A STUDY OF RUNOFF LOSSES FROM DIFFERENT SLOPES AND LENGTHS IN A SMALL WATERSHED

by

EMANUEL AZAR

B. S. in Agricultural Engineering
Virginia Polytechnic Institute
1933

A MAJOR THESIS

Submitted in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF SCIENCE IN AGRICULTURAL ENGINEERING

Virginia Polytechnic Institute
Blacksburg, Virginia

June, 1940

APPROVED

Course Adviser.   Dean, College of Agriculture

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

FOREWORD

Man is theoretically the master of Earth, but he can and has abused his stewardship. A tale of his negligence and destruction is written in the ruins to be found in the Sahara, the Central Asian deserts, arid parts of Palestine, Iraq, the Gobi Desert and North China. For these places, once thickly populated, are now almost uninhabited except for a few nomadic tribes, poor remnants of former cultures, fighting for their livelihood and existence over every trace of vegetation and every drop of water. Fierce dust- and sand-storms and shifting sand dunes cover ruins of cities and kingdoms once teeming with millions; and they cover millions of acres once clothed with delectable fruit and shade trees and gardens without end.

Such, then, is the story of man-made deserts caused by erosion, signs of which first appeared in the western United States in 1934 and 1935 in the form of duststorms. The federal and state governments of the United States have fully realized the dangers of erosion in recent years and are now determined to fight it in order to eliminate at the very start its ruinous effects.

ACKNOWLEDGEMENT

The author wishes to express his gratitude for valuable assistance rendered by different members of the Agricultural Engineering Department of the Virginia Polytechnic Institute which made possible the opportunity of conducting this problem. He especially wishes to recognize the constant advice freely given by
Project Supervisor of the Soil Conservation Service, without which the completion of the study would not have been possible. The author's sincere gratitude is also extended to for his help and advice throughout the study.

A STUDY OF RUNOFF LOSSES FROM DIFFERENT SLOPES AND LENGTHS IN A SMALL WATERSHED

INTRODUCTION

In recent years, both the state and federal governments of the United States have at last recognized erosion as a serious problem affecting the people of this land socially and economically, just as it affected the people of those kingdoms now buried in the sands of the deserts. Because of the seriousness of the problem, studies are being instituted on larger scopes than ever before and there is a greater realization of the pressing need for more adequate information about erosion, its causes, effects, prevention, and other related factors.

That intense rainstorms result in higher rates of runoff is an acknowledged fact. These rates of runoff play an important part in studies made by soil conservationists, and upon their studies will depend the success or failure of conservation practices. Soil conservationists have already espied the need for planning projects or designs that will take care of maximum runoffs which are to be expected at definite frequencies. The United States Geological Survey has collected records and made investigations of great value to engineers of navigation and flood control projects, as well as power developments and other such works which interest students of hydrology and soil conservation. Moreover, experiment stations in practically every state are cooperating with soil conservationists and soil specialists in attacking erosion problems facing the nation. The goal of all these investigations is towards finding means by which to help Nature in keeping the land so clothed that erosion may be kept within the natural limits. Hence, work is being conducted on many various problems.

One particular problem upon which more information is needed is that of runoff, its causes and effects in the Limestone Valley and Uplands Region in the State of Virginia. With the idea of making some contribution, therefore, that may help effect a solution by making available data for the above region, this problem was chosen as a subject for a Master's thesis.

REVIEW OF LITERATURE

When this study was established, there had been no investigations of runoff from small agricultural areas to be used as a basis in the design of erosion control structures. Moreover the only such study outstanding in the United States is that conducted by C. E. Ramser, in which he included records of rainfall and runoff from various watersheds, totaling 112 acres, in Madison County, Tennessee. This study has so far served as a foundation for the design of most erosion control operations, supplemented somewhat by studies conducted at different Erosion Experiment Stations, and the rational method evaluated by Ramser has been used extensively in predictions for runoff. There are of course other similar theoretical methods which have come and are coming into prominence.

The rational method for estimating the maximum rates of runoff from a watershed is founded upon the theory that such a rate for a given rainfall intensity would occur when all parts of the area under consideration are contributing to the flow. It is expressed by the equation: Q CIA. So far this method has proved to be the best, and has been widely used, but it does not take into account many of the factors which affect runoff.

Robert E. Horton, on the other hand, advances a theory which takes into consideration factors not specifically covered by the rational method above mentioned. He assumes that all, or nearly all, phases of surface runoff phenomena can be expressed rationally and quantitatively in terms of a few definite independent variables, but the theory has neither been proved or disproved as yet.

Other theoretical and empirical methods have also been advanced for use in the prediction of runoff, Leroy K. Sherman and M. M. Bernard being among those presenting equations for the analysis of surface runoff. M. M. Bernard's contribution to the method was the introduction of the distribution graph. The principle underlying Sherman's and Bernard's theory is: For any watershed, the surface runoff resulting from a unit storm is distributed, according to time, in a characteristic manner, and this distribution is independent of the intensity of the rainfall.

Despite the fact, however, that their method has generally become accepted, engineers and hydrologists who have made special studies in the field of runoff suggest that further research be conducted to determine more accurately the limitations encountered in the application of the unit hydrograph advanced by Sherman and Bernard. The unsettled issue is the question of the usefulness of the unit hydrograph as a basis for estimating runoff coefficients in cases where no discharge records whatsoever are available. In other words, a study should be made to show the effects of various factors ignored by the above theory. Such factors as size, shape and slopes of the watershed, cultivation and vegetative cover, duration and intensity of rainstorms, antecedent rainfall and other similar factors need to be considered.

Among methods advanced for the analysis of results secured from either small or large watersheds are those statistical ones presented in a recent publication by P. H. McGauhey, wherein he analyzes hydrologic data gathered in the State of Virginia.

One of the most recent publications on the subject of runoff, however, is that by D. B. Krimgold, wherein is stressed the need for runoff data and for the standardization of methods and procedures employed in obtaining results which would help solve the problem of runoff. For fewer problems are more baffling than the determination of rates and amounts of runoff, and the determination of the frequency of their occurrence. These phenomena, like other hydrologic ones, would be considered in the rational and economic design of a great number of engineering projects and undertakings, be they large or small. Considerable data, therefore, is needed for the determination of definite methods in the planning and design of different hydraulic works and conservation measures.

In order, then, that the needed data may be collected, projects have been instituted in areas where the erosion problem exists. A large amount of information would thus be made available in a standard form to engineers and students of runoff phenomena, the science of hydrology would be advanced, and the benefit to engineering and other professions would be great. The result may be the saving, through better control structures, of much wealth now lost to the nation.

Among such projects mentioned by Krimgold, may be listed the one with which this study deals.

OBJECTIVES AND SCOPE

Because there had never before been an investigation of the above nature in the Limestone Valley Region, this study was inaugurated (the Experiment Station and the Soil Conservation Service cooperating) with the following objectives in mind:

1. To determine the effects of slope lengths and rainfall intensities on the total runoff from different lengths and grades of land.
2. To determine losses of soil and plant food in runoff from these slopes under different cropping conditions.

Due to many difficulties encountered, the most important of which was lack of time, the above objectives had to be modified. As the study advanced, experiences gained from data and observations made it more and more apparent that the trend was: (1) To determine rates and amounts of runoff from samll watersheds typical of agricultural fields in the Limestone Valley Region to establish basic data for erosion control designs, and (2) To study fundamental factors pertaining to runoff phenomena on the watersheds in order that they might be applied to other similar areas. It was decided also that an effort would be made to observe losses of soil and plant foods in runoffs from the watersheds under the cropping condition at the time of study.

FACILITIES

Since this study was to deal with watersheds typical of small agricultural fields in the Limestone Valley Region, two watersheds were selected on the College Farm of the Virginia Polytechnic Institute and permission was obtained for the use of them. They are here referred to as Watershed No.II (W-II) and No.III (W-III).

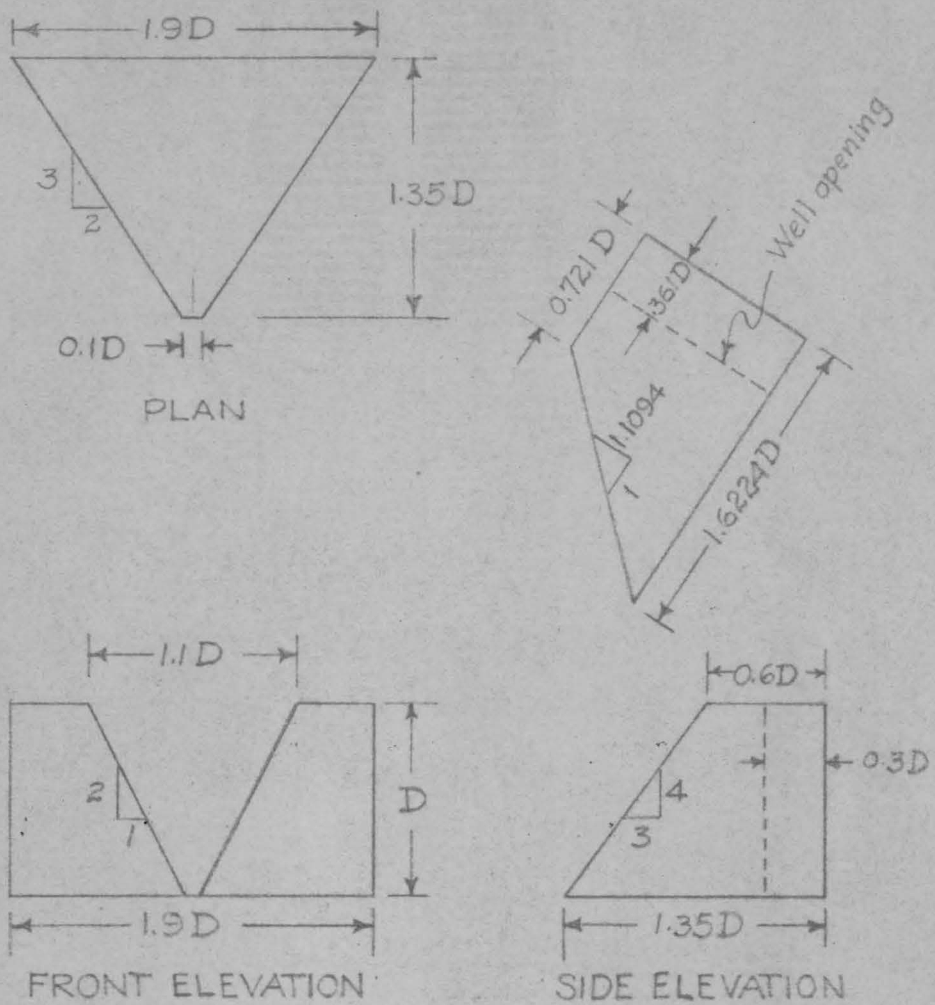
The Agricultural Engineering Department agreed to furnish certain equipment for the establishment of the study, and this was used as it was needed.

The Soil and Water Conservation Project of the Experiment Station, in cooperation with the Soil Conservation Service, furnished the equipment needed for permanent use. This included laboratory facilities, recording instruments and raingages to be used on the project. The staff of both agencies, moreover, has since rendered many suggestions and has assisted to a great degree in the installation of the equipment described briefly below.

Type-H Rate Measuring Flume.- This flume is similar to the well known measuring flume introduced by R. L. Parshall, except for sloping sides and a narrow restriction throat which enables more accurate measurements of low flows and greater freedom from silt depositions. The sharpness of the control affords unusual independence of upstream and downstream channel conditions. The proportions of the various size flumes and their capacities are shown in Fig.1

Friez Model FW-1 Recorder.- This recorder provides continuous record of stage at the time of runoff. It is equipped with a clock geared to make one full revolution in 6, 12 or 24 hours. Charts are placed on the clock cylinder and a pen registers the stage heights. Fig.2 shows this recorder in its shelter.

Standard Raingage.- The standard raingage is the one used by the United States Weather Bureau. It is so calibrated that the rain collected in the inside tube measures 12 inches to every actual inch of rainfall.



PROPORTIONS OF THE TYPE **H** FLUME

APPROXIMATE CAPACITIES	
DEPTH-D	CAPACITY
Feet	CFS
0.5	0.3+
0.75	1 −
1.0	2
1.5	5+
2.0	11
2.5	19+
3.0	30+

Note: For flumes less than 1 foot deep, the length of flume is made greater than 1.35D so that the float well may be attached

FIG. 1

Fig.2 View looking into instrument shelter at gaging station for Watershed No.III, showing Friez Water Level Recorder

<u>Friez Recording Raingage</u>.- The Friez raingage catches rainfall in a bucket which rests on springs. These springs cause the pen to move on the chart as the rain collects in the bucket. The chart is placed on a clock cylinder geared to make one complete revolution in 6, 12 or 24 hours, as may be desired. As much as 6 inches of rainfall can be registered on the chart. Fig.3 is a photographic view of this and the standard raingage installed on W-II and W-III.

Fig.3 View of Rainfall Measuring Station, showing standard and recording raingages at the upper reaches of Watershed No.II and No.III

THE WATERSHEDS STUDIED

In selecting this problem for study, an effort was made, as mentioned before, to conduct it on soils which are typical and representative of the Limestone Valley Region. It may be stated that in this region crop rotations are generally followed on soils derived from limestone parent rocks, that very steep slopes are prevalent due to the mountainous topography of the country, and that neither contour cultivation nor terracing are a common practice. Heavy or excessive rainstorms are not as common in this region as they are in other parts of the state, but serious and accelerated erosion does exist on the steep cultivated land.

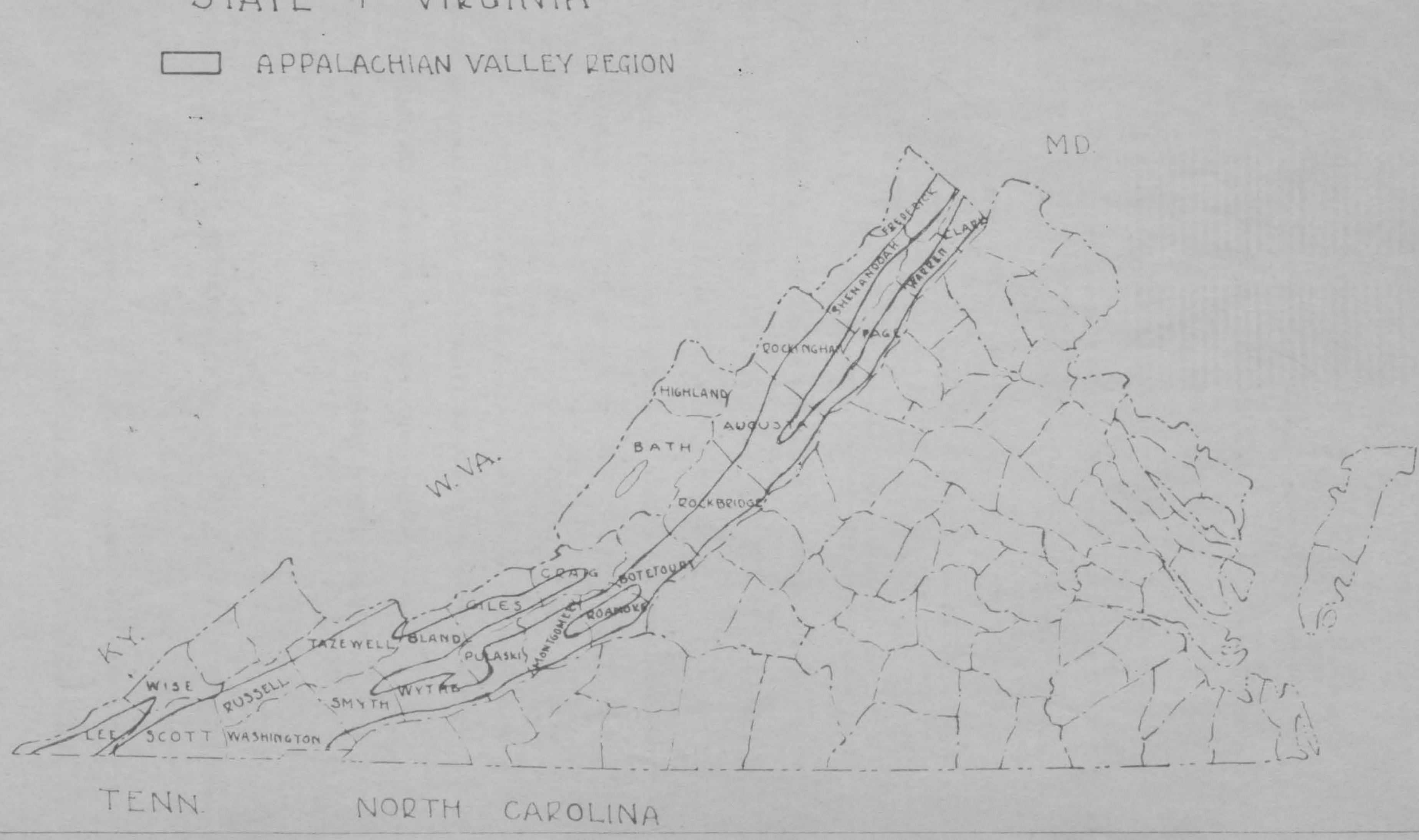
The soil of this region is a residual one, underlain by dolomitic limestone. It had lately been named Dunmore, and is considered as a cropland of the first degree. It is suitable to pasture and, above all, is characterized by a high degree of fertility.

This Limestone Valley Region, or sometimes called the Appalachian Valley Region, extends from Frederick and Clark counties in the northeast of Virginia to Lee county in the most southwesterly tip of the state, as shown on the map, Fig.4.

The College Farm of the Virginia Polytechnic Institute is situated in this region and, since some of the cultivated fields on it were ideal and available for this work, two small fields were selected which possessed the characteristics required for this study.

When the watersheds were chosen, several factors which govern success or failure of the study had to be taken into consideration. Some of the features to be considered were:

FIGURE-4


STATE OF VIRGINIA
APPALACHIAN VALLEY REGION
MD.
W. VA.
KY.
TENN.
NORTH CAROLINA
FREDERICK
CLARK
WARREN
SHENANDOAH
PAGE
ROCKINGHAM
HIGHLAND
AUGUSTA
BATH
ROCKBRIDGE
BOTETOURT
CRAIG
GILES
ROANOKE
MONTGOMERY
BLAND
PULASKI
TAZEWELL
WYTHE
SMYTH
RUSSELL
WISE
LEE
SCOTT
WASHINGTON

Size of the Watersheds.- This being the first study of its kind to be conducted in the Limestone Valley Region (with the exception of studies made on small plots by the Experiment Station at Blacksburg and in several counties of Southwest Virginia since January, 1937), it was deemed advisable to select areas of an average field size which were available on the College Farm. The size factor was considered important because results derived from small plots could be misleading when applied to larger areas due to various factors affecting runoff and soil losses. For instance, the effect of a few rodents in a small area such as that of a plot, the difficulting of duplicating natural furrows such as those in a field, a tendency of pushing the soil into unnatural positions, "human factors" in weighing soil and runoff losses, and extremely localized storms are liable to affect data collected from plots in one way or another despite all the efforts of the investigators.

Another reason, moreover, for considering the size factor important was the necessity of keeping down at a minimum the initial expense and the added expense of a probable change in the future. Thus watersheds of about 5.5 and 19 acres, respectively, were selected. It was possible to choose them adjacent to the Experiment Station plot studies and on similar soils which will receive the same precipitation and cultural treatment so that the results from the investigations could be correlated in the future.

Slopes.- The factor of slope was considered important. The watersheds were selected on slopes representative of large areas in the region. The direction of these slopes was also noticed because of the good or ill effects an exposure may have on the type and amount of vegetative cover on any land. In this case, most of the slopes on Watershed No.II were evenly divided between northerly, westerly and southerly exposures; whereas those on Watershed No.III had westerly and easterly exposures. The influence of direction is due to different factors. Northern and eastern exposures, for example, receive less direct sunlight than slopes having southern or western exposures. In consequence, the rate of evaporation and transpiration in the case of the former exposures are less than in the case of the latter. Furthermore the soil with northerly and easterly slopes is not as much affected by upheavals caused by freezing and thawing during the winter months, nor does the snow on them melt as rapidly as it does from southerly and westerly exposures. Also the vegetation on the northerly and easterly slopes is healthier, erosion is less, and more favorable conditions of moisture prevail. Naturally, because of the size of the watersheds, it was not possible to preclude undesirable slopes. In short, exposure was one of the interesting points to note during the progress of the study.

Land Use.- In conformation with the aim of the investigation, the two areas chosen were to be in uses similar to those of farms in this section of the state. The site of the watersheds, therefore, is one where the same rotation of crops has been practiced for many years, a three-year rotation of corn, wheat and hay crop. This rotation will continue on the watersheds.

Soil Type.- The soil of both watersheds is Dunmore and Emory silt loam, and its similarity should give more dependable results of runoff and erosion. Otherwise it would not be possible to compare results adequately. The two watersheds have a common boundary at the upper reaches of the field on which they were established, and their principal waterways are approximately the same in length.

Accessibility.- The watersheds are so located as to be fairly accessible, and the gaging stations on both can be reached with comparative ease.

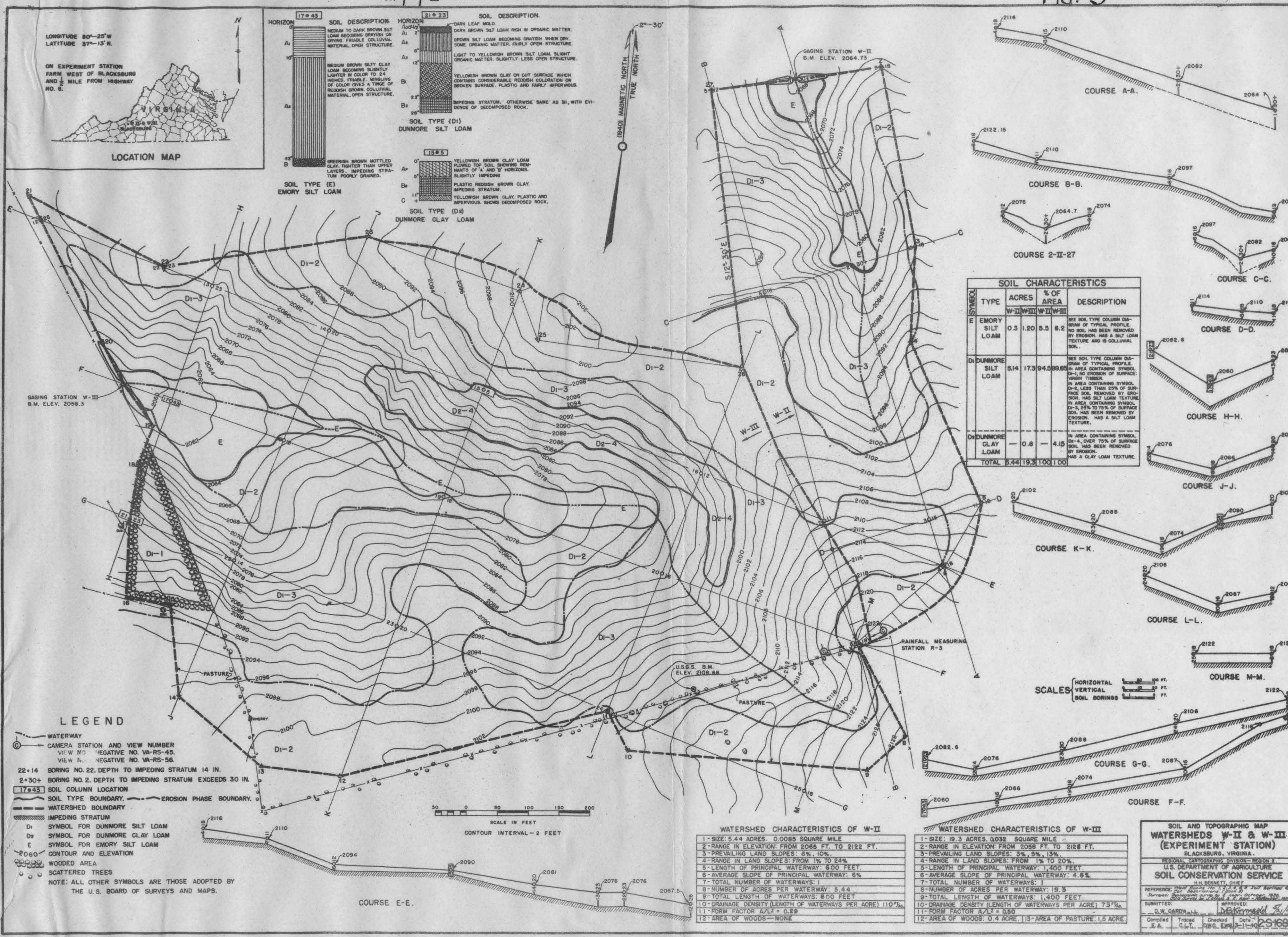
Watershed No.II

Watershed No.II of this study consists of 5.44 acres of cultivated land. The prevailing slopes vary from 6% to 10%, as shown on the topographic and soil map, Fig.5. The soil is almost entirely Dunmore silt loam, except for a very small amount of colluvial deposit of Emory silt loam in the narrow steep draw, occupying an area of about 0.3 acre in size. During the year 1939, this watershed was planted to corn and gave a very high yield because of the heavy application of fertilizers, turned-under green manure and farm manure previous to planting. A rotation of corn, wheat and clover has been followed on this and on Watershed No.III.

Watershed No.III

Watershed No.III contains 17.4 acres of cultivated land, 1.5 acres of pasture land and 0.4 acres of woodland, totaling 19.3 acres. It is adjacent to Watershed No.II and has had the same cultural treatment because both areas have been used as one field for many years. The slopes on this watershed range from 3% and 5% to 13%, as shown on the topographic and soil map, Fig.5. This basin contains 1.2 acres of colluvial deposit of Emory silt loam at the lower end of the draw. The soil is approximately 6.2% Emory silt loam, 86.6% Dunmore silt loam, and 4.2% Dunmore clay loam. The Emory silt loam is a colluvial deposit carried down to the foot of the slopes from the upper parts of the watershed, as located on the map, Fig.5. During the year 1939, the cultivated area of this was in corn, whereas clover occupied it in the preceding year of 1938.

FIG. 5



SOIL CHARACTERISTICS

SYMBOL	TYPE	ACRES W-II	ACRES W-III	% OF AREA W-II	% OF AREA W-III	DESCRIPTION
E	EMORY SILT LOAM	0.3	1.20	5.5	6.2	SEE SOIL TYPE COLUMN DIAGRAM OF TYPICAL PROFILE. NO SOIL HAS BEEN REMOVED BY EROSION. HAS A SILT LOAM TEXTURE AND IS COLLUVIAL SOIL.
D1	DUNMORE SILT LOAM	5.14	17.3	94.5	89.65	SEE SOIL TYPE COLUMN DIAGRAM OF TYPICAL PROFILE. IN AREA CONTAINING SYMBOL D1-1, NO EROSION OF SURFACE: VIRGIN TIMBER. IN AREA CONTAINING SYMBOL D1-2, LESS THAN 25% OF SURFACE SOIL REMOVED BY EROSION. HAS SILT LOAM TEXTURE. IN AREA CONTAINING SYMBOL D1-3, 25% TO 75% OF SURFACE SOIL HAS BEEN REMOVED BY EROSION. HAS A SILT LOAM TEXTURE.
D2	DUNMORE CLAY LOAM	—	0.8	—	4.15	IN AREA CONTAINING SYMBOL D2-4, OVER 75% OF SURFACE SOIL HAS BEEN REMOVED BY EROSION. HAS A CLAY LOAM TEXTURE.
	TOTAL	5.44	19.3	100	100	

WATERSHED CHARACTERISTICS OF W-II

1-SIZE: 5.44 ACRES. 0.0085 SQUARE MILE
2-RANGE IN ELEVATION: FROM 2065 FT. TO 2122 FT.
3-PREVAILING LAND SLOPES: 6%, 10%.
4-RANGE IN LAND SLOPES: FROM 1% TO 24%
5-LENGTH OF PRINCIPAL WATERWAY: 600 FEET.
6-AVERAGE SLOPE OF PRINCIPAL WATERWAY: 6%
7-TOTAL NUMBER OF WATERWAYS: 1
8-NUMBER OF ACRES PER WATERWAY: 5.44
9-TOTAL LENGTH OF WATERWAYS: 600 FEET
10-DRAINAGE DENSITY (LENGTH OF WATERWAYS PER ACRE) 110 FT/AC.
11-FORM FACTOR A/L^2 = 0.29
12-AREA OF WOODS—NONE

WATERSHED CHARACTERISTICS OF W-III

1-SIZE: 19.3 ACRES. 0.032 SQUARE MILE	
2-RANGE IN ELEVATION: FROM 2058 FT. TO 2128 FT.	
3-PREVAILING LAND SLOPES: 3%, 5%, 13%.	
4-RANGE IN LAND SLOPES: FROM 1% TO 20%.	
5-LENGTH OF PRINCIPAL WATERWAY: 1,400 FEET.	
6-AVERAGE SLOPE OF PRINCIPAL WATERWAY: 4.6%	
7-TOTAL NUMBER OF WATERWAYS: 1	
8-NUMBER OF ACRES PER WATERWAY: 19.3	
9-TOTAL LENGTH OF WATERWAYS: 1,400 FEET.	
10-DRAINAGE DENSITY (LENGTH OF WATERWAYS PER ACRE) 73 FT/AC.	
11-FORM FACTOR A/L^2 = 0.50	
12-AREA OF WOODS: 0.4 ACRE.	13-AREA OF PASTURE: 1.5 ACRE.

SOIL AND TOPOGRAPHIC MAP
WATERSHEDS W-II & W-III (EXPERIMENT STATION)
BLACKSBURG, VIRGINIA.

REGIONAL CARTOGRAPHIC DIVISION—REGION 2.
U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
H.H. BENNETT, CHIEF

REFERENCE: Field Books No. 1, 2, 3, 4, & 5 Soil borings & Col. Descriptions (Book 5)
Surveyed: Topographic survey by E. Axar - October 1939. Soil Survey by J. Elgin & E. Axar - [illegible]

SUBMITTED: D.W. CARDWELL
APPROVED: D.B. Krimgold 5/21/40

Compiled	Traced	Checked	Date	
E.A.	C.L.T.	DWC. EWG.	3-11-40	2-S-1684

Characteristics of Runoff from the Watersheds.

In order that the picture of these watersheds may become more complete, some of their hydrologic characteristics were also considered. Of these, some may be mentioned briefly in a few paragraphs.

Stream Flow.- The water courses draining both watersheds are dry throughout the year, except during and immediately after runoff producing rainstorms or in periods of melting snow.

Regimen of Stream.- Because the watersheds are small, it was expected that runoff from them would be of very short duration, and that the critical peak flows would persist only for a few minutes. It was also assumed that rapid response of stream flow to rainfall would be evidenced and that rapid fluctuations in stage would be common.

Characteristics of Water Courses.- Water courses on both watersheds are shallow swales with very little defined channels in the draws. On Watershed No.II, because of generally sharper slopes than those of W-III, the channel is somewhat more defined. At one or two points there are even slight evidences of gullying caused by runoff water.

INSTRUMENTATION AND PROCEDURE

In order to reproduce a picture of the watersheds in further detail, the topographic and soil characteristics had to be determined. For this purpose, the most accurate method of surveying was deemed necessary even if it entailed the use of considerable time, because the success of design and operation of the study depended on such a survey.

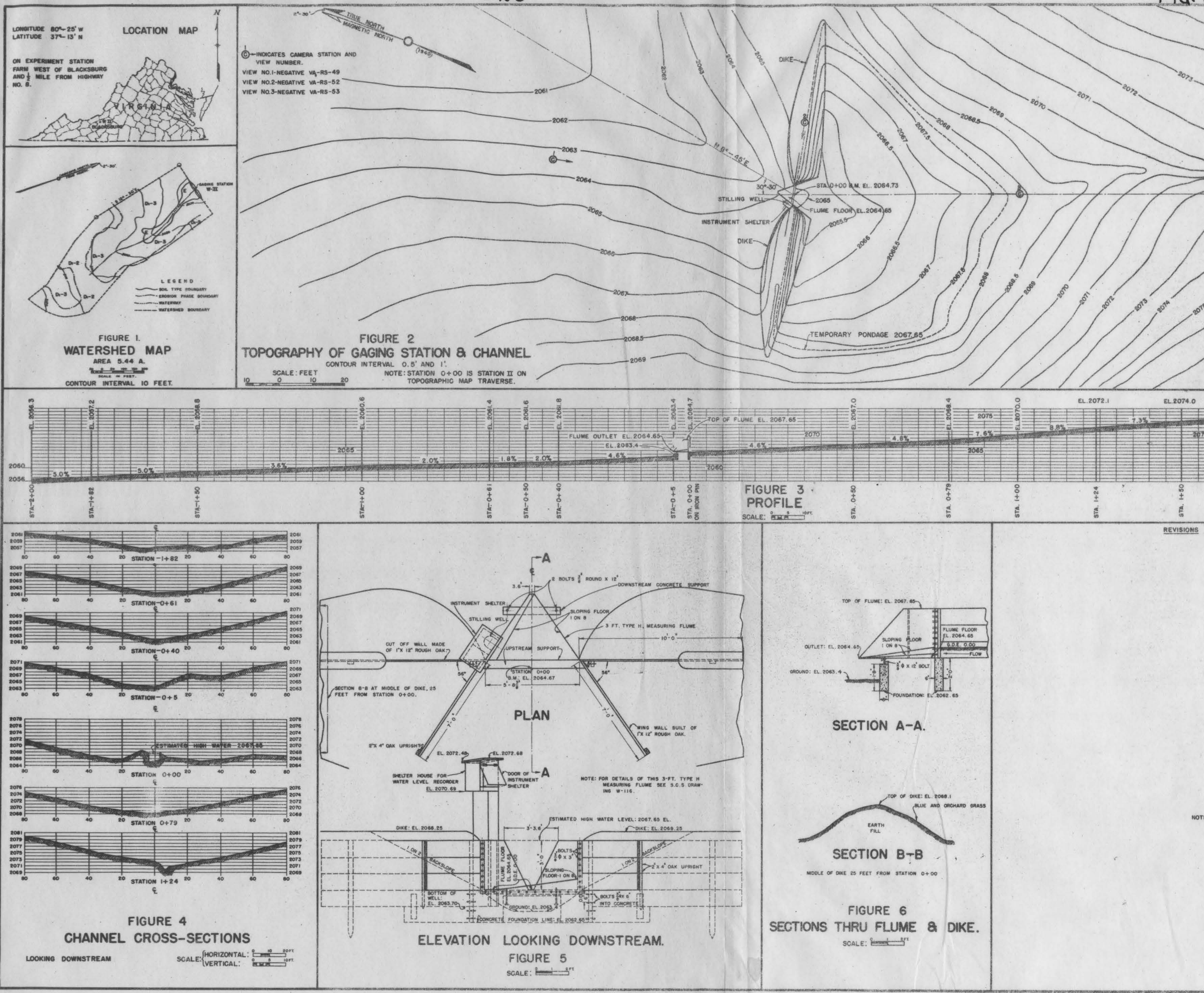
Survey of Site

The gridiron method was used in the topographic survey of the two watersheds. A contour map was then drawn of both, individual contours being spaced 2 feet apart to show all irregularities. Figure 5 illustrates the topographic features of the land, as reproduced from the original map, showing the location of installations and the boundary of the project.

Following the completion of the topographic survey of the watersheds, the drawing of the map from the survey notes and the actual installation of the runoff and rainfall measuring stations, a more detailed survey was conducted, the purpose of which was to draw: (1) A soil map and soil profiles or sections, (2) Crosssections of the main waterway or channel, (3) Dike cross sections, (4) Topographic map of the gaging station and channel, and (5) The profile of the channels.

The survey was completed in the early fall of 1939, and the final maps were drawn. Fig.5 is the "Watershed Map", showing the survey traverse, the watershed boundary for both W-II and W-III, the various watershed characteristics, the gaging stations, and the soil boundaries. Fig.6 is the final drawing of completed runoff measuring station for W-II. It is in complete detail and is self explanatory, clearly indicating differences in channel cross sections. The drawing for W-III

FIG. 6



NOTE: ALL ELEVATIONS ARE BASED UPON THE U.S.G.S. BENCH MARK NO. 275. ELEVATION OF FLUME FLOOR TAKEN AS 2064.65. G.D.E. = GAUGE DATUM ELEVATION.

FINAL DRAWING OF COMPLETED RUNOFF MEASURING STATION.
WATERSHED NO. II (EXPT. STA. FARM)
BLACKSBURG, VIRGINIA

REGIONAL CARTOGRAPHIC DIVISION — REGION 2
U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
H.H. BENNETT, CHIEF

SUBMITTED: O.W. CARDWELL
APPROVED:

is similar, therefore not included herein.

Design of Equipment

Both in the preliminary studies and final designs of the installations, previous work of the same nature was referred to. Since most of this work had, as already mentioned, been based on results obtained by C. E. Ramser, similar methods were sued in conducting the plans for this study.

The rational method for computing runoff was used as a basis, i.e. Q=CIA. "C", the coefficient of runoff, is the composite effect of many factors influencing runoff. "I", the rate of rainfall, depends upon the intensity for different durations equal to the time of concentration of the watershed in question. For the time of concentration takes care of influencing factors like slope, shape of the watershed and the character of the drainage channels. To a certain degree it is influenced by the vegetative cover, since the distance the water travels and its velocity depend largely upon these factors. These may make the time long or short, depending upon the degree of influence they exert in resisting or retarding the flow of water.

In case of W-II of this particular study, "I" was taken as 7.4 inches per hour, based on rates given by David L. Yarnell for from 6 to 8 minutes time of concentration, assuming frequency of runoff of 50 years. These estimations were presumed to be on the conservative side, since no data were available for use in a more accurate way. The coefficient of runoff used was 0.75, which is a figure given for rolling topography and because of the relatively absorptive character of the soil, the type of soil and the clean cultivation practised on the watershed.

Thus taking the rational method as a basis, calculations were made to determine the expected rate of runoff from each watershed. Due to economic considerations, however, it was not deemed feasible to design installations for W-III on as conservative a basis as the design for W-II, since the resulting increased expenditure would have made such a procedure undesirable at the time. Should additional capacity be required, as indicated by first results, steps will be taken to provide for this.

In planning the installations, because there was no data available which could be considered applicable to the local conditions, the design arrived at should not be considered at all accurate, nor could strict adherence to the design be required. This is true since, at best, the calculations might be considered merely rough estimates as regards the probable maximum discharge which would be experienced.

From the resulting calculations, which gave a rate of discharge of 30 cubic feet per second for W-II, a decision was made to use a Type-H flume with a depth of 3 feet to take care of this rate of runoff. This type of measuring device was selected for reasons to be discussed below.

Runoff Measuring Station.- Type-H Rate Measuring Flumes were installed to measure runoff on both W-II and W-III. This equipment has recently been developed at the National Bureau of Standards Hydraulic Laboratory by Mr. Howard L. Cook and his assistants in the Soil Conservation Service Research Division. It is better than the Parshall flume, as already mentioned, because of sloping sides and a narrow restriction throat which enables more accurate measurements of low flows and greater freedom from silt depositions.

Friez Model FW-1 recorders were installed in the instrument shelters surmounted upon the flume stilling well to provide a continuous record of stage. The clock gears used on this recorder will cause the chart on the clock to register one full revolution in six hours and will graphs of stage in the flume to be converted into discharge by means of rating tables provided by Mr. Cook.

Rainfall Measuring Equipment.- Since Watersheds No.II and No.III have a common boundary, only one rainfall measuring station was installed at a point in the upper reaches of the field to serve both. The station is composed of one Standard U.S. Weather Bureau type of raingage and one Friez Recording raingage. The latter is equipped with a clock cylinder geared to make one complete revolution in 12 hours. Thus with the clock well regulated, it will be possible to note on the chart the exact minute at which precipitation occurs, as well as the amount of rainfall. Fig.7 and Fig.8 show the plan and details of installation of the rainfall measuring station.

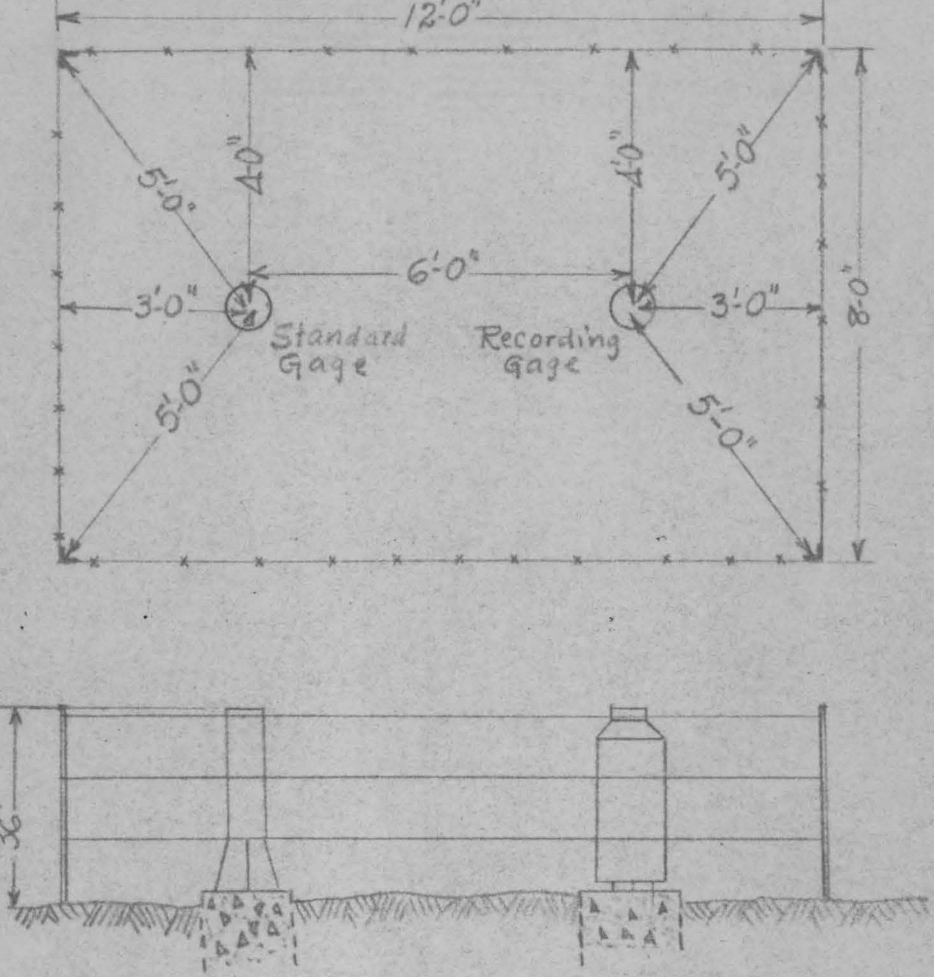
Construction of both the rainfall and runoff measuring stations was completed in the early spring of 1939, before the beginning of the runoff season.

Methods Employed in the Operation of Equipment

In operating the equipment on the runoff and rainfall measuring stations, the procedure followed may be set in short as follows:

Runoff Equipment.- For the measurement of runoff, a Friez Waterstage Recorder was used in this study. The complete installation is shown in Fig.2, which is a view of the flume and the shelter housing the waterstage recorder, and Fig.9 is a general view of the measuring station and the watershed.

Charts were placed on the clock cylinder of the waterstage recorder once a week and immediately following runoff periods. In addition inspec-



Note: Gage heights and fence posts at same elevation. In order to eliminate disturbing air currents, the posts were set without bracing above ground. Angle iron posts were used.

FIG. 7
PLAN AND ELEVATION OF ENCLOSURE FOR RAINFALL MEASURING STATION

PLATE

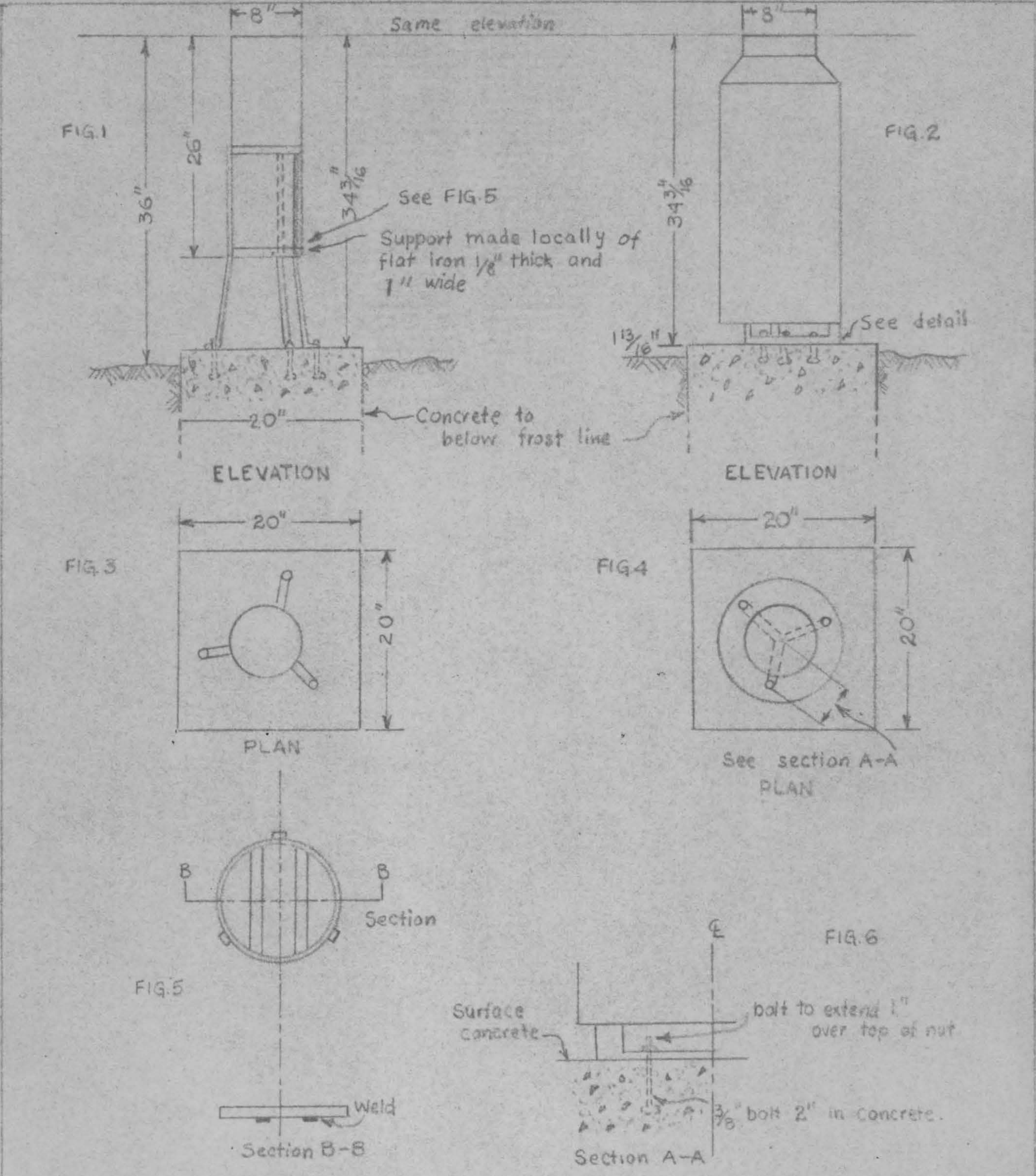


FIG. 8

DETAILS OF THE RAINFALL MEASURING STATION

Fig.9 A general view uphill of Watershed No.II, showing a Type-H Measuring Flume and instrument shelter.

tions were made in order that the recorder clocks may be synchronized with the raingage clock. This procedure was necessary so that simultaneous and comparative analysis of the records of rainfall and runoff may be obtained. The recorder clocks made one revolution every six hours, the charts used on them having a time scale of 1"- 25 minutes and stage scales of 5"-12 inches.

Upon removal of the chart, all pertinent remarks were made on it, such as time of placement, removal and inspections, chart readings at peaks and troughs, and rising and falling stages. This completed chart was then ready for analysis and the computation of actual runoff rates which are used in the plotting of runoff hydrographs to be d iscussed in due course.

Rainfall Equipment.- As already mentioned, a Standard and a Friez recording raingage were used for the measurement of rainfall.

Charts were placed on the Friez raingage once a week and immediately after each precipitation. These charts have time scales of 1"-1 hour and chart scales of 1"-1" of precipitation. Frequent inspections were made so that the clock time may be compared with the watch time, thus enabling the observer to adjust the clock and obtain close synchronization with the stage recorder clocks for more accurate results. Precipitations were measured from both the standard and recording gages, and these were in turn recorded in a notebook. The amount of water in each often varied due to wind or fast evaporation which takes place in the summer.

Methods of Analyzing Results

When the waterstage recorder and the recording raingage charts were taken in following a runoff, they were subjected to analysis. The steps followed in analyzing these results may be discussed briefly below:

Tabulation of Collected Records.- Table 1 is a summary of precipitation and runoff on W-II and W-III for the year ending December 31, 1939. It also shows the condition of the watersheds at the time these records were obtained. This is only a preliminary tabulation, the value of which lies in the fact that the important runoff producing rains are clearly indicated. These rains were later closely analyzed from the charts on which they were recorded. So were the corresponding runoff charts used for analysis.

The results in Table 1 do not give a true picture of the runoff from either of the two watersheds under discussion because, so far, few practical devices have been developed which will measure runoff accurately without constricting the channel and creating a certain amount of artificial pondage. And the Type-H flume is not an exception to this rule. A certain amount of pondage is expected to be caused by the contraction of the flume. This pondage, even though small, has to be considered in arriving at the correct rates of surface runoff, especially during high rates of change in stage which will take place through heavy rainstorms of very short durations. This rate of change may at times be great enough to make the rate of impounding during rising stages, or the rate at which the pond is draining out on falling stages, a large percentage of the value given by the rate of discharge of the flume.

Correction for Pondage.- Because of the role which pondage plays on runoff, means had to be found to correct for it. Fig.10 is a topographic map of the pondage at W-II. The contour at the maximum stage for which the flume was designed is called "Temporary Pondage". One-half foot contours were plotted between this stage and the notch elevation from notes of the survey made of the upstream and downstream channels.

SUMMARY OF PRECIPITATION AND RUNOFF ON

WATERSHED (W-2 & 3 Experiment Sta. Farm) for the year ending December 31, 1939 PROJECT AT Blacksburg, Va.

Rainfall Measuring Sta. R-3 Sheet 1 of 2 Sheets

Rainfall									Run-off (W-II)					Run-off (W-III)					Condition of Watershed
Date	Chart No.	Began (hour)	Duration hr.	Duration min.	Amount (inches)	Maximum Intensity (in/hr) 5 min.	15 min.	30 min.	Chart No.	Began (hour)	Ended (hour)	Maximum Rate C.F.S.	Maximum Rate in./hr.	Chart No.	Began (hour)	Ended (hour)	Maximum Rate C.F.S.	Maximum Rate in/hr.	
April 25	1	7:00PM	2	40	0.30	0.24	0.18	0.10	1	–	–	–	–	–	–	–	–	–	Land plowed and
28	2	10:46AM	0	30	0.18	0.60	0.28	0.18	1	–	–	–	–	–	–	–	–	–	disked. Corn
30	2	3:10PM	0	05	0.02	0.24	–	–	1	–	–	–	–	–	–	–	–	–	planted April
May 2	4	1:12PM	0	38	0.09	0.24	0.24	0.18	2	–	–	–	–	–	–	–	–	–	27-30
13	7	3:00AM	7	30	0.63	0.60	0.28	0.24	3	–	–	–	–	–	–	–	–	–	
22	9	1:48PM	0	07	0.09	0.48	–	–	5	–	–	–	–	–	–	–	–	–	Tillage May 11-14
27	10	12:39PM	0	13	0.07	0.36	–	–	5	–	–	–	–	–	–	–	–	–	Shoots 3 to 4 in high
28	10	2:43PM	0	09	0.12	0.96	–	–	5	–	–	–	–	–	–	–	–	–	
31	11	6:37PM	1	30	0.11	0.24	0.16	0.14	6	–	–	–	–	–	–	–	–	–	Second tillage of
June 2	12	1:38PM	0	20	0.52	2.84	2.00	–	6	1:40PM	2:15PM	0.052	0.009	7	1:37PM	2:15PM	0.003	–	corn. Corn 8 to 16 in.
2	12	3:40PM	6	25	0.30	0.36	0.20	0.15	6	–	–	–	–	–	–	–	–	–	high, laid by
3	12	5:10AM	0	50	0.17	0.36	0.20	0.14	6	–	–	–	–	–	–	–	–	–	
3	13	10:05AM	1	02	0.14	0.60	0.28	0.20	7	–	–	–	–	–	–	–	–	–	
8	14	3:24PM	0	05	0.18	2.16	–	–	7	–	–	–	–	–	–	–	–	–	
8	14	3:52PM	0	26	0.85	4.80	3.20	–	7	3:55PM	5:26PM	15.450	2.838	8	3:58PM	5:15PM	17.600	0.914 (1.36?)	Corn 1 to 2 Ft. high
12	15	Light	Showers		0.02	–	–	–	8	–	–	–	–	–	–	–	–	–	No weeds.
13	16	3:16PM	0	40	0.49	4.44	1.76	0.96	8	3:20PM	3:59PM	2.130	0.392	9	3:17PM	4:51PM	6.100	0.316	
18	17	4:15PM	4	08	} 0.26	Chart slipped from under			9	–	–	–	–	–	–	–	–	–	
19	17	11:45AM	0	10		Clamp. Readings no good.			9	–	–	–	–	–	–	–	–		
26	18	10:20PM	1	15	0.62	2.40	1.64	1.08	11	10:26PM	11:02PM	0.002	–	12	10:42PM	12:00M	0.009	–	
28	19	11:55AM	0	15	0.05	0.12	0.20	–	12	–	–	–	–	–	–	–	–	–	
28	19	6:27PM	1	03	0.25	0.84	0.60	0.48	12	–	–	–	–	–	–	–	–	–	
29	20	2:23PM	0	12	0.11	0.60	–	–	12	2:39PM	2:45PM	0.002	–	–	–	–	–	–	
29	20	4:00PM	0	40	0.68	2.64	1.68	1.20	12	4:23PM	6:15PM	1.995	0.366	13	4:23PM	Con't.	2.190	0.114	
30	21	10:56AM	0	07	0.12	1.44	–	–	13	10:59AM	11:20AM	0.119	0.022	13	Con't.	11:30AM	0.297	0.015	Corn 5 Ft. high
30	21	12:08PM	0	19	0.23	1.97	0.80	–	13	12:15PM	1:58PM	2.060	0.379	14	12:17PM	2:00PM	3.310	0.172	No weeds
July 4	22	2:30PM	2	55	0.15	0.84	0.32	0.16	14	–	–	–	–	–	–	–	–	–	
7	23	11:32AM	0	44	0.23	1.20	0.80	0.46	15	11:37AM	12:00N	0.004	0.001	16	11:36AM	12:30PM	0.723	0.038	
7	23	4:17PM	0	57	0.40	2.40	1.32	0.68	15	4:58PM	6:50PM	2.210	0.406	16	4:58PM	6:30PM	4.140	0.214	Corn 6 to 8 Ft. high
8	24	3:58PM	3	57	0.17	0.84	0.28	0.14	16	–	–	–	–	–	–	–	–	–	
14	25	4:21AM	1	37	0.54	2.64	1.40	0.76	16	4:27AM	6:30AM	2.160	0.397	17	4:27AM	6:40AM	3.470	0.180	Corn 8 to 12 Ft. high
18	26	6:20PM	0	33	0.31	2.88	1.04	0.60	17	6:31PM	7:31PM	1.570	0.289	18	6:32PM	8:00PM	1.610	0.083	Sparse weeds
19	26	3:27AM	0	05	0.07	0.84	–	–	17	–	–	–	–	–	–	–	–	–	
19	27	4:35PM	3	25	0.45	1.20	1.08	0.40	18	5:08PM	8:40PM	1.570	0.289	19	5:38PM	11:00PM	1.760	0.091	
20	27	4:25AM	3	35	0.31	0.36	0.20	0.12	18	1:26AM	8:00AM	Trace	–	19	5:21AM	10:20AM	0.094	0.005	
20	28	Intermittent	rain		0.15	0.48	0.20	0.08	19	–	–	–	–	20	7:28PM	8:30PM	0.103	0.005	
21	28	Intermittent	rain		0.28	0.24	0.12	0.04	19	–	–	–	–	20	7:24AM	11:00PM	0.011	0.001	
29	30	11:06AM	1	15	0.23	1.20	0.48	0.32	20	–	–	Trace	–	22	11:14AM	Con't.	0.078	0.004	
29	30	1:27PM	0	33	0.05	0.48	0.16	0.10	20	1:30PM	2:10PM	0.038	0.007	22	Con't.	"	0.026	0.001	
29	30	3:00PM	0	25	0.10	0.24	0.16	–	20	3:28PM	4:00PM	0.011	0.002	22	"	5:00PM	0.032	0.002	
Aug 2	31	4:20PM	1	00	0.64	3.60	2.04	1.10	21	4:22PM	6:30PM	3.890	0.715	23	4:26PM	6:00PM	4.620	0.230	
6	32	Showers			0.11	–	–	–	–	–	–	–	–	–	–	–	–	–	
7	33	3:22PM	1	38	0.55	3.00	1.20	0.72	23	3:33PM	5:40PM	2.380	0.437	25	3:36PM	6:15PM	2.210	0.115	
7	33	6:32PM	0	15	0.06	0.24	0.24	–	–	–	–	–	–	–	–	–	–	–	
13	34	1:31PM	0	09	0.13	0.72	–	–	–	–	–	–	–	–	–	–	–	–	

SUMMARY OF PRECIPITATION AND RUNOFF ON

WATERSHED W-2 & 3 (Expt. Station Farm) for the Year Ending December 31, 1939 PROJECT AT Blacksburg, Va

Rainfall Measuring Station R-3.

Rainfall									Run-off (W-II)					Run-off (W-III)					Condition of Watershed.
Date	Chart No.	Began (hour)	Duration hr.	Duration min.	Amount (inches)	Maximum Intensity (in/hr) 5 min.	15 min.	30 min.	Chart No.	Began (hour)	Ended (hour)	Maximum Rate (C.F.S.)	Maximum Rate (in./hr.)	Chart No.	Began (hour)	Ended (hour)	Maximum Rate (C.F.S.)	Maximum Rate (in./hr.)	
Aug. 14	34	5:39PM	3	21	0.11	0.36	0.16	0.14	25	6:15PM	7:30PM.	trace	–	–	–	–	–	–	
14	34	9:40PM	1	50	0.23	1.80	0.92	0.88	25	11:17PM.	12:00M.	0.982	0.181	27	11:23PM.	12:00M.	0.777	0.040	
15	35	1:37PM	1	11	1.08	3.60	2.60	1.84	26	1:57PM	4:00PM	6.940	1.280	28	1:59PM.	6:00PM	18.100	0.938	
17	36	6:50PM.	0	50	0.25	0.84	0.60	0.40	27	6:53PM.	8:00PM.	0.049	0.009	29	6:54PM.	8:30PM.	0.226	0.012.	
18	36	4:00AM	14	10	2.40	0.84	0.64	0.40	27	5:15AM	7:00PM.	1.113	0.208	29	6:08AM	8:00PM.	2.530	0.131	
23-25	37	Light Showers			0.07	–	–	–	–	–	–	–	–	–	–	–	–	–	
26	38	"	"		0.06	–	–	–	–	–	–	–	–	–	–	–	–	–	
Sept. 1	39	3:38PM	0	05	0.17	2.04	–	–	30	3:41PM.	7:00PM.	0.0939	0.017	–	–	–	–	–	
1-4	39	Light Showers			0.04	–	–	–	–	–	–	–	–	–	–	–	–	–	Started cutting corn
29	43	"	"		0.15	–	–	–	–	–	–	–	–	–	–	–	–	–	
30	44	1:27PM.	5	23	1.25	3.12	1.60	0.96	34	1:27PM.	7:45PM.	3.090	0.568	36	1:46P.M.	8:15P.M.	1.960	0.102	All corn cut from W-II leaving 4" stubble and practically no weeds. Corn cut from upper third of W-III by Sept. 30. Remainder covered by mature corn 10-12 ft. high.

– No run-off from Sept. 30 to Dec. 31, 1939 –

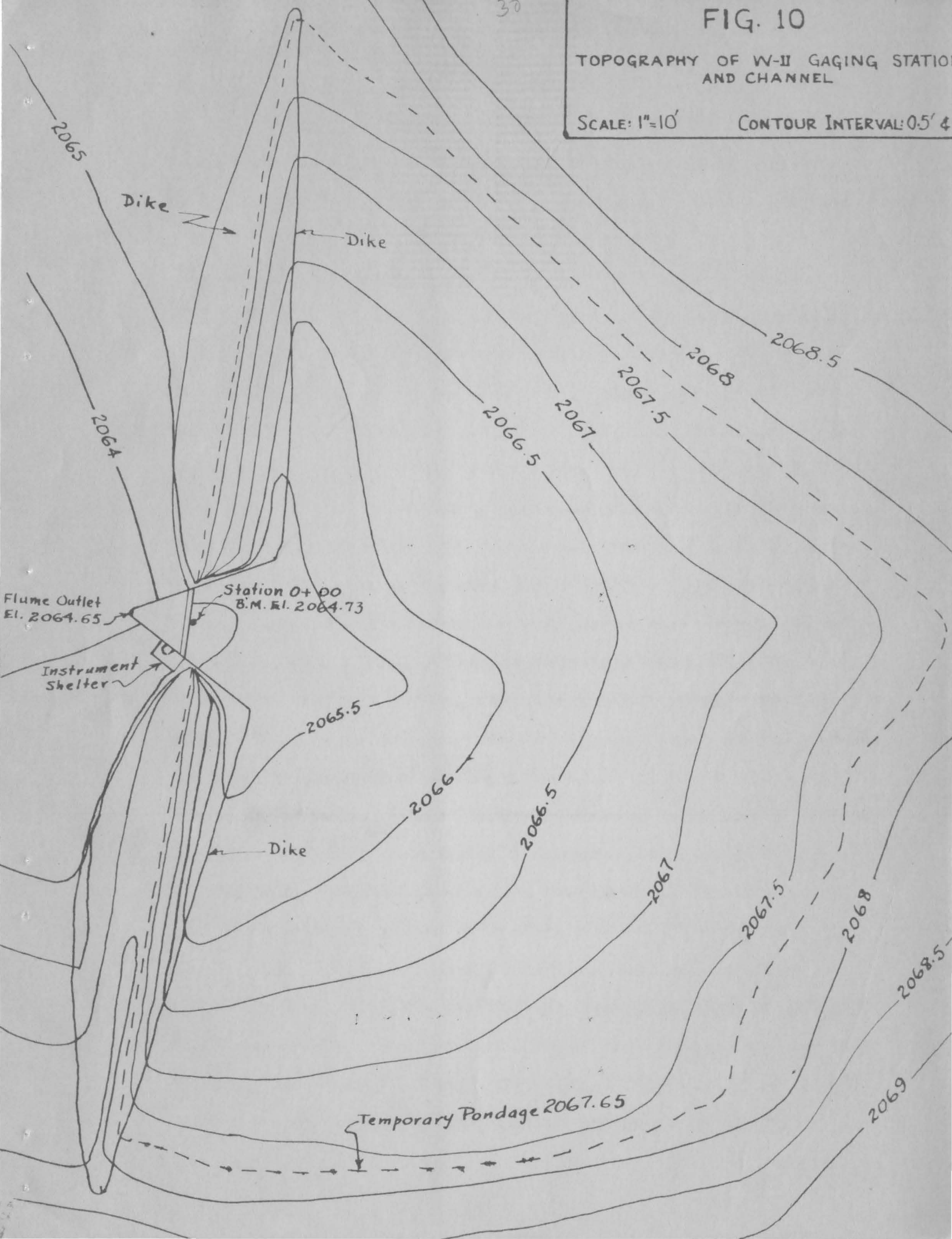


FIG. 10

TOPOGRAPHY OF W-II GAGING STATION AND CHANNEL

SCALE: 1"=10' CONTOUR INTERVAL: 0.5'

This area, in square feet, included within each of the 0.5 foot contours and the contour of the temporary pondage, which is also shown in Fig.6, was determined by means of a planimeter. The volume for 0.01 foot of stage, in cubic feet, corresponding to each of these contour elevations was determined by multiplying each of the areas by 0.01. The corresponding rates of ponding, in cubic feet per second for a rate of change in stage of 0.1 foot per minute, were obtained by dividing each of the volumes by 60. The values of areas, volumes, and rates of ponding were tabulated in columns 2, 3, and 5 of the table in Fig.11. Columns 1 and 4 of the table give mean sea level and the corresponding gage datum elevations of the contours, as well as of intermediate elevations. Stage gage datum elevations are those of the water surface upstream from the flume in reference to the elevation of the flume floor, which was taken as 0.00 foot. The several rates of ponding thus obtained for each 0.5 foot contour, as well as the gage datum elevation and the maximum stage of the temporary pondage, were plotted into a pondage correction curve. Fig.11 is the pondage correction curve for gaging station on W-II. It also shows the rates of ponding at each 0.1 foot of stage as incorporated in the table. Values for lesser intervals than 0.01 foot were not calculated since they could easily be determined by interpolation.

The pondage corrections were then incorporated in the final rating table for this station. This table gives values of flume discharge (Qw) for each 0.01 foot of stage in cubic feet per second and values of the pondage correction (Qp), in cubic feet per second, for rates of change in stage from 0.01 foot per minute to 0.09 foot per minute for each 0.1 foot of stage. The values for pondage correction, in the case of W-II, begin with 0.1 foot of stage, for below that the pondage is negligible.

CONTOUR ELEVATION feet (1)	AREA Sq. ft. 2	VOLUME for 0.01' of Stage Cu. ft. 3	STAGE G.D.E. ft. 4	RATE OF PONDING for 0.01'/Minute Change in Stage C.F.S. 5
2064.65	0	0	0.00	.000
			0.10	.001
			0.20	.003
			0.30	.005
2065.0	34	.34	0.35	.006
			0.40	.009
			0.50	.014
			0.60	.020
			0.70	.026
			0.80	.035
2065.5	244	2.44	0.85	.041
			0.90	.045
			1.00	.055
			1.10	.070
			1.20	.089
			1.30	.108
2066.0	753	7.53	1.35	.125
			1.40	.135
			1.50	.170
			1.60	.200
			1.70	.233
			1.80	.263
2066.5	1653	16.53	1.85	.276
			1.90	.295
			2.00	.324
			2.10	.346
			2.20	.390
			2.30	.423
2067.0	2615	26.15	2.35	.436
			2.40	.456
			2.50	.494
			2.60	.530
			2.70	.570
			2.80	.614
2067.5	3815	38.15	2.85	.636
			2.90	.660
2067.65	4378	43.78	3.00	.730

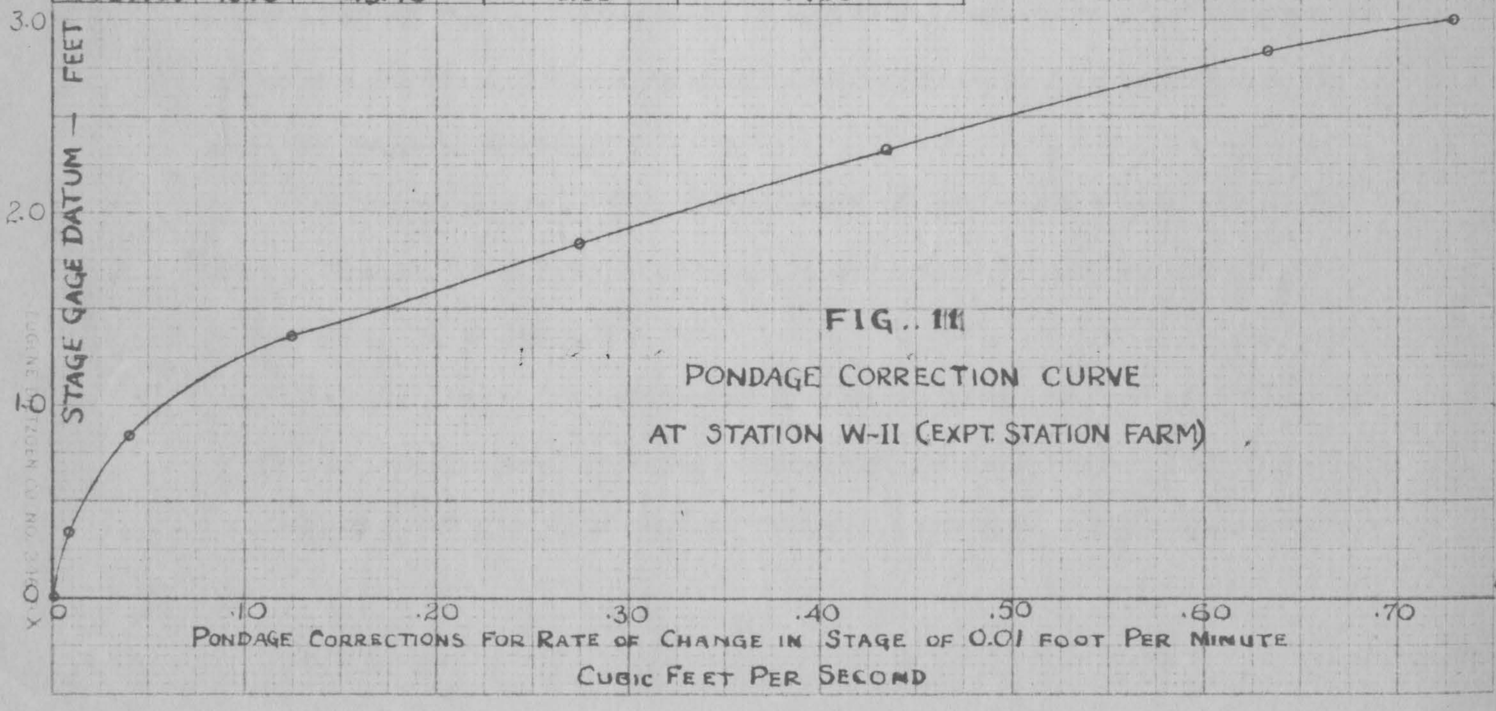


FIG. 11

PONDAGE CORRECTION CURVE

AT STATION W-II (EXPT. STATION FARM)

The use of a rating table and the application of the pondage correction are best demonstrated in Table 2, Fig.12, which is a record of runoff for the storm of June 8, 1939, from Watershed No.II. Other storms were analyzed and tabulated in the same manner.

From column 8 of Table 2, it may be noted that the stage at 4:05 p.m. was 2.235 feet. The value of discharge from the flume (Qw), as given in the rating table for W-II, is 15.40 cubic feet per second. The gage height or stage at 4:04 p.m. was 2.10 feet. This means that the stage was rising at a rate of 0.135 foot per minute immediately prior to the stage height of 2.235 feet. Consulting the rating table, it was found that the pondage correction (Qp) was 5.27 cubic feet per second. Adding "Qp" to "Qw" (since the stage is rising) would give 20.67 cubic feet per second, which is the true rate of discharge from the watershed. The same method was used in determining all the other values of pondage and discharge, adding the pondage correction to the rising stage and subtracting it in the case of falling stages.

The significance of the pondage correction is apparent, since with a rate of rise of only 0.135 foot per minute the value of "Qp" was over one-third that of "Qw". Negligence of pondage correction would, therefore, c cause great errors. The errors would multiply many fold as the rate of rise in stage increases.

The significance of the pondage correction is still more apparent when reference is made to the rating table for W-III, where the stage of 2.16 feet is considered.

The gage height on W-III at 4:06 p.m. is found to be 2.16 feet. Following the same method employed above, "Qw" is found to be 14.3 cubic feet per second, while "Qp" is 18.5 cubic feet per second. In other words the value of "Qp" was about 1.3 times greater than the rate of discharge from the flume. Moreover, the value of pondage (Qp) at 1.68 feet of stage was about double that of the discharge from the flume.

Another interesting point brought out by the use of rating tables is the time peaks are reached. It was found out that often a peak discharge may be reached before the maximum stage. On W-III, the maximum stage was 2.36 feet, yet the peak discharge occured when the stage was only 2.16 feet, which was three minutes before the stage of 2.36 feet was reached. Thus is proved a fact that a rise in stage does not necessarily mean a greater rate of discharge, and that the maximum rate of discharge may be reached before the maximum stage. Peaks and troughs, which would not otherwise have become evident, are also brought to light by the application of pondage correction.

Still another fact uncovered by the pondage correction is the actual end of runoff, which may be some minutes previous to the time shown by the runoff chart on the water stage recorder.

Of course, it should not be assumed from the foregoing discussion that pondage can be determined with an extreme degree of accuracy. The fact that the "human element" enters into the work, precludes such an assumption. Some errors can also be made in the survey of the "temporary pond", in plotting the topographic map of the pond, in planimetering the areas within each of the contours, and in the determination of the rates of change in stage. Notwithstanding all theso errors, however, the percentage of error which would result should pondage corrections be neglected is so great that it becomes imperative to use them.

Let the initial rate of runoff at 4:03 p.m. in Table 2 be considered as an example in this discussion. The values of "Qp" and "Qw" are 8.85

and 10.60 cubic feet per second, respectively. With an error of 20% due to the "human element", "Qp" would be either 7.08 feet per second or 10.62 cubic feet per second. Using the smaller value, Q Qw Qp, or 10.60 plus 7.08 totalling 17.68 cubic feet per second. Should the pondage correction be neglected altogether, the value of "Q" would be 10.60 cubic feet per second, which is about 60% of the small value and 50% of the high value. In any case it is too much below the true value of discharge obtained by the use of pondage correction. Moreover, the error due to human element can be reduced to a minimum by the exercise of care in the determination of pondage correction. It is probable that any such errors are within 3%.

Plotting Hydrographs of Records.- In order to make a contrast of the runoff characteristics of W-II and W-III, Table 2 and a similar one for W-III were used in the preparation of the hydrographs. Fig.12 is a hydrograph for the storm of June 8, 1939, and Fig.13 is one for the storm of August 15, 1939.

These figures show cumulative rainfall, rates of rainfall and runoff in a graphical form for both of the above rainstorms. Other hydrographs were also prepared from the principal storms, though not included in this thesis. All the hydrographs and tabulations were used to analize the results by the rational formula discussed herein.

The Rational Method.- Runoff coefficients were computed for several summer rainstorms which produced fairly high intensities. The highest short time intensity took place on June 8, 1939. Yet even this did not satisfy Yarnell's once-in-two-years expectancy of 5.2 inches per hour for a 5-minute duration.

Table 3 is an analysis of the high intensity rains by the rational formula, Q equals CI. The drainage area "A", usually used in this formula was eliminated by expressing the rate of runoff directly in surface inches per hour, viz: "Q" (in inches per hour) equals "Q" (in cubic feet per second) divided by "A" (in acres).

Taking the runoff for the storm of June 8, 1939, as an example, and referring to Fig.12 (for W-II), it is found that the rise in stage from the second rain started at 3:58 p.m. and reached peak discharge at 4:05 p.m. The cumulative rainfall for the seven minutes of rise amounted to 0.53 inches. Thus, using the above formula: "I" equals 0.53 times 60/7, which equals 4.69 inches per hour. "Q" equals 3.81 inches per hour (as shown on the runoff hydrograph). To determine the coefficient of runoff "C", therefore, the following equation is used:

$$C \quad Q/I \quad 3.81/4.69 \quad 0.814$$

The coefficient of runoff for Watershed No.II, therefore is 0.814. This same method was used in determining the value of "C" for all the other storms in Table 3.

PRESENTATION AND DISCUSSION OF RESULTS

In order to study the results from this study, several hydrographs were prepared of the principal rainstorms as already mentioned. Fig.12 and Fig.13 are hydrographs prepared for storms of June 8 and August 15, 1939. Other hydrographs which were prepared for other storms were not included here, for the above were deemed sufficient for an example. The method employed in their preparation and analysis is discussed below.

Hydrograph Preparation and Analysis

Records obtained from the rainfall measuring station serving Watersheds No.II and III were tabulated for the individual storms, as prepared in Table 2, and for others not included therein. From these tabulations, graphs of cumulative rainfall and rainfall intensity were prepared, as presented in the abovementioned figures.

Similarly, instantaneous values of stage were taken from the water level recorder charts which registered runoff. Rating tables and pondage corrections were applied to these stages for conversion into discharge rates. Values obtained in this manner were then plotted on the rainfall graphs, producing runoff hydrographs which can be properly related to the rains that caused them.

The figures, then, show cumulative rainfall graphs and histograms of rainfall intensities, runoff hydrographs, as well as the preceding precipitations which might have had some effect on the runoff caused by the storms. Table 2 is an example for a record of rainfall and runoff used to plot Fig.12

This figure shows a peak discharge of 3.81 inches per hour for W-II and 1.7 inches per hour for W-III. The runoff discharge was caused by a

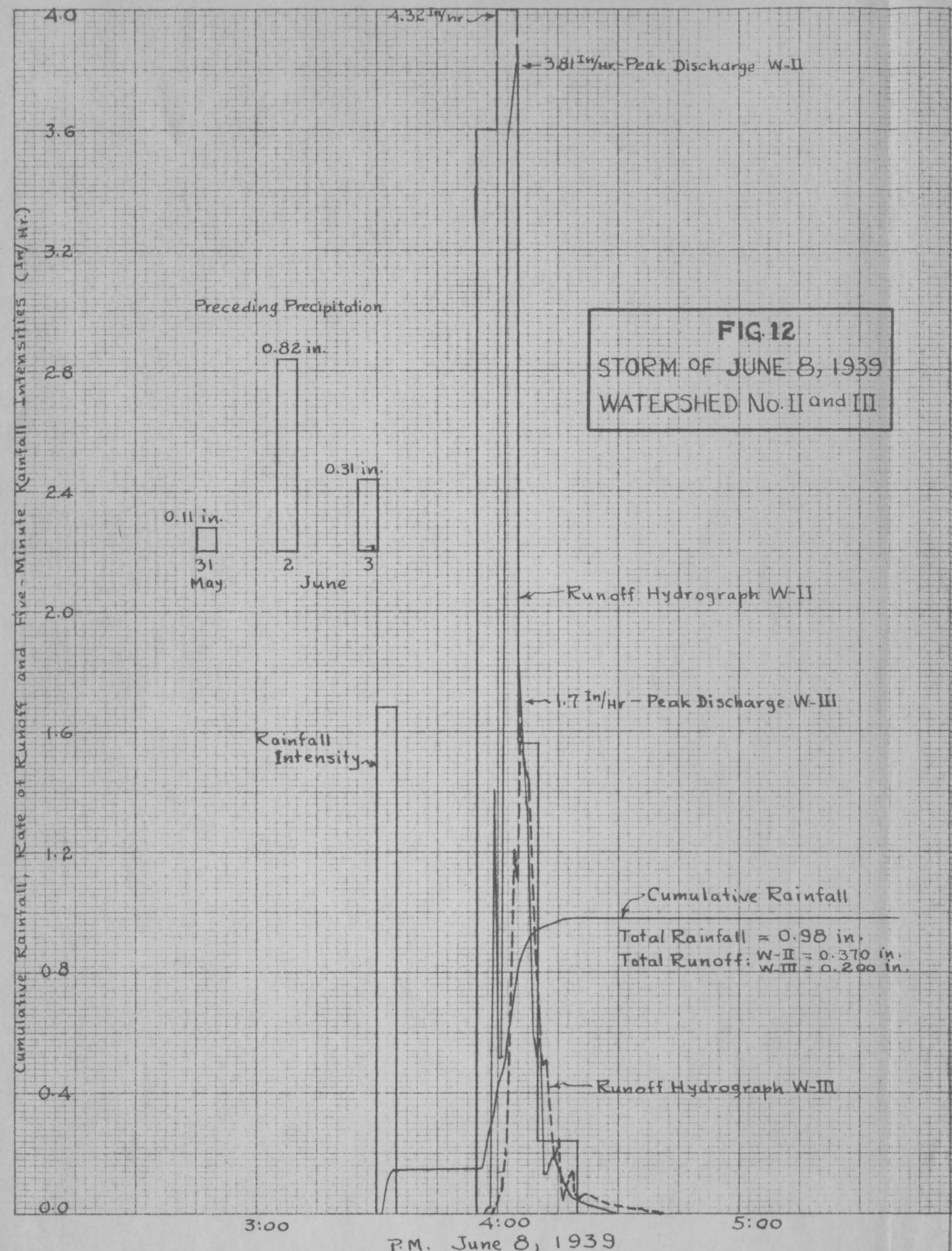


FIG 12
STORM OF JUNE 8, 1939
WATERSHED No. II and III

TABLE-2

RECORD OF RAINFALL AND RUNOFF for June 8, 1939 from Stations R-3 and W-II

RAINFALL

Date and Time (1)	Time Interval, Minutes (2)	Accumulated depth, Inches (3)	Depth for Time Interval, Inches 4	Intensity, In/Hr. (5)
June 8 3:31 P.		0		
:32		.10		
:33		.12		
:35	5	.14	.14	1.68
:55	20	.15	.01	.12
:56		.15		
:57		.20		
:58		.28		
:59		.35		
4:00P	5	.45	.30	3.60
:01		.48		
:02		.50		
:03		.60		
:04		.75		
:05	5	.81	.36	4.32
:06		.85		
:07		.88		
:08		.92		
:10	5	.94	.13	1.56
:12		.95		
:15	5	.96	.02	.24
:17		.97		
:20	5	.98	.02	.24
:22		.98		

RUNOFF

Date and Time (6)	Time Interval, Minutes 7	Gage height, feet. 8	Pondage Correction Qp, Sec. ft. 9	Flume Discharge Qw, Sec. ft. 10	Discharge Corrected for Pondage; Qp+Qw, Sec. ft. 11	Discharge Corrected for Pondage; Qp+Qw, In/Hr. 12
June 8						
3:55P	0	–.81	0	0	0	0
:56½	1½	0	0	0	0	0
:57	½	.30	.300	0.235	.535	.01
:58	1	.46	.22	.527	.747	.014
:59	1	1.10	4.48	3.16	7.64	1.40
:59½	½	1.245	2.58	4.14	6.72	1.24
4:00	½	1.19	.98	3.75	2.77	.51
:01	1	1.146	.31	3.45	3.14	.52
:02	1	1.60	9.80	7.20	17.00	3.12
:03	1	1.90	8.85	10.60	19.45	3.57
:04	1	2.10	7.12	13.40	20.52	3.77
:05	1	2.235	5.27	15.40	20.67	3.81
:06	1	2.12	4.10	13.50	9.40	1.73
:07	1	1.94	3.19	11.10	7.91	1.46
:08	1	1.80	2.74	9.38	6.64	1.22
:09	1	1.60	4.00	7.20	3.20	.59
:10	1	1.40	2.70	5.35	2.65	.49
:11	1	1.24	0.94	4.10	3.16	.58
:12	1	.90	1.37	2.06	.69	.13
:13	1	.73	0.28	1.33	1.05	.19
:14	1	.68	0.13	1.15	1.02	.19
:15	1	.58	0.20	.833	.633	.12
:16	1	.50	0.112	.621	.509	.093
:17	1	.36	.094	.330	.236	.043
:18	1	.27	.045	.193	.148	.027
:19	1	.31	.020	.249	.269	.049
:20	1	.30	-.005	.235	.230	.042
:21	1	.24	.021	.156	.135	.025
:22	1	.25	.015	.168	.183	.034
:23	1	.24	.003	.156	.153	.028
:24	1	.23	.003	.145	.142	.026
:25	1	.20	.009	.113	.104	.019
:26	1	.17	.012	.085	.073	.001
:29	3	.185	.002	.099	.101	.019
:58	29	.10	Readings below G.D.E = 0.17			
5:21P	23	.03	are in error due to silt.			
:26	5	.05				
6:07	41	.00				

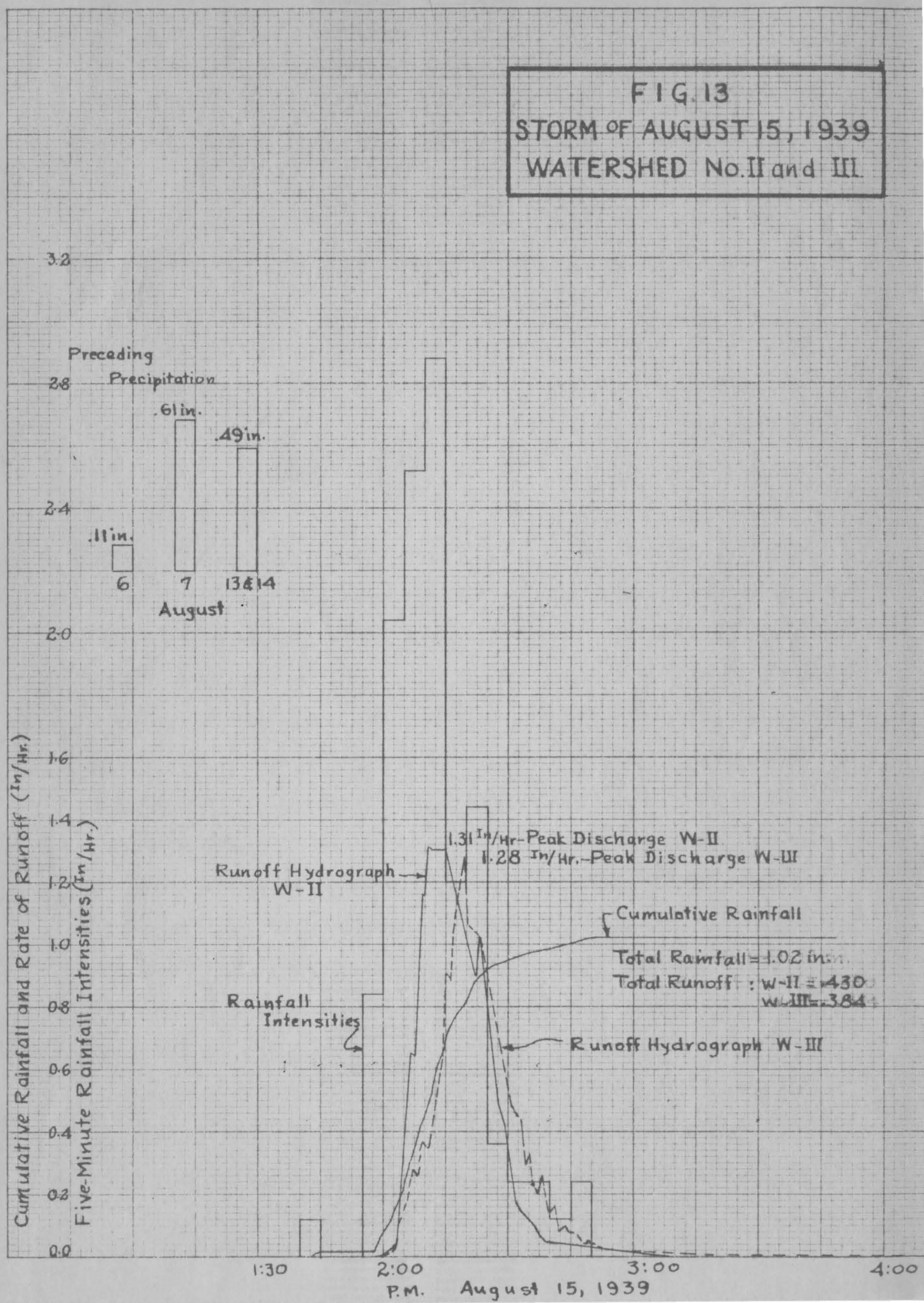


FIG. 13
STORM OF AUGUST 15, 1939
WATERSHED No. II and III.
Preceding Precipitation
.11 in.
.61 in.
.49 in.
6
7
13 & 14
August
Runoff Hydrograph W-II
1.31 In/Hr - Peak Discharge W-II
1.28 In/Hr. - Peak Discharge W-III
Cumulative Rainfall
Total Rainfall = 1.02 in.
Total Runoff : W-II = .430
W-III = .384
Rainfall Intensities
Runoff Hydrograph W-III
Cumulative Rainfall and Rate of Runoff (In/Hr.)
Five-Minute Rainfall Intensities (In/Hr.)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
2.0
2.4
2.8
3.2
1:30
2:00
3:00
4:00
P.M. August 15, 1939

total rainfall of 0.98 inches falling in 51 minutes. But the greater part of it fell in 12 minutes. During this period, the amount of rainfall was 0.75 inches. The first rain, which produced 0.15 inch, lasted only 5 minutes. It apparently did not have much direct effect, for no runoff resulted from it on either watershed. Peak discharge was reached at 4:05 p.m. on W-II and a minute later on W-III. The actual runoff started at 4:01 on both watersheds.

The storm of June 8 was a very flashy one. The hydrographs show clearly that most, if not all, of the runoff was caused by approximately 0.5 inch of rain. Apparently the 0.15 inch of rain which fell between 3:31 and 3:36 p.m. was retained by the ground, for there had been no appreciable precipitation for a few days previously. Retention of water by the soil was helped because the land was clean and the corn plants were only 1 to 2 feet high, as indicated in the remarks on Table 1, sheet 1. Moreover, the land had been tilled for the last time on June 2, 1939. All the conditions were, therefore, favorable for increased infiltration capacity of the soil. The high intensity flashiness of the storm, however, and the sparse cover played a disadvantage and brought about the high rate of runoff.

The storm of June 8 being a type to be expected in the Limestone Valley Region of the Appalachians of Virginia, it would seem of great importance to note its effects, specially should such a storm last a longer period and should it follow gentle rains which may have already saturated the soil.

In applying Ramser's rational method to this storm to determine the coefficient of runoff, an interesting point was brought to light. The time which elapsed between the start of rise on the hydrograph for W-II and the arrival at the peak, was found to be seven minutes. The total rain during this period was about a half inch, as mentioned before. Had the rain continued at the same intensity, the peak would have probably been reached at a later time and might have been higher. In short, if the time of concentration of the runoff water had been reached, the graph would have leveled off. This contention is proved by the hydrograph for the storm of August 15, 1939, to some degree, where there is a leveling-off following the peak of discharge.

Turning to the runoff hydrograph for W-III, it is found that the peak discharge was 1.7 inches per hour as compared with 3.81 inches per hour for W-II. This was undoubtedly due to the fact that the time of concentration for the bigger watershed was not reached. The rain slacked off too abruptly. From the analysis of other records for this watershed, it was found that the time required for the runoff water to concentrate is about 15 minutes. In this case it was only 8 minutes. It is, therefore, assumed that had the rainfall intensity continued it would have caused a higher rate of runoff.

On examining the topographic and soil map, Fig.5, it would be observed that the draw immediately above the gaging station for W-III is made up of Emory silt loam which extends to a depth of 45 inches and has a slope not exceeding 3%. When the rainstorms are of a short duration, this flat area of Emory silt loam plays an important part on runoff. It undoubtedly increases the time of concentration due to its ability to absorb huge quantities of water. It also slows up runoff water coming from the upper reaches and the sides of the watershed, giving it a low velocity and causing more time to be consumed before the water finally reaches the flume

In short, flashy storms would not give a true picture of the runoff behavior. This is especially true in the case of W-III. Slower and steadier rains of longer duration, allowing the colluvial deposit to be somewhat saturated to as near its maximum capacity as possible, should produce a clearer aspect of the way this watershed reacts to runoff and rainfall.

Fig. 13 is the hydrograph for the storm of August 15, 1939. It shows the hydrograph for W-II reaching its peak and leveling off for a period of four minutes (though actually the discharge at the peak is 0.01 inch per hour higher than the level section of the hydrograph). The peak for W-III practically equals that for W-II.

In this case, the time of concentration was 9 and 16 minutes for W-II and W-III, respectively. Significantly enough, the peak runoff on W-II was produced by 0.37 inch of rainfall and that on W-III by 0.63 inch of rainfall, the rest of the 1.01 inches of rain apparently was retained by the soil or fell after the time of concentration. Both being cultivated to the same crop and having the same type of soil, the coefficient of runoff, "C", should show their true behavior to rainfall. In this instance, "C" was 0.53 and 0.54 for W-II and W-III, respectively. As it might ordinarily be expected, the peak discharges should be reached at varying times. For this runoff, the peak discharge on W-II was reached at 2:11 p.m. and that on W-III at 2:19 p.m. In other words, W-III lagged 8 minutes behind W-II.

Because of the difference in the slopes and their lengths on the two watersheds, the above lagging seems logical. The steepness of the slopes on W-II, both on the sides and in the draw, give runoff water greater velocity and reduce the time required for it to travel from the farthest point of the draw down to the flume. On W-III, the slopes become gentler as they approach the draw, reducing the velocity of water. And, as the runoff water loses its velocity in the draw, the colluvial Emory soil absorbs it. Observing the hydrographs for W-III, it may be noted, specially in Fig.13, that the rises on the graphs are slower and gentler than those on the graphs for W-II, showing that the reaction of W-III to precipitation is slower. This will take place as long as the runoff water from the various temporary streams is gradually emptied into the main channel. Fig.12, however, proves the opposite. Runoff water from all over the area emptied into the channel two minutes after the beginning of the rain. The result was violent and the discharge rate was great for almost as short a period, jumping from 0.00 to 1.00 inches per hour in abput two minutes. In order, then, to obtain similar peak discharges for W-II and W-III, a rainfall of high intensity and long duration should occur.

Variation of Runoff Coefficients

Table 3 is a summary of analysis, by the rational formula Q CIA, of the important rainstorms which produced runoff. It is an attempt to evaluate differences in the time of concentration for the various runoffs. Ramser's definition of the coefficient of runoff, "C", is: The ratio of the rate of runoff to the rate of rainfall. In this study, therefore, an attempt is made to relate the peak discharge to the average rainfall intensity during the concentration period, for it is the rainfall intensity at this period which causes and affects the runoff rate. Should the intensity continue unabated during and after the peak discharge has been reached, the graphical picture as reproduced on the water level recorder chart and on the hydrograph would be a straight

TABLE III

ANALYSIS OF HIGH INTENSITY STORMS OVER BLACKSBURG, VA.

BY THE RATIONAL FORMULA

Date 1939	Previous rains		WATERSHED NO. II						WATERSHED NO. III						Remarks
			Period of rise	Average rain intensity during period of rise	Maximum rate of runoff	Coefficient by Rational formula	Rain-Amt. & duration prior to period of rise		Period of rise	Average rain intensity during period of rise	Maximum rate of runoff	Coefficient by Rational formula	Rain-Amt. & duration prior to period of rise		Condition of watershed
	Date.	Amt.	Min.	Inches/hr.	In/hr.		In.	Min.	Min.	Inches/hr.	In/hr.		In.	Min.	
June 8	6-8 6-3 6-2	.18 .31 .82	7	4.69	3.810	0.81	.28	7		See Note*					Corn 1-2 feet high. Last tillage 6-2. No weeds.
June 29	6-28 6-26 6-19	.30 .62 .26	7	2.31	.473	0.21	.28	22	10 1/2	1.83	.161	0.09	.15	17	Corn 5 feet high. Land clean.
July 7	7-7 7-4 6-30	.23 .15 .35	7	1.89	.512	0.27	.28	77		See Note*					Corn 6-8 feet high. Sparse weeds.
Aug. 2	7-29 7-21	.38 .28	7	1.80	.776	0.43	.30	5	13	0.78	.339	0.44	.39	7	Corn 8-12 feet high. Sparse weeds.
Aug. 15	8-14 8-13 8-7	.36 .13 .61	9	2.46	1.310	0.53	.13	8	16	2.36	1.280	0.54	.16	9	-ditto-

* Note:

Rain of insufficient duration to satisfy time of concentration.

line for as long as the intensity remains the same.

It is interesting, therefore, to note the close agreement of the coefficients for the storms of August 2 and 15, 1939. In the case of June 29, the coefficients for both watersheds were lower than any in the table. That for W-III is probably too low, due to the fact that the time of concentration was not reached, but it was included for comparison. Most probably the amount of rain prior to the period of rise was not sufficient to saturate the Emory deposit and allow more runoff water to reach the flume.

Significantly, the same amount of rain had been absorbed by the soil prior to period of rise despite the long or short duration prior to the period in question. This is specially true in the case of the first three storms. In the case of the storms for August 2 and 15, the amounts prior to the period of rise compare quite favorably for W-II and W-III, so do the durations.

As indicated by the note on the table, the analysis for June 8 and July 7, 1939, for W-III were not included because the rains were insufficient to satisfy the time of concentration.

The condition of the watersheds at the time of runoff probably explains in part the behavior of the two watersheds to the various rainstorms. As the season progressed, the soil had become packed by the successive rains. At the same time the foliage of the corn plants broke the force of the raindrops and prevented a great deal of them from reaching the land below as fast as they dropped. This in turn increased the time required for the runoff water to concentrate. It became necessary, then, that the rains must be of a longer duration and a greater intensity in order that the true coefficient of runoff may result. The coefficient of runoff, in fact, decreased as the season progressed, except for unusual cases when it was lower at an earlier date. This is evident when reference is made to the coefficient of runoff on June 8. For that storm, the coefficient of runoff for W-II is 0.81. At no other time subsequently was it higher than half the above figure. Apparently, as the corn crop matures, the infiltration capacity of the soil is increased by the interference which its foliage causes. As already mentioned, the foliage probably slows the rain as it falls, and this in turn gives the soil more time to absorb a greater amount of the water which reaches it.

Erosion Caused by Runoff

Thus far only runoff and its analysis have been discussed. The effect of runoff on erosion from the two watersheds may be briefly demonstrated by Fig.14, which is a topographic map of the silt deposit caused by the storm of June 8 on W-II. The effect of this storm on W-III could not be shown as clearly because of the flat colluvial land at the approach to the flume, which slowed up the runoff water and caused most of the silt, except for a negligible amount, to be deposited in the draw. Fig.15 is a photographic view of the silt deposited in the flume on W-II on June 8, 1939. It reached the height of about 0.3 foot in the center of the flume. How much more was carried down the draw below the flume could only be guessed. From observations made immediately following the runoff, it was not a negligible amount. For 300 feet or more below the station, there were clear traces of silt, and this was by far much finer than that deposited at and above the flume. Fine silt deposit was also noticed below W-III and about one inch of it in the flume.

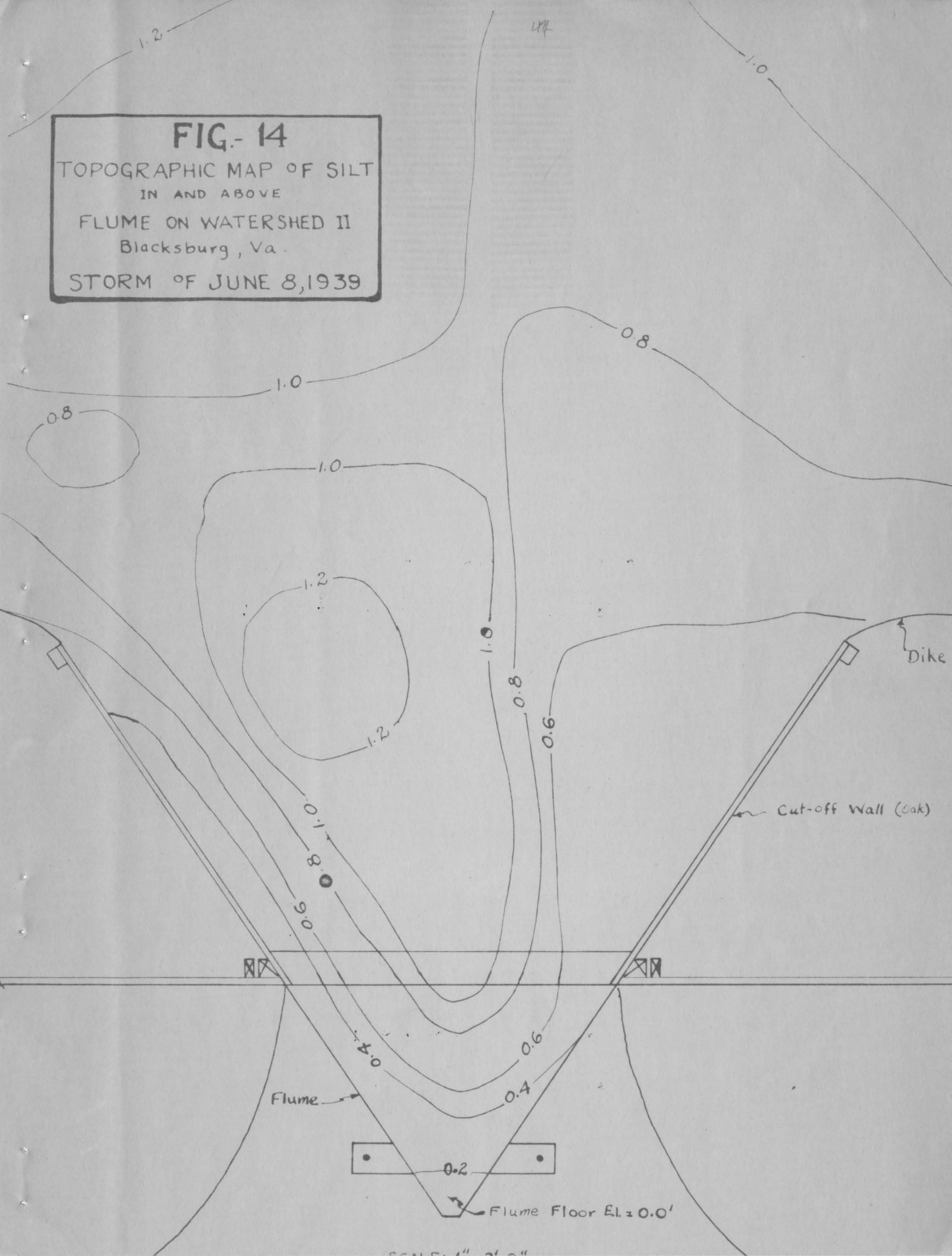


FIG.- 14
TOPOGRAPHIC MAP OF SILT
IN AND ABOVE
FLUME ON WATERSHED II
Blacksburg, Va.
STORM OF JUNE 8, 1939

Fig.15 View of silt in flume on Watershed No.II after the storm of June 8, 1939. Philadelphia Rod is resting on flume floor and showing depth of silt in flume.

No definite statement could be made as to the rate of erosion on either watershed. The appreciable deposit of colluvial soil in the draws (43 inches deep) of both watersheds would, however, tell part of the story. Moreover, galls or bald spots at different points are clear evidences of advanced erosion. One such bald spot of a good size may be noticed on Fig.5. It was large enough to be mapped. It is interesting to note that this spot is situated on the slope of the watershed which has a northerly direction. There were other such spots, but they were too small to map. When the watersheds are in wheat or corn, these spots stand out clearly. Erosion is so advanced on them that 75% or more of the top soil has been washed away. No special effort was made to determine the amount of soil removed by runoff water, as no practical methods could be used on areas so large. The soil map, Fig.5, is probably the best picture of the condition of the watersheds in respect to erosion. The soil ranges from virgin in the woods (D -1), where even the "Ao" horizon is present and where no erosion other than the slow natural one is present, to D -4, where over 75% of the top soil has been removed by runoff water. The main cause for the accelerated erosion shown by the galls on both watersheds is the poor cultural practice of making furrows parallel with the slopes of the land, i.e. up and down the slopes. This cause for erosion could be eliminated by a change of method in plowing the land, making furrows which run parallel to the contours of the land. Erosion at the present or past rates would undoubtedly expand the areas from which the top soil has been washed away.

CONCLUSIONS AND RECOMMENDATIONS

Although data collected thus far from the two watersheds under study make definite conclusions untimely, they have, at the same time, made it possible to make certain preliminary conclusions. Further collection of records and their close analysis would undoubtedly shed a brighter light on the problem of runoff in the Limestone Valley Region, and on the subject of engineering designs to be used for the control of runoff water. The fact that during all the period covered by this study not one thunderstorm produced an intensity of short duration to satisfy Yarnell's once-in-two-year expectancy for the region, should warrant closer and further study of runoff records if definite results are to be obtained and used in the plan of engineering designs.

From the records thus far collected, it appears that in order either of the two watersheds may reach its peak discharge, the time of concentration for the watershed must be satisfied. This should take place when the storm is of a sufficiently high intensity and long duration. Fig.13 is a good illustration of this point because, especially on W-II , the peak discharge was reached and it continued four minutes at about the same rate. It shows that the rain continued after the peak discharge was reached; but, more important yet, that the intensity of the rain continued unabated.

The similarity or dissimilarity of watersheds can be reflected by the coefficients of runoff obtained from records for the same rains. In the case of Watersheds No.II and III, this is mirrored for each of the storms listed in Table 3. Coefficients for the two watersheds coincided closely when the time of concentration for each was satisfied. Significantly, also, these coefficients became smaller with the progress of the growing season of the corn crop. The fact that they compared closely for the different storms no doubt reflects the similar characteristics of the two areas as to cover crop, topography and soil type. When coefficients of runoff for the complete rotation of crops used in the Limestone Valley Region of the Appalachians of Virginia (i.e. corn, wheat and clover) have been developed in due course, the task of the engineer, in planning control designs for this area, will be greatly facilitated.

A further interesting point shown by Table 3 is that the infiltration capacity of the soil increased as the corn approached maturity. This is revealed by the tendency of the runoff coefficients to become smaller with the advance of the growing season. Sine the runoff coefficient "C" is the ratio of the rate of runoff to the rate of rainfall intensity during the period of discharge, a decrease in "C" would show that the soil had been absorbing the runoff water despite the continuance of the intensity of rainfall. The smaller coefficients may also be explained by the fact that the mature cover crop tends to slow up the raindrops as they hit its dense foliage and decreases the velocity of runoff water, thus allowing the rain and runoff water to be absorbed.

One last point is that of erosion. Despite the high yields of crops on these two watersheds, this yield being maintained by the heavy application of stable and green manures, as well as commercial fertilizers, erosion has and will proceed at a pace not at all natural, as indicated by the presence of eroded areas on the topographic and soil map, Fig.5. Profiles of the soil tell part of the story, of the top soil having been removed away. These profiles explain the situation further when they show that the Dunmore soil becomes tighter with depth, the "B2" hroizon being a water impeding layer. Consequently, when the top soil has become saturated partially or fully, depending upon the intensity of rainfall, the rest of the rainfall water becomes runoff water. Runoff water becomes great when the rains are flashy and hard, giving little time to the soil to absorb the precipitation water. It is necessary, then, to help the absorptive capacity of soils by increasing the time of travel of the runoff water and using cultural methods which tend to reduce runoff.

Briefly stated, therefore, this study, through its revelation of the behavior of Dunmore soil and the runoff coefficient of this soil, should help in the preliminary design of runoff control structures. Continuation of the study would further reveal other factors not brought to light herein due to the brevity of time, and it should help in the evaluation of the true runoff coefficients upon which many hydraulic designs are so dependent.

---***---

I. BIBLIOGRAPHY OF REFERENCE

1. Russell, I. C. 1902 Geology and Water Resources of the Snake River Plains of Idaho. U.S.Geol.Sur. Bull. 199, 192 pp., illus.

2. Duley, F. L. and Miller, M. F. 1923 Erosion and Surface Run-off Under Different Soil Conditions. Mo.Agr.Exp.Sta. Res. Bull. 63, 50 pp., illus.

3. Ramser, C. E. 1927 Runoff from Small Agricultural Areas. Rept. Jour.Agric.Res., Vol.34 No.9, 1927

4. Miser, H. D. 1924 The San Juan Canyon, Southeastern Utah. A Geographic and Hydrographic Reconnaissance. U.S.Geol. Sur. Water Supply Paper 538, 80 pp., illus.

5. Duley, F. L. and Miller, M. F. 1930 Influence of Forest Litter on Runoff, Percolation, and Erosion. Jour. For.28: 474-491, illus.

6. Bennet, H. H. 1932 Relation of Erosien to Vegetative Changes. Sci. Monthly 35: 385-415, illus.

7. Miller, M.F. and Krusikoph, H. H. 1932 The Influence of Systems of Cropping and Methods of Culture on Surface Runoff and Soil Erosion. Mo. Agric. Exp. Sta. Res. Bull. 177

8. Horton, R. E. 1935 Surface Runoff Phenomena. Part I, Horton Hydraulic Lab. Pub. 101, Feb, 1935

9. Musgrave, G. W. 1935 The Infiltration Capacity of Soils in Relation to the Control of Surface Runoff and Erosion. Jour.Am. Soc. Agron. 27: 336-345

10. Yarnell, D. L. 1935 Rainfall Intensity-Frequency Data. U.S.D.A. Misc. Pub. No.204, Aug, 1935

11. Davis, F. L. 1936 A Study of the Uniformity of Soil Types and of the Fundamental Differences Between Different Soil Series. Alab. Exp. Sta. Bull.244.

12. Cardwell, D. W. 1937 Rainfall and Runoff Mimeo. Soil Cons. Service Spartanburg, S. C.

13. Duley, F. L. and Kelly, L. L. 1938 Effect of Soil Type, Slope, and Surface Conditions on Intake of Water. Univ. Neb. Agr. Exp. Sta. Res. Bull. 112

14. Krimgold, D. B. 1938. Research on Runoff from Small Drainage Basins. Agric. Eng., October, 1938

15. McGauhey, P. H. 1938 Hydrology of Virginia, Part I, Va. Eng. Exp. Sta. Ser. Bull. 33, April, 1938

16. Krimgold, D. B. and Weber, J. L. 1939 Pondage Corrections Involved in Measuring of Runoff from Small Drainage Basins. U.S.D.A. Mimeo. November, 1939

17. Barter, E. F. 1939 The Unit Hydrograph Principle Applied to Small Watersheds. Proc. Am. Soc. of Civ. Eng., Vol.65 No.7, September, 1939