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RUNOFF AND SOIL MOISTURE

BY

JOHN WILLIAM CLARK, JR.

A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

MASTER OF SCIENCE, IN CIVIL ENGINEERING

Rolla, Missouri

1953

Approved by - V. A. C. Gevecker

Associate Professor of Civil Engineering

ACKNOWLEDGMENTS

The author wishes to express his appreciation to Professor V. A. C. Gevecker for his guidance and encouragement during the writing of this thesis and the work prior to its preparation and to Professor E. W. Carlton for his ready consultation and advice.

Thanks are offerred to Mr. H. C. Bolon, District Engineer, Rolla District, Water Resources Division, U. S. Geological Survey and to Mr. Vern Alexander, Area Engineer, U. S. Weather Bureau, Kansas City, Missouri. The study would have been impossible without the aid of these individuals and their agencies. Although some official data were used, the studies made and the conclusions reached are entirely those of the author.

Deep appreciation is offerred to my wife for her aid in preparation of the manuscript and for typing the thesis and for helping to make the time available for this study.

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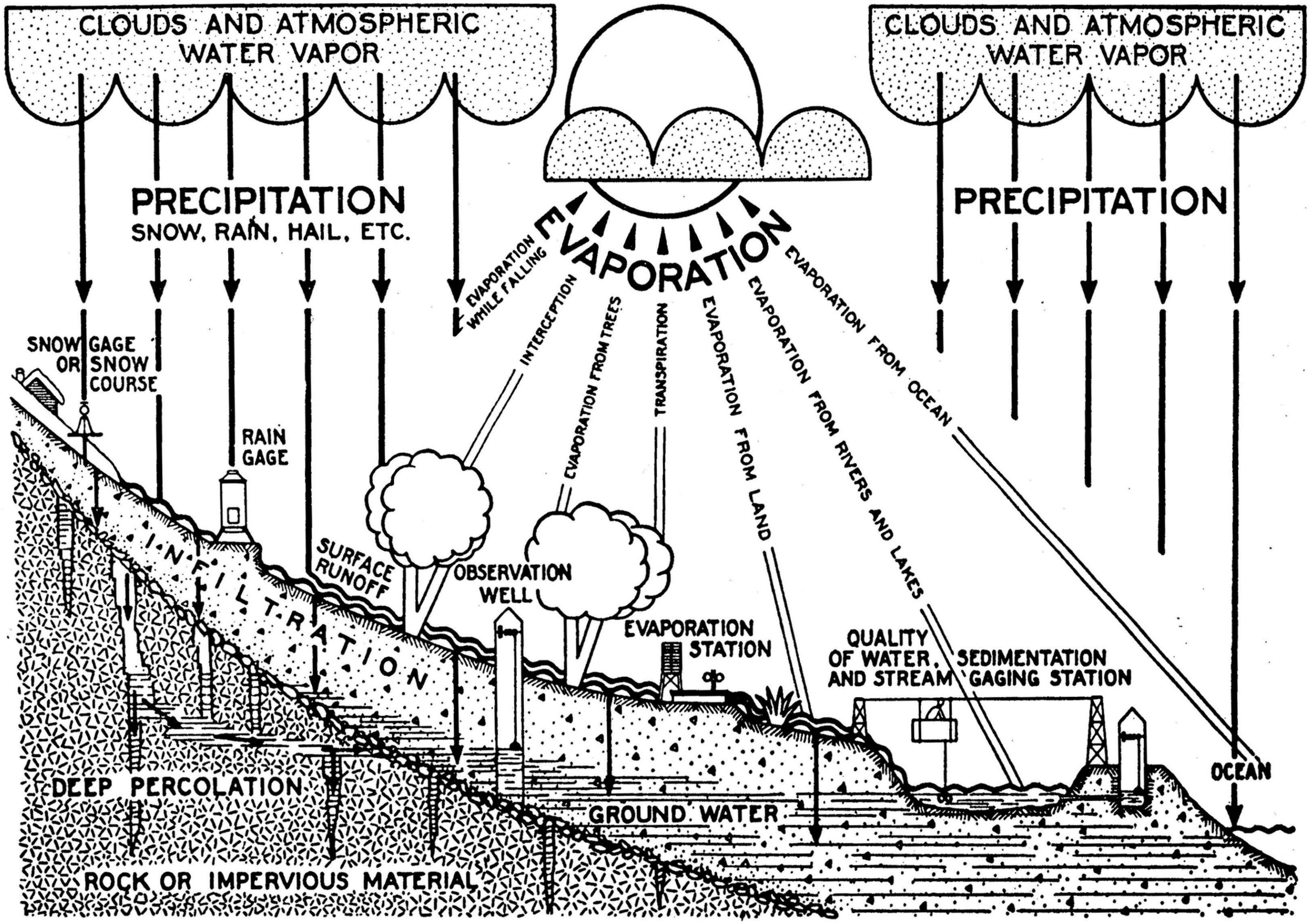

Fig. 1.—The Hydrologic Cycle

INTRODUCTION

Hydrology is the science treating of water from the time it hits the earth until it leaves the earth. This never ending movement of water is called the "hydrologic cycle" and is best summarized graphically (fig. 1). (1)

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(1) Thorndike, Saville, Basic Principles of Water Behavior, Headwaters Control and Use, U.S.D.A., Washington, D.C., April, 1937, p. 1

The hydrologist is primarily concerned with rainfall, runoff and evaporation. One of the basic aims of the science is to compute the surface runoff from any rain on a given area. Surface runoff is here considered as that water which reaches the channels without penetrating the ground, plus subsurface storm flow. Subsurface storm flow is slower than surface runoff but faster than ground water flow. There is no clear division between surface runoff and subsurface flow and the two are considered as surface runoff in this study.

"A problem of prime importance to the river forecaster is that of estimating what portion of the rain falling during a storm will be absorbed by the soil and what portion will run off the land surface, thus contributing to flood flows. This problem is directly related to the moisture content of the soil and, consequently, observations of soil moisture should be of direct benefit in flood forecasting. Moreover, soil-moisture data are a valuable adjunct to the climatological records which for many years have been collected by the Weather Bureau." (2)

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(2) U.S. Weather Bureau, Installation and Operation of a Soil-Moisture Station, Provisional Bulletin, p. 3, 1949.

Small area drainage basins are particularly important in highway engineering. A few years ago 51 percent (3) of all funds spent for State-Federal water way

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(3) Searcy, J. K., Hydrology of Small Drainage Areas, Thesis, Missouri School of Mines and Metallurgy, p. 2, 1952.

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structures were for spans of 20 feet or less. "The hydrologic data available for the design of small drainage structures is pitifully small when one considers the investment that is being made in such structures." (4)

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(4) Izzard, Carl F., Progress Report--Highway Research Board, Research Paper No. 11-B, p. 3, 1950.

In recent years the U.S. Geological Survey, Water

Resources Division, has directed considerable work toward the collection of basic data on small drainage areas. This information should prove invaluable to state where these studies are going on with the present trend in increased highway construction. Any additional information on the rainfall runoff relation of a small watershed would be of practical value because of the short periods of record of existing data and in many cases the complete absence of data.

There are many variables in the rainfall runoff relationship for any drainage basin; total precipitation, rate of precipitation, soil moisture, surface slope, type of vegetation, type of soil, distribution of precipitation, temperature, humidity, season of the year, etc. The many variables become more complex as the size of the drainage area is increased. If the drainage area is decreased, the variables become less complex but an additional error is introduced in expanding the relationships to an area of larger size for practical application.

This thesis is directed toward the collection of basic data on soil moisture in relation to runoff. A natural drainage basin of 0.227 square miles (measured by transit stadia survey) was selected for this study.

REVIEW OF LITERATURE

There is evidence that rainfall measurements were made in India as early as the fourth century B.C. and Nile River Floods were noted by the Egyptians many years before the birth of Christ, but hydrology as we now know it is a young science. One of the earliest modern texts, "Notes on Hydrology" by Daniel W. Mead, was published in 1904 and expanded to a larger and more thorough work in 1919. The "Elements of Hydrology" by Adolph F. Meyer was published in 1917. These books represented a start on quantitative research that is being carried on to the present. Modern industrial demands for electric power and river navigation, along with national interests on flood control and conservation of natural resources, have stimulated the growth of hydrology in the last few years. Several books have been published and many articles written for technical publications, along with the many engineering school bulletins. The bulk of our present knowledge of hydrology has come directly or indirectly from several U.S. Government agencies:

Weather Bureau

Geological Survey, Water Resources Division

Bureau of Reclamation

Department of Agriculture

Corps of Engineers

The work of these agencies has been published through

Their many government publications and by employees writing articles for technical publications, mainly through the American Society of Civil Engineers and the Transactions of the American Geophysical Union.

The normal laboratory method for determining soil moisture by direct sampling is not suitable for runoff studies and many methods have been devised. In 1897, Bardner [5] proposed a method for the measurement of soil

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(5) Linsley, R. K., M. A. Kohler and J. L. H. Paulhus, Applied Hydrology, p. 296, 1949.

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moisture by electrical resistance of the soil. His plan was to bury two electrodes in the ground and measure the electrical resistance between them. This method proved to be unsatisfactory because of changes in salt content of the soil and variable contact resistance between the soil and the electrodes. Shaw and Bauer [6] have shown

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(6) Ibid.

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that the heat conductivity of the soil is a reliable index of soil moisture. Many types of soil moisture meters have been developed in the last few years using the changing properties of a porous block and rating these properties to soil moisture. The block's moisture content determines its heat conductivity, electrical resistance, and capacitance.

The electrical resistance method for determining soil moisture developed by G. J. Bouyoucos and A. H. Mick (7) was used in this study.

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(7) Bouyoucos, G. J. and A. H. Mick, An Electrical Resistance Method for the Measurement of Soil Moisture, Michigan State College. Technical Bulletin 172, April, 1940.

Colman and Hendrix (8) introduced the idea of using

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(8) Colman, E. A. and T. M. Hendrix, The Fiberglas Electrical Soil-Moisture Instrument, Soil Science, Vol. 67, pp. 425-438, 1949.

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fiberglas units which gave reliable results from saturation to the wilting point but they did not respond properly after prolonged drying. (9) R. E. Youker (10)

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(9) Youker, R. E. and F. R. Dreibelbis, An Improved Soil-Moisture Measuring Unit for Hydrologic Studies, Transactions, American Geophysical Union, Vol. 32, pp. 447-449, June, 1951.
(10) Ibid.

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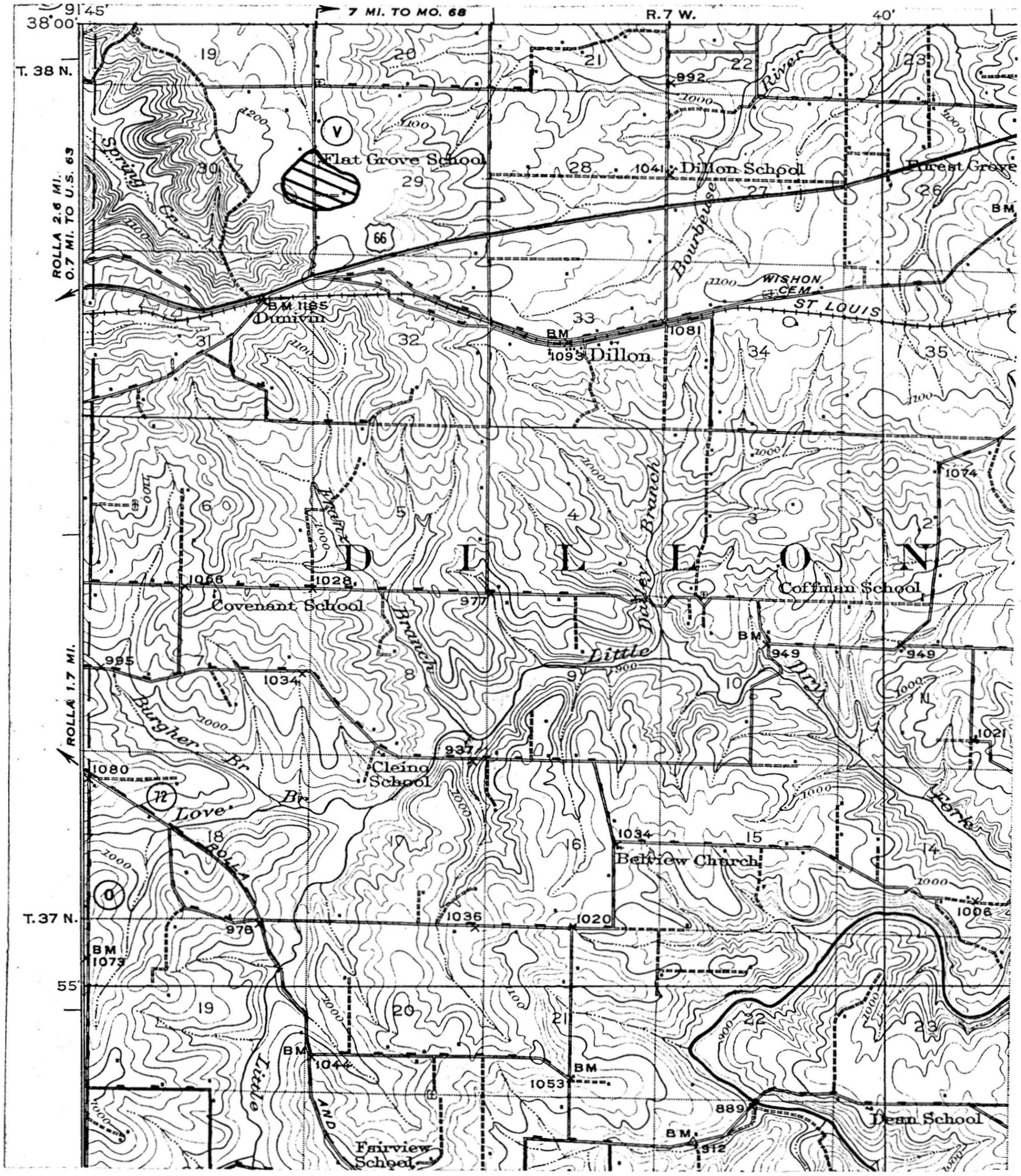
developed an improved block from the Bouyoucos plaster block by placing fiberglas over the electrodes in the plaster. This block is reported to have good resistance relationship to the saturation point but commercial blocks were not available of this type and the ones manufactured by the writer did not seem as good as the Bouyoucos blocks that were used in the study. Mr. Verne Alexander, Area Engineer, U.S. Weather Bureau, Kansas City, Missouri, has devoted considerable spare time to soil moisture-runoff studies. There is need for additional research on an improved soil moisture block or on some other method for determining soil moisture in the undisturbed state without direct sampling.

DISCUSSION

In January, 1952, with the aid of Mr. H. C. Bolon, District Engineer, U. S. Geological Survey, Water Resources Division, Rolla, Missouri, a small drainage area, "Lanes Fork near Rolla" (fig. 2) was selected for the study.. This small stream is in the northwest part of the Meramec River basin and is part of the headwater of the Bourbeuse River, which empties into the Meramec, which, in turn, empties into the Mississippi River 18 miles below St. Louis, Missouri. The Geological Survey had installed a temporary recorder on "Lanes Fork near Rolla" in August, 1951, to study the time of travel of peaks from this temporary recorder to another recorder located 7 3/4 miles downstream. After selection of the area, the recorder was fitted with a tape to show gage height and a concrete slab was poured around the base of the 18 inch corrugated pipe stilling basin to check settlement. The recorder (fig. 3) is a model A-35, manufactured by Stevens Instrument Company in 1951. The recorder chart (fig. 23) is controlled by a weight driven clock that pulls the paper through the instrument at a constant rate of 2.4 inches per day. The water elevation is marked on the recorder chart by an ink pen actuated by a float on the water surface in the stilling well. This gives continuous record of all water elevations. The position of the pin in relation to the water elevation was checked



Scale, 1/62,500--Contour Interval, 20 feet

FIG. 2 MAP SHOWING LANES FORK DRAINAGE AREA periodically and marked on the recorder chart.

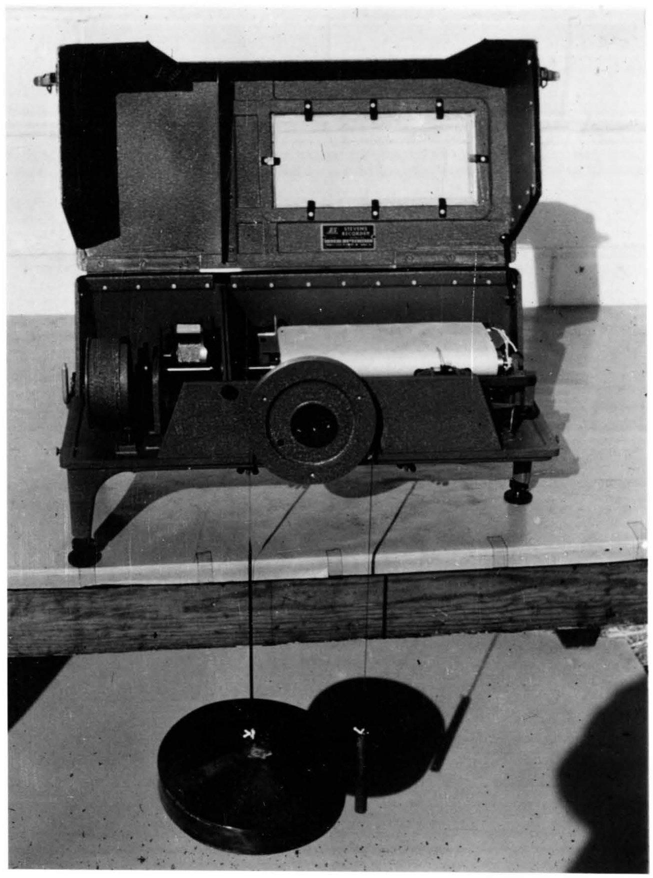


FIG. 3 STEVENS WATER STAGE RECORDER MODEL A-35 SHOWING TAPE WITH FLOAT AND COUNTERWEIGHT

Two out-staffs showing water elevation were installed on each side of the stream, 3 feet downstream from the recorder (fig. 4). A knife edge "V" notched weir was constructed in a concrete cut-off wall (fig. 5) 10 feet

Downstream from the recorder. The knife edges of the weir were made from road grader scraper blades set in concrete.

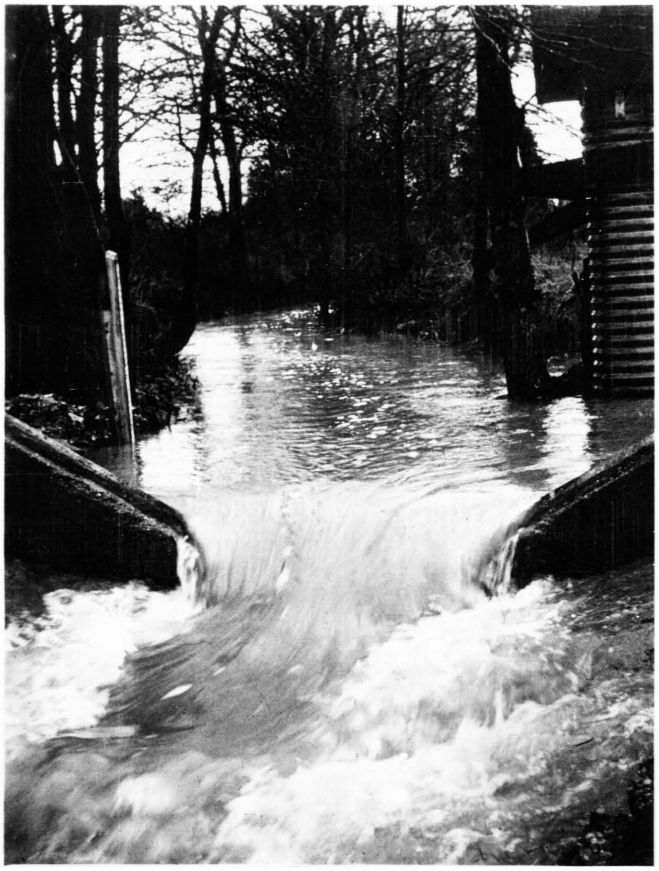


FIG. 4 RIGHT STAFF GAGE AND RECORDER INSTALLATION

The concrete cut-off wall extends into each bank to undisturbed soil and through the gravel bottom of the stream bed to hard pan. This wall is to cut off flow of water through the gravel. A concrete apron 4 feet wide was constructed on the downstream side of the cut-off wall to prevent undercutting from flow through the weir. The banks of the stream were stablized with riprap 4 feet upstream from the weir and 6 feet downstream. The channel below the weir was straightened and cleared to help get-away conditions and prevent submergence of the weir.

FIG. 5 LEFT STAFF GAGE AND WEIR

Levels were run to the two out-staffs, to the water level inside the stilling well, to the weir, and to three bench marks set in the immediate area to check settlement or change in any of the relationships. The "V" notched weir was rated for discharge in relation to the recorder gage height. The point of zero flow was taken from levels and checked by observation. The lowest measurement was made by observing the time required to fill a bucket of known volume. The rest of the measurements were made with standard current meters (fig. 6). These meters were rated in the Bureau of Standards laboratory.

FIG. 6 STANDARD (LARGE) AND PYGMY CURRENT METERS

A mean curve was drawn through the discharge measurements as shown in Table 1, allowing equal weight to all measurements (fig. 7).

Discharge measurement number 7 will be given in detail to show method used. On April 4, 1952, the following discharge measurement was made with a standard price current meter, No. 1735, rated in the U.S. Bureau of Standards in July, 1951. The meter was free and clean prior to the measurement and the cups spun free before and after the measurement. The cross section

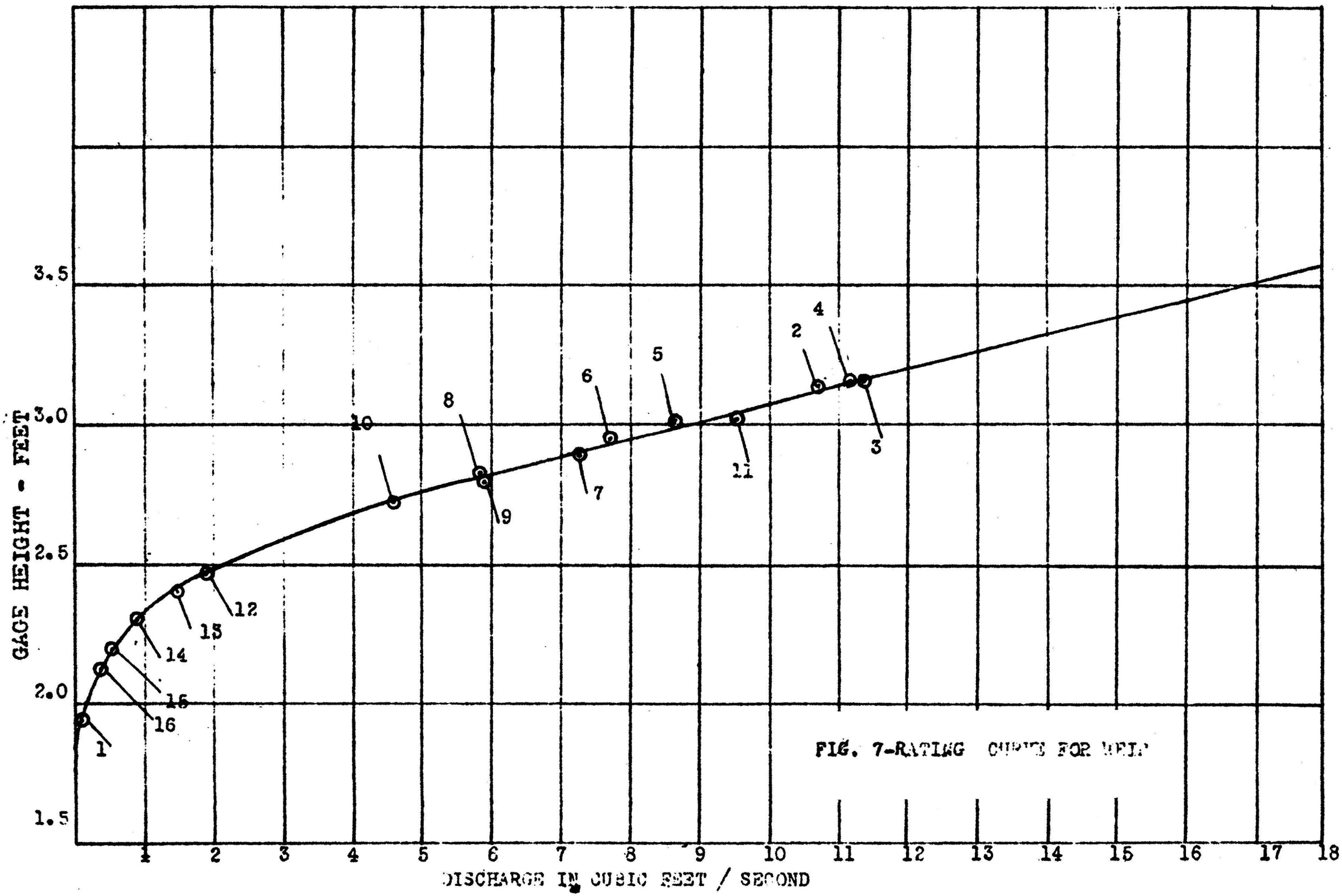


FIG. 7-RATING CURVE FOR WEIR

measured was about 25 feet below the control weir and was relatively the same in all measurements. The cross section was uniform with an improved concrete bottom and was 4 feet wide.

TABLE 1 -- DISCHARGE MEASUREMENTS

No.	Area in Sq. Ft.	Mean Vel. Ft./sec.	Gage Ht. in Ft.	Discharge c.f.s.	G.H. Change while Meas.
1			1.945	0.0252	0
2	3.14	3.53	3.15	11.1	-0.005
3	3.16	3.57	3.145	11.3	+0.01
4	3.20	3.37	3.132	10.8	-0.005
5	2.79	3.07	3.008	8.56	-0.005
6	2.61	2.93	2.945	7.65	-0.01
7	2.59	2.78	2.895	7.21	-0.01
8	2.36	2.49	2.835	5.89	-0.01
9	2.40	2.47	2.795	5.93	-0.01
10	2.16	2.12	2.735	4.58	-0.01
11	3.06	3.13	3.005	9.59	+0.01
12	1.48	1.30	2.480	1.93	-0.03
13	1.38	1.09	2.400	1.50	-0.02
14	1.11	0.752	2.300	0.846	-0.02
15	0.845	0.593	2.215	0.501	-0.02
16	0.695	0.550	2.160	0.382	-0.01

The flow was fairly steady with a slight surge. The control was clean and very little debris was moving in the stream.

Time	Water Stage Recorder Tape reading	Left staff Gage	Right staff Gage
01:43p.m.	2.90	2.90	2.90
01:45p.m.	Start measurement at Right water's edge		
01.55p.m.	Finish measurement at Left water's edge		
01.57p.m.	2.895	2.89	2.89

Correct mean gage height 2.895 feet

Distance from Initial point	Depth	Observation Depth from Water Surface	Revolutions of Meter	Time in Seconds
Right water's edge				
0	.62	Estimate velocity equal 2/3 following velocity		
.5	.62	.25	40	48
1.0	.64	.26	40	41
1.5	.66	.26	60	45
2.0	.66	.26	60	42
2.5	.66	.26	80	48
3.0	.66	.26	80	48
3.5	.64	.26	60	44
4.0	.64	Estimate velocity = 2/3 preceding Velocity		
Left water's edge				

Distance from Initial point	Mean velocity Ft./Second	Area of Section Sq. Ft.	Width of Section Ft.	Discharge in c.f.s.
0	1.24	0.16	0.25	0.198
.5	1.86	.31	.5	.577
1.0	2.17	.32	.5	.695
1.5	2.95	.33	.5	.975
2.0	3.16	.33	.5	1.042
2.5	3.69	.33	.5	1.217
3.0	3.69	.33	.5	1.217
3.5	3.02	.32	.5	.966
4.0	2.01	.16	.25	.322
			Total	7.21

The mean velocity is 2.78 feet/second and the mean area is 2.59 square feet.

The measurement was made from an improvised bridge over the cross section and the only obstruction not normal to the channel was the wading rod and current meter.

This measurement is representative of all discharge measurements except number 1, which was made by catching water in a large bucket below the weir. The water depths were measured with a wading rod graduated to 0.1 of a foot and the widths were marked off with a metallic tape. The revolutions of the meter were audibly counted through clicks in earphones connected to the meter shaft and the time measured with a stop watch. The velocities were taken directly from a rating table furnished with the meter from the U.S. Bureau of Standards. The normal procedure as used by the Water Resources, U. S. Geological Survey, was followed in making all discharge measurements. The discharges for all points in time on the recorder chart were taken from this mean curve for the computation of runoff.

On March 1, 1951, a recording rain gage was installed on the edge of the drainage area near the water stage recorder (fig. 8). The rain gage recorder charts were removed within 24 hours after each rain or at the end of 7 days without rain. A fairly complete record for the period of study was obtained.

The soil moisture was obtained daily according to the method outlined by G. J. Bouyoucos and A. H. Mick. The apparatus consists of absorption blocks, Bouyoucos bridge and electrical thermisters.

The absorption blocks (fig. 9) were made of plaster of paris. It is a very porous material, holding, when

FIG. 8 RECORDING RAIN GAGE WITH SHIELD LIFTED

saturated, about 68% of its dry weight of water and gives good surface contact to electrodes buried in the block, due to its property of expanding upon setting. The pore spaces of plaster of paris are of the proper size to facilitate capillary movement. It rapidly attains equilibrium with its surroundings and does not deteriorate quickly under normal field conditions. The electrodes molded inside the moisture block (fig. 9) were carefully spaced to give comparable readings between blocks. The moisture blocks were manufactured by the Wood and Metal

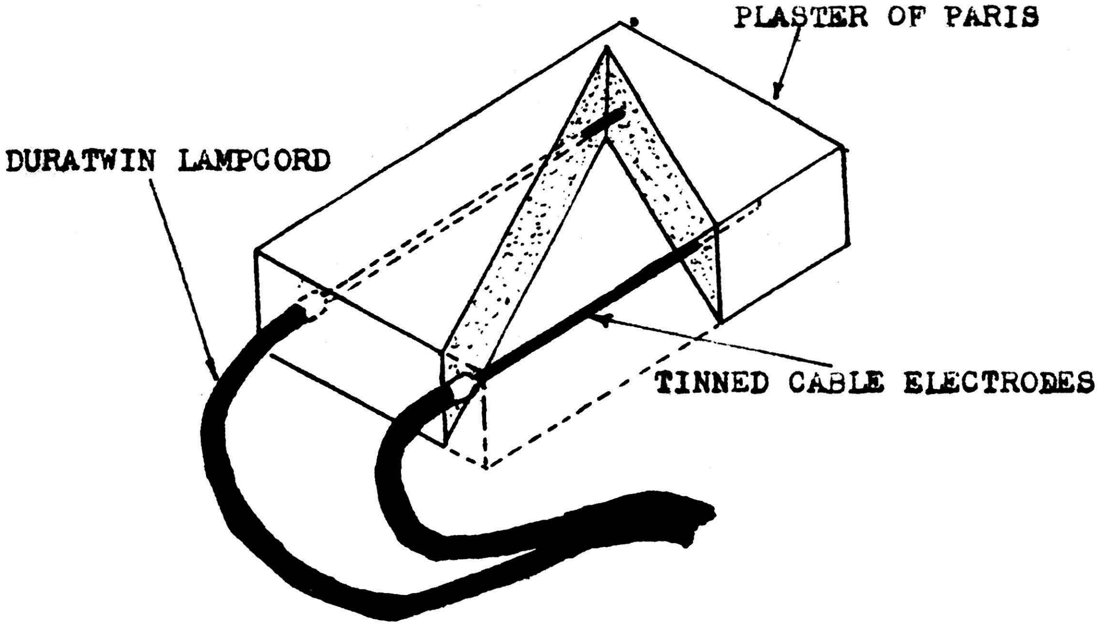


FIG.9 -BOUYOUCOS MOISTURE BLOCK

Products Company, Bloomfield Hills, Michigan.

The Bouyoucos bridge (fig. 10), an adaptation of

FIG. 10 Bouyoucos Bridge

the Wheatstone bridge, was used to measure the resistance of the moisture blocks and temperature elements. A battery operated vacuum tube audio-oscillator supplied 1,000 cycle alternating current to the bridge circuit. Alternating current was necessary because of electrolysis and polarization in the block when direct current was used. By means of ear phones (fig. 12) the circuit was tuned to the "null" point and the resistance read on a logarithmic potentiometer reheostat with a six inch dial.

Temperature changes caused variations in the resistance of the absorption blocks at a constant moisture content. Therefore, soil temperatures were taken

FIG. 11 THERMISTER -- SOIL TEMPERATURE ELEMENT

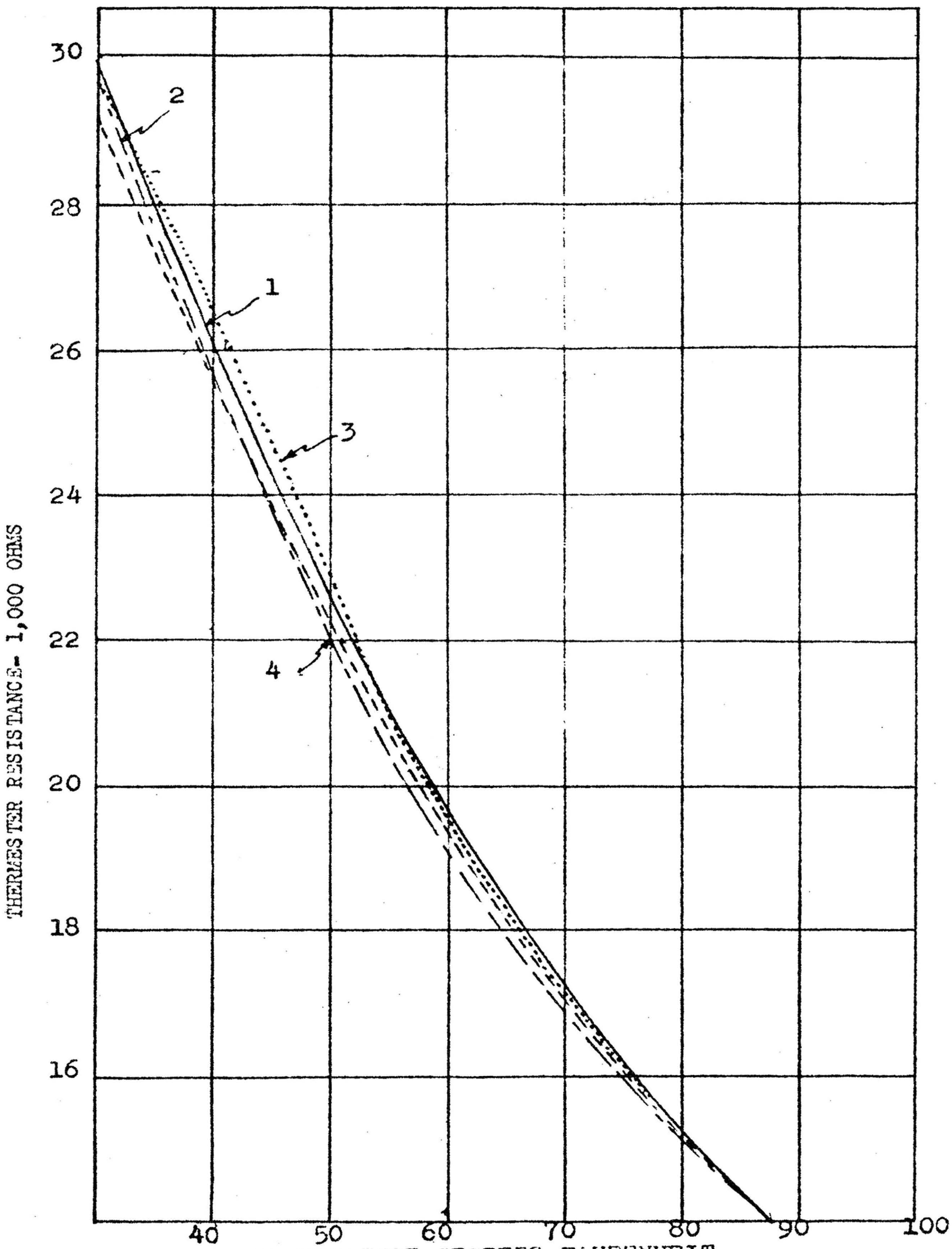
for each block resistance reading. The soil temperature elements (fig. 11) were essentially thermister resistance-elements similar to those used in Weather Bureau radiosondes. The temperature elements were embedded in plastic to protect them from damage when buried in the ground. Each element was calibrated at 32, 50, 68 and 86°F by the U. S. Weather Bureau. A mean curve was drawn through the calibrated points (fig. 14) and corrected temperatures were taken from the curves. All moisture block resistance readings were corrected to 70°F as standard (fig. 22).

FIG. 12 STRAIGHTENED PORTION OF STREAM CHANNEL BELOW WEIR

The moisture blocks and thermisters were buried on a gentle grass covered slope (fig. 15) at depths of 10, 20, 30, 50 and 100 cm., as shown in fig. 16. A hole was dug with a post hole digger to a depth of about 3 feet. This hole was for the pipe support of the shelter house. About 5 feet uphill from the first hole, excavation was started in order to bury the moisture blocks. The sod was carefully removed from approximately a 2 feet square area and dug to a depth of about 2 feet. All soil was

FIG. 13 RECORDER INSTALLATION AND UPSTREAM CHANNEL FROM WEIR

placed on a large canvas in order of removal from the hole. A 6 inch diameter hole was excavated on the up-slope side of the 2 feet square hole (fig. 17) and carried to a depth of 100 cm. from the surface. Small



TEMPERATURE-DEGREES FAHRENHEIT

FIG. 14 SOIL TEMPERATURE CALIBRATION CURVES cavities were dug in the upslope side of the excavation with the aid of a screwdriver, and the moisture block and thermister placed on the same level about 4 inches apart. The blocks and thermisters were carefully tamped

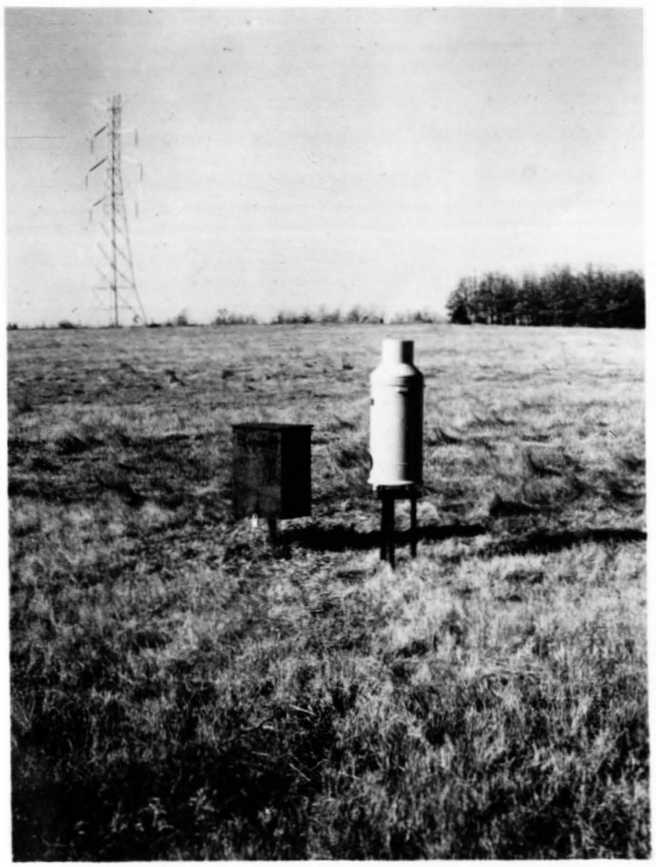


FIG. 15 INSTALLATION OF SOIL MOISTURE BLOCKS AND RAIN GAGE

in with soil from the same level. The soil was carefully tamped back in the excavation in the reverse order in which it was taken out and sealed with the sod cap.

FIG. 16 - INSTALLATION OF SOIL MOISTURE BLOCKS

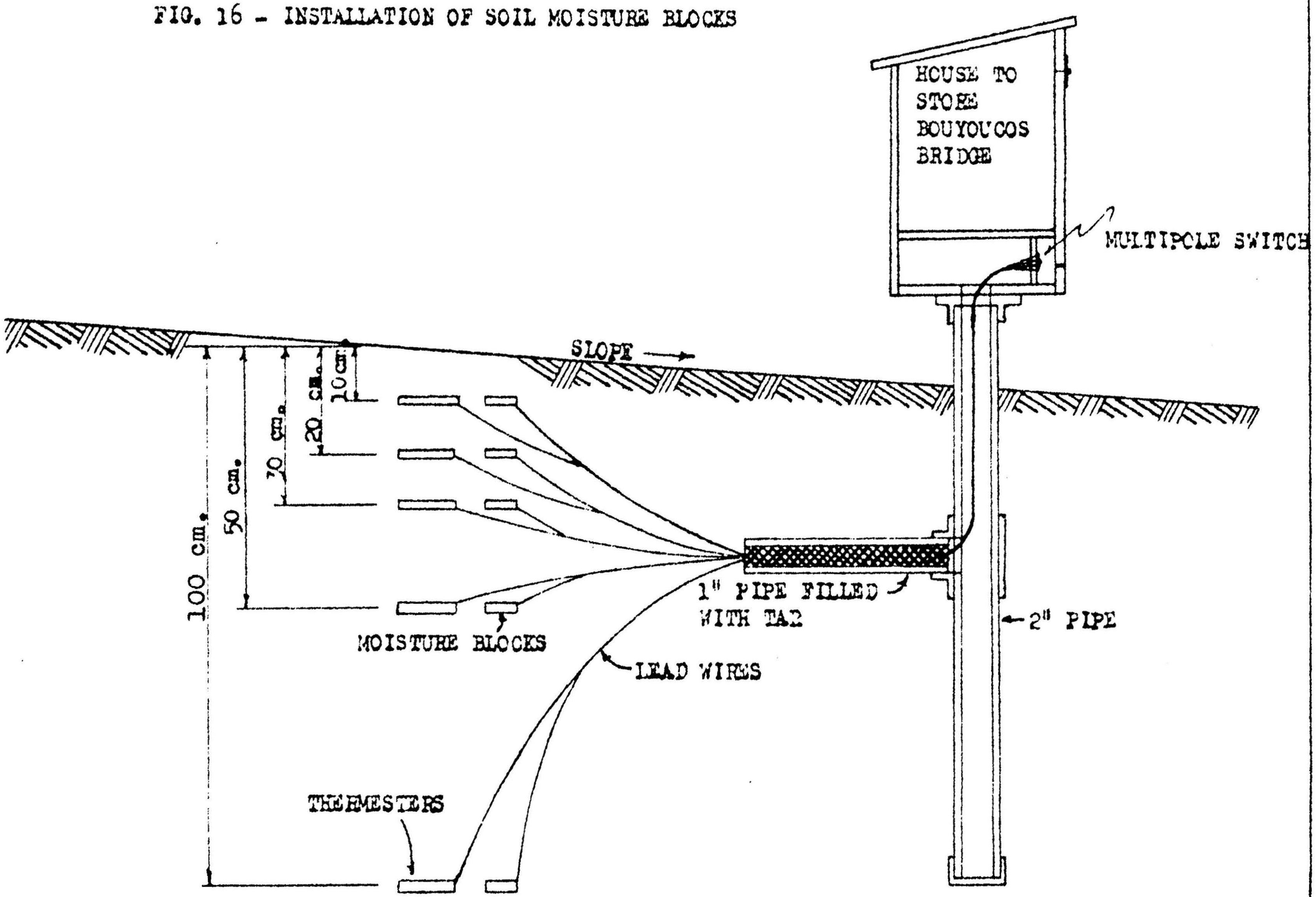
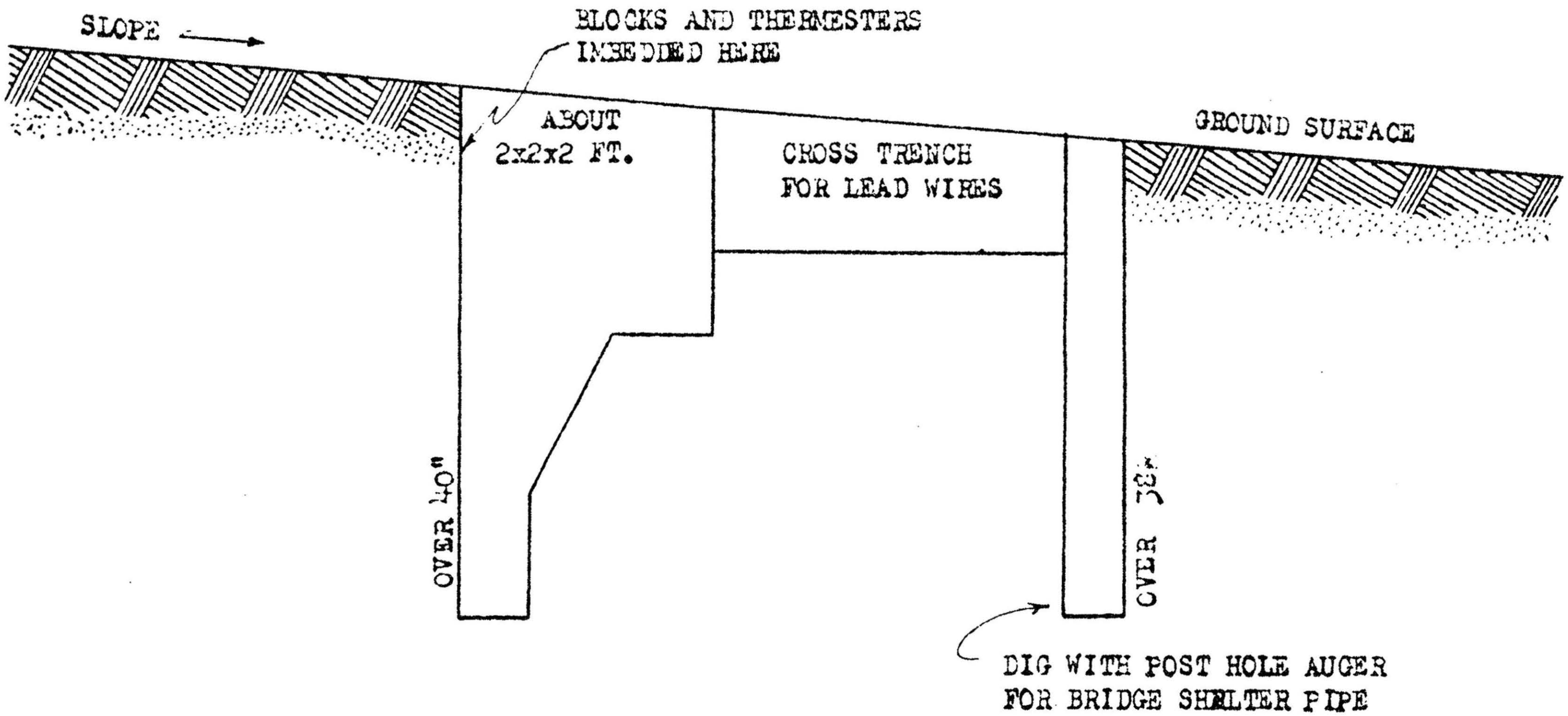


FIG. 17 - CROSS SECTION OF EXCAVATION FOR INSTALLATION OF MOISTURE BLOCKS



About 1,000 gr. of soil sample was taken from each depth for future tests. The moisture block and temperature resistance readings were taken daily. As the resistance at different levels varied, soil samples were taken in the field and the soil moisture, per cent of dry weight, determined in the laboratory.

The soil moisture determinations of Dec. 15, 1952, will be given in detail to show procedure.

At 4:30 p.m. the resistance of the soil moisture blocks and thermisters was observed.

Depth	Resistance of Moisture Block-Ohms	Resistance of Thermister, Ohms
10 cm.	1,060	27,500
20 cm.	800	26,000
30 cm.	610	24,000
50 cm.	1,080	24,000

A hole was excavated with a post hole digger and soil samples taken from the various depths and placed in the metal sample cans. The cans were previously weighed and marked for the proper depth. The covers were placed on the cans and taken to the laboratory and weighed.

The sample cans were then placed in the drying oven, temperature 105°C, until a constant weight was reached.

The cans were removed Dec. 17, 1952, and placed in a desicator to cool and then weighed again.

Depth	Weight wet soil + can - grams	Weight can gr.	Weight Wet Soil-gr.
10 cm.	495.5	97.6	397.9
20 cm.	500.3	98.8	401.5
30 cm.	469.2	98.1	371.1
50 cm.	483.5	100.1	383.4

Depth	Dry Wt. Soil + Can gr.	Weight Can gr.	Dry Weight Soil gr.
10 cm.	418.7	97.6	321.1
20 cm.	431.8	98.8	333.0
30 cm.	394.9	98.1	296.8
50 cm.	411.9	100.1	311.8

The percent soil moisture was taken as the percent of the oven dry weight.

Depth	Wt. Wet Soil gr.	Dry Wt. Soil gr.	Wt. Water gr.	% Soil Moisture
10 cm.	397.9	321.1	76.8	23.9
20 cm.	401.5	333.0	68.5	20.6
30 cm.	371.1	296.8	74.3	25.0
50 cm.	383.4	311.8	71.6	23.0

The resistance reading for the thermisters were entered on the temperature calibration curve (fig. 14) and the temperature in degrees Fahrenheit computed. The moisture block resistance readings were corrected to

70°F. by entering Fig. 22 with the observed soil temperature and the block resistance, and the block resistance for 70°F interpolated.

Depth	Soil Temp. °F	Block Cor. Res. Readings Ohms	% Soil Moisture
10 cm.	36	610	23.9
20 cm.	38.5	510	20.6
30 cm.	46.5	460	25.0
50 cm.	43.5	740	23.0

These resistances and temperatures were plotted on the soil moisture graph (fig. 18) to develop the soil moisture curves. This procedure was followed in all soil moisture determinations.

The curves were further checked in the laboratory by taking resistance blocks that had a comparable resistance to the ones buried in the ground. The blocks were compared by placing the blocks in distilled water at 70°F and measuring the resistance. A number 10 can was punched with several very small holes in the bottom and 3 inches up around each side. A sample of soil with water added to beyond the saturation point was placed in the can and a moisture block compacted in the upper 3 inches of soil. This procedure was carried on for each soil level. The cans of soil were air dried and resistances measured and soil moisture determined as the

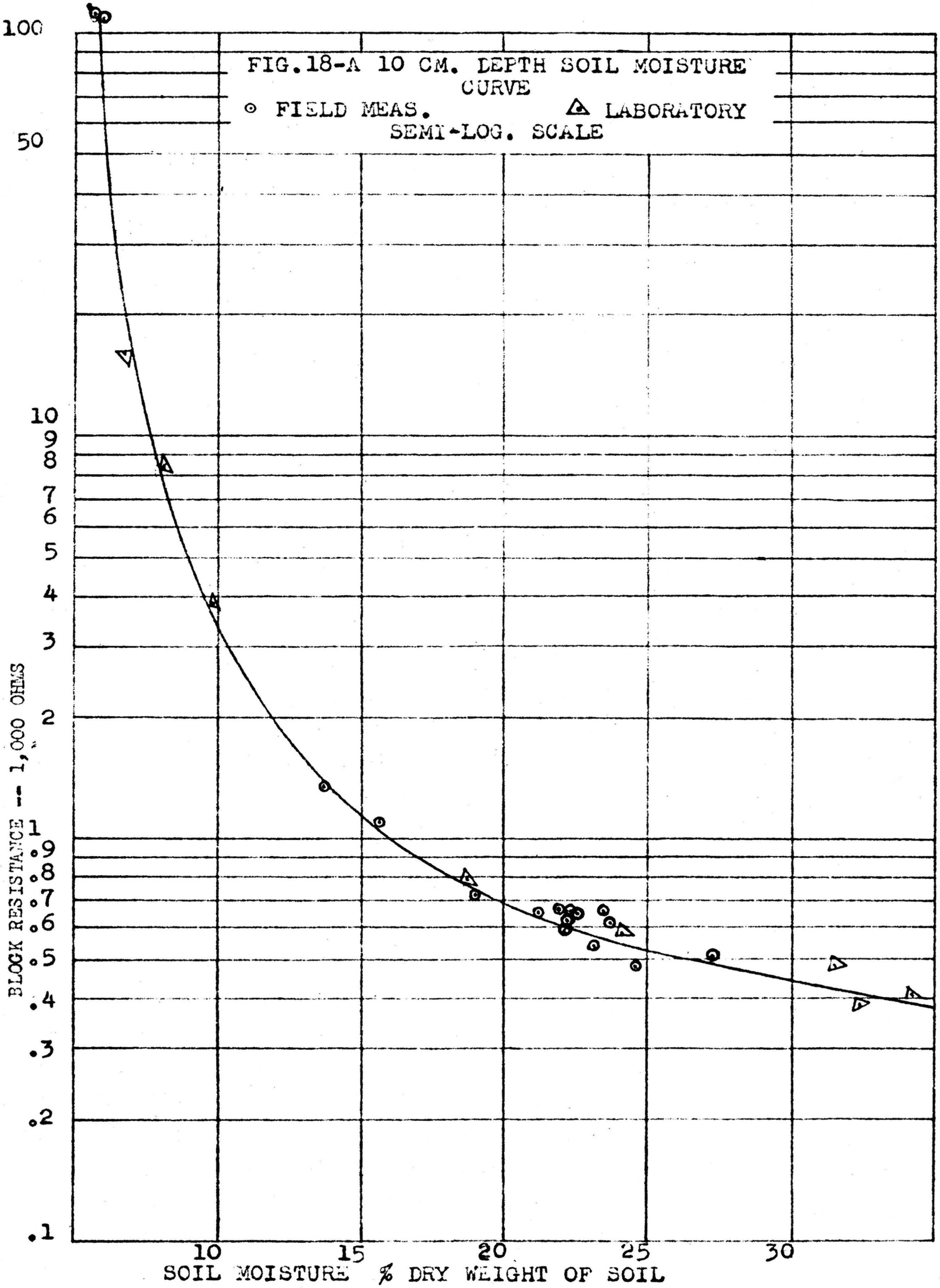


FIG. 18-A 10 CM. DEPTH SOIL MOISTURE CURVE
FIELD MEAS.
LABORATORY
SEMI-LOG. SCALE
BLOCK RESISTANCE - 1,000 OHMS
100
50
10
9
8
7
6
5
4
3
2
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
10
15
20
25
30
SOIL MOISTURE % DRY WEIGHT OF SOIL

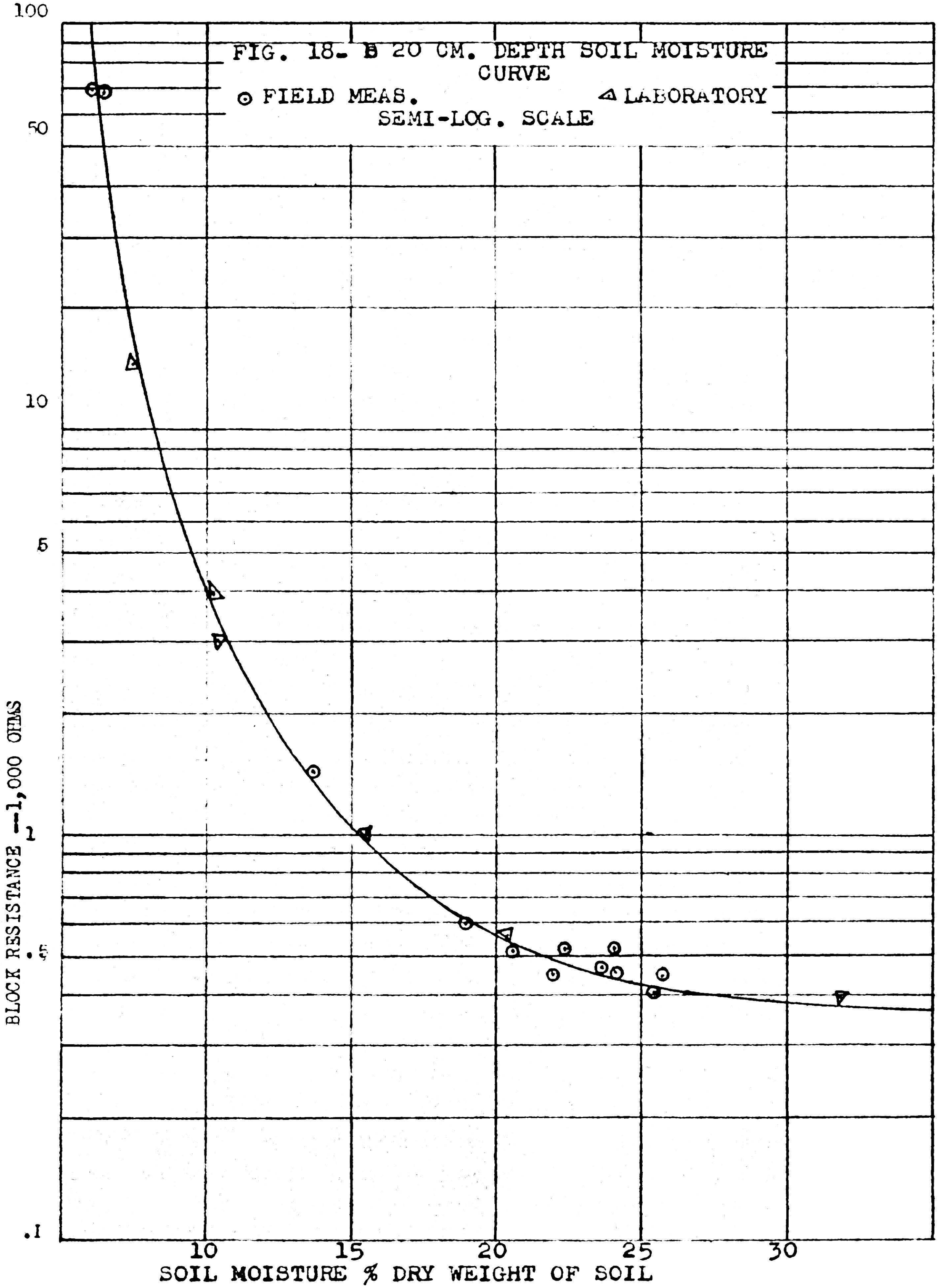


FIG. 18- B 20 CM. DEPTH SOIL MOISTURE CURVE
FIELD MEAS.
LABORATORY
SEMI-LOG. SCALE
BLOCK RESISTANCE —1,000 OHMS
100
50
10
5
1
.5
.1
10
15
20
25
30
SOIL MOISTURE % DRY WEIGHT OF SOIL

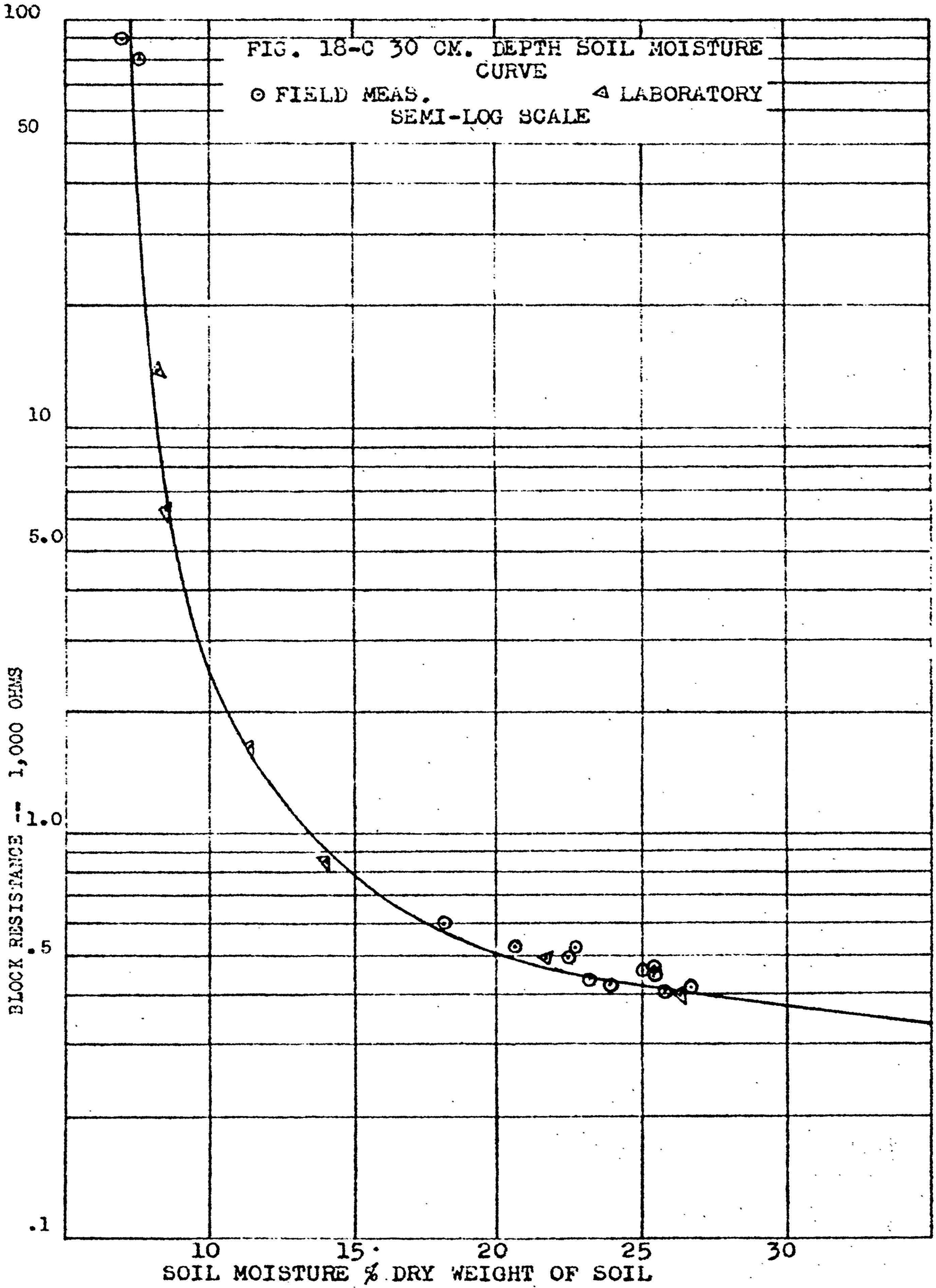


FIG. 18-C 30 CM. DEPTH SOIL MOISTURE CURVE
⊙ FIELD MEAS.
◁ LABORATORY
SEMI-LOG SCALE
100
50
10
5.0
1.0
.5
.1
10
15
20
25
30
SOIL MOISTURE % DRY WEIGHT OF SOIL
BLOCK RESISTANCE -- 1,000 OHMS

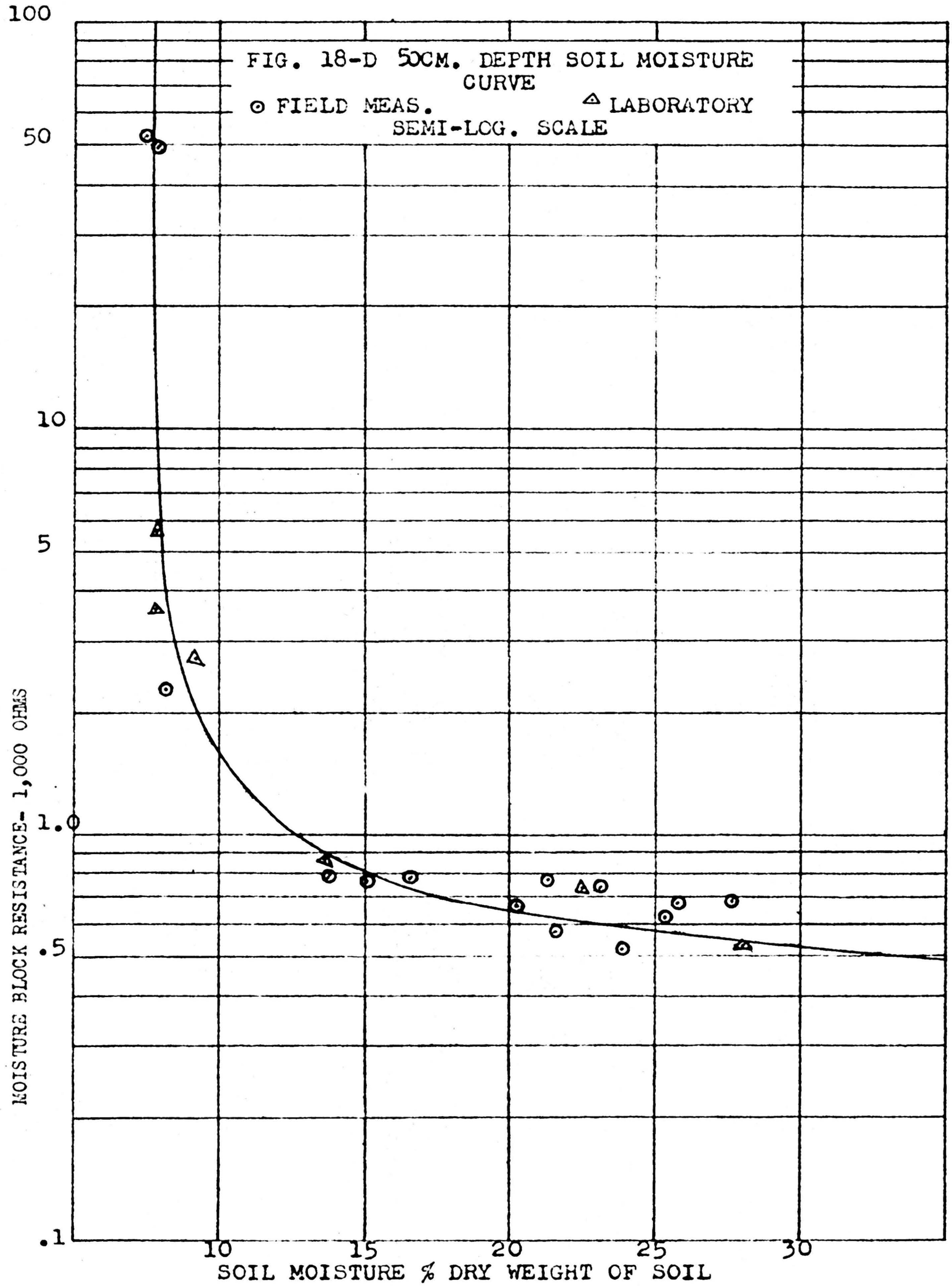


FIG. 18-D 50CM. DEPTH SOIL MOISTURE CURVE
⊙ FIELD MEAS.
△ LABORATORY
SEMI-LOG. SCALE
100
50
10
5
1.0
.5
.1
10
15
20
25
30
MOISTURE BLOCK RESISTANCE- 1,000 OHMS
SOIL MOISTURE % DRY WEIGHT OF SOIL

drying continued. The soil sample was taken approximately equally above and below the block from the soil adjacent to the block. A portion of soil was dug out of the can following each block removed and broken up in order to tamp the block back in again. The soil moisture resistance relationship as determined in the laboratory plots in smaller percentage of a mean curve than those made in the field, due to non-homogeneity of the field soil samples. All points, both laboratory and field, were given equal weight and a smooth curve was drawn. All soil moistures used in the study were taken from the curves.

A closed traverse was run through points on the boundary of the drainage area by means of transit and stadia and the area found to be 0.227 square miles by double meridian distance.

Fig. 19 shows the vegetative cover over the area and the cultivation during the period of study. The vegetation cover of the drainage area is divided into three classes, (1) second growth timber; about 36 acres, (2) Cultivation - corn, about 10 acres, (3) grass land, about 100 acres. The second growth timber is in the NE 1/4 of the drainage area and along with a portion of the Rolla Airport, contributes all of the runoff of the right fork of the stream with the exception of a short strip of highway drainage. All of the cultivated land is in the left fork of the drainage area and is located in the

FIG. 19-A FROM RAIN GAGE LOOKING UPSTREAM

NW 1/4 of the basin. All of the grass land is under pasture except the Rolla Airport area and this is mowed and free from brush. The second growth timber is typical of cut over land in this area and is composed principally of oak trees about 3 inches in diameter, 18 feet tall and thickly spaced. The ground under the trees is covered with a thick leaf mat about 2 inches deep.

The area is relatively flat with an average slope of about 1 percent. The drainage area is well defined

FIG. 19-B LOOKING UPSTREAM FROM COUNTY HIGHWAY "V" IN SECOND GROWTH TIMBER

FIG. 19-C CULTIVATED PORTION OF DRAINAGE AREA

except in the area of the Rolla airfield, where the exact water shed divide is difficult to delineate, due to the flatness of the area.

FIG. 19-D NORTH AREA OF ROLLA AIRPORT IN DRAINAGE AREA

The soil is the Lebanon silt loam, which is widely distributed in small irregular areas throughout the Ozark plateau area (fig. 20). Horizon A is almost a pure silt, very low in organic material. Horizon B is a buff colored silty clay loam with occasional pieces of chert throughout. Horizon C is a buff to yellow colored plastic clay with a lot of chert of all sizes throughout. Horizon D is a hard pan layer of chert fragments cemented together by reddish clay and seems to form an impervious

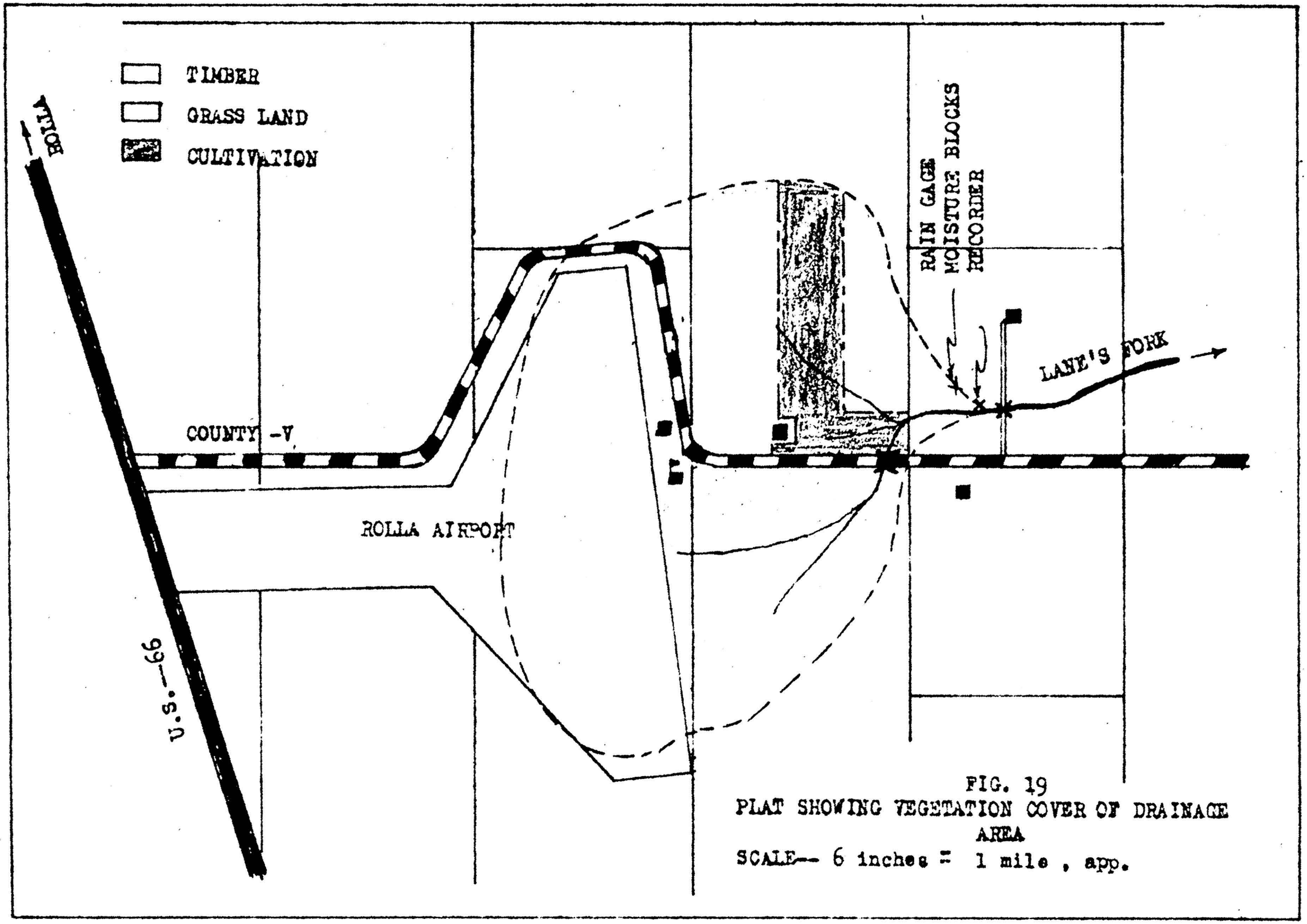


FIG. 19
PLAT SHOWING VEGETATION COVER OF DRAINAGE AREA
SCALE-- 6 inches = 1 mile , app.

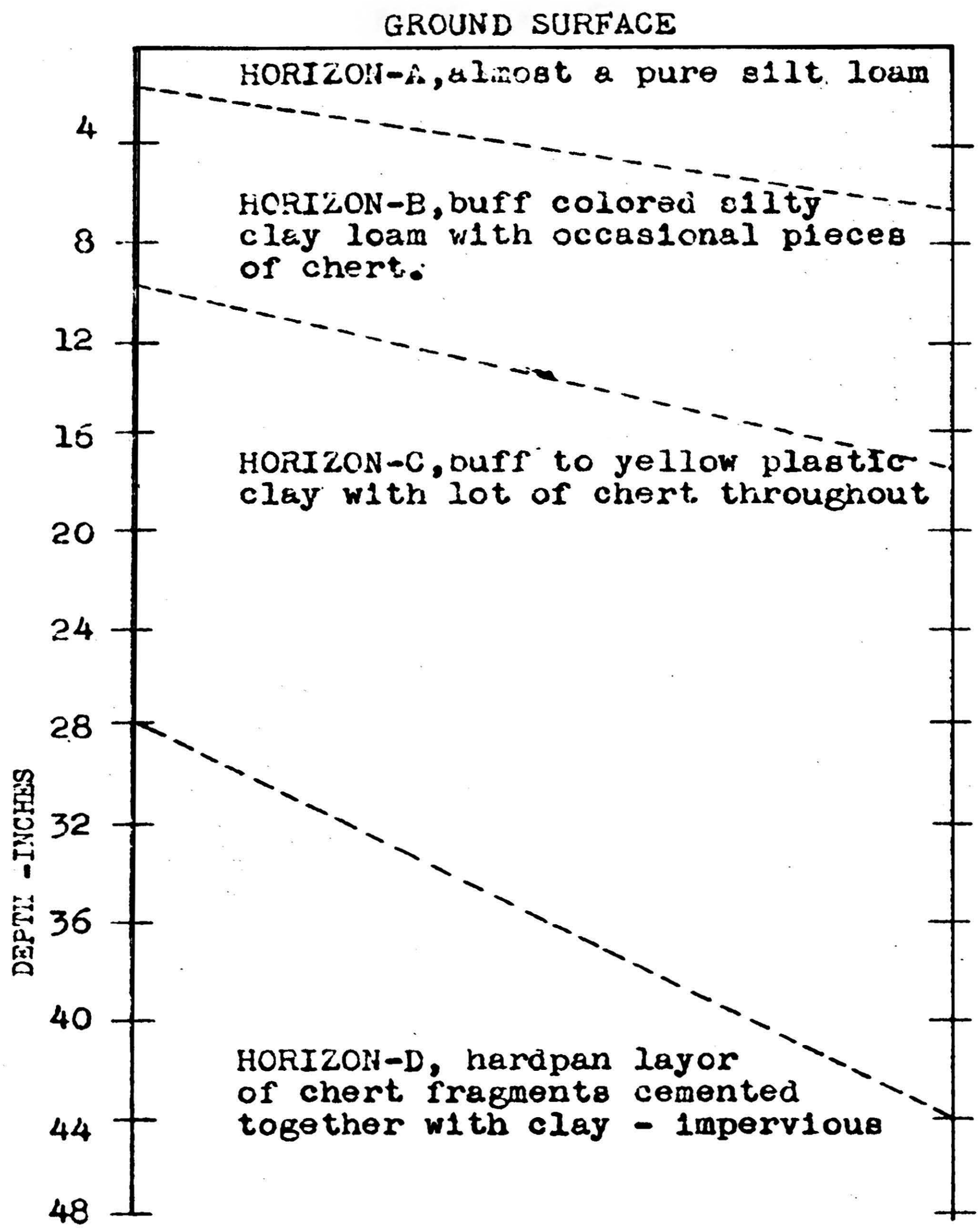


FIG.20, TYPICAL SOIL PROFILE IN AREA

layer to both capillary and percolating water.

A fairly complete record of soil moisture and temperature was obtained for the period of study, except for the few days as shown in Fig. 24. Soil moisture observations were made prior to all rains during the period. The missing days of record during the month of August were due to an electrical short that developed in the low voltage circuit of the Bouyoucos bridge and burned out 3 batteries before the trouble was found. The missing days in the latter part of December were during periods of no rainfall and soil moisture readings were being taken on the laboratory samples.

The 100 cm. depth soil moisture block must have shorted out during installation because the resistance readings were less than when the block was in distilled water and did not increase much as the soil dried out. After direct sampling of the soil at the 100 cm. depth and soil moisture determined with no corresponding change in resistance readings, observations were discontinued at this depth. Since transmission rates are much slower at the 100 cm. depth than in the top soil, little use is made of the available storage space at this depth during periods of rainfall.

The storm of May 24, 1952, will be given in detail

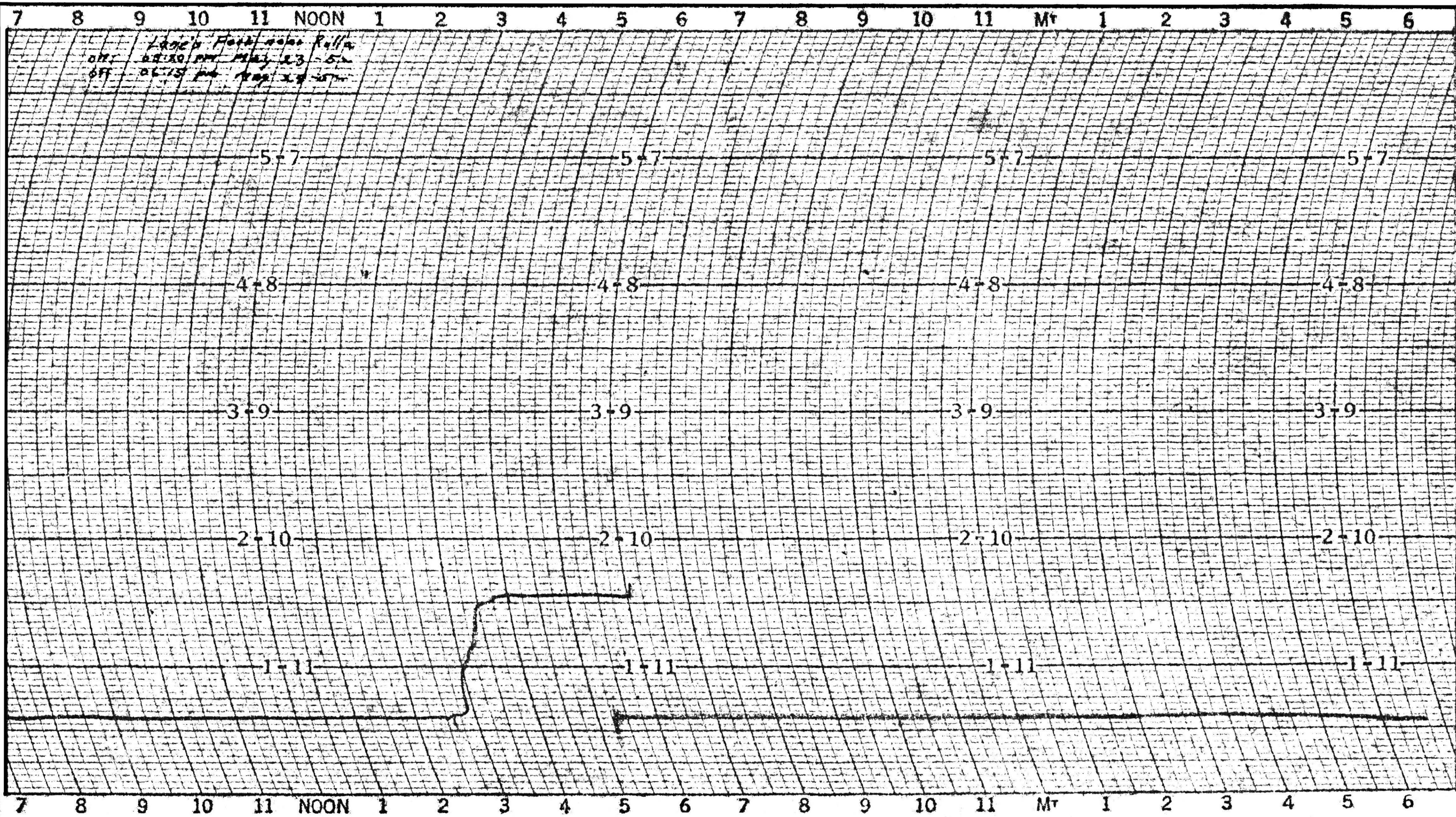


Fig. 21, Rain Gage Chart for Storm of May 24,1952 as an example to show methods used in this study. As noted on the chart from the rain gage (fig. 21), the chart was placed on the rain gage at 05:20 p.m., May 23, and taken off at 06:15 p.m., May 24. The clock was 10 minutes slow when the chart was removed so a time correction had to be applied and it was assumed that the correction was introduced gradually, due to the clock running slow. From the chart, the rain started at 02:37 p.m., May 24, and stopped at 04:00 p.m., May 24. Using a 9 minute time correction at this point on the chart corrects the time the rain started to 02:46 p.m. and stopped to 04:09 p.m., for a duration of 1 hour and 24 minutes and a total rainfall of 0.95 inches. The soil moisture resistance readings were made at 05:25 p.m., May 23.

Depth	Resistance of Moisture Block-Ohms	Resistance of Thermister-Ohms
10 cm.	11,000	18,000
20 cm.	4,900	18,200
30 cm.	620	18,200
50 cm.	1,180	18,800

The thermister resistances were entered on the graph, (fig. 14) and the temperature in °F picked off. The block resistances with the temperature were entered on the chart (fig. 22) and corrected to a standard temperature of 70°F.

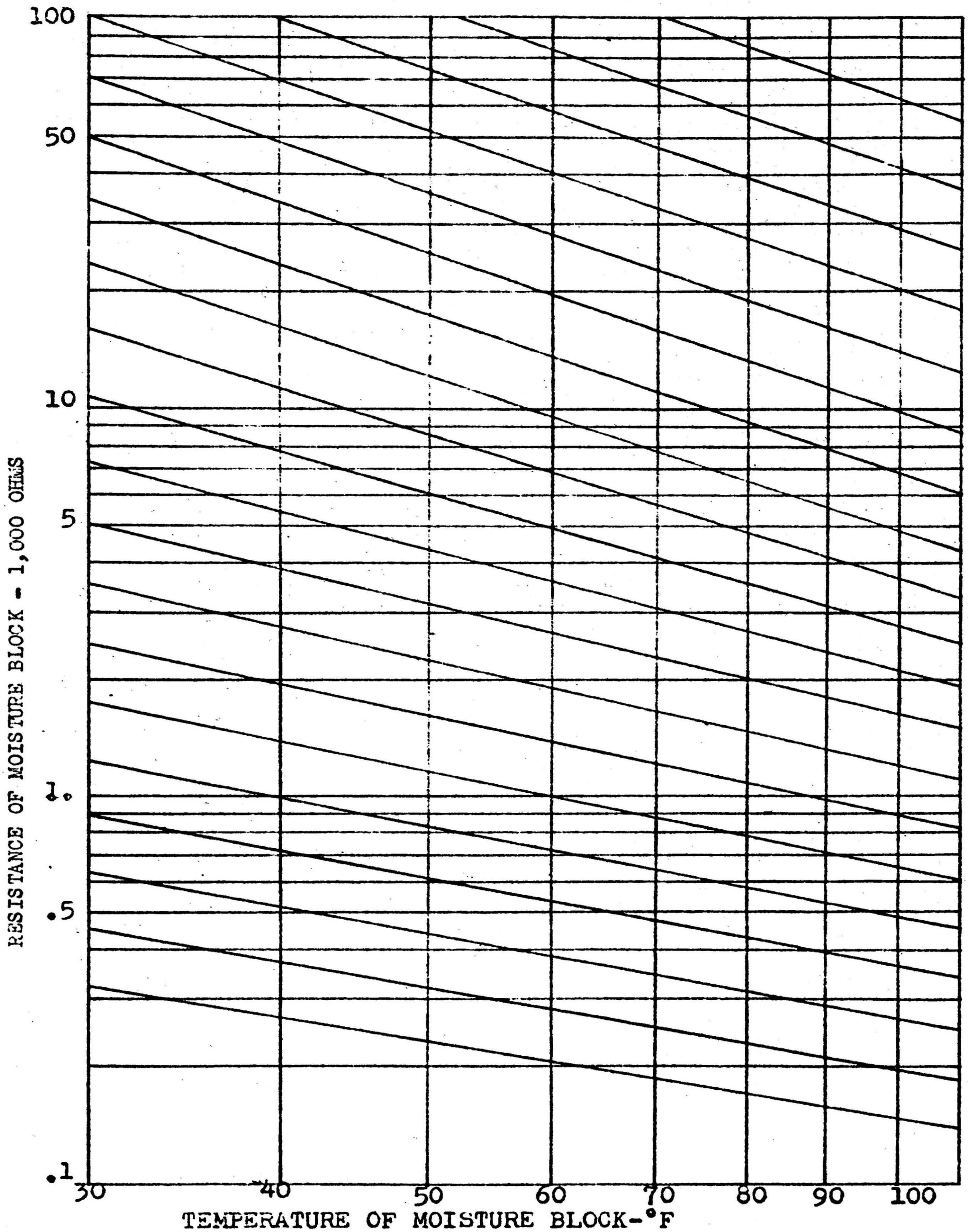

100
50
10
5
1.
.5
.1
RESISTANCE OF MOISTURE BLOCK - 1,000 OHMS
30
40
50
60
70
80
90
100
TEMPERATURE OF MOISTURE BLOCK-°F

FIG. 22

Depth	Temp. °F	Corrected Res. of Moisture Block-Ohms
10 cm.	66.8	10,100
20 cm.	65	4,650
30 cm.	64.8	580
50 cm.	61.3	1,050

The corrected block resistance was entered on the soil moisture curves (fig. 18) and the soil moisture determined.

Depth	Soil Moisture - % Dry Weight
10 cm.	7.3
20 cm.	9.3
30 cm.	17.7
50 cm.	12.5

The gage height graph from the water stage recorder (fig. 23) for May 24, 1952, shows the water level started to rise at 02:00 p.m. An inspection was made on the recorder on May 19 and the time was 1 hour slow and another inspection was made on May 27 and the time was 1 hour and 15 minutes slow, so a correction of 1 hour and 10 minutes slow was assumed. This corrects the time the water level started to rise to 03:10 p.m., or 24 minutes after the rain started. The stream bed was dry at the time the rain started and depression storage in the channel had to be satisfied before flow started. The two crests on the recorder gage height graph are typical

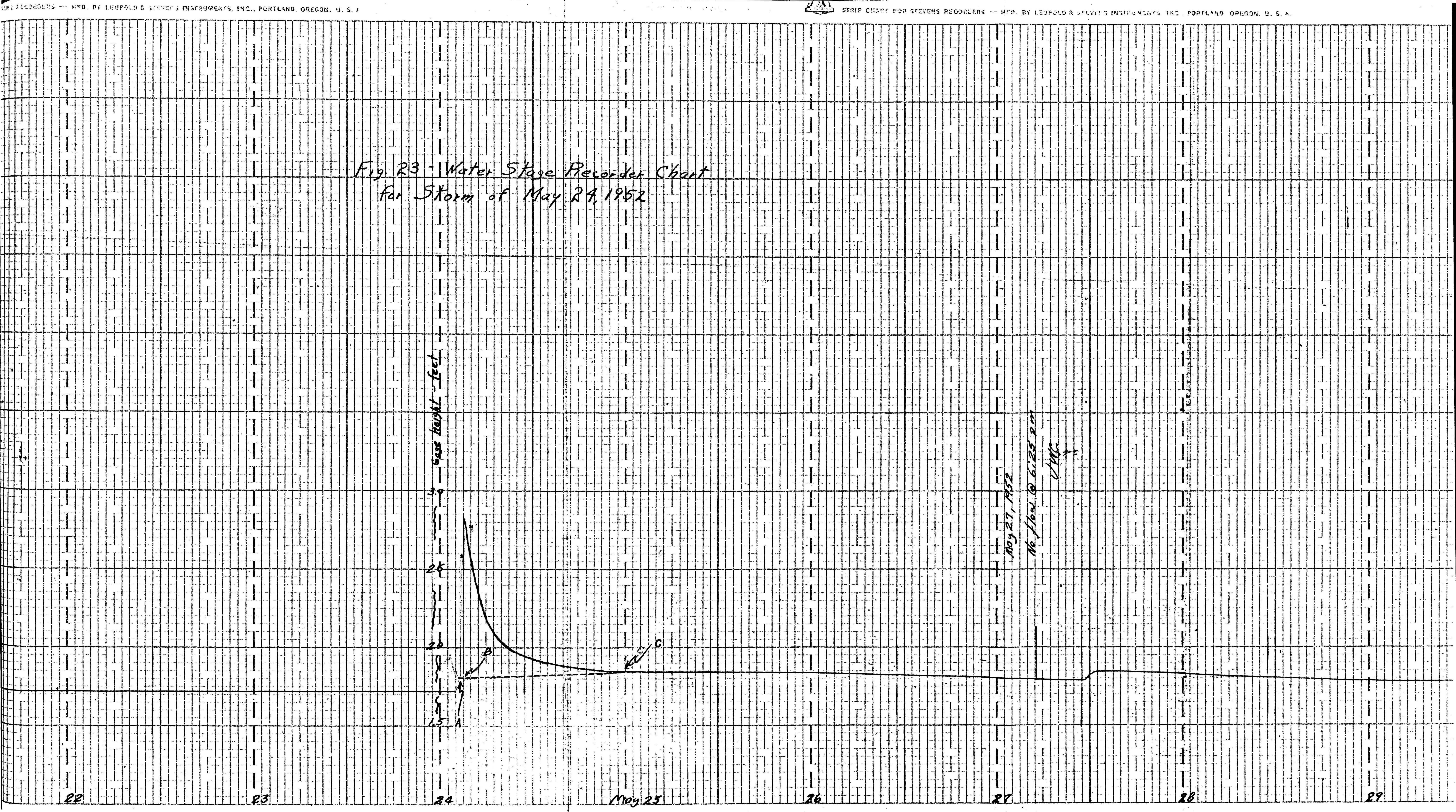


Fig. 23 - Water Stage Recorder Chart for Storm of May 24, 1952

of this stream. The stream forks about 300 feet upstream from the recorder and the left fork (right and left looking downstream) drains about 1/4 of the drainage area and is all grazing land and cultivated fields. The right fork drains about 3/4 of the drainage area and takes in all of the wooded area and the rest in grass land. The first crest represents the flow coming out of the left fork and the second crest is from the right fork.

To separate surface runoff from base flow, the recession rate of the base flow is continued to a point directly beneath the highest crest, as shown in Fig. 23, point B. As the stream was dry, a level line was drawn at the point of zero flow. A point was selected on the recession curve, point C, after the storm crest, where the recession curve deviates radically from a straight line and this point was connected to the point under the crest, point C. This line, ABC, represents the base flow. There are several theories on the separation of base flow from storm runoff. "For the purpose of forecasting, runoff is assumed to fall into two classes - (1) base, or groundwater, flow and (2) direct runoff. Many methods have been suggested for the separation of these two components in the hydrograph. The selection of method is not as important as the consistent use of a single method throughout the study." (11)

(11) Kohler, M. A. and R. K. Linsley, Predicting the Runoff from Storm Rainfall, U. S. Weather Bureau, Research Paper No. 34, P. 2, September, 1951

The storm of May 24, was subdivided by the hour and the discharge for the average gage height picked off the rating curve (fig. 7).

Hour	Gage Height	Discharge in c.f.s.	Base Flow in c.f.s.
1	2.70	4.14	0
2	2.58	2.82	0
3	2.34	1.10	0
4	2.20	.480	0
5	2.11	.264	0
6	2.04	.156	0
7	1.99	.092	0
8	1.97	.076	0
9	1.94	.052	0
10	1.93	.044	0.002
11	1.92	.036	0.002
12	1.90	.020	0.002
13	1.89	.018	0.002
14	1.88	.015	0.002
15	1.88	.015	0.004
16	1.87	.013	0.004
17	1.86	.011	0.004
18	1.86	.011	0.004
19	1.85	.009	0.007
20	1.85	.009	0.007
21	1.85	.009	0.007
22	1.85	.009	0.009
	Total	9.399	0.056

The base flow 0.056 c.f.s. was subtracted from the total discharge 9.399 c.f.s. and the storm runoff was

9.343 c.f.s. for 1 hour. This is converted to inches of rainfall over the whole drainage area.

9.343 x 60 x 60 = 33,836.4 c.f.s. = Total discharge

Drainage area = 0.227 square miles.

27,878,400 sq. feet in sq. mile.

0.227 x 27,878,400 = 6,328,396.8 sq. feet in drainage area.

Inches of runoff over basin $= \frac{33,836.4 \times 12}{6,328,396.8} = 0.064$ inches.

The rainfall was 0.95 inch, less 0.064 inch, giving 0.886 inch basin recharge. Basin recharge is considered as total rainfall less runoff and includes depression storage, interception and infiltration.

The U.S. Weather Bureau uses a coaxial graphical correlation of give variables in river forecasting. (12)

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(12) Ibid.

These variables are antecedent precipitation index, basin recharge, week of year, storm duration, and total rainfall. The antecedent precipitation index is an indication of moisture deficiency over the basin arrived at by imperically weighing all rainfall for a definite time prior to and including the storm in question.

The U. S. Weather Bureau, River Forecast Center at St. Louis, Missouri, employs the following procedure for computing antecedent precipitation index (API).(13)

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(13) Light, Phillip, Hydrologist in charge River Forecast Center, St. Louis, Missouri, by private communication.

$$\text{API today} = \left(\text{API yesterday} + 24 \text{ hour rain ending today}\right) \times 0.9$$

The duration is used as the number of hours of rainfall in excess of 0.2 inches in six hours. No weight is given to intervening lulls. The week number is the calendar date of the storm expressed as weeks since January 1.

It appears that soil moisture should be a more reliable indication of moisture deficiency than weighing past rainfall.

The following coaxial relation for Lanes Fork near Rolla was developed by the procedure as outlined by the U. S. Weather Bureau[14], with the exception that soil

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(14) Kohler, M. A. and R. K. Linsley, op.cit.

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moisture was used as an indication of moisture deficiency instead of an antecedent precipitation index. All storms were computed as previously outlined and total precipitation, basin recharge, runoff, soil moisture, storm duration and week of the year determined.

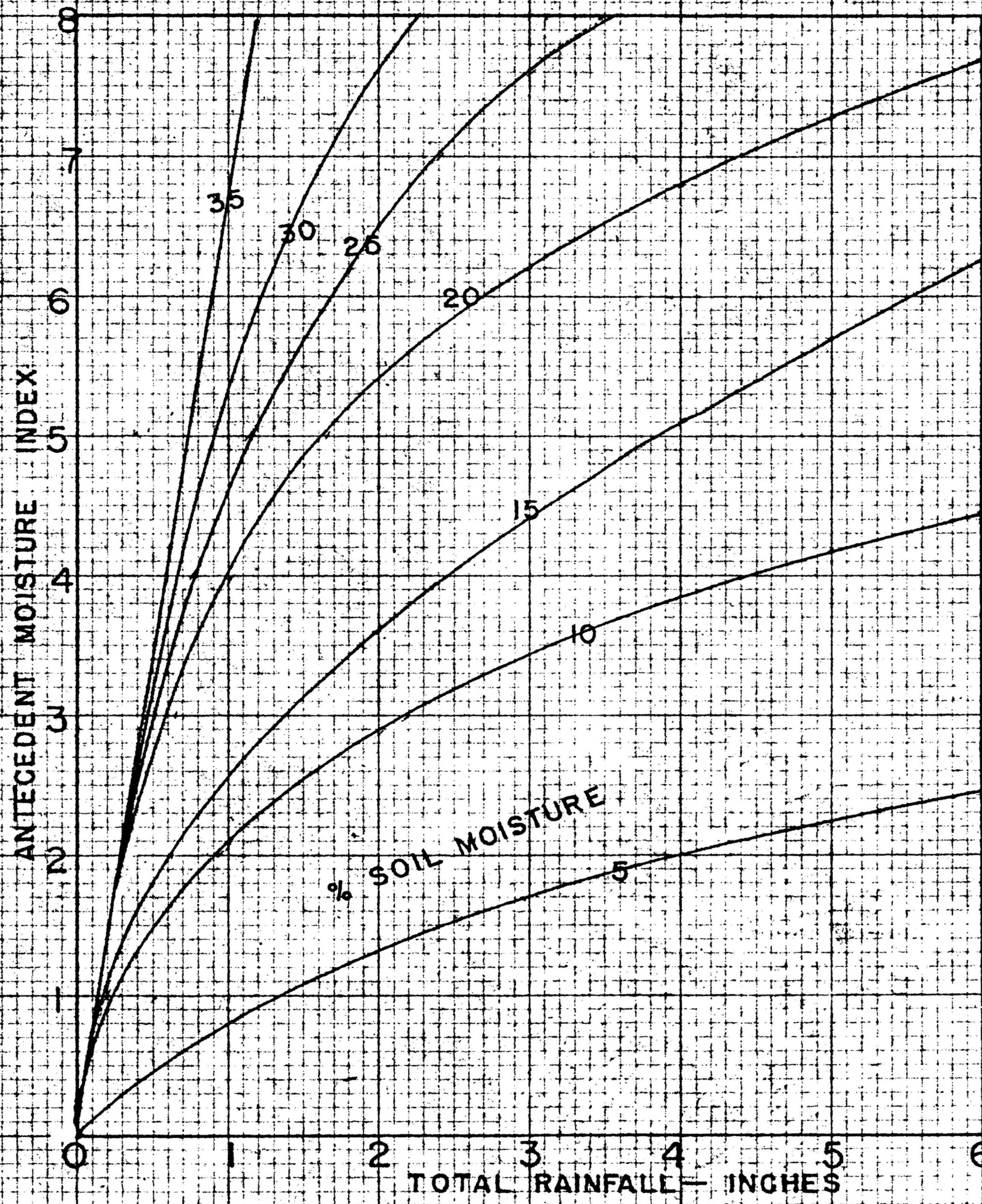

FIG. 24-A SOIL MOISTURE CURVES

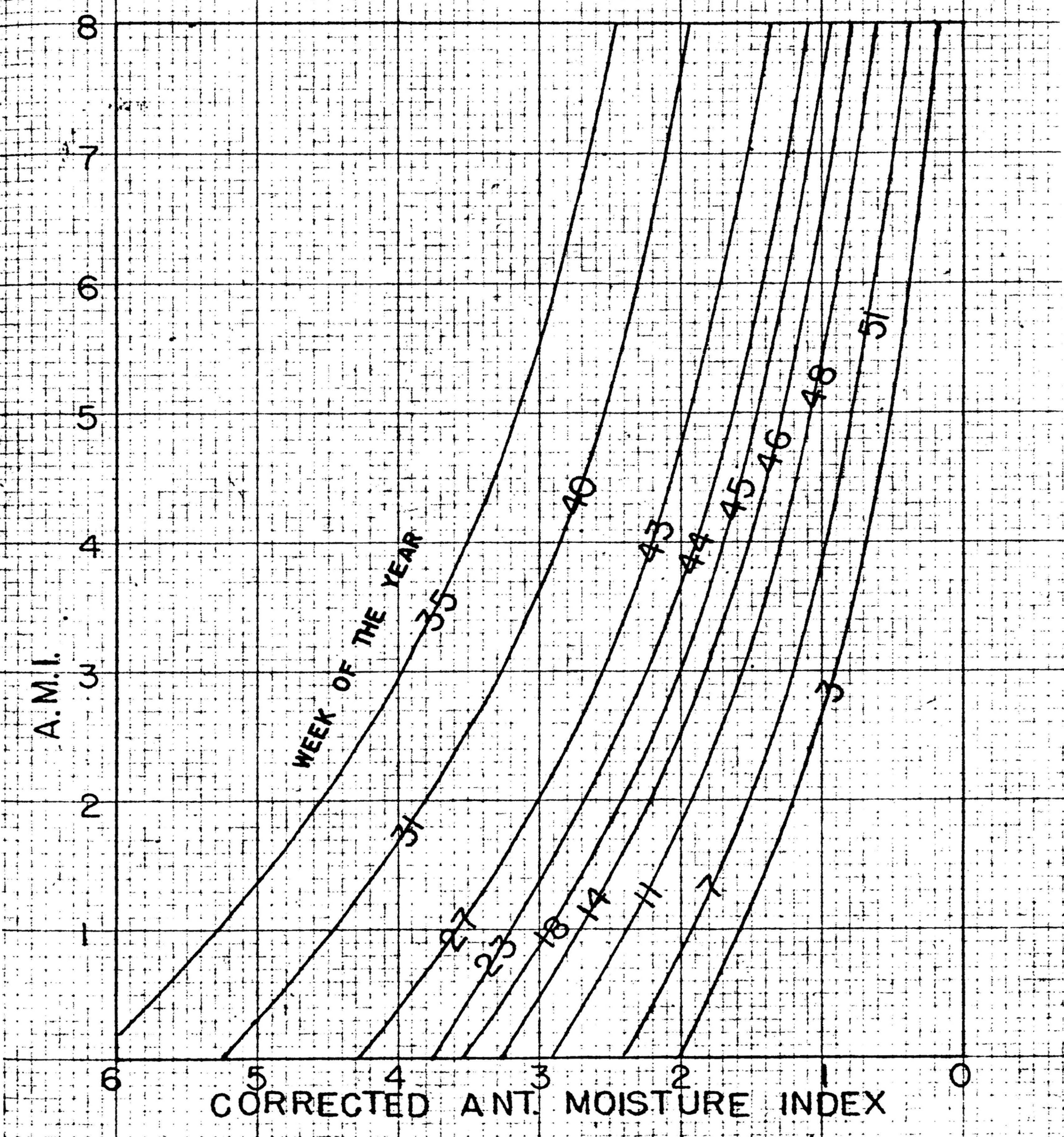

FIG. 24-B WEEK OF THE YEAR CURVES

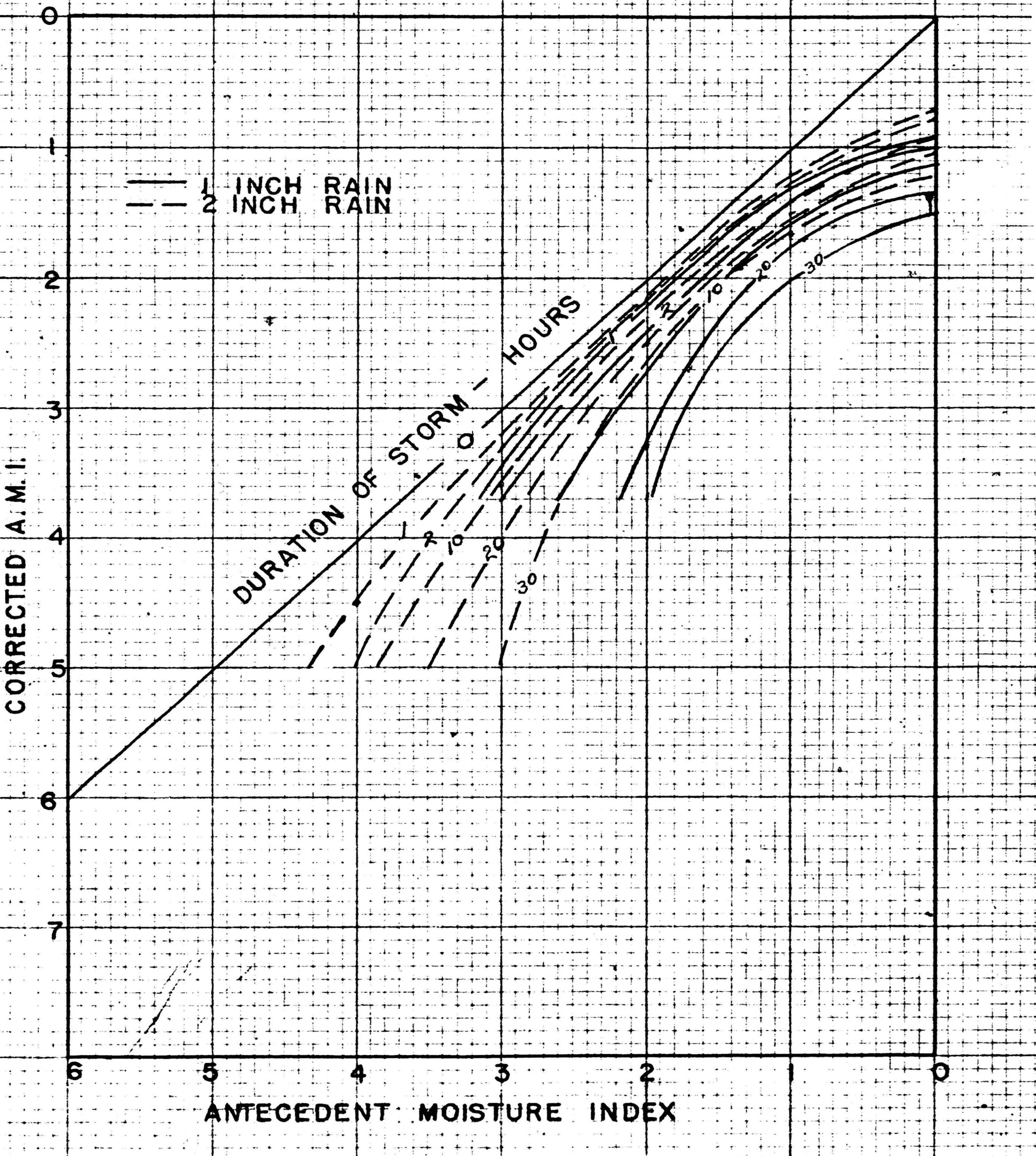

FIG. 24-C RAINFALL DURATION CURVES

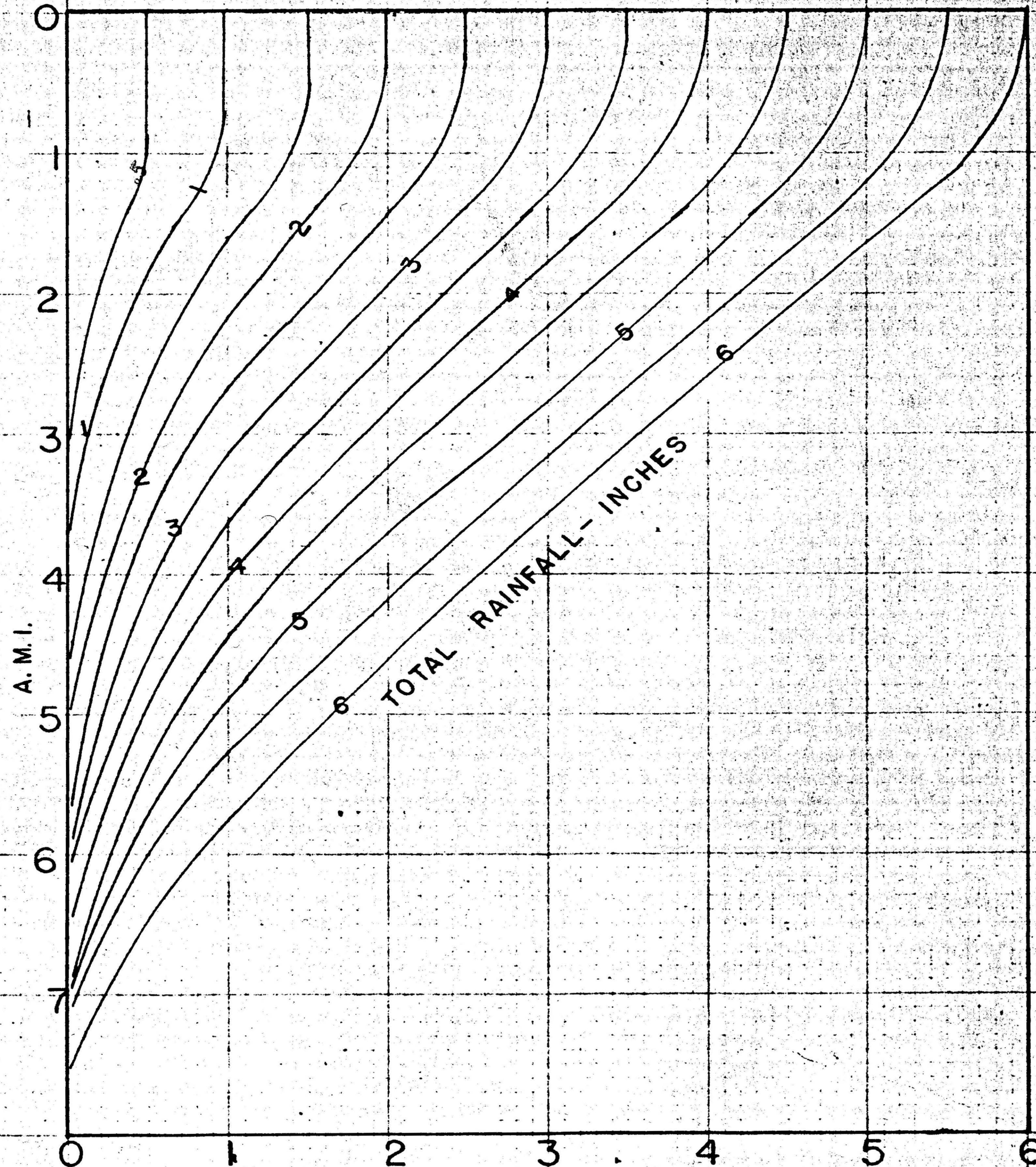

FIG.–24-D, RAINFALL CURVES

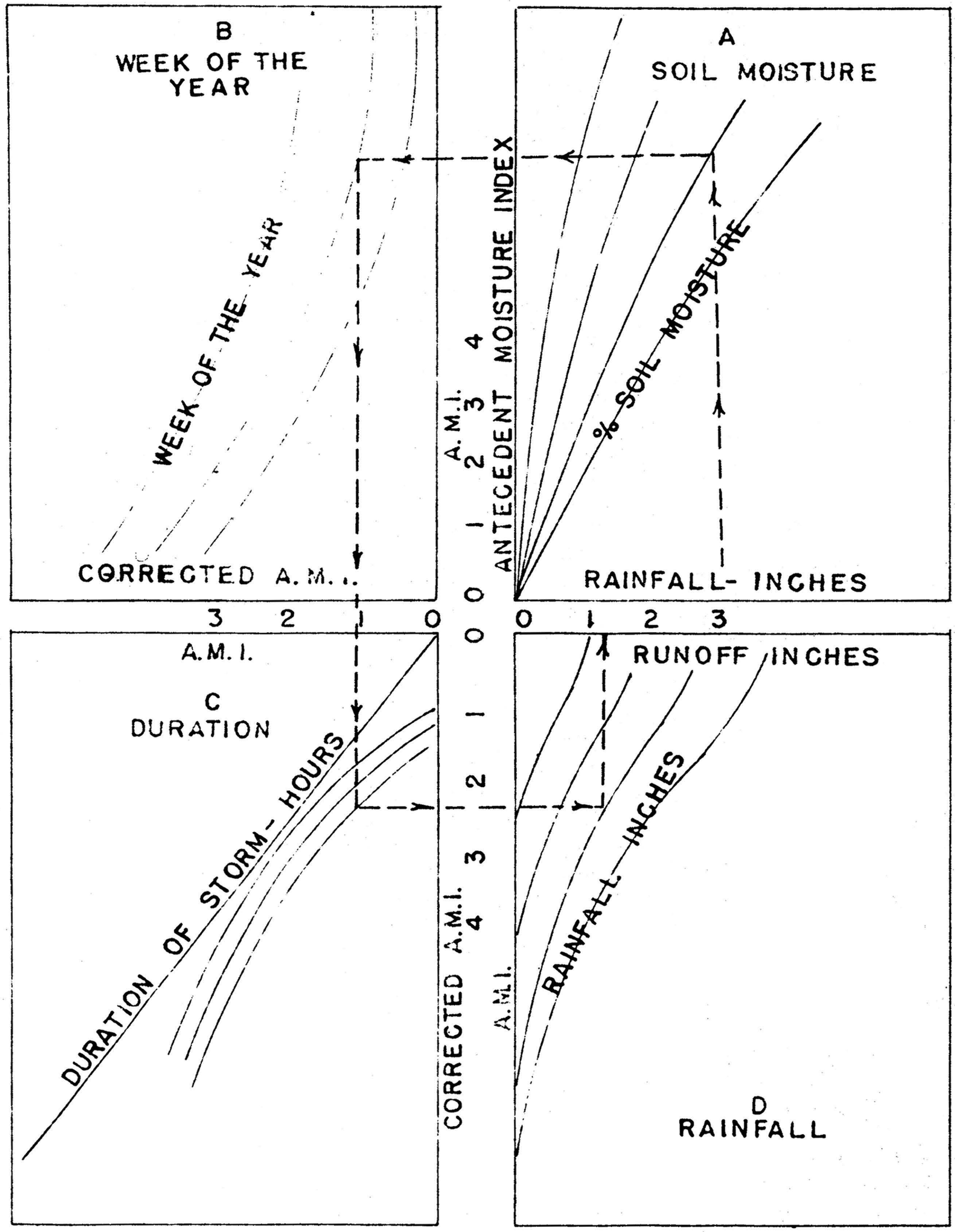

FIG. 25 – CURVE RELATIONSHIPS

The Duration curves (fig. 24-C) and the soil moisture curves (fig. 24-A) were developed by the writer. The week of the year curves (fig. 24-B) and precipitation curves (fig. 24-D) were developed by the U. S. Weather Bureau and are the curves currently used in their river stage forecasting for the Bourbeuse River basin.

The use of five variables in which each variable is dependent upon the values of the other variables makes analytical correlation very difficult. The coaxial relationship curves (fig. 24) give good results and make it easier to weigh deviations from the normal by graphical relationships. The curves must be used by someone familiar with the physical characteristics of the basin and in touch with the current lead or lag of the seasons. The curves should not be used indiscriminately as concrete fact without the aid of experience.

As previously stated, the week of the year curves (fig. 24-B) and the rainfall curves (fig. 24-D) were developed by the U. S. Weather Bureau and considered correct and not shifted in this study. The storm duration curves (fig. 24-C) were developed first. The curves were constructed by theoretical reasoning from a study of the rainfall charts and the shape of the runoff curves (fig. 24-C). The rainfall charts were studied with particular emphasis on the periods of low intensity at any period during the storm. The duration curves should correct the runoff for losses beyond those of an instantaneous storm. Therefore, the increased loss to runoff from a 1 inch rain in 5 minutes over a 1 inch rain in 5 hours must be due to infiltration rates at any period during the storm. After careful study of the rainfall charts the following infiltration rates were assumed and used to develop the duration curves.

0.1 inches	first hour
0.05 inches	second hour
0.01 inches	each hour thereafter

Because the curves directly reflect losses to runoff from total precipitation, a different family of curves would be necessary for every value of total precipitation, but that would not be practical and far beyond the accuracy limits of this study. Two families of curves were developed to cover the storms of the study, a 1 inch rain and a 2 inch rain. Additional curves could be quickly developed for storms of greater amounts of precipitation but were not necessary to cover the storms of the period of the problem. The limiting parameters are duration and total rainfall. The 0 duration curve represents an instantaneous rain and all losses are taken care of by the week of the year curves; therefore, the curve is a straight line of 45° slope going through the zero point on the antecedent moisture index, with matching scales on all graphs. The duration curves for 1, 2, 10, 20 and 30 hours were developed by using the above infiltration rates and the rainfall curves (fig. 24-D). The 1 hour curve for a 1 inch rain was constructed as follows: the rainfall curve for a 1 inch rain was entered at all runoff points from 0 to 1 inch at every .1 of an inch and a point located on the duration curve that would show a runoff equal to the total runoff entered with less 0.1 inch for 1 hour duration. This gives a curve that reflects the shape of the rainfall curve, and all the duration curves were developed in this way. Once developed, the curves were considered as correct and not shifted. The U. S. Weather Bureau currently uses a set of duration curves, all having a 45° slope and are straight lines throughout. This type of curve reflects the rainfall curves of flood producing rains in the central portion of the graph but gives considerable error in the 1 inch rainfall and less range falling in the outer limits of the graph.

The soil moisture curves (fig. 24-A) were developed last. All periods of rainfall were tabulated, along with runoff, soil moisture prior to the storm, week of the year, and duration of storm (table 2). These values were then entered through the runoff curves in reverse order and plotted on the soil moisture graph with antecedent moisture index plotted against total precipitation. The soil moisture prior to each storm was noted on the plotting and a family of curves with some variation was drawn through the points to represent different values of soil moisture. The soil moisture curves increase the antecedent moisture index as the soil moisture increases and this decreases the effect of the season of the year and gives increased runoff.

The week of the year curves (fig. 24-B) reflect the extremely variable effect of the season of the year on runoff. A 2 inch rain with 5% soil moisture could produce 1.55 inches of runoff in the 3rd week of the year and fall low in the 0 runoff range in the 35th week of the year. Thus, a 2 inch rain in a low soil moisture period could be affected from 0 to maximum runoff, according to the season of the year in which it fell. This seems logical when the differences in interception, evaporation and transpiration are considered for the maximum extremes. A 2 inch rain with 35% soil moisture could produce 2 inches of runoff during the 3rd week of the year and 0.9 inches during the 35th week of the year. Both of these examples represent the very extreme conditions that probably would not happen very often. The 5% soil moisture in January would represent an extremely dry condition and the 35% soil moisture in August would probably only represent a period of a few hours duration immediately following a heavy rain. These curves are for specific basins.

FIG.-26 DAILY AIR TEMPERATURE RANGE

The rainfall curves (fig. 24-D) as used by the U. S. Weather Bureau, Middle Mississippi River Forecast Center, are the same for all basins and are supported by a long period of record. Any change in one set of curves could affect the shape and position of the other curves, due to the method of development, as the variables are joint functions.

The four runoff curves (fig. 24), once developed, should be plotted on one large graph paper with matching scales, as shown in fig. 25. With the curves in the form as shown in fig. 25, as a multi-variable coaxial relation, it gives a quick and accurate means of solving for runoff. The two parameters, total precipitation and duration, are placed last so that runoff will not be shown as a negative number or greater than total precipitation.

Fig. 26 [15] shows the daily air temperature range at

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(15) U. S. Weather Bureau, Climatological Data, Vol. LVI, Number 3-12, 1952

The official weather observation station on the Missouri School of Mines campus at Rolla. The maximum and minimum temperatures were plotted as daily temperature range limits. The soil temperatures fluctuated considerably from day to day but held a general seasonal trend as shown in fig. 27-A,B,C, and D for the different soil levels. The greater the soil depth, the smother the seasonal trend seemed to be. The surface temperatures reached a maximum of 104°F during the hot period of June 27 to July 1 and a minimum of 11°F on November 27. The soil temperatures were probably affected more by direct sunlight than by a warm air mass and a record of cloud cover would be of interest in additional study here. There was considerable lag in reaching maximum temperatures in the soil. The greater the depth, the greater the lag. The 10 cm. depth soil reached a maximum temperature of 103°F during the period of June 26 to June 30 and its minimum temperature of 36°F during the period of December 26-30. The 10 cm. depth generally reflected the air temperature immediately. The 20 cm. depth soil reached its maximum temperature of 93.5°F during the period of July 26-29 and a minimum of 36°F on March 17. This represents a lag of one month over maximum air temperatures. The 30 cm. depth soil reached a maximum of 93.5°F on July 29 and a minimum of 36°F during the period of Dec. 26-31. This represents about the same lag as the 20 cm. depth soil. The 50 cm. depth soil reached a maximum of 90.5°F on Aug. 2 and a minimum of 41.5°F during the periods of Dec. 23-31 and March 24-27. This gives a lag of about 34 days behind the surface air temperatures. The soil temperature variations were dampened by the absorption of heat in the summer and the liberating of heat in the winter by the soil depths. The greater the soil depth, the less the slope of the seasonal trend of soil temperatures.

TABLE 2 -- RAINFALL AND RUNOFF

Date		Rainfall Inches	Duration Hours	Runoff Inches
March	17	.75	15	.63
	22	.11	1.1	.01
April	4	1.58	19.5	1.16
	9	.55	4.5	.18
	12	.70	14	.68
	23	.11	3.5	0
May	10	.15	3	0
	17	.25	1.5	0
	18	.10	.25	0
	24	.95	1.4	.06
	28	.35	1.75	.01
June	22	.10	1	0
July	3	.10	1	0
	7	.95	6	0
	14	2.15	20	.10
	15	.20	.1	.01
	30	.85	2.75	0
Aug.	4	.15	.1	.01
	5	.25	.33	0
	11	1.95	9.5	.14
	14	.40	.33	0
	15	.30	.33	0
	18	.50	3	0
	21	1.15	7	.10
Sept.	17	.15	.1	0
	20	.23	4	0
Oct.	5	.40	12	0
Nov.	25	.85	17	.11
Dec.	3	.65	8	.06
	22	.75	9	.02

FIG. 27 A — 10 CM. DAILY SOIL MOISTURE AND TEMPERATURE GRAPH

FIG. 27 B — 20 CM. DAILY SOIL MOISTURE AND SOIL TEMPERATURE GRAPH

FIG. 27C– 30 CM. DAILY SOIL MOISTURE AND TEMPERATURE GRAPH

FIG. 27.D — 50 CM. DAILY SOIL MOISTURE AND TEMPERATURE GRAPH

CONCLUSIONS

The over-all problem of soil moisture and runoff is far too large and complex for a solution by one individual with limited data. In most hydrologic studies it is necessary to have a period of record over several years to collect the necessary information prior to attempting any study of relationships. This is necessary to cover all of the ranges of soil moisture at the various seasons of the year and to have a wide range of rainfall data. The period of this study covered an extremely dry June, September, October and November, with a rather wet August. There were no storms of high precipitation, necessary to give the outer shape of the curves.

After a certain amount of rainfall it seems logical.to assume that the runoff characteristics affected by soil moisture at the beginning of a storm would have little measurable effect. From this assumption, the soil moisture curves would break upward and after a period of transition, reflect the maximum extreme soil moisture conditions.

The weakest part of this approach to runoff is the effect of the week of the year. The curves as drawn reflect an average condition which is not readily definable. The deviation from this average condition can be considerable, as previously brought out in the example of extreme conditions. A theoretical year with definite boundaries on temperature, evaporation and condition of seasonal plants could be selected from a long period of complete record. This theoretical year could serve as a base and the week of the year corrected by comparison with the theoretical year and observed conditions. This should tend to reduce the percentage of error now involved.

On the basis of this study the following specific conclusions in regard to soil moisture and runoff were made:

1. There is a definite relationship between soil moisture and runoff. This relationship is supported by the widespread use of the antecedent rainfall index which has proven a valuable tool in river stage forecasting by the U. S. Weather Bureau. The soil moisture index is a refinement of the antecedent rainfall index and tends to bring the calculated values into closer agreement with the actual values. In the range of flood producing storms, the difference between the two indexes becomes nil.

2. There is need for additional study to develop this relationship. Several years of record would be necessary to define the soil moisture curves properly. It is necessary to have dry years in order to establish the low soil moisture ranges and wet years to establish the

high soil moisture ranges. There is need for record covering flood producing storms to establish the shape of the outer limits of the curves.

3. There is need for a better method or a more accurate soil moisture block to measure soil moisture without taking direct samples. The Bouyoucos soil moisture block is not accurate enough in the low soil moisture ranges and around the saturation point. There is need for a soil moisture device to define the soil moisture through all ranges of the soil. The most promising solution lies in the field of atomic radiation.

4. A continuous record of soil moisture with an accurate time scale is needed, so that complex storms can be separated into individual rainfalls. In order to use complex storms, it is necessary to know the soil moisture at the beginning of the storm. An apparatus designed to give a complete graph of soil moisture with an accurate time scale would make it possible to plot all storms.

5. The soil moisture blocks should be buried one year or more before the study period begins in order to have infiltration rates similar to those in the surrounding undisturbed soil. In making infiltration studies with moisture blocks or other soil moisture apparatus that must be buried in the ground, proper compaction of the soil is necessary. The infiltration rates in the disturbed area

were much faster than in the surrounding undisturbed soil. Placing the necessary apparatus in the ground one year or so prior to the actual observation period should eliminate considerable error.

6. This study should be carried on at the present location and other similar studies started on areas of different topographical features and vegetative cover. By continuing this study at its present location, time effect on the runoff relationships could be observed. There should be some change in the soil moisture curves as the soil around the blocks returns to a near normal state. The soil moisture blocks should be re-rated until the relationship becomes stabilized. Studies could be commenced in the Rolla area on different types of vegetative cover and various surface slopes. Daily readings of block resistance could be made on all moisture blocks in the various areas for a short period of time. The recession rates of the soil moisture blocks in the newly established areas could be compared with the present station. After the comparison was established, the soil moisture at the new stations could be observed weekly and the soil moisture approximated for the missing periods. This approximate period should be accurate enough for runoff studies.

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VITA

John William Clark, Jr. was born on May 29, 1920, at Centralia, Illinois, the son of John William and Ida (Bozarth) Clark.

He received his elementary and high school education in the public schools of Centralia, Illinois, graduating in 1938.

After graduation from high school he worked as an electric welder for the R. G. Le Tourneau Company, Peoria, Illinois, until August, 1940.

In September, 1940, he enrolled in the Centralia Jr. College and graduated in 1942, completing two years of pre-engineering.

He entered the U. S. Navy as a Seaman in June, 1942, and served four years during the war as Seaman 2d Class, Aviation Cadet, Ensign, Lieutenant Jr. Grade and Senior Lieutenant. Twenty-seven months were spent overseas, during which time he was awarded the Navy D. F. C. for aerial action off Guadalcanal.

Upon receiving orders to inactive duty in the Navy in April, 1946, he returned to Centralia, Illinois and purchased half interest in a local hardware store and worked in that capacity until November, 1947, at which time he sold his hardware interest.

In April, 1946, he was elected Finance Commissioner of the City of Centralia, Illinois, for a four year term, during which time considerable progress was made by the city in public improvement.

He helped organize the Clinton County Sand and Gravel Company to dredge sand and gravel from the Kaskaskia River near Posey, Illinois, in the spring of 1948. This company was severely crippled by summer floods in 1948 and 1949 and was dissolved in August, 1949.

He entered the Missouri School of Mines, Rolla, Missouri, in September, 1949, and completed the requirements for the degree of Bachelor of Science in Civil Engineering in January, 1951. He immediately started working on the requirements for a Master's degree.

He received the Mid-Missouri Section, American Society of Civil Engineers award for the outstanding civil engineering graduate in 1951.

He was employed as a hydraulic engineer by the U. S. Geological Survey, Water Resources Division, Rolla, Missouri, in August, 1951, in which capacity he is still working.

He was united in marriage on May 19, 1946, in St. Louis, Missouri to Jacqueline Delores Milz. Their children are

Douglas William, born June 7, 1949, and Scott Hurley, born January 23, 1953.