TEXAS WATER DEVELOPMENT BOARD

REPORT 54

HYDROLOGIC STUDIES OF SMALL WATERSHEDS

PIN OAK CREEK, TRINITY RIVER BASIN, TEXAS 1956-62

By

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ABSTRACT

Presented in this report are data and analyses of hydrologic investigations made on a 17.6-square-mile watershed study area prior to the development of floodwater-retarding structures.

A detailed geologic investigation revealed that the soil and rock units in this study area have a very low permeability. This condition probably affects the rainfall-runoff relationship, suspended sediment-size distribution, and duration of streamflow. The rock units should provide excellent materials for floodwater-retarding and conservation structures. As a result of the hydrogeologic conditions, there is no base flow in the watershed.

U.S. Weather Bureau records show that the average annual long-term rainfall in the area is about 37 inches. During the six-year period covered by this report, the average annual rainfall in the study area was 41.20 inches.

A rain gage density analysis indicated that, for this small study area, two-thirds of the time one centrally located rain gage recorded rainfall within +15 and -13 percent of the average rainfall computed from five gages in the watershed. Using two-gage combinations (extreme east-west and extreme north-south) improved the correlation only slightly. Uneven rainfall distribution, even within this small study area, was attributed to the convective thunderstorms which dominate the rainfall pattern in the Blackland Prairies physiographic region of Texas. Maximum deviation occurred when the average rainfall was less than 1 inch.

Rainfall magnitude and frequency curves were developed for the study area.

A procudure for estimating the runoff from sequential storm periods up to 15 days is presented. The procedure combines isohyetal values, antecedent conditions, and the 1- to 15-day rainfall recurrence probability values. The resulting values are then substituted in the graphical coaxial rainfall-runoff relationship developed for this study area. The procedure is useful in determining the location, number, and design capacities of reservoirs, and in flood-routing procedures required to protect a watershed project.

A unit-hydrograph analysis indicated that this watershed may have two average unit hydrographs, one characterizing the convective thunderstorm and the other a more general frontal-type storm.

Total sediment yield of the study area for the period from October 1956 to September 1962 was 246,000 tons, which is equivalent to a computed 3.1 acre-feet per square mile per year. If the suspended sediment had been deposited in a reservoir operating with moderate drawdown, the sediment would have occupied a volume of 191 acre-feet. Average size distribution of the suspended sediment was 74 percent clay, 22 percent silt, and 4 percent sand, which results from the fine-grained character of the rocks and soils in the watershed.

Chemically the water is suitable for irrigation, domestic use, and most industrial uses. The dissolved-solids content ranged from 89 to 430 ppm (parts per million) during this study period.

Average runoff during the six-year study period was 10.58 inches per year. The runoff varied from a minimum of 5.85 inches out of a total rainfall of 41.87 inches during 1958, to a maximum of 18.91 inches runoff out of a total of 53.00 inches rainfall during 1957. The maximum and minimum annual consumption (rainfall less runoff) during the six-year period was 86 and 64 percent of rainfall, respectively, and the average was 76 percent. A graphical correlation technique is presented comparing the seasonal effects with the average monthly consumption. This correlation was found to be compatible with the coaxial multiple correlation curves developed for this study area.

Future studies should compare the after-development conditions with the before-development conditions that are presented in this report as to the shape and slope of the flow-duration curve; the peak discharge and shape of the unit hydrograph; the graphical coaxial multiple-correlation relationship; runoff rates and volumes; and the suspended-sediment regimen, since each reflects certain characteristic variables of basin runoff.

HYDROLOGIC STUDIES OF SMALL WATERSHEDS

PIN OAK CREEK, TRINITY RIVER BASIN

TEXAS 1956-62

INTRODUCTION

As a result of the Flood Control Acts of 1936 and 1944 and the Watershed Protection and Flood Prevention Act (Public Law 566), as amended, the U.S. Soil Conservation Service (SCS) is charged with the responsibility for initiating measures to conserve the agricultural lands of our nation.

Part of the plan to accomplish this conservation program is to reduce downstream flood frequency and magnitude by constructing a series of small upstream floodwater-retarding structures. These structures pond the natural runoff and release it through relatively small outlets, thereby lessening the peak discharge and prolonging the duration of flow below the structures. That portion of the sediment-laden runoff which is retained below the fixed drop-outlet level of the floodwater-retarding structure (Figure 1) is removed by evaporation, seepage, transpiration, or by uses of man. Therefore, the structures reduce the frequency and magnitude of downstream flooding and, to some extent, the total basin outflow.

As of September 30, 1966, 1,081 floodwater-retarding structures had been built in nine river basins in Texas. These structures partially control runoff from an area of 4,349 square miles. A total of 3,438 structure sites has been found economically and physically feasible in Texas according to reports of the U.S. Study Commission-Texas (1962) and the Soil Conservation Service (1963). About 31 percent of the feasible structures had been completed by the end of the 1966 water year.

Construction of floodwater-retarding structures in the Trinity River basin in Texas began in 1950. As of September 30, 1966, 546 structures with a floodwater-retarding capacity of 432,200 acre-feet had been built in the upper two-thirds of the Trinity River basin.

Numerous water resources planning agencies have expressed interest in the effect of these floodwater-retarding structures upon the quantity and mode of occurrence of surface runoff downstream from developed watersheds. Hydrologists, cognizant of the opportunity afforded by the developed areas, are striving to obtain critically lacking hydrologic data on small watersheds.

Water supplies, directly or indirectly, more human needs than does any other natural resource. The supply of water is often deficient to meet these needs; therefore, conflicts of interest may develop. Wise decisions must be

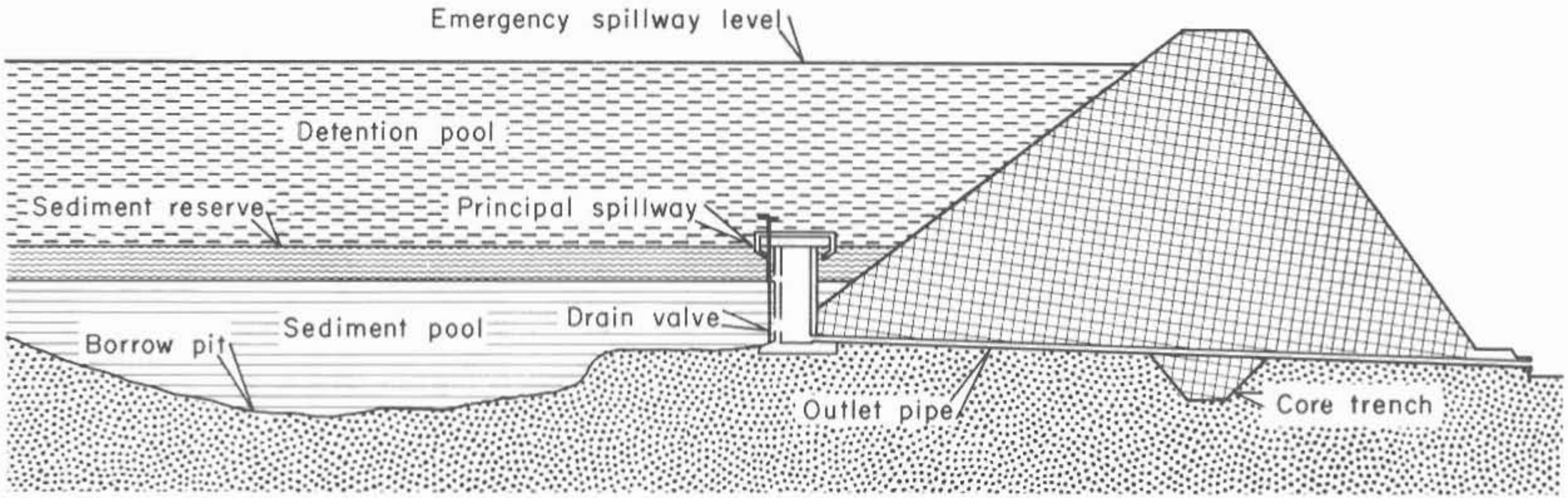


Figure 1

Section of a Typical Floodwater - Retarding Structure

U. S. Geological Survey in cooperation with the Texas Water Development Board

made for solving these conflicts of water uses (municipal supply, irrigation, industrial, recreational, and others) and for optimum utilization and conservation of available water. These decisions depend upon factual information concerning the amount and variability of the supply along with an impartial analysis defining how various water-management methods will affect the regimen of streamflow. The small watershed studies of the U.S. Geological Survey are oriented to provide this needed information.

History of the Statewide Small Watershed Project

The U.S. Geological Survey, in cooperation with the U.S. Soil Conservation Service and the Texas Water Development Board, began a program in 1951 for appraising the hydrologic effects of the floodwater-retarding structures. The Geological Survey is presently making studies in Texas in 11 small watersheds which have been or will be developed with floodwater-retarding structures (Figure 2). These studies are being made in cooperation with the Texas Water Development Board, the Soil Conservation Service, San Antonio River Authority, city of Dallas, and the Tarrant County Water Control and Improvement District No. 1. In the 11 study areas, chosen on an areal basis, data are being collected in watersheds having a variety of climatic, topographic, geologic, and soil conditions which affect the local hydrologic environment. In four of the small watershed study areas, of which Pin Oak Creek is one, rainfall and streamflow records were collected prior to construction of the structures, thus affording the opportunity for analysis of conditions before and after development. Data pertaining to the investigations in each of the 11 study areas is given in Table 1.

Purpose and Scope of Hydrologic Studies

The broad purpose of the statewide small watershed investigations is to collect data and define hydrologic criteria which can be applied to the many developed and undeveloped areas of the State for purposes of planning and design. Periodic evaluations of, and reports on, these investigations are essential to insure well oriented data-collection programs. Specific objectives within the broad purpose of the investigations are as follows:

1. To obtain the basic hydrologic data on small watersheds needed to satisfy the broad purpose.

2. To obtain the basic data which will aid in determining the net effect of floodwater-retarding structures on the regiment of streamflow at downstream points.

3. To determine the effect of the structures on the underlying groundwater reservoir.

4. To determine the effect of the structures on the sediment yield of the watershed and to determine the trap efficiency of the structures.

5. To develop computation techniques that will give more accurate estimates of runoff resulting from a given amount of rainfall on small watersheds.

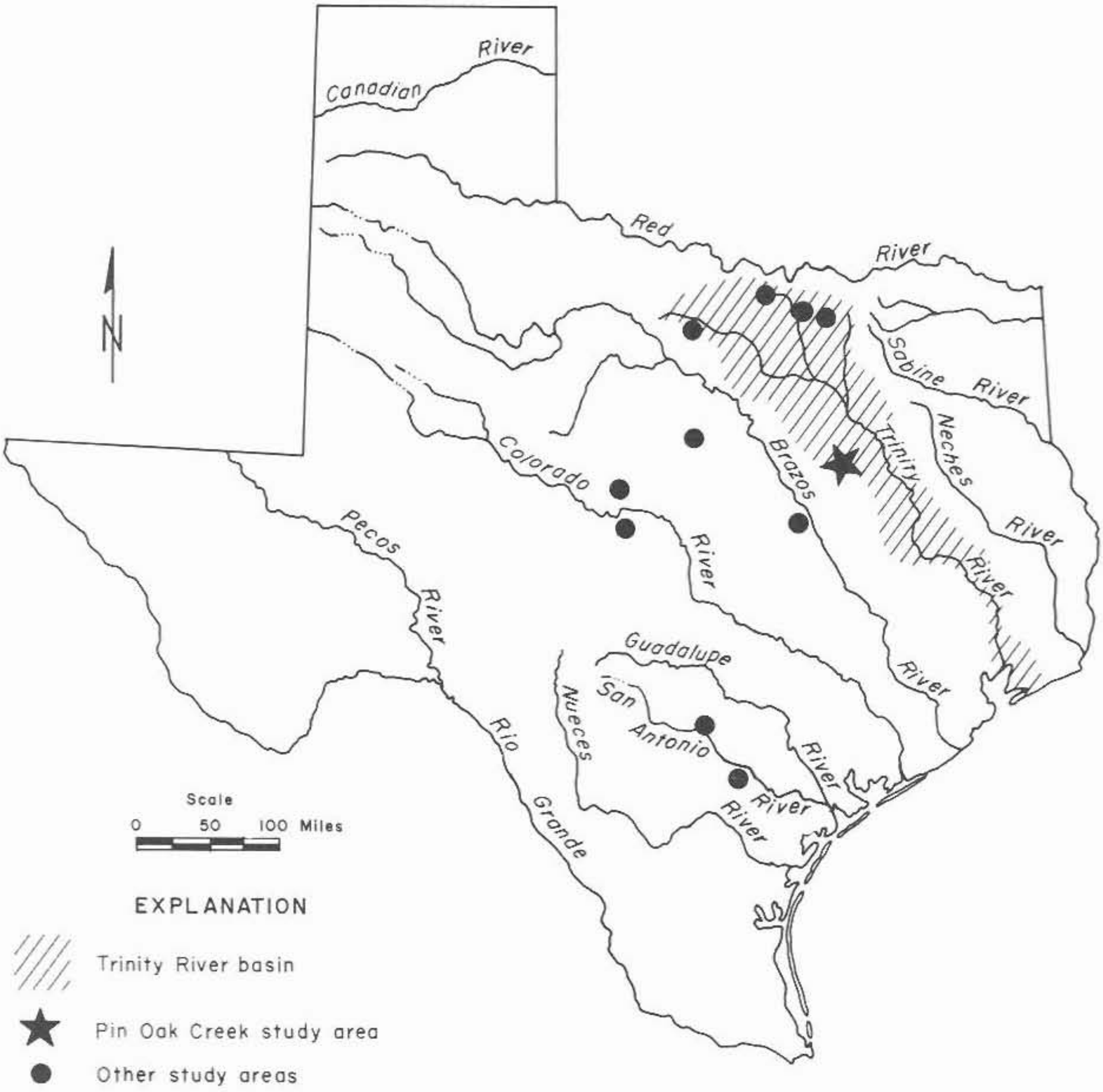


Figure 2

Locations of Pin Oak Creek and Other Small Watershed Study Areas

U. S. Geological Survey in cooperation with the Texas Water Development Board

Table 1.--Small watershed study areas in Texas as of September 30, 1966.

Watershed	Drainage area above stream-gaging station (sq mi)	Date hydrologic data collection began	Floodwater-retarding structures above stream-gaging station	Period the structures were built
Trinity River basin:				
North Creek near Jacksboro	21.6	Aug. 1956	None	--
Elm Fork Trinity River near Muenster	46.0	July 1956	14	1954-57, 63
Little Elm Creek near Aubrey	75.5	June 1956	8	1965-66
Honey Creek near McKinney	39.0	July 1951	12	1951-57
Pin Oak Creek near Hubbard	17.6	Sept. 1956	6	1962-63, 65
Brazos River basin:				
Green Creek near Alexander	45.5	Oct. 1954	8	1954-56
Cow Bayou near Mooreville	79.6	Sept. 1954	26	1955-58, 64-65
Colorado River basin:				
1/ Deep Creek near Mercury	43.9	June 1951	5	1951-53
1/ Dry Prong Deep Creek near Mercury	8.31	do	1	1951
Mukewater Creek near Trickham	70.0	Aug. 1951	6	1961-62, 65
San Antonio River basin:				
Calaveras Creek near Elmendorf	77.2	Aug. 1954	9	1954-58
Escondido Creek at Kenedy	*72.4	July 1954	10	1954-58

* 8.43 sq mi above Escondido Creek subwatershed No. 11 (Dry Escondido Creek) near Kenedy is below the stream-gaging station and is not included in these totals.

1/ Considered as a single study area.

6. To develop relationships between maximum rates of rainfall and runoff in small watersheds that will enable more accurate design of small storm-drainage structures.

7. To check the applicability of flood-routing procedures and techniques for small watersheds.

8. To determine the minimum instrumentation necessary for making reliable estimates of total storm inflow to the structures.

9. To determine the quality of the surface water as related to its use potentials and how its flocculating characteristics affect the sediment-trap efficiency of the pool.

One or more interpretive reports on each of these 11 rural small watershed investigations will be published. Thus far, the following six have been prepared:

1. "Hydrologic studies of small watersheds, Honey Creek basin, Collin and Grayson Counties, Texas, 1953-59"

2. "Hydrologic studies of small watersheds, Deep Creek, Colorado River basin, Texas, 1951-61"

3. "Hydrologic studies of small watersheds, Elm Fork, Trinity River basin, Montague and Cooke Counties, Texas, 1956-60"

4. "Hydrologic studies of small watersheds, Mukewater Creek, Colorado River basin, Texas, 1952-60"

5. "Hydrologic studies of small watersheds, Little Elm Creek, Trinity River basin, Texas, 1956-62"

6. "Hydrologic studies of small watersheds, Escondido Creek, San Antonio River basin, Texas, 1955-63"

The first three and the last of the above reports are on study areas in which floodwater-retarding structures were constructed prior to or concurrent with the initiation of the statewide program. In the other two reports, as in this report, the hydrologic data and analysis cover a period prior to the construction of floodwater-retarding structures. For each of the 11 study areas, an annual basic data report has been prepared since 1960. In addition to these 11 rural small watershed areas under study, basic hydrologic data are also being collected on small urban watersheds in Austin, Dallas, and Houston.

Purpose and Scope of This Report

Results of hydrologic investigations in the upper Pin Oak Creek watershed area near Hubbard are evaluated in this report. Only the results of investigations during water years 1957-62, which were prior to construction of floodwater-retarding structures by the Soil Conservation Service, are presented here. The purpose of this report is to present the results of the hydrologic investigations and such analyses as will accomplish the following objectives:

1. Evaluate the soils and geologic rock units in this study area for use in determining the expected ground-water influence on the basin water budget.

2. Present additional basic hydrologic data on a small undeveloped watershed so as to aid in the fuure determination of the net effect of floodwater-retarding structures.

3. Determine the minimum instrumentation necessary for making reliable estimates of storm inflow and outflow from the structures and the watershed as a whole.

4. Apply a method to predict the rainfall and runoff from a sequential recurrence interval.

5. Apply to this watershed techniques for more accurately estimating runoff resulting from given storm conditions. These techniques may then be used in other geologically and hydrologically similar watersheds for more accurate design of small storm-drainage structures.

6. Analyze the sediment yield for later use in determining the changes in sediment regimen downstream from the structures.

7. Analyze the water quality as to its potential use and to its sedimentation and flocculation chracteristics.

Acknowledgments

Fieldwork was done by the engineering staff of the U.S. Geological Survey subdistrict office in Fort Worth, Texas, under J. H. Montgomery, subdistrict chief; and the staff of the U.S. Weather Bureau Regional Office, Fort Worth, Texas, under R. J. MacConnell, regional hydrologist.

Grateful acknowledgment is made for the financial assistance and cooperation of the Texas Water Development Board (formerly Texas Water Commission), John J. Vandertulip, chief engineer; and the Tarrant County Water Control and Improvement District No. 1, Ben Hickey, general manager.

Sections of the report involving sedimentation analyses were prepared by C. T. Welborn, engineer, U.S. Geological Survey, Austin, Texas.

The compilation of the report and the preparation of the other sections of the report were made by J. T. Smith, hydrologist, under the direct supervision of Trigg Twichell, district chief, Water Resources Division, U.S. Geological Survey, Austin, Texas.

WATERSHED FEATURES

Pin Oak Creek rises at Hubbard in the southeastern corner of Hill County and flows eastward about 14 miles along the Limestone-Navarro county line. Turning northeastward, it flows an additional 14 miles in southwestern Navarro County where it empties into Richland Creek northwest of Richland. Pin Oak Creek drains a triangular-shaped basin area of about 109,500 acres, or about 171 square miles.

This report is concerned only with that part of the watershed above the Geological Survey stream-gaging station located on the main channel at the State Highway 171 bridge 5.8 miles southeast of Hubbard. The total area above the stream-gaging station is 17.6 square miles, or about 10 percent of the watershed. Figure 3 shows the area covered by this report.

Land Use and Developments

Land in the basin areas above and adjacent to the reservoir sites consists of approximately 70 percent pastureland. The remaining 30 percent is cultivated, much of it contour terraced. Downstream from the reservoir sites about 80 percent of the land is cultivated and approximately one-half of this is terraced. A fairly small part, approximately 15 percent, of the land is wooded, this being primarily the areas adjacent to the stream channels.

Basically the rural watershed economy is agricultural, with cotton, grain sorghums, corn, and Johnson grass hay being the predominant crops. Beef-cattle production is a major source of income.

Runoff from 55 percent of the drainage area (9.7 square miles of the total 17.6 square miles) above the stream-gaging station, Pin Oak Creek near Hubbard, is controlled by six floodwater-retarding structures which were constructed during water years 1963-65, subsequent to the period covered by this report. These structures have a total capacity of 3,480 acre-feet, of which 629 acre-feet is sediment-storage capacity and 2,851 acre-feet is floodwater-detention capacity.

Climate

Climate of the study area is temperate and subhumid with a prevailing south wind. Rainfall in the watershed is produced from various types of storms. Long-duration, low-intensity storms, triggered by the southward moving continental polar fronts, are common during the fall and winter. Similar general storms occur during the summer when the remnants of hurricanes move inland from the Gulf of Mexico. The most common storm occurring from April to September is the squall line thunderstorm. Individual excessive rains causing serious floodwater and sediment damage may occur during any season, but are most frequent in the spring. The maximum rainfall recorded during any one-month period during 88 years of record at Corsicana was 17.76 inches in April 1957. The average rainfall over the Pin Oak Creek study area for April 1957 was 15.65 inches.

In this study area the normal (normal being the average annual for the 30-year period from 1931 through 1960) precipitation is 37.06 inches per year based on U.S. Weather Bureau records at Corsicana. At Corsicana the minimum annual precipitation of 19.36 inches occurred in 1917, and the maximum annual precipitation was 61.50 inches in 1957. During the six-year period covered by this report (1956-62), range in annual precipitation at Corsicana was from 28.36 inches in 1956 to 61.50 inches in 1957 with the mean annual being 42.05 inches, approximately 5 inches greater than the 1931-60 normal. The six-year mean annual rainfall was 41.20 inches in the Pin Oak Creek watershed.

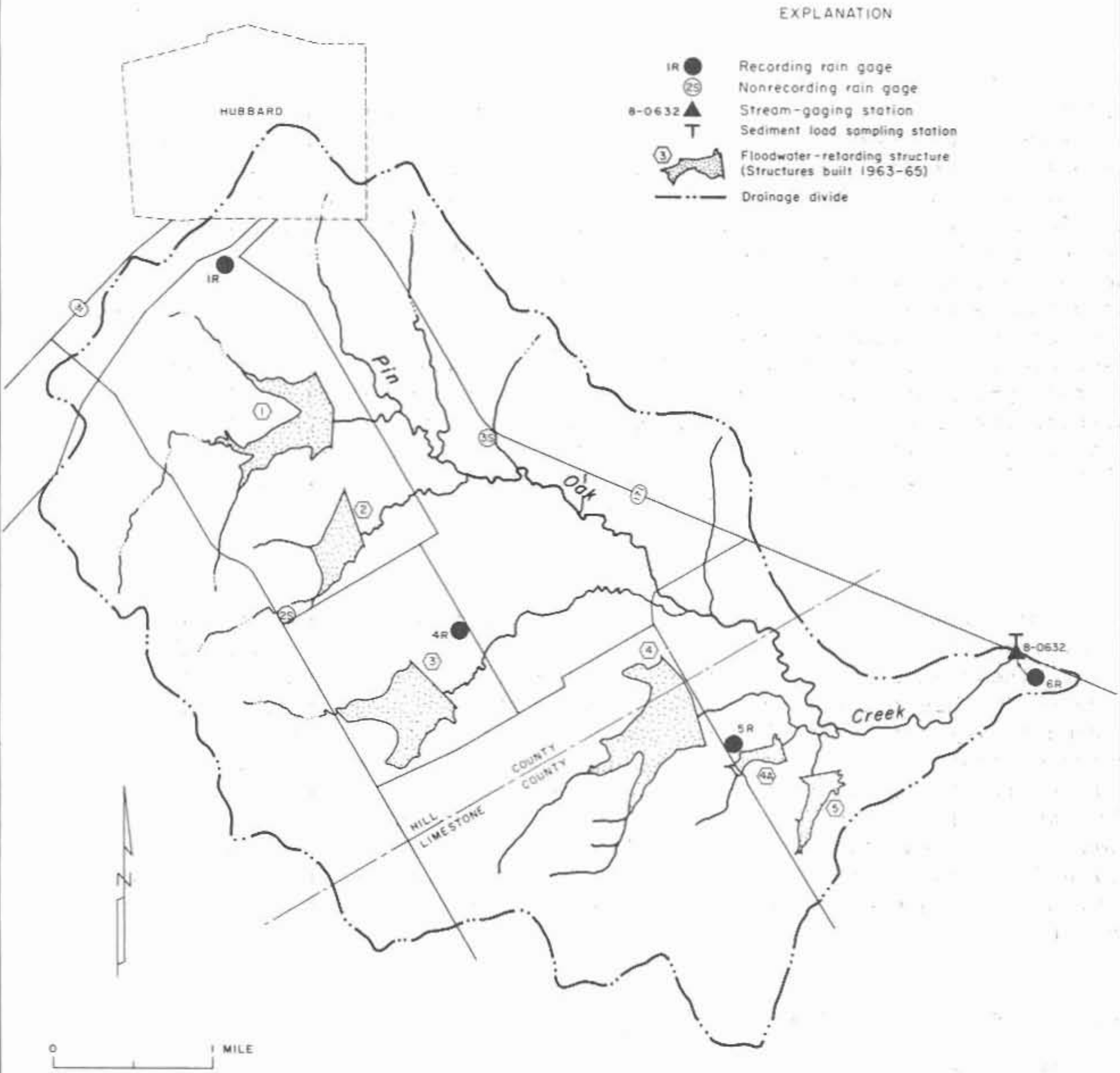


Figure 3

Locations of Floodwater-Retarding Structures and Hydrologic Instrument Installations

U.S. Geological Survey in cooperation with the Texas Water Development Board

Base from U.S. Geological Survey topographic maps

Mean annual temperature is about 66°F, a mean maximum of about 97°F occurring in July and August and the mean minimum of about 36°F occurring in January. Extremes of 113°F and -7°F have been recorded. Average growing season is 247 days, the period between the killing frosts that occur from around November 19 to March 17. Light snowfall occurs in December, January, and February, averag ing about two inches annually.

Topography

The topography in the study area is gently rolling with broad flat valleys and some flat hilltops. Primarily, the watershed is a plain dissected by numerous intermittent streams which have cut narrow shallow channels with a dendritic pattern. The topographic plain slopes southeastward about 17 feet per mile. Maximum relief is about 210 feet, ranging from an elevation of about 460 feet above mean sea level at the stream-gaging station to about 670 feet on the divide above reservoir site 1. Local relief varies from 50 to 100 feet. Bottomlands along the main channel are nearly level. The main channel changes in altitude from about 650 feet at the basin divide at Hubbard to 555 feet at the Valley View Cemetery immediately south of Hubbard. This is a fall of 95 feet along a 7,300 foot channel distance for a slope of about 69 feet per mile in the uppermost part of the watershed. From the cemetery to the stream-gaging station the channel gradient averages about 12 feet per mile. Generally, the tributaries above the floodwater-retarding structure locations have a slope of 60 to 100 feet per mile. The main-channel profile is shown in Figure 4.

Geologic Units

Two members of the Taylor Marl of Late Cretaceous age, the Uvalde Gravel of Pliocene(?) age, and alluvium of Quaternary age are exposed in the study area. These geologic units in the portion of the Pin Oak Creek watershed covered in this report are entirely within the Blackland Prairies physiographic region of Texas (Figure 5). The geologic units yield insignificant amounts of water because of their low permeability. Another indication of the low permeability is the conspicuous absence of wells in the study area. Nearly all of the water for livestock and domestic use is obtained from dug tanks or cisterns. Some wells in the surrounding area have obtained water at shallow depths in the Wolfe City Sand Member, but some wells go dry seasonally and others require many hours to accumulate a few buckets of water which is reported to be of poor quality.

Wolfe City Sand Member of the Taylor Marl

The most extensive and oldest geologic unit in the study area is the Wolfe City Sand Member of the Taylor Marl. It is exposed in shallow gullies and roadside ditches and will be exposed in the pools formed by floodwater-retarding structures 1, 2, 3, and 4. The Wolfe City Sand Member consists of mottled tan, red, and bluish-gray silty clay with small lenticules of very fine sandstone. Calcareous accumulations are common in the upper two or three feet of the Wolfe City just below the overlying soil zone. These accumulations consist of hard nodules up to one inch in diameter or of soft white clayey globules up to three inches in diameter. Locally these calcareous masses may occur as thin beds, but are generally well disseminated in the clay which forms the C-horizon in the soil zone.

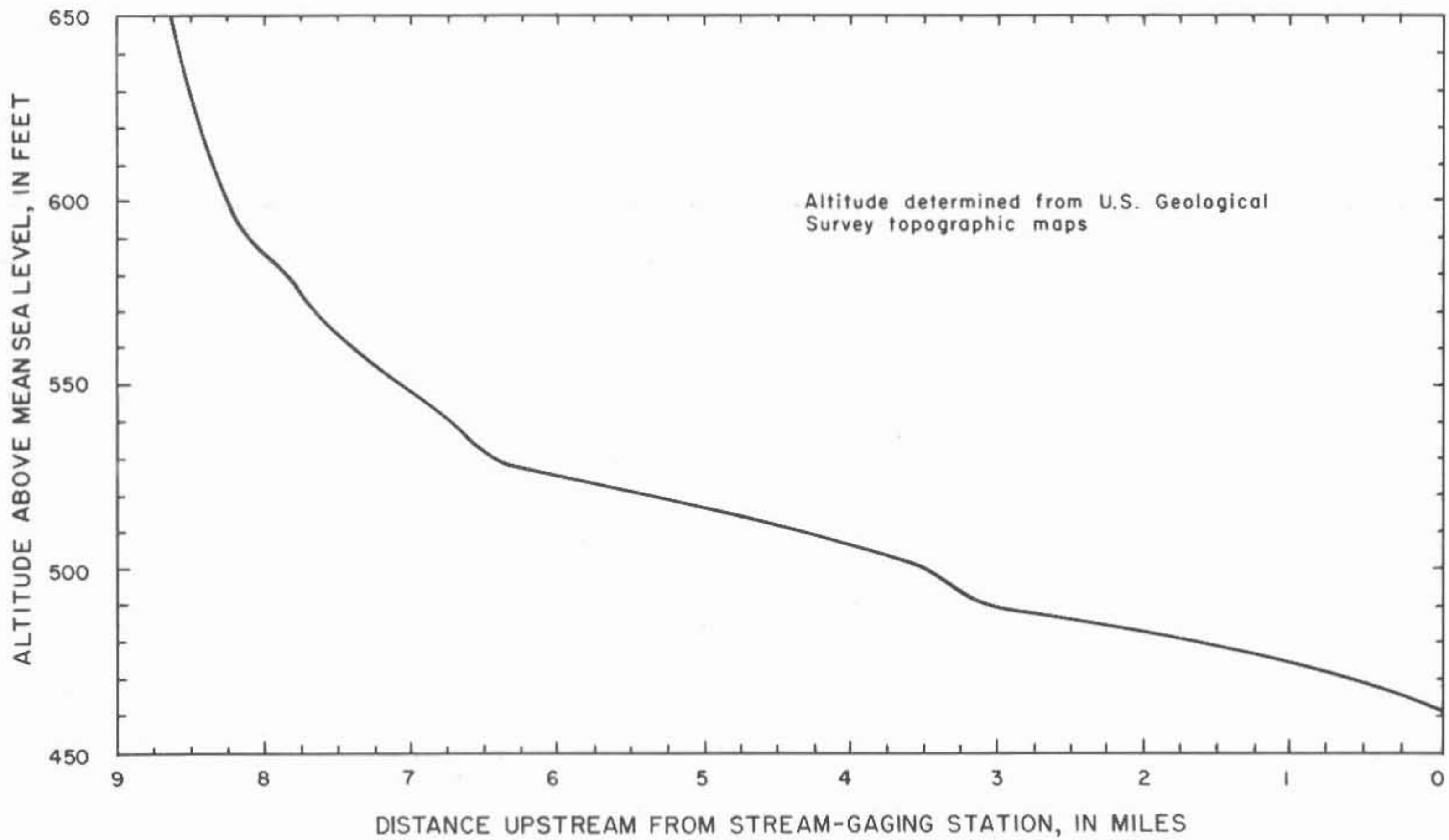


Figure 4

Streambed Profile of Pin Oak Creek

U. S. Geological Survey in cooperation with the Texas Water Development Board

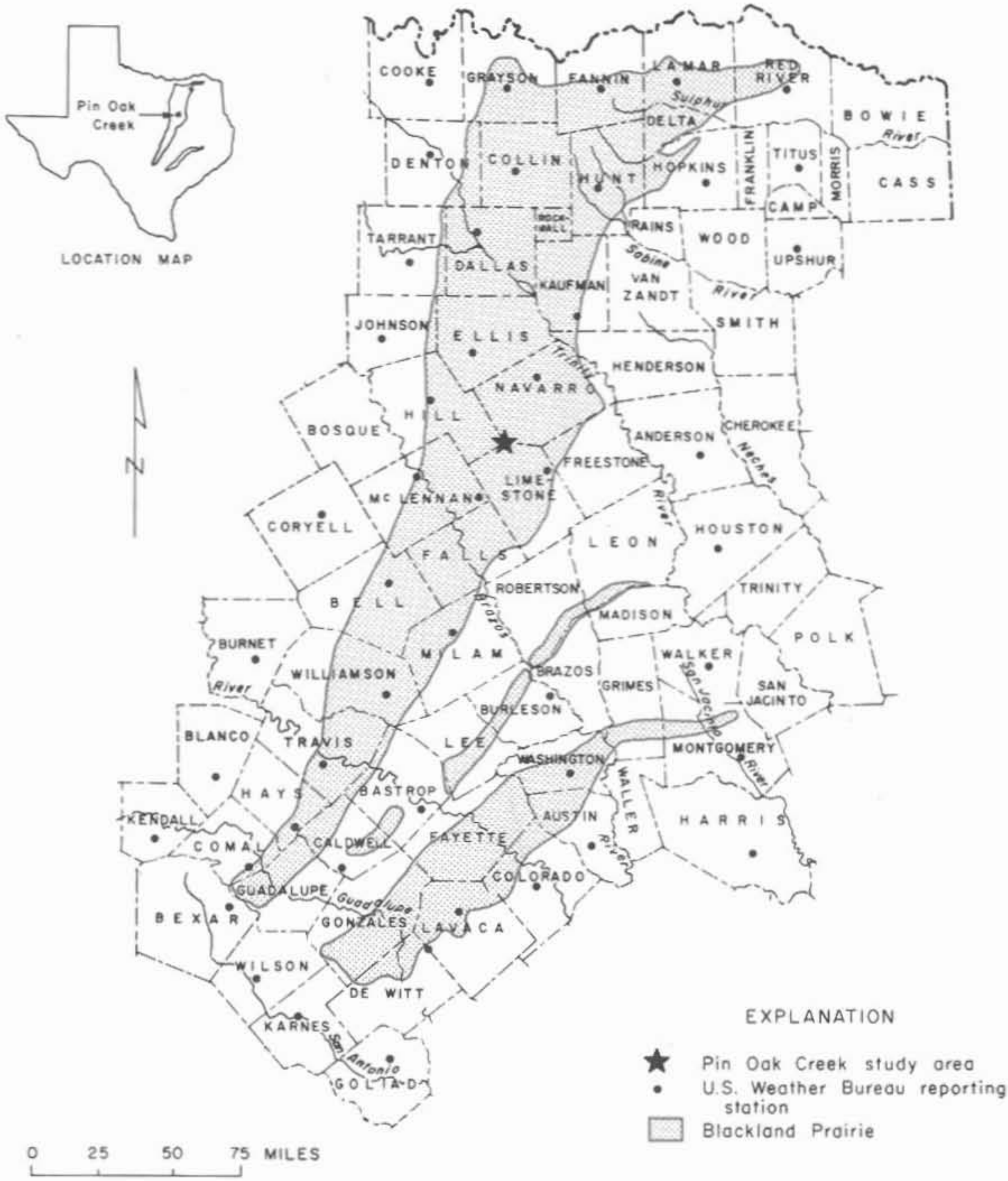


Figure 5

Pin Oak Creek Watershed in the Blackland Prairies Physiographic Region and Locations of U. S. Weather Bureau Rainfall Reporting Stations

U. S. Geological Survey in cooperation with the Texas Water Development Board

After Knisel (1965)

During a field investigation made May 6 and 7, 1965, approximately two weeks after the last rainfall in the area, the calcareous zone in the Wolfe City Sand Member was still moist and pliable, whereas the overlying soil zone and the underlying clay were dry. This may indicate that the overlying soil and the calcareous zone are relatively more absorptive than the underlying clay. The thinness, low permeability, and limited areal extent of this highly oxidized zone preclude the possibilities of its contributing significantly to streamflow.

Pecan Gap Chalk Member of the Taylor Marl

Exposures of the overlying Pecan Gap Chalk Member are oxidized in the study area and occur only in the main channels near the stream-gaging station. The Pecan Gap will be exposed in the pool to be formed by floodwater-retarding structure 5. The exposures, where seen, consisted of a soft, clayey gray chalk which easily weathered into spheroidal shapes. One such exposure in a long pool in the main channel of the creek at the State Highway 171 bridge was observed to hold water during the entire field investigation. There was no flow through this ponded reach most of this time. Thus, the Pecan Gap Chalk Member appeared to have low permeability.

Uvalde Gravel

Small exposures of gravel are disseminated in the soils on the top and slopes of many of the hills in the study area. At most, the depth of the gravel is about 18 inches, but is generally less than one foot. The gravel consists of angular to well-rounded sand to cobble-size fragments of quartzite, granite, chert, petrified wood, conglomerate, quartz, red jasper, and clay balls. Although these deposits yield no water, they tend to retard runoff and erosion and facilitate infiltration of water to the underlying material.

Alluvium

Alluvium of Quaternary age is distributed along the channels of the streams and their tributaries. The deposits, which are very thin, consist of silt and clay transported downstream from the uplands. In the main channel downstream from proposed floodwater-retarding structure sites 4, 4a, and 5, small alluvial deposits of sand and gravel were noted. These deposits, which are confined to the narrow channel bed, do not have any significant hydrological effect upon runoff or recharge within the study area.

Soil Cover

The U.S. Soil Conservation Service has mapped the soils in the area in detail. Deep, fairly well-developed soils cover the study area. Figure 6 shows the general distribution of the soil units in the vicinity of the reservoir sites.

The following is an explanation of soil terminology used in Figure 6:

Deep--more than 20 inches of soil material which is readily penetrated by plant roots.

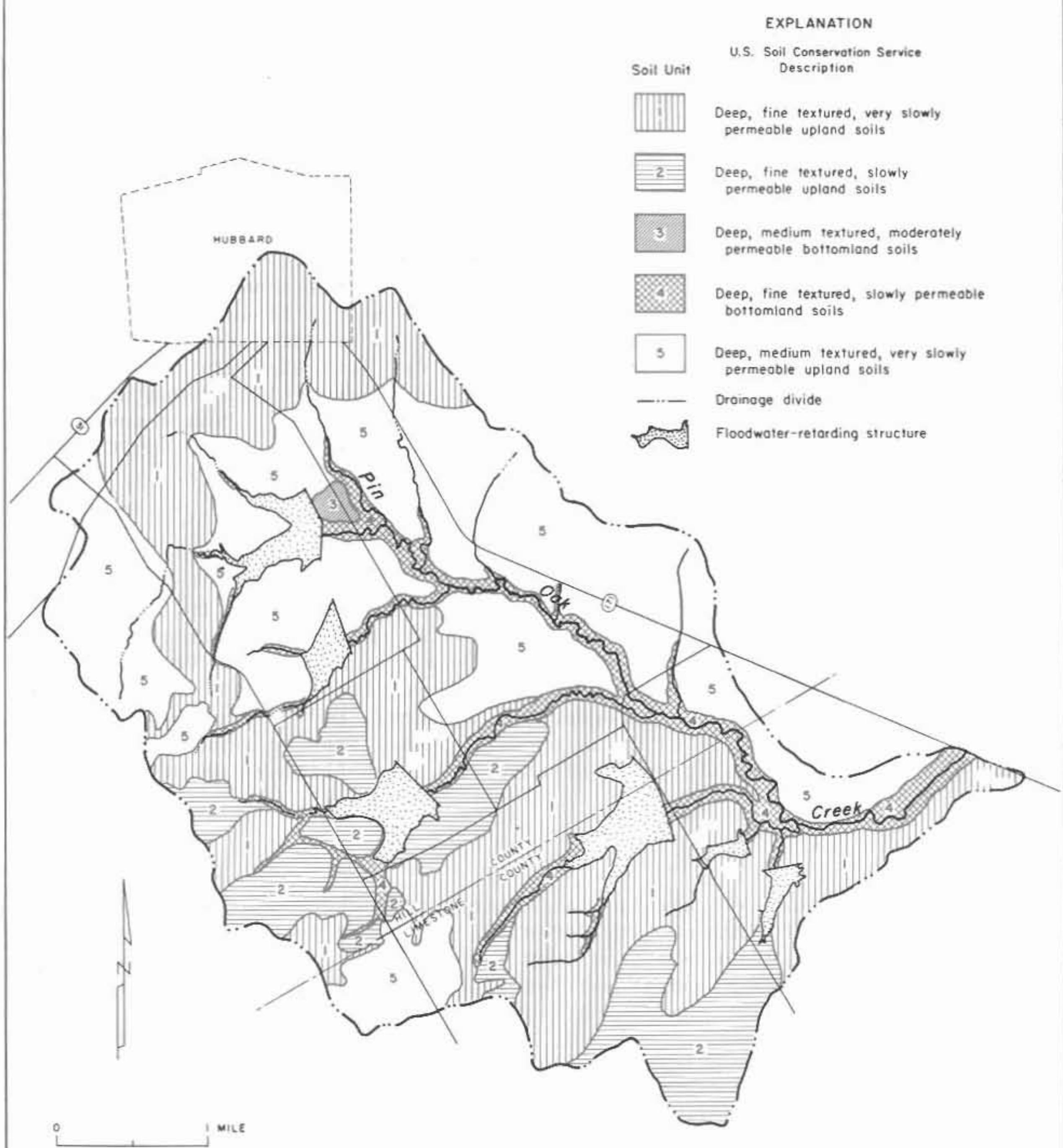


Figure 6

Generalized Distribution of Soil Types Adjacent to the Reservoirs

U.S. Geological Survey in cooperation with the Texas Water Development Board

Fine-textured--clay, silty clay, clay loam, and silty clay loam.

Medium textured--silt loam, loam, very fine sandy loam to sandy loam.

Slowly permeable--crumbly and granular clay, silty clay, and clay loam. Structure is fine to irregular, angular, blocky, and coarse prismatic.

Very slowly permeable--dense clay or semi-clay pans. Structure is massive, forming irregular angular blocks, platy, and fragmental.

Generally, the main difference between "slowly permeable" and "very slowly permeable" soils is due to the clay structure and content in the soil types. When dry, the "slowly permeable" soil contracts to a greater degree than the "very slowly permeable" soil. The contraction cracks increase the voids and thus increases the total infiltration capacity of the soil. Both soils become almost impervious after saturation.

The soils as well as the geologic units in the study area have very low permeability. Stock tanks, terraces, and natural depressions in the study area hold water for long periods. The soil types classified in the area by the Soil Conservation service indicate all types to be "slowly" to "very slowly permeable." Mr. E. D. Lewis, soil scientist with the Soil Conservation Service at Hubbard, reported that the only moderately permeable soil in the study area is a small terraced area immediately downstream from reservoir 1 (Figure 6). This moderately permeable soil area, however, is too confined to be hydrologically significant.

HYDROLOGIC DATA COLLECTION

Rainfall

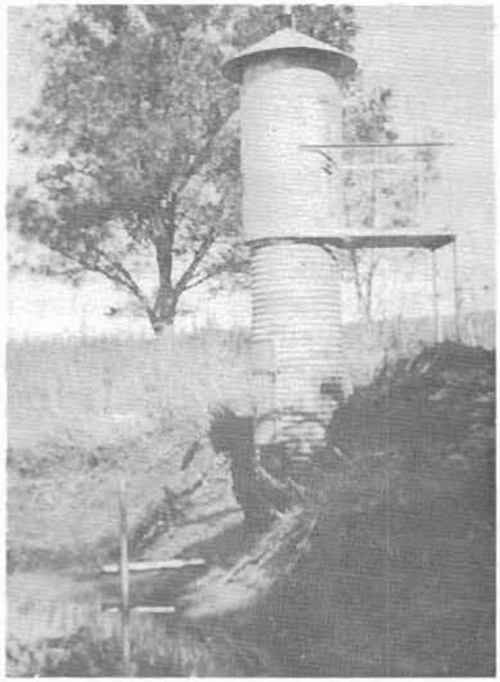
In this study area, equipment for the collection of rainfall data consists of a U.S. Geological Survey-type tipping-bucket recording rain gage at the stream-gaging station 08-0632.00, Pin Oak Creek near Hubbard, and five other rain gages. The tipping-bucket rain gage was installed October 18, 1956. Of the five other rain gages, three are Weather Bureau (USWB) 8-inch recording gages (Figure 7A) and two are USWB 8-inch nonrecording rain gages. These gages were put into operation the week of December 3, 1956. Locations for the rain gages are in accordance with the USWB procedures for obtaining the best geometric coverage of the study area (Figure 3). This network of rain gages, except for the USGS-type tipping-bucket, is operated and maintained by Weather Bureau personnel through an agreement with the Geological Survey.

Inspection of rainfall records for this report period, December 1956 through September 1962, indicates that the data are of acceptable accuracy. In addition to the rainfall data collected within this study area, 88 consecutive years of rainfall data are available from the Weather Bureau station at Corsicana, about 26 miles northeast of the study area.

Runoff

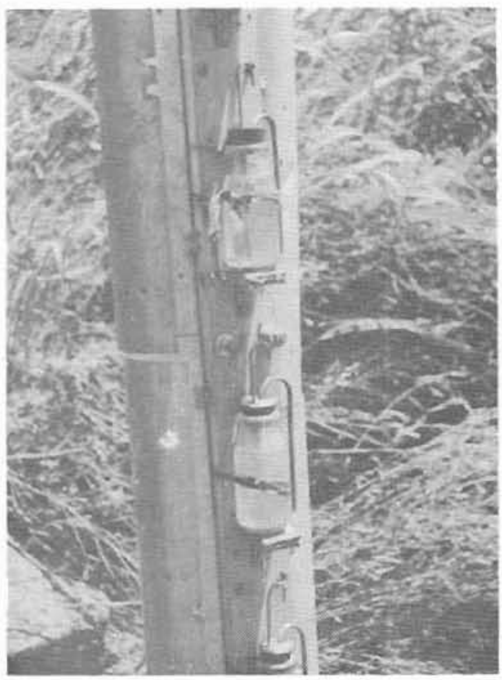
Streamflow data for the study area are collected at the U.S. Geological Survey stream-gaging station 08-0632.00, Pin Oak Creek near Hubbard (Figures 3

7 A.--Recording rain gage



7 B.--Recording stream-gaging station

7 C.--Suspended-sediment sampling station



7 D.--Automatic single-stage samplers

Figure 7

Hydrologic Instrument Installations Typical of Those in Pin Oak Creek Watershed

U.S. Geological Survey in cooperation with the Texas Water Development Board

and 7B). This station was established September 1, 1956. A Stevens A-35 continuous water-stage recorder was installed on September 19, 1956. Since September 19, continuous records of stream-stage and discharge have been obtained. There was no flow from September 1-19, 1956.

Streamflow data for the period September 1956 through September 1962 are rated excellent. Data presented in this report are divided into one-year periods known as "water year." A water year begins October 1 and ends Septe - ber 30 and is designated by the calendar year in which it ends. Thus, the one-year period from October 1, 1956, to September 30, 1957, is denoted the "1957 water year." Streamflow records collected in this study area have been published annually by the Geological Survey in the Surface Water Records of Texas.

Fluvial Sediment

Instrumentation

Fluvial sediment collecting equipment installed at the stream-gaging station consists of a type-A sounding reel with attached USD-43 sampler (United States Depth-integrated). This instrument is attached to a platform mounted at the upstream side of the bridge (Figure 7D). The platform and equipment are centered over the main channel of the creek. Most of the suspended-sediment samples are collected using the USD-43 sampler. This sampler, when lowered to the streambed and raised again at a constant rate, collects a quantity of water-sediment mixture. The sample, therefore, is a depth-integrated mixture which is representative of the streamflow at a particular time and place. The USD-43 sampler can collect a water-sediment mixture to within 0.3 foot of the streambed. Because the main channel of Pin Oak Creek is narrow, about 30 feet wide at the gaging station, and because the suspended-sediment particles are relatively fine, the concentration of the water-sediment mixture collected by the USD-43 sampler in the center of streamflow is assumed to be the mean sediment concentration for the entire streamflow cross section.

Also, a series of automatic single-stage samplers is used to collect suspended-sediment samples during rising stages. These single-stage samplers are attached to a board, and the samples are arranged at one-foot stage intervals. The series of automatic single-stage samplers is fastened to a reinforced concrete bridge pier on the right bank of the main channel. Figure 7D shows an installation of a series of automatic single-stage samplers.

Period of Sampling

Collection of suspended-sediment data began in October 1956 and was discontinued in September 1960. In September 1962, sediment collection was resumed. Sediment discharge for the missing period, October 1960 through August 1962, was computed from the sediment-discharge versus water-discharge relationship and the results are included in Table 2. The sediment-discharge versus water-discharge relationship is based on the data collected from October 1956 through September 1960--the available period of record preceding construction of the floodwater-retarding structures.

Table 2.--Monthly and annual summary of water and suspended-sediment discharge, Pin Oak Creek near Hubbard, Texas.

Month	Water discharge		Suspended sediment					
			Load (tons)	Daily load (tons)			Concentration (ppm)	
	Cfs-days	Acre-feet		Mean	Maximum	Minimum	Weighted mean	Maximum daily
1956								
October	0	0	0	--	--	--	--	--
November	876.8	1,740	7,980	266	7,900	0	3,370	4,150
December	6.6	13	8.0	.3	7.2	0	499	517
1957								
January	23.0	46	59.4	1.9	36	0	957	1,150
February	199.1	395	1,900	68	1,890	0	3,540	2,760
March	392.5	779	3,460	112	1,130	0	3,270	3,290
April	4,968.0	9,850	39,300	1,310	12,200	0	2,930	4,100
May	1,796.1	3,560	16,300	526	8,000	0	3,360	5,130
June	695.4	1,380	8,940	298	5,510	0	4,770	5,160
July-August	0	0	0	--	--	--	--	--
September	5.6	11	51.0	1.7	51	0	3,380	1,060
Water year 1956-57	8,963.1	17,770	77,998.4	214	12,200	0	3,220	5,160
October	325.1	645	3,240	105	1,850	0	3,700	4,400
November	170.8	339	978	33	727	0	2,120	2,040
December	0	0	0	--	--	--	--	--
1958								
January	28.7	57	51.3	1.7	39	0	662	770
February	30.6	61	82.4	2.9	60	0	997	892
March	4.3	8.5	8.8	.3	8.7	0	758	504
April	122.7	243	2,500	83	1,570	0	7,550	4,220
May	601.6	1,190	4,120	133	2,880	0	2,540	1,720
June-July	0	0	0	--	--	--	--	--
August	1,161.3	2,300	7,230	233	7,040	0	2,310	2,160
September	325.7	646	3,750	125	1,860	0	4,260	2,280
Water year 1957-58	2,770.8	5,490	21,960.5	60.2	7,040	0	2,940	4,400

Table 2.--Monthly and annual summary of water and suspended-sediment discharge, Pin Oak Creek near Hubbard, Texas.--Continued

Month	Water discharge		Suspended sediment					
			Load (tons)	Daily load (tons)			Concentration (ppm)	
	Cfs-days	Acre-feet		Mean	Maximum	Minimum	Weighted mean	Maximum daily
1958								
October	49.5	98	734	24	454	0	5,490	2,300
November	21.4	42	85.2	2.8	84	0	1,470	1,330
December	18.8	37	15.9	.5	9.2	0	313	531
1959								
January	5.9	12	.3	t/	t/	0	19	--
February	374.2	742	3,010	108	2,910	t/	2,980	3,030
March	21.5	43	17.2	.6	6.7	.1	296	412
April	551.6	1,090	5,440	181	2,170	0	3,650	4,080
May	816.3	1,620	7,110	229	5,640	t/	3,230	2,850
June	2,181.7	4,330	16,300	543	5,700	0	2,770	2,880
July	40.2	80	218	7.0	78	0	2,010	1,710
August-September	0	0	0	--	--	--	--	--
Water year 1958-59	4,081.1	8,090	32,930.6	90.2	5,700	0	2,990	4,080
October	955.6	1,900	6,490	21	5,080	0	2,520	2,780
November	42.3	84	162	5.4	156	0	1,420	1,480
December	788.0	1,560	2,680	86	1,430	t/	1,260	1,460
1960								
January	500.9	994	1,340	43	725	.1	991	1,090
February	87.9	174	83.3	2.9	76	.1	351	639
March	65.5	130	46.5	1.5	19	t/	263	698
April	111.0	220	934	31	720	0	3,120	2,210
May	70.3	139	584	19	572	0	3,080	2,130
June	130.7	259	1,050	35	1,020	0	2,980	2,550
July	0	0	0	--	--	--	--	--
August	137.2	272	615	20	308	0	1,660	1,170
September	0	0	0	--	--	--	--	--
Water year 1959-60	2,889.4	5,730	13,984.8	38.2	5,080	0	1,790	2,780

t/ Less than 0.05 ton.

Table 2.--Monthly and annual summary of water and suspended-sediment discharge, Pin Oak Creek near Hubbard, Texas.--Continued

Month	Water discharge		Suspended sediment						
			Load (tons)	Daily load (tons)			Concentration (ppm)		
	Cfs-days	Acre-feet		Mean	Maximum	Miminum	Weighted mean	Maximum daily	
1960									
October	499.1	990	4,800 e/	155	4,200	0	3,560	4,050	
November	52.4	104	280 e/	9.3	250	0	1,980	3,560	
December	2,244.6	4,450	19,000 e/	613	9,000	0	3,140	2,980	
1961									
January	2,330.4	4,620	18,000 e/	581	7,500	t/	2,860	3,420	
February	1,209.5	2,400	10,000 e/	357	4,500	t/	3,060	4,240	
March	325.2	645	3,200 e/	103	2,000	t/	3,640	5,070	
April	111.1	220	770 e/	25.7	700	t/	2,570	4,630	
May	10.9	22	20 e/	.6	20	0	680	1,190	
June	1,576.7	3,130	16,000 e/	533	7,000	0	3,760	3,520	
July	9.1	18	5 e/	.2	.3	0	204	80	
August	0	0	0	--	--	--	--	--	
September	58.2	115	520 e/	17.3	500	0	3,310	4,410	
Water year 1960-61	8,427.2	16,700	72,595	199	9,000	0	3,190	5,070	
October	5.7	11	10 e/	0.3	6	0	650	370	
November	952.8	1,890	8,200 e/	273	8,000	0	3,190	3,330	
December	381.8	757	2,700 e/	87.1	1,900	t/	2,620	4,720	
1962									
January	12.7	25	10 e/	.3	5	t/	293	1,030	
February	268.7	533	2,800 e/	100	1,800	t/	3,860	4,980	
March	56.9	113	310 e/	10.0	300	t/	2,020	3,700	
April	766.5	1,520	7,000 e/	233	7,000	t/	3,380	3,570	
May	84.4	167	950 e/	30.6	950	0	4,170	4,630	
June	398.8	791	4,300 e/	143	2,700	0	3,990	4,520	
July	.1	.2	t/	t/	t/	0	--	--	
August	0	0	0	--	--	--	--	--	
September	26.2	52	180	6.0	180	0	2,540	2,560	
Water year 1961-62	2,954.6	5,860	26,460	72.5	8,000	0	3,320	4,980	
1956-62 water years	30,086.2	59,640	245,929.3	112	12,200	0	3,030	5,160	

e/ Estimated.
t/ Less than 0.05 ton.

Rainfall

A tabulation of all individual storm rainfall records and of all monthly and annual totals for the period December 1956 to September 1962 is given in Table 3.

For the purpose of this report, a "storm" is defined as any period of rainfall, regardless of magnitude, separated in general by a minimum of six hours from the occurrence of other rainfall. Daily rainfall observed at the nonrecording gages is distributed to storm periods on the basis of the recorded rainfall.

Rain-Gage Density Analysis

One purpose of this report is to determine the minimum instrumentation necessary for determining the average rainfall over the study area. A reliable rain-gage network is imperative for making estimates of runoff. Therefore, an analysis was made to evaluate the areal network in regard to coverage by the rain gages operated during this report period.

A rain-gage density study consists primarily of comparing the arithmetic mean storm rainfall as indicated by various combinations of the rain gages in the study area. Only those storms with an average rainfall of 0.40 inch or greater were plotted for this study (Table 3). There were 170 storms selected on this basis.

The variability in areal distribution of storm rainfall for the Pin Oak Creek study area during the period covered by this report is evaluated by three simple graphical comparisons. In each of these comparisons the average storm rainfall (arithmetic mean) for five rain gages was plotted as the independent variable (abscissa scale). The average storm rainfall for the following gage and combinations of gages was plotted as the dependent variable (ordinate scale): 4R, 1R, and 5R (recording type), and 2S and 3S (non-recording type). This grouping of gages facilitates a comparison for the recording and non-recording gages as well as any influence from storm direction. Rain gage 6-T (tipping-bucket gage) was not used, as data indicate that this gage was not consistent in operation.

For each graphical analysis (Figures 8, 9, and 10), the standard error of estimate was computed using a 67 percent (two-thirds) confidence limit. The standard error of estimate was computed from the line of equal rainfall which is the curve of relation.

The following conclusions are derived from Table 3 and Figures 3, 8, 9, and 10:

1. Figure 8 shows that two-thirds of the storm rainfalls measured at gage 4R are within +15 and -13 percent of the mean rainfall measured at all five gages. This gage is the one most centrally located within the study area.

Table 3.--Summary of storm rainfall, in inches, for Pin Oak Creek study area, December 1956 to September 1962.

Date of storm	Storm averages	Gage number 1-R	2-S	3-S	4-R	5-R
		Rain gages installed in December 1956				
1956						
Dec. 6	0.15	0.08	0.24	0.20	0.08	0.14
17-18	.86	.80	.82	.84	.85	1.00
19	.87	.87	.93	1.00	.83	.80
Monthly totals	1.88	1.75	1.99	2.04	1.76	1.94
1957						
Jan. 4	.39	.33	.40	.43	.40	.40
21	.07	.13	.08	.02	.08	.05
22	.21	.12	.20	.24	.25	.22
23	.18	.15	.17	.20	.20	.17
26-27	.60	.46	.49	.59	.65	.80
29	.06	.06	.06	.05	.07	.05
30-31	.27	.30	.22	.37	.30	.17
Monthly totals	1.78	1.55	1.62	1.90	1.95	1.86
Feb. 1	1.11	1.14	1.16	1.08	1.02	1.15
18	.60	.47	.59	.69	.62	.65
19	.17	.18	.19	.15	.20	.15
22-23	.56	.55	.55	.56	.58	.58
24	.11	.10	.14	.12	.09	.10
Monthly totals	2.55	2.44	2.63	2.60	2.51	2.63
Mar. 11	.73	.95	.84	.78	.60	.50
17	1.39	1.53	1.24	1.33	1.45	1.40
20	1.23	1.28	1.17	1.30	1.27	1.13
27	.48	.35	.40	.31	.60	.75
31	.79	.90	.80	.83	.68	.75
Monthly totals	4.62	5.01	4.45	4.55	4.60	4.53
Apr. 3	.22	.40	.25	.13	.11	.20
7	.01	.05	0	0	0	0
16	.08	.08	.10	.08	.08	.07
19	.24	.22	.32	.33	.25	.10
19-20	7.10	9.14	7.58	7.50	6.21	5.05
21	1.32	1.50	1.32	1.31	1.30	1.16
22	.35	.31	6.38	.38	.35	.32
23	2.55	2.90	2.68	2.44	2.30	2.45
24	1.32	1.62	1.25	1.42	1.10	1.22
26-27	1.60	1.81	1.66	1.54	1.53	1.48
28	.64	.57	.59	.68	.70	.66
30	.22	.28	.20	.18	.21	.22
Monthly totals	15.65	18.88	16.33	15.99	14.14	12.93
May 1	.63	.89	.75	.70	.44	.35
3	.56	.57	.29	.72	.54	.70
9	.52	.65	.56	.44	.40	.55
11	1.76	2.66	2.00	1.68	1.32	1.15
13	2.36	2.20	1.99	2.33	2.26	3.00
18	.05	.05	0	.10	.08	.04
22	.35	.48	.43	.31	.27	.27
23	.47	.40	.53	.52	.45	.43
25-26	.60	.78	.56	.62	.50	.53
31	.94	.85	.81	.83	1.00	1.20
Monthly totals	8.24	9.53	7.92	8.25	7.26	8.22
June 1-2	.63	1.09	.70	.46	.50	.41
3-4	1.36	1.00	1.98	1.42	1.90	.50
4	1.31	.78	.48	1.34	1.95	2.00
12	.03	.05	trace	0	.08	.04
18	.19	.30	.40	0	.20	.05
23	.05	.13	0	0	.08	.03
Monthly totals	3.57	3.35	3.56	3.22	4.71	3.03
July 20	.04	.10	.06	0	.04	0
Monthly totals	.04	.10	.06	0	.04	0
Aug. 10	.51	.58	.63	.43	.50	.40
29	.13	.30	.13	.03	.20	0
Monthly totals	.64	.88	.76	.46	.70	.40
Sept. 3	.79	.67	.55	.94	.90	.88
6-7	1.18	.84	1.35	1.11	1.35	1.25
21-22	3.58	3.55	3.73	3.76	3.83	3.02
Monthly totals	5.55	5.06	5.63	5.81	6.08	5.15
1957 WATER YEAR TOTALS	--	--	--	--	--	--
1957						
Oct. 13-14	3.66	3.42	3.50	3.85	3.88	--
15	.88	.80	1.02	.88	.82	--
21-22	.82	.77	.86	.87	.76	--
Monthly totals	5.36	4.99	5.38	5.60	[illegible]	--
Nov. 2	.04	.05	.03	.03	.05	.05
3	.20	.22	.15	.27	.18	.18
4	.10	.08	.15	.12	.08	.07
4	.05	.04	.07	.06	.04	.03
5-6	.62	.52	.63	.65	.64	.66
7	.35	.65	.32	.33	.26	.16
11-13	.57	.81	.42	.43	.58	.61
14	.13	.02	.30	.30	.02	0
16-18	.52	.38	.05	.95	.72	--
21-22	.63	.49	.95	.52	.55	--
23-24	.74	.66	.88	.74	.70	--
Monthly totals	3.95	3.92	3.95	4.40	3.82	--
Dec. 6	.18	.15	.22	.20	.16	--
18	.02	0	0	.02	.07	--
22	.03	.08	trace	.03	0	--
24-25	.54	.56	.56	.58	.47	--
27	.06	.07	.08	0	.07	--
Monthly totals	.83	.86	.86	.83	.77	--
1957 CALENDAR YEAR TOTALS	52.78	56.57	53.15	53.61	52.06	--
1958						
Jan. 12-13	1.04	1.05	1.04	1.13	.96	--
19-20	1.06	1.05	1.08	1.06	1.05	--
28	.34	.30	.34	.30	.39	.38
Monthly totals	2.44	2.40	2.46	2.49	2.40	--
Feb. 6	.01	0	.05	0	0	0
9-10	.65	.70	.63	.65	.70	.58
14	.14	0	.14	.18	.20	.20
20	.01	0	.03	(.03)	0	0
21	.07	.07	.02	(.03)	.15	.10
21-23	.95	.86	1.02	1.04	.95	.86
26	.13	.18	.06	.17	.10	.14
Monthly totals	1.96	1.81	1.95	2.10	2.10	1.88
Mar. 1	.12	.11	.15	.15	.10	.10
4	.20	.20	(.47)	(.28)	.18	.08
4-5	.08	.03	(.10)	(.10)	.06	.10
6	.15	.08	.18	.18	.12	.20
8	.11	.08	.16	.15	.12	.06
12	.28	.28	.28	.27	.26	.30
21-22	.77	.67	.80	.79	.78	.79
28	.03	0	.03	.05	0	.05
Monthly totals	1.74	1.45	1.97	1.97	1.62	1.68
Apr. 8-9	.45	.15	.66	.53	.50	.40
13	.71	.58	.67	.71	.79	.78
18	.28	.27	.27	.34	.24	.30
20	.53	.52	.62	.50	.53	.47
21	.55	.37	.37	.50	.73	.78
25	.07	.20	trace	0	.08	.05
26	.48	.64	.53	.63	.36	.25
29	.67	.28	.81	.52	.85	.88
30	.38	.36	.36	.36	.40	.43
Monthly totals	4.12	3.37	4.29	4.09	4.48	4.34
May 1	.11	.09	.09	.20	.08	.07
2-3	1.78	1.72	1.64	1.78	1.70	2.04
14	.35	.33	.40	.20	.43	.40
28	1.39	1.70	1.82	1.38	1.20	.84
Monthly totals	3.63	3.84	3.95	3.56	3.41	3.35
June 8	.07	.10	.14	.08	.05	0
16-17	1.30	1.28	1.64	1.05	1.40	1.15
21-22	.37	.31	.39	.43	.38	.32
26	.37	.31	.32	.36	.41	.44
Monthly totals	2.11	2.00	2.49	1.92	2.24	1.91

Table 3.--Summary of storm rainfall, in inches, for Pin Oak Creek study area, December 1956 to September 1962--Continued

Date of storm	Storm averages	Gage number 1-R	2-S	3-S	4-R	5-R
	Rain gages installed in December 1956					
1958						
July 5	0.50	0.60	0.58	0.55	0.40	0.39
6	.52	.25	.58	.55	.58	.62
7	.09	.04	0	.13	.08	.20
22	.05	0	0	0	0	.25
Monthly totals	1.16	.89	1.16	1.23	1.06	1.46
August 17-18	3.08	3.67	2.62	3.74	2.58	2.77
22	.12	.24	.10	.03	.25	0
23	.25	.32	.23	.22	.30	.20
24	5.76	5.24	5.82	6.09	6.45	5.18
Monthly totals	9.21	9.47	8.77	10.08	9.58	8.15
Sept. 5	.07	.05	.08	.10	.06	.04
6	.18	.10	.15	.18	.23	.25
7	.11	.07	.15	.09	.11	.15
8	.71	.99	.63	.66	.85	.40
11	.53	.05	.08	.90	.86	.78
16	.22	.05	.04	.14	.15	.72
19	1.92	2.40	1.58	1.63	1.70	2.27
22	1.00	.63	.85	1.30	.79	1.43
26-27	.06	--	.08	.05	.05	.05
30	.41	--	.31	.74	.35	.24
Monthly totals	5.21	--	3.95	5.79	5.15	6.33
1958 WATER YEAR TOTALS	41.72	--	41.18	44.06	42.11	--
Oct. 2- 3	.54	(.33)	.43	1.18	.40	.39
8- 9	.68	.86	.79	.54	.75	.47
11	.04	.10	trace	.02	.05	.04
17	.36	0	.07	.30	.82	.61
21	.55	.11	.51	.46	.77	.91
26	.35	(.2)	.38	.40	.40	.37
28	.04	0	.05	.05	.03	.05
29	.04	(.1)	.07	0	0	.05
Monthly totals	2.60	1.67	2.30	2.95	3.22	2.89
Nov. 5	.02	0	trace	.09	0	0
14	.32	.65	.22	.30	.13	.30
16-17	.17	0	.27	.25	.24	.11
27-28	1.67	1.95	1.68	1.64	1.59	1.49
Monthly totals	2.18	2.60	2.17	2.28	1.96	1.90
Dec. 1	.41	(.4)	.42	.45	.38	.41
22	.05	0	.08	0	.10	.07
30-31	.82	.75	.83	.98	.76	.79
Monthly totals	1.28	1.15	1.33	1.43	1.24	1.27
1958 CALENDAR YEAR TOTALS	37.64	--	36.79	39.89	38.46	--
1959						
Jan. 8	.06	0	.08	.07	.10	.05
14	.01	0	.02	.02	0	0
29-30	.30	.30	.32	.30	.29	.31
Monthly totals	.37	.30	.42	.39	.39	.36
Feb. 1- 2	.67	.67	.55	.70	.74	.71
3	.22	.12	.26	.23	.21	.26
10	.01	0	trace	0	0	.05
12	.44	.36	.46	.47	.50	.40
13-14	1.20	1.04	1.45	1.23	1.21	1.08
19	.33	.35	.35	.35	.32	.30
20	.02	0	0	0	.07	.05
22	.06	0	.09	.04	.08	.07
23	0	0	.02	0	0	0
25-26	.08	0	.10	.16	.05	.07
Monthly totals	3.03	2.54	3.28	3.18	3.18	2.99
Mar. 4- 5	.38	.38	.39	.42	.38	.35
11	.02	0	0	0	.04	.05
21	.09	.20	0	0	.07	(.2)
25	.63	.50	.69	.78	.67	.50
29	.02	.04	trace	0	0	.05
31	.01	0	0	0	.05	0
Monthly totals	1.15	1.12	1.08	1.20	1.21	1.15
Mar. 31-Apr. 1	.30	.16	.31	.34	.36	.31
3	.01	0	0	0	.02	.03
6	<.01	0	0	0	0	<.05
8	1.23	.91	1.19	1.35	1.34	1.36
9	.07	.05	.10	.20	0	0
10	.26	.15	.15	.22	.41	.39
11	1.35	1.19	1.49	1.42	1.32	1.34
14	.15	.16	.19	.21	0	.18
15	.01	0	.03	0	0	0
16-17	.71	.59	.67	.85	.46	.96
19	.65	.90	.62	.41	.39	.91
Monthly totals	4.75	4.11	4.75	5.00	4.30	5.53

Date of storm	Storm averages	Gage number 1-R	2-S	3-S	4-R	5-R
	Rain gages installed in December 1956					
1959						
May 2	0.68	0.05	0.79	0.92	0.75	0.90
5	.04	0	.09	0	.05	.07
8	.04	.05	0	.10	--	0
10	2.17	2.49	3.41	1.73	--	1.05
11	1.45	1.63	1.45	1.15	--	1.56
14	.07	0	.02	0	--	.07
15-16	.16	.10	.15	.22	--	.15
22-23	1.10	1.16	1.17	.98	--	1.10
23-24	.83	.94	.97	.81	--	.60
Monthly totals	6.49	6.42	8.05	5.91	--	5.50
June 2	.32	.31	.37	.28	--	.31
4	.73	.66	.73	.74	--	.78
5	1.03	1.00	1.00	1.21	--	.90
9	.39	.07	1.33	0	--	.16
12	.28	.03	.38	.40	--	.30
20	1.00	.80	.91	.96	--	1.33
22	2.27	1.67	2.03	2.14	--	3.04
23	2.82	3.66	2.57	2.71	--	2.32
24-25	.52	.41	.47	.49	--	.69
Monthly totals	9.31	8.61	9.79	8.93	--	9.83
July 2	.02	.06	0	0	--	.03
10	.01	0	trace	0	--	.03
15	.02	.03	0	0	--	.05
20	.98	1.04	1.08	.98	--	.80
20-21	.90	1.06	1.09	.98	--	.47
24	.66	.90	.65	.46	--	.65
25	.09	0	.09	.26	--	0
26-27	.30	.17	.31	.51	--	(.2)
Monthly totals	2.98	3.26	3.22	3.19	--	2.23
Aug. 9	0	0	.01	0	0	0
14	.01	.03	.04	0	0	0
23	0	0	.02	0	0	0
25	.06	0	.29	0	0	0
26	.29	.50	.27	.24	.23	.20
27	.36	0	.75	.45	.33	.28
31	.65	.71	.74	.60	.58	.64
Monthly totals	1.37	1.24	2.12	1.29	1.14	1.12
Sept. 8	.01	0	.03	0	0	0
13-14	.31	.27	.40	.29	.30	.29
22	.21	.15	.03	.34	.17	.35
23	.01	0	.02	.05	0	0
24	.02	0	.07	.03	0	0
25	.13	(.10)	.08	0	.13	.32
29-30	.55	.13	.86	.70	.66	.41
Monthly totals	1.24	.65	1.49	1.41	1.26	1.37
1959 WATER YEAR TOTALS	36.75	33.67	40.00	37.16	--	36.14
1959						
Oct. 1	.29	0	.02	.88	.33	.24
3	1.33	1.20	1.34	1.27	1.30	1.54
4	4.41	3.95	4.61	4.36	4.44	4.71
13	1.64	1.76	1.65	1.55	1.63	1.62
29-30	.35	(.25)	.25	.59	.26	.40
31	.39	(.45)	.50	.26	.34	.38
Monthly totals	8.41	7.61	8.37	8.91	8.30	8.89
Nov. 1	.12	(.12)	trace	0	.15	.31
4- 5	.99	(1.20)	.89	.90	.90	1.05
11	.05	.02	.07	.10	.02	.02
13-15	.38	.28	.35	.60	.35	.33
Monthly totals	1.54	1.62	1.31	1.60	1.42	1.71
Dec. 10-11	.57	.15	.70	.85	.26	.91
15-16	2.49	3.12	2.62	2.17	2.45	2.10
17-18	.15	.14	.18	.15	.17	.12
24	.11	.15	.01	0	.20	.20
27	.29	.25	.33	.32	.22	.35
31	1.17	1.15	1.15	1.13	1.20	1.20
Monthly totals	4.78	4.96	4.99	4.62	4.50	4.88
1959 CALENDAR YEAR TOTALS	45.42	42.44	48.87	45.63	--	45.56
1960						
Jan. 2	.08	.10	.12	.07	.05	.08
4- 5	.95	.90	.95	.98	.94	.97
12	.20	.10	.20	.20	.22	.27
13	.28	.20	.30	.32	.26	.30
16	.53	.36	.59	.65	.55	.52
26	.03	.05	.01	.04	.03	.03
31	.01	0	0	0	0	.04
Monthly totals	2.08	1.71	2.17	2.26	2.05	2.21

Table 3.--Summary of storm rainfall, in inches, for the [illegible] Creek study area, December 1956 to September 1962.--Continued

Date of storm	Storm averages	Gage number 1-R	2-S	3-S	4-R	5-R
Rain gages installed in December 1956						
1960						
Feb. 1	0.76	0.75	0.75	0.84	0.77	0.70
15	.23	--	.24	.26	.26	.15
17	.06	--	.07	.08	.02	.05
20	.33	--	.40	.20	.36	.35
24-25	.42	--	.43	.55	.39	.30
29	.02	--	trace	trace	.04	.03
Monthly totals	1.82	(1.90)	1.89	1.93	1.84	1.58
Mar. 1	.44	(.45)	.44	.47	.46	.40
2	.06	.10	.01	0	.10	.10
13-14	.23	.15	.17	.38	.25	.20
25	.40	.45	.38	.25	.40	.53
30	.37	.30	.39	.27	.42	.48
Monthly totals	1.50	1.45	1.39	1.37	1.63	1.71
Apr. 6	.04	.10	trace	.09	0	.02
15	.78	.73	.80	.89	.85	.65
20-23	.35	.22	.43	.46	.30	.33
27	1.03	.62	1.27	.82	1.32	1.10
29	.89	.70	.98	.84	1.12	.80
Monthly totals	3.09	2.37	3.48	3.10	3.59	2.90
May 4-5	1.10	1.15	1.08	1.10	1.20	.98
20	.87	.98	.82	.82	.80	.95
23	.56	.51	.50	.57	.62	.60
30	.05	.10	trace	.06	.03	.05
Monthly totals	2.58	2.74	2.40	2.55	2.65	2.58
June 12	.67	.60	.60	.76	.72	.67
13	.49	.35	.40	.51	.49	.72
24-26	3.33	3.25	3.40	3.12	3.29	3.57
Monthly totals	4.49	4.20	4.40	4.39	4.50	4.96
July 16	.08	.05	.18	.08	.06	.02
29	.14	.23	.06	.16	.21	.03
Monthly totals	.22	.28	.24	.24	.27	.05
Aug. 10	1.21	--	1.60	--	1.10	.92
14	.44	--	.60	--	.36	.35
19	1.84	--	2.52	--	2.03	.98
21	2.43	--	2.72	--	2.35	2.22
27	.07	--	.10	--	.05	.06
30	.91	--	trace	1.52	1.25	.85
Monthly totals	6.90	(4.80)	7.54	5.52	7.14	5.38
Sept. 24-25	.82	.71	1.21	.71	.62	.85
25	.29	.12	.33	.34	.39	.25
26-27	.30	.38	.41	.18	.24	.27
Monthly totals	1.41	1.21	1.95	1.23	1.25	1.37
1960 WATER YEAR TOTALS	38.82	34.85	40.13	37.72	39.14	38.22
Oct. 5	.12	.20	.10	.10	.10	.09
6	.35	.45	.65	.16	.22	.28
13-14	2.45	2.43	2.24	2.35	2.62	2.63
18	2.49	2.85	2.34	2.07	2.62	2.55
23	.02	0	0	0	0	.10
25	.61	.45	.74	.71	.68	.47
28-29	.48	.36	.48	.52	.47	.57
Monthly totals	6.52	6.74	6.55	5.91	6.71	6.69
Nov. 8	.20	.11	.22	.22	.22	.25
11	.52	.49	.75	.38	.50	.50
20-21	1.05	.75	1.50	1.00	1.00	1.00
21-22	.11	.07	.10	.10	.06	.20
Monthly totals	1.88	1.42	2.57	1.70	1.78	1.95
Dec. 4	.22	.06	0	.40	.38	.26
6-8	5.36	5.19	6.83	5.90	5.50	4.37
9-10	1.05	1.00	.91	.90	.85	1.57
14	.10	.10	trace	.17	.13	.11
30-31	1.10	.85	1.36	1.10	1.06	1.13
Monthly totals	7.83	7.20	9.10	8.47	7.92	7.44
1960 CALENDAR YEAR TOTALS	40.52	36.02	43.68	38.67	41.33	38.82
1961						
Jan. 6-8	3.77	4.00	4.01	2.56	3.94	4.35
11-12	1.86	1.95	2.02	2.00	1.98	1.37
24	.45	.52	.50	.42	.42	.40
26	.01	0	0	0	0	.05
27	.11	.10	(.10)	.10	.13	.12
Monthly totals	6.20	6.57	6.63	5.08	6.47	6.29
Feb. 5-7	2.20	2.05	2.50	2.29	2.10	2.05
15-16	1.58	1.56	1.49	1.61	1.70	1.53
17	.04	.06	0	.05	.04	.05
19	.11	(0)	trace	0	.08	.45
20	.45	(.10)	.12	.81	.68	.52
24	.29	(.70)	.72	.03	trace	trace
Monthly totals	4.67	4.47	4.83	4.79	4.60	4.60
Mar. 6	0.03	0	0	0.05	0.05	0.05
16	1.85	--	1.84	1.96	1.80	1.80
17	.11	--	0	.13	.18	.12
19	.02	--	0	0	0	.08
26	.75	--	.46	1.40	.58	.55
27	.33	--	.36	.30	.52	.15
30	.25	--	.32	.28	.27	.12
Monthly totals	3.34	--	2.98	4.12	3.40	2.87
Apr. 8	.56	--	.56	.53	.52	.63
12	0	--	0	.02	0	0
28	1.60	--	1.75	1.56	1.78	1.33
Monthly totals	2.16	--	2.31	2.11	2.30	1.96
May 1	.01	(0)	0	0	.03	.03
5	.02	(0)	0	.05	.02	.02
8	.82	(.80)	.78	.76	.83	.93
22	.25	.22	.24	.29	.25	.24
23	.28	.27	.28	.34	.26	.25
25-26	.66	.71	.61	.90	.62	.47
Monthly totals	2.04	2.00	1.91	2.34	2.01	1.94
June 5-6	.31	.11	.30	.38	.27	.47
11	.19	.04	.56	.06	.27	.04
14	.58	.13	.70	.96	.38	.75
15-16	4.53	4.88	4.97	4.84	3.88	4.10
17-18	3.54	3.80	3.31	3.90	3.12	3.55
19	.01	0	0	0	.05	0
25	1.00	1.00	.95	1.03	1.15	.88
Monthly totals	10.16	9.96	10.79	11.17	9.12	9.79
July 1	.06	--	0	0	.10	.15
3	.41	--	.40	.64	.32	.27
4	.01	--	0	0	0	.03
7	.08	--	0	0	.10	.20
8	.02	--	trace	0	.05	.05
9	.08	--	.16	.14	0	0
13	.04	--	0	0	.05	.10
16	.48	--	.68	.10	.46	.70
22	.02	--	0	0	0	.08
23	.24	--	.18	.26	.25	.26
Monthly totals	1.44	--	1.42	1.14	1.33	1.84
Aug. 13	.01	0	0	0	0	.05
29	.51	.93	.50	.43	.38	.30
Monthly totals	.52	.93	.50	.43	.38	.35
Sept. 4	.04	.17	0	trace	0	.05
11-12	4.29	4.10	4.40	4.60	3.90	4.47
27	0	0	0	trace	0	0
28	.03	0	0	0	.10	.04
Monthly totals	4.36	4.27	4.40	4.60	4.00	4.56
1961 WATER YEAR TOTALS	51.32	--	53.99	51.86	50.02	50.28
Oct. 2	1.38	1.10	1.50	1.54	1.50	1.25
9	.82	1.10	1.18	.65	.65	.50
10	.30	.20	.36	.25	.25	.44
25	.35	.02	.92	.16	.65	.01
31	.20	.15	.50	.17	.15	.04
Monthly totals	3.05	2.57	4.46	2.77	3.23	2.24
Nov. 2	.64	--	.58	.83	.75	.42
10	.03	0	0	.05	.10	.01
13	1.16	1.40	1.25	1.21	1.10	.85
15	.13	--	0	.20	.17	.14
21-22	3.58	3.85	3.46	3.44	3.55	3.60
Monthly totals	5.54	--	5.29	5.73	5.67	5.02
Dec. 4-5	.28	--	.25	.30	.27	.32
5-6	.30	--	.17	.26	.42	.35
8	.10	--	.10	.10	.11	.09
8-9	.38	--	.20	.56	.34	.43
11	.11	--	.10	.10	.12	.12
14	.32	--	.36	.30	.25	.35
15-16	.81	.60	.78	.98	.80	.88
17	.46	.42	.52	.50	.45	.43
Monthly totals	2.76	--	2.48	3.10	2.76	2.97
1961 CALENDAR YEAR TOTALS	46.24	--	48.00	47.38	45.27	44.43
1962						
Jan. 3	.24	.20	.21	.30	.34	.25
10	.12	--	.10	.15	.10	.13
21	.26	--	.25	.20	.23	.37
26	.30	--	.40	.31	.25	.21
Monthly totals	.92	--	.96	.96	.82	.96
Feb. 15	1.88	1.50	2.50	1.85	1.85	1.48
18	.61	.60	.60	.57	.71	.36
23	.64	.65	.67	.70	.64	.53
26	.03	0	.10	0	.03	0
Monthly totals	3.16	2.75	3.87	3.12	3.23	2.37

Table 3.--Summary of storm rainfall, in inches, for Pin Oak Creek study area, December 1956 to September 1962.--Continued

Date of storm	Storm averages	Gage number 1-R	2-S	3-S	4-R	5-R
	Rain gages installed in December 1956					
1962						
Mar. 10	0.85	--	0.90	0.88	0.83	0.80
14	.15	--	.10	.17	.17	.17
20	.07	--	0	.16	.10	.01
24	.10	--	0	.18	.08	.12
Monthly totals	1.17	--	1.00	1.39	1.18	1.10
Apr. 4	.28	--	.55	.20	.18	.18
5	.33	--	.33	.37	.31	.30
16	.22	0.17	.02	.30	.33	.28
22-23	1.17	.71	1.29	1.28	1.40	1.15
24	.54	.54	.57	.75	.54	.28
27	3.07	2.67	3.20	3.12	3.07	3.30
30	.14	.30	0	.20	.03	.18
Monthly totals	5.75	--	5.96	6.22	5.86	5.67
May 28-29	2.83	2.78	2.73	2.86	2.76	3.00
Monthly totals	2.83	2.78	2.73	2.86	2.76	3.00
June 1	.11	.12	.10	.11	.10	.10
1-2	.42	.47	.42	.51	.40	.30
[illegible]	.69	.37	.71	.62	.74	1.00
7	.17	.15	.18	.22	.15	.16
8-A	.66	.62	.96	.60	.63	.50
8-B	1.29	1.52	1.14	1.30	1.17	1.30
9	.28	.13	.37	.30	.46	.16
June 10	0.01	0	0	0.05	0	0
13	.08	.15	.03	.21	.01	.01
26	.89	.80	1.04	1.15	.80	.64
27	.05	.02	0	.13	0	.12
28	.60	.34	.60	.50	.55	1.00
29	.65	.97	1.00	.77	.38	.14
Monthly totals	5.90	5.66	6.55	6.47	5.39	5.41
July 16	.12	.05	.02	.05	.35	.14
Monthly totals	.12	.05	.02	.05	.35	.14
Aug. 24	.11	.15	.05	.17	.10	.10
Monthly totals	.11	.15	.05	.17	.10	.10
Sept. 1	.15	.05	.01	.08	.17	.45
5	.59	.17	.40	1.21	.89	.30
6	.23	.46	.26	.16	.11	.14
7- 8	2.75	2.50	2.15	3.37	2.90	2.85
17	.07	.06	.02	.06	.02	.21
26	.10	.25	.05	.11	.05	.05
30	.05	.05	.01	.05	.06	.07
Monthly totals	3.94	3.54	2.90	5.04	4.20	4.07
1962 WATER YEAR TOTALS	35.25	--	36.27	37.88	35.55	33.47

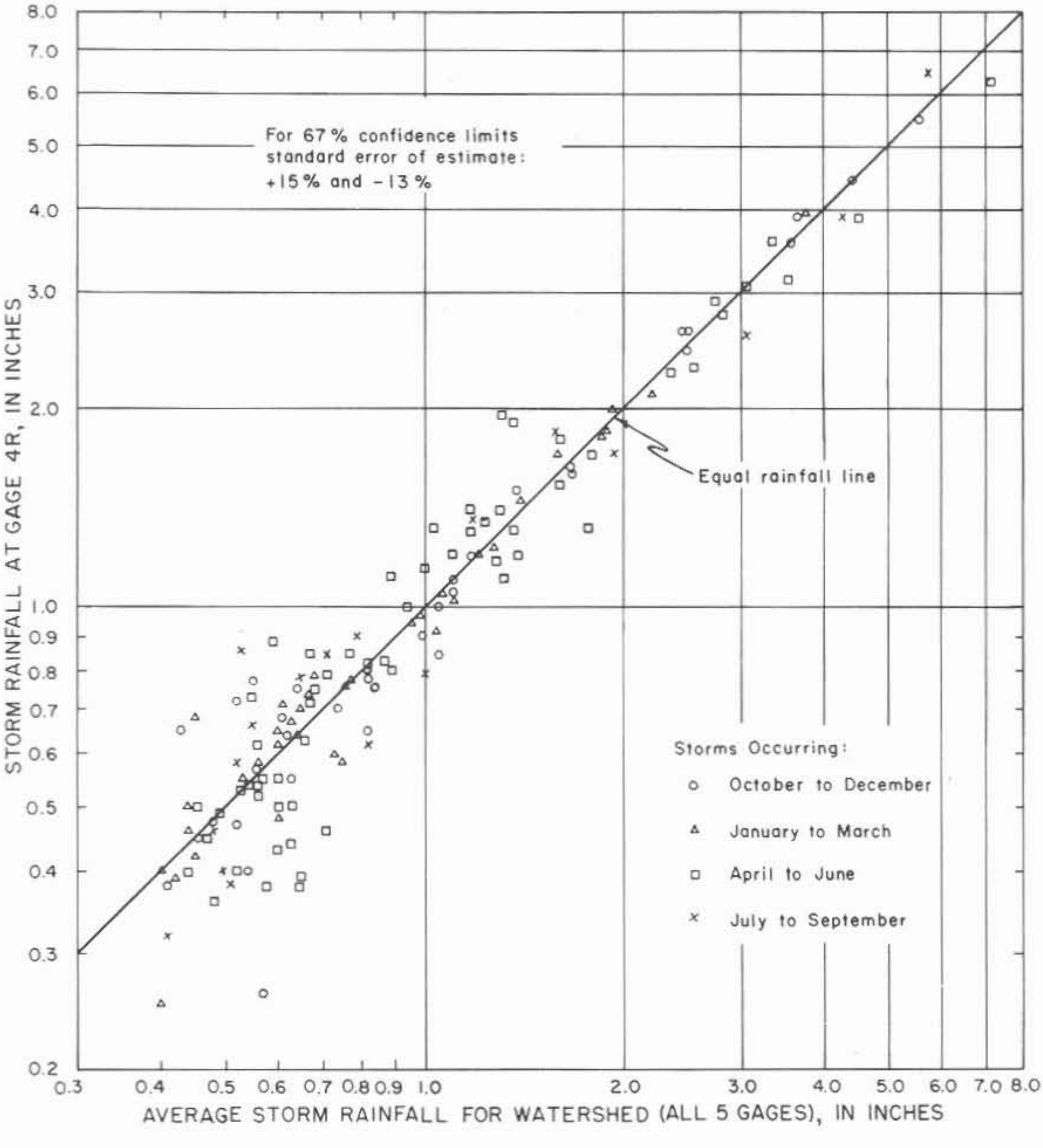


Figure 8

Comparison of Concurrent Storm Rainfall, 1 Gage (4R) and 5 Gages

U.S. Geological Survey in cooperation with the Texas Water Development Board

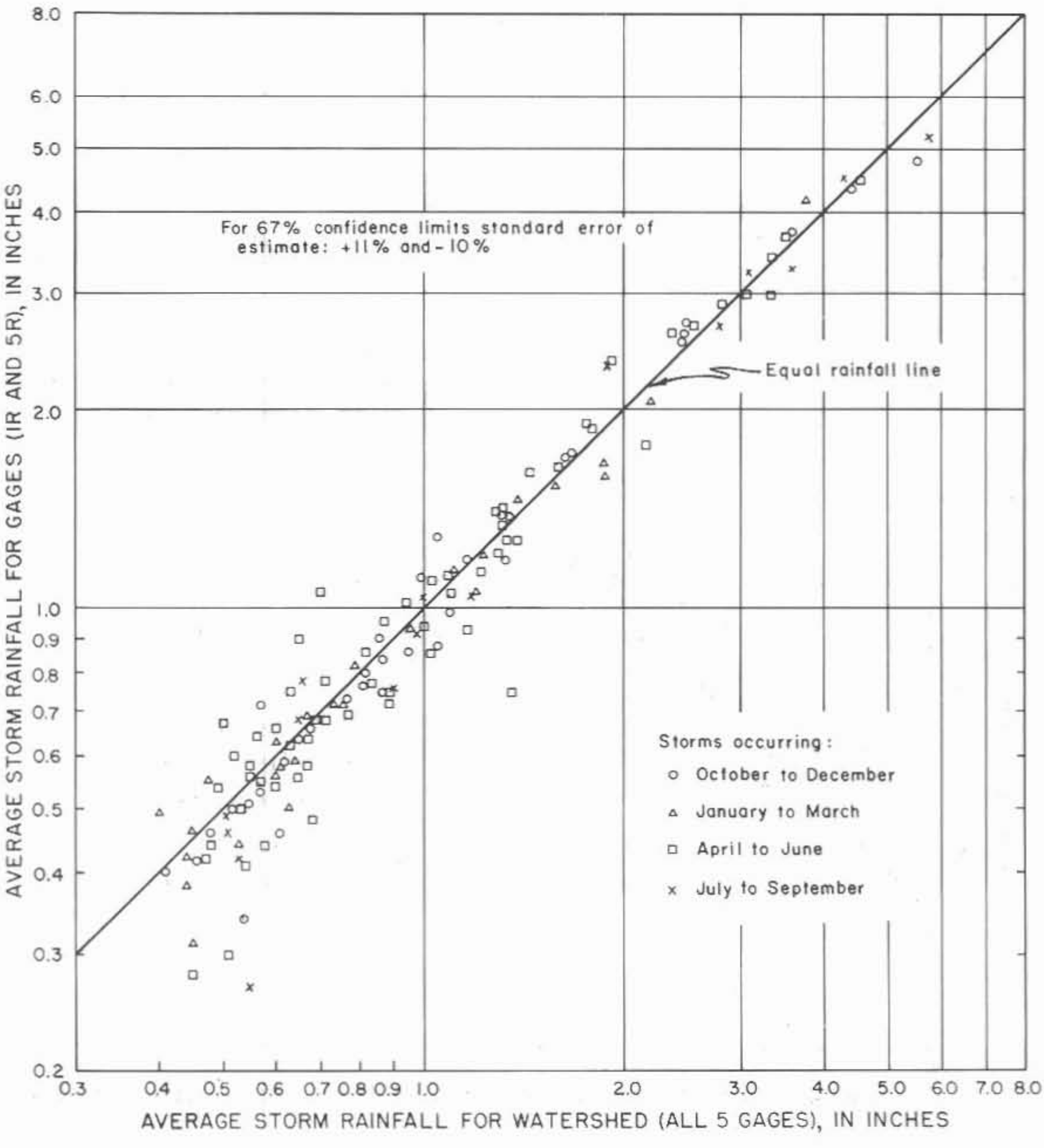


Figure 9

Comparison of Concurrent Storm Rainfall, 2 Gages (North and South) and 5 Gages

U. S. Geological Survey in cooperation with the Texas Water Development Board

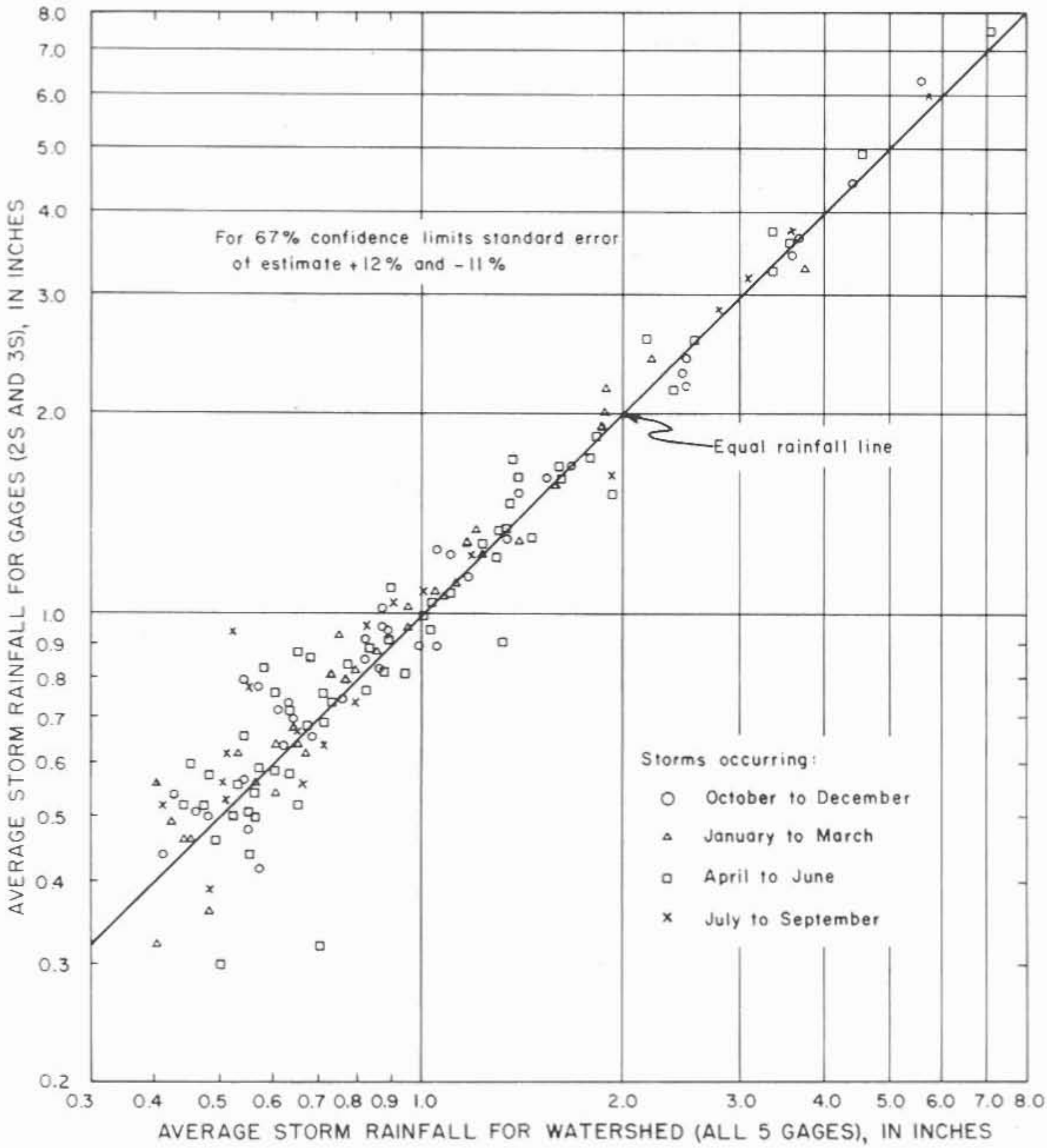


Figure 10

Comparison of Concurrent Storm Rainfall, 2 Gages (East and West) and 5 Gages

U. S. Geological Survey in cooperation with the Texas Water Development Board

2. Using the average of recording rain gages 1R and 5R (Figure 9), which are the most extreme north and south gages in the study area, storm rainfall may be determined within +11 percent and -10 percent of the average rainfall as determined from all five rain gages.

3. The average of the non-recording rain gages 2S and 3S (Figure 10), which are the extreme east and west gages used in the study area, is within +12 percent and -11 percent of the average rainfall as determined from all five rain gages.

4. Extent of scatter from the line of equal yield is less above 2.0 inches, indicating that these storms are more general in areal distribution.

5. The maximum scatter occurs when the average storm rainfall is less than 1.0 inch. This is expected because of the more uneven areal distribution of rainfall from isolated thunderstorms which occur frequently in this area. However, the overall comparisons indicate that for this watershed the areal distribution of storm rainfall is fairly uniform.

6. The five rain gages distributed as shown in Figure 3 seem to compose a reliable rain-gage network with a density of one rain gage for every 3.5 square miles in this study area.

7. The tipping-bucket gage (6T) at the streamflow-gaging station should be replaced with a float-operated recording gage. This would insure more consistent gage operations and more accurate recording of rainfall.

8. The results of the comparisons using the average precipitation from two gages (Figures 9 and 10) show that very little difference can be attributed to direction of storm movement or recording versus non-recording rain gages for this watershed. This lack of variation between these two combinations of rain gages may be partly attributed to the small size of the watershed and the uniform distribution of the gages. The standard errors of estimate (11 percent in Figure 9, and 12 percent in Figure 10) are considered very good for a series of concurrent occurrences in nature. Many of the points which deviated widely from the mean would be eliminated if storms of less than one-inch rainfall had been omitted.

Magnitude and Frequency

Hershfield (1961) compiled an isohyetal atlas showing long record rainfall duration and frequency for a large number of the Weather Bureau's hydrologic data and observational stations. The curves are based on the partial-duration frequency series. For any point within the United States a rainfall magnitude-frequency relationship can be constructed from these isohyetal maps. As Hershfield (1961) pointed out, the standard error of estimate is about 10 percent for a relatively flat region such as the Pin Oak Creek study area.

Figure 11 is the rainfall magnitude-frequency relationship for the Pin Oak Creek study area as constructed from the Weather Bureau isohyetal maps. This relationship shows the expected average maximum depth and frequency (recurrence interval) of storm rainfall for storm durations of 0.5, 1.0, 2.0, 3.0, 6.0, 12.0, and 24.0 hours. These curves can be used to determine the recurrence interval and storm rainfall increments expected in the study area.

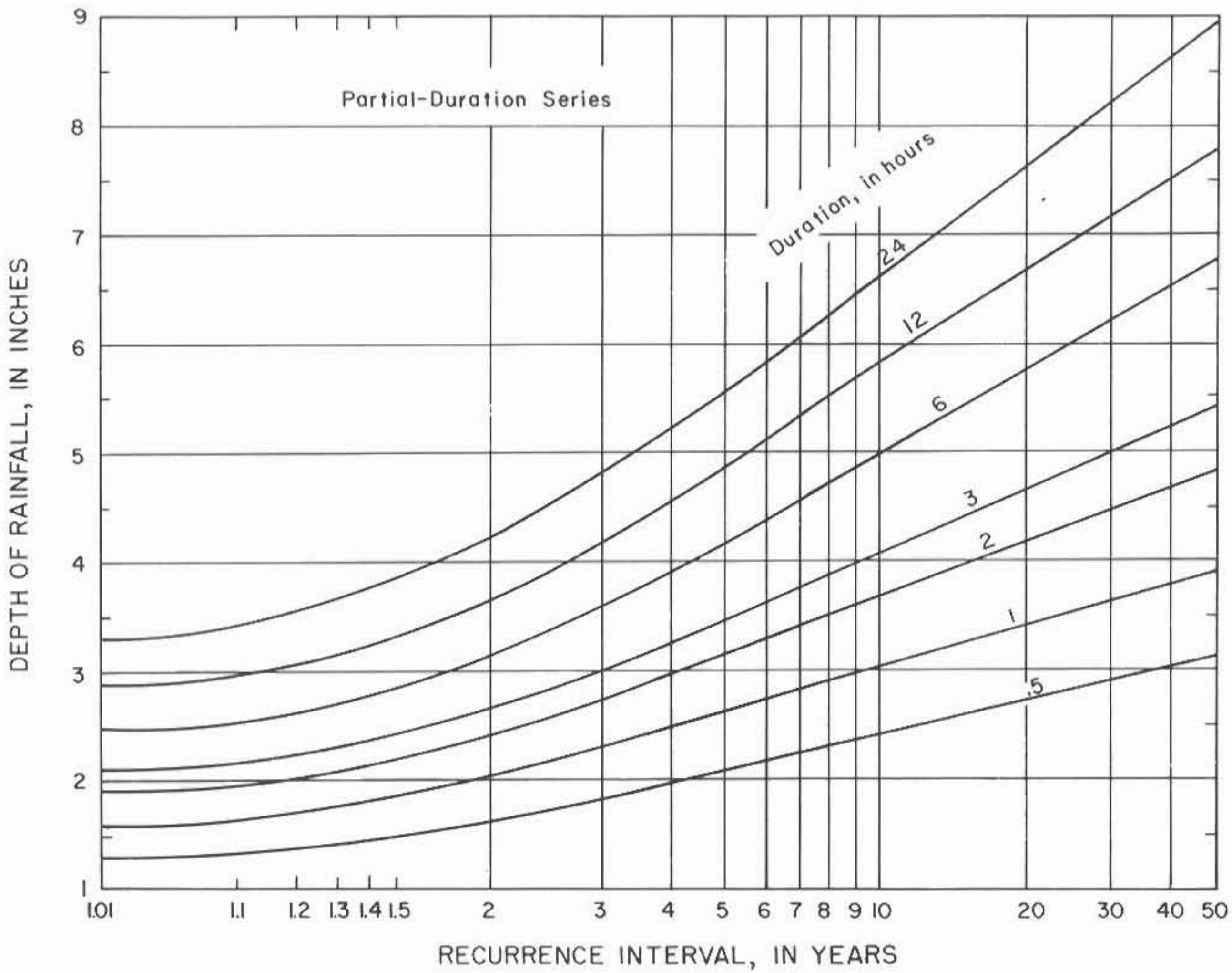


Figure 11

Rainfall Magnitude - Frequency Curves

U. S. Geological Survey in cooperation with the Texas Water Development Board

Isohyetal maps, more detailed than those given by Hershfield, have been drawn for the Blacklands of Texas by Knisel (1965). These maps are based on the annual frequency series. Two of the maps are shown in Figures 12 and 13.

Knisel also found that the maximum annual 24-hour rainfall was associated most frequently with the summertime convective thunderstorm type of occurrence. A cause of the increased thunderstorm activity in the Blackland Prairies during the summer months may be that temperatures recorded by the Weather Bureau at Blackland Prairie stations generally 8°F to 10°F higher at 10 p.m. than in surrounding light-colored soil areas (Figures 12 and 13). Land-surface heating is a necessary factor for the occurrence of a convective thunderstorm.

An indication of the magnitude and frequency of storm rainfall experienced in the study area during 1957-62 is given in Table 4. The largest 24-hour rainfall (7.34 inches) that occurred during the period covered by this report has a recurrence interval of about 16 years. However, a sufficient number of moderate storms did occur to indicate that this six-year period was probably above average for storm magnitude and frequency.

Because more flood-control reservoirs are being built, the need has increased for data on longer storm periods. Because of the low-release rates of the structures, several days are required to safely discharge the impounded floodwaters. Weather conditions frequently result in a sequential recurrence of runoff over a period greater than one day. In this regard Knisel developed a graphical relation (Figure 14) for the Blackland Prairie area. The left portion of Figure 14 is a Gumbel frequency chart which relates 1-day rainfall to the return period. The right portion of this chart is a graph based on regression equations for determining linear relations between the 1-day and 2-day, 1-day and 4-day, 1-day and 7-day, and 1-day and 15-day storm durations.

Table 4.--Magnitude and frequency of 24-hour storm rainfall for Pin Oak Creek study area during 1957-62.

Calendar year	Annual rainfall (inches)	Number of storms during period having 24-hour rainfall total as indicated						
		1-2 in.	2-3 in.	3-4 in.	4-5 in.	5-6 in.	6-8 in.	>8 in.
1957	52.90	4	2	3	0	0	1	0
1958	37.37	7	2	0	0	0	1	0
1959	44.30	7	1	1	1	1	0	0
1960	39.44	4	5	0	0	0	0	0
1961	45.26	7	2	1	1	0	0	0
1962	27.96	2	3	2	0	0	0	0

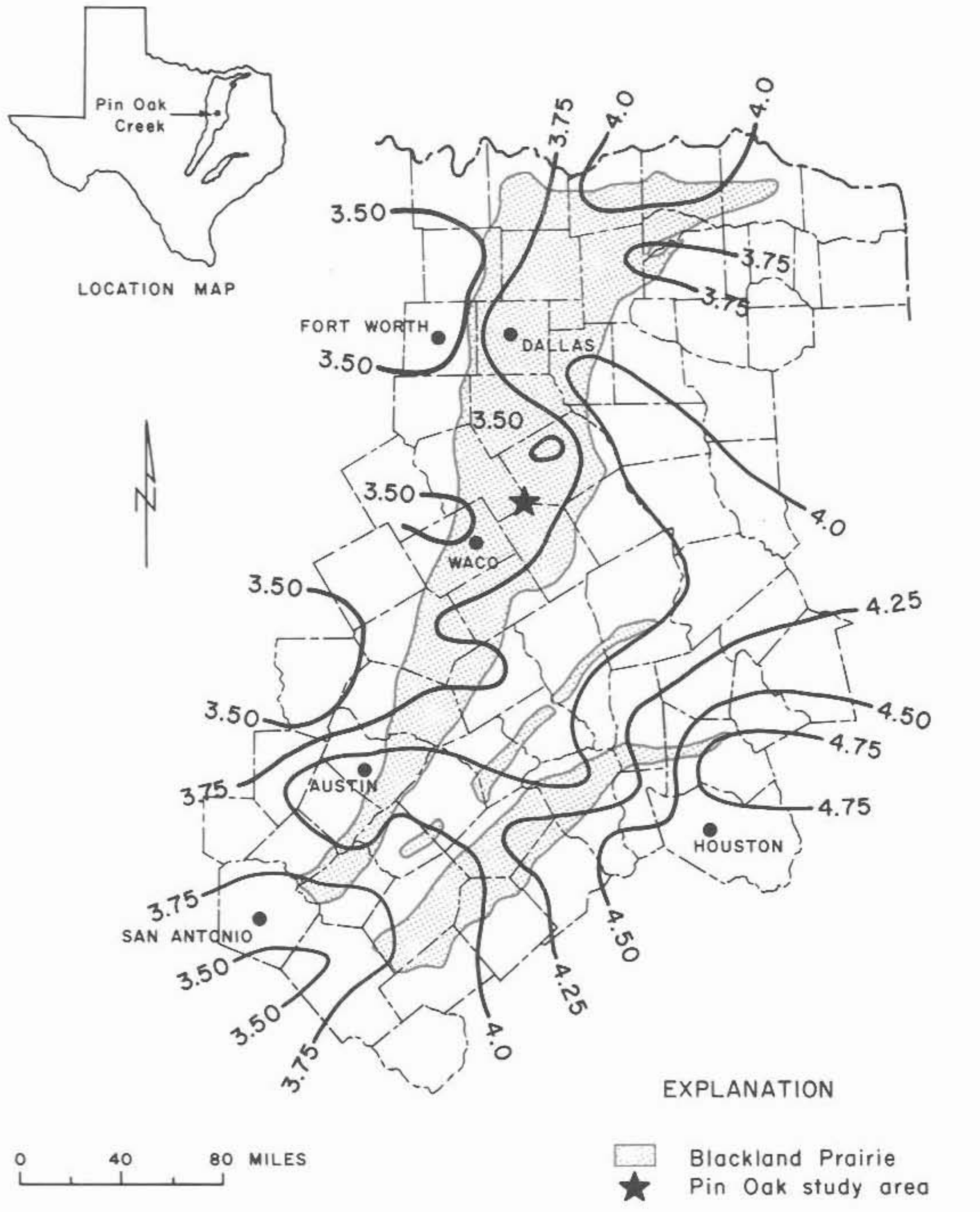


Figure 12

Lines of Maximum 1-Day Rainfall (Inches) Expected to Recur at 2-Year Intervals in the Blackland Prairies of Texas

U. S. Geological Survey in cooperation with the Texas Water Development Board

After Knisel (1965)

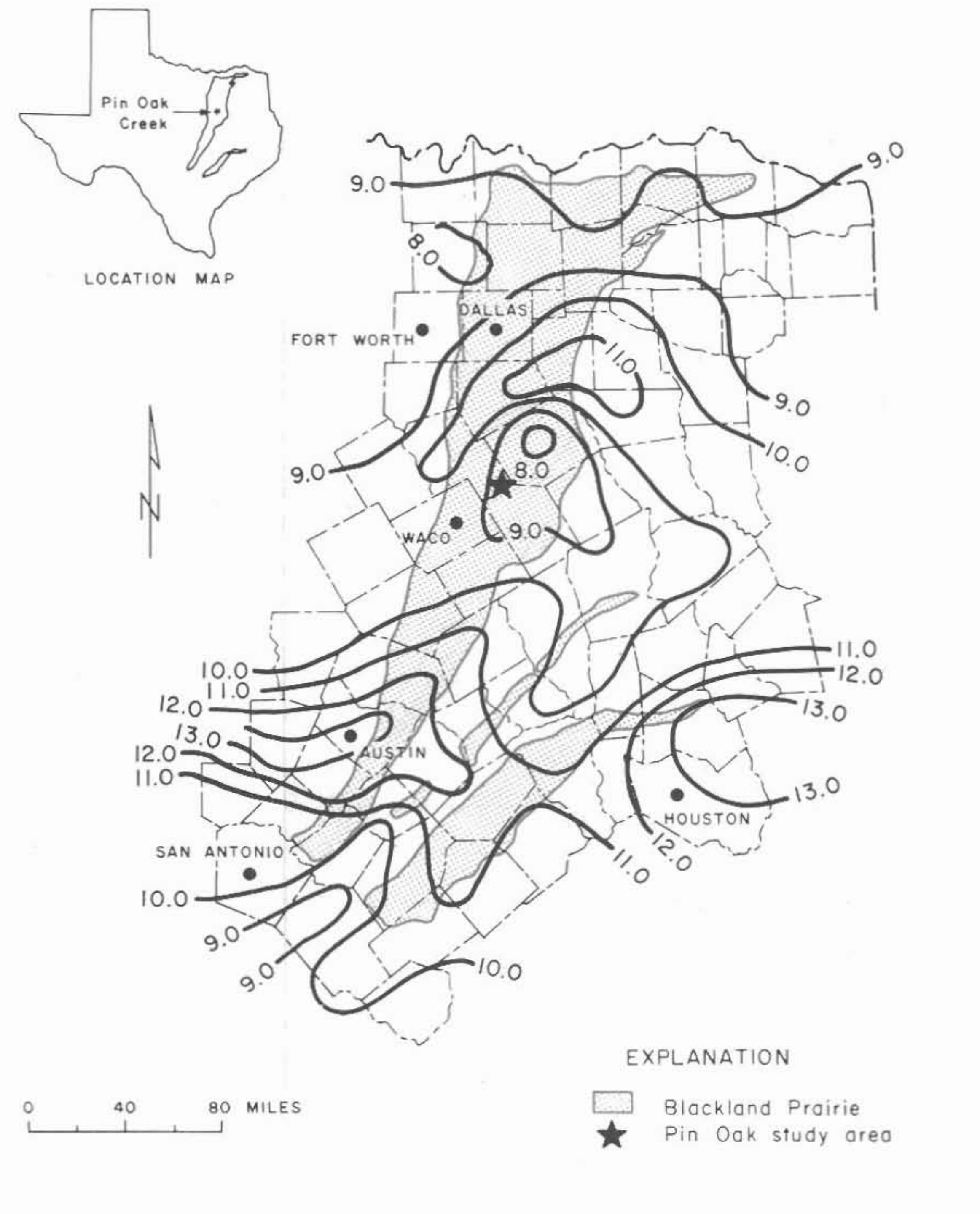


Figure 13
Lines of Maximum 1-Day Rainfall (Inches) Expected to Recur at 100-Year Intervals in the Blackland Prairies of Texas

U. S. Geological Survey in cooperation with the Texas Water Development Board

After Knisel (1965)

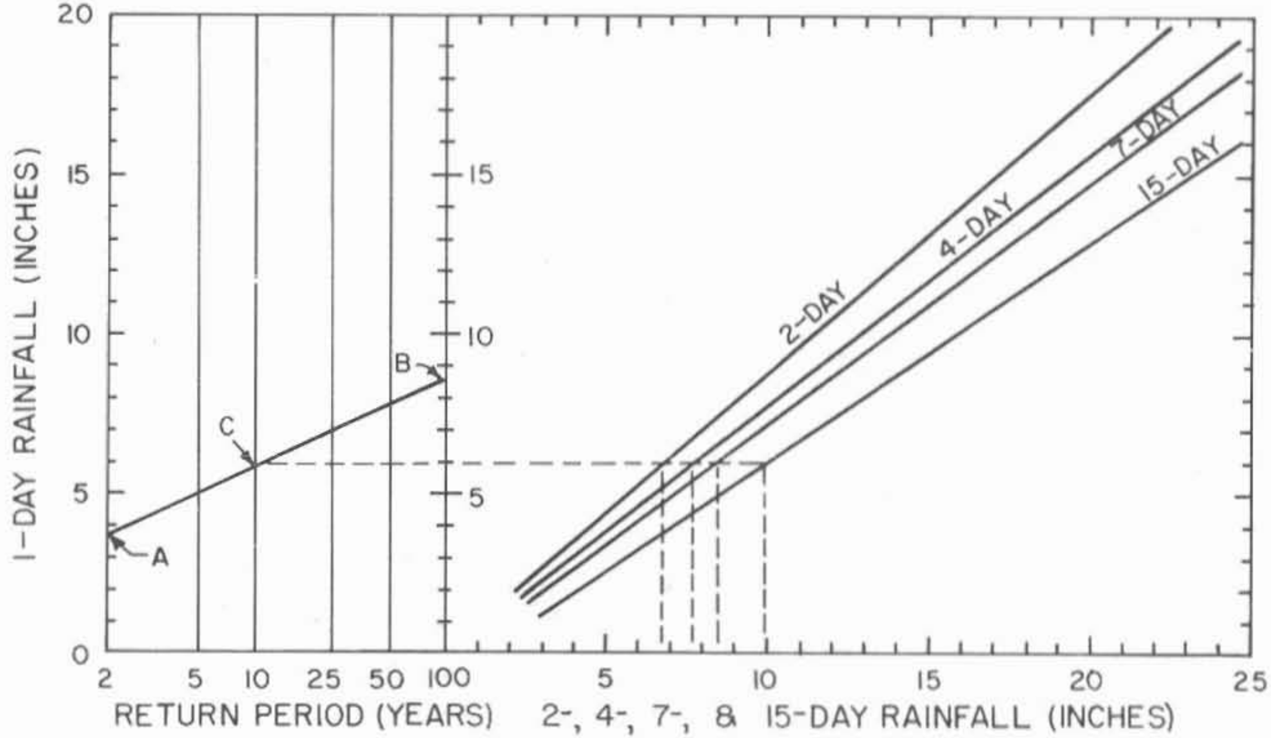


Figure 14

Graphical Method for Determining 1-to 15-Day Rainfall Amounts for Return Periods Between 2 and 100 Years

U. S. Geological Survey in cooperation with the Texas Water Development Board

Knisel (1965)

When the chart in Figure 14, is used in conjunction with the isohyetal maps (Figures 12 and 13), rainfall amounts may be determined for any combination of storm periods from 1 to 15 days with recurrence intervals from 2 to 100 years. An estimate of the average 10-year rainfall in the Pin Oak Creek study area for 1, 2, 4, 7, and 15 days is made in the following manner. From Figure 12 the 1-day rainfall with a 2-year recurrence is about 3.65 inches and is plotted as point "A" on the chart (Figure 14). The 1-day rainfall with a 100-year recurrence is about 8.70 inches as determined from Figure 13 and is plotted as point "B" on the chart (Figure 14). A straight line drawn connecting points "A" and "B" intersects the 10-year recurrence line at point "C." Point "C" indicates 6.0 inches of rainfall for a 1-day period recurring at 10-year intervals. Rainfall amounts for the 2- to 15-day periods are determined by following the dashed horizontal line to the right until it intersects with the storm-period curves. At the appropriate intersection, the rainfall amounts are determined by projecting vertically downward to the abscissa. Estimates for days between the storm periods indicated by the curves can be made by interpolation. The reliability of this procedure for estimating rainfall amounts and recurrence was found to be with ±15 percent by Knisel.

Runoff

Hydrologists and engineers are continually seeking methods for determining the complex behavior and characteristics of flood runoff. Rainfall and runoff relationships have been studied with intent to develop design data for waterway structures. Needless to say, these structures need be both adequate and safe. If the estimated flood magnitude is too great, funds may be wasted on an oversized structure and site. Conversely, if the estimated flood magnitude is too small, the structure may be destroyed with much resulting damage.

Among the early researchers in hydrology was L. K. Sherman (1932) who presented the unit-hydrograph concept. The unit hydrograph has proven to be a highly effective hydrologic tool for determing how runoff is distributed in time. Fundamental concepts of the unit-hydrograph relationships are presented by W. G. Hoyt and others (1936), Mitchell (1948), and Linsley and others (1949).

Unit Hydrograph Analyses

Mitchell (1948) stated: "A unit hydrograph is a hydrograph of direct runoff resulting from one inch of precipitation excess occurring in unit time." Definition of the following terms is necessary. "Precipitation excess" is the total rainfall minus the basin abstractions which prevent direct runoff. "Unit time," hereafter referred to as the "unit-hydrograph duration," is the optimum duration for the occurrence of precipitation excess. In general, the unit-hydrograph duration should be about 20 percent of the time interval between the beginning of a short high-intensity storm and the peak discharge of the corresponding runoff. The "storm duration" is the actual time during which the precipitation excess is occurring. Obviously, the storm duration may vary with the individual storms and should not be confused with the unit-hydrograph duration.

A storm-hydrograph study was made for the Pin Oak Creek watershed to determine if unit hydrographs could be obtained which would aid in defining the runoff characteristics of the watershed prior to the development of the floodwater-retarding structures. A similar study, using after-structure-development characteristics, is anticipated for comparison. This before-development and after-development unit hydrograph comparison should afford evaluation of the hydrologic effects of small-watershed developments.

In any one drainage basin under ideal conditions, the precipitation excess occurring in a unit of time should produce similar unit hydrographs. However, Linsley and others (1949, p. 446) note that if the storms show a wide variation in rainfall distribution or intensity, it is necessary to develop several unit hydrographs and note on each the general characteristics of the storm. Thunderstorms, with high intensity rainfall of short duration, tend to produce a higher peak discharge than low intensity long-duration storms.

Generally, it is difficult to select from rainfall and streamflow records a type of storm which will produce an ideal unit hydrograph for a particular watershed. Because nature never provides abundant ideal conditions suitable for unit-hydrograph computations, it is necessary to modify and refine the basic unit hydrograph treatment for distributing the runoff of a natural watershed. What constitutes a uniformly distributed storm is largely a matter of judgment. Adherence to the following criteria is necessary when selecting storms for computation of a watershed-unit hydrograph.

1. The actual storm rainfall excess period should be approximately equal to the unit-hydrograph duration. Usually, it is permissible to allow the rainfall excess period to vary between -50 and +200 percent of the unit-hydrograph duration.

2. The storm must have been fairly uniform over the watershed, all gages showing an appreciable depth of rainfall.

3. Runoff following the storm must have been uninterrupted by the effects of freezing and unaccompanied by melt water.

4. The storm period must be isolated--that is, it should follow a period of low streamflow, and no subsequent rainfall and discharge peaks should occur until the normal recession has been resumed.

A simple unit hydrograph is constructed by multiplying the ordinates (discharge) in cfs (cubic feet per second) of the storm hydrograph by the ratio obtained when the total storm runoff, in inches, is divided into one inch. However, in many cases the storm durations may overlap, and the procedure for obtaining the unit hydrograph is not so simple. Flow that must be eliminated is: (1) that portion which is derived from ground-water effluent, commonly referred to as base flow; (2) the recession flow of direct runoff from any preceding storm; and (3) any subsequent increase in flow from a succeeding storm.

Storm hydrographs of 14 storms essentially meeting the foregoing criteria were selected for analyses. Of these selected storms four were complex and necessitated the segregation of flow. The unit hydrographs were plotted and superimposed to determine if a correlation exists between rainfall duration, time of rise, and unit-hydrograph peak. Long-duration and low-intensity rainfall necessitated discarding three storms which had unit hydrographs well out of character with the other 11 unit hydrographs.

Two rather distinct groupings of unit hydrographs resulted from the superimposed plottings. Apparently, Pin Oak Creek is one of those basins, as indicated by Linsley and others (1949), which may have two average unit hydrographs that characterize two types of storms (Figure 15, hydrograph A; and Figure 16, hydrograph B). Five of the unit hydrographs comprising one group are shown in Figure 15. The pertinent storms and data for the hydrographs are listed in Table 5 to facilitate identification and discussion.

Evidence of the variation in intensity, distribution, and resulting runoff is best shown by Figure 15 and Table 5. Period of rise is defined as the time interval on the rising limb of the unit hydrograph between the minimum and maximum discharge. The time of rise ranges from slightly over 3 hours for hydrograph 7 to 6 hours for hydrograph 4. An average time of rise for hydrographs 4 and 7 would, therefore, be about 4.7 hours. This time approximates the 5-hour time of rise indicated by hydrographs 5, 6, and 10, which were well distributed. Hydrographs 4 and 7 were produced from short-duration, high-intensity storms (Table 5). However, hydrograph 4 was produced from a storm having the greater intensity and runoff at the upper end of the watershed. Conversely, hydrograph 7 represents a storm having the greater intensity and runoff at the lower end of the watershed. The average one-hour duration unit hydrograph for the convective-type summer thunderstorm is shown by hydrograph A.

Figure 16 shows six unit hydrographs which comprise the second group of plottings. These hydrographs show the effects of moderate to long-duration (2 to 8 hours) storms having low to moderate intensities (Table 5). Storms of this type are general storms, usually occurring during the fall and winter or they may be remnants of hurricanes moving inland. It may be seen from Table 5 and Figure 16 that the time of rise, 5 to 7 hours, and the discharge, 1,300 to 1,470 cfs, for all six storms are fairly consistent. Only hydrograph 8 appears to be out of character with other storms in this group. Although the storm represented by hydrograph 8 had an ideal sharp burst of rainfall, characteristic of a thunderstorm, the intensity tapered slowly, thus extending the runoff duration. This low-intensity climax to the storm appears to account for the broadened and lower-peak discharge of hydrograph 8. An average one-hour duration-unit-hydrograph for the frontal type general storm is shown by hydrograph B.

Caution must be excercised in attempting to apply unit hydrographs derived from general storms (Figure 16) to extreme storms, such as the one represented by hydrograph 7 (Figure 15). Generally, extreme floods will produce a somewhat higher unit-hydrograph peak discharge than ordinary storms. Also, caution should be taken in applying unit hydrographs to storms with nonuniform-rainfall intensity. This would be like applying hydrograph 1 (Figure 16) to the storm which produced hydrograph 4 (Figure 15). Variable rainfall intensity is more likely to be reflected in unit hydrographs for a small watershed like Pin Oak Creek than in unit hydrographs for a large watershed.

Rainfall-Runoff Relationships

Agencies concerned with the design and operation of water-control projects, highway improvements, and urban planning are called upon to relate storm rainfall to the resulting runoff. For water-supply projects, the total runoff from the watershed must be determined, whereas for some structural projects only

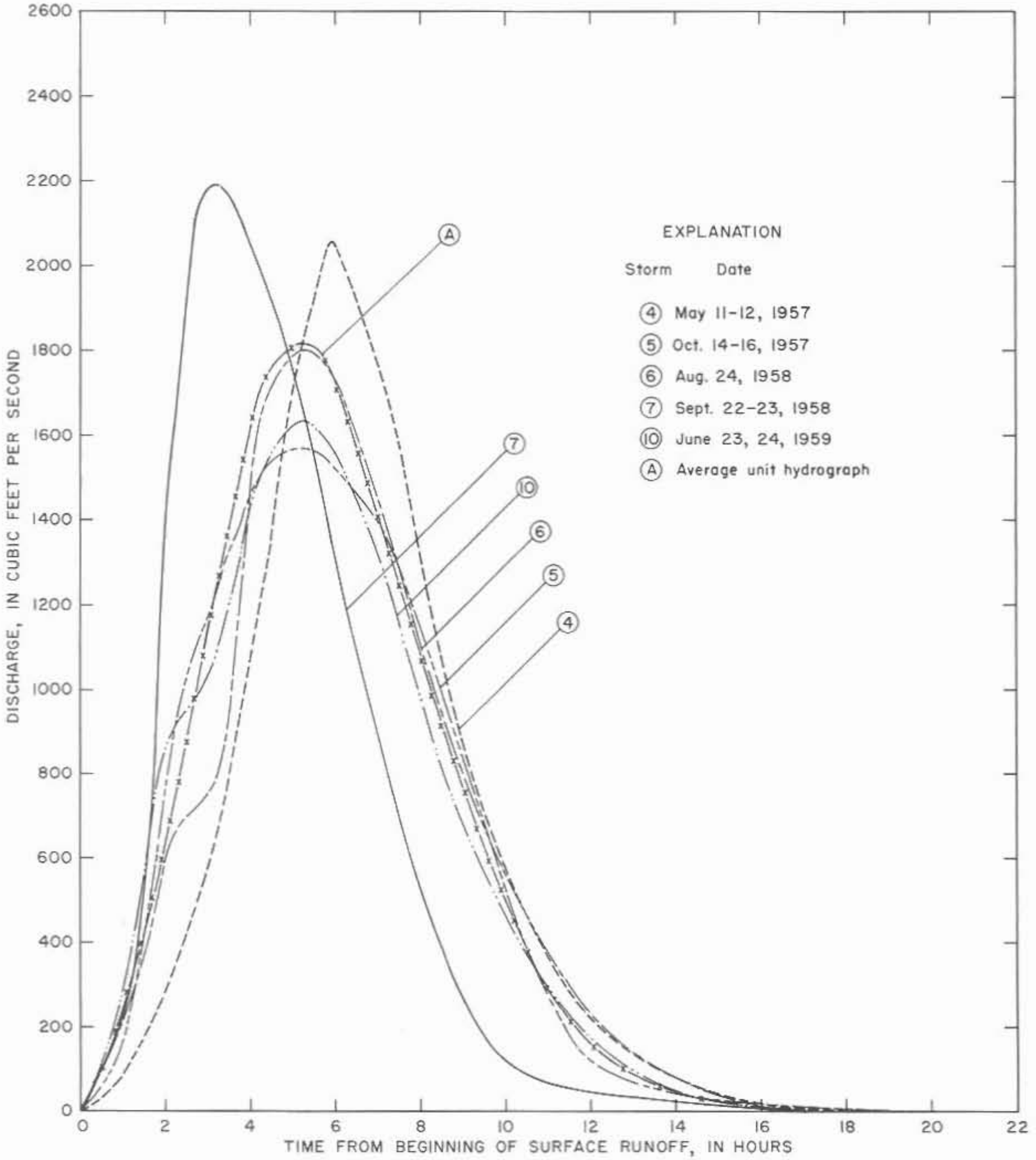


Figure 15

Unit Hydrographs Resulting from Convection-Type Storms

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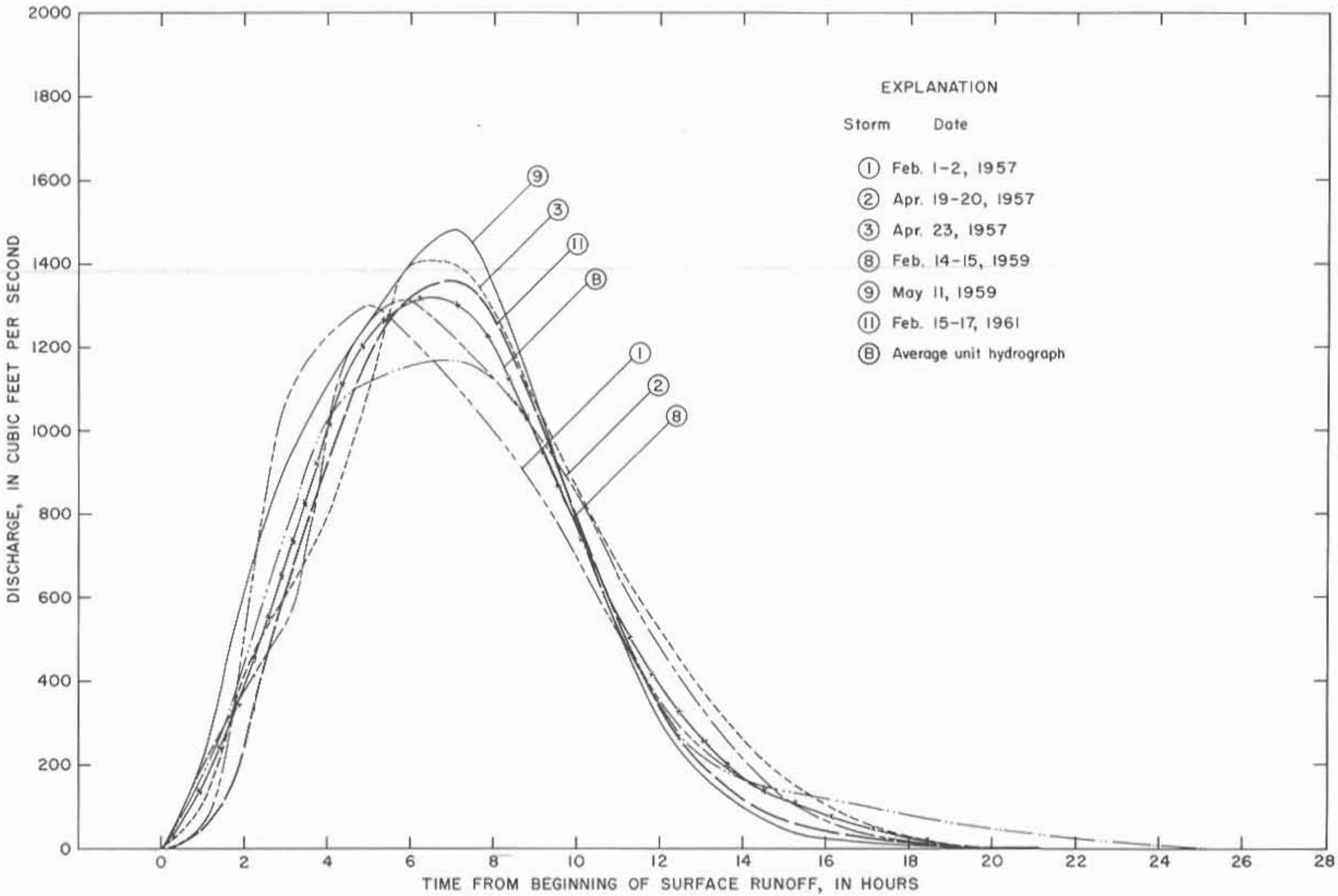

Figure 16

Unit Hydrographs Resulting from General Frontal-Type Storm

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Table 5.--Storms and resulting unit-hydrograph characteristics.

Storm designation	Date of storm	Average rainfall (in.)	Average intensity of rainfall (in. per hr)	Runoff (in.)	Peak discharge (cfs)	Period of rise (hrs)	Time base (hrs)
1	Feb. 1- 2, 1957	1.11	0.22	0.37	1,300	5	20
2	Apr. 19-20, 1957	7.10	.68	3.22	1,310	6	20
3	Apr. 23, 1957	2.55	.32	2.28	1,400	6	20
4	May 11-12, 1957	1.76	1.12	1.08	2,080	6	20
5	Oct. 15, 1957	.88	.26	.37	1,560	5	19
6	Aug. 24, 1958	5.76	.85	2.41	1,800	5	20
7	Sept. 22-23, 1958	1.00	.60	.35	2,190	3	20
8	Feb. 14-15, 1959	1.20	.28	.55	1,170	7	26
9	May 11, 1959	1.45	1.00	1.16	1,470	7	21
10	June 23-24, 1959	2.82	.96	2.49	1,630	5	21
11	Feb. 15-17, 1961	1.58	.22	.88	1,360	7	20
A	--	--	--	--	1,820	5	20
B	--	--	--	--	1,310	6	21

Storm A = Average hydrograph of storms 4, 5, 6, 7, and 10.
Storm B = Average hydrograph of storms 1, 2, 3, 8, 9, and 11.

peak rates of runoff are important. One of the most important applications of rainfall-runoff relationships is in the formulation of flood-stage forecasting and warning procedures.

Numerous methods for estimating runoff have been devised; however, the relationship defies an exact mathematical solution because of the large number of variables which have to be considered. One of the first and simplest methods was the rainfall versus runoff plottings which generally showed very poor correlation. This method, even when combined with regression factors, fails to consider the effects of enough variables.

Hydrologists readily realize that many variables affect the rainfall-runoff relationship. The amount of runoff resulting from a given storm is dependent upon numerous parameters which include: amount, duration, intensity, and areal distribution of rainfall; antecedent soil moisture content; topographic features such as depression storage, watershed configuration, basin and channel slopes; geologic environment including subsurface structures and types of soil cover and its distribution; water-table configuration; infiltration rates; land-management practices; vegetal cover; and seasonal variations in weather.

Rational Formula

The more successful methods used in dealing with these complex interrelationships require extensive data collection and knowledge about the particular basin under consideration. The rational formula as discussed by Rouse (1950) is restrictive because only peak discharge can be predicted. The formula is:

$$Q = C\ I\ A \qquad (1)$$

where: Q is peak discharge in cubic feet per second,

C represents a constant indicative of basin characteristics, primarily a function of the antecedent soil conditions and (or) impervious cover,

I is rainfall intensity in inches per hour, and

A represents the drainage area in acres.

The formula is based on the premise that the entire watershed is contributing runoff at a percentage rate "C" of the rainfall intensity. This formula is most applicable to very small watersheds, particularly in urban areas where the vegetal and man-made cover does not reflect serious seasonal changes. Therefore, this method is considered impractical for use in the Pin Oak Creek watershed.

Soils Infiltration Rate

A more detailed method involves techniques capable of evaluating the infiltration rate of the various soils within a watershed. However, such procedures as discussed by Cook (1946) require considerable field testing of soils and detailed observations of cover characteristics in order to prepare infiltration curves for the watershed.

Graphical Coaxial-Correlation Analysis

Of the several advanced methods of multiple correlation analyses, the graphical coaxial correlation technique as outlined by Kohler and Linsley (1951) has been found to be the most suitable and accurate procedure for determination of runoff from rainfall.

Essentially this method involves an interrelation of the hydrologic variables adapted to three sets of curves which describe the selected parameters most influential on runoff from an individual watershed. Parameters used to predict runoff from rainfall for the Pin Oak Creek watershed are antecedent soil moisture conditions, seasonal effects of weather, effective duration of storm, and total storm rainfall. In an individual watershed, topographic and geologic conditions remain essentially constant. Land-management practices produced no detectable runoff variations during the period of record. Effects of vegetal cover vary with the season and with agricultural practices which, in part, may be compensated for by the seasonal set of curves.

The variables representing the antecedent soil moisture conditions may be combined into a factor known as the antecedent-precipitation index (API). The API is dependent upon the hydrogeologic environment which primarily is evaluated as a measure of the soil-moisture conditions prior to each storm period. Because of the soil-water infiltration relationship, a measurement of the soil-moisture content prior to each storm would be desirable, although not feasible.

A determination of the API was made using the formula:

$$API_t = API_o K^t \qquad (2)$$

where: API_o represents the initial antecedent precipitation index,

API_t is the antecedent precipitation index "t" days after the initial determination, and

K^t represents a predetermined exponentially varied factor based upon climatic and physiographic characteristics of a basin.

The factor K is largely a function of the potential evapotranspiration. Because the Pin Oak Creek watershed lies within a subhumid region, potential evapotranspiration is rather large. Greater than 90 percent runoff is possible within the watershed, depending upon the intensity of the thunderstorm and the API immediately preceding the storm. Therefore, a value of 0.92 for the factor K appears reasonable and was used in this study.

A graphical method for obtaining the API for a given day is illustrated by curves in Figure 17. This set of curves was plotted from data given in "Hydrology for Engineers," by Linsley, Kohler, and Paulhus (1958, p. 328).

When computing the API by this method, it is assumed that soil moisture is depleted at an exponential rate during periods of no precipitation. The value of API_o was obtained by starting with the end of a long period of no precipitation (prior to the first storm analyzed) and assigning a low non-critical value to API_t. Minimum effect on API_o is found after a prolonged dry period (a minimum of 20 days) as the API_t rapidly approaches the true value and zero in time. When rainfall occurs, the total rainfall is not contributing to the residual-moisture content of the soil so the amount of runoff should be subtracted from

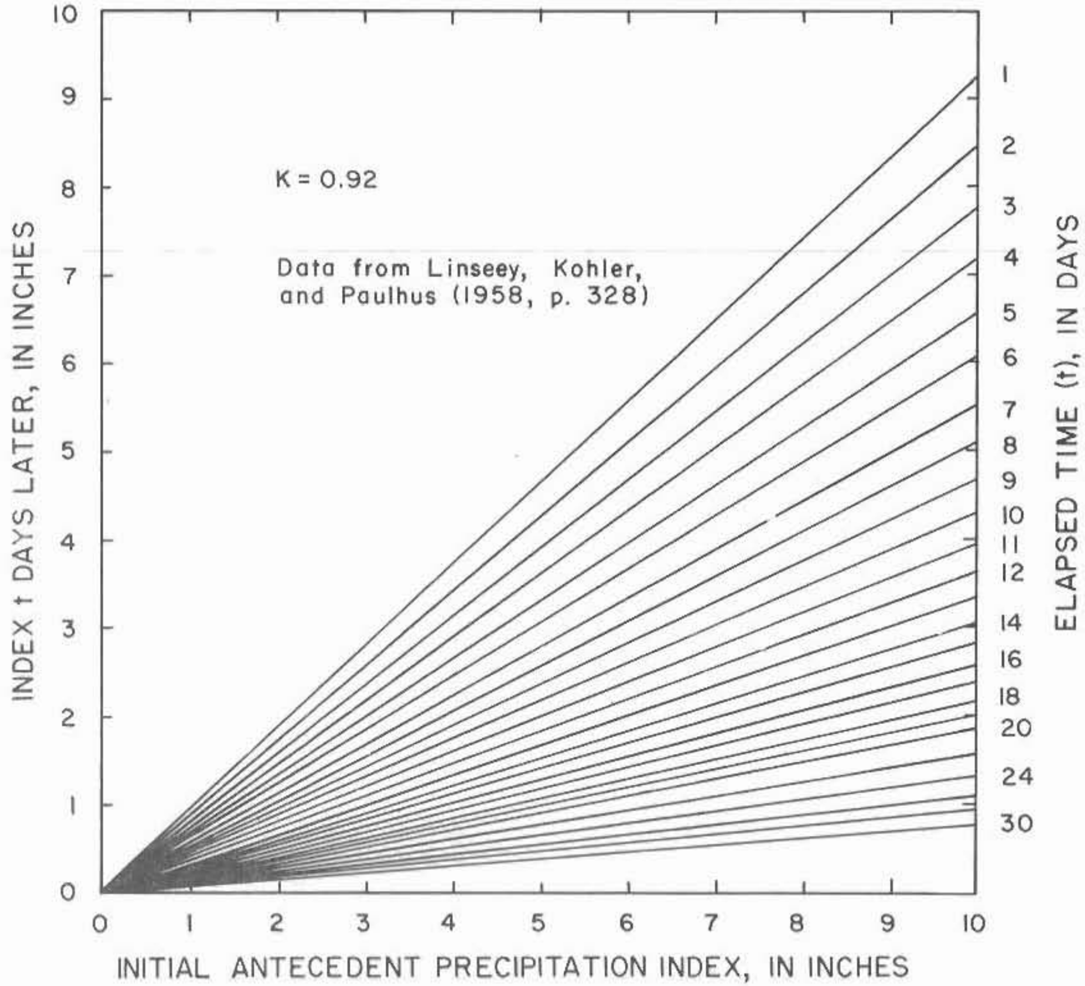

Figure 17

Chart for Computing Initial Antecedent Precipitation Index (API)

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the average precipitation. The residual or actual basin recharge should then be added to the API_t. This refinement, however, does not justify the added computations; therefore, the average precipitation was used for graphical computations of the API in this report. An example of the computation technique is shown in Figure 18. Snowfall and freezing temperatures were of very minor consequence during the period of investigation and did not affect any of the storm data used.

It should also be noted that as the API value approaches 7 or greater the effects of the antecedent conditions are at a minimum. Beyond this point, for all practical purposes, the soil and vegetation in the basin would be saturated.

Preparation of Data

In preparing storm data for use with the graphical coaxial correlation, certain criteria need be considered. Extended storm periods should be divided into definite units or "effective storm periods" that are based on the hydrograph analysis. For purposes of this report, an "effective storm period" is defined as the sum of the hourly increments in which rainfall intensity was at least 0.25 inch per hour plus one-half of the intervening rainfall accumulation periods of lesser intensity. If the total rainfall time period was used for these complex intermittent "rain and no rain" storms, the runoff-producing portion of the storm would be distorted. Frequently rainfall begins slowly, intensifies, and then tapers off near the end of the storm. In many thunderstorms, rainfall of a relatively constant intensity is exhibited and the total storm period and the effective storm period may be considered equal.

A relatively uniform areal distribution of rainfall is desirable. In larger watersheds, rainfall distribution tends to become more erratic than in the smaller study areas. This nonuniformity is found more in areas where localized summer thunderstorms occur. In these areas an optimum density raingage network is desirable. It is then possible to subdivide the large watershed into small areas, thus facilitating the computation of the runoff contribution of each subarea. Because necessity of subdivision was not indicated in this 17-square-mile study area, the average of all rain gages was used.

Storm runoff, in inches, was computed for each storm from the total discharge measured at the stream-gaging station. When streamflow was occurring immediately preceding the storm analyzed, the streamflow was subtracted from the total storm runoff. Base flow was not normally found in this study area, thus eliminating the problem of segregating the ground-water component of the basin discharge.

Results of Coaxial Correlation Analysis

Twenty-five storms were selected which essentially met the foregoing criteria and for which storm hydrographs could be isolated. Table 6 gives a tabulation of data used to construct the graphical coaxial-correlation diagram (Figure 19). The distribution of rainfall for each storm selected is shown in Table 3.

After establishment of the rainfall-runoff relationship, runoff from any individual storm may be estimated. It is necessary to determine four factors for any storm: API, month of year, effective duration of rainfall, and the

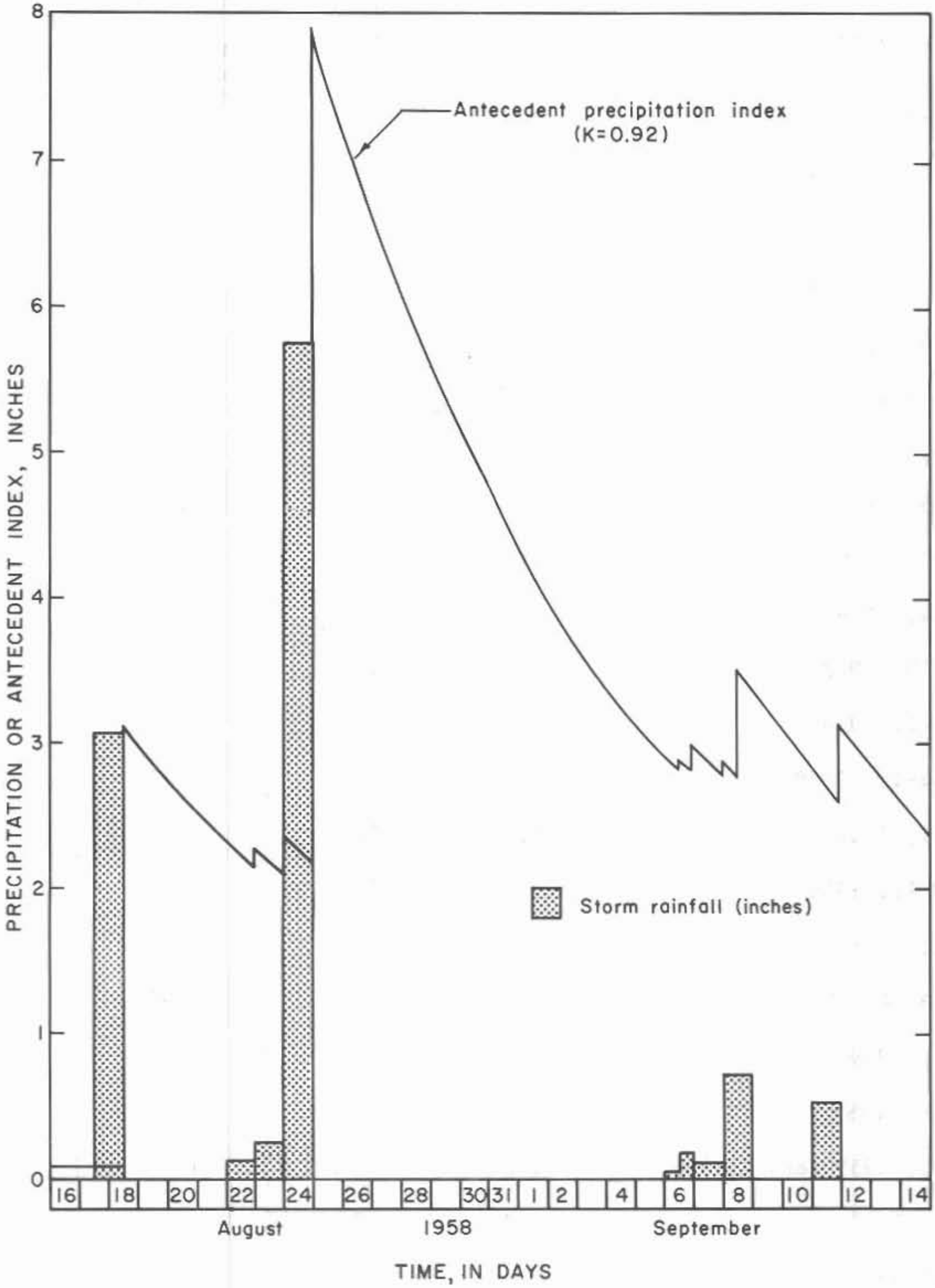

Figure 18

Graphical Method for Determining the Antecedent Precipitation Index (API)

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Table 6.--Storm parameters used in deriving coaxial rainfall-runoff relation.

Date of storm	API (inches)	Storm duration (hours)	Weighted mean rainfall (inches)	Storm runoff (inches)
Feb. 1-2, 1957	0.95	6	1.11	0.40
Apr. 19-20, 1957	.58	10	7.18	4.57
Apr. 23, 1957	8.20	6	2.72	2.30
Apr. 24-25, 1957	10.18	2	1.35	1.05
Apr. 26-27, 1957	9.70	4	1.52	1.10
May 11-12, 1957	4.90	3.5	1.66	1.09
May 13, 1957	5.80	4	2.46	1.96
Oct. 15, 1957	4.10	3	.78	.36
May 2-3, 1958	2.07	7	1.76	1.14
Aug. 24, 1958	2.34	7	5.62	2.40
Sept. 19, 1958	2.91	11	2.00	.29
Sept. 22, 1958	.17	4	.90	.34
Feb. 14-15, 1959	.95	4	1.10	.55
Apr. 11, 1959	1.75	12	1.30	.23
May 10-11, 1959	.86	11	3.41	1.38
June 22, 1959	1.73	6	2.22	1.45
June 23-24, 1959	3.55	3	2.82	2.46
Oct. 4, 1959	2.08	12	4.44	1.70
Dec. 15, 1959	.52	17	2.43	1.12
Dec. 31, 1959-Jan. 1, 1960	1.20	6.5	1.17	.49
Jan. 5, 1960	1.75	9	.96	.52
Oct. 18-19, 1960	2.40	4	2.49	.93
Dec. 6-7, 1960	.80	15	2.20	1.05
Feb. 15-16, 1961	1.54	5	1.16	.88
June 17, 1961 June 18, 1961	5.03	13	3.50	2.30

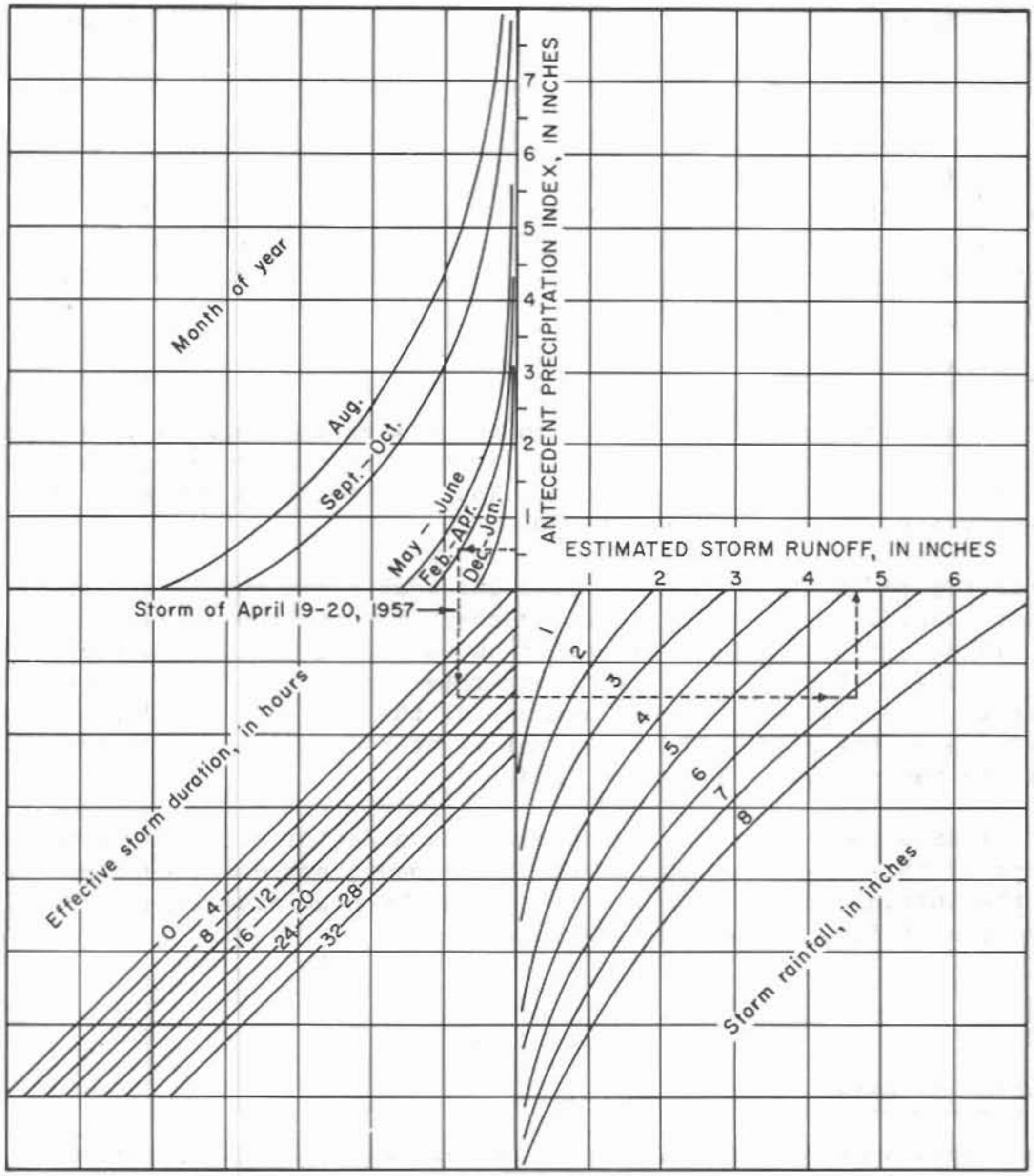

Figure 19

Coaxial Rainfall-Runoff Relation for Estimating Runoff

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total storm rainfall. The dashed line in Figure 19 illustrates the mechanics of using the coaxial relationships for the storm of April 19-20, 1957. Values for this storm example may be found in Table 6.

To estimate the runoff for a storm with rainfall of selected recurrence interval, the rainfall values, as determined from Figure 14 along with the appropriate API, may be substituted into the coaxial diagram (Figure 19). The resulting estimates are useful in the design of nearby floodwater-retarding structures.

The rainfall-runoff relationship derived in this report will be used in evaluating the effects of the floodwater-retarding structures now completed. A comparison of runoff relationships after development with runoff relationships given in this report will be made after sufficient data are collected.

Flow-Duration Analysis

Flow-duration curves are useful in appraising the regimen of a stream. The shape and slope of the curve are indicative of the hydrologic and geologic characteristics of the drainage basin. The flow-duration curve for the Pin Oak Creek study area is given in Figure 20.

From Figure 20 it is apparent that the peak storm runoff occurs and subsides very rapidly. This sharp rise, rather flat peak duration, and rapid decline in runoff are characteristic of uncontrolled small watershed areas with a moderate basin slope and a slow to moderately permeable soil cover. From this curve it is also seen that for 50 percent of the 1957-62 period there was no streamflow past the gaging station. This factor is additional evidence that there is no base flow in the study area.

After-development conditions should show a definite change in the shape and slope of the flow-duration curve. The floodwater-retarding structures will retard the initial runoff, thereby lessening the peak discharge and prolonging the duration of flow below the structures.

Sediment

Preparation of Data

Suspended sediment samples are collected daily or at more frequent intervals during periods of high streamflow. The concentration of the suspended sediments, in parts per million (ppm), is plotted on a copy of the recorded gage-height chart. A continuous curve is drawn between the sample points on the basis of all pertinent observations and the decision of the computer.

When the streamflow and sediment concentration are reasonably constant during a day, that daily average sediment concentration, daily average streamflow, and a conversion constant are multiplied together to obtain the sediment discharge in tons per day. If the streamflow and sediment concentration vary widely during a day, the sediment discharge computation is based on the average concentration defined by the continuous curve and by the average streamflow for intervals of a day.

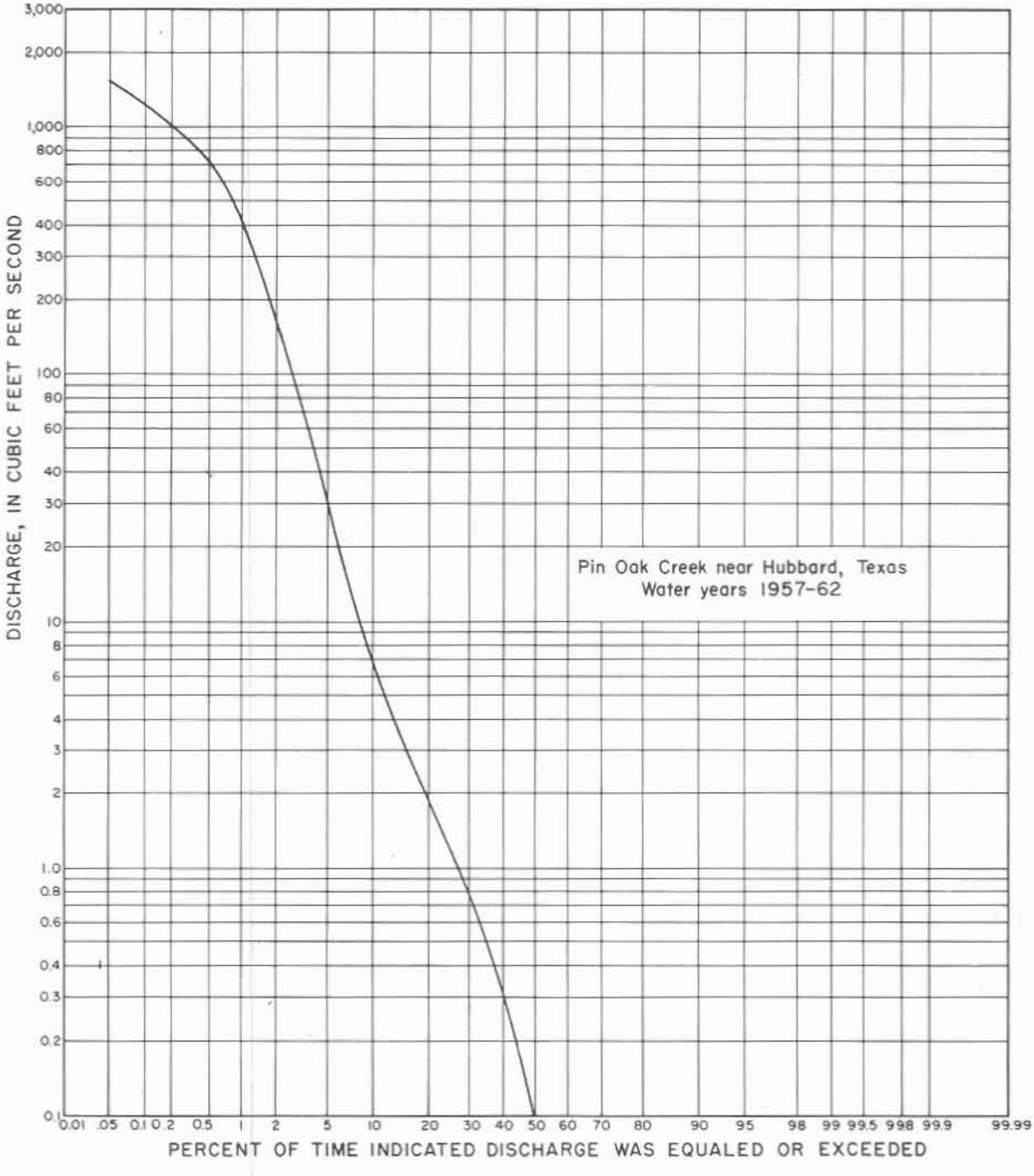

Figure 20

Duration Curve of Daily Discharge

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Figure 21 illustrates the water-discharge and suspenced-sediment concentration relationship for the March 20-21, 1957 storm in the Pin Oak Creek study area.

The total suspended-sediment load is calculated by multiplying the suspended-sediment concentration by the total water discharge. It is assumed that the depth-integrated water-sediment mixture is a representative sample of the entire channel discharge.

The unmeasured load consists of sediment particles moving in the unsampled zone (within 0.3 foot of the streambed). This sediment load consists of suspended particles, saltation particles, and particles moving in contact with the bed. Because the measured suspended load is 96 percent clay and silt, and because few sand bars are in the stream, the total sediment discharge is assumed to be the product of the measured suspended-sediment concentration, total water discharge, and the unit weight of the suspended sediment.

Suspended-Sediment Discharge

Suspended-sediment discharge fluctuates with changes in water discharge, turbulence, and temperature of the water, and with the availability of the various sizes of the sediment particles. These fluctuations of suspended-sediment discharge are usually rapid and may have only a general relation with the water discharge. The curves in Figure 22 show that in general the suspended-sediment discharge varies with the same water discharge rates. The upper curve in Figure 22 indicates the average sediment discharge for rising stages, and the lower curve represents the average sediment discharge for falling stages at the Pin Oak Creek gaging station. The relationship between suspended-sediment discharge and water discharge can be used to estimate the suspended-sediment discharge for periods of missing record.

From Table 2 it may be seen that for the water years 1957-62, Pin Oak Creek near Hubbard discharged about 246,000 tons of sediment. Daily sediment loads ranged from 0 to 12,200 tons. The mean daily sediment load was 112 tons. The watershed sediment yield was 2,330 tons per square mile per year, or equivalent to a computed 3.1 acre-feet per square mile per year.

Figure 23 is a bar graph illustrating the average monthly water discharge and sediment discharge for the Pin Oak Creek study area for the water years 1957-62. It shows that the greatest amount of water and sediment is discharged during the months of April, May, and June. Approximately 50 percent of the total water and 54 percent of the total sediment was discharged during these months for the six years of record. It is noted that the months of April, May, and June are also closely related on the graphical coaxial-analysis curves in Figure 19. July, being the driest month, had an average water discharge of 16 acre-feet and an average sediment discharge of 37 tons during the six-year period of record. Similar data collected after development of the watershed will show any reduction in the sediment discharge and variation in monthly distribution.

A double-mass curve (Figure 24) of cumulative sediment runoff may be used for studying trends in sediment yield and for detecting the effects of land-management practices on the sediment yield. The slope of the double-mass curve defines the mean sediment concentration during the period of record for the Pin Oak Creek study area.

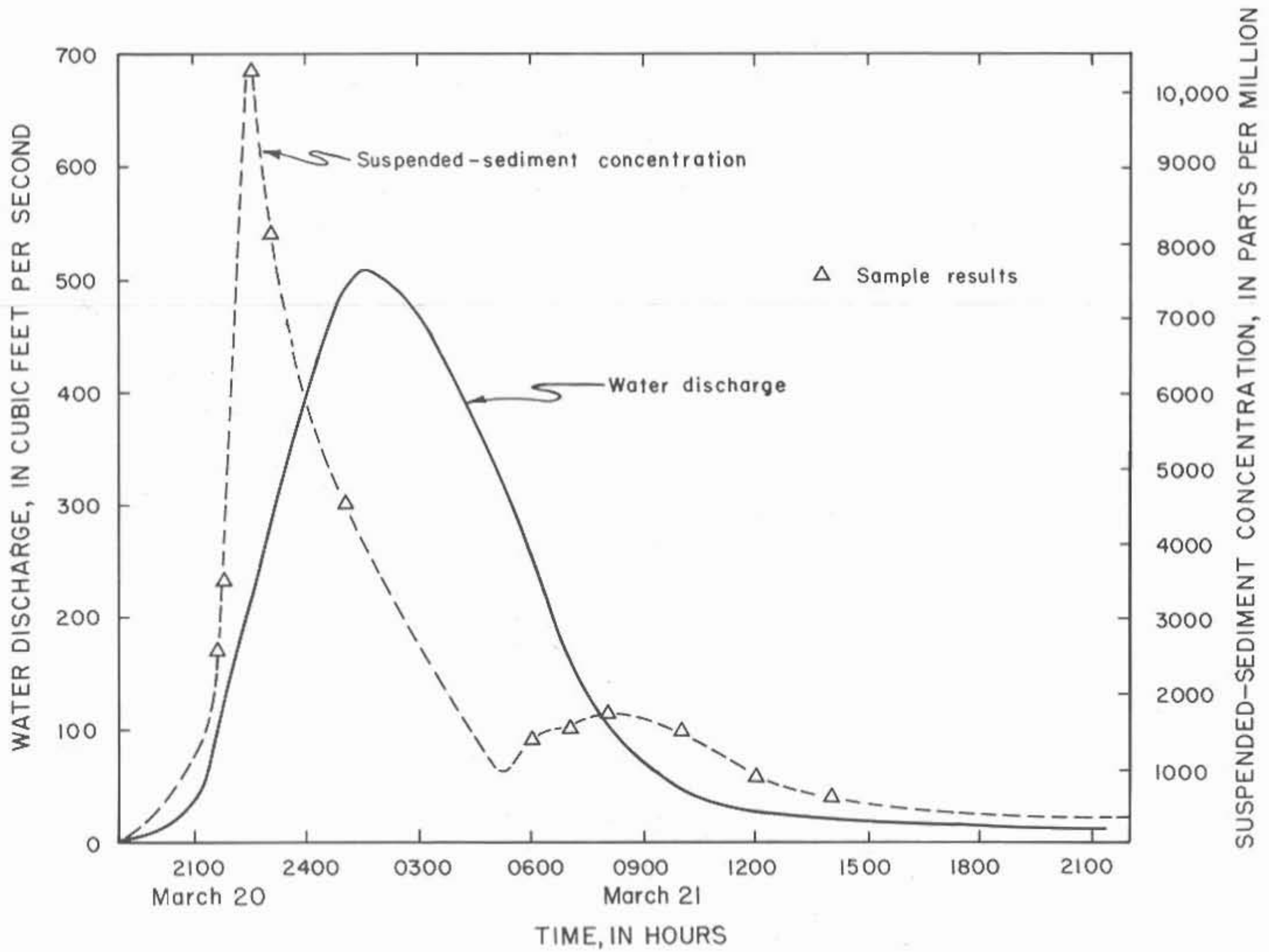

Figure 21

Water Discharge and Suspended-Sediment Concentration for Storm of March 20-21, 1957

U. S. Geological Survey in cooperation with the Texas Water Development Board

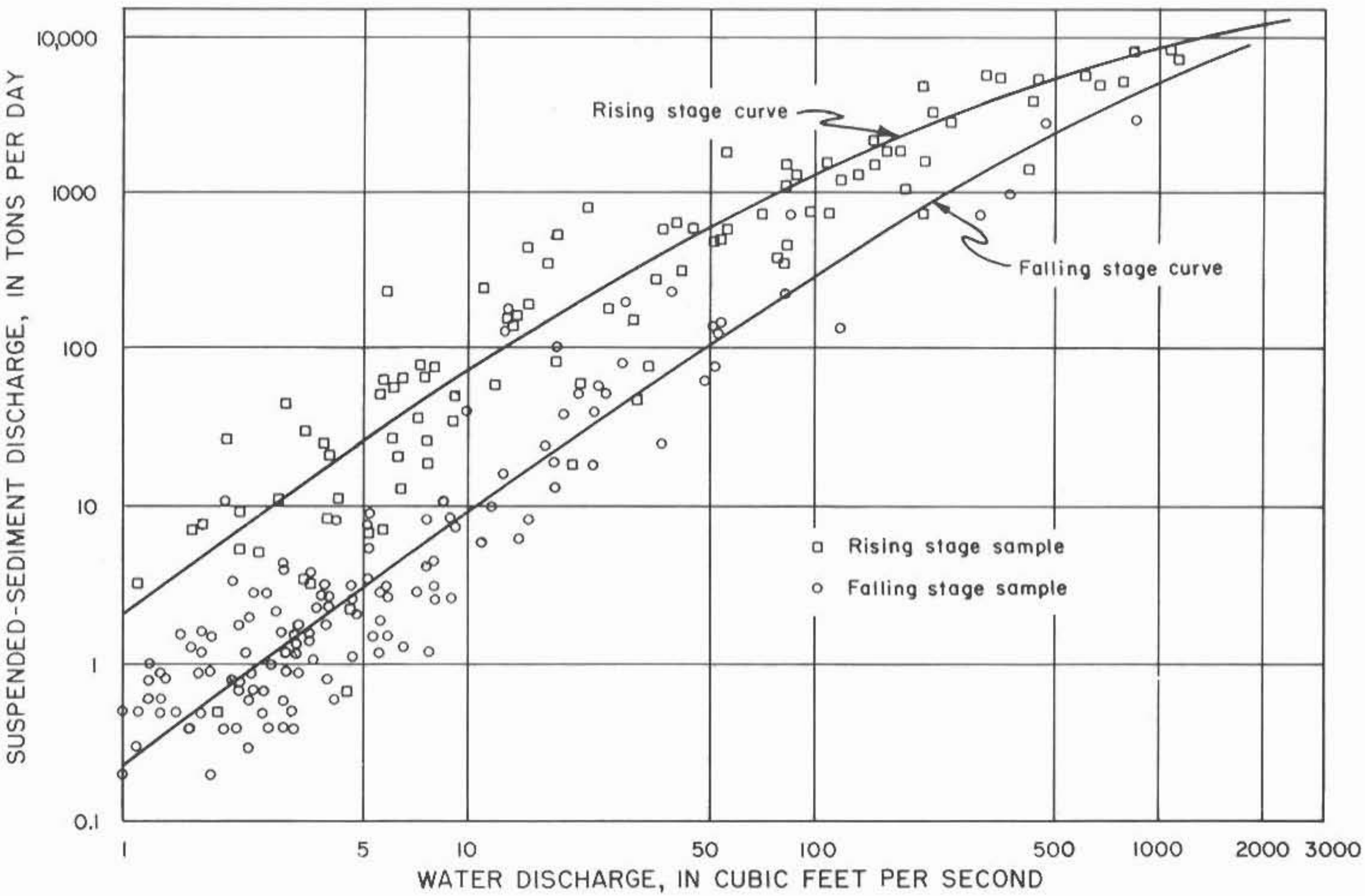

Figure 22

Relation of Suspended-Sediment Discharge to Water Discharge

U. S. Geological Survey in cooperation with the Texas Water Development Board

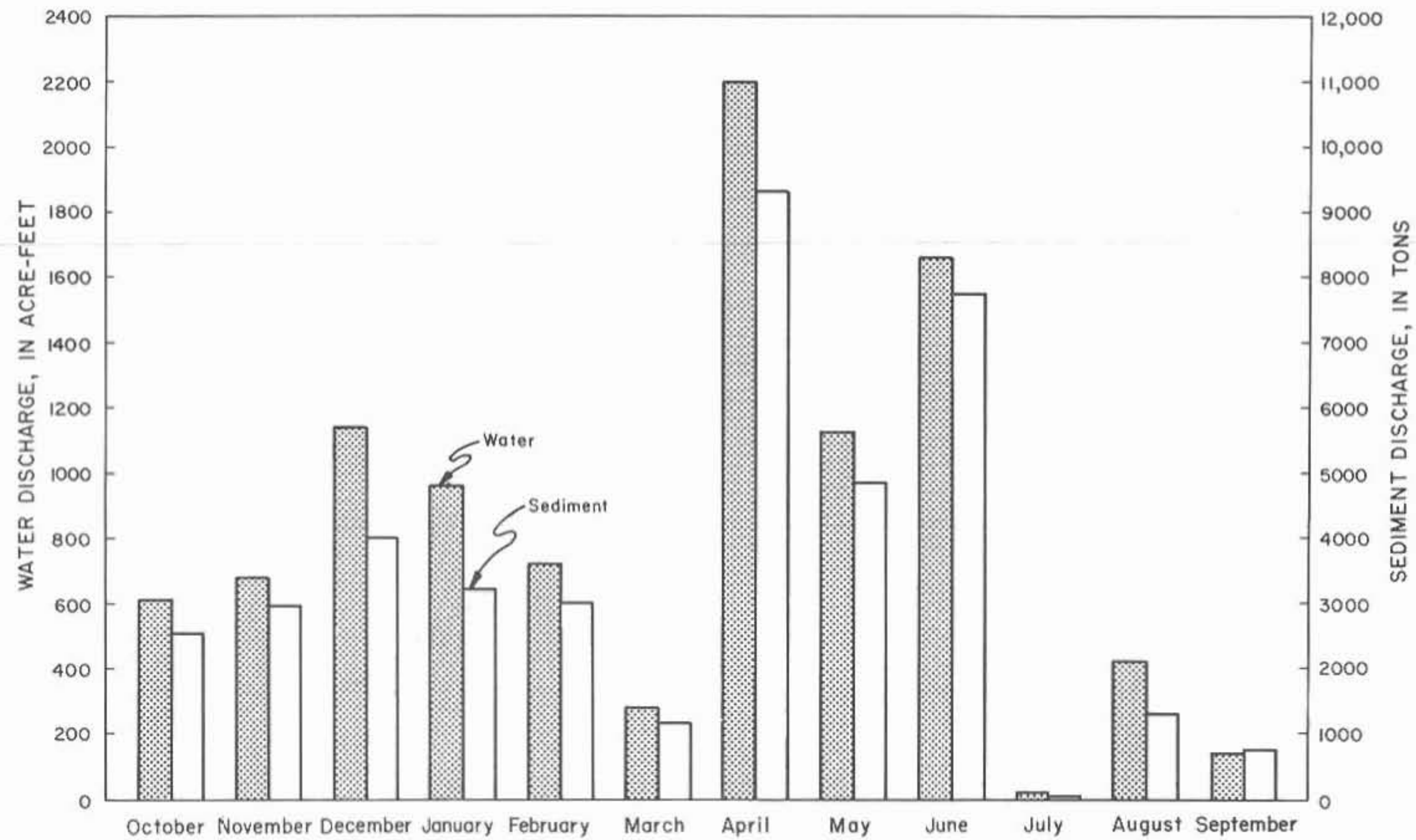

Figure 23

Average Monthly Water and Sediment Discharge, Water Years 1957-62

U.S. Geological Survey in cooperation with the Texas Water Development Board

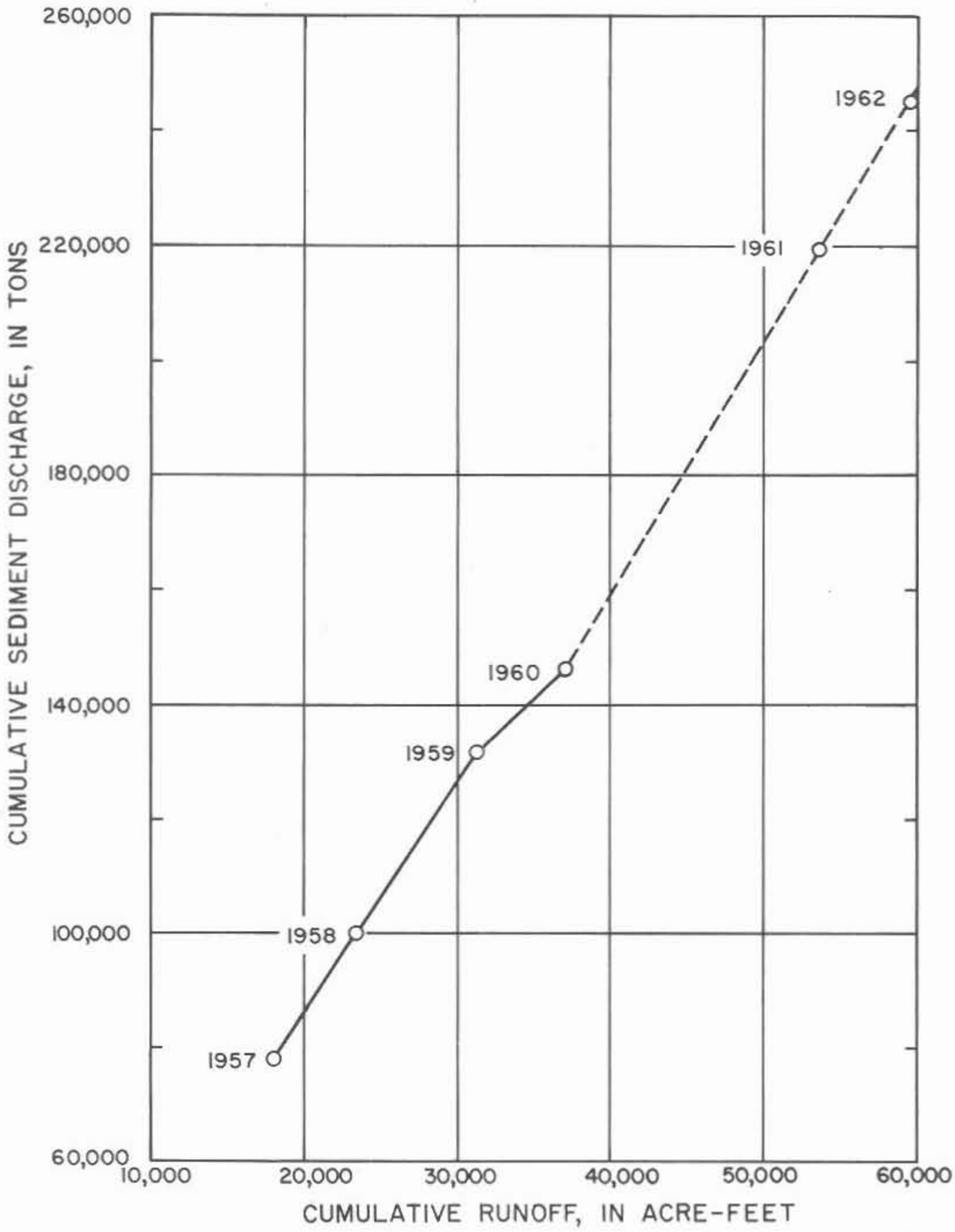

Figure 24

Relationship Between Sediment and Water Discharge for Water Years 1957 - 62

U. S. Geological Survey in cooperation with the Texas Water Development Board

No conclusive sediment-yield trends can be determined from Figure 24. For the 1961 and 1962 water years, the sediment record was estimated on the basis of the sediment-discharge water-discharge relation for the four previous water years. The 1960 water year may show a temporary trend (Figure 24); however, there are insufficient data to verify this conclusion. This trend, if it is such, is significant with that which is expected to be defined in a future comparison with data collected after development.

Size Distribution of Suspended Sediment

Particle-size distributions were determined from 80 suspended-sediment samples collected during water years 1957-60 at Pin Oak Creek (Table 7). These samples were collected for stream discharges ranging from 0.7 to 3,310 cfs. No samples were collected during the 1961 and 1962 water years.

Of the 80 samples, 15 were analyzed in native water. Analyses in native water were made to indicate the degree of flocculation which might be expected during deposition under natural conditions. The remaining 65 samples were analyzed in distilled water containing sodium hexametaphosphate as a dispersing agent so that the true particle-size distribution could be determined.

The average size-distribution of sediment particles (Figure 25) shows that 74 percent of the sediment is clay, 22 percent is silt, and 4 percent is sand. This distribution represents the suspended-sediment regimen before the watershed has been developed with floodwater-retarding structures. When several years of data are collected after the structures are in operation, analyses will be made to show any changes in sediment regimen.

Specific Weight of Sediment Deposition

The specific weight of a deposit formed from the suspended sediment that is carried into a reservoir can be computed by a formula derived by Lane and Koelzer (1943), in which the particle-size distribution, compaction time, and reservoir operation are considered. According to this formula, which has been modified to express the size distribution by weight rather than volume (Wark, J. W., and others, 1961), the initial specific weight =

$$\frac{100}{\frac{\text{percent clay}}{30} + \frac{\text{percent silt}}{65} + \frac{\text{percent sand}}{93}}$$

The percentages of clay, silt, and sand are 74, 22, and 4, respectively. Therefore, the initial specific weight of the sediment is 35 pounds per cubic foot.

Computation of the depletion rate of a reservoir caused by sedimentation requires a knowledge of how the initial specific weight of a sediment deposit will be affected by time and the method of reservoir operation. Assume that Pin Oak Creek had been depositing sediment in a reservoir for 50 years and that the reservoir was operated at a moderate drawdown. The specific weight of the sediment deposit would be:

$$W_{50} = \frac{100}{\frac{\text{Percent clay}}{46+K \log T} + \frac{\text{percent silt}}{74+K \log T} + \frac{\text{percent sand}}{93}}$$

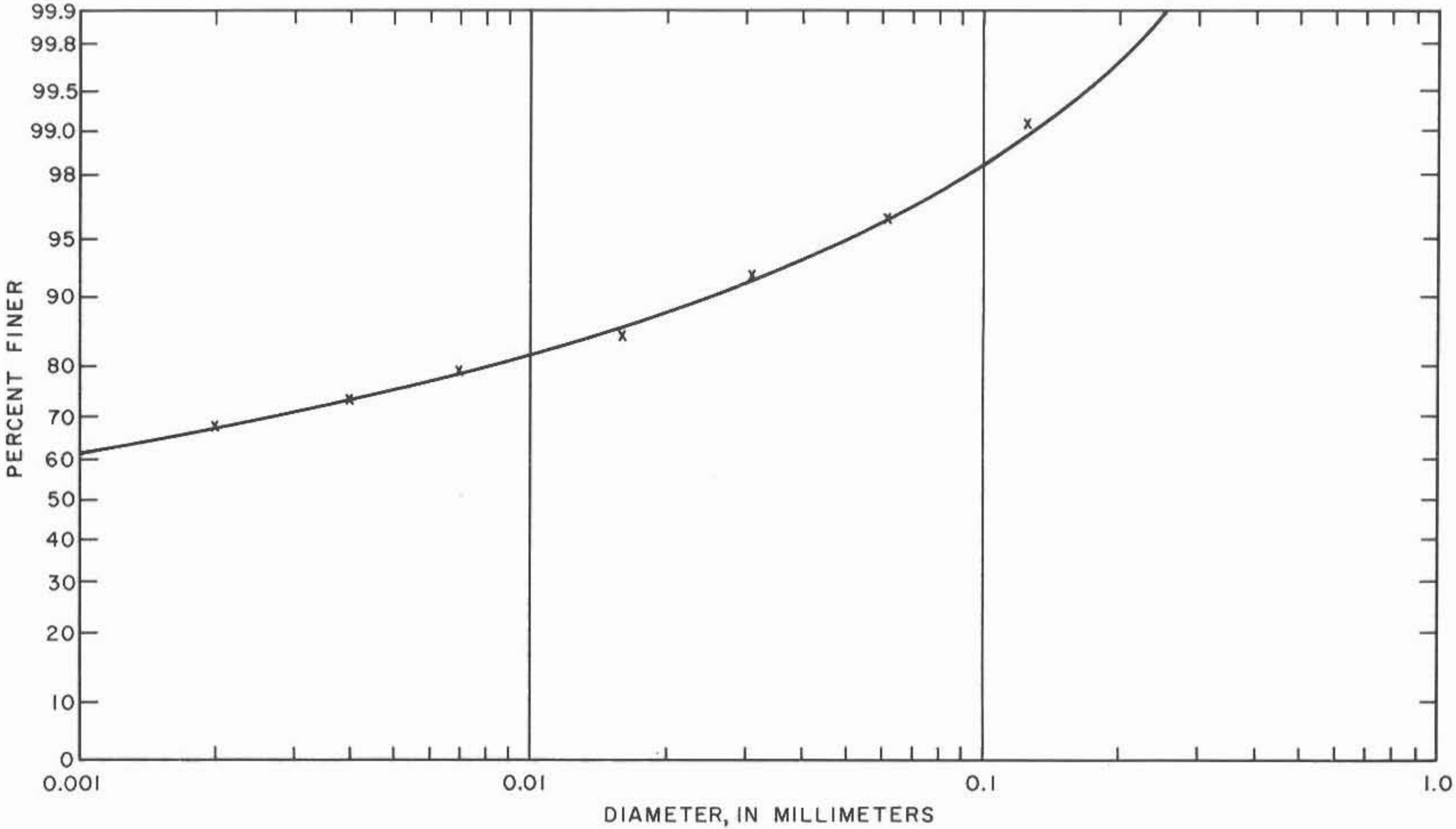

Figure 25

Average Particle Size Distribution of Suspended Sediment, Water Years, 1957-60

U. S. Geological Survey in cooperation with the Texas Water Development Board

Table 7.--Particle-size analyses of suspended-sediment samples for Pin Oak Creek near Hubbard, Texas.

[Methods of analysis: S, sieve; P, pipette; W, in distilled water; C, chemically dispersed; M, mechanically dispersed; B, bottom-withdrawal tube; N, in native water]

Date of collection	Time	Water temperature (°F)	Discharge (cfs)	Suspended sediment: Concentration of sample (ppm)	Suspended sediment: Discharge (tons per day)	Percent finer than indicated size, in millimeters: 0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	1.000	Methods of analysis
Nov. 4, 1956------	0745	--	1,030	3,740	10,400	--	77	84	90	94	97	99	100	--		SPWCM
Do.-------------	1300	--	1,870	3.040	15,300	73	81	86	92	96	97	99	100	--		SBWCM
Do.-------------	1500	--	1,470	1,840	7,300	79	86	89	93	96	97	98	99	100		SBWCM
Dec. 20-----------	1330	--	4.1	780	86	97	98	99	99	99	99	99	99	100		SBWCM
Jan. 27, 1957-----	1330	36	22	4,140	246	--	85	91	94	98	99	99	100	--		SPWCM
Feb. 1------------	0600	49	484	5,830	7,600	--	66	71	80	85	96	99	100	--		SPWCM
Mar. 17-----------	1830	62	48	1,290	1,670	76	82	84	88	90	91	93	98	100		SBWCM
Do.-------------	2230	62	258	4,670	3,250	68	73	80	87	89	95	98	99	100		SBWCM
Mar. 18-----------	1000	61	33	773	69	83	90	91	96	98	98	99	99	100		SBWCM
Mar. 21-----------	0700	57	252	1,560	1,060	70	76	81	87	94	96	99	100	--		SBWCM
Mar. 27-----------	1900	52	124	26,200	8,770	--	33	62	78	83	96	99	100	--		SPN
Do.-------------	1900	52	124	26,200	8,770	--	72	78	84	95	97	99	100	--		SPWCM
Do.-------------	2100	51	96	8,110	2,100	--	75	81	--	98	99	100	--	--		SPWCM
Mar. 31-----------	1830	60	8.5	3,920	90	79	87	89	94	96	98	99	99	100		SBWCM
Apr. 20-----------	0800	64	3,310	2,100	10,700	75	81	86	94	97	98	99	99	100		SBWCM
Do.-------------	1900	71	81	1,980	433	66	74	81	85	88	96	99	99	100		SBWCM
Apr. 23-----------	0600	63	215	6,280	3,650	--	70	73	77	88	95	99	100	--		SPWCM
Do.-------------	0700	62	988	9,070	24,200	--	70	73	82	90	98	100	--	--		SPWCM
Apr. 24-----------	1700	66	926	14,200	35,500	--	72	79	88	96	98	100	--	--		SPWCM
Do.-------------	1900	66	1,260	4,870	16,600	--	73	80	88	95	97	99	100	--		SPWCM
May 3-------------	1900	70	425	2,810	3,220	58	64	72	77	86	93	99	99	100		SBWCM
May 25------------	1900	75	96	13,500	3,500	--	13	57	70	81	98	99	100	--		SPN
Do.-------------	1900	75	96	13,500	3,500	--	62	66	72	79	99	99	100	--		SPWCM
May 31------------	0600	71	168	8,700	3,950	--	79	85	90	96	98	100	--	--		SPWCM
June 3------------	1530	73	252	15,000	10,200	--	12	69	81	91	96	99	100	--		SPN
Do.-------------	1530	73	252	15,000	10,200	--	74	82	87	94	99	99	100	--		SPWCM
Sept. 22----------	1600	71	27	2,360	172	45	65	80	92	96	98	100	--	--		SBN
Do.-------------	1600	71	27	2,360	172	67	77	82	87	93	95	97	99	100		SBWCM
Oct. 13-----------	1630	63	3.6	3,560	346	--	87	93	95	99	100	--	--	--		SPWCM
Oct. 14-----------	0730	63	50	3,840	518	--	58	90	97	99	100	--	--	--		SPN
Do.-------------	0730	63	50	3,840	518	--	84	93	98	99	100	--	--	--		SPWCM
Oct. 15-----------	2430	64	364	7,000	6,880	62	68	75	81	85	95	98	99	100		SBWCM
Nov. 8------------	0900	56	1.8	604	29	94	98	98	99	99	99	99	100	--		SBWCM
Nov. 18-----------	0630	56	57	3,770	580	23	55	90	92	94	97	100	--	--		SBN
Do.-------------	0630	56	57	3,770	580	66	74	80	86	93	97	100	--	--		SBWCM
Nov. 24-----------	0930	42	225	1,910	1,160	64	68	75	80	88	92	98	100	--		SBWCM
Mar. 23, 1958-----	0900	60	11	1,360	40	71	76	84	91	96	98	100	--	--		SBWCM
Apr. 21-----------	2030	61	142	13,600	5,210	70	77	82	86	87	98	100	--	--		SBWCM
Apr. 30-----------	0700	59	81	2,370	518	30	49	81	89	97	98	100	--	--		SBN
Do.-------------	0700	59	81	2,370	518	76	85	88	93	97	98	100	--	--		SBWCM
May 2-------------	1700	67	8	1,380	30	76	80	84	88	94	98	100	--	--		SBWCM
May 29------------	0630	72	18	2,540	1,230	74	85	90	95	96	99	100	--	--		SBWCM

Table 7.--Particle-size analyses of suspended-sediment samples for Pin Oak Creek near Hubbard, Texas.--Continued

[Methods of analysis: S, sieve; P, pipette; W, in distilled water; C, chemically dispersed; M, mechanically dispersed; B, bottom-withdrawal tube; N, in native water]

Date of collection	Time	Water temperature (°F)	Discharge (cfs)	Suspended sediment												Methods of analysis
				Concentration of sample (ppm)	Discharge (tons per day)	Percent finer than indicated size, in millimeters										
						0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	1.000	
Aug. 18, 1958-----	1130	75	74	5,840	1,170	25	38	67	81	91	95	--	99	100		SBN
Do.-------------	1130	75	74	5,840	1,170	62	71	77	86	92	95	99	100	--		SBWCM
Aug. 23----------	1330	78	9.3	1,780	45	82	91	95	98	99	100	--	--	--		BWCM
Sept. 11----------	1400	77	3.1	6,080	51	30	47	73	89	96	98	100	--	--		SBN
Do.-------------	1400	77	3.1	6,080	51	69	74	85	92	95	98	99	100	--		SBWCM
Sept. 16----------	1400	76	.7	2,770	5	83	92	96	99	100	--	--	--	--		BWCM
Sept. 22----------	1600	76	765	4,050	8,370	17	13	82	88	93	96	99	100	--		SBN
Do.-------------	1600	76	765	4,050	8,370	72	83	86	91	94	96	99	100	--		SBWCM
Oct. 9------------	0700	70	15	2,640	111	37	64	87	95	98	99	99	100	--		SBN
Do.-------------	0700	70	15	2,640	111	79	89	93	95	96	99	100	--	--		SBWCM
Nov. 28-----------	0753	42	40	2,080	225	71	78	85	88	93	96	99	100	--		SBWCM
Feb. 14, 1959-----	1516	60	166	2,000	896	62	70	76	82	89	96	98	99	100		SBWCM
Apr. 10-----------	0657	--	21	6,050	343	6	10	68	96	96	97	98	99	100		SBN
Do.-------------	0657	--	21	6,050	343	74	85	90	94	97	98	99	100	--		SBWCM
Apr. 11-----------	1150	53	508	5,020	6,890	63	71	76	81	89	94	99	100	--		SBWCM
Apr. 19-----------	1449	69	310	5,380	4,500	72	83	88	94	97	99	99	100	--		SBWCM
May 11------------	0642	62	1,100	9,920	29,500	68	72	79	88	92	96	99	100	--		SBWCM
May 23------------	1655	70	14	1,860	70	83	94	98	100	--	--	--	--	--		BWCM
May 24------------	0740	68	186	3,680	1,850	62	68	75	81	86	95	99	100	--		SBWCM
June 5------------	1130	70	281	3,940	2,990	27	44	57	74	90	98	100	--	--		SBN
Do.-------------	1130	70	281	3,940	2,990	68	70	75	83	93	99	100	--	--		SBWCM
June 22-----------	1044	72	1,800	2,000	9,720	71	83	89	92	95	98	98	100	--		BWCM
July 21-----------	1550	78	14	3,540	134	79	98	98	98	99	99	100	--	--		BWCM
July 27-----------	1840	76	25	6,500	439	--	84	90	96	100	--	--	--	--		SPWCM
Oct. 4------------	0820	70	1,340	3,640	13,200	16	20	65	76	89	93	99	100	--		SBN
Do.-------------	0820	70	1,340	3,640	13,200	62	72	77	84	92	95	99	100	--		SBWCM
Nov. 4------------	1300	68	245	896	593	84	87	91	95	99	99	100	--	--		SBWCM
Dec. 15-----------	1535	58	988	1,670	4,450	64	69	76	79	87	93	98	99	100		SBWCM
Dec. 31-----------	1600	42	434	3,120	3,660	--	65	69	71	83	91	99	100	--		SPWCM
Jan. 1, 1960------	1400	38	364	1,920	1,890	14	37	61	68	83	93	97	99	100		SBN
Do.-------------	1400	38	364	1,920	1,890	36	62	69	74	82	92	98	100	--		SBWCM
Feb. 3------------	0930	49	32	2,550	220	--	80	83	88	95	99	100	--	--		SPWCM
Apr. 28-----------	0620	66	35	1,940	183	83	83	89	94	97	99	100	--	--		SBWCM
Apr. 29-----------	1415	64	144	13,800	5,370	--	74	78	83	91	95	99	100	--		SPWCM
May 5-------------	0730	68	264	2,170	1,550	--	82	83	85	93	97	99	100	--		SPWCM
June 26-----------	0800	71	186	3,310	1,660	--	79	85	89	93	97	99	100	--		SPWCM
Aug. 21-----------	1000	73	1	2,440	7	--	65	--	80	--	98	99	100	--		SPWCM
Do.-------------	0130	83	92	5,840	1,450	--	51	--	70	--	92	98	100	--		SPWCM

where: W_{50} is specific weight of sediment after 50 years of compaction,

K is the coefficient of compaction,

T is the time in years,

and the constants 46, 74, and 93 represent the specific weight of clay, silt, and sand, respectively, in pounds per cubic foot. The specific weight of the sediment deposit after 50 years of compaction would be 68 pounds per cubic foot.

Water Quality

The results of chemical analyses of five samples collected from Pin Oak Creek near Hubbard in 1956-58 are shown in Table 8. These data indicate that the dissolved-solids content of the samples ranged from 89 to 430 ppm and that the water is a calcium-bicarbonate type. Calcium bicarbonate ions in the water tend to increase the rate of flocculation of clay particles, thus accelerating their settling in a reservoir.

The water has a low-sodium (alkali) hazard and a low to medium salinity hazard; therefore, it should be suitable for irrigation in this area. The chemical constituents of the water meet the limits set by the U.S. Public Health Service for drinking water standards, and with a minimum of treatment the water would be suitable for most industrial uses.

Water Budget of Study Area

Water-Accounting Method

To properly evaluate the hydrology of a watershed, the factors which comprise the water budget should be determined from a representative climatic cycle. Data, therefore, should include the extremes of runoff as well as periods of normal runoff. Water years 1957-62 covered in this report represent an above-normal (annual long-term normal is 37.06 inches at Corsicana) period of rainfall and runoff. The 1957 water year was extremely wet with 52.95 inches of rainfall.

The accounting for water which enters and leaves a watershed is the conception of a water budget used in this report. A simple accounting method used for the Pin Oak Creek study area prior to development of floodwater-retarding structures is:

$$C = R - Q$$

where: C is the total water consumption in the study area,

R is the average rainfall on the study area (snowfall is very minor), and

Q is the amount of outflow from the study area.

Consumption (C) is defined as the difference between rainfall (R) and runoff (Q) within the study area. However, consumption encompasses such factors

Table 8.--Chemical analyses of Pin Oak Creek near Hubbard, Texas.

[All data except specific conductance and pH are in parts per million. Analyses by U.S. Geological Survey.]

Date of collection	Discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Non-carbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH
Nov. 4-5, 1956--------		6.6	0.08	23	2.0	5.5	2.6	78		11	1.8	0.5	2.0		101	0.14		65	1	0.3	159	7.6
Oct. 15-20, 1957------		12		32	2.5	14		97		29	4.8	.6	2.2		158	.21		90	11	.6	237	7.7
Aug. 24, 1958---------		7.8		22	1.4	4.8	3.0	73		8.6	1.5	.4	3.5		89	.12		61	8	.3	144	7.8
Aug. 26-30------------		17		58	6.8	77		202	9	96	40	.6	1.5		430	.58		172	0	2.5	641	8.4
Sept. 11-12-----------		15		34	2.9	36		112		61	10	.7	3.5		218	.30		97	5	1.6	346	8.1

as infiltration, evaporation, and transpiration. Data were not available to separate these factors.

In this study area, water entering (R) and water leaving (Q) can be determined quite accurately. Water entering the study area is measured by the rain-gage network having an average density of one gage for every 3.5 square miles. The outflow from the study area is determined from a continuous recording of streamflow. Because there is no base flow in the study area, Q is the surface runoff as recorded at the stream-gaging station.

Inflow, Outflow, and Consumption

Table 9 shows the water budget for Pin Oak Creek near Hubbard for the period October 1956 through September 1962.

Annual consumption ranged from a minimum of 64 percent of rainfall for the 1957 and 1961 water years (the two water years of highest precipitation) to a maximum of 86 percent for the 1958 water year. The total consumption for this six-year period amounted to 191.32 inches, or about 76 percent of the 254.82 inches of total rainfall over the study area. This six-year average percent is probably lower than that to be expected over a long period as above-average rainfall occurred during the 1957-62 water years. Note that for the 1959 and 1960 water years (the two water years approaching the long-term normal precipitation of 37.06 inches), the percentages of rainfall consumed are 77 and 84, respectively.

Seasonal Consumption Relationships

Figure 26 is a graphical illustration of the seasonal variation of the average monthly consumption for the six years of record. From this graph it may be seen that numerous seasonal variables (precipitation; temperature changes; rate of growth, type, and abundance of vegetation; farming practices; antecedent precipitation conditions; evapotranspiration; and soil-moisture absorption and releases rates) affect seasonal changes in consumption. Generally, Figure 26 shows that as precipitation increases a decrease occurs in percent of rainfall consumed; as temperature increases, an increase occurs in percent of rainfall consumed.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The soils and the geologic rock units in the Pin Oak creek study area have a very low permeability and probably affect the rainfall-runoff relationship, suspended-sediment size-distribution and yield, base flow, watershed consumption, and streamflow duration. Small alluvial deposits, which are relatively thin in the study area, seem to have no significant effect upon runoff or recharge.

An analysis of the rain-gage network for the study area shows that two-thirds of the time one centrally located rain area recorded within +15 and -13 percent of the average rainfall measured at all five gages. Two-gage combinations (extreme east-west and extreme north-south rain gages) were found to increase the accuracy to +11 and -10 percent, and to +12 and -11 percent,

Table 9.--Water budgets for Pin Oak Creek watershed, water years 1957-62.

Monthly budgets

Month and year		Average rainfall (inches)	Runoff (inches)	Watershed consumption		Average daily temperature[a]	
				Inches	Percent	Maximum (°F)	Minimum (°F)
October	1956	[b] 1.86	0	1.86	100	85.3	56.3
	1957	5.36	.69	4.67	87	73.4	50.1
	1958	2.61	.10	2.51	96	75.6	55.4
	1959	8.41	2.02	6.39	76	79.4	54.8
	1960	6.48	1.05	5.43	84	82.0	59.9
	1961	3.05	.01	3.04	100	79.7	54.2
Average		4.63	.64	3.98	86	79.2	55.1
November	1956	[b] 6.58	1.85	4.73	72	64.7	38.4
	1957	4.02	.36	3.66	91	61.8	43.5
	1958	2.18	.05	2.13	98	70.8	44.9
	1959	1.51	.09	1.42	94	64.6	37.4
	1960	1.90	.11	1.79	94	70.4	45.5
	1961	5.43	2.01	3.42	63	65.0	43.3
Average		3.60	.74	2.86	79	66.2	42.2
December	1956	1.90	.01	1.89	99	62.9	38.5
	1957	.83	0	.83	100	64.1	39.9
	1958	1.28	.04	1.24	97	56.4	31.9
	1959	4.76	1.66	3.10	65	61.8	40.1
	1960	7.87	4.74	3.13	40	53.3	36.1
	1961	2.83	.81	2.02	71	56.8	37.1
Average		3.24	1.21	2.04	62	59.2	37.3
January	1957	1.78	.05	1.73	97	53.4	35.1
	1958	2.44	.06	2.38	98	55.4	33.7
	1959	.37	.01	.36	97	53.3	30.3
	1960	2.23	1.06	1.17	52	53.9	36.7
	1961	6.07	4.92	1.15	19	52.8	31.7
	1962	.92	.03	.89	97	49.3	26.5
Average		2.30	1.02	1.28	56	53.0	32.3
February	1957	2.56	.42	2.14	84	62.8	45.6
	1958	1.97	.06	1.91	97	53.5	34.9
	1959	3.03	.79	2.24	74	57.1	38.5
	1960	1.96	.19	1.77	90	54.9	32.7
	1961	4.65	2.55	2.10	45	63.3	42.1
	1962	3.15	.57	2.58	83	--	--
Average		2.89	.76	2.12	73	58.3	38.8
March	1957	4.63	.83	3.80	82	64.5	42.0
	1958	1.74	.01	1.73	99	59.5	40.8
	1959	1.15	.05	1.10	96	69.0	40.6
	1960	1.58	.14	1.44	91	60.3	39.1
	1961	3.17	.69	2.48	78	72.2	49.1
	1962	1.17	.12	1.05	90	65.1	41.4
Average		2.24	.31	1.93	87	65.1	42.2

Monthly budgets

Month and year		Average rainfall (inches)	Runoff (inches)	Watershed consumption		Average daily temperature[a]	
				Inches	Percent	Maximum (°F)	Minimum (°F)
April	1957	15.65	10.48	5.17	33	71.6	52.1
	1958	4.11	.26	3.85	94	72.9	51.5
	1959	4.74	1.16	3.58	76	73.0	50.8
	1960	3.01	.23	2.78	92	81.0	56.4
	1961	1.94	.23	1.71	88	76.5	51.6
	1962	5.93	1.62	4.31	73	74.1	53.3
Average		5.90	2.33	3.57	61	74.8	52.6
May	1957	8.24	3.79	4.45	54	81.4	61.9
	1958	3.62	1.27	2.35	65	85.3	61.5
	1959	6.47	1.72	4.75	73	84.0	65.5
	1960	2.45	.15	2.30	94	84.2	59.2
	1961	2.02	.02	2.00	99	84.5	62.4
	1962	2.83	.18	2.65	94	86.1	64.5
Average		4.27	1.19	3.08	72	84.2	62.5
June	1957	3.57	1.47	2.10	59	89.1	68.8
	1958	2.11	0	2.11	100	94.0	70.8
	1959	9.29	4.60	4.69	50	89.2	69.0
	1960	4.46	.28	4.18	94	94.6	69.7
	1961	9.69	3.33	6.36	66	87.1	68.5
	1962	5.90	.84	5.06	86	89.1	68.7
Average		5.84	1.75	4.08	70	90.5	69.2
July	1957	.04	0	.04	100	100.0	73.7
	1958	1.16	0	1.16	100	97.4	73.9
	1959	2.98	.08	2.90	97	93.5	72.1
	1960	.20	0	.20	100	97.9	73.7
	1961	1.49	.02	1.47	99	90.4	72.4
	1962	.12	0	.12	100	95.3	73.0
Average		1.00	.02	.98	98	95.8	73.1
August	1957	.64	0	.64	100	96.3	70.1
	1958	9.21	2.45	6.76	73	98.0	72.3
	1959	1.38	0	1.38	100	97.0	72.5
	1960	5.95	.29	5.66	95	96.8	73.3
	1961	.45	0	.45	100	95.1	70.3
	1962	.11	0	.11	100	99.7	73.3
Average		2.96	.46	2.50	84	97.2	72.0
September	1957	5.55	.01	5.54	100	87.6	61.4
	1958	5.30	.69	4.61	87	87.7	68.6
	1959	1.24	0	1.24	100	92.9	67.7
	1960	1.35	0	1.35	100	93.8	66.9
	1961	4.24	.12	4.12	97	89.3	67.3
	1962	3.95	.06	3.89	98	89.7	67.7
Average		3.60	.15	3.46	96	90.2	66.6

Summary of Budgets

Water year	1957	1958	1959	1960	1961	1962	Average
Rainfall, in inches	53.00	41.87	36.72	37.87	49.97	35.39	42.47
Runoff, in inches	18.91	5.85	8.60	6.11	17.78	6.25	10.58
Consumption, in inches	34.09	36.02	28.12	31.76	32.19	29.14	31.89
Consumption, in percent	64	86	77	84	64	82	76

[a] Temperatures at U.S. Weather Bureau station at Corsicana, approximately 24 miles northeast of study area.

[b] Rainfall at U.S. Weather Bureau rain gage at Dawson, approximately 5 miles northeast of study area.

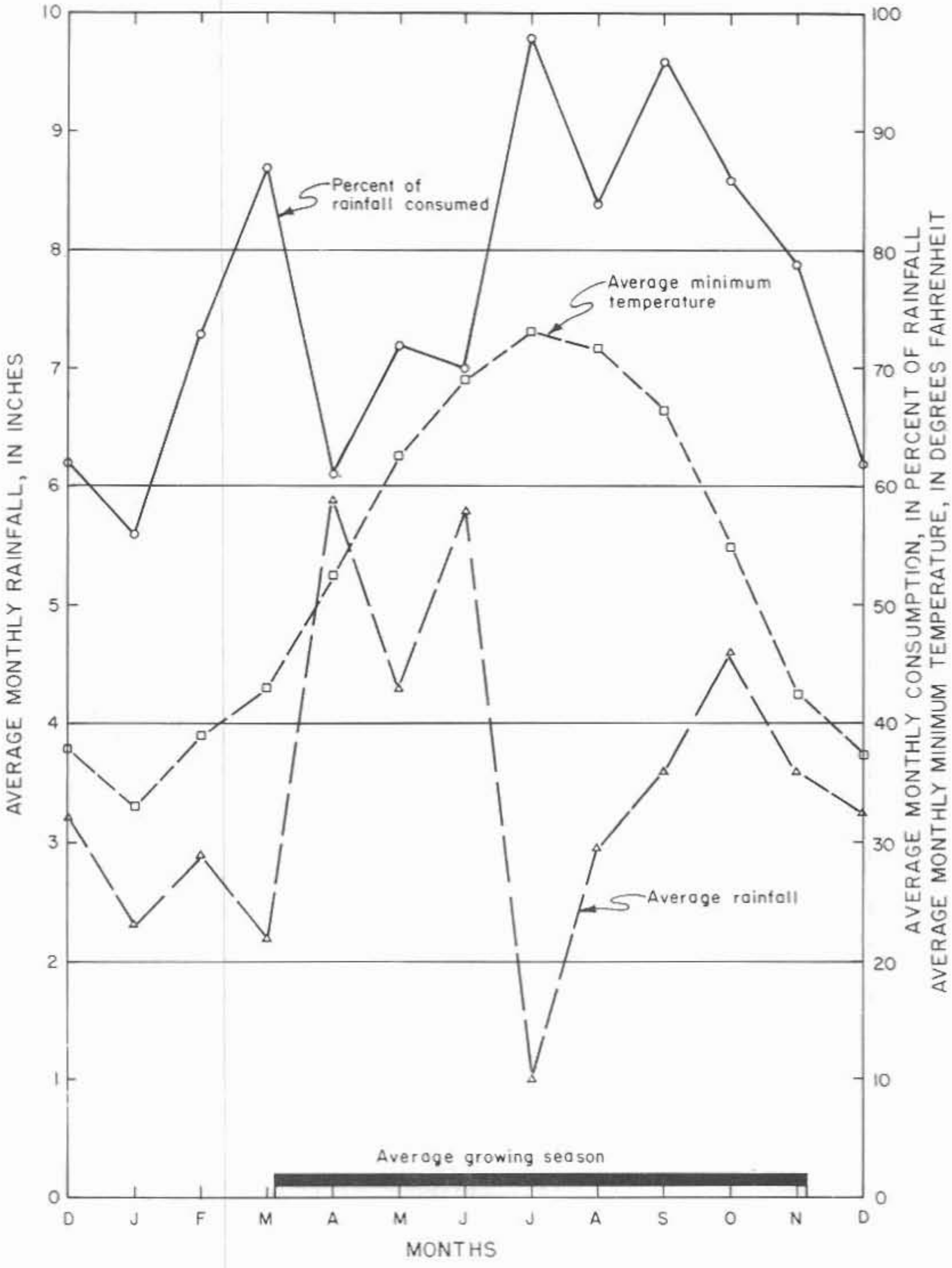

Figure 26

Average Monthly Variations in Watershed Consumption, Rainfall, and Temperature for the Water Years 1957-62

U. S. Geological Survey in cooperation with the Texas Water Development Board

respectively. The maximum scatter occurs when the average storm rainfall is less than 1 inch. The five rain gages in the study area seem to compose a reliable rain-gage network having a density of one gage for every 3.5 square miles. However, the tipping-bucket gage (data obtained was generally unreliable and, therefore, not used in this report) at the stream-gaging station should be replaced with a float-operated recording gage. This addition of a reliable rain gage would increase the rain-gage density and would aid in the evaluation of after-development conditions.

Rainfall magnitude and frequency curves were developed for this study area from long-term Weather Bureau data. A plot of rainfall for the storms experienced in the study area on these frequency curves indicated that no unusually large storm occurred during the period of record. It is probable that the period of record (1956-62) experienced above-average runoff (10.58 inches per year) from above average rainfall (42.47 inches per year). The rainfall magnitude and frequency analysis was extended to afford an estimate of rainfall in the study area from sequential storm periods for 1 to 15 days. The probable magnitude and frequency of sequential storm periods should be an important factor to be considered in future operation of flood-control reservoirs located in the vicinity of watersheds developed with numerous floodwater-retarding structures. Reliability of the sequential recurrence procedure is within ±15 percent.

Sufficient streamflow data have not been collected in the study area for a reliable flood-frequency analysis.

Although the Pin Oak Creek study area appears to be geologically and hydrologically uniform and simple, two rather distinct unit-hydrograph durations were found. The two average unit hydrographs are attributed to the two types of storms that occur in the basin. One average unit-hydrograph developed shows the effects of frontal-type, long-duration storms. The other average unit-hydrograph developed shows the effects of the short-duration convective thunderstorm which is common to the study area.

The coaxial rainfall-runoff relationship derived for this study area seems to be reliable enough to show accurately changes expected in the relationship after the watershed is developed with floodwater-retarding structures. Most of the antecedent conditions were directly related to seasonal changes.

The flow-duration analysis indicated that for 50 percent of the days in the six-year period of record there was no streamflow out of the study area. After development of the watershed with floodwater-retarding structures, the flow-duration curve should show extensive changes. Definition of these changes will afford an accurate evaluation of the effects the structures have on the regimen of downstream streamflow.

During the study period the total sediment yield of the study area was 246,000 tons, which is equivalent to a computed 3.1 acre-feet per square mile per year. The initial specific weight of the sediment in Pin Oak Creek was found to be 35 pounds per cubic foot. Average particle size-distribution analyses showed the suspended sediment to be 74 percent clay, 22 percent silt, and 4 percent sand. Continued sediment studies in the watershed will show the effects of the floodwater-retarding structures on the sediment regimen.

Chemical analyses of the streamflow show that the water is suitable for irrigation in the study area. The analyses also found that the chemical constituents of the water meet the limits set by the U.S. Public Health Service for drinking water standards, and with little treatment the water would be suitable for most industrial uses. The dissolved-solids content ranged from 89 to 430 ppm.

The water budget for the study area showed that the minimum annual consumption was 64 percent of the rainfall which occurred during the 1957 and 1961 water years, which were the two years with highest precipitation. The maximum annual consumption was 86 percent of the rainfall in the 1958 water year. The total consumption for this six-year study period was 191.32 inches, or about 76 percent of the 254.82 inches of rainfall on the study area. Runoff during the six-year period averaged 10.58 inches per year.

To provide more complete hydrologic data on similar pilot watershed projects, it is recommended that two ground-water observation wells be operated for a period of years adjacent to at least one proposed reservoir before construction and for several years after construction. Recording ground-water fluctuations before and after development would provide a basis for evaluating recharge, if any, from the reservoirs. An aquifer pumping test should be made to determine the permeability of the rock units and the recharge effects of the reservoirs.