RUN-OFF CHARACTERISTICS OF AGRICULTURAL AREAS IN NORTH CENTRAL OKLAHOMA

By

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INTRODUCTION

The general aim of the hydrologic investigations herein reported was to determine the rates and amounts of runoff from small agricultural areas. In this initial year of investigation the primary achievement was to select suitable watersheds for runoff measurements and to establish rainfall and runoff gaging installations. Various physical characteristics of the watersheds were evaluated and storm records obtained. Published analytical procedures were applied to the collected data for the determination of watershed runoff coefficients and infiltration capacities.

One of the principal reasons for initiating this study was to obtain design data applicable to North Central Oklahoma. Available data for design purposes are meager for this locality. These data are needed for the economical design of all mechanical structures for conveying and impounding runoff.

To acquire data with the least expenditure of funds, existing highway culverts were used as flow measuring devices. The relatively rough measurements obtained were thought to furnish more accurate design data for this locality than those data obtained through transposition from other experimental watersheds of dissimilar characteristics.

REVIEW OF LITERATURE

The determination of rates and amounts of runoff and their frequency of occurrence has been a major problem confronting engineers and hydrologists for centuries. Many early false teachings and hypotheses prevailed until the latter part of the 17th century when Marriotte, Perrault and Hally abandoned the theories of the past and began active experimental work.

> Marriotte, who discovered Marriotte's law of gases, also known as Boyle's law, probably deserves more than any other man the distinction of being regarded as the founder of ground-water hydrology, perhaps I should say the entire science of hydrology. In his publications, which appeared after his death in 1684, he defended vigorously the infiltration theory and created much of the modern thought on the subject.[11]

Innumerable experiments and studies of runoff have been made since these men first observed and studied hydrologic phenomena. Theories and hypotheses have been advanced and cast aside. At present hydrologists continue to formulate hypotheses based on pure rationalizations. However, even though the definite laws governing hydrologic phenomena are unknown, many of the important basic factors entering into the runoff phenomena have been revealed. These factors are being applied in the development of methods to estimate runoff.

In an attempt to develop methods and formulas for estimating runoff, a large number of empirical runoff formulas and curves have been developed by engineers in the United States and elsewhere. Munson[12] listed a portion of these formulas, including Kuichling's $Q = CIA$, which are applicable to the design of drainage structures.

In general, the majority of these formulas and curves were developed to offer a simple means to determine runoff rates and amounts for design purposes. The investigators did not attempt to insolate various rainfall and runoff relationships. Often only one variable, the drainage area size, was contained in the formula. Kuichling's formula and others include rainfall intensity as a variable, in addition to drainage area size.

Undoubtedly the so-called "rational formula", $Q = CIA$, has been the most universally applied empirical formula in the design of erosion control structures, sewers, highway culverts, and other hydraulic structures on comparatively small drainage areas. Jarvis[6] made the following statement in his discussion of the rational method:

> The formula used in connection with this method is one of the most convenient yet devised for showing the relation of rainfall to maximum expected runoff from areas within the range of its proper use, as follows:
>
> $$Q = CIA$$
>
> where Q = maximum runoff, in cfs.
>
> C = the percentage of average rainfall appearing as runoff at the end of the prescribed period at the point of observation.
>
> I = average rainfall intensity prevailing during the period in inches per hour.
>
> A = drainage area in acres.

Ramser[13] described the rational method as follows:

> In the rational method of computing runoff, the various factors influencing runoff are provided for in the formula $Q = CIA$. C, the coefficient of runoff, is the composite effect of all factors influencing runoff which have been mentioned. I, the rate of rainfall to be provided for, depends upon the intensity for different durations of rainfall for the particular locality, and the duration to be used for any particular watershed is equal to the time of concentration of that watershed. Thus the time of concentration takes care of such influencing factors as the shape and slopes of the watershed and the arrangement and character of the drainage channels. To a certain extent, also, it takes account of the vegetation on the water-

shed, since the distance traveled and the velocity of the water depend partly upon these factors.

The measurements of runoff from small agricultural areas made by Ramser in 1917 and 1918 and the discussion of the factors affecting runoff as a result of his observations, are undoubtedly the most valuable data resulting from early experimentation.

At that time Ramser stated, "There are many interdependent factors entering into the relation between rainfall and runoff and it is practically impossible to evaluate all of them accurately." Krimgold[9] more recently points out that the runoff studies which followed served to dispel the idea that rates of runoff could be arrived at by obtaining a few values of C and of times of concentration. The results of these studies showed that rates of runoff from small natural drainage basins are not a simple function of the rate of rainfall, and that the expectancy of runoff is not the same as the expectancy of rainfall intensities. In addition, great variations in peak rates of runoff caused by constantly changing vegetal cover, structure of surface soil, and soil moisture condition overshadow the relation of runoff to the intensity of rainfall.

Hydrologists now recognize the irrationality involved in estimating runoff rate as a percentage of rainfall. Runoff is essentially a residual and can only be rationally evaluated as rainfall minus loss, of which infiltration is a major part. It is now possible to estimate surface runoff as the approximate equivalent of excess rainfall. In 1940, Horner[4] stated that as rapidly as specific values of infiltration capacity can be made available to the engineer the practice of applying a coefficient of runoff to precipitation may be expected to be abandoned.

The design data as published by Ramser in 1927 continues to be the basis upon which the majority of the soil and water conservation structures are designed. However, great advancement has been attained in the analysis of the hydrograph and the development of the infiltration theory.

Sherman[18] set forth the principles of the "unit hydrograph" in 1932. This method is based upon the hypothesis that in any drainage basin surface runoff from rainfall that occurs in a given unit of time will produce hydrographs in which the bases are approximately equal and the ordinates vary with the intensity of net rainfall. The unit hydrograph method appears to be quite satisfactory when applied to large drainage basins. However, for small watersheds the hypothesis is not rational and is not useful for the synthesis of the runoff hydrograph.

The papers published by Horton[5,6] in 1933 and 1935 contained the guiding principles and method of attack to synthesize the hydrograph. This synthesis was based upon the infiltration concept. A hydrograph of runoff for a particular drainage basin was estimated for an assumed storm by first knowing the standard infiltration capacity curve for the watershed. Many investigators are now studying and developing methods of deriving infiltration capacity curves.

In developing infiltration curves, rates of infiltration must be derived indirectly from the rainfall and runoff measurements obtained from plot and watershed studies. Infiltrometers have been used extensively to provide a controlled, artificial rainfall on small plots.

Controlled application of water is desirable since any derived rates of infiltration are necessarily approximate unless the rate of runoff is constant and the volume of surface water in storage does not change.

Infiltration capacity curves may be derived by various methods. In infiltrometer plot studies a first approximation to the infiltration rate at any instant can be obtained by the difference between rainfall and runoff rates.[7] When surface and channel storage cannot be neglected, as in small watershed studies, the procedures used in deriving any infiltration curve is more complex. Several techniques for deriving infiltration curves have been developed. Generally the analysis must be carried out through a series of successive approximations and for this reason is quite different from the technique that is applied to sprinkling plot study.

Horner[4] and other investigators have presented mathematical approaches for the determination of watershed infiltration capacity curves and Schiff[15] has recently presented a graphical derivation of infiltration capacity curves. This method was based upon the time condensation principle published by Holtan.[3]

When the infiltration capacity curves for the different soil-cover-condition complexes have been derived, the curves are then applied to a given rainfall to estimate the runoff for each complex. The runoff volumes are then summed to obtain the design runoff for the watershed.

Investigators of hydrologic phenomena predict that the infiltration theory of surface runoff will provide the desired satisfactory design data needed by engineers to economically design all mechanical structures for conveying and impounding runoff from small watersheds.

Runoff Studies in Oklahoma

In 1929 observations were started at Guthrie, Oklahoma on 13 watersheds ranging in size from 2.5 to 100 acres. Measurements of rainfall and runoff on these watersheds have been made continuously since. In 1939 studies were started at Cherokee, Oklahoma on 9 watersheds ranging in size from 1.8 to 8.5 acres. In addition at Cherokee there are a total of 48 plots and terraced areas up to 4 acres in size on which observations are made. For several years following 1938 measurements were made of rainfall and runoff from 4 watersheds near Muskogee, Oklahoma. They were small watersheds ranging in size from 14 to 61.4 acres. It will be noted that the largest watershed in these studies had an area of 100 acres.

From these very small areas there is quite a jump to the size of watersheds included in the next group of runoff studies. These studies are the gagings of the various streams by the U. S. Geological Survey in that part of Oklahoma lying in the Arkansas River Basin. Twenty-three water stage recording gages are included in these studies. These gages are mainly on the larger streams and rivers whose drainage areas are measured in square miles.

Between the two extremes of the small and the large watersheds is a range of drainage area sizes on which there are no data.

DESCRIPTION OF PROJECT

This study was initiated by selecting five watersheds typical of the Reddish Prairies of Oklahoma. The watersheds are located 15 miles north of Stillwater, Oklahoma in Noble County. The area is part of the Otoe Indian Reservation and the Black Bear Creek Watershed.

The general relief is moderately rolling to rolling, 4 to 10 percent slopes predominating. The drainage pattern is well developed on all but the smallest watershed.

All drainage basins are covered with a tall and short native grass mixture. Only a small portion of the area is not virgin sod, and all portions once cultivated have returned to native grass.

The predominating upland soil catina is Vernon, Renfrow, Kirkland, which were formed over Red-Beds shale parent material. Some soil types developed over sandstone and alluvium are also present. In general, the soils are slowly to very slowly permeable.

Period of Record

Gages to measure rainfall and runoff of three watersheds were installed in June, 1951. Data of storms occurring through October are tabulated. Complete detailed records of only one watershed are published in this report, but a few records for other watersheds are included.

Description of the Watersheds

Watershed No. 1, (W1), contains 15 acres. As may be seen in figure 1, the shape is roughly rectangular. The length is about three times the width. It can be noted that no gullies have developed in the drainage pattern. The waterway is, in effect, a broad grassy swale. The distance from the farthest point on the watershed to the gaging station is approximately 1500 feet. Upland soil types, Renfrow silt loam and Renfrow silty clay loam, are found on a 5 percent prevailing land slope. These soil types are deep, fine textured, and very slowly permeable.

The entire watershed is virgin sod supporting native grasses, 20 percent tall grasses, 75 percent short grasses, and 5 percent annuals. All of the area is pastured. At present, the cover is typical of areas in fair condition for Noble County, Oklahoma.

Watershed No. 3, (W3), contains 90 acres and is adjacent to W1. (See figure 1). The shape is roughly rectangular with the length slightly less than twice the width. The drainage pattern is well developed. Three waterways fan out to completely dissect the watershed. From the farthest point on the watershed to the gaging station is approximately 3300 feet.

The prevailing land slopes of the upland soil types are 4 percent for Renfrow silt loam and silty clay loam, which comprise 55 percent of the watershed area, and 10 percent slope for Renfrow silty clay loam found on the steeper slopes bordering the waterways (35 percent of the area). The remaining 10 percent of the watershed area is occupied by Miller clay, a bottomland soil type on a 1 percent slope. These soil types are all deep, fine textured, and very slowly permeable.

Covered with native grasses, 40 percent tall grasses, 50 percent

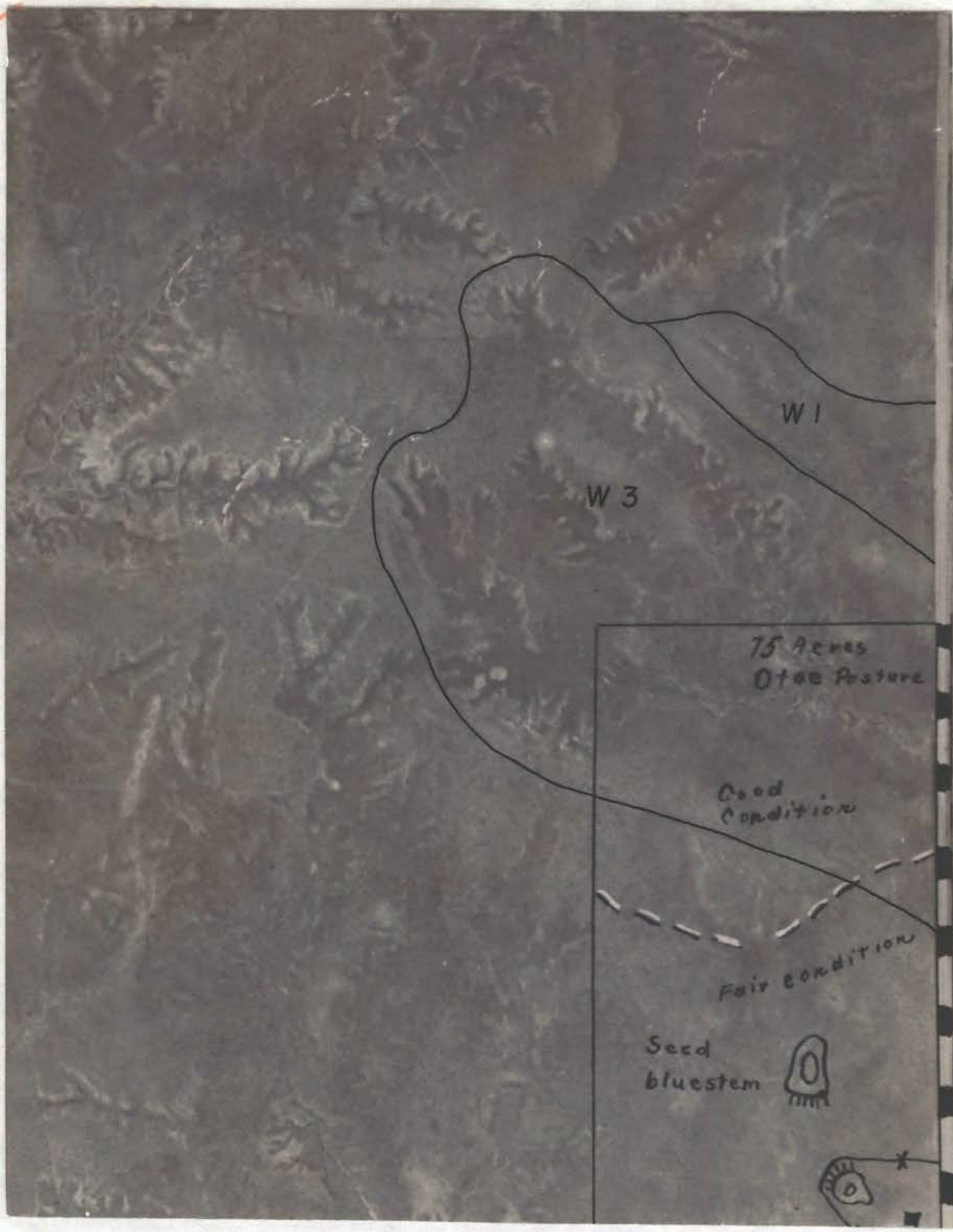


Figure 1. An aerial photograph of watersheds 1 and 3.

short grasses and 10 percent annuals, the range condition averages fair. All of this virgin grassland is pastured.

Watershed No. 4, (W4), contains 210 acres. The shape is likewise roughly rectangular as shown in figure 2. The length is slightly greater than twice the width. A main channel extends nearly to the rim of the watershed and many waterways dissect the area. The distance from the farthest point on the watershed to the gaging station is approximately 7000 feet.

Fifty-five percent of the watershed area is in upland soils with a prevailing slope of 4 percent. The upland soil types vary as to origin and type of parent material. Renfrow very fine sandy loam, silt loam, and silty clay loam, and Kirkland silt loam are soil types developed over Red-Beds shale. These deep, medium to fine textured, very slowly permeable soils occupy 40 percent of the watershed area. Lucien very fine sandy loam, which occupies 10 percent of the watershed area, is developed over sandstone. It is a shallow, medium textured, permeable soil. Five percent of the watershed is composed of Albion loam, a shallow, medium textured, permeable soil type developed on upland alluvium. Bottomland alluvium occupies 10 percent of the watershed area. The soil type is Gowen silty clay loam, a deep, fine textured, slowly permeable soil on a 1 percent slope. The remainder of the watershed, 35 percent, is classified as rough, broken land (Vernon soil material) with a slope of 10 percent or over.

Native grasses cover the entire watershed; 90 percent of the grassland is used as pasture and 10 percent as meadow. About 25

Figure 2. An aerial photograph of watershed 4.

acres of the pasture land is an abandoned cultivated field which appears to have been allowed to return to grass approximately fifteen to twenty years ago. In general, the watershed is covered with 50 percent tall grasses, 30 percent short grasses and 20 percent annuals. Cover conditions are quite varied, ranging from poor on the abandoned cultivated land to excellent on the virgin sod.

Views of W1, W3, and W4 taken from the respective runoff gaging stations and from points near the upper rim of the watersheds are shown in figures 3 through 8.

Watersheds 2 and 5 were not placed in operation. Further study after the initial selection showed that the culverts were of inadequate capacity to confine the peak rates of runoff.

Figure 3. Watershed 1 from the runoff gaging station.

Figure 4. Watershed 1 from near the upper end of the watershed.

Figure 5. Watershed 3 from the runoff gaging station.

Figure 6. Watershed 3 from near the upper end of the watershed

Figure 7. Watershed 4 from the runoff gaging station.

Figure 8. Watershed 4 from near the upper end of the watershed.

METHOD OF PROCEDURE

Selection of the Watersheds

In this study the size of the watershed was to be the variable in the experimental sense. Therefore, watersheds were chosen as nearly similar in cover, soil and topographic features as existing local terrain permitted.

W1, 15 acres, and W3, 90 acres, have a common boundary and are located in the northeast quarter of Section 34. W4, 210 acres, is located in Section 27, immediately north of Section 34. This close grouping of watersheds tends to eliminate the physical variables other than size of watershed.

A governing factor in the selection of a watershed was the suitability of the culvert at the watershed terminus. The culvert had to be of adequate size to confine peak flows of runoff from all storms. In addition, the head at the entrance to the culvert was to control the discharge rate for all flows. This control is possible only for short culverts with a free outfall or where the slope of the culvert floor is sufficiently steep to result in supercritical flow. Culverts where backwater will affect discharge rate can be used only if the tailwater head is measured.

INSTRUMENTATION AND METHODOLOGY

Precipitation

Measuring Devices

Rainfall amount and intensity were measured by Friez recording rain and snow gages. Each gage was mounted on three, creosoted posts driven flush with the ground, and centered in a ten foot square, barbed-wire enclosure. A rain gage installation is shown in figure 9.

Theoretically, when one rain gage is used for a watershed it should be placed at the center of gravity of the area. However, practical consideration of access influenced the location of the gages. The rain gage for the adjacent watersheds, W1 and W3, (R3), was located near the road and approximately on the watershed divide. The rain gage for W4, (R4), was located about 0.7 of a mile from the main highway adjacent to a trail along the rim of the watershed. One gage for a 210 acre watershed may be insufficient for studies of the rainfall-runoff relationship, but it should be sufficient to test the rainfall experience for "normalcy".

Permission was obtained from the various property owners for access to the watersheds and for the installation of equipment.

The Friez rain gage has a 9 inch capacity and is operated on chart scales of one inch equals two-thirds inch of rainfall, and of one inch equals approximately 2 hours when geared to make one revolution each 24 hours. This permitted time to be read accurately to the nearest 5 minutes, and rainfall depth to be read to the nearest 0.01 of an inch.

Standard rain gages were not used, but total amount of rainfall

Figure 9. A recording rain gage installation.

was checked by using a 1000 milliliter graduated cylinder to obtain a volumetric measurement. This measurement was then converted to inches of rainfall.

The gages were serviced once each week and after each day of rain.

Methods of Computation

An example of the tabulation and computation of rainfall data for the storm of July 14, 1951, is to be found in the Appendix, table 1. The accumulated depth was tabulated for each significant change in rate of rainfall, and the rainfall depth for the intervening interval computed. Rainfall intensity for these intervals was then evaluated. Maximum depth and intensity for selected time intervals of 5 minutes, 15 minutes, 30 minutes and one hour were computed for each storm period. A storm period was arbitrarily defined as the length of time from the beginning of rainfall to the end of rainfall with no intervening period without precipitation of greater length than one hour. Any precipitation of less than 0.05 inch was considered as a trace and was not recorded.

Accuracy of Records

Owing to the relatively level relief in the vicinity of the installations and the absence of trees and buildings, the exposure of each gage was good. The installation near the highway was set away from the road about 150 feet to eliminate the possibility of faulty catch due to air turbulence created by highway traffic.

During high winds the amount of rainfall caught in the gages may be in error. A deficit of catch was indicated by the storm of July 15 when high winds occurred. For this storm the accumulated runoff exceeded the measured accumulated rainfall for W3. However, this deficit of catch may have been the result of non-uniform distribution of rainfall.

The records of R3 may be in slight error because a lag correction, determined by calibration, was necessary for the recorded amount of rainfall to compare with the measured catch.

Runoff

Measuring Devices

As was previously mentioned, existing highway culverts were used as rate measuring devices. Culvert C4, the outlet of W4, is a twin-barreled, monolithic concrete structure. The dimensions of C4 are 4 feet deep by 8 feet wide. Culvert C3 is 4 feet deep by 8 feet wide. C1 is 3 feet by 3 feet. The latter are single-barreled, monolithic concrete culverts. The upstream wingwalls for all culverts are located at an angle of approximately 30 degrees with the centerline of the culvert.

A 1:12 scale model of C3 was calibrated at the Stillwater Outdoor Hydraulic Laboratory to determine the relationship between water depth and rate of flow.[2] Modeling apparatus is shown in figure 10. The channel approach and stilling-well were likewise modeled as shown in figure 11. In the model study surface elevations were taken at two locations, one foot upstream from the culvert entrance along the centerline of the culvert and one foot from the culvert entrance along the line of the wingwall. The last mentioned location is that of the stilling-well.

Figure 10. A view of the culvert model calibration apparatus.

Figure 11. A view of the model culvert entrance, channel approach and stilling-well.

Identical surface elevation readings were taken at both locations.

Considering the topography existing at the culvert entrances, and the problem of access, the most practical location for the stilling-well was near the end of one upstream wingwall. In this study, all stilling-wells were located 12 feet from the culvert entrance along the line of the wingwall.

Corrugated pipe was used for stilling-wells. Vertical slot openings were cut for a distance of four feet from the bottom. The openings overlap in adjacent rows which are about 6 inches apart. Three creosoted fence posts were bolted tangent to the well and 120 degrees apart. Before the post holes were dug and the well set into place, a tractor and fresno were used to excavate the channel approach slightly below the culvert apron. This excavation enabled the float operating the FW1 recorder to fall below the datum plane. The FW1 recorders were housed on top of the stilling-wells.

Runoff measuring stations C3, and C4 are shown in figures 12 and 13. Although it is not evident from the figures, the recorders were sufficiently elevated to record the water stage as long as runoff from the watersheds was confined to the culverts.

The water-stage recorders, geared to make one revolution every 12 hours, operated on chart scales of one inch equals 25 minutes and one inch equals 0.25 foot of stage.

Methods of Computation

Records of water stage were first corrected for improper time and stage height recordings. Time corrections were often necessary due to

Figure 12. Culvert C3 and water stage recorder.

Figure 13. Culvert C4 and water stage recorder.

fast or slow clock mechanisms or sometimes due to improper time settings. Instrument irregularities, float suspension caused by silting, and the raising of the float and counter-weight tape from the recorder wheel by clinging debris necessitated occasional stage height corrections.

Rates of culvert discharge and pondage corrections[10] were initially established in a rating table for each culvert. This rating table converted records of stage to rates of runoff from watershed and records of change in stage to pondage corrections.

The head-discharge calibration curve for C3, a result of the model study, is given in figure 14. Since the dimensions for a single barrel of C4, a twin-barreled structure, are comparable to those of C3, the discharge for a given head was assumed to be twice as great for C4 as for C3. The head-discharge curve for C1, (figure 15), was estimated from the laws governing critical depth and orifice flow phenomena. The weir control of C1 is geometrically proportional to C3 if water stage does not exceed 2.25 feet. Exceeding 2.25 feet but less than the depth required for submergence of the culvert opening, 4.5 feet, the stage head to the 3/2 power governs discharge. When the culvert opening becomes submerged, the discharge is proportional to head to the 1/2 power, where the head is the distance from the water surface to the center of the culvert opening.

The pondage correction was essential to evaluate the true rate of runoff from the watershed. This correction accounted for water storage behind the highway fill. To determine the rate of storage or ponding for a given rate of change in stage, a topographic survey of the ponded area (see figures 16, 17 and 18 in the Appendix) was required. The

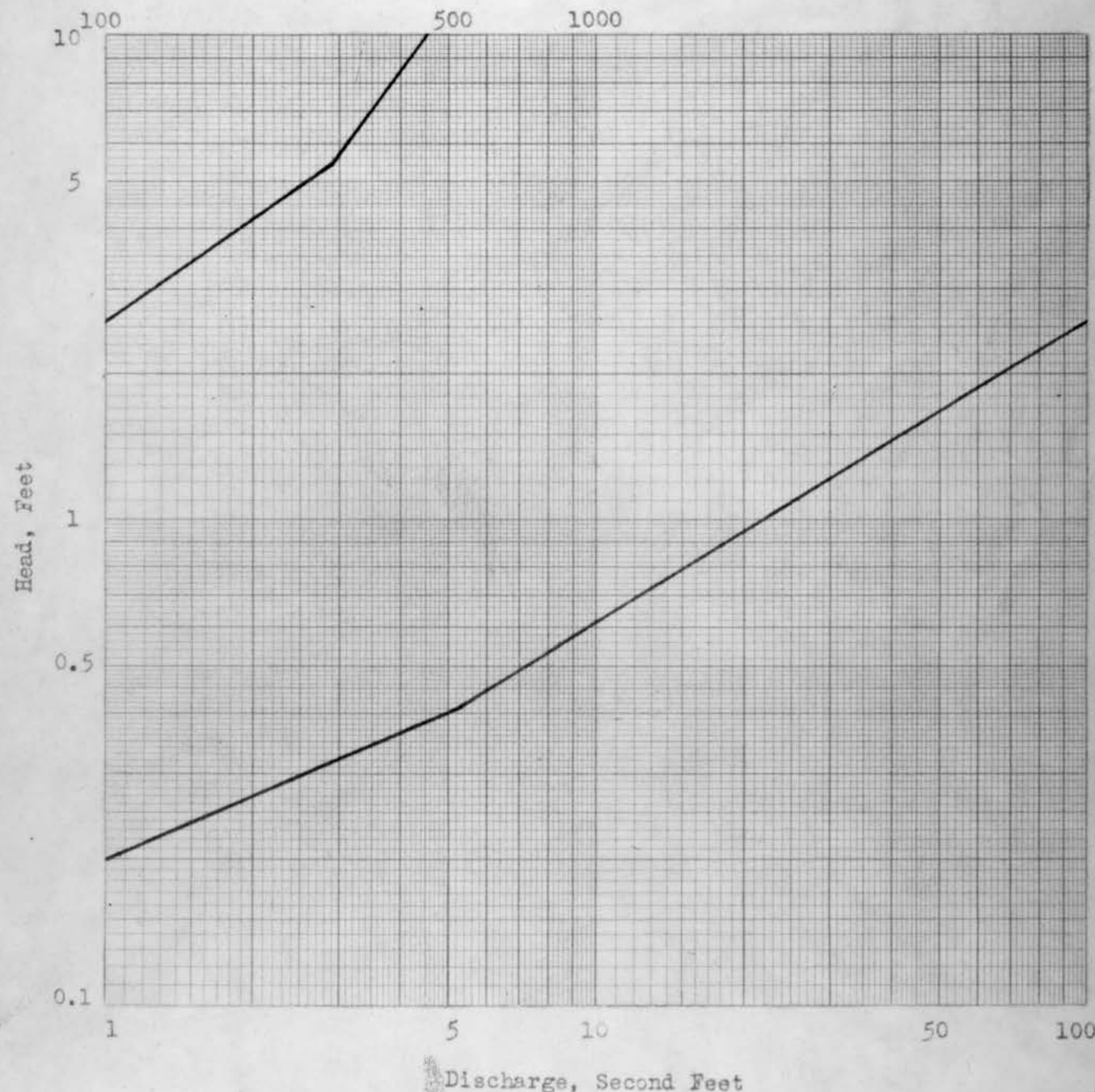


FIG. 14 CALIBRATED HEAD-DISCHARGE CURVE FOR CULVERT C3.

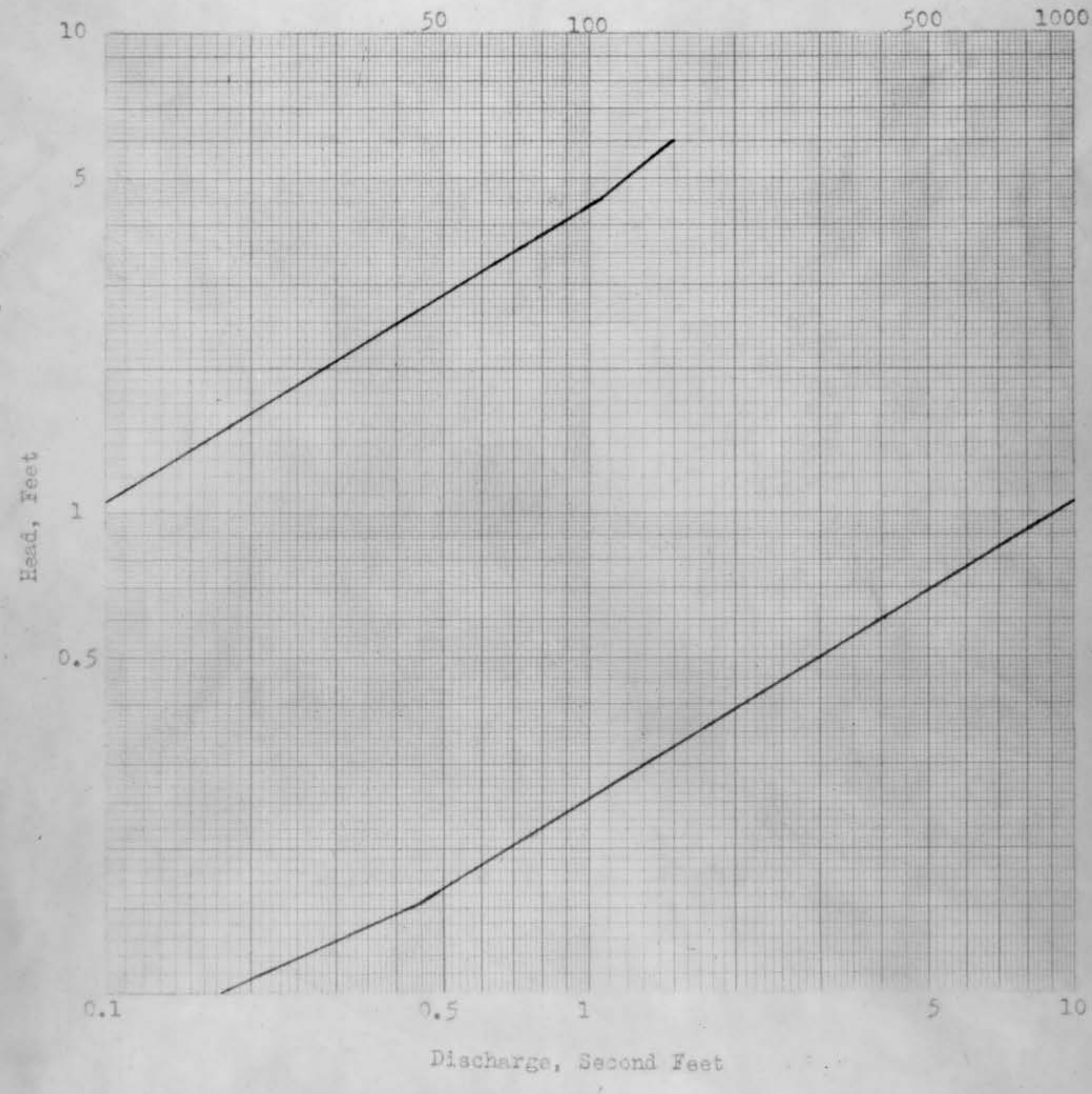


FIG. 15 ESTIMATED HEAD-DISCHARGE CURVE FOR CULVERT C1.

pondage correction calculations for W4 are given in table 2 in the Appendix.

The rate of ponding was algebraically added to the rate of culvert discharge to establish the true runoff rate from the watershed at any instant. The discharge for each tabulated time was then averaged with that for the preceding time, and this average discharge for the time interval was converted to runoff amount in inches. The runoff amounts for each time interval were then accumulated to establish the mass runoff curve.

An example of the tabulation and computation of runoff data from W4 for the storm of July 14, 1951, is found in the Appendix, table 3.

The data of any storm which failed to exceed a maximum stage of 0.1 foot were not tabulated. The amount and rate of runoff would be insignificant, and would lack accuracy in analysis since factors other than head greatly influence the rate of runoff at such low flows.

Accuracy of Records

For most storms, the records are reasonably accurate. However, silting at C4 caused the receding flows to be slightly in error for a few early storms. This silting may have been caused partially by the local disturbance of the highway embankment and culvert approach as a result of the excavation and installation of the stilling-well. After the loosened earth had once again become stabilized, the silting problem was not severe. In addition, sediment was much more prevalent in the channel of W4 than in W3, so more silting was to be expected.

Debris clinging to the tape caused the tape to raise off the nibs of the recorder wheel in one instance. Since this occurred on but one occasion, no provision was made to correct this difficulty. Figures 19 and 20 illustrate the amount of debris carried by the high water of the storm of July 15. The peak rate of runoff recorded during this period of study resulted from this storm.

Conduct of the Range Survey

A range survey was made the latter part of August, 1951, to determine and classify the existing vegetal cover of the watersheds. This survey was conducted with the assistance of experienced range conservationists from the Soil Conservation Service.

Although many methods have been suggested and used for classifying grass cover as to its effect upon infiltration, no one method has been universally adopted. Generally cover has been classified as to density. Observations of grass density by any given method may vary considerably for a given plot if measured by different individuals. In attempting to eliminate this individual variation of measurement and to minimize the time required for classification, an accepted practice of range condition classification used by the Soil Conservation Service was adopted.

Within a watershed, plots representative of an area of the watershed were chosen. A plot consisted of an area of 10 square feet, 3.16 feet on a side. Stakes were set at the corners of the square and a string was drawn taut around the stakes. The forage of a grass clump immediately below the string was proportionally divided according to

Figure 19. Approach to Culvert 4 showing debris collected by fence.

Figure 20. Channel approach and water-stage recorder at Culvert 4.

its bisection by the string line. An example of a staked plot is shown in figure 21.

All litter within the plot was gathered and sacked before species counts were made. The plants of western ragweed, an indicator of plants that invade pastures with overgrazing, were clipped, counted, and sacked. The occurrence and number of plants of all species were noted and a percent based upon the portion of the plot area covered was assigned to each major species occurring within the plot. The forage was then clipped as closely to the ground as possible and sacked. A clipped plot is shown in figure 22.

Azimuths to various points of reference were recorded for each plot so that plots of future surveys could easily be established within the vicinity.

As determined by the guide shown in table 4, a range condition classification was assigned to each plot. By weighting the plot classifications within a segment of a watershed a range condition class was established for that segment.

In this survey maximum and average height of forage was determined in the laboratory after clipping, but in future surveys it would be preferable to determine these values in the field previous to clipping. Weight of forage, litter and ragweed were obtained in the laboratory after all clipping and litter were of equal moisture content.

Figure 21. A staked range survey plot.

Figure 22. A clipped range survey plot.

Table 4. Guide for determining range condition classes and range sites, Noble County, Oklahoma.

Key Climax plants	Allowable percent by sites: Site numbers* 1	2	3	Other plants that invade with overgrazing
Big bluestem	-	-	-	All annuals
Indian grass	-	-	-	Silver bluestem
Switchgrass	-	-	-	Broomsedge bluestem
Little bluestem	-	-	-	Splitbeard bluestem
Tall dropseed	-	-	-	Windmill grass
Perennial legumes (native)	-	-	-	Tumble grass
Palatable per. forbes	-	-	-	Fall witchgrass
Sideoats grama	5%	5%	15%	Thistles
Purpletop	5%	10%	0	Ironweed
Hairy grama	5%	5%	5%	Western ragweed
Blue grama	5%	5%	5%	Persimmon
Buffalo grass	0	0	10	Summac
Scribner's panicum	5%	5%	5%	
Meadow tall dropseed	5%	5%	5%	
Woody plants	0	x	x	

Range condition class	Percent climax plants
Excellent	75 - 100
Good	50 - 75
Fair	25 - 50
Poor	0 - 25

* Site description:

Site 1 - Prairie upland
Site 2 - Timbered site
Site 3 - Very shallow

0 - None, or only a trace in site
\- - Decreaser; unlimited in site
x - Percentage allowable based on original cover

PRESENTATION AND ANALYSIS OF DATA

Tabular Rainfall and Runoff Data

Summaries of rainfall and runoff data for W4 are tabulated in tables 5 and 6.

Coefficient of Runoff Determination

The first analysis of the rainfall and runoff data undertaken was to determine the coefficient C in the formula Q = CIA.[13] Q, the maximum rate of runoff in cubic feet per second for a given storm, and A, the area of the watershed in acres had been established. Before C, the runoff coefficient, could be computed, I was evaluated. I is the average rainfall intensity for the time of concentration in cubic feet per second per acre, or approximately in inches per hour. Time of concentration is the time required for the water to flow from the farthest point on the watershed to the gaging station. Time of concentration was determined for each storm by noting the time which elapsed from the beginning of the first significant rise, discounting any rise caused by rain falling into the channel, to the maximum rise as recorded by the water stage recorder. This maximum rate of surface runoff for a storm usually occurs when every part of the watershed is contributing to the runoff being measured at the gaging station.

> As pointed out by Schiff,[16] "the maximum excess rainfall, that is, differences between rainfall intensities and corresponding infiltration rates, lasting for a time equal to the time of concentration usually will produce this maximum rate of surface runoff. There are cases when the intensity of rainfall is so great for a period of time less than the time of concentration as to produce the "maximum rate of surface runoff for a specific watershed."

Table 5. Summary of rainfall data for watershed 4.

Date	Time began	Duration of precipitation		Total amount	Intensity Maximum for period of 5 min.	15 min.	30 min.	1 hr.	Duration average
1951		hr.	min.	in.	in./hr.	in./hr.	in./hr.	in./hr.	in./hr.
June 15	3:36 AM	0	56	0.38	1.20	0.92	0.50	0.25	0.41
21	1:16 AM	0	25	0.14	1.20	0.48	0.28	0.14	0.34
21	5:16 AM	0	25	0.38	1.80	1.16	0.76	0.38	0.91
28	8:36 PM	0	14	0.24	2.28	0.96	0.48	0.24	1.03
30	12:24 AM	3	20	2.54	5.04	2.56	1.66	1.04	0.76
July 3	9:45 PM	1	27	0.35	2.16	0.92	0.48	0.38	0.24
14	4:55 AM	6	25	2.75	3.60	2.04	1.12	0.85	0.43
15	2:48 AM	1	47	3.06	8.40	4.88	3.50	2.45	1.72
31	7:44 AM	0	45	0.37	0.72	0.46	0.46	0.37	0.49
31	9:31 AM	0	14	0.09	0.60	0.20	0.10	0.07	0.39
31	11:59 AM	0	42	0.24	0.96	0.52	0.32	0.22	0.34
Aug. 10	2:18 PM	1	27	1.30	4.80	3.48	2.00	1.25	0.90
26	2:23 PM	0	20	0.55	3.00	2.12	1.10	0.55	1.65
Sept. 5	8:25 AM	0	55	0.45	1.54	1.00	0.66	0.45	0.49
6	12:06 AM	0	10	0.05	0.30	0.20	0.10	0.05	0.30
6	1:24 AM	0	58	0.08	0.28	0.28	0.16	0.08	0.08
6	5:22 AM	4	0	1.39	2.04	0.88	0.54	0.48	0.35
7	1:23 AM	0	30	0.47	1.68	1.28	0.94	0.47	0.94
7	10:23 AM	2	20	0.31	0.72	0.28	0.16	0.10	0.13
8	12:39 AM	1	45	0.27	0.36	0.24	0.14	0.11	0.15
8	5:54 AM	1	40	0.13	0.24	0.24	0.12	0.08	0.08
9	9:05 AM	0	50	0.57	2.16	1.04	0.98	0.54	0.68
9	3:03 PM	0	40	1.14	4.44	3.04	2.08	1.14	1.71
14	9:44 AM	1	10	0.75	4.20	2.00	1.10	0.63	0.64

Table 5. (cont.)

Date	Time began	Duration of precipitation		Total amount	Intensity Maximum for period of 5 min.	15 min.	30 min.	1 hr.	Duration average
1951		hr.	min.	in.	in./hr.	in./hr.	in./hr.	in./hr.	in./hr.
Oct. 5	9:50 PM	0	45	0.11	0.24	0.20	0.12	0.11	0.15
6	1:00 AM	1	0	0.40	1.20	0.60	0.30	0.15	0.40
14	9:17 AM	1	30	0.59	1.20	0.80	0.50	0.35	0.39
15	5:47 AM	0	3	0.08	0.96	0.32	0.16	0.08	1.60
26	10:12 PM	0	45	0.44	1.44	0.80	0.56	0.40	0.59
27	12:47 AM	0	10	0.07	0.42	0.28	0.14	0.07	0.42
29	2:23 AM	1	20	0.45	0.48	0.40	0.36	0.30	0.34
31	4:50 AM	5	50	0.55	0.24	0.20	0.16	0.12	0.09

Table 6. Summary of runoff data for watershed 4.

Date 1951	Time rise began	Total amount	Maximum rate			Period of rise		Rainfall minus runoff	Remarks
		in.	cfs.	in/hr.	time	hr.	min.		
June 15	3:37 AM	0.057	3.7	0.017	4:43 AM	1	6	0.323	
21	5:16 AM*	------	2.7	0.013	6:25 AM*	1	9	------	1,2
30	12:32 AM	0.980*	54.4	0.257	4:11 AM	3	39	1.560	
July 3	9:47 PM	0.196*	22.8	0.108	11:06 PM	1	19	0.154*	1
14	7:08 AM	0.808*	100.2	0.473	10:11 AM	3	3	1.942*	1
15	2:50 AM*	1.729*	344.2	1.626	4:26 AM	1	36*	1.331*	1
Aug. 10	2:46 PM	0.009	2.5	0.012	3:40 PM	0	54	1.291	
Sept. 6	9:50 AM	0.007	1.2	0.006	11:26 AM	1	36	1.383	
7	1:40 AM	0.020	4.2	0.020	2:40 AM	1	0	0.450	
9	9:50 AM	0.064	14.5	0.068	10:34 AM	0	44	0.506	
9	3:05 PM	0.580	170.0	0.803	3:51 PM	0	46	0.560	
14	6:28 AM	0.101	6.8	0.032	10:38 AM	4	10	0.649	
Oct. 29	4:03 AM	0.019	2.0	0.009	5:06 AM	1	3	0.431	
31	6:30 AM	0.064	4.2	0.020	10:51 AM	4	21	0.486	

* Estimated
1 Sediment holding float
2 No record of ending time

Therefore it is possible for the time of concentration computed for individual storms to vary as they did in this analysis. As determined by averaging this value for all storms, the time of concentration for W4 was about one hour.

As previously given, the distance from the farthest point on the watershed to the gaging station is about 7000 feet. Using one hour as the time of concentration the average velocity of flow would be about 2 feet per second. This appears to be a satisfactory value for the watershed because it agrees with published values.

Of the 14 storms which resulted in runoff, only five appeared to be applicable for use in establishing C. After making the first approximation of the time of concentration, it was found that several storms were of insufficient duration to lend themselves to analysis. The remainder of the storms not applicable were of low rainfall intensity, or were preceded by periods of little or no rainfall such that the percent of soil moisture was low. In both instances, the infiltration rate would be sufficient to take care of the greater portion of the rainfall. Little excess rainfall would be available to contribute to runoff.

Comparable with Ramser's study, the most satisfactory values of C were obtained from the more intense storms in which soil saturation was approached. Since these were the storms which produced peak rates of runoff, it seems reasonable to assume that the values obtained would be satisfactory for use in estimating peak flows.

The results of the field measurements and computations are given in table 7.

Table 7. Coefficients of runoff for watershed 4.

Area, 210 acres; Average time of concentration - 1 hour.

Date		Time significant rise began	Time of maximum rate of runoff	Time of concentration (T.C.)	Rainfall intensity for T.C.	Maximum rate of runoff (Q)	Runoff coefficient (C)	Rainfall prior to T.C.period
1951				min.	in./hr.	cfs.		in.
June	30	1:09 AM	1:52 AM	43	1.04	52.7	0.24	0.80
July	3	9:54 PM	11:06 PM	72	0.38	22.8	0.29	0.00
	14	7:50 AM	8:43 AM	53	0.85	23.8	0.13	1.00
	15	3:10 AM	4:26 AM	76	2.45	344.2	0.67	0.35
Sept.	9	3:05 PM	3:51 PM	46	1.14	170.0	0.71	0.20

From a study of the five storms tabulated, it seems that initial soil moisture contents greatly affected the values of C for all of the storms. The C values for the latter two storms listed were exceptionally high. However, this probably was due to almost saturated soil conditions at the beginning of rainfall and to the higher intensity of rainfall. The other three storms were of lesser intensity and occurred when the soil moisture content was undoubtedly lower.

Since no soil moisture content determinations were made, the percent of soil moisture previous to and during the analyzed storms can only be estimated.

In establishing a coefficient of runoff design value for a particular watershed and for similar watersheds, Ramser gave the greatest weight to the results of the most intense rains. The results of this analysis indicate that a satisfactory value of C for W4 and similar watersheds would be 0.70.

Derivation of Infiltration Curves

In this analysis infiltration curves were derived from the storm data of July 14 for W3 and W4. Fundamentally, these curves should be derived only for a given soil-cover-condition complex, but to gain some knowledge of the infiltration characteristics of the watershed as a whole the curves shown in figures 23 and 24 were derived. These infiltration curves were derived by a graphical method presented by Schiff.[15]

Before the method of procedure used is described, the following terms, acceptable to most hydrologists, and the symbols used by Schiff[16] are defined:

Note - All rates are in inches per hour.
All mass or accumulated quantities are in inches.

1. Interception storage (Si) - Retention of precipitation by and on the vegetation, commonly referred to as interception.

2. Ground rainfall (P_g) - All precipitation not retained by the vegetation which reaches the ground.

3. Rate of Rainfall (i) - Intensity of precipitation.

4. Infiltration - The passage of water through the surface of the soil into the soil mass.

5. Mass infiltration (F) - accumulated infiltration.

6. Infiltration capacity (fc) - The rate at which infiltration would take place at any instant were the supply to equal or exceed this capacity.

7. Infiltration potential (fp) - The rate at which infiltration would take place at a given soil-moisture content, at any instant, were the supply to equal or exceed this potential rate. Infiltration poten-

tial, fp, is used only when rates of rainfall are less than infiltration capacity, fc.

8. Excess rainfall (E) - The amount of rain in excess of infiltration. This is the computed supply going to detention storage and surface runoff.

9. Detention storage (Ds) - The average depth of water on the watershed at any specific time. After cessation of precipitation, part of this detention storage may infiltrate into the soil, while the remainder of the storage will eventually become channel flow.

10. Depression storage (Vd) - Water trapped on the surface in natural and artificial depressions. Water retained as depression storage does not contribute to channel flow through surface runoff.

11. Retention (R) - The sum of interception (Si) depression storage (Vd), and mass infiltration (F). All rainfall that does not appear as channel flow through surface runoff.

The graphical method of deriving infiltration capacity curves is as follows:

1. The histogram of rainfall intensity and the curves of accumulated rainfall and runoff were plotted from the computed rainfall and runoff data.

2. A straight line "precipitation" reference line was drawn approximately parallel to the high intensity portion of the accumulated ground rainfall curve, Pg.

This straight line, mass curve of rainfall was suggested by Holtan[3] for the purpose of eliminating the periods during which rainfall rate was less than infiltration capacity rate.

3. A constant value of interception storage (0.1 inch) was subtracted from the accumulated rainfall curve (P) to obtain the accumulated ground rainfall curve (Pg).

Published records indicate that interception storage remains nearly constant during rainfall although subject to precipitation intensity and to wind effect. Interception will generally range from 0.05 inch to 0.20 inch when the precipitation in a storm period exceeds 0.5 inch.

4. Mass retention was plotted to the same condensed time scale as the precipitation reference line by plotting various values of mass runoff to the condensed scale immediately below the related mass rainfall. Points on the mass runoff curve, Qsm, were selected where detention storage values were close to zero. Detention storage is close to zero when depression storage has been satisfied and surface runoff is about to start and when runoff is nearly to the end. When the quantity of recession flow associated with a particular rate of flow can be estimated, as was the case for W4 at the trough point on the hydrograph, another point on the R plotted reference line can be established. A smooth curve was drawn through these plotted points. This curve represents retention with detention storage eliminated.

5. The mass retention curve (R) was plotted below the Pg curve by plotting various values of mass retention from the R plotted to reference line immediately below the Pg curve for related point on the precipitation reference line. Sufficient points were thus located to establish the R curve.

6. Points of Pg-Qs for any instant were plotted to establish Pg-Qs curve. At any instant the precipitation reaching the ground

must contribute to runoff and/or detention storage, depression storage, infiltration. The latter two items are included in R and Qs has already been subtracted. Therefore, the distance between the R and Pg - Qs curves represents depth of detention storage, Ds.

7. The estimated mass infiltration curve (F) constructed was based on the following facts and assumptions:

a. The initial rate of infiltration for any soil of relatively low moisture content is the greatest at the beginning of precipitation.

b. The first three hours of precipitation of low intensity satisfied interception and depression storage.

c. Infiltration at capacity rate began soon after the high intensity precipitation began and when runoff rate significantly increased.

d. Depression storage (R-F) had a maximum value of 0.2 inch when runoff began, when detention storage was a maximum value, and when the peak rate of runoff occurred. Published data indicate that Ds may be as high as 0.2 inch for good pasture.

e. The infiltration rate for very slowly permeable soils approaches 0.10 inch per hour after three hours when the average initial soil moisture content of the soil is estimated to be 0.30.

f. Depression storage was in continuous existence during infiltration.

8. The infiltration rate curve was plotted from slope of the assumed F curve.

9. The accumulated excess rainfall, the summation of $(i_g - f_p)(t_2 - t_1)$,

is the theoretical surface supply to runoff. It was evaluated and checked against the actual measured runoff. (Successive approximations of F were made until the above check was reasonably close as ascertained from published studies.)

10. The computed accumulated supply to surface runoff was then plotted. (Q_{sc} = accumulated excess rainfall - detention storage.)

As can be noted from the figures, the computed Qsc differs from the Qsm. Schiff stated that "the shape and position of the Qsm curve represents the effect of physiography of the watershed upon the Qsc curve." Perhaps the amount by which Qsc precedes the Qsm is a measure of the time of concentration. Another possible indication of the time of concentration is the time lag between the occurrence of the maximum depth of detention storage and the maximum rate of runoff.

The infiltration curve derived by this graphical method was labeled fp as Schiff[15] did. However, the curve may be neither an infiltration potential curve nor an infiltration capacity curve. Periods existed when the rainfall rate greatly exceeded the infiltration rate, during which time infiltration capacity rates were possible. There were other periods when this possibility did not exist. During periods of rainfall, the soil slowly regains its capacity to absorb water, which line should then be called an infiltration potential curve. Because of the time condensation, the infiltration curve derived is neither a capacity curve nor a potential curve.

Tabular Range Survey Data

A summary of the range survey data for W1, W3, and W4 is tabulated in table 8.

Results of the Range Survey

Major Grass Species Noted

Big bluestem	Andropogon furcatus
Little bluestem	Andropogon scoparius
Indiangrass	Sorghastrum nutans
Switchgrass	Panicum virgatum
Tall dropseed	Sporobolus asper
Sideoats grama	Bouteloua curtipendula
Hairy grama	Bouteloua hirsuta
Blue grama	Bouteloua gracilis
Buffalograss	Buchloe dactyloides
Scribner's panicum	Panicum scribnerianum
Meadow tall dropseed	Sporobolus heterolepis
Silver bluestem	Andropogon saccharoides
Windmillgrass	Chloris verticillata
Fall witchgrass	Leptoloma cognatum
Plains lovegrass	Eragrostis intermedia
Threeawn	Aristida oligantha
Purpletop	Triodia flava
Fringeleaf paspalum	Paspalum cilialifolium

Table 8. Summary of range survey, conducted August 30 and 31, 1951.

Watershed and plot number	Condition class	Weight, air dry basis: Forage	Litter	Ragweed	Height of forage: Maximum	Average	Perennial grasses: Tall	Short	Annual grasses
		grams	grams	grams	inches	inches	percent	percent	percent
1-1	Fair	460	285	17	40	32	---------no record--------		
1-2	Poor	142	166	72	20	15	15	75	10
1-3	Poor	229	60	46	24	15	50	50	0
1-4	Poor	220	51	18	18	12	5	95	0
3-1	Fair	292	53	3	24	18	45	55	5
3-2	Good	309	74	10	36	20	70	30	0
3-3	Poor	234	104	31	24	18	20	65	15
3-4	Poor	35*	0	0	4	3	30	55	15
3-5	Poor	205	15	5	24	12	30	55	15
3-6	Fair	259	96	20	15	12	60	25	15
4-1	Poor	145	0	13	12	9	0	25	75
4-2	Fair	161	10*	9	12	6	20	60	20
4-3	Poor	126	157	95	15	12	0	0	100
4-4	Excellent	273	128	0	15	9	60	40	0
4-5	Excellent	-------------Clipped meadow---------------					90	5	5
4-6	Excellent	693	319	0	42	30	90	10	0
4-7	Fair	160	10*	8	12	9	30	55	15
4-8	Fair	238	41	0	18	12	60	35	5
4-9	Excellent	357	190	15	20	12	85	15	0
4-10	Fair	204	16	22	12	9	25	75	0
4-11	Excellent	544	146	8	36	24	90	10	0

* Estimated

Adequacy of the Cover Classification System

In this survey grass cover was divided into four classes of range cover condition; excellent, good, fair and poor. This classification, based upon the occurrence of key climax plants, was originally established as a Soil Conservation Service work unit guide for determining safe stocking rates. How well it serves to classify grass cover will be indicated in this discussion.

The following discussion and classification of grass cover appears in the Hydrology Handbook:[1]

> Grasses increase infiltration capacity by affording protection against raindrop impact, by providing a layer of humus and litter, and by changing the character of the soil itself. The infiltration under a grass cover then depends not only on the density and the kind of plants, but also on the length of time the area has been in grass and on the management of the land. The classifications of grass cover follow:
>
> Good - dense vegetal cover of high quality grass having extensive root systems; area previously in grass for several years; if pasture, properly managed (not overgrazed.)
>
> Medium - vegetal density from 80 percent to 30 percent of that on "good" areas with good quality grasses having extensive root systems; area in grass at least 2 years; if pasture, area well managed (not overgrazed).
>
> Poor - density of vegetation less than 30 percent of that on "good" areas; sparse growth of low quality grass; poor management (overgrazed or otherwise abused).

The above classification points out that density is the vegetal cover characteristic which has the most effect upon infiltration. In the classification based on key climax plants it so happens that the preferable native grasses for grazing generally do produce the more dense cover. The broader leafed, more luxuriantly growing grasses are more dense and are of greater forage quality for stock. Likewise, the more luxuriantly growing key climax grasses generally produce larger amounts of litter over a period of years, dependent upon pasture management. The greatest exception to this as determined in the survey was W4, plot 3. A comparatively large amount of litter was developed under a cover that was predominantly annual threeawn. The plot was located within an abandoned cultivated field which was now included with unbroken prairie supporting superior grasses. Due to selection by livestock the threeawn evidently was never grazed and all forage produced contributed to the litter accumulation.

Figure 25 showing the litter produced under threeawn cover for this plot should be compared with figure 26 below it. The lack of litter in the latter picture is more representative of conditions existing under cover composed of annual grasses such as threeawn and windmill. The range condition of both plots was classified as poor.

Sideoats grama is limited in allowable percent by site and thus has minor influence on the range condition class, but it did appear to produce a large quantity of litter. Plot 2 of W1 and plot 3 of W3 were both classified as poor range condition. However, they did produce comparatively large quantities of litter, as shown in figures 27 and 28. Sideoats grama was the predominate grass in both plots.

Figure 29 illustrates a poor range condition plot which had a small amount of litter and representative amount of forage; silver bluestem, 30 percent, hairy grama, 20 percent, and sideoats grama, 15 percent, were, the major grass species.

By comparison, figure 30 shows a representative amount of forage

Figure 25. Vegetal cover of plot 3, watershed 4. Range condition poor.

Figure 26. Vegetal cover of plot 1, watershed 4. Range condition poor.

Figure 27. Vegetal cover of plot 2, watershed 1.
Range condition poor.

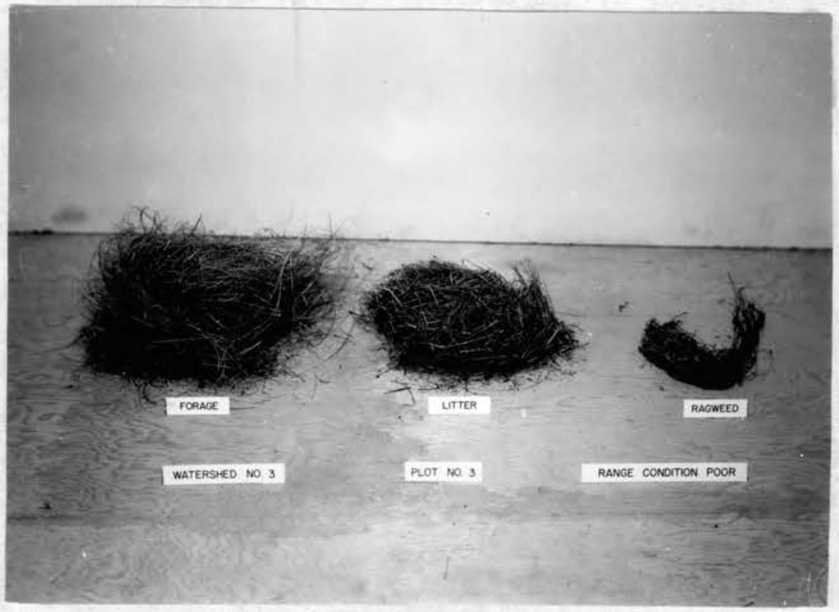


Figure 28. Vegetal cover of plot 3, watershed 3.
Range condition poor.

Figure 29. Vegetal cover of plot 5, watershed 3. Range condition poor.

Figure 30. Vegetal cover of plot 2, watershed 3. Range condition good.

and litter for a plot in good range condition. The plot consisted of 30 percent little bluestem, 25 percent big bluestem, 20 percent buffalograss, 15 percent silver bluestem and 10 percent sideoats grama.

The forage and litter yields of a plot in excellent range condition are shown in figure 31. The species occurring within the plot were little bluestem, 70 percent, big bluestem and Indiangrass, 10 percent, gummy lovegrass and Scribner's panicum, 5 percent, and a trace of switchgrass and sideoats grama. The plot forage yield on an acre basis would amount to almost 3.5 tons of cured hay, and the litter yield was almost one-half of the forage yield.

These figures presented do show that range condition class is an indicator of the density of vegetal cover, forage and litter, but that it is not infallible.

This system of classification is likewise an indication of the extensiveness of the root system, years in grass, and proper management of the pasture, which are factors other than density included in the cited classification of grass cover. In general, the key climax grasses and other perennials will have a more extensive root system than the invader annual and perennial grasses and weeds. If a pasture has once been cultivated and then abandoned, the period of years since abandonment can be approximated by studying the species of grasses present, and will be proportional to the number of key climax plants in evidence. This number of climax plants present is the accepted method of determining proper management and safe stocking rate.

After further study minor changes can be made in the allowable

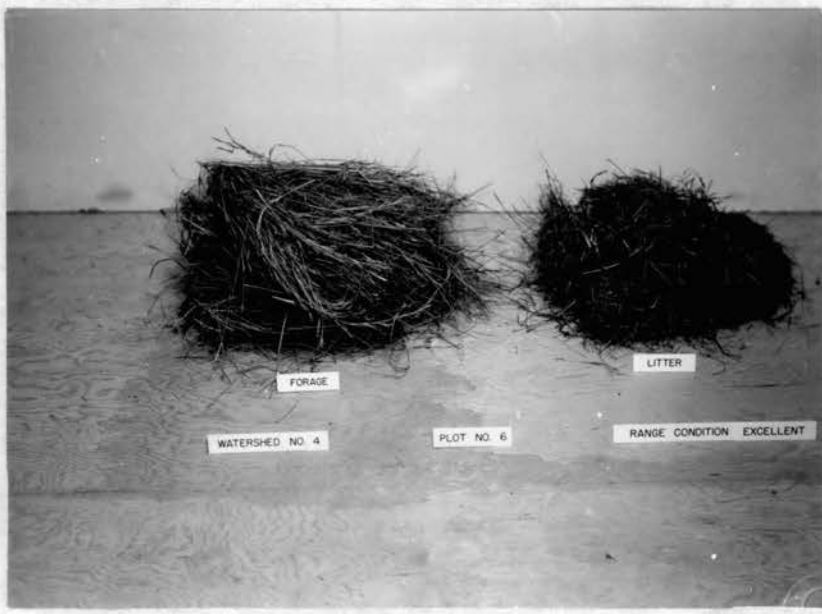


Figure 31. Vegetal cover of plot 6, watershed 4. Range condition excellent.

percent by site of grasses, such as sideoats grama, to reflect the capacity to produce forage and litter. This system of classification, when combined with utilization estimates, should be quite acceptable as a method to evaluate the hydrologic characteristics of grass cover.

Watershed Range Condition Classes

The range condition class boundaries within a watershed were located after the plot studies were completed. Site boundaries and fence lines greatly influence the establishment of range condition class boundaries since both influence the grazing of livestock. Figure 4 illustrates a change in grass cover which often occurs at a fence line. The near pasture has been overgrazed and was in poor condition while the far pasture supports a much superior grass cover and was in good condition.

The range condition classes for W4 are shown in figure 32. The watershed as a unit averaged a high good. In comparison, W1 and W3 averaged a low fair as shown in figure 33.

Cultural Practices Noted

The field of meadow in W4 was mowed about August 20 just previous to the range survey.

The 40-acre pasture which includes the major portion of W1 and part of W3 was not grazed until September. The pasture which includes the southeast portion of W3 was very lightly grazed during the season but the western portion of W3 was overgrazed. The major portion of W4 was properly stocked and grazed during the entire season.

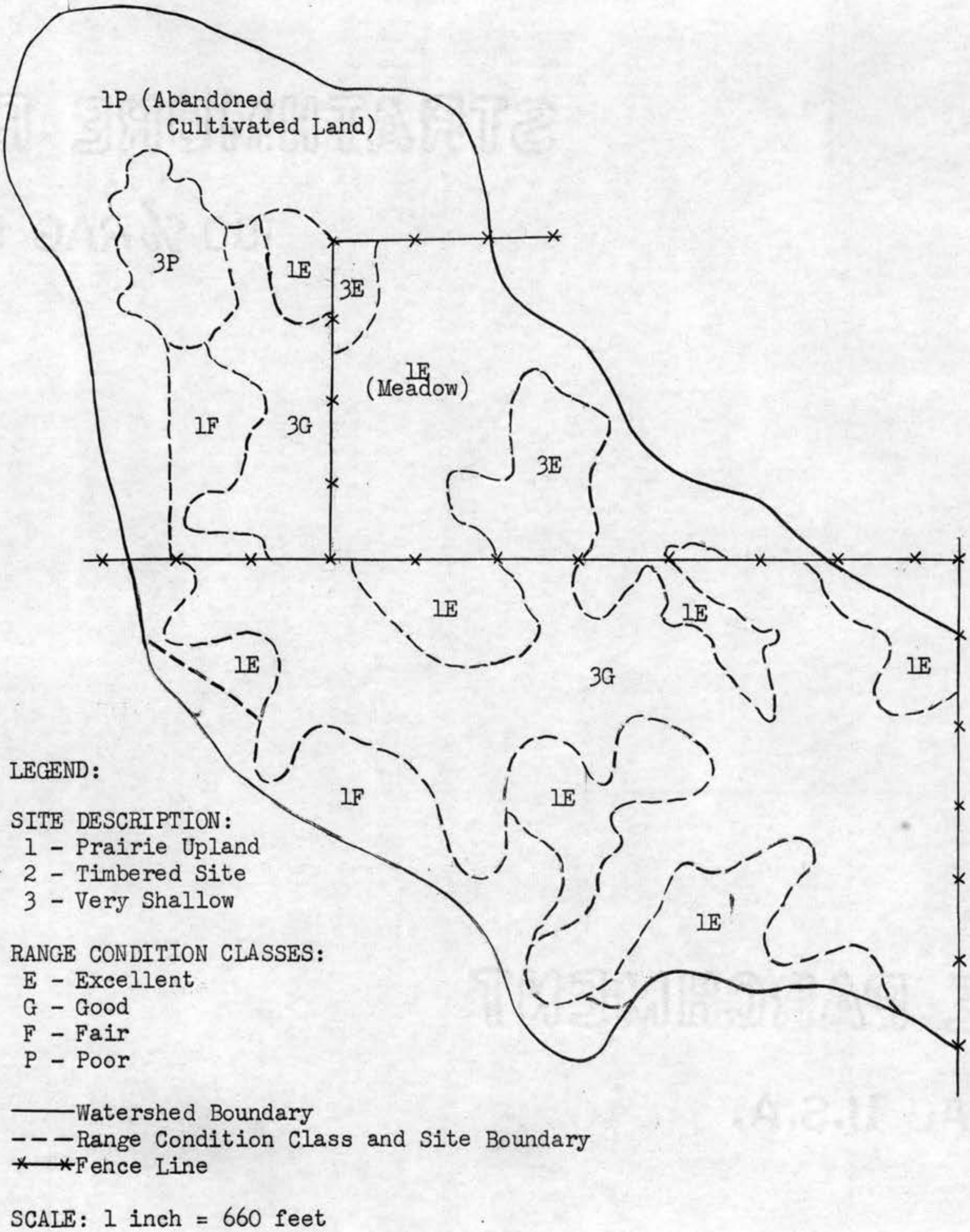
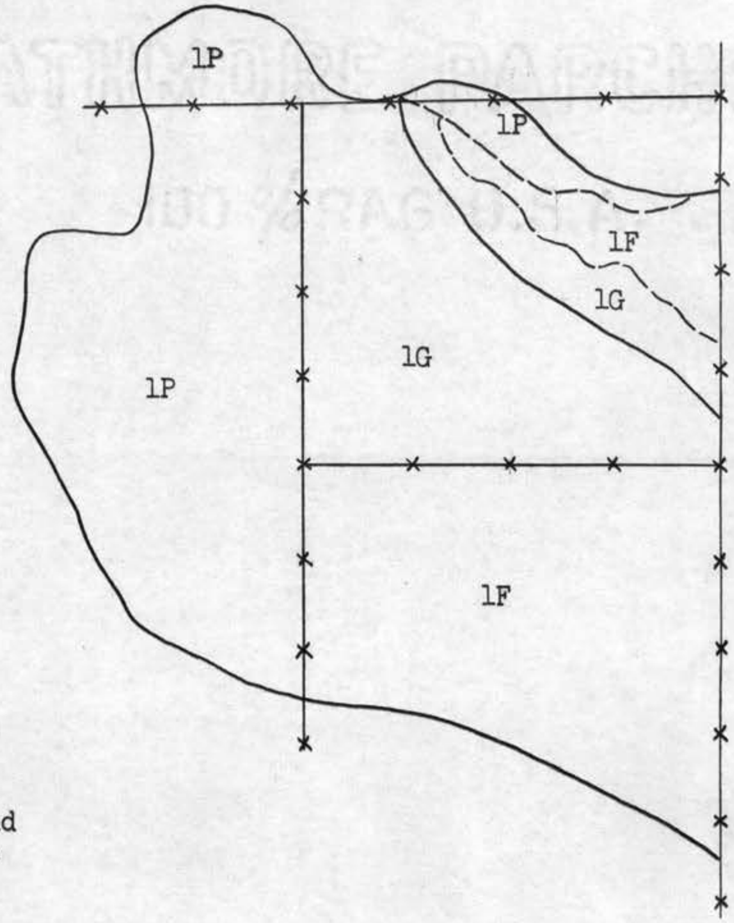


FIG. 32 -RANGE CONDITION CLASSES FOR WATERSHED 4; AUGUST, 1951



LEGEND:

SITE DESCRIPTION:
1 - Prairie Upland
2 - Timbered Site
3 - Very Shallow

RANGE CONDITION CLASSES:
E - Excellent
G - Good
F - Fair
P - Poor

——Watershed Boundary
- - -Range Condition Class and Site Boundary
-x—x-Fence Line

SCALE: 1 inch = 660 feet

FIG. 33-RANGE CONDITION CLASSES FOR WATERSHEDS 1 AND 3; AUGUST, 1951

Effect of Grass Cover on Surface Runoff

It is well known that the density of grass cover affects the depth of detention of surface runoff. Horton[6] has shown that the rate of runoff is a function of the average depth of surface detention and expresses the relation between the two as follows:

$$q = KD_s^M$$

where q is the direct surface runoff rate, D_s is the average depth of surface detention, K is a coefficient depending on the slope and characteristics of the surface, and M is an exponent depending on the degree of turbulence of the flow. If the overland flow is turbulent the rate of surface runoff should be proportional to the 5/3 power of the depth.

As previously pointed out in the procedure of deriving infiltration curves, the maximum depth of detention storage occurred at a time previous to the peak rate of runoff. Using this indicated time interval between these two peaks, other points of detention storage and rate of runoff were selected and plotted. A straight line was drawn through the plotted points of W4. The slope of this line is approximately 5/3, which indicates that the flow was turbulent. A line of theoretical slope for turbulent flow is shown in comparison. (See figure 34.)

The line drawn through the plotted points of W3 parallel to that of W4 is not a good determination, but all of the points plotted for W3 were to the left of those plotted for W4. The lower values of detention storage for W3 for a given discharge indicate a less dense grass cover as was observed in the range survey.

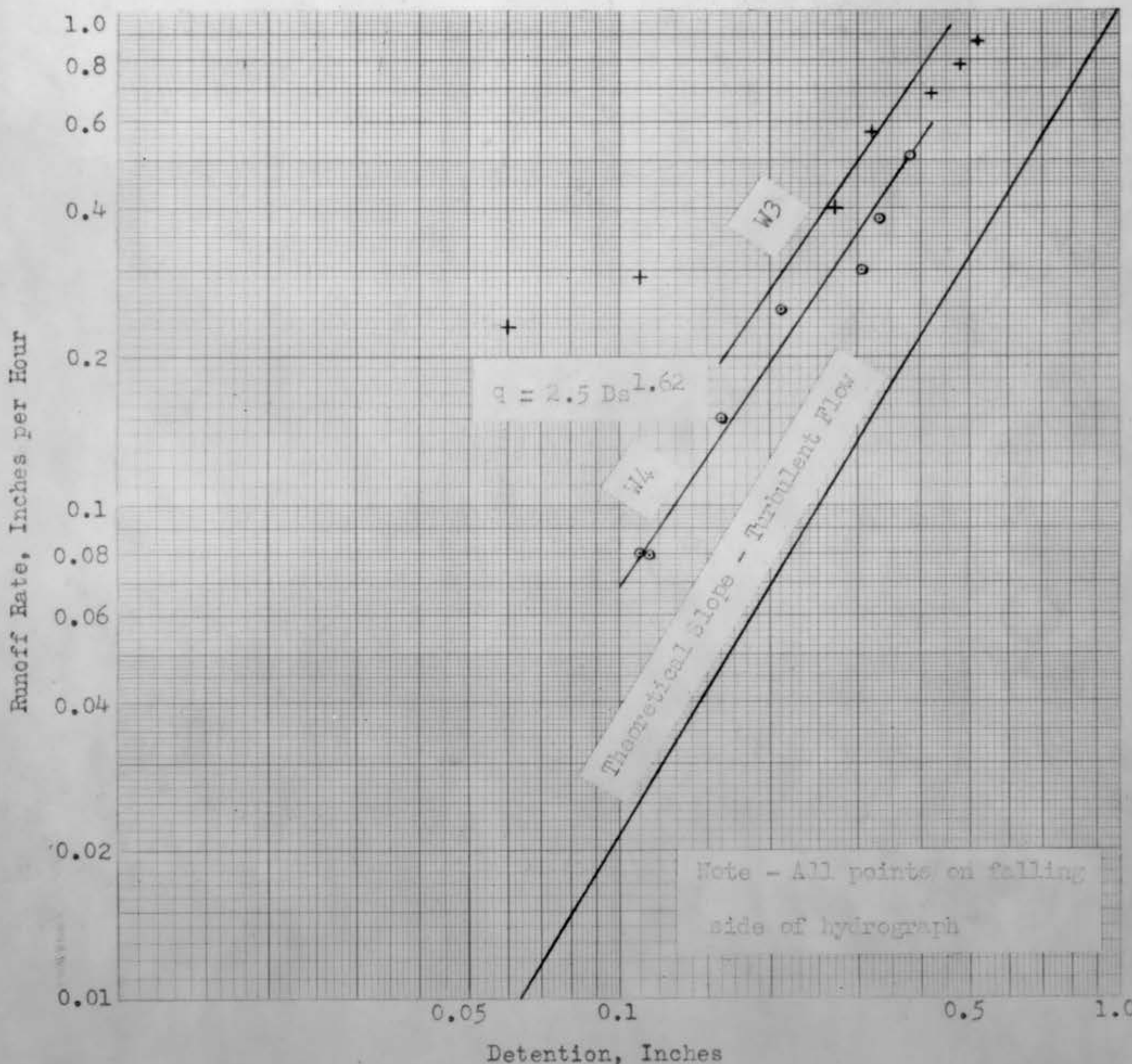


FIG. 34 DISCHARGE - SURFACE DETENTION DEPTH RELATIONSHIP FOR WATERSHEDS 3 AND 4; BASED ON STORM OF JULY 14, 1951.

CONCLUSIONS

In this compilation and analysis of rainfall and runoff data gathered over a period of less than five months, a limited number of facts have been revealed which can be applied in the design of structures to convey and impound runoff water. Other pertinent information was disclosed, but further study is necessary to verify the results.

The peak rate of runoff recorded during this period of study was produced by the storm of July 15, 1951. A momentary runoff rate of 5.2 inches per hour was determined as the peak flow from watershed 3.

That pondage corrections are essential to establish accurate rates of runoff was likewise indicated by this storm. The storm resulted in a flow of 317 cubic feet per second through the culvert C3. When the pondage correction was applied, the determined flow from the watershed was 472 cubic feet per second. Corrections of 50 percent were not uncommon in the computations of runoff data.

Likewise, this pondage correction when applied to the culvert discharge affects the indicated time of occurrence of the peak flow. For the previously mentioned storm the actual, corrected time of peak flow occurred 15 minutes before the time of peak flow as indicated by the water stage recorder.

When pondage corrections are taken into consideration, the use of existing highway culverts as flow measuring devices is practical and offers a means of getting runoff data at a reasonable cost.

Difficulty was encountered in the coefficient of runoff determinations. As previous investigators have noted, the time of concentration for a given watershed and the determined values of C vary from one storm to another. An average time of concentration of one hour was determined for W4. A suitable design value of C for W4 was estimated to be 0.7. However, this value is extremely high and should be verified by further study.

The results of the infiltration curve derivations indicated that W4 has a greater initial infiltration capacity than W3. This indication is reasonable since the soils of W4, in general, are slightly more permeable than those of W3.

The effect of grass cover on surface runoff was revealed in the plotting of detention storage for various rates of runoff from W3 and W4. Detention storage was higher for a given rate of runoff on W 4 than on W3. This higher detention value was probably due to the more dense grass cover on W4.

The derived infiltration curves are not applicable as design data for watersheds other than for those for which they were derived. When used with the runoff-detention relationship and the time of concentration determined in this study, the infiltration curve can be used for the synthesis of a hydrograph of runoff from that watershed.

SUMMARY

Design data applicable to North Central Oklahoma is needed by engineers for the economical design of structures to convey and impound runoff. To obtain design data, three experimental watersheds were selected approximately 15 miles north of Stillwater, Oklahoma. The watersheds are 15, 90, and 210 acres in area.

These watersheds are typical of the virgin grass-covered range lands in this locality. As determined by a range survey, the range condition class varied from poor to excellent within the watersheds. The soils of these watersheds, found on slopes of 1 to 10 percent, are slowly to very slowly permeable.

The period of record for this study extended from June 15 to October 31, 1951. Only the detailed records of one watershed are included in this report.

Recording gages were installed to measure rainfall and runoff. Existing highway culverts were used as flow measuring devices. From the analysis of the rainfall and runoff records, the following findings and conclusions were determined:

1. The peak rate of runoff recorded during this period of study was 5.2 inches per hour.

2. To establish accurate rates of runoff, pondage corrections are essential. Corrections of 50 percent were not uncommon.

3. The coefficient of runoff, based on a time of concentration of one hour, was determined to be 0.7 for watershed 4.

4. A rate of runoff-surface detention depth relationship was determined as a result of the infiltration curve derivations. When this relationship is combined with the derived infiltration curve and the determined time of concentration, a hydrograph of runoff can be synthesized.

SUGGESTIONS FOR FURTHER STUDY

1. Determine annual watershed yields. Preparations have been made to install weir sills, copied after Villemonte's[19] design, in the culverts to increase the accuracy of low flow measurement.

2. Determine antecedent moisture conditions periodically.

3. Analyze the infiltration capacities of soil-cover-condition complex segments within the watersheds. This analysis can best be accomplished through infiltrometer studies.

4. Acquire more detailed information on the permanent characteristics of the drainage basins. This includes a complete topographic survey and soil survey.

5. Conduct monthly range utilization surveys. Utilization estimates in conjunction with range condition class estimates would improve the classification of grass cover as to hydrologic characteristics.

APPENDIX

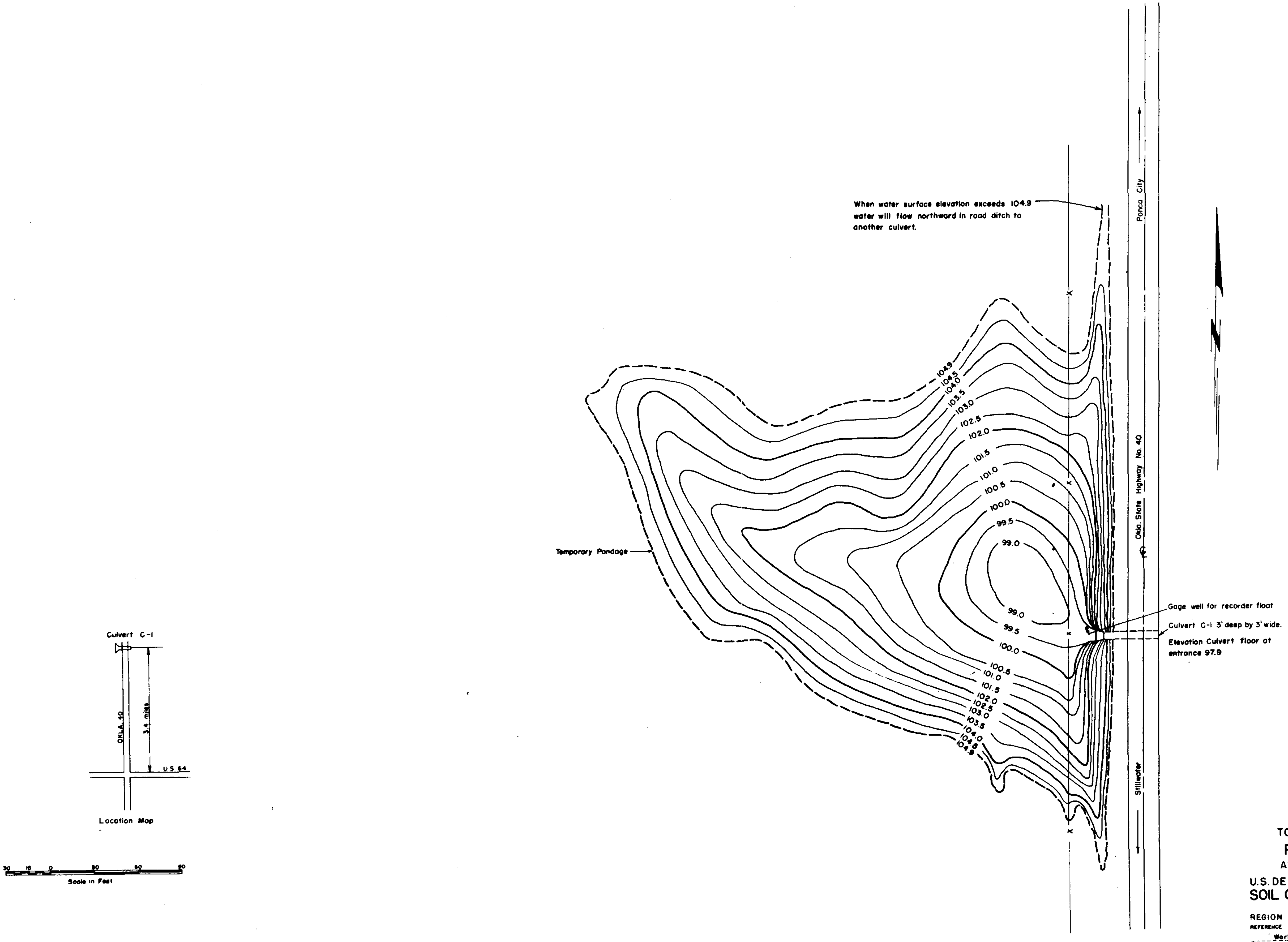


Figure 16.
TOPOGRAPHIC MAP OF
PONDED AREA
ABOVE CULVERT C-1

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
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REGION 4 DIRECTOR – LOUIS P. MERRILL
REFERENCE Working Plan R-2-4-1 Stillwater
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SURVEYED F.R.C. COMPILED T.L.W. TRACED W.C.B. CHECKED G.L.B. DATE 12-7-51
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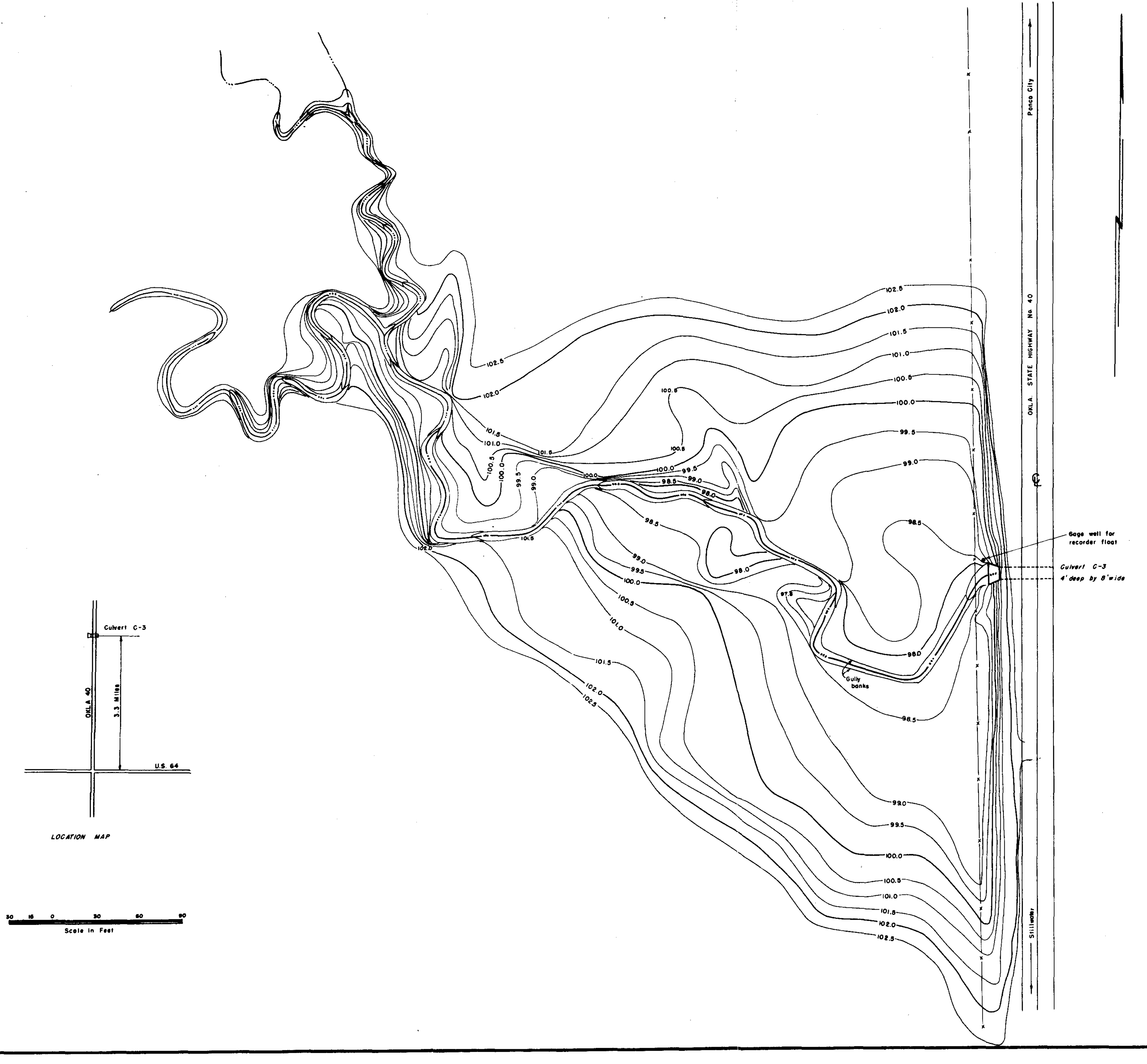

Figure 17.
TOPOGRAPHIC MAP OF
PONDED AREA
ABOVE CULVERT C-3

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SURVEYED	COMPILED	TRACED	CHECKED	DATE	
F.R.C.	T.L.W.	A.J.H.	G.L.B.	8-23-51	4-R-8216

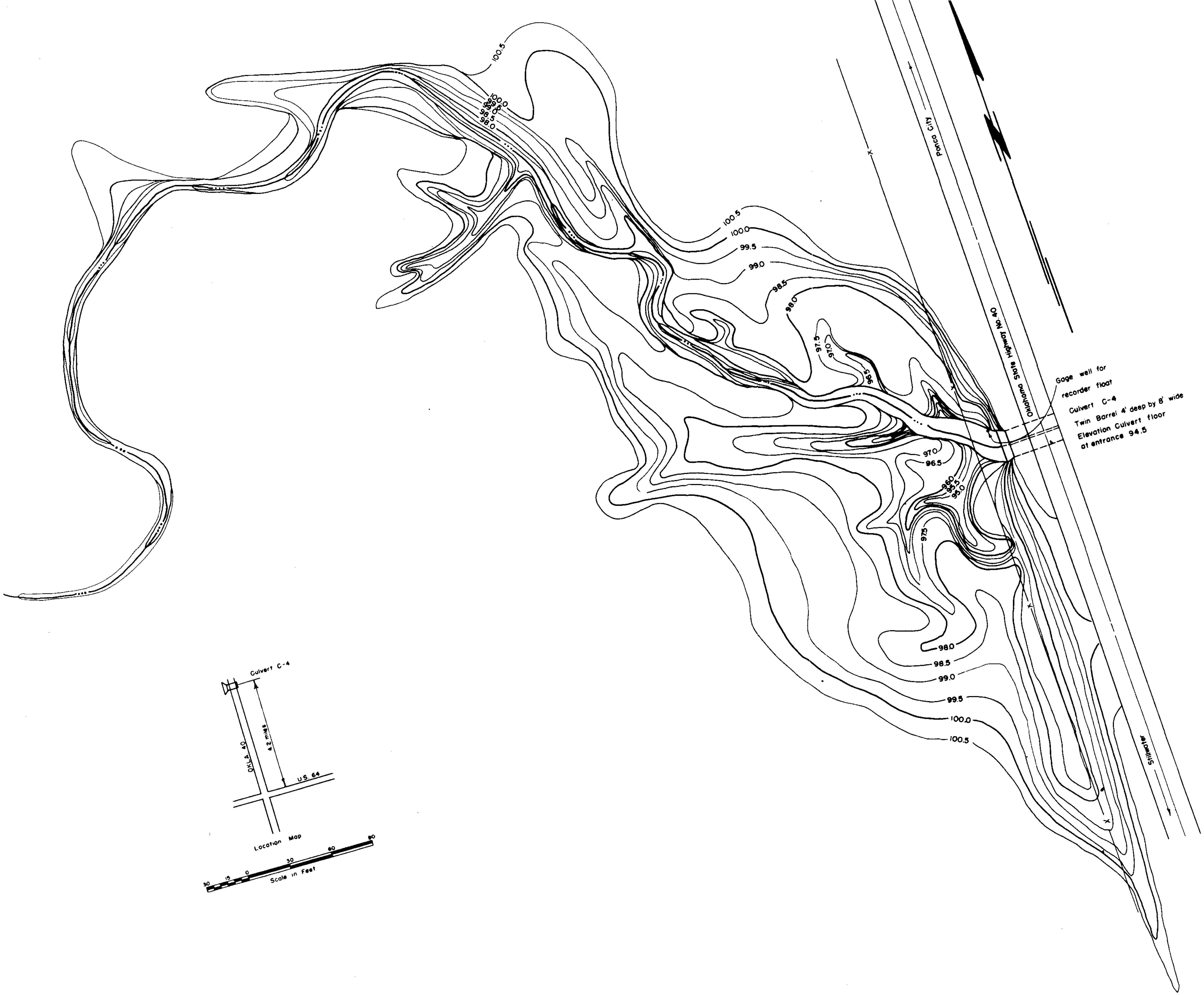

Figure 18.
TOPOGRAPHIC MAP OF
PONDED AREA
ABOVE CULVERT C-4

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REFERENCE: Working Plan R-2-4-1 Stillwater

CARTOGRAPHIC APPROVAL	TECHNICAL APPROVAL
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SURVEYED	COMPILED	TRACED	CHECKED	DATE
F.R.C.	T.L.W.	W.C.B.	G.L.B.	12-10-51

4-R-828

Table 1. Rainfall data for watershed 4.

Date	Time	Indicated mass depth	Depth for time interval	Time interval	Intensity
		in.	in.	min.	in./hr.
1951	AM				
7/14	4:55	0			
	5.00	0.30	0.30	5	3.60
	5:10	0.35	0.05	10	0.30
	5:25	0.39	0.04	15	0.16
	5:45	0.39	0	20	0
	6:40	0.50	0.11	55	0.12
	7:00	0.70	0.20	20	0.60
	7:25	0.95	0.25	25	0.60
	7:40	0.97	0.02	15	0.08
	7:50	0.99	0.02	10	0.12
	7:55	1.02	0.03	5	0.36
	8:05	1.45	0.43	10	2.58
	8:10	1.53	0.08	5	0.96
	8:15	1.54	0.01	5	0.12
	8:20	1.55	0.01	5	0.12
	8:50	1.57	0.02	30	0.04
	8:56	1.63	0.06	6	0.60
	9:02	1.63	0	6	0
	9:07	1.75	0.12	5	1.44
	9:12	1.78	0.03	5	0.36
	9:19	1.89	0.11	7	0.94
	9:27	1.93	0.04	8	0.30
	9:40	2.32	0.39	13	1.80
	9:45	2.40	0.08	5	0.96
	10:10	2.50	0.10	25	0.24
	10:27	2.60	0.10	17	0.35
	10:47	2.62	0.02	20	0.06
	11:05	2.70	0.08	18	0.27
	11:35	2.72	0.02	30	0.04
	11:40	2.75	0.03	5	0.36

Max. intensity (in./hr.) for:

5 min. - 3.60
15 min. - 2.04
30 min. - 1.12
60 min. - 0.85
Duration average - 0.43 in./hr.

Table 2. Pondage Correction Calculations
for watershed 4.

Contour elevation	Area	Volume for 0.01 ft. of stage	Stage G.D.E.	Rate of ponding for 0.01 ft./min. in stage
ft.	sq.ft.	cu.ft.	ft.	sec.ft.
94.49			0	
94.5	2,286	22.9	0.01	0.382
95.0	3,348	33.5	0.51	0.558
95.5	4,599	46.0	1.01	0.767
96.0	6,426	64.3	1.51	1.072
96.5	9,954	99.5	2.01	1.658
97.0	13,590	135.9	2.51	2.265
97.5	20,160	201.6	3.01	3.360
98.0	33,183	331.8	3.51	5.530
98.5	51,471	514.7	4.01	8.578
99.0	68,202	682.0	4.51	11.367
99.5	86,157	861.6	5.01	14.360
100.0	106,209	1062.1	5.51	17.702
100.5	126,981	1269.8	6.01	21.163

Table 3. Storm runoff data for watershed 4.

Date and time	Time interval	Gage height	Rate of change in stage	Pondage correction Q_p	Culvert discharge Q_c	Discharge corrected for pondage	Runoff per interval	Accumulated runoff
	min.	ft.	ft./min.	cfs.	cfs.	cfs.	in. x10^4	in.
July 14 AM								
7:08	0	0	0	0	0	0	0	0
7:18	10	0.054	0.005	0.2	0.1	0.3	1.2	0
7:22	4	0.06	0.001	0	0.1	0.1	0.6	0
7:30	8	0.07	0.001	0	0.2	0.2	0.9	0
7:35	5	0.076	0.001	0	0.2	0.2	0.8	0
7:41	6	0.092	0.003	0.1	0.3	0.4	1.4	0.001
7:50	9	0.10	0.001	0	0.4	0.4	2.8	0.001
8:02	12	0.106	0.001	0	0.5	0.5	4.2	0.001
8:19	17	0.334	0.013	0.6	6.6	7.2	51.5	0.006
8:23	4	0.34	0.002	0.1	6.8	6.9	22.2	0.009
8:27	4	0.38	0.010	0.5	8.8	9.3	25.5	0.011
8:33	6	0.50	0.020	1.1	14.4	15.5	58.6	0.017
8:39	6	0.62	0.020	1.2	20.6	21.8	88.1	0.026
8:41	2	0.64	0.010	0.6	21.8	22.4	34.8	0.029
8:43	2	0.66	0.010	0.6	22.8	23.4	36.0	0.033
8:46	3	0.67	0	0	23.4	23.4	55.2	0.038
8:50	4	0.65	0.005	-0.3	22.4	22.1	71.6	0.046
8:58	8	0.58	0.009	-0.5	18.2	17.7	124.7	0.058
9:17	19	0.48	0.005	-0.3	13.4	13.1	230.3	0.081
9:22	5	0.474	0	0	13.2	13.2	51.7	0.086

Table 3. (cont.)

Date and time	Time interval	Gage height	Rate of change in stage	Pondage correction Q_p	Culvert discharge Q_c	Discharge corrected for pondage	Runoff per interval	Accumulated runoff
	min.	ft.	ft./min.	cfs.	cfs.	cfs.	in. x10[4]	in.
9.27	5	0.48	0.001	0.1	13.4	13.5	52.5	0.091
9:32	5	0.50	0.004	0.2	14.4	14.6	55.3	0.097
9:42	10	0.70	0.020	1.3	25.0	26.3	160.9	0.113
9:47	5	0.88	0.036	2.6	36.4	39.0	119.1	0.125
9:52	5	1.08	0.040	3.1	50.6	53.7	182.4	0.143
9:55	3	1.18	0.033	3.0	58.4	61.4	135.9	0.157
9:57	2	1.30	0.060	5.7	68.0	73.7	106.3	0.167
10:00	3	1.40	0.033	3.3	76.0	79.3	180.6	0.186
10:04	4	1.50	0.025	2.6	85.6	88.2	263.6	0.212
10:06	2	1.55	0.025	2.8	90.4	93.2	142.8	0.226
10:08	2	1.60	0.025	3.0	95.0	98.0	150.5	0.241
10:09	1	1.62	0.020	2.4	97.0	99.4	77.7	0.249
10:11	2	1.64	0.010	1.2	99.0	100.2	157.1	0.265
10:14	3	1.65	0	0	100.0	100.0	236.3	0.288
10:16	2	1.64	-0.005	-0.6	99.0	98.4	156.1	0.304
10:18	2	1.62	-0.010	-1.2	97.0	95.8	152.8	0.319
10:19	1	1.60	-0.007	-0.8	95.0	94.2	223.8	0.342
10:24	5	1.50	-0.020	-2.1	85.6	83.5	349.6	0.377
10:33	9	1.30	-0.022	-2.1	68.0	65.9	529.1	0.429
10:46	13	1.10	-0.016	-1.3	52.0	50.7	596.5	0.489
11:02	16	0.90	-0.013	-0.9	37.6	36.7	550.3	0.544
11:29	26	0.70	-0.008	-0.5	25.0	24.5	626.1	0.607

Table 3. (cont.)

Date and time	Time interval	Gage height	Rate of change in stage	Pondage correction Q_p	Culvert discharge Q_c	Discharge corrected for pondage	Runoff per interval	Accumulated runoff
	min.	ft.	ft./min.	cfs.	cfs.	cfs.	in. $\times 10^4$	in.
PM								
12:20	51	0.50	-0.004	-0.2	14.4	14.2	776.7	0.684
1:47	87	0.30	-0.002	-0.1	5.1	5.0	657.3	0.750
3:07	80	0.26	-0.001	-0.1	3.7	3.6	270.7	0.777
5:07	120	0.24	-0.000	-0	3.0	3.0	311.7	0.808

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TYPIST PAGE

THESIS TITLE:

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NAME OF AUTHOR: TED L. WILLRICH

THESIS ADVISER: E. W. SCHROEDER

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