average clay content of the soils in the plots.
2. The average soil moisture storage increased with an increase in depth on all slopes at each site. The logarithmic function of depth (ln D) was highly significant and most dominant among the selected factors in explaining the per cent variations in soil moisture storage.
3. The average soil moisture storage did not show any uniform variation with increase in slope on all depths at any site. The average total soil moisture storage showed a definite decrease with increasing slope, except at the moderate slope, on all sites.

4. The infiltration rates decreased with time, reaching an asymptotic rate in 30 to 60 minutes. The rates of water application appeared to cause marked differences in the infiltration rates.
5. Slope had no significant effect on infiltration rates.
6. The infiltration rates did not seem to account for any per cent variation in soil moisture storage when depth was expressed as an independent variable in the regression equation.

From this study it appeared that the soil moisture storage at the three sites was probably associated with the amount and distribution of clay in situ, and thus emphasized the factor of soil heterogeneity within the watershed. There was no uniform trend of variation in soil moisture storage with slope at any depth, but a decrease in soil moisture storage with an increase in slope was apparent. Mathematical relationships developed between observed soil moisture and depth, slope, and infiltration rate indicated that infiltration rate made almost no contribution in explaining the per cent variation in soil moisture storage. Soil depth was highly significant and the most dominant factor in affecting soil moisture storage.

# BIBLIOGRAPHY

BIBLIOGRAPHY


1. Anderson, R. L., and T. A. Bancroft. Statistical Theory in Research. New York: McGraw-Hill Book Company, Inc., 1952.

2. Barnett, A. P. "How Intense Rainfall Affects Runoff and Soil Erosion," Agricultural Engineering, 39:703-707, 711, November, 1958.

3. Bertrand, A. R., and J. F. Parr. Design and Operation of the Purdue Sprinkling Infiltrometer. Purdue Agricultural Experiment Station, Research Bulletin 723, August, 1961.

4. Betson, R. P. "What is Watershed Runoff?," Journal of Geophysical Research, 69:1541-1552, April, 1964.

5. Bianchi, W. C., and E. E. Haskell, Jr. "Field Measurements of Soil Water Movement during Artificial Ground-Water Recharge," Transactions of the American Society of Agricultural Engineers, 7:341-343, November, 1964.

6. Bodman, G. B., and E. A. Colman. "Moisture and Energy Conditions During Downward Entry of Water into Soils," Soil Science Society of American Proceedings, 8:116-122, November, 1943.

7. Dreibelbis, F. R. "Some Aspects of Watershed Hydrology as Determined from Soil Moisture Data," Journal of Geophysical Research, 67:3425-3435, August, 1962.

8. Duley, F. L., and O. E. Hays. "The Effect of the Degree of Slope on Runoff and Soil Erosion," Journal of Agricultural Research, 45:349-360, September, 1932.

9. _____, and L. L. Kelly. Effect of Soil Type, Slope, and Surface Conditions on Intake of Water. Nebraska Agricultural Experiment Station Research Bulletin 112, May, 1939.

10. Edlefson, N. E., and G. B. Bodman. "Field Measurements of Water Movement Through a Silt Sloam Soil," Agronomy Journal, 33:713-731, August, 1941.

11. Harrold, L. L. "Minimum Water Yield from Small Agricultural Watersheds," Transactions of the American Geophysical Union, 38:201-208, April, 1957.

12. Hendrickson, B. H., et al. Runoff and Erosion Control Studies on Cecil Soil in the Southern Piedmont. Agricultural Research Service,

United States Department of Agriculture Technical Bulletin 1281, 1963.

13. Hewlett, J. D. "Soil Moisture as a Source of Base Flow from Steep Mountain Watersheds," Southeastern Forest Experiment Station, Asheville, North Carolina, paper 132, October, 1961.

14. Horton, R. E. "Analysis of Runoff-plat Experiments with Varying Infiltration Capacity," Transactions of the American Geophysical Union, 21:693-711, August, 1939.

15. Hursh, C. R., and P. W. Fletcher. "Soil Profile as a Natural Reservoir," Soil Science Society of American Proceedings, 7:480-486, November, 1942.

16. Johnson, P. O., and R. W. B. Jackson. Modern Statistical Methods: Descriptive and Inductive. Chicago: Rand McNally and Company, 1959.

17. Kempthorne, O. The Design and Analysis of Experiments. New York: John Wiley and Sons, Inc., 1952.

18. Kohnke, H. "A Method for Studying Infiltration," Soil Science Society of American Proceedings, 3:296-302, November, 1938.

19. Krimgold, D. D., and O. Beenhouwer. "Estimating Infiltration," Agricultural Engineering, 35:719-725, October, 1954.

20. Marston, R. B. "Influence of Vegetation Cover on Soil Moisture in Southeastern Ohio," Soil Science Society of American Proceedings, 26:605-608, December, 1962.

21. Musgrave, G. W., and G. R. Free. "Preliminary Report on a Determination of Comparitive Infiltration-rates on Some Major Soil-types," Transactions of the American Geophysical Union, 18: 345-349, July, 1937.

22. Neal, J. H. The Effect of the Degree of Slope and Rainfall Characteristics on Runoff and Soil Erosion. Missouri Agricultural Experiment Station, Research Bulletin 280, April, 1938.

23. Nixon, P. R., and G. P. Lawless. "Translocation of Moisture with Time in Unsaturated Soil Profiles," Journal of Geophysical Research, 65:655-661, February, 1960.

24. _____, and G. O. Schwab. "Water Yield Prediction Based on Watershed Characteristics," The American Society of Agricultural Engineers Paper No. J2969, 1956.

25. Parks, W. L., and T. J. Longwell. "Soil Moisture--Tennessee's Greatest Water Reservoir," Tennessee Farm and Home Science, Progress Report 47, 1963.

26. Reinhart, K. G. "Approximating Soil Moisture Storage in Experimental Watersheds by Means of Precipitation and Streamflow Records," Soil Science Society of American Proceedings, 28:575-578, July-August, 1964.

27. Robins, J. S., et al. "Unsaturated Flow of Water in Field Soils and Its Effect on Soil Moisture Investigations," Soil Science Society of American Proceedings, 18:344-347, July, 1954.

28. Russell, M. B., and A. Klute. "Movement of Water in Soils," Agricultural Engineering, 35:808-810, November, 1954.

29. Select Committee on National Water Resources, United States Senate. Water Resources Activities in the United States: Water Supply and Demand. Committee Print Number 32, 86th Congress, Second Session, 1960.

30. _____. Water Resources Activities in the United States: Estimated Water Requirements for Agricultural Purposes and Their Effects on Water Supplies. Committee Print Number 13, 86th Congress, Second Session, 1960.

31. Sinha, L. K. "Corn Yields as a Function of Specified Production Factors Expressed as Variables in Quadratic Prediction Equations," Unpublished Master's thesis, The University of Tennessee, Knoxville, 1963.

32. Smith, D. D., et al. Investigations in Erosion Control and Reclamation of Eroded Shelby and Related Soils at the Conservation Station, Bethany, Missouri, 1930-1942. The United States Department of Agriculture, Technical Bulletin 883, 1945.

33. Snedecor, G. W. Statistical Methods. 5th edition. The Iowa State College Press, Ames, Iowa. 1956.

# APPENDIX

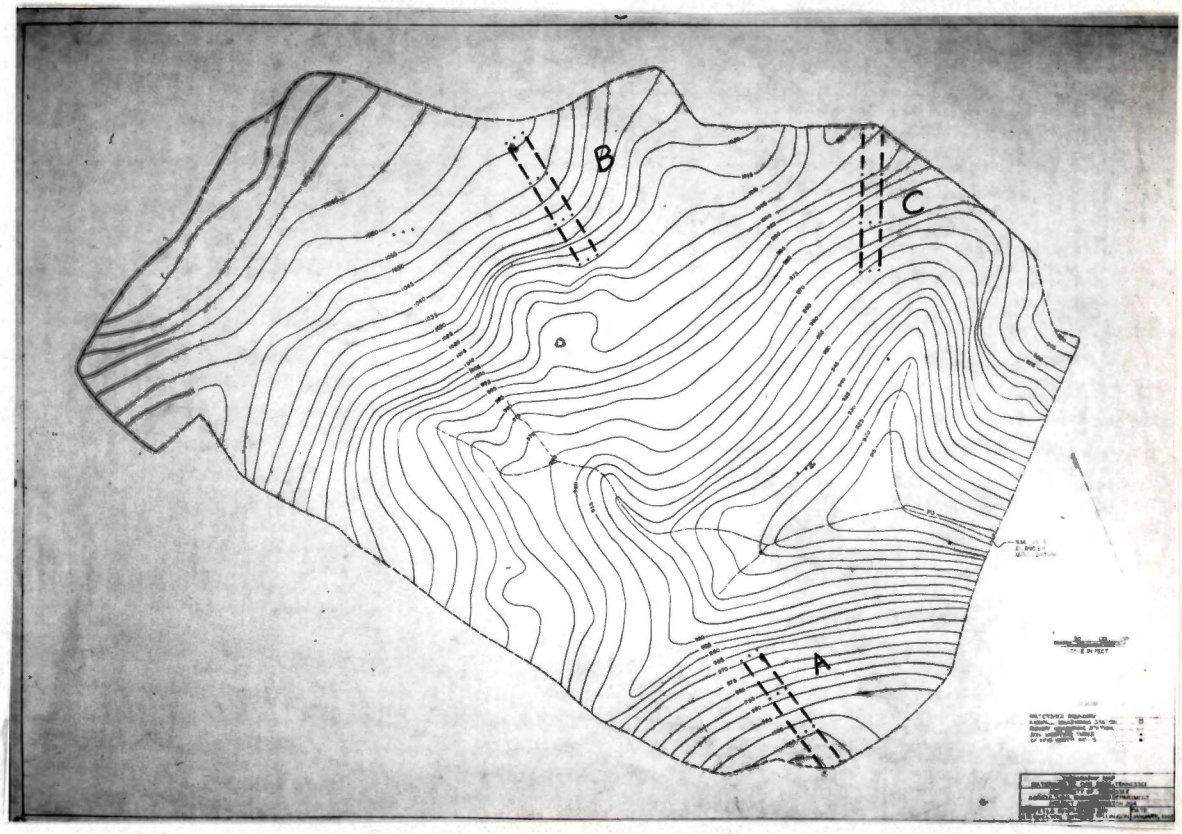



Figure 13. Topographic map of the watershed showing location of the sites.

TABLE XI

THE EXACT SLOPE (PER CENT) AT WHICH THE ACCESS TUBES ARE LOCATED ON EACH SITE

| Site | Soil Moisture Access Tube | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | Av. | 4 | 5 | 6 | Av. | 7 | 8 | 9 | Av. | 10 | 11 | 12 | Av. |
| A | 0 | 0 | 0 | 0 | 5.79 | 7.32 | 7.14 | 6.75 | 16.63 | 16.37 | 17.51 | 16.84 | 20.14 | 19.64 | 19.08 | 19.62 |
| B | 0 | 0 | 0 | 0 | 6.60 | 7.17 | 8.17 | 7.31 | 13.36 | 13.58 | 12.77 | 13.24 | 21.11 | 20.42 | 20.41 | 20.65 |
| C | 0 | 0 | 0 | 0 | 9.37 | 6.74 | 6.69 | 7.60 | 11.70 | 17.20 | 16.08 | 14.99 | 19.04 | 20.55 | 19.19 | 19.59 |
| Av. | | | | 0 | | | | 7.22 | | | | 15.02 | | | | 19.95 |

TABLE XII

SPECIFICATIONS OF THE NOZZLES[a] USED IN THE RAINFALL SIMULATORS

| Nozzle Catalog No. (Male) | App. Orif. Dia. (in.) | Pipe Size (in.) | Capacity--gpm at psi Pressure | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 5 | 7 | 10 | 15 | 20 | 30 | 40 | 60 | 80 | 100 | 150 |
| WSSM 10 | 3/32 | 1/2 | 0.35 | 0.42 | 0.50 | 0.61 | 0.71 | 0.87 | 1.00 | 1.20 | 1.40 | 1.60 | 1.90 |
| WSSM 20 | 7/64 | 1/2 | 0.71 | 0.84 | 1.00 | 1.20 | 1.40 | 1.70 | 2.00 | 2.40 | 2.80 | 3.20 | 3.90 |

[a]The nozzles were manufactured by the Delavan Manufacturing Company, West Des Moines, Iowa.

TABLE XIII

THE EQUIVALENT PER CENT MOISTURE BY VOLUME OF THE NEUTRON COUNTS

| Counts (1/2 min.) | Moisture (per cent) | Counts (1/2 min.) | Moisture (per cent) |
|---|---|---|---|
| | Sub Surface P-19 Moisture Meter Depth Probe | | |
| 500 | 6.50 | 2250 | 22.60 |
| 550 | 7.00 | 2300 | 23.00 |
| 600 | 7.40 | 2350 | 23.50 |
| 650 | 7.80 | 2400 | 24.00 |
| 700 | 8.30 | 2450 | 24.50 |
| 750 | 8.75 | 2500 | 24.90 |
| 800 | 9.25 | 2550 | 25.40 |
| 850 | 9.75 | 2600 | 25.90 |
| 900 | 10.20 | 2650 | 26.25 |
| 950 | 10.70 | 2700 | 26.75 |
| 1000 | 11.20 | 2750 | 27.25 |
| 1050 | 11.60 | 2800 | 27.75 |
| 1100 | 12.00 | 2850 | 28.25 |
| 1150 | 12.50 | 2900 | 28.50 |
| 1200 | 13.00 | 2950 | 29.00 |
| 1250 | 13.40 | 3000 | 29.50 |
| 1300 | 13.90 | 3050 | 30.00 |
| 1350 | 14.25 | 3100 | 30.50 |
| 1400 | 14.75 | 3150 | 31.00 |
| 1450 | 15.25 | 3200 | 31.50 |
| 1500 | 15.75 | 3250 | 31.80 |
| 1550 | 16.20 | 3300 | 32.30 |
| 1600 | 16.60 | 3350 | 32.80 |
| 1650 | 17.10 | 3400 | 33.25 |
| 1700 | 17.50 | 3450 | 33.70 |
| 1750 | 18.00 | 3500 | 34.20 |
| 1800 | 18.40 | 3550 | 34.60 |
| 1850 | 18.90 | 3600 | 35.00 |
| 1900 | 19.40 | 3650 | 35.50 |
| 1950 | 19.80 | 3700 | 36.00 |
| 2000 | 20.25 | 3750 | 36.50 |
| 2050 | 20.75 | 3800 | 37.00 |
| 2100 | 21.25 | 3850 | 37.40 |
| 2150 | 21.75 | 3900 | 37.80 |
| 2200 | 22.20 | 3950 | 38.30 |

TABLE XIII (CONTINUED)

| Counts (1/2 min.) | Moisture (per cent) | Counts (1/2 min.) | Moisture (per cent) |
|---|---|---|---|
| 4000 | 38.80 | 5500 | 52.70 |
| 4050 | 39.30 | 5550 | 53.20 |
| 4100 | 39.70 | 5600 | 53.60 |
| 4150 | 40.20 | 5650 | 54.10 |
| 4200 | 40.60 | 5700 | 54.50 |
| 4250 | 41.10 | 5750 | 55.00 |
| 4300 | 41.50 | 5800 | 55.50 |
| 4350 | 42.00 | 5850 | 56.00 |
| 4400 | 42.50 | 5900 | 56.40 |
| 4450 | 43.00 | 5950 | 56.90 |
| 4500 | 43.50 | 6000 | 57.30 |
| 4550 | 44.00 | 6050 | 57.80 |
| 4600 | 44.50 | 6100 | 58.30 |
| 4650 | 45.00 | 6150 | 58.70 |
| 4700 | 45.40 | 6200 | 59.20 |
| 4750 | 45.80 | 6250 | 59.60 |
| 4800 | 46.20 | 6300 | 60.25 |
| 4850 | 46.60 | 6350 | 60.75 |
| 4900 | 47.10 | 6400 | 61.25 |
| 4950 | 47.50 | 6450 | 61.75 |
| 5000 | 48.00 | 6500 | 62.25 |
| 5050 | 48.50 | 6550 | 62.60 |
| 5100 | 49.00 | 6600 | 63.00 |
| 5150 | 49.50 | 6650 | 63.50 |
| 5200 | 49.90 | 6700 | 64.00 |
| 5250 | 50.40 | 6750 | 64.50 |
| 5300 | 50.90 | 6800 | 65.00 |
| 5350 | 51.30 | 6850 | 65.50 |
| 5400 | 51.80 | 6900 | 66.00 |
| 5450 | 52.30 | | |

Surface
P-21 Moisture Meter Surface Probe

| | | | |
|---|---|---|---|
| 1000 | 6.50 | 1300 | 9.00 |
| 1050 | 7.00 | 1350 | 9.25 |
| 1100 | 7.50 | 1400 | 9.50 |
| 1150 | 7.75 | 1450 | 10.00 |
| 1200 | 8.00 | 1500 | 10.25 |
| 1250 | 8.50 | 1550 | 10.50 |

TABLE XIII (CONTINUED)

| Counts (1/2 min.) | Moisture (per cent) | Counts (1/2 min.) | Moisture (per cent) |
|---|---|---|---|
| 1600 | 11.00 | 3600 | 23.75 |
| 1650 | 11.35 | 3650 | 24.25 |
| 1700 | 11.75 | 3700 | 24.50 |
| 1750 | 12.00 | 3750 | 24.75 |
| 1800 | 12.35 | 3800 | 25.00 |
| 1850 | 12.65 | 3850 | 25.50 |
| 1900 | 13.00 | 3900 | 25.75 |
| 1950 | 13.25 | 3950 | 26.00 |
| 2000 | 13.50 | 4000 | 26.50 |
| 2050 | 14.00 | 4050 | 26.75 |
| 2100 | 14.25 | 4100 | 27.00 |
| 2150 | 14.50 | 4150 | 27.50 |
| 2200 | 15.00 | 4200 | 27.75 |
| 2250 | 15.25 | 4250 | 28.00 |
| 2300 | 15.50 | 4300 | 28.50 |
| 2350 | 15.75 | 4350 | 28.75 |
| 2400 | 16.25 | 4400 | 29.00 |
| 2450 | 16.50 | 4450 | 29.50 |
| 2500 | 16.75 | 4500 | 29.75 |
| 2550 | 17.25 | 4550 | 30.00 |
| 2600 | 17.50 | 4600 | 30.50 |
| 2650 | 17.75 | 4650 | 30.75 |
| 2700 | 18.15 | 4700 | 31.00 |
| 2750 | 18.50 | 4750 | 31.50 |
| 2800 | 18.75 | 4800 | 31.75 |
| 2850 | 19.00 | 4850 | 32.00 |
| 2900 | 19.35 | 4900 | 32.40 |
| 2950 | 19.75 | 4950 | 32.75 |
| 3000 | 20.00 | 5000 | 33.00 |
| 3050 | 20.25 | 5050 | 33.25 |
| 3100 | 20.75 | 5100 | 33.50 |
| 3150 | 21.00 | 5150 | 33.75 |
| 3200 | 21.50 | 5200 | 34.20 |
| 3250 | 21.75 | 5250 | 34.50 |
| 3300 | 22.00 | 5300 | 35.00 |
| 3350 | 22.25 | 5350 | 35.25 |
| 3400 | 22.75 | 5400 | 35.50 |
| 3450 | 23.00 | 5450 | 35.80 |
| 3500 | 23.25 | 5500 | 36.10 |
| 3550 | 23.50 | 5550 | 36.50 |

TABLE XIII (CONTINUED)

| Counts (1/2 min.) | Moisture (per cent) | Counts (1/2 min.) | Moisture (per cent) |
|---|---|---|---|
| 5600 | 37.00 | 5850 | 38.50 |
| 5650 | 37.25 | 5900 | 38.75 |
| 5700 | 37.50 | 5950 | 39.00 |
| 5750 | 38.75 | 6000 | 39.50 |
| 5800 | 38.00 | | |

TABLE XIV

SOIL MOISTURE DATA (INCHES)

| Date | Slope | Site A Depth (feet) 1 | 2 | 3 | 4 | 5 | Site B Depth (feet) 1 | 2 | 3 | 4 | 5 | Site C Depth (feet) 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9/10/1964 | Flat | 1.51 | 3.47 | 4.42 | 4.77 | 4.87 | 1.56 | 3.04 | 4.17 | 4.78 | 5.05 | 1.86 | 4.47 | 5.27 | 5.47 | 5.10 |
| | Moderate | 1.78 | 3.44 | 4.36 | 4.94 | 5.36 | 1.32 | 2.61 | 3.80 | 4.59 | 4.77 | 1.52 | 4.12 | 5.45 | 5.65 | 5.79 |
| | Mod. Steep | 1.62 | 3.49 | 4.16 | 4.27 | 4.40 | 1.41 | 3.17 | 4.07 | 4.42 | 5.03 | 1.42 | 3.30 | 4.59 | 5.26 | 5.50 |
| | Steep | 1.74 | 2.76 | 3.86 | 4.78 | 4.88 | 1.28 | 2.88 | 3.81 | 4.24 | 4.79 | 1.57 | 3.03 | 4.11 | 4.71 | 4.90 |
| 9/17/1964 | Flat | 1.52 | 3.44 | 4.31 | 4.66 | 4.82 | 1.47 | 3.00 | 4.21 | 4.94 | 5.25 | 1.92 | 4.56 | 5.31 | 5.61 | 5.25 |
| | Moderate | 1.72 | 3.36 | 4.25 | 4.96 | 5.52 | 1.22 | 2.44 | 3.85 | 4.85 | 4.95 | 1.56 | 4.27 | 5.52 | 5.86 | 6.09 |
| | Mod. Steep | 1.60 | 3.61 | 4.31 | 4.59 | 4.76 | 1.23 | 3.03 | 4.11 | 4.50 | 5.15 | 1.36 | 3.35 | 4.76 | 5.40 | 5.66 |
| | Steep | 1.65 | 2.83 | 3.99 | 4.94 | 5.23 | 1.25 | 2.81 | 3.87 | 4.50 | 4.83 | 1.37 | 2.90 | 4.24 | 5.06 | 5.17 |
| 9/23/1964 | Flat | 1.74 | 3.67 | 4.61 | 4.83 | 4.99 | 1.64 | 3.14 | 4.40 | 4.97 | 5.28 | 1.91 | 4.55 | 5.30 | 5.43 | 5.12 |
| | Moderate | 1.83 | 3.33 | 4.25 | 4.99 | 5.60 | 1.52 | 2.60 | 3.97 | 4.83 | 4.93 | 1.61 | 4.11 | 5.54 | 5.78 | 5.99 |
| | Mod. Steep | 1.73 | 3.53 | 4.30 | 4.56 | 4.70 | 1.54 | 3.19 | 4.24 | 4.62 | 5.31 | 1.53 | 3.32 | 4.87 | 5.49 | 5.72 |
| | Steep | 1.80 | 2.81 | 4.01 | 5.04 | 5.29 | 1.36 | 2.79 | 3.88 | 4.64 | 4.97 | 1.63 | 2.93 | 4.16 | 4.98 | 5.25 |
| 10/5/1964 | Flat | 3.02 | 4.24 | 4.82 | 4.83 | 4.91 | 2.76 | 3.61 | 4.44 | 5.07 | 5.23 | 3.65 | 5.20 | 5.60 | 5.70 | 5.31 |
| | Moderate | 2.95 | 3.76 | 4.66 | 5.20 | 5.64 | 2.79 | 2.97 | 4.11 | 5.04 | 5.14 | 3.08 | 4.69 | 5.63 | 5.94 | 6.21 |
| | Mod. Steep | 3.13 | 3.94 | 4.29 | 4.54 | 4.63 | 2.94 | 3.77 | 4.38 | 4.91 | 5.57 | 2.91 | 4.18 | 5.09 | 5.70 | 5.99 |
| | Steep | 3.20 | 3.38 | 4.19 | 5.03 | 5.23 | 2.62 | 3.41 | 4.02 | 4.76 | 5.10 | 2.86 | 3.69 | 4.30 | 5.02 | 5.34 |
| 10/12/1964 | Flat | 2.88 | 4.28 | 4.90 | 4.90 | 4.86 | 2.18 | 3.62 | 4.56 | 5.16 | 5.43 | 2.92 | 5.14 | 5.54 | 5.58 | 5.24 |
| | Moderate | 2.64 | 3.90 | 4.74 | 5.20 | 5.58 | 2.18 | 3.12 | 4.10 | 5.00 | 5.15 | 2.45 | 4.63 | 5.59 | 5.81 | 5.98 |
| | Mod. Steep | 2.57 | 4.20 | 4.60 | 4.90 | 5.11 | 2.37 | 3.79 | 4.44 | 4.79 | 5.48 | 2.28 | 4.07 | 5.00 | 5.53 | 5.57 |
| | Steep | 2.32 | 3.17 | 4.18 | 5.34 | 5.64 | 1.97 | 3.46 | 4.17 | 4.76 | 5.06 | 2.10 | 3.41 | 4.30 | 4.86 | 5.22 |
| 10/19/1964 | Flat | 3.03 | 4.34 | 4.96 | 4.85 | 4.91 | 2.51 | 3.45 | 4.45 | 5.09 | 5.49 | 3.32 | 5.09 | 5.52 | 5.74 | 5.37 |
| | Moderate | 2.88 | 3.92 | 4.80 | 5.40 | 5.61 | 2.38 | 3.07 | 4.12 | 4.90 | 5.01 | 2.62 | 4.24 | 5.37 | 5.96 | 6.29 |
| | Mod. Steep | 2.85 | 4.34 | 4.84 | 5.05 | 5.07 | 2.42 | 3.76 | 4.47 | 4.76 | 5.41 | 2.43 | 3.96 | 4.96 | 5.59 | 5.81 |
| | Steep | 2.80 | 3.37 | 4.47 | 5.40 | 5.59 | 2.13 | 3.48 | 3.95 | 4.72 | 5.16 | 2.37 | 3.61 | 4.43 | 5.11 | 5.38 |
| 10/26/1964 | Flat | 2.27 | 3.97 | 4.72 | 4.77 | 4.85 | 1.99 | 3.62 | 4.58 | 5.04 | 5.43 | 2.57 | 4.90 | 5.42 | 5.64 | 5.23 |
| | Moderate | 2.45 | 3.89 | 4.74 | 5.16 | 5.49 | 1.92 | 3.01 | 4.03 | 4.89 | 5.07 | 2.29 | 4.46 | 5.59 | 5.90 | 6.11 |
| | Mod. Steep | 2.45 | 4.03 | 4.61 | 4.80 | 4.92 | 1.95 | 3.41 | 4.12 | 4.53 | 5.25 | 2.06 | 3.79 | 4.77 | 5.34 | 5.64 |
| | Steep | 2.22 | 3.13 | 4.64 | 5.29 | 5.17 | 1.71 | 3.07 | 3.80 | 4.38 | 4.75 | 2.00 | 3.16 | 3.99 | 4.79 | 5.05 |
| 11/2/1964 | Flat | 2.61 | 4.31 | 5.09 | 5.02 | 5.01 | 2.32 | 3.51 | 4.48 | 5.03 | 5.36 | 2.84 | 5.06 | 5.51 | 5.65 | 5.17 |
| | Moderate | 2.60 | 4.00 | 4.80 | 5.36 | 5.83 | 2.11 | 2.96 | 4.05 | 4.91 | 5.02 | 2.31 | 4.71 | 5.78 | 5.96 | 5.76 |
| | Mod. Steep | 2.62 | 4.28 | 4.69 | 5.06 | 5.39 | 2.17 | 3.63 | 4.33 | 4.71 | 5.21 | 2.23 | 3.98 | 5.07 | 5.62 | 5.82 |
| | Steep | 2.34 | 3.25 | 4.53 | 5.44 | 5.55 | 1.77 | 3.18 | 4.00 | 4.60 | 5.00 | 2.13 | 3.64 | 4.53 | 5.11 | 5.41 |

TABLE XIV (CONTINUED)

| Date | Slope | Site A Depth (feet) 1 | 2 | 3 | 4 | 5 | Site B Depth (feet) 1 | 2 | 3 | 4 | 5 | Site C Depth (feet) 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11/9/1964 | Flat | 3.06 | 3.98 | 4.73 | 4.76 | 4.74 | 2.77 | 3.49 | 4.44 | 4.93 | 5.03 | 3.36 | 4.94 | 5.45 | 5.50 | 5.08 |
| | Moderate | 2.99 | 3.99 | 4.90 | 5.37 | 5.63 | 2.53 | 2.89 | 3.93 | 4.81 | 5.07 | 2.71 | 4.72 | 5.63 | 5.91 | 6.18 |
| | Mod. Steep | 3.06 | 4.34 | 4.74 | 4.80 | 4.94 | 2.53 | 3.57 | 4.27 | 4.70 | 5.40 | 2.62 | 3.88 | 4.92 | 5.53 | 5.80 |
| | Steep | 2.71 | 3.41 | 4.58 | 5.35 | 5.57 | 2.28 | 3.08 | 3.98 | 4.63 | 4.49 | 2.47 | 3.38 | 4.24 | 4.97 | 5.24 |
| 11/16/1964 | Flat | 2.60 | 4.14 | 4.87 | 4.87 | 4.92 | 2.35 | 3.43 | 4.46 | 5.08 | 5.38 | 2.99 | 4.87 | 5.40 | 5.49 | 5.09 |
| | Moderate | 2.74 | 4.03 | 4.75 | 5.15 | 5.76 | 2.13 | 2.82 | 3.95 | 4.95 | 5.16 | 2.34 | 4.36 | 5.41 | 5.72 | 5.89 |
| | Mod. Steep | 2.95 | 4.30 | 4.70 | 4.97 | 5.07 | 2.24 | 3.62 | 4.33 | 4.69 | 5.35 | 2.24 | 3.79 | 4.77 | 5.38 | 5.68 |
| | Steep | 2.68 | 3.20 | 4.23 | 5.37 | 5.52 | 1.97 | 2.76 | 3.93 | 4.60 | 4.94 | 2.32 | 3.65 | 4.12 | 4.82 | 5.08 |
| 12/15/1964 | Flat | 3.23 | 4.64 | 5.51 | 6.12 | 6.12 | 3.23 | 4.70 | 5.44 | 5.88 | 6.27 | 3.55 | 5.46 | 5.72 | 5.81 | 5.50 |
| | Moderate | 3.18 | 4.41 | 5.16 | 5.92 | 6.44 | 3.07 | 4.07 | 4.77 | 5.31 | 5.44 | 3.36 | 5.30 | 6.07 | 6.20 | 6.43 |
| | Mod. Steep | 3.37 | 4.91 | 5.23 | 5.28 | 5.45 | 3.07 | 4.35 | 4.81 | 5.27 | 5.74 | 3.20 | 4.75 | 5.44 | 5.95 | 6.17 |
| | Steep | 3.00 | 3.84 | 4.95 | 5.58 | 5.72 | 3.14 | 4.36 | 4.74 | 5.01 | 5.18 | 3.06 | 4.12 | 4.87 | 5.38 | 5.58 |

TABLE XV

INFILTROMETER DATA

| Year | Month | Day | Slope | Av. Rainfall Intensity (iph) | Antecedent Moisture (in.) at Five Depths (in.) | | | | | Mass Infiltration (in.) at Selected Time Intervals (min.) | | | | | | | | Infiltration Rate (iph) at Selected Time Intervals (min.) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0-12 | 12-24 | 24-36 | 36-48 | 48-60 | 5 | 15 | 30 | 60 | 90 | 120 | 150 | 180 | 5 | 15 | 30 | 60 | 90 | 120 | 150 | 180 |
| 1964 | Oct. | 23 | Flat | 2.06 | 3.33 | 4.69 | 5.19 | 5.25 | 6.22 | .172 | .515 | 1.01 | 1.96 | 2.87 | 3.74 | 4.59 | 5.44 | 2.06 | 2.06 | 2.02 | 1.96 | 1.91 | 1.87 | 1.84 | 1.81 |
| | Nov. | 10 | Flat | 2.06 | 3.27 | 4.68 | 5.02 | 5.35 | 6.49 | .172 | .495 | .91 | 1.49 | 1.99 | 2.50 | 2.97 | 3.21 | 2.06 | 1.98 | 1.82 | 1.49 | 1.33 | 1.25 | 1.19 | 1.07 |
| | Oct. | 28 | Moderate | 2.06 | 3.85 | 4.07 | 4.38 | 5.00 | 5.92 | .172 | .415 | .59 | .80 | 1.00 | 1.17 | 1.35 | 1.62 | 2.06 | 1.66 | 1.18 | .80 | .67 | .585 | .54 | .54 |
| | Nov. | 4 | Moderate | 2.06 | 4.06 | 4.26 | 4.62 | 5.29 | 5.93 | .152 | .265 | .33 | .54 | .72 | .98 | 1.11 | 1.36 | 1.82 | 1.06 | .66 | .54 | .48 | .49 | .44 | .42 |
| | | 18 | Moderate | 2.06 | 3.74 | 4.27 | 4.60 | 5.26 | 6.10 | .142 | .215 | .31 | .54 | .74 | .96 | 1.15 | 1.37 | 1.70 | .86 | .67 | .54 | .49 | .48 | .46 | .44 |
| | Oct. | 20 | Mod. Steep | 2.06 | 2.54 | 3.75 | 4.27 | 4.22 | 4.07 | .172 | .495 | .98 | 1.95 | 2.90 | 3.81 | 4.72 | 5.61 | 2.06 | 1.98 | 1.96 | 1.95 | 1.93 | 1.91 | 1.89 | 1.87 |
| | Nov. | 11 | Mod. Steep | 2.06 | 3.75 | 4.46 | 4.72 | 4.60 | 4.51 | .172 | .465 | .85 | 1.61 | 2.29 | 2.86 | 3.41 | 4.07 | 2.06 | 1.86 | 1.70 | 1.61 | 1.53 | 1.43 | 1.36 | 1.36 |
| | Oct. | 27 | Steep | 2.06 | 3.66 | 4.36 | 3.88 | 4.63 | 5.02 | .172 | .475 | .94 | 1.75 | 2.48 | 3.28 | 3.84 | 4.54 | 2.06 | 1.96 | 1.88 | 1.75 | 1.65 | 1.64 | 1.54 | 1.51 |
| | Nov. | 3 | Steep | 2.06 | 3.48 | 3.87 | 4.18 | 4.93 | 5.22 | .172 | .495 | .95 | 1.69 | 2.37 | 3.04 | 3.63 | 4.20 | 2.06 | 1.98 | 1.90 | 1.69 | 1.58 | 1.52 | 1.45 | 1.40 |
| | | 17 | Steep | 2.06 | 3.67 | 4.08 | 4.41 | 5.10 | 5.33 | .152 | .375 | .66 | 1.23 | 1.66 | 2.02 | 2.39 | 2.76 | 1.82 | 1.50 | 1.32 | 1.23 | 1.11 | 1.01 | .96 | .92 |
| | Oct. | 28 | Flat | 3.83 | 3.73 | 4.60 | 5.04 | 5.32 | 6.29 | .319 | .916 | 1.635 | 2.98 | 4.045 | 5.11 | 6.205 | 7.099 | 3.83 | 3.66 | 3.27 | 2.98 | 2.70 | 2.56 | 2.48 | 2.37 |
| | Nov. | 4 | Flat | 3.83 | 3.64 | 4.68 | 5.13 | 5.43 | 6.35 | .319 | .896 | 1.655 | 2.90 | 4.245 | 5.55 | 6.805 | | 3.83 | 3.58 | 3.31 | 2.90 | 2.83 | 2.78 | 2.72 | |
| | | 18 | Flat | 3.83 | 3.58 | 4.66 | 4.97 | 5.24 | 6.24 | .299 | .756 | 1.215 | 2.21 | 3.165 | 4.12 | 5.075 | | 3.59 | 3.02 | 2.43 | 2.21 | 2.11 | 2.06 | 2.03 | |
| | Oct. | 23 | Moderate | 3.83 | 3.35 | 4.10 | 4.41 | 5.06 | 5.89 | .289 | .856 | 1.375 | 2.62 | 3.785 | 4.80 | 5.785 | | 3.47 | 3.42 | 2.75 | 2.62 | 2.52 | 2.40 | 2.31 | |
| | | 10 | Moderate | 3.83 | 3.95 | 4.41 | 4.74 | 5.46 | 6.16 | .269 | .456 | .715 | 1.07 | 1.325 | 1.54 | 1.735 | | 3.23 | 1.82 | 1.43 | 1.07 | .88 | .77 | .69 | |
| | Oct. | 27 | Mod. Steep | 3.83 | 3.35 | 4.27 | 4.44 | 4.30 | 4.27 | .319 | .936 | 1.805 | 3.46 | 4.985 | 6.60 | 7.725 | | 3.83 | 3.74 | 3.61 | 3.46 | 3.32 | 3.30 | 3.09 | |
| | Nov. | 3 | Mod. Steep | 3.83 | 3.71 | 4.40 | 4.68 | 4.57 | 4.46 | .319 | .916 | 1.725 | 3.22 | 4.705 | 6.11 | 7.315 | | 3.83 | 3.66 | 3.45 | 3.22 | 3.14 | 3.06 | 2.93 | |
| | | 17 | Mod. Steep | 3.83 | 3.56 | 4.49 | 4.79 | 4.60 | 4.52 | .289 | .606 | 1.095 | 1.80 | 2.34 | 2.87 | 3.405 | | 3.47 | 2.42 | 2.19 | 1.80 | 1.56 | 1.44 | 1.38 | |
| | Oct. | 20 | Steep | 3.83 | 3.33 | 3.50 | 3.94 | 4.37 | 4.60 | .319 | .866 | 1.585 | 3.04 | 4.455 | 5.10 | 7.195 | | 3.83 | 3.46 | 3.17 | 3.04 | 2.97 | 2.91 | 2.88 | |
| | Nov. | 11 | Steep | 3.83 | 3.82 | 3.96 | 4.30 | 5.08 | 5.28 | .279 | .576 | 1.115 | 1.70 | 2.155 | 2.58 | 3.305 | | 3.35 | 2.30 | 2.23 | 1.70 | 1.44 | 1.29 | 1.32 | |