Low-Flow Characteristics of Streams in the Mississippi Embayment in Southern Arkansas, Northern Louisiana and Northeastern Texas

By PAUL R. SPEER, MARION S. HINES, A. J. CALANDRO, *and others*

With a section on QUALITY OF THE WATER

By H. G. JEFFERY

WATER RESOURCES OF THE MISSISSIPPI EMBAYMENT

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The magnitude, duration, frequency of recurrence, and chemical composition of low flows

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LOW-FLOW CHARACTERISTICS OF STREAMS IN THE MISSISSIPPI EMBAYMENT IN SOUTHERN ARKANSAS, NORTHERN LOUISIANA, AND NORTHEASTERN TEXAS

By Paul R. Speer, Marion S. Hines, A. J. Calandro, and others

ABSTRACT

The low-flow characteristics of a stream largely govern the type and economics of its utilization. The magnitude, duration, and frequency of low flows included in this report are used both to determine whether a water-utilization project can be operated without storage, and if not, to determine the amount of storage required to provide the minimum flow needed.

When direct runoff from precipitation ceases, the flow of streams is governed by the volume of water in ground storage and by the rate at which the ground water discharges into the stream. The character and distribution of the geologic formations within stream basins exert a major influence on the quality and quantity of the low flows of streams.

Manmade changes to the land and to the stream systems probably have altered the regimen of flow of many streams.

Limited low-flow data, in cubic feet per second per square mile, for 50 daily-record gaging stations and 106 partial-record gaging stations, are summarized for ready comparison. The summary gives the minimum average 7- and 30-day discharges that may be expected to recur at 2- and 10-year intervals and gives the flow at the 90- and 95-percent duration points. More detailed data on the magnitude and frequency of low flows and on flow duration, in cubic feet per second, are given for the 50 daily-record gaging stations.

The 7-day low flows at the 2-year recurrence interval, expressed on a per-square-mile basis, are used to demonstrate areal variations of low flow in the study area. These low-flow indices range from 0 to 0.20 cubic foot per second per square mile.

Drafts that may be made from specified amounts of storage with a chance of deficiency of once in 10 or 20 years on a long-term average are related to the 7-day 2-year low flow to permit preliminary estimates to be made of the storage required to supplement natural low flows.

Chemical analyses of the surface water, as determined from samples collected at 36 sites during low-flow periods, show that the dissolved solids range from 12 to 12,900 ppm (parts per million); hardness ranges from 6 to 1,010 ppm; and the iron content ranges from 0.00 to 1.2 ppm. The higher values of dissolved solids and of hardness are from streams that contain oil-field wastes. Exclusive of these streams, the dissolved solids range from 12 to 855 ppm, and the hardness ranges from 6 to 433 ppm. The surface waters in the study area generally would be suitable without treatment for certain uses, such as cooling, but for municipal and most industrial uses, the waters would require some treatment.

The results of the study suggest fields for further investigation to define additional phases of the hydrologic systems and to determine the effect that manmade changes to the stream systems may have on the low flows of the streams and on the ground-water systems.

INTRODUCTION

In the Mississippi embayment in southern Arkansas, northern Louisiana, and northeastern Texas, large supplies of fresh water are available from both surface and underground sources. The area has a high average annual precipitation and in addition, several major streams originate outside the area. The water resources of the area, therefore, are more than ample to meet the needs for many years in the future, and the anticipated problems in water supply are those of distribution and providing storage to meet the demands.

In the past, many parts of the area have been subjected to devastating floods, and much attention has been centered on flood control, drainage, and improving the channel hydraulics of the streams. In recent years, however, rapid economic development within the study area has resulted in an increased consumptive use of water, to the extent that serious shortages have occurred during periods of low streamflow. Knowledge of the areal availability of water during critical periods of low flow is paramount to the orderly economic growth of the area.

The flow characteristics of a stream and the chemical, physical, and biological properties of its water are the basis for utilizing its flow, and these factors exert a major influence on the economics of its development. These characteristics vary with time, with location, and with manmade changes. Of particular significance for utilization of a stream are the magnitude of the low flow, the duration and frequency of a specified discharge, and the quality of the water during the low-flow periods. The low-flow characteristics in this report include amounts of water available for use without storage, and these amounts also may be used to estimate the storage required to provide the minimum flow needed; included also is an indication of the chemical quality of the water in the streams during low flow.

Streamflow records used in the analysis for this report were collected over a period of many years by the U.S. Geological Survey in cooperation with the Arkansas Geological Commission, the Louisiana Department of Public Works, the Louisiana Department of Highways, the Texas Water Commission, and the Sabine River Compact Administration. Other records were obtained through cooperation with Federal agencies—the Army Corps of Engineers, the Mississippi River Commission, and the Public Health Service. The records were processed by electronic computer in the Washington office of the U.S. Geological Survey under the direction of W. L. Isherwood, hydraulic engineer.

The records were analyzed and the part of this report that concerns streams in the three States was prepared by the following: For southern Arkansas and northeastern Texas, Marion S. Hines, assisted by L. D. Hauth and John Sullavan, under the general direction of John L. Saunders, succeeded by I. D. Yost, district engineer; and for northern Louisiana, A. J. Calandro, under the technical supervision of Leland V. Page, and under the general direction of F. N. Hansen, district engineer. Technical supervision of quality-of-water analyses and preparation of the section of the report on "Quality of the water" were under the direction of J. H. Hubble, district chemist. Other parts of the report were prepared, the results coordinated and reviewed, and the report assembled by Paul R. Speer, staff engineer. Technical guidance on analytical procedure and format was provided by C. H. Hardison, staff engineer. The report was prepared under the direction of E. M. Cushing.

The principal authors gratefully acknowledge the assistance of E. M. Cushing, R. L. Hosman, and A. T. Long, who prepared the subsection on "Geology," participated in the determination of the geologic units contributing to the low flows of the streams, reviewed the section on "Factors affecting low flow," and offered many helpful suggestions which have been incorporated into the report.

PURPOSE AND SCOPE

The purpose of the current phase of the investigations in the Mississippi embayment is to define the hydrologic systems. Because most of the area is underlain by aquifers which yield large quantities of water to wells, ground water is the most readily available source of fresh-water supply in the embayment. Surface waters are available to those users who have access to the streams. In defining the hydrologic systems of the area, ground water and the low flows of the surface water are virtually one water and cannot be separated. The results of the studies on surface water and the results of the studies on ground water, published as separate chapters of this professional-paper series, complement each other in the definition of the hydrologic systems.

The purpose of this chapter is to present data that will facilitate evaluation of the characteristics of the low flow of the streams within the embayment in southern Arkansas, northern Louisiana, and northeastern Texas. It deals with surface water and with the relation of the underlying aquifers to low streamflow. The low-flow characteristics of streams at 156 sites in the study area are given in this chapter. Other chapters of this series contain similar data for other parts of the embayment (fig. 1).

Data essential to the planned development of water resources include: the magnitude of the low flow, the length of the period that a specific discharge continues or is not exceeded, the frequency at which this discharge recurs, and the quality of the water during the low-flow periods. These data also are useful in the determination of the recurrence of flows that are qualitatively unsuitable for specific uses and in the determination of the economic feasibility of designing storage capacity needed to produce certain minimum flows of acceptable minimum quality. The data included herein will enable designers to determine the magnitude and frequency of low flows at specific sites at the same time that they study the economics of development.

The data presented for specific sites consist of (1) frequency data showing the average intervals, in years, between low-flow discharges for periods of selected length, (2) flow-duration data showing the percentage of the reference period during which the flow equaled or exceeded given rates of flow, and (3) chemical quality of the stream water at various sites during low flow.

DEFINITION OF TERMS

Most of the hydrologic terms used in this report are defined by Langbein and Iseri (1960). Other selected terms, as used in this report, are defined as follows:

Aquifer. A formation, group of formations, or part of a formation that is water bearing.

Climatic year. The year beginning April 1 and ending March 31 of the following calendar year.

Low-flow frequency curve. A graph showing as abscissa the recurrence interval (average return period), in years, at which the lowest mean flow for a selected number of days during a climatic year may be expected to be no greater than a specified discharge, plotted as ordinate.

Low-flow index. The median annual 7-day low flow, in cubic feet per second per square mile.

Median annual 7-day low flow. The annual 7-day low flow having a recurrence interval of 2 years (7-day 2-year low flow); that is, the mean flow for 7 consecutive days to be expected as an annual minimum 1 year out of 2, on the average.

Partial-record station. A particular site on a stream at which limited streamflow data, usually consisting of sufficient streamflow measurements to establish a low-flow relation with the daily record at a nearby station, are collected over a period of years for use in hydrologic analyses.

DESCRIPTION OF THE AREA

The area of the embayment covered by this chapter (fig. 1) includes 21,000 square miles in southern Arkansas, 11,100 square miles in northern Louisiana, and 4,000 square miles in northeastern Texas.

Drainage from the area is to the Mississippi River and its tributary basins. The principal tributary basins are Bayou Bartholomew and the lower ends of the St. Francis, White, Arkansas, Ouachita, and Red Rivers. The natural stream patterns are extremely irregular and meandering. The channels have fairly flat slopes and are interspersed with abandoned channels and water courses. The streams are sluggish. Many of the channels have been altered by man to facilitate drainage of the land and to improve the hydraulics of the channels.

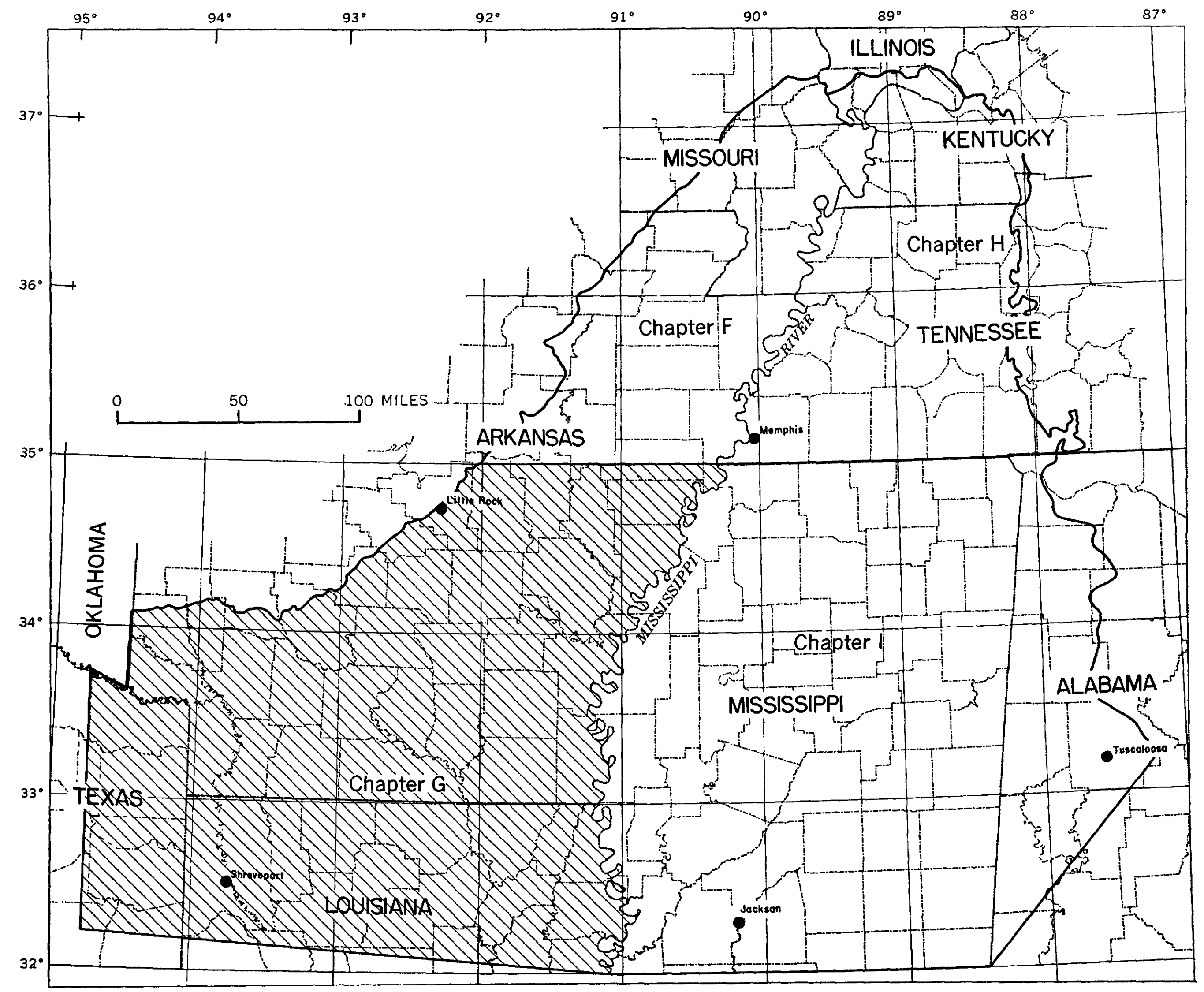

FIGURE 1.—Map of Mississippi embayment showing areas covered by four chapters of this series on low-flow characteristics of streams. Area covered by this chapter is shaded.

The Red River is distinctive in the area in that it occupies a structural depression analogous to that of the Mississippi River (Fenneman, 1938, p. 115). The sediment load of the Red River and the extensive forested areas in the basin have made the river subject to clogging by driftwood which, in the past, has formed "rafts" in the channel. The last of these, the Great Raft, probably began in the 15th century and before its removal in 1873 had created a lake 160 miles long extending upstream almost to the Arkansas line. The effects of these obstructions were: to build a broad alluvial flood plain; to create lakes 5 to 25 miles long, such as Lake Bistineau, in the tributary valleys; and to force the Red River to adopt new courses at various places.

CLIMATE

The climate of the area is warm and humid. The average annual precipitation ranges from about 48 to 52 inches. Nearly all of the precipitation is in the form of rain, but measurable snowfall does occur. The area lies in the paths of the rain-producing storm centers that move northeastward off the Gulf of Mexico and the dry continental airmasses that move west to east across the continent. Occasionally a cold airmass invades as far south as northern Louisiana, becomes stationary, and produces prolonged rains. The temperatures range from an average low of about 32°F during January in central Arkansas to an average high of about 96°F during July in northeastern Texas.

PHYSIOGRAPHY

The Mississippi embayment, a part of the Coastal Plain province, is an extensive lowland in a great structural trough between the Appalachian and Interior Highlands (Fenneman, 1938, p. 96). It has been formed by subsidence of the trough, aggradation, differential weathering, erosion, and crustal movement. During much of its existence, the embayment has been submerged by the sea, and since the embayment last emerged, the Mississippi River has followed close to the axis of the trough. Figure 2 shows the large physiographic districts in the area covered by this report.

The St. Francis Basin, north of the Arkansas River, and the Tensas Basin, south of the Arkansas River, occupy a belt ranging from about 30 to 100 miles wide that lies west of the Mississippi River. The basins are fairly flat flood plains of Quaternary age, interspersed with sluggish meandering streams. Crowleys Ridge, in the St. Francis Basin near the northeast corner of the area, is composed of Tertiary deposits capped by Quaternary sediments and rises 100 to 150 feet above the alluvial plain of the St. Francis Basin. In the geologic past, Crowleys Ridge was a major divide between two great rivers that contributed to the aggradation of the alluvial plain of the embayment. The Grand Prairie region is the local name for that part of the St. Francis Basin in Arkansas that lies between Bayou Meto and the White River and extends from about Wattensaw Bayou on the north to the Arkansas River on the south.

The East Texas Timber Belt lies primarily on the Tertiary and occupies most of the study area west of the St. Francis and Tensas Basins. The topography is fairly flat, but is slightly more expressive than that in the St. Francis and Tensas Basins.

The Black Prairie in northeastern Texas covers the Upper Cretaceous except for the basal (Woodbine) sands (Fenneman, 1938, p. 103).

The area of the Mississippi embayment in southwestern Arkansas is marked by three cuestas. The northernmost of these, the Lockesburg Wold, is the bordering belt of low sand-and-gravel hills and uplands (Fenneman, 1938, p. 107) of the lower part of the Upper Cretaceous. South of the Lockesburg Wold, the Saratoga Wold is underlain by the Nacatoch Sand of late Cretaceous age; farther south, the Sulphur Wold is on the zone of the sandy Wilcox beds of Eocene age.

GEOLOGY

The area covered by this report was periodically occupied by the sea in the geologic past and has been filled by sediments ranging in age from Jurassic to Quaternary. These deposits are several thousand feet thick near the axis of the embayment in the southeastern part of the area, and they gradually thin updip to the north and northwest toward the margin of the embayment. Units ranging in age from Cretaceous to Quaternary crop out within the area (pl. 1), and Paleozoic rocks ranging from Ordovician to Pennsylvanian crop out along the periphery of the embayment. Cushing, Boswell, and Hosman (1964) give a general description of the units of Cretaceous age and younger.

The major geologic units that crop out in the area of study are given in table 1. The sand units, which contribute most of the water to the base flow of streams, include the Trinity Group, the Woodbine and Tokio Formations, the Wilcox Formation or Group, the Carrizo Sand, the Mount Selman Formation, the Sparta Sand, the Cockfield Formation, and the alluvium and terrace deposits.

TABLE 1.—*Geologic units cropping out in study area*

Northeastern Texas

(Bowie, Cass, Marion, and Harrison Counties)

- Quaternary System
  - Alluvium and terrace deposits
- Tertiary System
  - Eocene Series
    - Claiborne Group
      - Sparta Sand
      - Mount Selman Formation
        - Weches Greensand Member
        - Queen City Sand Member
        - Reklaw Member
      - Carrizo Sand
    - Wilcox Formation
  - Paleocene Series
    - Midway Group
      - Wills Point Formation
      - Kincaid Formation
- Creaceous System
  - Upper Cretaceous Series
    - Navarro Group undifferentiated
    - Taylor Marl
    - Annona Chalk

Northern Louisiana

(North of 32d parallel)

- Quaternary System
  - Alluvium and terrace deposits
- Tertiary System
  - Eocene Series
    - Claiborne Group
      - Cockfield Formation
      - Cook Mountain Formation
      - Sparta Sand
      - Cane River Formation
      - Carrizo Sand
  - Eocene and Paleocene Series
    - Wilcox Group [1]
      - Dolet Hills Formation
      - Naborton Formation

Northern Louisiana—Continued

(North of 32d parallel)

  - Paleocene Series
    - Midway Group
      - Porters Creek Clay
      - Clayton Formation

Arkansas

- Quaternary System
  - Alluvium and terrace deposits
  - Loess
- Tertiary System
  - Pliocene(?) deposits
  - Eocene Series
    - Jackson Group undifferentiated
    - Claiborne Group
      - Cockfield Formation
      - Cook Mountain Formation
      - Sparta Sand
      - Cane River Formation
      - Carrizo Sand
    - Wilcox Group undifferentiated [2]
  - Paleocene Series
    - Midway Group [3]
      - Porters Creek Clay
      - Clayton Formation
- Cretaceous System
  - Upper Cretaceous Series
    - Arkadelphia Marl
    - Nacatoch Sand
    - Saratoga Chalk
    - Marlbrook Marl
    - Annona Chalk
    - Ozan Formation
    - Brownstown Marl
    - Tokio Formation
    - Woodbine Formation
  - Lower Cretaceous Series
    - Trinity Group undifferentiated
- Paleozoic rocks undifferentiated

[1] Wilcox Group (Eocene Series) undifferentiated. Wilcox Group (Paleocene Series), upper part undifferentiated; Dolet Hills and Naborton Formations are lower two units.

[2] In ascending order, Wilcox Group in Arkansas bauxite area is composed of Berger Formation, Saline Formation, and Detonti Sand.

[3] In ascending order, Midway Group in Arkansas bauxite area is composed of Kincaid Formation and Wills Point Formation.

MANMADE CHANGES

Settlers brought about changes in the area that probably have affected the low flows of the streams. These changes may be divided into two groups: (1) changes applied to the land in converting it to man's beneficial use, such as irrigation, drainage, land utilization, urban development, changes in agricultural crops, and intensity of cultivation, and (2) changes in the stream systems, such as diversions, development of levees, construction of dams for impounding water, and changes in stream channels. Some changes were begun before records of streamflow were obtained in the area, and others have been made so gradually that, even if the effects could be isolated, it would require many subsequent years of record to define them.

Many streams in the embayment in southern Arkansas, northern Louisiana, and northeastern Texas are affected by manmade changes. Water is diverted to and from the streams, channels have been dredged, levees have been constructed, large areas have been drained, and dams have been built for flood protection, for recreational facilities, and to make water available for agricultural, municipal, or industrial uses.

The effects of many manmade changes are not permanent. Dredged channels may become partially filled with sediment, or they may erode deeper due to increased

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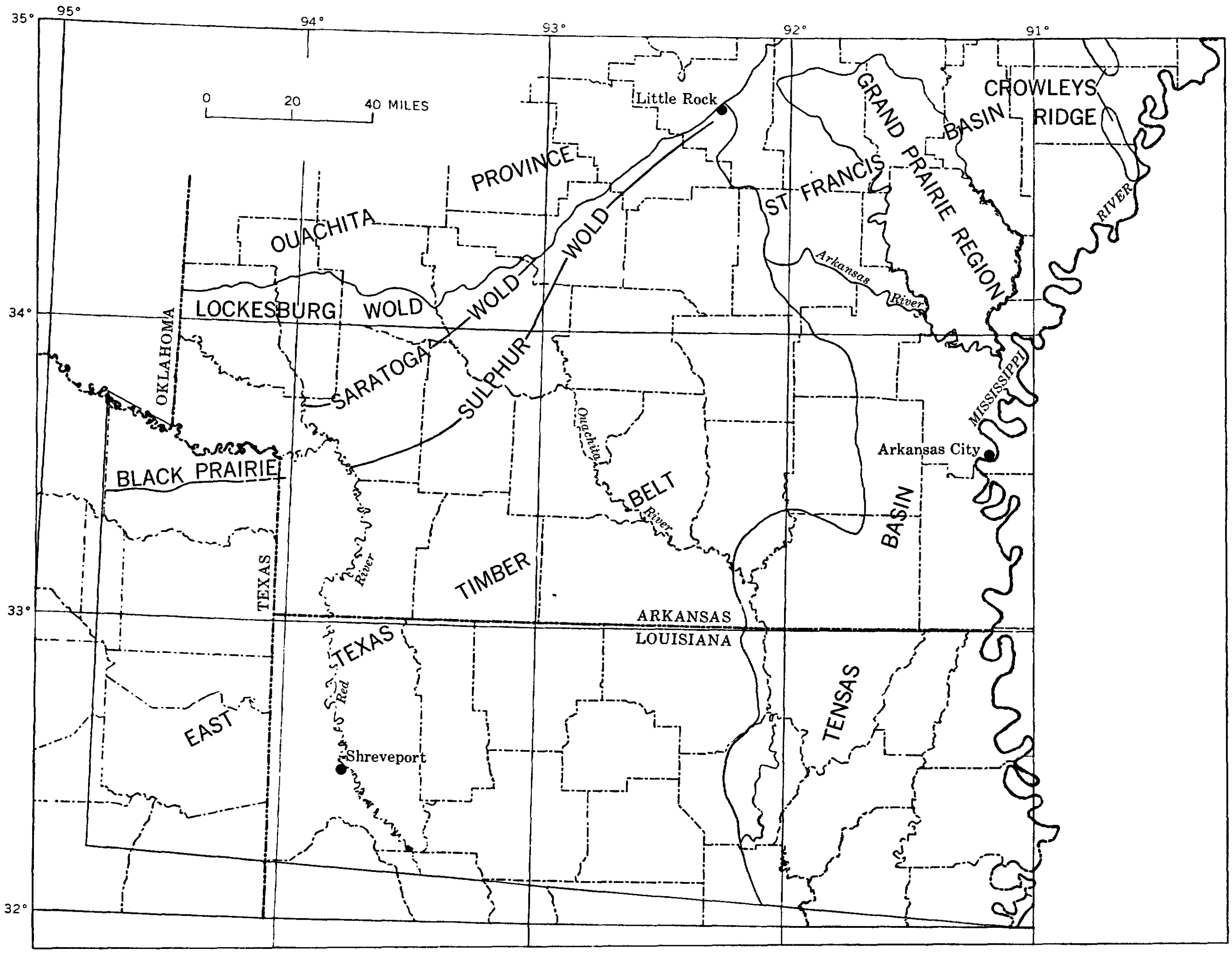

FIGURE 2.—Physiography of the study area. After Fenneman (1938) and others.

velocity of flow. Channel clearing and snagging are temporary improvements because of the regrowth of vegetation and reaccumulation of debris. On the other hand, major reservoirs that have been created on many of the streams have material effects of a permanent nature on downstream flows. Attempting to describe all the manmade changes or to evaluate quantitatively the effects that they may have produced on the streamflow is beyond the scope of this report, but some of the major changes that may aid interpretation of the low-flow characteristics are described briefly in the following paragraphs. The major part of the information was obtained from publications of the Corps of Engineers.

ST. FRANCIS RIVER BASIN

Low flows of the St. Francis River have been affected by regulation at Wappapello Reservoir in Missouri since 1941, by operation of the locks and siphons at Marked Tree, Ark., since 1925, and by numerous drainage projects in the basin. Channel cutoffs have been dredged and other channel improvements completed along the lower St. Francis River. The L'Anguille River channel has been cleared for about 5 miles upstream from the mouth as part of the St. Francis River basin project. Additional channel and drainage improvements are proposed (1964) for both the St. Francis and L'Anguille Rivers.

WHITE RIVER BASIN

The low flows in the lower end of the White River are regulated by six reservoirs, the first in operation being the Norfork Reservoir in 1943. Construction of the dam for a seventh reservoir was started in 1961. Rarely, the daily discharge of the lower White River may be affected also by leakage and unusual operations at locks and smaller dams upstream.

Some levee and channel-improvement work has been done along the lower White River and its tributaries. Extensive channel improvements have been proposed for approximately 195 miles of Cache River and approximately 90 miles of Bayou De View.

ARKANSAS RIVER BASIN

Efforts to improve the Arkansas River began as early as 1832. Early projects by the Corps of Engineers and municipal agencies were primarily to protect towns and cities from floods, to prevent erosion of the riverbanks, and to improve navigation. Dikes were constructed to direct the flow, and revetments were installed to prevent scour and to stabilize the banks. The Arkansas River enters the Mississippi embayment at Little Rock, Ark. From this point to the mouth, levees have been built at several points along the river, and cutoff channels have been dredged to bypass some of the more tortuous bends. At least seven such cutoffs, some of which shortened the channel as much as 6 miles, were constructed during the period 1952–56. Some levee work has been done on tributaries upstream from Little Rock, such as in the Spadra Creek project, which may affect the low flow of the Arkansas River within the embayment by limiting the area and frequency of flooding of the alluvial valley.

Numerous diversions for irrigation and the operation of many reserviors throughout the Arkansas River basin have greatly altered the low flows of the Arkansas River. The Corps of Engineers is presently engaged (1964) in a multiple-purpose project which combines the development of flood control, navigation, hydroelectric power, and related facilities on the Arkansas River and tributaries. Under this plan, navigation will be provided from the Mississippi River upstream into Oklahoma. The project includes the creation of seven reservoirs in eastern Oklahoma and two in western Arkansas.

In the Grand Prairie region (fig. 2), irrigation is probably the major operation affecting the low flow of the streams. Ricefields are alternately flooded and drained during the growing season, and most of the irrigation water that is derived from ground water is not returned to the ground, but is either lost by evapotranspiration or is diverted to the streams. As a result of heavy pumping of water from the Quaternary aquifer, the ground-water table along the Arkansas River in parts of Lincoln, Jefferson, and Arkansas Counties slopes away from the river, and this condition probably causes some of the flow in the Arkansas to be diverted into the ground water in this reach of the channel. Overdevelopment of ground-water supplies in the Grand Prairie region is shifting the emphasis on water supply to surface-water sources.

In the Grand Prairie region and in the Bayou Meto basin, a project is authorized for the Corps of Engineers to do channel-improvement work on Bayou Meto, Little Bayou Meto, Salt Bayou, Wabbaseka Bayou, and Bradley Slough to provide for flood control and drainage and to supply supplemental water for agricultural purposes in the Grand Prairie region. Only the preliminary planning has been done on this project to date (1963).

OUACHITA RIVER BASIN

Low flows of the Ouachita River have been affected by storage in Lake Ouachita since 1952, Lake Hamilton since 1932, and Lake Catherine since 1925, all in the vicinity of Hot Springs, Ark., and by storage in Lake Greeson on the Little Missouri River since 1949. Upstream from Lake Ouachita, there is no known regulation affecting low flows.

A 6.5-foot channel is maintained on the Ouachita River from Camden, Ark., to the mouth. Six locks and dams below Arkadelphia, two of which are in Arkansas, may cause some regulation, but the effect on daily flow is considered to be of no consequence. The Corps of Engineers has under construction a project which provides for a 9-foot channel and new locks and dams to replace locks and dams 2 to 8. Work on the 9-foot channel from Camden to Arkadelphia, Ark., is now inactive (1965).

Some channel-improvement work has been completed on Little Missouri River below Murfreesboro, Ark., on Ozan Creek from the mouth to 15 miles upstream, and on Terre Noire Creek from the mouth to 24.4 miles upstream. Most of this work is being done under current projects. Similar work has been done on other tributary streams under previous projects, but information on this work is not readily available.

There have been no channel improvements or enlargements in the Bayou Bartholomew basin during the period of record on this stream. Water is diverted each year during the growing season above the gaging station near Beekman, La. (7–3645), for irrigation of approximately 1,000 acres of rice. Chemin-a-Haut Lake (capacity, 150 acre-ft) on Chemin-a-Haut Bayou, tributary to Bayou Bartholomew upstream from Beekman, was created in 1949.

Considerable channel-improvement work was done in the Boeuf River, the Tensas River, and the Bayou Macon basins during 1942–56 by the Corps of Engineers and by the Louisiana Department of Public Works. This work mostly resulted in the deepening and straightening of the channels. The Boeuf River channel is to be shortened 3.6 miles when the remainder of the cutoff and realinement work in Chicot County, Ark., is finished. Canals 18, 19, 43, and 81 in the Boeuf River basin are undergoing improvements (1963). A small amount of channel-improvement work is being done on Bayou Macon in Chicot County, Ark.

The Louisiana portion of work in the Boeuf River, Tensas River, and Bayou Macon basins by the Corps of Engineers consists of the clearing, snagging, straightening, and enlarging of approximately 530 miles of channel on the Boeuf River, the Tensas River, Bayou La Fourche, Bayou Macon, Big Creek, and Big Colewa Bayou. Improvements on about 288 miles were completed as of June 1956. The Louisiana Department of Public Works cleared, enlarged, and realined channels in 13 bayous during the period 1949–57. The Bayou La Fourche cutoff loop was completed in 1956 to provide a larger outlet into the Boeuf River.

There have been no channel improvements in Bayou D'Arbonne basin during the period of records. Corney Lake (capacity, 28,000 acre-ft) on Corney Bayou above the gaging station near Lillie, La. (7–3660), was created in 1940.

Cheniere Brake Lake (capacity 15,000 acre-ft) on Cheniere Creek, which is a tributary of the Ouachita River 13 miles downstream from Monroe, La., was created in 1944.

Information from the Louisiana Department of Public Works indicates that very few, if any, channel improvements have been made in Dugdemona River basin. Water for industrial use is pumped from wells at Hodge, La., and part of the effluent is discharged continuously into the Dugdemona River about 7 miles above the gaging station near Jonesboro, La. (7–3715). The effluent, which contains waste material, is stored in a reservoir and released when the riverflow is sufficient to materially dilute the effluent.

The Soil Conservation Service projects in the Ouachita River basin included the Randolph-Walnut Lake project in Desha County, Ark., completed in 1961, which provided for the improvement of 24 miles of drainage channel which is tributary to canal 19 near Dumas; the Arkansas City project in Desha County, completed in 1963, which provided for the improvement of 23 miles of channel on a tributary to canal 81; and the improvement of 28 miles of channel on Camp Bayou and on laterals near Wilmot, Ashley County, Ark., completed in 1959.

RED RIVER BASIN

Channel improvements and levee projects have been completed at many places along the Red River and on several tributaries. The banks and channel of Walnut Bayou have been improved from the Oklahoma line to the mouth. The flow of McKinney Bayou and its tributary, Barkman Creek, is diverted into the Red River 3 miles west of Ogden, Ark. Levee construction and channel improvement have been completed on McKinney Bayou from near Texarkana to the mouth. Downstream from Ogden, on the Red River, 159 miles of levees on the left bank, 235 miles of levees on the right bank, and 14.2 miles of revetment or bank protection have been built.

Several small lakes and reservoirs have been created on the Red River and tributaries west of the embayment. Lake Texoma created by Denison Dam on the Red River near Denison, Tex., impounds runoff from 39,719 square miles. Six major reservoirs on tributaries of the Red River below Denison Dam have been or are being created (1963).

Work on the Sulphur River and tributaries in Texas, consisting of the construction of levees, the improvement and straightening of the channel, and the removal of accumulated snags and other debris, has been completed on the main stem above Lake Texarkana, on the North, Middle, and South Sulphur Rivers, and on Journigan, Cane, Mustang, and Cuthand Creeks. Lake Texarkana (capacity, 119,700 acre-ft) was created in 1957 for flood control and water conservation.

Lake O' the Pines (capacity, 842,100 acre-ft), on Cypress Creek about 8 miles west of Jefferson, Tex., was created in 1958. Between Jefferson, Tex., and Shreveport, La., dredging and straightening the channel, removing obstructions, and clearing banks have been completed on 66 miles of Cypress Creek.

Downstream from the Arkansas line, there are a number of depressions near the mouth of the tributaries of the Red River which were occupied by lakes created by the Great Raft before its removal (p. G4). Some of these depressions have been utilized for the creation of lakes for flood-control, water-supply, and recreational purposes.

Black Lake (capacity not known), on Black Bayou upstream from the gaging station near Gilliam, La. (7–3475), was created in 1945 for recreational purposes. In 1955, the crest of the dam was raised to enlarge the lake to a capacity of 17,750 acre-ft. Water is pumped from Red River into Black Bayou basin downstream from Gilliam for the supplemental irrigation of approximately 600 acres.

The channels of Kelly Bayou and many of its tributaries were cleared, enlarged, and realined in 1943 by the Louisiana Department of Public Works. During dry periods each year, approximately 600 acres of croplands is irrigated, using water diverted from Kelly Bayou downstream from the gaging station near Hosston, La. (7–3470).

Caddo Lake (capacity, 170,000 acre-ft), 5.5 miles above the gaging station on Twelvemile Bayou near Dixie, La. (7–3480), was created in December 1914 for navigation and irrigation purposes. It provides a 4-foot navigable depth upstream to Jefferson, Tex. Each year water is pumped from Twelvemile Bayou upstream from Dixie for irrigation of approximately 200 acres of land. Cross Lake (capacity, 9,920 acre-ft) on Cross Bayou, a tributary to Twelvemile Bayou 16 miles downstream from Dixie, was created in 1925 for municipal water-supply, flood-control, and recreational purposes.

Wallace Lake (capacity, 96,100 acre-ft), a flood-control reservoir on Wallace Bayou, was created in 1946.

The enlarging, snagging, and clearing of 21 miles of the channel of Bayou Pierre from near Shreveport, La., downstream to the mouth of its right-bank tributary, Wallace (Cypress) Bayou, were completed in 1950. The improvement of the lower 30 miles of Bayou Pierre channel was completed in 1939.

Lake Bistineau (capacity, more than 120,400 acre-ft) on Bayou Dorcheat downstream from the gaging station near Minden, La. (7–3490), was created in 1943 for recreation.

Channel improvements, which consisted of 2.4 miles of channel snagging and clearing and 5.4 miles of channel enlargement on Bodcau Bayou downstream from the gaging station near Sarepta, La. (7–3495), and on Red Chute and Loggy Bayous, were completed in 1948. Bodcau Lake (capacity, 357,300 acre-ft), a flood-control reservior downstream from Sarepta, was created in 1948. Ivan Lake (capacity, approx. 5,000 acre-ft) on Caney Creek, which is a tributary to Bodcau Bayou about 7 miles downstream from Sarepta, was created in 1957 for recreation. Water used by a papermill upstream from Sarepta is pumped from wells and later discharged into Bodcau Bayou. The effluent is stored in a reservoir and released when the flow of the bayou is sufficient to dilute the waste.

Channel improvements, which included the clearing, enlarging, and realining of the channels of Black Lake Bayou and some of its tributaries, were completed in 1949 by the Louisiana Department of Public Works. Kepler Creek Lake (capacity, 14,500 acre-ft), on a tributary to Black Lake Bayou upstream from Castor, La. (7–3525), was created for recreation in 1958.

FARM PONDS AND LAKES

The U.S. Department of Agriculture has assisted in the creation and improvement of many small ponds in the study area. Many other water impoundments have been created by other agencies, individuals, and private organizations. The Arkansas Conservation Needs Committee estimates that there are presently 26,200 farm ponds and lakes, 40 acres or less in size, in the Mississippi embayment in Arkansas. It is estimated that more than 5,600 small impoundments having a total capacity of about 60,000 acre-ft were created in northern Louisiana during the period 1938–55.

Listed below are those lakes covering 1,000 acres or more, excluding those mentioned elsewhere in this section, that are in the Mississippi embayment in Arkansas and Texas:

Lake	*Stream*	*County*	*Area (acres)*
Arkansas:			
Chicot	Connerly and Ferry Bayou	Chicot	4,124
Grassy	Yellow Creek	Hempstead	3,600
Horseshoe	Fish Bayou and Boggy Bayou	Crittenden	1,904
Melwood Old River	Mississippi River	Phillips	1,240
Old River 66	do	do	3,030
Old Town	McGhee Bayou	do	4,000
Peckerwood	Lagrue Bayou	Prairie	3,165
Earling	Bodeau Creek	Lafayette	7,000
Seven Devils	Cutoff Creek	Drew	2,500
White Oak	Whiteoak Creek	Ouachita	2,600
Texas:			
Lake Cherokee	Cherokee Bayou	Rusk	3,479

The effect of most of these impoundments on streamflow is extremely local, but the very large number of small ponds in certain areas may influence the low-flow characteristics of some streams, and the effect of the ponds should be considered in the low-flow appraisal of streams within a basin.

LOW-FLOW CHARACTERISTICS

Streamflow data used in this report are (1) continuous records of flow obtained at 50 daily-record gaging stations, and (2) limited data collected systematically over a period of years at 106 low-flow partial-record stations.

So that the low-flow characteristics of one stream could be compared with those of another, all data were adjusted to the common reference period, 1929–57. (See section on "Method of study" for further discussion on the reference period.) In the area, 5 daily-record gaging stations have complete records for the selected period, and 39 other daily-record stations have 15 years or more of record during the reference period. Daily-record stations having less than 5 years of record during this period are designated as partial-record stations. Data recorded through 1963 were used to define the low-flow characteristics at partial-record stations.

Average annual precipitation in Arkansas and northern Louisiana from 1891 to 1957 was about 49 inches, and that from 1929 to 1957 was 48.6 inches. Thus, the average during the reference period was approximately equivalent to that since 1891. The spatial and within-the-year distribution of precipitation and many other factors, however, influence the quantity and rate of runoff, so that firm conclusions on the representativeness of streamflow patterns during the reference period cannot be drawn from the average precipitation alone.

The low-flow characteristics for all streams analyzed in the study are summarized in table 2. The stations are all in Part 7 except Sabine River at Logansport, La., which is in Part 8, and are listed in the downstream order corresponding to that currently used by the U.S. Geological Survey in surface-water reports. The station number is the permanent nationwide number assigned to the station and is used throughout the report. In assigning the numbers, no distinction is made between daily-record stations and partial-record stations. For some of the stations for which three or more of the selected items are zero flow, additional flow data are given in parenthesis with appropriate reference notes.. The last column of the table enables the user of the data to construct the relation curve between the partial-record station and the daily-record station and to interpolate additional data if desired. Some of the partial-record stations were related with other partial-record stations; for each such station the number of the other station is shown in parenthesis.

TABLE 2.—*Low-flow characteristics of streams in the study area*

[Data are adjusted to period 1929–57 on basis of relation to data at other gaging stations. Class of station: D, daily-record gaging station; P, partial-record or short-term daily-record station. Figures given for the 7-day 2-year annual low flow are the indices of low flow used in this report]

Station	Station name	Class of station	Drainage area (sq mi)	Annual low flow, in cubic feet per second per square mile, for indicated period of consecutive days and for indicated recurrence interval, in years				Flow, in cubic feet per second per square mile, which was equaled or exceeded for indicated percent of time		Daily-record station with which partial-record station is correlated [1]
				7-day		30-day				
				2-yr	10-yr	2-yr	10-yr	90	95	
	Part 7. Lower Mississippi River basin									
	St. Francis River basin									
7-0479.2	Fifteen Mile Bayou near West Memphis, Ark.	P	51.0	([2] 0.012)	0	0.005	0	0.008	0	7-0479.5
0479.4	L'Anguille River near Wynne, Ark	P	503	([2] .032)	0	([2] .015)	0	.022	.001	7-0479.5
0479.5	L'Anguille River at Palestine, Ark	D	807	([2] .029)	0	.012	0	.019	.001	---------------
	White River basin									
0768	Bayou des Arc near Garner, Ark	P	97.1	([2] .017)	0	.004	0	.003	0	7-0760
0768.5	Cypress Bayou near Bebee, Ark	P	163	0	0	([2] .002)	0	([3] .007)	0	7-0760
0769.5	Wattensaw Bayou near Hazen, Ark	P	195	.001	0	.002	0	.002	.001	7-0775
0779.5	Big Creek at Popular Grove, Ark	P	389	([2] .021)	0	.008	0	.014	0	7-0479.5
0779.7	Big Cypress Creek at Turner, Ark	P	125	.001	0	.005	0	.008	.001	7-3630
0780	Lagrue Bayou near Stuttgart, Ark	D	175	.001	0	.007	.001	.009	.001	---------------
	Arkansas River basin									
2636	Fourche Creek at Little Rock, Ark	P	162	.001	0	.004	([4] .001)	.005	.001	7-3630
2640	Bayou Meto near Lonoke, Ark	P	203	.010	.001	.019	.004	.018	.009	7-0775
2642	Two Prairie Bayou at Carlisle, Ark	P	149	.001	0	.003	0	.002	.001	7-0775
2645	Bayou Meto near Stuttgart, Ark	D	560	0	0	.001	0	0	0	---------------
2652	Little Bayou Meto at Reydel, Ark	P	450	0	0	0	0	0	0	7-3635
	Red River basin									
3369	Walnut Bayou near Foreman, Ark	P	83.6	([2] .001)	0	([2] .003)	0	([5] .005)	0	7-3450
3369.5	Barkman Creek near Leary, Tex	P	31.5	([2] .009)	0	.007	0	([5] .009)	0	7-3450
3395	Rolling Fork near De Queen, Ark	D	181	.002	([4] .001)	.007	.001	.007	.002	---------------
3400	Little River near Horatio, Ark	D	2,674	.007	.001	.015	.002	.016	.006	---------------
3405	Cossatot River near De Queen, Ark	D	361	.019	.005	.030	.008	.036	.022	---------------
3410	Saline River near Dierks, Ark	D	124	.001	0	.002	0	.003	.002	---------------
3421.5	Manice Bayou near Canfield, Ark	P	109	.002	([4] .001)	.003	.001	.005	.002	7-3658
3423.5	McKinney Bayou near Garland, Ark	P	169	0	0	0	0	.001	0	7-3658
3425	South Sulphur River near Cooper, Tex	D	527	0	0	([2] .001)	0	([3] .001)	0	---------------
3430	North Sulphur River near Cooper, Tex	D	276	0	0	([2] .004)	0	([5] .001)	0	---------------
3432	Sulphur River near Talco, Tex	P	1,365	0	0	0	0	([5] .001)	0	7-3385
3435	Whiteoak Creek near Talco, Tex	D	494	.001	0	.001	0	.001	.001	---------------
3440	Sulphur River near Darden, Tex	D	2,774	.001	0	.002	0	.002	0	---------------
3441	Caney Creek near Redwater, Tex	P	18	([2] .023)	0	.016	0	([5] .023)	0	7-3450
3443	Aiken Creek near Texarkana, Tex	P	12.2	([2] .020)	0	.013	0	([5] .020)	0	7-3450
3445	Cypress Creek near Pittsburg, Tex	D	366	.002	0	.006	0	.004	0	---------------
3450	Boggy Creek near Daingerfield, Tex	D	72	([2] .001)	0	([2] .008)	0	([5] .001)	0	---------------
3460	Cypress Creek near Jefferson, Tex	D	850	.005	([4] .001)	.008	([4] .002)	.008	.003	---------------
3460.2	Kelly Creek near Marietta, Tex	P	50.5	([2] .001)	0	([2] .029)	0	([5] .002)	0	7-3445
3460.4	Hughes Creek near Avinger, Tex	P	48.6	([2] .008)	0	.001	0	([5] .010)	0	7-3445
3460.6	Moccasin Creek near Harleton, Tex	P	30.5	([2] .004)	0	.001	0	([5] .004)	0	7-3450
3460.8	Prewitt Creek near Karnack, Tex	P	29.5	.003	.001	.005	.001	.008	.003	7-3658
3461	Kitchen Creek near Smithland, Tex	P	27	0	0	0	0	([5] .002)	0	7-3658
3461.2	Jims Bayou near Kildare, Tex	P	83	0	0	0	0	([3] .027	0	7-3490
3461.4	Frazier Creek near Linden, Tex	P	47.9	.001	0	.001	0	.003	.001	7-3658
3463.2	Black Bayou near Atlanta, Tex	P	52.1	.002	0	.003	0	.007	.002	7-3658
3464	Black Bayou near Rodessa, La	P	113	.003	.001	.004	.002	.003	.002	7-3475
3465	Black Bayou near Hosston, La	P	231	.002	0	.004	.001	.002	.001	7-3475
3470	Kelly Bayou near Hosston, La	D	116	.02	.02	.03	.02	.03	.02	---------------
3475	Black Bayou near Gilliam, La	D	364	.02	.009	.02	.01	.02	.01	---------------

See footnotes at end of table.

TABLE 2.—*Low-flow characteristics of streams in the study area*—Continued

Station	Station name	Class of station	Drainage area (sq mi)	Annual low flow, in cubic feet per second per square mile, for indicated period of consecutive days and for indicated recurrence interval, in years: 7-day, 2-yr	7-day, 10-yr	30-day, 2-yr	30-day, 10-yr	Flow, in cubic feet per second per square mile, which was equaled or exceeded for indicated percent of time: 90	95	Daily-record station with which partial-record station is correlated [1]
	Part 7. Lower Mississippi River basin—Continued									
	Red River basin—Continued									
7-3480	Twelvemile Bayou near Dixie, La.	D	3,137	0.003	0.002	0.005	0.002	0.005	0.003	
3482	Paw Paw Bayou near Greenwood, La.	P	78	0	0	0	0	([5].001)	0	7-3510
3486	Bayou Dorcheat near Buckner, Ark.	P	101	([2].002)	0	([2].006)	0	.001	0	7-3658
3487	Bayou Dorcheat near Springhill, La.	P	605	0	0	0	0	([5].002)	0	7-3490
3487.6	Black Bayou at Leton, La.	P	49.8	([2].002)	0	([2].008)	0	([5].001)	0	(7-3488)
3488	Flat Lick Bayou near Leton, La.	P	66.9	.001	0	.001	0	.001	.001	7-3495
3489	Brushy Creek near Hortman, La.	P	16.1	0	0	0	0	0	0	
3490	Bayou Dorcheat near Minden, La.	D	1,097	.001	0	.002	0	.002	.001	
3491	Brushy Creek near Sibley, La.	P	43.6	.01	.005	.02	.007	.02	.01	(7-3488)
3492	Clarke Bayou near Haughton, La.	P	35.1	([2].003)	([4].001)	([4].007)	([4].001)	([5].003)	0	(7-3488)
3494.3	Bodcau Creek at Stamps, Ark.	P	234	0	0	([2].006)	0	([5].009)	0	7-3658
3495	Bodcau Bayou near Sarepta, La.	D	546	.001	0	.001	0	.002	.001	
3496	Caney Creek near Cotton Valley, La.	P	63.9	0	0	0	0	([3].001)	0	(7-3498)
3496.5	Bodcau Bayou near Shreveport, La.	D	683	([2].006)	0	.001	0	([5].005)	0	
3498	Cypress Bayou near Benton, La.	P	133	([2].001)	0	.001	0	.001	0	7-3470
3498.4	Black Bayou at Benton, La.	P	17.2	0	0	0	0	0	0	
3500	Loggy Bayou near Ninock, La.	D	2,628	.007	.001	.01	.001	.006	.004	
3510	Boggy Bayou near Keithville, La.	D	79	([2].001)	0	([2].005)	0	([5].002)	0	
3515	Cypress Bayou near Keithville, La.	D	66	([2].002)	0	([2].003)	0	([5].001)	0	
3515.5	Wallace (Cypress) Bayou near Shreveport, La.	D	266	([2].001)	0	([2].003)	0	([3].001)	0	
3516.7	Rambin Bayou near Frierson, La.	P	59.6	0	0	([2].001)	0	([3].03)	0	(8-0226)
3517	Bayou Na Bonchasse near Mansfield, La.	P	19.5	.04	([6])	.05	([6])	([6])	([6])	8-0235
3517.2	Buffalo Bayou near Naborton, La.	P	17.7	0	([6])	.002	([6])	([6])	([6])	(7-3517)
3517.6	Bayou Terre Blanc near Allen, La.	P	26.6	0	([6])	.001	([6])	.001	([6])	7-3535, 7-3720
3520	Saline Bayou near Lucky, La.	D	154	.07	.035	.08	.04	.08	.06	
3521	Saline Bayou near Goldonna, La.	P	293	.09	.04	.11	.05	.11	.08	7-3520
3522	Black Lake Bayou near Minden, La.	P	38.6	.004	.001	.006	.002	.006	.004	7-3495, 7-3520
3522.5	Bear Creek near Ada, La.	P	53.1	.001	0	.001	0	.001	.001	7-3520
3523	Black Lake Creek near Gibsland, La.	P	46.1	([2].003)	0	.003	0	.002	0	7-3650
3523.5	Leathermans Creek near Gibsland, La.	P	57	.004	.002	.005	.002	.006	.001	(7-3488)
3524	Kepler Creek near Sparta, La.	P	21.1	.20	.16	.21	.17	.21	.19	7-3520
3525	Black Lake Bayou near Castor, La.	D	423	.03	.02	.04	.02	.04	.03	
3526	Mill Creek near Castor, La.	P	21.5	.08	.05	.09	.05	.09	.07	7-3520
3527	Castor Creek at Castor, La.	P	27.9	.16	.12	.18	.13	.18	.16	7-3520
3527.5	Brushy Creek near Liberty, La.	P	13.3	.005	.001	.007	.002	.007	.004	7-3520
3528	Grand Bayou near Coushatta, La.	P	93.9	([2].002)	0	([2].003)	0	([3].005)	0	7-3520
3530	Saline Bayou near Clarence, La.	D	1,386	.005	0	.01	0	.01	.007	
	Ouachita River basin									
3560	Ouachita River near Mount Ida, Ark.	D	410	.039	.014	.063	.020	.076	.046	
3587	Gulpha Creek near Hot Springs, Ark.	P	50.2	.028	.009	.044	.013	.049	.030	7-3598
3596	Caddo River at Caddo Gap, Ark.	P	115	.15	.077	.20	.096	.22	.16	7-3598
3598	Caddo River near Alpine, Ark.	D	312	.077	.038	.10	.048	.11	.080	
3601	L'Eau Frais Creek at Joan, Ark.	P	79.4	.020	.005	.035	.008	.039	.021	7-3598
3602	Little Missouri River near Langley, Ark.	P	66.5	.19	.11	.23	.13	.24	.19	7-3598
3608	Muddy Fork Creek near Murfreesboro, Ark.	D	121	([2].008)	0	.001	0	.001	0	
3610	Little Missouri River near Murfreesboro, Ark.	D	380	.020	.008	.032	.012	.034	.021	
3612	Ozan Creek near McCaskill, Ark.	P	148	([2].004)	0	([2].051)	0	.001	0	7-3405
3615	Antoine River at Antoine, Ark.	D	181	.001	([4].001)	.002	.001	.002	.001	
3616.5	Terre Rouge Creek near Prescott, Ark.	P	231	.001	0	.002	0	.003	.001	7-3598
3617	Caney Creek near Bluff City, Ark.	P	167	([2].004)	0	.001	0	.001	0	7-3598
3618	Terre Noire Creek near Gurdon, Ark.	P	250	.001	0	.002	0	.003	.001	7-3598
3618.5	Tulip Creek near Pine Grove, Ark.	P	152	.009	([6])	.014	([6])	.016	.009	7-3598
3619	Bayou Freeo near Eagle Mills, Ark.	P	94.8	.001	0	.001	0	.003	.001	7-3658
3621	Smackover Creek near Smackover, Ark.	P	377	.012	.008	.014	.010	.016	.012	7-3658
3625	Moro Creek near Fordyce, Ark.	D	216	0	0	0	0	0	0	
3625.5	Moro Creek near Banks, Ark.	P	374	0	0	.001	0	([5].001)	0	7-3635
3626	Alum Fork at Crows, Ark.	P	123	.010	.002	.018	.004	.020	.010	7-3630
3627	Middle Fork at Crows, Ark.	P	109	.033	.009	.052	.015	.59	.033	7-3630
3628	South Fork near Hot Springs, Ark.	P	12.9	.071	.022	.11	.036	.12	.071	7-3630
3629	North Fork near Benton, Ark.	P	132	.005	.001	.011	.001	.013	.005	7-3630
3630	Saline River at Benton, Ark.	D	569	.021	.005	.035	.009	.040	.021	
3631	Francois Creek near Poyen, Ark.	P	84.1	.001	0	.003	([4].001)	.005	.001	7-3630
3633	Hurricane Creek near Sheridan, Ark.	P	205	.007	.001	.013	.003	.015	.007	7-3630
3635	Saline River at Rye, Ark.	D	2,062	.013	.004	.019	.006	.020	.011	
3637	Hudgin Creek near Pansey, Ark.	P	90.3	0	0	0	0	([3].016)	0	7-3658
3640.2	Eagle Creek at Hermitage, Ark.	P	167	0	0	0	0	([3].001)	0	7-3625
3640.6	Bayou Lapile at Strong, Ark.	P	93.3	([6])	([6])	([6])	([6])	.005	([6])	7-3658
3641.5	Bayou Bartholomew near McGehee, Ark.	P	592	.022	.008	.034	.010	.036	.020	7-3635

See footnotes at end of table.

TABLE 2.—*Low-flow characteristics of streams in the study area*—Continued

Station	Station name	Class of station	Drainage area (sq mi)	Annual low flow, in cubic feet per second per square mile, for indicated period of consecutive days and for indicated recurrence interval, in years				Flow, in cubic feet per second per square mile, which was equaled or exceeded for indicated percent of time		Daily-record station with which partial-record station is correlated [1]
				7-day		30-day				
				2-yr	10-yr	2-yr	10-yr	90	95	
	Part 7. Lower Mississippi River basin—Continued									
	Ouachita River basin—Continued									
7-3641.7	Cutoff Creek near Selma, Ark.	P	88.4	0	0	0	0	([3] 0.008)	0	7-3658
3642.5	Chemin-a-Haut Creek near Berlin, Ark.	P	216	0	0	0	0	0	0	(7-3643)
3643	Chemin-a-Haut Bayou (Creek) near Beekman, La.	P	271	.002	0	.002	.001	.002	.001	7-3680
3645	Bayou Bartholomew near Beekman, La.	D	1,645	.063	.03	.07	.04	.07	.05	----------
3646	Bayou de Loutre near El Dorado, Ark.	P	78.4	([6])	([6])	([6])	([6])	([6])	([6])	7-3658
3647	Bayou de Loutre near Laran, La.	P	141	.06	.03	.08	.04	.08	.06	7-3635
3647.5	Bayou de Loutre at De Loutre, La.	P	302	.03	([6])	.04	([6])	.03	([6])	7-3647
3648	Bayou D'Arbonne at Homer, La.	P	30.0	([2] .002)	0	([2] .02)	0	0	([6])	(7-3662)
3649	Big Creek near Vienna, La.	P	68.9	([2] .02)	0	([2] .03)	0	([5] .01)	0	7-3650
3650	Bayou D'Arbonne near Dubach, La.	D	355	([2] .01)	0	.001	0	.001	0	----------
3651	Cypress Creek near Unionville, La.	P	63.3	.001	0	.003	0	.003	.001	7-3520
3653	Middle Fork Bayou D'Arbonne near Colquitt, La.	P	43.9	([2] .001)	0	([2] .01)	([6])	([3] .06)	0	(7-3662)
3655	Middle Fork Bayou D'Arbonne near Bernice, La.	D	178	([2] .006)	0	.001	0	([5] .003)	0	----------
3658	Cornie Bayou near Three Creeks, Ark.	D	180	.002	.001	.003	.001	.005	.002	----------
3658.5	Little Corney Bayou near Summerfield, La.	P	54.0	.003	([6])	.005	([6])	.004	([6])	(7-3647)
3659	Three Creek near Three Creeks, Ark.	P	46	.014	.010	.016	.011	.020	.014	7-3658
3660	Corney Bayou near Lillie, La.	D	462	.003	0	.007	0	.006	.003	----------
3661	Little Cornie Bayou near Junction City, Ark.	P	98.2	([6])	([6])	.012	([6])	.018	([6])	7-3658
3662	Little Cornie Bayou near Lillie, La.	P	208	.002	0	.006	0	.006	.003	7-3635
3663.5	Stowe Creek near Farmerville, La.	P	29.0	([2] .01)	0	([2] .02)	0	([5] .005)	0	7-3705
3664	Bayou Choudrant at Tremont, La.	P	87.5	.03	([6])	.03	([6])	.03	([6])	7-3650, 7-3705
3673	North Cheniere Creek at Cheniere, La.	P	38	.02	.006	.03	.008	.03	.02	(7-3662)
3675	Cheniere Creek near Bawcomville, La.	P	134	0	([6])	.001	([6])	.001	([6])	7-3705
3680	Boeuf River near Girard, La.	D	1,226	.05	.03	.06	.03	.06	.05	----------
3685	Big Colewa Bayou near Oak Grove, La.	D	42	0	0	([2] .01)	0	0	0	----------
3685.2	Big Creek at Holly Ridge, La.	P	71	.008	([6])	.008	([6])	([6])	([6])	7-3685
3685.4	Big Creek at Mangham, La.	P	347	.06	.03	.07	.04	.07	.05	7-3680
3685.6	Little Creek near Mangham, La.	P	25.1	0	([6])	([6])	([6])	([6])	([6])	----------
3687.5	Bayou Galion near Mer Rouge, La.	P	22.9	0	0	([2] .001)	0	([3] .001)	0	(7-3643)
3690	Bayou La Fourche near Crew Lake, La.	D	361	.01	.003	.02	.004	.02	.01	----------
3692	Turkey Creek at Winnsboro, La.	P	101	.002	.001	.003	.002	.003	.003	7-3680, 7-3695
3695	Tensas River at Tendal, La.	D	309	.03	.01	.04	.01	.03	.02	----------
3700	Bayou Macon near Delhi, La.	D	782	.12	.07	.15	.08	.14	.11	----------
3702	Castor Creek at Chatham, La.	P	60	.001	([6])	.002	([6])	.002	0	7-3705
3704	Bills Creek near Mount Pleasant, La.	P	24.7	([2] .001)	0	([2] .002)	0	([5] .002)	0	7-3705
3705	Castor Creek near Grayson, La.	D	271	([2] .01)	0	.001)	0	.001	0	----------
3706	Bayou Beaucoup near Cotton Plant, La.	P	127	([2] .007)	0	([2] .01)	0	([5] .004)	([6])	7-3720
3708.2	Dugdemona River near Quitman, La.	P	117	.010	.002	.016	.003	.015	.009	7-3720
3709.3	Cypress Creek at Quitman, La.	P	46.0	([2] .006)	0	([2] .02)	0	([5] .006)	0	7-3520
3710	Garrett Creek at Jonesboro, La.	D	2.14	.07	.006	.10	.02	.09	.05	----------
3710.5	Dukedall Creek near Danville, La.	P	19.5	.09	.01	.11	.03	.10	.06	7-3710
3715	Dugdemona River near Jonesboro, La.	D	347	.01	.005	.02	.007	.02	.01	----------
3718	Big Creek near Dodson, La.	P	81	.001	([6])	.001	([6])	.001	.001	7-3715, 7-3720
3720	Dugdemona River near Winnfield, La.	D	654	.005	0	.009	.001	.008	.004	----------
	Part 8. Western Gulf of Mexico basins									
	Sabine River basin									
8-0225	Sabine River at Logansport, La.	D	4,858	0.015	0.005	0.021	0.005	0.018	0.010	----------

[1] Station numbers shown in parentheses are partial-record stations.
[2] Figure is for 1.2-yr recurrence interval; 2-yr figure is 0.
[3] Figure is for 70 percent of time; figures for 80 percent and 90 percent are 0.
[4] Figure is for 5-yr recurrence interval; 10-yr figure is 0.
[5] Figure is for 80 percent of time; figure for 90 percent is 0.
[6] Relation curve not defined in this range.

The low-flow data in table 2 are presented in cubic feet per second per square mile to facilitate comparison of flows of streams with different size drainage areas. It should not be inferred, however, that the yield is uniform throughout a drainage basin. On the contrary, the low-flow yields usually differ between tributary streams within a drainage basin and within reaches on a single stream. For example, based on use of the median annual (2-year) 7-day low flow as the index, the low-flow indices for streams in the Saline River basin (7-3626 to 7-3629) above the gaging station at Benton, Ark. (7-3630), range from 0.005 to 0.071 cfs per sq mi (cubic foot per second per square mile). It can also be seen that streams having smaller drainage areas may have the lower low-flow indices. The differences in low-flow indices are primarily due to the difference in hydraulic characteristics of the aquifer supplying water to the stream, the depth of incision of the stream, and the interrelation of the hydraulic characteristics of the aquifer and of the stream. The location of the stations in table 2 is shown on plate 1. The station numbers shown on the plate are the same as those used in table 2. The low-flow index (7-day 2-year low flow) for each station is given in parenthesis near the station symbol. For a few of the stations on the plate a dash is shown in the parenthesis, which means that the relation with the daily-discharge station is not defined in this range.

LOW-FLOW FREQUENCY

Low-flow frequency data for 50 daily-record gaging stations are presented in table 3. Similar data for the partial-record stations have not been computed because of the limited basic information available at these locations. The data in table 3 can be plotted on graph paper similar to that used in figure 3 if a graphical presentation is desired.

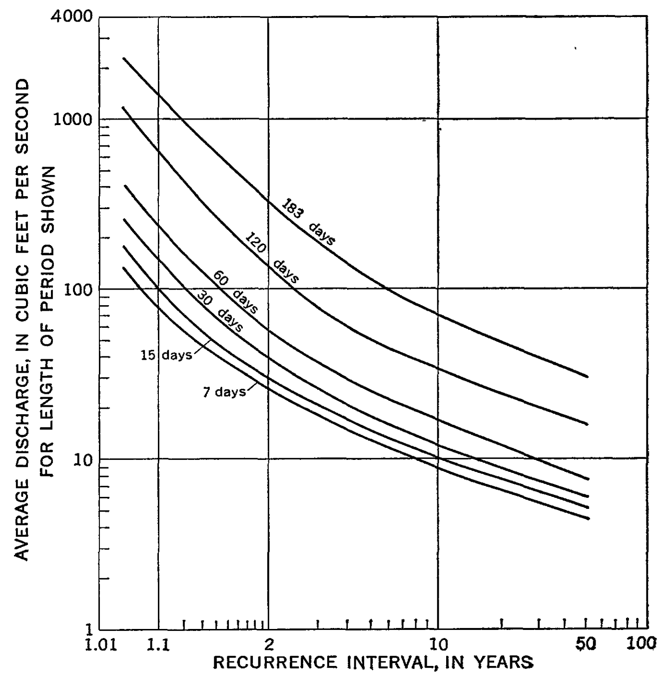

FIGURE 3.—Magnitude and frequency of annual low flow for Saline River near Rye, Ark., 1929–57.

TABLE 3.—*Magnitude and frequency of annual low flow at daily-record gaging stations in the study area*

[Data are adjusted to period April 1929–March 1958 on basis of relation to data at other gaging stations]

Station	Station name	Drainage area (sq mi)	Period (consecutive days)	Annual low flow, in cubic feet per second, for indicated recurrence interval, in years: 1.03	1.2	2	5	10	20	50
	Part 7. Lower Mississippi River basin									
	St. Francis River basin									
7-0479.5	L'Anguille River at Palestine, Ark	807	7	94	23	0	0	0	0	0
			15	154	36	.4	0	0	0	0
			30	245	72	9.4	0	0	0	0
			60	385	142	42	14	7.2	3.6	.6
			120	790	375	143	57	36	24	13
			183	1,400	720	295	106	60	35	18
	White River basin									
0780	Lagrue Bayou near Stuttgart, Ark	175	7	5.7	.7	.1	0	0	0	0
			15	17	2.3	.4	.1	0	0	0
			30	34	8.0	1.3	.3	.1	.1	0
			60	52	22	7.5	1.9	.9	.4	.2
			120	147	55	18	6.8	4.0	1.9	.7
			183	270	118	42	16	9.2	5.7	3.2
	Arkansas River basin									
2645	Bayou Meto near Stuttgart, Ark	560	7	17	.2	0	0	0	0	0
			15	36	2.3	0	0	0	0	0
			30	62	16	.6	0	0	0	0
			60	160	60	13	.6	.1	0	0
			120	420	160	44	9.1	3.0	0	0
			183	590	274	98	28	12	2.3	.2
	Red River basin									
3395	Rolling Fork near De Queen, Ark	181	7	17	3.9	.4	.1	0	0	0
			15	24	5.7	.6	.1	0	0	0
			30	49	11	1.3	.1	.1	0	0
			60	74	23	3.6	.3	.1	.1	0
			120	158	80	16	3.0	.8	.3	.1
			183	272	162	65	16	8.6	4.8	1.8
3400	Little River near Horatio, Ark	2,674	7	265	71	18	5.0	2.7	1.6	.8
			15	400	100	24	6.0	3.2	1.8	1.0
			30	660	170	39	9.1	4.5	2.5	1.3
			60	1,100	315	67	15	7.3	3.8	1.9
			120	2,200	1,140	295	61	32	16	7.3
			183	3,300	2,300	1,080	320	190	122	75

793-634—66——3

TABLE 3.—*Magnitude and frequency of annual low flow at daily-record gaging stations in the study area*—Continued

Station	Station name	Drainage area (sq mi)	Period (consecutive days)	Annual low flow, in cubic feet per second, for indicated recurrence interval, in years: 1.03	1.2	2	5	10	20	50
	Part 7. Lower Mississippi River basin—Continued									
	Red River basin—Continued									
7-3405	Cossatot River near De Queen, Ark	361	7	52	19	7.0	2.9	1.8	1.2	0.7
			15	69	25	9.1	3.6	2.2	1.5	.9
			30	150	39	11	4.6	3.0	2.1	1.4
			60	220	68	17	6.9	4.6	3.2	2.2
			120	370	200	49	15	9.2	6.6	4.6
			183	570	370	155	46	25	16	9.3
3410	Saline River at Dierks, Ark	124	7	10	2.0	.1	0	0	0	0
			15	14	3.9	.2	0	0	0	0
			30	35	6.8	.3	0	0	0	0
			60	56	14	1.4	.1	0	0	0
			120	111	48	9.4	.9	.2	.1	0
			183	188	103	40	10	3.5	1.1	.2
3425	South Sulphur River near Cooper, Tex	527	7	2.7	0	0	0	0	0	0
			15	4.9	.1	0	0	0	0	0
			30	33	.6	0	0	0	0	0
			60	87	4.2	0	0	0	0	0
			120	205	62	3.4	0	0	0	0
			183	510	170	44	12	6.0	3.2	1.5
3430	North Sulphur River near Cooper, Tex	276	7	3.4	0	0	0	0	0	0
			15	6.8	.1	0	0	0	0	0
			30	15	1.1	0	0	0	0	0
			60	33	5.0	.5	.1	0	0	0
			120	103	26	3.5	.5	.2	.1	0
			183	180	90	26	3.9	1.8	1.0	.5
3435	Whiteoak Creek near Talco, Tex	494	7	2.7	.8	.4	.1	0	0	0
			15	4.1	1.0	.5	.2	.1	0	0
			30	27	3.1	.7	.2	.1	0	0
			60	85	15	1.9	.4	.1	0	0
			120	275	83	15	1.4	.4	.2	.1
			183	610	210	55	14	4.5	1.3	.6
3440	Sulphur River near Darden, Tex	2,774	7	26	8.9	1.7	.1	0	0	0
			15	35	12	2.4	.2	0	0	0
			30	136	31	5.6	.4	0	0	0
			60	430	85	19	1.2	.1	0	0
			120	1,500	380	86	16	1.9	.2	0
			183	3,300	1,080	284	83	39	16	4.1
3445	Cypress Creek near Pittsburg, Tex	366	7	19	6.5	.7	0	0	0	0
			15	22	8.4	1.1	0	0	0	0
			30	36	13	2.3	0	0	0	0
			60	66	21	5.1	.2	0	0	0
			120	148	48	13	3.0	.4	0	0
			183	385	128	32	9.5	4.9	2.2	.3
3450	Boggy Creek near Daingerfield, Tex	72	7	1.9	.1	0	0	0	0	0
			15	2.7	.2	0	0	0	0	0
			30	5.1	.6	0	0	0	0	0
			60	10	2.4	0	0	0	0	0
			120	29	7.0	.6	0	0	0	0
			183	96	23	4.4	.3	0	0	0
3460	Cypress Creek near Jefferson, Tex	850	7	44	16	4.2	.7	.1	0	0
			15	51	20	5.2	.9	.2	0	0
			30	84	30	6.9	1.3	.3	0	0
			60	143	49	12	2.5	.8	.1	0
			120	330	108	30	7.8	3.3	1.3	.2
			183	840	280	76	22	12	6.8	3.2
3470	Kelly Bayou near Hosston, La	116	7	7.8	4.6	2.7	2.0	1.8	1.6	1.4
			15	8.9	5.2	3.0	2.2	2.0	1.8	1.5
			30	11	6.3	3.5	2.5	2.2	2.0	1.7
			60	17	9.2	4.8	3.1	2.8	2.5	2.2
			120	34	17	7.8	4.6	3.9	3.4	2.9
			183	77	34	14	7.3	5.6	4.8	4.1
3475	Black Bayou near Gilliam, La	364	7	25	12	5.8	3.7	3.2	2.9	2.4
			15	33	14	6.6	4.2	3.6	3.2	2.7
			30	46	18	8.1	4.9	4.2	3.7	3.1
			60	80	29	11	5.9	4.8	4.2	3.5
			120	159	54	17	7.8	5.9	4.9	4.1
			183	311	112	34	12	8.4	6.4	4.8
3480	Twelvemile Bayou near Dixie, La	3,137	7	65	25	11	6.6	5.5	4.6	3.7
			15	101	32	13	7.4	6.2	5.2	4.2
			30	210	52	16	8.5	6.8	5.7	4.5
			60	550	129	26	11	7.9	6.6	5.2
			120	1,390	345	62	17	11	8.8	7.0
			183	2,920	900	201	44	22	14	10
3490	Bayou Dorcheat near Minden, La	1,097	7	42	8.8	1.1	.2	.1	0	0
			15	53	11	1.3	.2	.1	0	0
			30	70	15	1.9	.3	.1	0	0
			60	140	32	4.0	.5	.2	.1	0
			120	420	104	15	2.1	.7	.3	.1
			183	810	275	61	12	4.6	2.1	.8

TABLE 3.—*Magnitude and frequency of annual low flow at daily-record gaging stations in the study area*—Continued

Station	Station name	Drainage area (sq mi)	Period (consecutive days)	Annual low flow, in cubic feet per second, for indicated recurrence interval, in years						
				1.03	1.2	2	5	10	20	50
	Part 7. Lower Mississippi River basin—Continued									
	Red River basin—Continued									
7-3495	Bodcau Bayou near Sarepta, La	546	7	7.4	1.8	0.4	0.2	0.1	0.1	0.1
			15	11	2.5	.5	.2	.2	.1	.1
			30	19	4.4	.8	.3	.2	.2	.1
			60	60	13	2.0	.6	.4	.3	.2
			120	225	52	6.9	1.6	1.0	.8	.5
			183	550	172	36	6.3	3.1	2.0	1.2
3496.5	Bodcau Bayou near Shreveport, La	683	7	25	4.0	.2	0	0	0.	0
			15	35	5.7	.3	0	0	0	0
			30	51	8.4	.6	0	0	0	0
			60	101	20	1.6	0	0	0	0
			120	258	64	8.8	.7	.1	0	0
			183	500	178	42	6.9	2.0	.6	.1
3500	Loggy Bayou near Ninock, La	2,628	7	133	58	18	5.2	2.5	1.4	.9
			15	166	70	22	6.1	2.9	1.6	1.0
			30	247	99	29	7.8	3.6	2.0	1.2
			60	500	173	44	11	5.1	2.8	1.5
			120	1,160	400	100	23	11	6.0	3.3
			183	2,600	950	263	71	38	24	14
3510	Boggy Bayou near Keithville, La	79	7	.7	.1	0	0	0	0	0
			15	1.0	.1	0	0	0	0	0
			30	1.9	.4	0	0	0	0	0
			60	3.9	.8	.1	0	0	0	0
			120	15	3.1	.3	0	0	0	0
			183	37	10	1.7	.3	.1	.1	0
3515	Cypress Bayou near Keithville, La	66	7	.5	.1	0	0	0	0	0
			15	.7	.1	0	0	0	0	0
			30	1.8	.2	0	0	0	0	0
			60	6.5	.8	0	0	0	0	0
			120	28	3.3	.2	0	0	0	0
			183	58	14	1.9	.2	0	0	0
3515.5	Cypress Bayou near Shreveport, La	266	7	3.5	.2	0	0	0	0	0
			15	6.0	.4	0	0	0	0	0
			30	10	.8	0	0	0	0	0
			60	30	3.3	.1	0	0	0	0
			120	97	20	.8	0	0	0	0
			183	219	68	8.3	.3	0	0	0
3520	Saline Bayou near Lucky, La	154	7	28	18	11	6.8	5.4	4.3	3.2
			15	30	20	12	7.2	5.8	4.6	3.4
			30	32	21	13	7.9	6.2	5.0	3.8
			60	42	27	16	9.3	7.1	5.7	4.2
			120	86	44	22	13	9.7	7.8	5.8
			183	139	68	33	20	16	13	9.8
3525	Black Lake Bayou near Castor, La	423	7	52	27	15	8.8	6.8	5.4	4.0
			15	58	30	16	9.6	7.3	5.8	4.3
			30	66	34	18	10	8.0	6.4	4.7
			60	96	48	22	12	9.3	7.2	5.2
			120	215	98	39	18	13	10	7.3
			183	420	184	70	31	22	17	12
3530	Saline Bayou near Clarence, La	1,386	7	136	40	6.8	.8	.2	.1	0
			15	210	60	10	1.3	.3	.1	0
			30	318	90	16	1.9	.5	.1	0
			60	515	162	32	4.5	1.2	.4	.1
			120	930	360	95	19	6.6	2.4	.6
			183	1,500	730	270	79	37	19	8.6
	Ouachita River basin									
560	Ouachita River near Mount Ida, Ark	410	7	67	34	16	8.4	5.6	3.8	2.3
			15	85	41	21	10	6.7	4.5	2.7
			30	119	55	26	13	8.4	5.6	3.4
			60	184	85	37	18	11	7.5	4.5
			120	414	198	72	34	24	18	12
			183	680	362	189	88	58	41	29
3598	Caddo River near Alpine, Ark	312	7	72	42	24	16	12	9.5	7.3
			15	87	46	27	17	13	11	8.1
			30	114	58	32	20	15	12	9.2
			60	150	81	40	23	18	14	11
			120	317	152	66	36	28	22	16
			183	560	280	125	62	44	34	26
3608	Muddy Fork Creek near Murfreesboro, Ark.	121	7	4.3	1.0	0	0	0	0	0
			15	6.7	1.4	0	0	0	0	0
			30	22	2.9	.1	0	0	0	0
			60	34	7.3	.8	0	0	0	0
			120	87	33	4.3	.6	0	0	0
			183	163	76	22	3.5	1.5	.6	0
3610	Little Missouri River near Murfreesboro, Ark.	380	7	55	20	7.5	4.1	3.0	1.7	1.1
			15	69	26	9.2	4.9	3.5	2.1	1.3
			30	100	38	12	6.4	4.7	3.3	1.6
			60	165	62	19	9.3	6.6	4.8	2.2
			120	390	160	49	18	13	9.7	6.5
			183	600	315	130	52	30	21	14

TABLE 3.—*Magnitude and frequency of annual low flow at daily-record gaging stations in the study area*—Continued

Station	Station name	Drainage area (sq mi)	Period (consecutive days)	Annual low flow, in cubic feet per second, for indicated recurrence interval, in years						
				1.03	1.2	2	5	10	20	50
Part 7. Lower Mississippi River basin—Continued										
	Ouachita River basin—Continued									
7-3615	Antoine River near Antoine, Ark	181	7	6.5	1.5	0.1	0.1	0	0	0
			15	9.9	2.2	.2	.1	0	0	0
			30	16	4.2	.4	.1	.1	0	0
			60	26	8.6	1.1	.1	.1	0	0
			120	99	29	5.3	.7	.2	.1	.1
			183	270	79	19	4.9	1.8	.5	.2
3625	Moro Creek near Fordyce, Ark	216	7	0	0	0	0	0	0	0
			15	0	0	0	0	0	0	0
			30	.7	0	0	0	0	0	0
			60	2.6	.2	0	0	0	0	0
			120	24	2.8	.1	0	0	0	0
			183	162	45	7.3	.6	0	0	0
3630	Saline River at Benton, Ark	569	7	62	28	12	5.3	2.7	1.4	.6
			15	83	34	15	6.8	3.6	1.9	.8
			30	121	48	20	9.0	5.0	2.7	1.2
			60	189	75	28	11	6.9	4.5	1.9
			120	399	194	65	26	18	12	6.8
			183	710	372	153	55	35	24	15
3635	Saline River near Rye, Ark	2,062	7	133	56	26	13	9.0	6.6	4.5
			15	177	70	30	15	10	7.7	5.2
			30	256	101	39	18	12	9.0	6.0
			60	406	161	56	25	17	12	7.7
			120	1,170	428	133	50	34	24	16
			183	2,270	960	329	115	71	49	30
3645	Bayou Bartholomew near Beekman, La	1,645	7	247	160	103	70	57	49	40
			15	278	174	110	75	62	52	42
			30	339	200	121	80	66	55	44
			60	490	260	144	90	71	60	48
			120	943	459	211	123	96	80	62
			183	1,660	770	330	179	143	116	88
3650	Bayou D'Arbonne near Dubach, La	355	7	23	4.7	.1	0	0	0	0
			15	28	6.3	.2	0	0	0	0
			30	36	8.7	.5	0	0	0	0
			60	68	18	2.5	.2	0	0	0
			120	168	50	9.9	1.5	.5	.2	.1
			183	323	125	34	7.3	2.8	1.2	.4
3655	Middle Fork Bayou D'Arbonne near Bernice, La.	178	7	6.8	1.1	0	0	0	0	0
			15	9.2	1.5	0	0	0	0	0
			30	12	2.0	.1	0	0	0	0
			60	26	5.4	.5	0	0	0	0
			120	74	20	3.0	.3	.1	0	0
			183	156	54	12	1.8	.6	.2	.1
3658	Cornie Bayou near Three Creeks, Ark	180	7	4.7	1.2	.3	.1	.1	0	0
			15	5.9	1.6	.4	.1	.1	0	0
			30	10	2.6	.5	.2	.1	.1	0
			60	20	7.8	2.3	.7	.5	.3	.2
			120	53	18	5.3	1.8	1.0	.7	.4
			183	132	44	13	5.0	3.0	1.9	1.2
3660	Corney Bayou near Lillie, La	462	7	23	7.6	1.4	.1	0	0	0
			15	31	11	2.2	.2	0	0	0
			30	41	14	3.3	.5	.1	0	0
			60	66	25	6.4	1.2	.3	.1	0
			120	127	51	14	3.0	1.1	.4	.1
			183	229	100	33	10	5.0	2.7	1.1
3680	Boeuf River near Girard, La	1,226	7	122	87	60	44	38	35	31
			15	134	94	64	46	40	36	32
			30	171	112	69	48	42	37	33
			60	238	139	78	53	44	40	34
			120	420	216	105	64	52	44	38
			183	660	320	148	87	68	57	46
3685	Big Colewa Bayou near Oak Grove, La	42	7	.7	.1	0	0	0	0	0
			15	1.2	.1	0	0	0	0	0
			30	2.6	.4	0	0	0	0	0
			60	6.1	1.3	.1	0	0	0	0
			120	15	4.6	.6	0	0	0	0
			183	46	19	5.3	1.0	.3	.1	0
3690	Bayou La Fourche near Crew Lake, La	361	7	38	14	4.7	1.9	1.2	.9	.6
			15	52	18	5.7	2.2	1.4	1.0	.7
			30	93	27	7.1	2.6	1.6	1.1	.8
			60	184	46	10	3.2	2.0	1.4	.9
			120	435	120	25	6.0	3.1	1.9	1.2
			183	905	275	62	14	7.0	4.0	2.2
3695	Tensas River at Tendal, La	309	7	27	15	8.2	5.0	3.9	3.3	2.8
			15	32	18	9.2	5.4	4.2	3.5	2.9
			30	46	23	11	6.0	4.5	3.7	3.1
			60	82	33	13	6.7	5.0	4.1	3.4
			120	202	68	21	9.4	6.6	5.0	3.8
			183	373	129	40	16	11	7.6	5.4

TABLE 3.—*Magnitude and frequency of annual low flow at daily-record gaging stations in the study area*—Continued

Station	Station name	Drainage area (sq mi)	Period (consecutive days)	Annual low flow, in cubic feet per second, for indicated recurrence interval, in years						
				1.03	1.2	2	5	10	20	50
	Part 7. Lower Mississippi River basin—Continued									
	Ouachita River basin—Continued									
7-3700	Bayou Macon near Delhi, La.	782	7	223	152	98	65	54	48	40
			15	249	168	107	70	57	50	42
			30	312	194	117	75	61	53	45
			60	418	243	136	84	66	57	47
			120	690	372	188	108	82	67	54
			183	1,110	535	263	151	116	92	71
3705	Castor Creek near Grayson, La.	271	7	9.0	2.7	.1	0	0	0	0
			15	11	3.4	.1	0	0	0	0
			30	13	4.3	.2	0	0	0	0
			60	25	9.3	1.4	0	0	0	0
			120	63	23	4.1	.1	0	0	0
			183	133	60	18	3.8	1.0	.2	0
3710	Garrett Creek at Jonesboro, La.	2.14	7	.6	.3	.2	0	0	0	0
			15	.6	.4	.2	.1	0	0	0
			30	.7	.4	.2	.1	.1	0	0
			60	.9	.6	.3	.1	.1	0	0
			120	2.5	1.1	.5	.2	.1	.1	.1
			183	10	3.6	1.2	.5	.4	.2	.2
3715	Dugdemona River near Jonesboro, La.	347	7	18	8.5	4.3	2.5	1.8	1.3	.8
			15	24	11	5.2	2.9	2.1	1.5	1.0
			30	34	14	6.4	3.5	2.5	1.8	1.2
			60	74	25	9.1	4.4	3.1	2.2	1.5
			120	187	54	15	5.8	4.0	2.8	1.9
			183	380	117	30	9.0	5.7	4.1	2.6
3720	Dugdemona River near Winnfield, La.	654	7	28	9.9	3.1	.8	.3	.1	0
			15	38	13	4.0	1.1	.4	.1	0
			30	57	19	5.7	1.5	.6	.2	.1
			60	153	39	10	3.0	1.4	.7	.3
			120	396	99	18	5.3	2.7	1.5	.8
			183	725	235	48	11	5.3	3.0	1.5
	Part 8. Western Gulf of Mexico basins									
	Sabine River basin									
8-0225	Sabine River at Logansport, La.	4,858	7	372	183	74	32	22	17	13
			15	433	209	84	35	24	18	14
			30	619	278	103	39	26	20	15
			60	1,030	424	140	49	31	23	17
			120	2,190	798	233	75	46	35	26
			183	4,060	1,650	551	207	136	94	58

In table 3, the probability of occurrence is given in terms of the average time interval between indicated low flows. For example, the lowest average discharge for 7 consecutive days on the Saline River near Rye, Ark. (7–3635), may be equal to or less than 13 cfs (cubic feet per second) at average intervals of 5 years on a long-term basis. The chance of occurrence in 1 year is 1 in 5, or 20 percent. These recurrence intervals are averages and do not imply any regularity of recurrence. During the period of record, 1938–57, the 7-day minimum flow near Rye was less than 13 cfs (the 5-year event) in 1938, 1943, 1954, and 1956. Thus, during the 20-year period, the 5-year event occurred four times; this recurrence is in agreement with the probable frequency. The intervals between these occurrences, however, which are 5, 11, and 2 years, demonstrate that there was not a regularity of recurrence.

The data in table 3 can be used to estimate the probable future magnitude and frequency of low flows at the indicated locations, if it is assumed that the climatological conditions experienced during the reference period 1929–57 will not change materially, and provided also that the effects of manmade changes are considered in making the estimates.

FLOW DURATION

Flow-duration data for the 50 daily-record gaging stations are presented in table 4. Just as for the low-flow frequency data, flow-duration data are not shown for the partial-record stations. The data in table 4 can be plotted on logarithmic-probability paper similar to that used in figure 4, if a graphical presentation is desired.

TABLE 4.—*Duration of daily flow at daily-record gaging stations in the study area*

[Data are adjusted to period October 1928–September 1957 on basis of relation to data at other gaging stations]

Station	Station name	Drainage area (sq mi)	Flow, in cubic feet per second, which was equaled or exceeded for indicated percent of time																
			99.5	99	98	95	90	80	70	60	50	40	30	20	10	5	2	1	0.5
	Part 7. Lower Mississippi River basin																		
	St. Francis River basin																		
7-0479.5	L'Anguille River at Palestine, Ark.	807	0	0	0	0.5	15	52	120	240	455	820	1,280	2,000	3,400	5,100	7,800	10,200	13,000
	White River basin																		
0780	Lagrue Bayou near Stuttgart, Ark.	175	0	0	0	.2	1.6	4.6	8.7	17	35	82	164	305	610	990	1,700	2,410	3,360
	Arkansas River basin																		
2645	Bayou Meto near Stuttgart, Ark.	560	0	0	0	0	0	5.6	36	75	200	470	745	1,060	1,530	1,990	2,600	3,090	3,540
	Red River basin																		
3395	Rolling Fork near De Queen, Ark.	181	0	0	.1	.4	1.2	4.7	12	28	56	100	160	295	680	1,320	2,700	4,200	6,200
3400	Little River near Horatio, Ark.	2,674	3.2	4.3	6.4	16	43	130	290	540	970	1,680	2,800	4,800	10,600	18,000	30,000	39,500	49,500
3405	Cossatot River near De Queen, Ark.	361	2.3	3.2	4.6	8.0	13	27	50	87	145	237	385	655	1,290	2,400	4,950	8,000	12,200
3410	Saline River near Dierks, Ark.	124	0	.1	.1	.2	.4	3.1	9.8	21	38	69	124	225	445	790	1,580	2,550	4,000
3425	South Sulphur River near Cooper, Tex.	527	0	0	0	0	0	.1	.4	1.4	4.0	11	28	90	430	1,460	4,100	6,950	10,200
3430	North Sulphur River near Cooper, Tex.	276	0	0	0	0	0	.2	.7	1.8	4.3	9.6	20	45	138	465	2,100	5,800	14,700
3435	Whiteoak Creek near Talco, Tex.	494	0	.1	.1	.3	.6	2.2	5.6	14	33	92	262	740	2,000	3,650	5,900	7,600	9,300
3440	Sulphur River near Darden, Tex.	2,774	0	0	.1	1.1	5.0	19	50	112	240	570	1,280	2,950	7,000	12,200	20,800	28,000	36,000
3445	Cypress Creek near Pittsburg, Tex.	366	0	0	0	.1	1.3	7.3	16	29	50	84	143	245	540	1,060	2,380	4,300	8,000
3450	Boggy Creek near Daingerfield, Tex.	72	0	0	0	0	0	.1	.7	3.2	8.6	18	33	56	114	232	580	1,140	2,600
3460	Cypress Creek near Jefferson, Tex.	850	0	.1	.7	2.4	6.4	21	46	95	185	336	575	920	1,660	2,700	4,700	7,000	10,900
3470	Kelly Bayou near Hosston, La.	116	1.8	1.9	2.2	2.7	3.4	5.3	8.2	13	24	44	80	146	294	471	795	1,120	1,510
3475	Black Bayou near Gilliam, La.	364	3.6	4.0	4.4	5.2	6.5	11	21	48	113	213	349	600	1,030	1,560	2,420	3,220	4,100
3480	Twelvemile Bayou near Dixie, La.	3,137	5.7	7.2	8.2	10	14	29	97	385	1,010	2,020	3,280	5,050	8,100	11,500	16,200	20,400	25,000
3490	Bayou Dorcheat near Minden, La.	1,097	0	0	.1	.7	2.5	8.4	32	96	255	630	1,090	1,790	3,320	5,250	8,350	10,900	13,500
3495	Bodcau Bayou near Sarepta, La.	546	.2	.3	.4	.6	1.0	2.9	11	38	135	330	590	970	1,710	2,610	4,010	5,270	6,790
3496.5	Bodcau Bayou near Shreveport, La.	683	0	0	0	.1	.3	3.1	17	88	265	585	950	1,470	2,220	--------	--------	--------	--------
3500	Loggy Bayou near Ninock, La.	2,628	1.8	2.9	4.9	9.8	17	40	87	275	1,000	1,900	2,910	4,140	6,450	9,200	13,000	16,500	20,000
3510	Boggy Bayou near Keithville, La.	79	0	0	0	0	0	.2	.6	1.7	4.4	9.4	20	48	152	355	870	1,500	2,300
3515	Cypress Bayou near Keithville, La.	66	0	0	0	0	0	.1	.4	1.3	3.2	6.6	14	32	108	295	940	1,820	3,050
3515.5	Cypress Bayou near Shreveport, La.	266	0	0	0	0	0	0	.3	8.5	45	123	262	510	905	1,150	1,480	1,700	--------
3520	Saline Bayou near Lucky, La.	154	6.0	6.7	7.8	10	13	18	26	38	57	86	134	221	428	715	1,210	1,690	2,230
3525	Black Lake Bayou near Castor, La.	423	8.1	9.2	11	14	18	26	42	84	225	360	530	810	1,440	2,210	3,550	4,750	6,100
3530	Saline Bayou near Clarence, La.	1,386	.9	1.7	3.6	9.6	19	48	118	380	850	1,450	1,980	2,720	3,900	5,050	6,400	7,500	8,800
	Ouachita River basin																		
3560	Ouachita River near Mount Ida, Ark.	410	4.7	6.9	10	19	31	50	76	126	220	348	518	860	1,660	2,900	5,420	7,950	10,800
3598	Caddo River near Alpine, Ark.	312	12	15	18	25	34	52	74	103	152	230	348	580	1,200	2,200	4,490	7,200	11,300
3608	Muddy Fork Creek near Murfreesboro, Ark.	121	0	0	0	0	.1	1.1	4.5	12	27	50	89	165	345	630	1,480	2,900	5,300
3610	Little Missouri River near Murfreesboro, Ark.	380	3.4	4.1	5.1	7.9	13	25	47	82	145	250	420	720	1,450	2,500	4,700	7,000	10,000
3615	Antoine River at Antoine, Ark.	181	0	0	0	.1	.4	2.4	9.0	24	51	95	152	273	605	1,150	2,410	4,000	6,300
3625	Moro Creek near Fordyce, Ark.	216	0	0	0	0	0	0	.1	1.8	10	39	117	267	630	1,150	2,200	3,380	5,000
3630	Saline River at Benton, Ark.	569	1.2	2.3	4.7	12	23	44	72	118	198	328	520	890	1,890	3,500	7,100	11,400	17,400
3635	Saline River near Rye, Ark.	2,062	8.4	11	14	23	41	84	153	287	553	1,190	2,390	4,090	7,350	11,100	17,500	23,600	31,100

7-3645	Bayou Bartholomew near Beekman, La.	1,645	56	62	71	88	112	159	227	345	600	1,210	2,170	3,500	5,200	6,400	7,520	8,350	9,180
3650	Bayou D'Arbonne near Dubach La.	355	0	0	0	0	.3	3.4	15	48	118	212	358	610	1,160	1,900	3,220	4,580	6,250
3655	Middle Fork Bayou D'Arbonne near Bernice, La.	178	0	0	0	0	0	.6	4.2	18	47	98	174	302	600	1,010	1,780	2,560	3,550
3658	Cornie Bayou near Three Creeks, Ark.	180	0	0	0	.3	.9	3.0	7.3	16	32	66	136	266	558	920	1,480	1,950	2,430
3660	Corney Bayou near Lillie, La.	462	0	0	0	1.2	3.0	9.0	24	52	101	185	320	580	1,190	2,060	3,570	4,900	6,100
3680	Boeuf River near Girard, La.	1,226	39	42	47	56	68	90	116	155	237	415	700	1,060	1,580	1,970	2,310	2,450	2,510
3685	Big Colewa Bayou near Oak Grove, La.	42	0	0	0	0	0	0	0	.4	2.3	7.4	18	48	142	290	550	790	1,100
3690	Bayou La Fourche near Crew Lake, La.	361	1.5	1.9	2.6	4.4	7.7	17	38	77	165	425	1,040	2,200	4,350	6,400	9,000	11,000	13,000
3695	Tensas River at Tendal, La.	309	4.2	4.8	5.6	7.4	10	16	26	42	71	137	257	490	990	1,520	2,120	2,490	2,750
3700	Bayou Macon near Delhi, La.	782	56	62	69	84	106	151	221	335	535	780	1,190	1,750	2,680	3,360	4,010	4,350	5,500
3705	Castor Creek near Grayson, La.	271	0	0	0	0	.2	1.6	5.6	16	38	85	167	315	740	1,300	2,220	3,170	4,300
3710	Garrett Creek at Jonesboro, La.	2.14	0	0	0	.1	.2	.4	.5	.7	1.0	1.7	3.2	8.3	34	112	312	565	860
3715	Dugdemona River near Jonesboro, La.	347	.9	1.4	2.0	3.4	5.4	9.2	15	33	74	152	279	520	1,090	1,860	3,350	4,650	5,800
3720	Dugdemona River near Winnfield, La.	654	.3	.5	.7	2.7	5.4	10	22	57	167	355	622	1,070	2,120	3,520	6,050	8,130	9,980

Part 8. Western Gulf of Mexico basins

	Sabine River basin																		
8-0225	Sabine River at Logansport, La.	4,858	20.2	23.8	29.8	48.2	86.1	187	361	675	1,270	2,250	3700	6,000	9,950	14,300	21,100	27,000	33,800

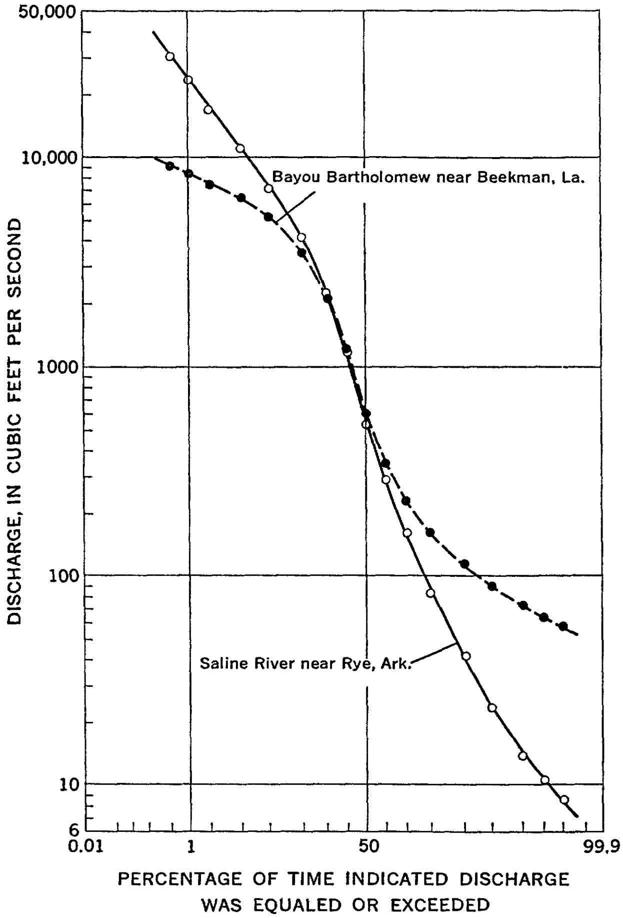

FIGURE 4.—Flow-duration curves for Saline River near Rye, Ark. (drainage area, 2,062 sq mi), and Bayou Bartholomew near Beekman, La. (drainage area, 1,645 sq mi), 1929–57.

The slope of the duration curve is determined by the hydrologic and geologic characteristics of the river basin upstream from the station, and the slope of the curve is a quantitative measure of the variability of the streamflow. The slopes of the duration curves for streams having large low-flow yields are flatter than those for streams having small low-flow yields. For example, the duration curve for Bayou Bartholomew near Beekman, La. (fig. 4), shows a much lower variability and a higher low-flow yield per square mile than does the duration curve for Saline River near Rye, Ark. Thus, the flow-duration data in table 4 are excellent for comparing the flow characteristics of different streams and may be used for preliminary planning, but detailed studies will require further analysis and use of the low-flow frequency data shown in table 3.

The flow-duration data in table 4 are for the complete reference period, 1929–57; the flow-duration data for any particular year can deviate from the data in table 4. For example, during 1943, a year of extremely low flow on Black Lake Bayou near Castor, La. (7–3525), the daily discharge equaled or exceeded 43 cfs only 52 percent of the time, whereas during the reference period, the discharge equaled or exceed 42 cfs 70 percent of the time.

The adjusted data in table 4 can be used to predict the long-term distribution of future flows at the indicated locations, if it is assumed that the climatological conditions experienced during the reference period, 1929–57, will not change materially, and provided that the effects of manmade changes are also considered in the computation.

FACTORS AFFECTING LOW FLOW

Water that sustains the flow of streams during long periods of no precipitation comes from prior precipitation that has been temporarily diverted. Inasmuch as the natural diversion of this water is through temporary storage in the geologic units, the low flows of streams is governed by the release of the stored water.

The ability of geologic units to release water from storage depends on their composition, and the movement of water through the units depends on their hydrologic character and the hydraulic gradient. The principal natural factors influencing the base flow of streams are: (1) permeability and porosity of the geologic units, (2) interrelation of the water surface in the streams to the elevation of the water table and to the base of the aquifers, (3) slope of the water table, and (4) rate of evapotranspiration.

The low flows of some of the streams described in this report may have been altered from their natural flows by manmade practices. Heavy pumping of ground water near the stream, for example, may lower the water table and permit the stream to yield some of its flow to adjacent aquifers, and the dredging of stream channels may increase or decrease the natural low flows of the stream. In addition, water is withdrawn from the streams for irrigation in many sections of the study area. The effect of these manmade changes limits the interpretation than can be made of the relation between geologic units and the low flow of the streams.

It is not possible to say generally that, in an area where one stream shows an index of a given unit yield, all streams in the area have the same index. Generally, the index differs from stream to stream and may differ at different locations on the same stream. The indices are the same only where the physical characteristics of the factors affecting the low flow are the same. However, the index does provide a means of comparing the yield of different areas and provides a basis for study of the factors affecting low flow.

The low-flow characteristics of the streams are compared by using the 7-day low flow for the 2-year recurrence interval, shown in table 2, as an index of low flow. The discharge for this median annual 7-day low flow is expressed in cubic feet per second per square mile to minimize the effect of size of drainage areas and thus to emphasize the effects of basin geology.

A study of the data in table 2 indicates large differences in the low-flow yields of the streams in the area, which can be attributed to the basin geology. The most noticeable differences in low-flow yields are between streams that head in the mountains and foothills outside the embayment and those that head in the embayment. The mountains and foothills outside the embayment are underlain by Paleozoic rocks which collectively constitute the major contributor to the low flow of the streams in the embayment. Streams in the Paleozoic rocks that are incised to sufficient depth to intercept the ground water have high low-flow indices. As these streams enter the embayment, they cross outcrops of Cretaceous and Tertiary deposits, and some of the streams enter broad alluvial valleys. In this belt just inside the boundary of the embayment, many of the streams experience decreases in low-flow yield.

Within the embayment, the geologic units that contribute appreciable water to the low flow of the streams are: the alluvium and the sand units in the Claiborne Group—the Carrizo Sand and Mount Selman Formation in Texas and the Carrizo Sand and Cane River Formation in Arkansas and Louisiana; the Sparta Sand; the Cook Mountain Formation; and the Cockfield Formation. The low-flow indices for streams that derive their base flow from the alluvium are generally low, but the alluvium is an important contributor to the base flow of the embayment streams because it is exposed over such a large part of the study area.

ST. FRANCIS RIVER BASIN

The major part of the St. Francis River basin lies north of lat 35° N., which is outside the area covered in this chapter. Low flows of the main stem of the St. Francis River are not shown because it is regulated by reservoirs upstream. Fifteen Mile Bayou, the major eastern tributary entering the St. Francis River within the study area, has a low-flow index of zero at the gaging station near West Memphis, Ark. (7–0479.2). This low value probably is the result of diversions for irrigation in the vicinity of West Memphis. The L'Anguille River, which lies west of Crowleys Ridge and cuts through the ridge near its southern end, flows through a narrow band of alluvium. Most of its eastern tributaries are in Quarternary terrace deposits. Some originate in the loess mantle of Crowleys Ridge which is underlain by sand and gravel, and where the tributaries leave the ridge, they flow across outcrops of the Claiborne Group. The low-flow index of zero for L'Anguille River near Wynne (7–0479.4) and at Palestine (7–0479.5), Ark., is indicative of the low yield of the terrace deposits which predominate west of Crowleys Ridge.

WHITE RIVER BASIN

The White River enters the study area at the mouth of Bayou des Arc in Arkansas. Flow in the main stem is regulated by numerous reservoirs and diversions upstream. Bayou des Arc (7–0768) and Cypress Bayou (7–0768.5), which have low-flow indices of zero, head in Paleozoic rocks and, after entering the embayment, flow through alluvium and terrace deposits. The base flow of these streams probably increases downstream (derived from water in the alluvium) from the gaging stations, which are near the margin of the embayment.

Wattensaw Bayou near Hazen (7–0769.5) and Lagrue Bayou near Stuttgart (7–0780), Ark., which have low-flow indices of 0.001 cfs per sq mi, receive their base flow almost entirely from Quaternary terrace deposits. Small parts of their basins near the White River are in the alluvium, and the headwaters of Wattensaw Bayou are in Tertiary sediments. Flow of many of the tributaries along the southern reach of the White River are affected periodically by diversions for irrigation.

The Cache River may be affected by diversions for irrigation in the extreme upper part of the basin. At Patterson, Ark., which is about 20 miles north of where the stream crosses into the study area, the effects from irrigation, if any, are less noticeable; the index at Patterson is 0.042 cfs per sq mi. The base flow probably is derived from the alluvium. Big Creek at Poplar Grove (7–0779.5) and its tributary Big Cypress Creek at Turner (7–0779.7), which have indices of 0 and 0.001 cfs per sq mi, respectively, are in Quaternary deposits. The low flows of both streams may be affected by diversions for irrigation.

ARKANSAS RIVER BASIN

The Arkansas River enters the embayment at Little Rock, Ark. The flow of the main stem is affected by diversions and regulated by many reservoirs upstream. The effect of this regulation on low flows is not known. The Corps of Engineers multipurpose project in the Arkansas River basin, now in progress, will have a beneficial effect on low flows of the Arkansas River. The magnitude of the increase in low flows due to the multipurpose project can only be estimated, but a 50-percent increase would not be unreasonable, depending upon the operation at the nine flood-control reservoirs in eastern Oklahoma and western Arkansas.

The Arkansas River immediately west and south of Little Rock is in a very narrow alluvial valley; it has no major tributaries in the embayment. The Maumelle River, which drains an area of Paleozoic rocks, enters the Arkansas River just outside the embayment boundary. Flows in the lower reach of Maumelle River are regulated by Lake Maumelle, and the yield of this area is unknown. Fourche Creek which flows around the southern edge of Little Rock has a low-flow index at the gaging station (7–2636) of 0.001 cfs per sq mi, but the effect of urban and industrial development in the Little Rock area on the low flow of this stream has not been determined.

East of Bayou Meto, the Grand Prairie region (fig. 2) is covered by terrace deposits. Low-flow indices in this area are 0.001 cfs per sq mi or less at all the gaging stations except Bayou Meto near Lonoke, Ark. (7–2640), which has an index of 0.010 cfs per sq mi. Bayou Meto near Lonoke is affected by drainage from irrigation and from a large minnow farm. Water for irrigation is pumped from many shallow wells and is diverted from many streams and reservoirs in the Grand Prairie region. The water table in the area has been progressively lowering for many years, and in some reaches along the Arkansas River, the water table slopes away from the river.

OUACHITA RIVER BASIN

The Ouachita River and many of its tributaries head in the Ouachita Mountains west of the embayment, and at the gaging station near Mount Ida, Ark. (7–3560), which is above any known regulation on the Ouachita River, the index is 0.039 cfs per sq mi. A series of dams, which maintains a year-round navigable depth on the main stem of the Ouachita River from Camden, Ark., to its mouth, prevents the obtaining of accurate low-flow measurements. The low-flow characteristics, therefore, are not determined.

The tributary streams entering the Ouachita River upstream from the Little Missouri River have indices ranging from 0.020 to 0.15 cfs per sq mi. Caddo River at Caddo Gap, Ark. (7–3596), which has a low-flow index of 0.15 cfs per sq mi, drains an area of Paleozoic rocks. The Caddo River between Caddo Gap and Alpine (7–3598), Ark., and Gulpha Creek above the gaging station near Hot Springs, Ark. (7–3587), are also in the Paleozoic rocks; the Caddo River in this reach has a computed index of 0.037 cfs per sq mi and Gulpha Creek has an index of 0.028 cfs per sq mi. L'Eau Frais Creek receives its base flow from the lower part of the Claiborne Group; at Joan, Ark. (7–3601), the low-flow index for this stream is 0.020 cfs per sq mi.

Low-flow indices of the Little Missouri River and its tributaries vary considerably. At upper elevations, the Little Missouri River basin is in Paleozoic rocks. At the gaging station near Langley (7–3602), the index is 0.19 cfs per sq mi, which is reasonably consistent with that for Caddo River at Caddo Gap. Downstream from Langley, the Little Missouri flows through the Paleozoic foothills and enters the embayment in a broad alluvial valley as it crosses the outcrop of the Trinity Group of the Lower Cretaceous Series. The low flow decreases between Langley and the gaging station near Murfreesboro, Ark. (7–3610), where the index is 0.020 cfs per sq mi. The decrease in flow is attributed to loss of water into the alluvium.

At the gaging sites on the tributaries, Muddy Fork (7–3608), Ozan Creek (7–3612), Antoine River (7–3615), Terre Rouge Creek (7–3616.5), Caney Creek (7–3617), and Terre Noire Creek (7–3618), the indices are 0.001 cfs per sq mi or less. Most of these streams head in the Paleozoic rocks or in the Tokio Formation of the Upper Cretaceous Series. In addition, Terre Rouge Caney, and Terre Noire Creeks cross outcrops of the Nacatoch Sand of the Upper Cretaceous Series or the Wilcox, Claiborne, or Midway Groups of the Paleocene and Eocene Series, but the yield from these geologic units to these streams is very low.

Below the mouth of the Little Missouri River, tributaries to the Ouachita River from the south side, near El Dorado, Ark., which are in the sands and clays of the Claiborne Group, generally have higher indices than tributaries to the Ouachita from the north side, which are mostly in Quaternary terrace deposits. Smackover Creek near Smackover (7–3621), which is a south-side tributary, has an index of 0.012 cfs per sq mi, whereas Tulip Creek (7–3618.5), Bayou Freeo (7–3619), Moro Creek (7–3625.5), and Eagle Creek (7–3640.2), which are north-side tributaries, have indices that range from 0 to 0.009 cfs per sq mi.

The upper tributaries to the Saline River in the northern tip of the Ouachita River basin in Arkansas drain Paleozoic rocks. The index of the Middle Fork at Crows (7–3627) is 0.033 cfs per sq mi, and the South Fork near Hot Springs (7–3628) has an index of 0.071 cfs per sq mi. Lower indices occur on Alum Fork (7–3626), index 0.010 cfs per sq mi, and on North Fork (7–3629), index 0.005 cfs per sq mi. As the Saline River leaves the Paleozoic rocks and flows across the embayment, the low-flow indices of the main stem decrease; at Benton (7–3630), the index is 0.021 cfs per sq mi, whereas near Rye (7–3635), it is 0.013 cfs per sq mi. Most of the Saline River tributaries within the embayment are in the Midway, Wilcox, and Claiborne Groups, and, in addition, Hurricane Creek (7–3633) has some exposure to the Paleozoic rocks near the boundary of the embayment. The alluvial valley of the Saline River between Benton and Rison crosses the sands and clays of the Wilcox and Claiborne Groups, and from Rison to Rye it crosses clays of the Jackson Group. The Jackson Group is not considered an aquifer, and the decrease in low flow between Benton and Rye is not unreasonable because the tributaries in this general area are low-yielding streams having indices of 0.001 to 0.007 cfs per sq mi. Hudgin Creek near Pansey, Ark. (7–3637), which lies east of the Saline River and drains partly from the Quaternary terrace deposits and partly from outcrops of the Jackson group, has an index of zero.

Bayou Bartholomew, the Boeuf River, the Tensas River, and Bayou Macon are eastern tributaries of the Ouachita River. Bayou Bartholomew is in an abandoned course of the Arkansas River. The main stem of Bayou Bartholomew lies in the alluvium from near Pine Bluff, Ark., to its mouth. Many of its tributaries which enter from the west head either in the Jackson Group or in terrace deposits and flow across terrace deposits to the alluvial valley of the main stem. Tributaries entering from the east are in the alluvium or in terrace deposits. The low-flow index of Bayou Bartholomew is 0.022 cfs per sq mi near McGehee, Ark. (7–3641.5), and at the gaging station near Beekman, La. (7–3645), the index is 0.063 cfs per sq mi. The index at McGehee may be affected by diversions for irrigation upstream, which have less effect on the Beekman index.

The Boeuf River, Tensas River, and Bayou Macon basins are in the alluvium. The Boeuf River basin includes the tributaries, Big Colewa Bayou, Big Creek, Bayou La Fourche, and Turkey Creek. The Tensas River basin includes the major tributary Bayou Macon and a network of small streams, some of which follow abandoned channels of the large streams that drained the area. Gaging stations in Louisiana on the main stems, Boeuf River near Girard (7–3680), Tensas River at Tendal (7–3695), and Bayou Macon near Delhi (7–3700), have low-flow indices of 0.05, 0.03, and 0.12 cfs per sq mi, respectively. These stations are on a line approximately east-west at lat 32°30′ N.; because the streams here are cut into aquifers in the basal part of the alluvium, they have high low-flow yields.

In the Bouef River basin in Louisiana, Big Creek at Holly Ridge (7–3685.2) and at Mangham (7–3685.4), has low-flow indices of 0.008 and 0.06 cfs per sq mi, respectively. The Mangham station has the higher index because it is farther west than the Holly Ridge station where the alluvial deposits are thinner, and it is south of the latitude where most of the large streams are cut into the basal part of the alluvium, which results in higher low-flow yields. Bayou La Fourche near Crew Lake (7–3690) and Turkey Creek at Winnsboro (7–3692), which also are cut into this shallow layer of alluvial material, have low-flow indices of 0.01 and 0.002 cfs per sq mi, respectively. Big Colewa Bayou near Oak Grove (7–3685), Little Creek near Mangham (7–3685.6), and Bayou Galion near Mer Rouge (7–3687.5), all have low-flow indices of zero. This is probably due to the streams not being cut deep enough into the high-yielding alluvial aquifer.

The western tributaries of the lower Ouachita River immediately south of El Dorado, Ark., which have low-flow indices ranging from near 0 to 0.06 cfs per sq mi, lie in the Claiborne Group or in Quaternary terrace deposits underlain by the Claiborne Group.

Bayou de Loutre near Laran, La. (7–3647), which lies in the low-yielding Cockfield Formation of the Claiborne Group, has a low-flow index of 0.06 cfs per sq mi. The index may be affected by the influent of wastes from oil-field operations upstream. The downstream station, at De Loutre, La. (7–3647.5), which has a lower index of 0.03 cfs per sq mi, is in the Cook Mountain Formation of the Claiborne Group. The fact the drainage area at the gaging station at De Loutre is more than twice the drainage area near Laran indicates that there is little or no yield to this stream from the Cook Mountain Formation.

Bayou D'Arbonne and most of its tributaries (7–3648 to 7–3663.5) have little or no sustained flow during dry periods. Most of the Bayou D'Arbonne basin is in the Cook Mountain Formation. Three Creek near Three Creeks, Ark. (7–3659), has a low-flow index of 0.014 cfs per sq mi, which may be caused by the influent of oil-field wastes.

The Ouachita River tributary, Cheniere Creek near Bawcomville (7–3675), and its tributary, North Cheniere Creek at Cheniere (7–3673), which derive their base flow mostly from the alluvium, have low-flow indices of 0 and 0.02 cfs per sq mi, respectively.

Streams in the Castor Creek basin in Louisiana (7–3702 to 7–3706) are in the low-yielding Cook Mountain and Cockfield Formations and in Quaternary terraces. The upstream gaging station, Castor Creek at Chatham (7–3702), has a low-flow index of 0.001 cfs per sq mi and is the only station in the Castor Creek basin that has an index greater than zero. Although Castor Creek lies predominantly in the Cook Mountain Formation, its probable partial contact with the Sparta Sand of the Claiborne Group may result in some low-flow yield.

Streams in the Dugdemona River basin have higher sustained low flows than streams in the Castor Creek basin. Dugdemona River upstream from Jonesboro, La., derives its base flow from the Sparta Sand. The stream has a low-flow index of 0.01 cfs per sq mi near Quitman (7–3708.2) and near Jonesboro (7–3715). The reach of the channel between Jonesboro and Winnfield is cut into the alluvium and terrace deposits, and the low-flow index near Winnfield (7–3720) is 0.005 cfs per sq mi. Two small tributaries, Garrett Creek at Jonesboro (7–3710) and Dukedall Creek near Danville (7–3710.5), which have low-flow indices of 0.07 and 0.09 cfs per sq mi, respectively, lie wholly in the Sparta Sand. Big Creek near Dodson, La. (7–3718), which has an index of 0.001 cfs per sq mi, probably receives its small base flow from local terrace deposits.

RED RIVER BASIN

The low flows of the main stem of the Red River are affected by regulation from reservoirs upstream, and the low-flow characteristics have not been determined. However, the low-flow characteristics of the numerous tributaries are indicative of streams within the basin in the embayment.

The Little River and its main tributaries from the north, which rise outside the embayment, have low-flow indices ranging from 0.001 to 0.019 cfs per sq mi. Within the embayment, the Little River and its northern tributaries cross Cretaceous outcrops, which contain aquifers of the Trinity Group, the Woodbine and Tokio Formations, and the Nacatoch Sand. Rolling Fork upstream from De Queen, Ark. (7–3395), index 0.002 cfs per sq mi, and its tributary, Robinson Creek, are in Paleozoic rocks; and few small tributaries to Rolling Fork flow across the Trinity Group. The Cossatot River heads in the Paleozoic rocks, and its valley cuts through the Trinity Group and Woodbine Formation of the Cretaceous System. Cossatot River near De Queen, Ark. (7–3405), index 0.019 cfs per sq mi, is fed by many tributaries; in addition, because the total length of the Cossatot River system of channels is much greater than that of Rolling Fork, the Cossatot River has a great opportunity for interception of ground water. Saline River upstream from Dierks, Ark. (7–3410), which has an index of 0.001 cfs per sq mi, is in Paleozoic rocks. Downstream from Dierks, within the embayment, the stream cuts through the Trinity Group and the Woodbine and Tokio Formations. The index on the main stem of Little River near Horatio, Ark. (7–3400), is 0.007 cfs per sq mi, which compares favorably with the indices for its tributaries. Tributaries from the south downstream from Horatio are in terrace deposits.

As the Red River flows through the gently rolling hill country of the embayment in Arkansas and Texas, it is fed by many small tributaries of low yield. Walnut Bayou (7–3369), Barkman Creek (7–3369.5), and McKinney Bayou (7–3423.5) all have low-flow indices of zero at the gaging sites. They are all near the edge of the alluvium. Manice Bayou near Canfield (7–3421.5), which has an index of 0.002 cfs per sq mi, is in the alluvium.

The western limit of the study area in Texas is long 94°45′ W. The gaging station on the main stem of the Sulphur River near Talco, Tex. (7–3432), and those on the North Sulphur (7–3430) and South Sulphur (7–3425) Rivers near Cooper, Tex., all of which are outside of the study area, have low-flow indices of zero. Upstream from Talco, the Sulphur River and its tributaries entering from the north are underlain by the Navarro Group and by the Taylor Marl of Cretaceous age. The South Sulphur River flows through the Navarro and the Midway Groups. Whiteoak Creek near Talco (7–3435), which has an index of 0.001 cfs per sq mi, flows through the Midway Group almost parallel to the Sulphur River and a few miles to the south of it. Sulphur River tributaries to the north, in the vicinity of Texarkana (7–3441 and 7–3443), are underlain by the Midway Group and Wilcox Formation and have indices of zero.

Cypress Creek lies in the Wilcox Formation and the Claiborne Group. It is in an area of slightly higher yield in Texas than that of the Sulphur River. Along the main stem and tributaries of Cypress Creek, the indices range from 0 to 0.005 cfs per sq mi. The index increase of 0.003 cfs per sq mi on the main stem of Cypress Creek between Pittsburg (7–3445) and Jefferson (7–3460) may be due to yield from the Claiborne Group. Regulation by Lake O' the Pines since 1958 has completely changed the low-flow regime at Jefferson. The tributaries to the Cypress Creek-Twelvemile Bayou basin that enter downstream from Jefferson have indices that range from 0 to 0.02 cfs per sq mi. Prewitt Creek near Karnack, Tex. (7–3460.8), a southern tributary to Cypress Creek, is underlain by the Reklaw Member of the Mount Selman Formation, the Carrizo Sand, and the Wilcox Formation, and has an index of 0.003 cfs per sq mi. The Black Bayou basin, a tributary to Cypress Creek from the north, lies in the lower part of the Claiborne Group and in Quaternary terrace deposits upstream from Hosston, La. (7–3465), and has low-flow indices of 0.002 to 0.003 cfs per sq mi. Cross Bayou, which includes the Paw Paw Bayou drainage, lies in the Wilcox Group and Quaternary terrace deposits; Paw Paw Bayou near Greenwood, La. (7–3482), has a low-flow index of zero. Kelly Bayou near Hosston (7–3470) and the lower reach of Black Bayou in the vicinity of Gilliam, La. (7–3475), both of which have a low-flow index of 0.02 cfs per sq mi, are in dredged channels which cut into the Quaternary alluvium.

Bayou Pierre, a western tributary of the Red River in Louisiana, has two gaged tributaries, Boggy Bayou (7–3510) and Cypress Bayou (7–3515). These streams, both of which have a low-flow index of zero, are in the Midway Group. Bayou Na Bonchasse near Mansfield, La. (7–3517), in the Bayou Pierre basin, has a low-flow index of 0.04 cfs per sq mi; this stream is also in the Midway Group, but it is probably incised into sands of the Wilcox Group and thus has the higher index. The headwater of Bayou Na Bonchasse lies partly in the Midway Group, which contributes very little to the total yield. Two streams that lie in the Eocene and Paleocene Series are Buffalo Bayou near Naborton, La. (7–3517.2), and Bayou Terre Blanc near Allen, La. (7–3517.6); both streams are cut into the Naborton Formation of the Wilcox Group, which is composed of calcareous and lignitic sands, silts, and clays. These streams have low-flow indices of zero. Rambin Bayou near Frierson, La. (7–3516.7), which has a low-flow index of zero, lies mostly in Quaternary terraces.

The eastern tributaries to the Red River in Arkansas, downstream from the Little River, are in an area of low yield that extends south into northern Louisiana. In the Loggy Bayou basin, 10 of the 15 gaging locations have an index of zero. The streams in the Loggy Bayou basin in Louisiana north of about lat 32°30′ N. lie mostly in Quaternary terrace deposits and are not cut deep enough into the geologic units to reach the ground-water levels. Black Bayou at Leton, La. (7–3487.6), lies principally in the Cook Mountain Formation of the Claiborne Group. Two streams in this basin, Bayou Dorcheat near Minden, La. (7–3490), and Bodcau Bayou near Sarepta, La. (7–3495), have a low-flow index of 0.001 cfs per sq mi. These streams flow out of the Wilcox Group or Claiborne Group and are predominantly in Quaternary terrace deposits, but they have some contact with the Quaternary alluvium. The Quaternary alluvium presumably contributes the base-flow yield. The two streamflow stations south of lat 32°30′ N., Brushy Creek near Sibley (7–3491) and Loggy Bayou near Ninoch (7–3500), La., have low-flow indices of 0.01 and 0.007 cfs per sq mi, respectively. Brushy Creek above the station near Sibley has contact with the Sparta Sand of the Claiborne Group, whereas the lower reaches of Loggy Bayou have considerable contact with the Quaternary alluvium.

The low-flow indices of streams in the Saline Bayou basin in Louisiana range from 0 to 0.20 cfs per sq mi. Streams which derive their base flow from the Sparta Sand have indices of 0.07 cfs per sq mi or higher, whereas streams which derive their base flow from Quaternary deposits or the Cook Mountain Formation have lower indices. The following are the low-flow indices for the streams that derive their base flow from the Sparta Sand: Saline Bayou near Lucky (7–3520), 0.07 cfs per sq mi; Saline Bayou near Goldonna (7–3521), 0.09 cfs per sq mi; Kepler Creek near Sparta (7–3524), 0.20 cfs per sq mi; and Castor Creek at Castor (7–3527), 0.16 cfs per sq mi. Black Lake Bayou near Minden (7–3522) has a low-flow index of 0.004 cfs per sq mi, whereas at the downstream gaging station near Castor (7–3525), which is in the alluvium and terrace deposits, the low-flow index is 0.03 cfs per sq mi; the increase in yield is derived from high-yielding tributaries which are in the Sparta Sand. The lower part of the Saline Bayou basin is in the alluvium, and the low-flow index near Clarence (7–3530) is only 0.005 cfs per sq mi. The decrease in yield between Goldonna and Clarence is attributed to the low-yielding tributary area and to large evapotranspiration losses in the intervening chain of shallow lakes. Two tributaries in this low-yielding area, which have low-flow indices of zero, are Black Lake Creek near Gibsland (7–3523), which is in the Cook Mountain Formation, and Grand Bayou near Coushatta (7–3528), which is in terrace deposits.

MAJOR FLOODS AND GROUND-WATER RECHARGE

Streams may be divided into two general categories in relation to ground water: (1) effluent streams which receive water from underground sources and (2) influent streams which yield water to underground reservoirs. Effluent streams are more numerous in the humid zones, and influent streams are characteristic of the arid regions. In the Mississippi embayment, most of the streams are usually effluent but may become influent during periods of drought. During periods of high stage, also, an effluent stream may become influent, or at least cease to be effluent, during which time the normal ground-water yield is held in storage.

Ground-water recharge during times of floods on effluent streams is generally temporary. This water is stored during the period of high stage on the river and is released soon after the flood recedes.

Along the Arkansas River, a definite relation exists between river stage and the elevation of the ground water. Typical hydrographs of the Arkansas River and of wells near Pine Bluff are shown in figure 5. In the Arkansas River valley, this relation becomes less detectable as the distance from the river increases, and the relation is almost imperceptible at distances of 3 to 4 miles. Wells 1, 2, and 3 are 2.0 miles, 0.4 mile, and 0.3 mile, respectively, from the river.

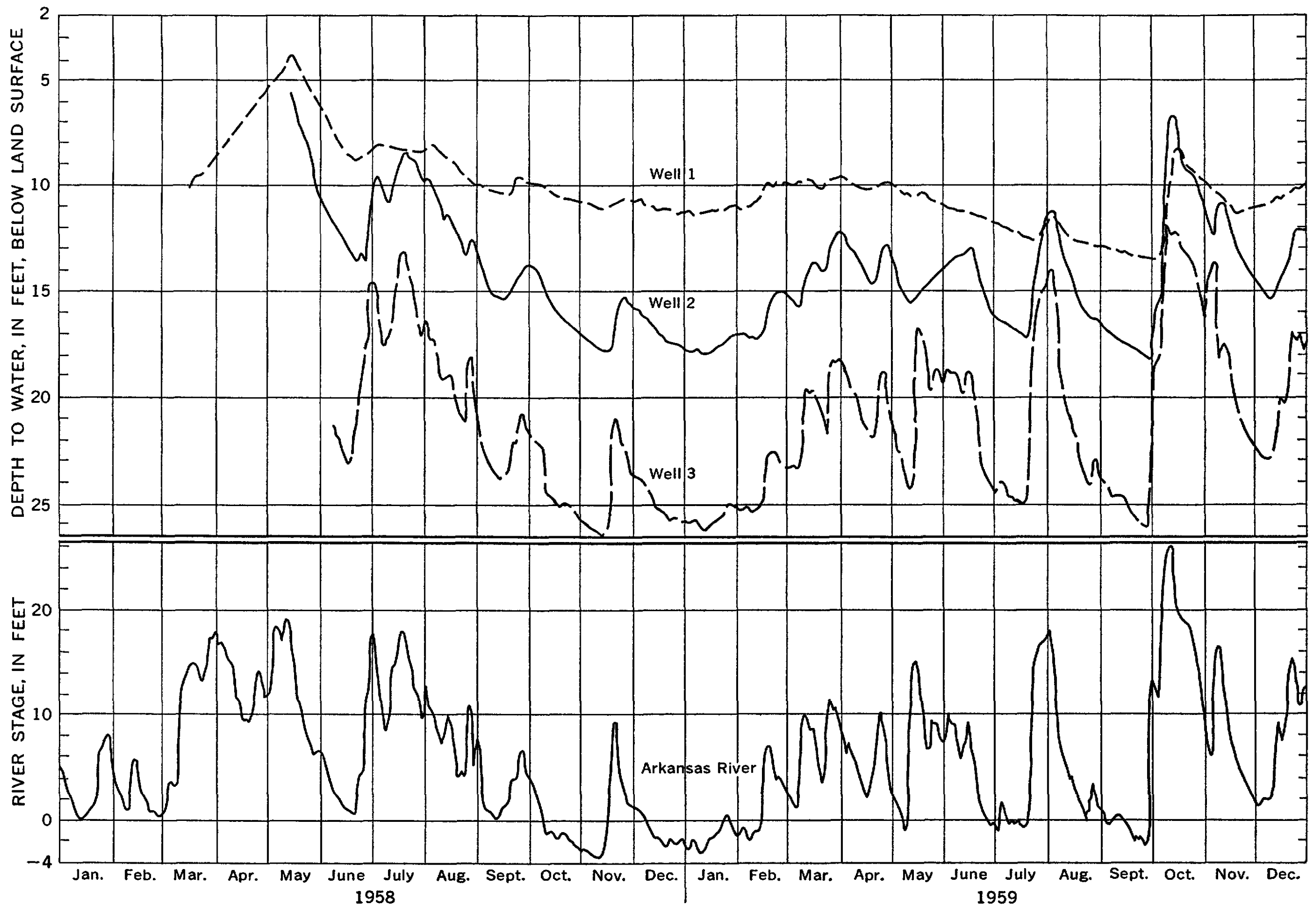

FIGURE 5.—Arkansas River and wells near Pine Bluff, Ark., 1958–59.

As illustrated in figure 5, it is recognized that an evaluation of changes in ground-water level should give consideration to the effects of changes in river stage. Recharge effects may be evident at locations fairly remote from the flooded area depending on the characteristics and extent of the aquifers adjacent to the stream.

LOW FLOWS AND GROUND-WATER FLUCTUATIONS

In the discussion of factors affecting low flow (p. G20), the first factor expresses the influence of the fixed physical properties of the aquifer in contact with or adjacent to the stream, and the other three are variable factors that need to be considered in relating the water level in the aquifers to the low flow. Because the geologic units are the natural storage reservoirs that sustain base flow, fluctuation in the ground-water table (or in the water surface in the streams) and the resulting variation in the slope of the water table toward the stream influence the rate at which the aquifer yields water to the stream at low flow. Thus, the fluctuations in the base flow of a stream are related to the fluctuations of the ground water in the geologic units from which the stream receives its base flow, and the ground-water yield to a stream is represented approximately by the base flow of the stream.

For streams that receive their base flow from a single geologic unit, the elevation of the ground water in the geologic unit is generally an index of the base flow. Very few streams, however, receive their base flow from a single geologic unit, and the relation becomes extremely complex for the larger streams that may receive their base flow from several geologic units. In addition, in many parts of the study area, evapotranspiration exerts a seasonal effect on streamflow which is difficult to evaluate.

The volume of ground water available to support low flow is the volume of water in the aquifers adjacent to the stream and at an elevation higher than that of the water surface in the stream. The size of the surface drainage area, then, is not always a dependable basis for appraising the low-flow characteristics of streams, because (1) the limits of the ground-water aquifer may not coincide with the surface drainage area and (2) there is great variation in the characteristics of each geologic unit from which the base flow of a stream is derived. The variations in the runoff per square mile presented in table 2 demonstrate the effect of the underground factors on base flow and provide an index for use in further investigation into the physical basis for the areal variation in the low-flow yields. In estimating low-flow characteristics, discharge measurements of low flow at the site should be available, and consideration should be given to the low-flow characteristics of other streams in similar geologic settings.

METHOD OF STUDY

The method used to analyze basic data and to obtain the low-flow frequency and flow-duration data presented in this report is mainly graphical. The procedure consisted of smoothing the low-flow data for long-term records by comparison with data from other long-term stations, and of then adjusting the shorter records to the reference period through their relations with the long-term records. Statistical principles were used as a guide in evaluating the relations.

The following long-term stations served as a basis for the low-flow analyses in southern Arkansas, northern Louisiana, and northeastern Texas:

Station	*Station name*
7-0375	St. Francis River near Patterson, Mo.
7-0570	Buffalo River near Rush, Ark.
7-3635	Saline River near Rye, Ark.
7-3645	Bayou Batholomew near Beekman, La.
8-0135	Calcasieu River near Oberlin, La.
8-0225	Sabine River at Logansport, La.
8-0335	Neches River near Rockland, Tex.

Smoothed low-flow frequency curves for these stations were taken from a report by Hardison and Martin (1963). Flow-duration curves were obtained by drawing smooth curves through the plots of the observed data for the reference period and giving some consideration to the shape of the flow-duration curves at other long-term stations.

Index stations were selected from the remaining stations having long records to obtain a representative distribution over the area. The low-flow records at these index stations were related to those at the long-term stations and then were used as a base to which to relate the flow data at stations having records shorter than those at the index stations. Data from daily-record stations having less than 5 years of record and data from low-flow partial-record stations were related to the data from one of the long-term stations.

The reference period used for this study is the 29-year period 1929-57, because this period was the longest for which a representative number of records was available at the selected long-term stations and at the index stations. The annual minimum discharges used in the low-flow frequencies are the lowest in each climatic year; hence the periods of low flow, which usually occur in the summer and fall, are included in the same year. The flow-duration sequences are for complete water years.

Low-flow frequency and flow-duration results for partial-record stations and for daily-record stations having only a few years of continuous record are much less accurate than are similar results for the longer term stations, because the data relate to a smaller range of discharge and a smaller variety of experience.

More detailed descriptions of the methods used in the study and the analyses of the records are given by Speer, Golden, Patterson, and others (1964).

BASIC DATA FOR THE ANALYSIS

The basic data for the results presented in this report are the records of discharge collected at 50 daily-record and 106 partial-record stations in or adjacent to the Mississippi embayment in southern Arkansas, northern Louisiana, and northeastern Texas. Location of the stations is shown on plate 1. The names of the stations are given in table 2.

Most of the streamflow records used in the analysis have been published annually in reports of the Geological Survey; a few were furnished by other agencies. The United States is divided into 14 parts to facilitate publication of the records. All the records in the area covered by this report are in Part 7 (fig. 6), Lower Mississippi River basin, except the Sabine River at Logansport, La., which is in Part 8, Western Gulf of Mexico basins.

Records of daily discharge for gaging stations having five or more complete consecutive water years not affected by regulation or diversion were processed by an electronic computer to obtain (1) the lowest mean discharge occurring during each year for selected numbers of consecutive days and (2) the number of daily flows each year between selected limits of discharges (Speer, 1960). If the natural flow at a station became materially regulated or was affected by diversions as the result of manmade changes, the data for the record so affected were not used. Records for less than 5 complete years were not processed by electronic computer but were analyzed as low-flow partial-record stations.

DRAFT-STORAGE RELATIONS

The discharges given in table 2, 3, and 4 are indications of the natural flow of the streams. Storage must be provided for drafts greater than the natural flow. The amount of such storage and the frequency with which it is required provide a basis for obtaining an

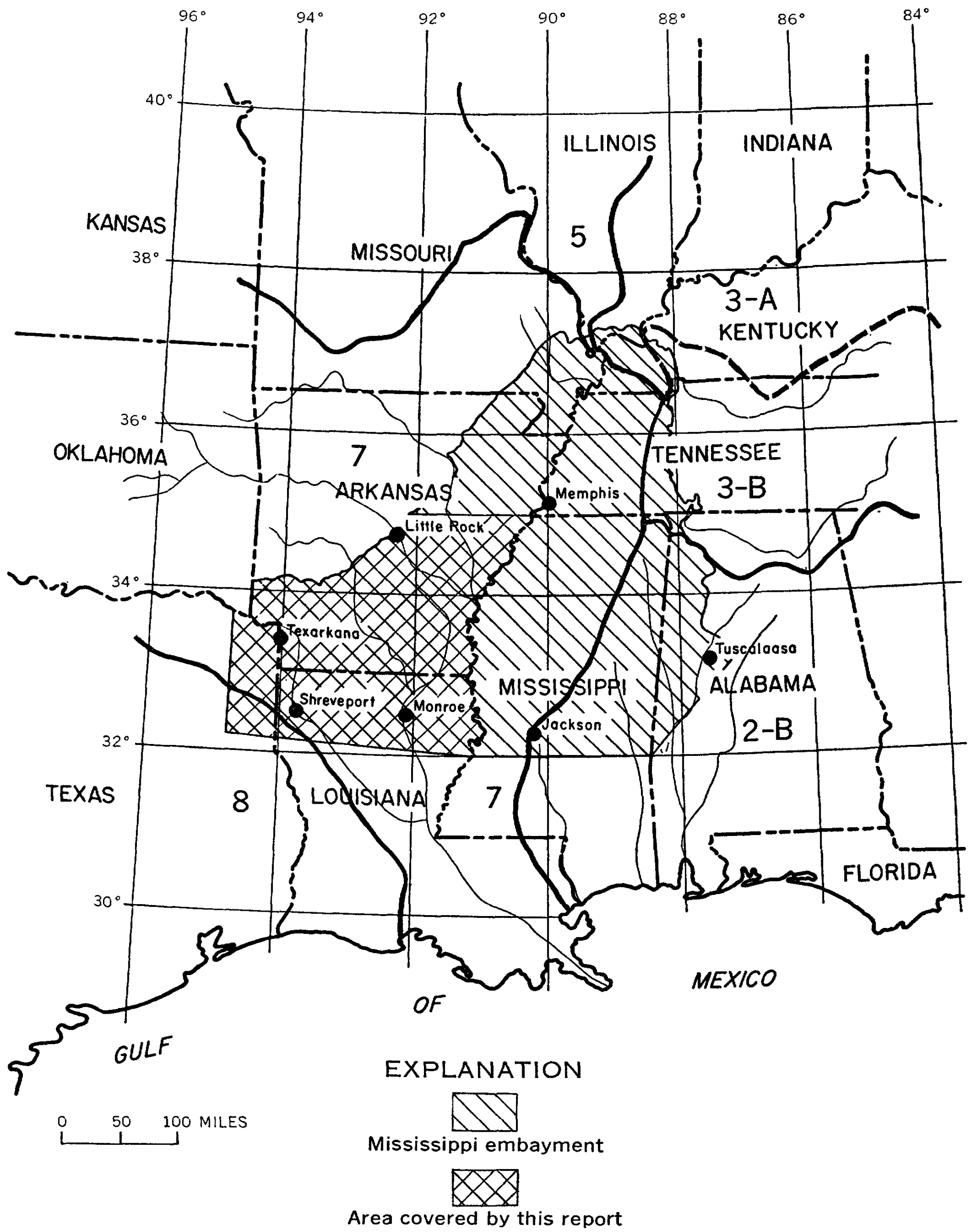

FIGURE 6.—Map of Mississippi embayment showing areas covered, by numbered parts, for which streamflow records are published in reports on surface-water supply.

economic balance between the cost of the storage and the loss resulting from an insufficient supply at periodic intervals. The low-flow frequency data for the 50 stations in table 3 were used to estimate the draft that may be maintained from specified amounts of storage.

To provide a means for estimating the storage required for various drafts at other sites, the storage-required frequency data are related to the median annual 7-day (7-day 2-year) low flows as shown in figures 7 and 8. This index of low flow, which is the same as that used, in the section on "Factors affecting low flow," is given in table 2 for 88 sites in the study area. For other sites, the index usually can be estimated by making a few measurements of low flow and relating the measured discharge to the concurrent discharge at the nearest site listed in table 2 at which an acceptable correlation can be obtained (Searcy, 1959, p. 20). Application of frequency data for intermittent streams to storage problems is not recommended. At present, techniques are not sufficiently well developed to permit

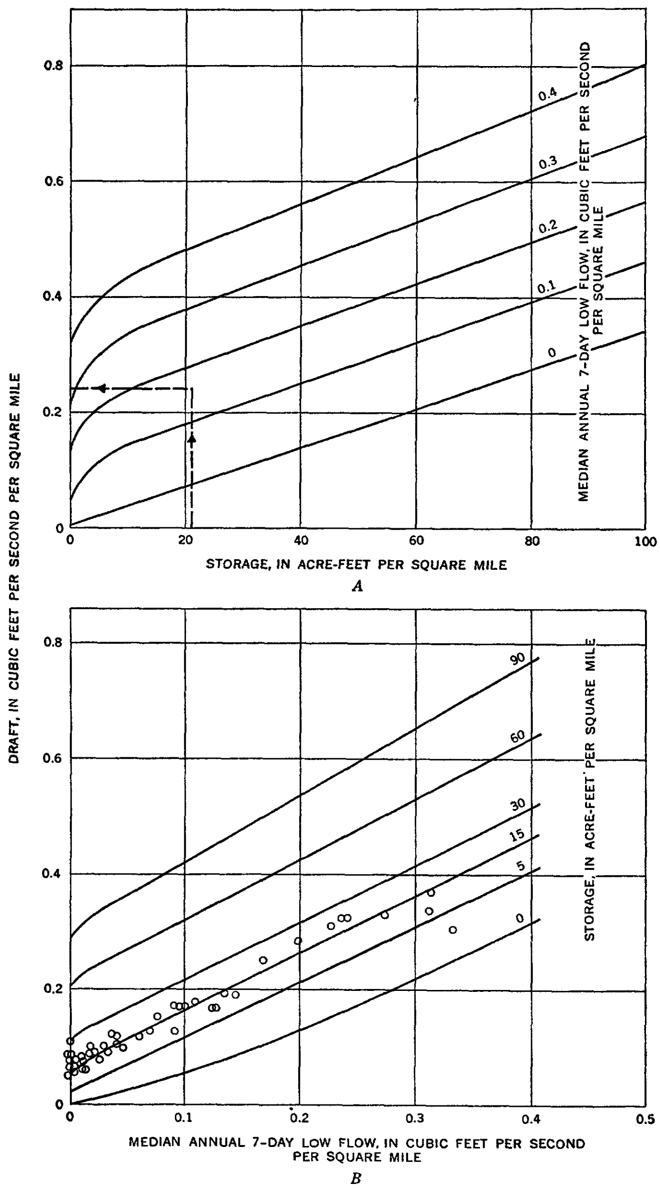

Figure 7.—Areal draft-storage relations for a 10-year recurrence interval as a function of the median annual 7-day low flow, for storage of 0, 5, 15, 30, 60, and 90 acre-ft per sq mi.

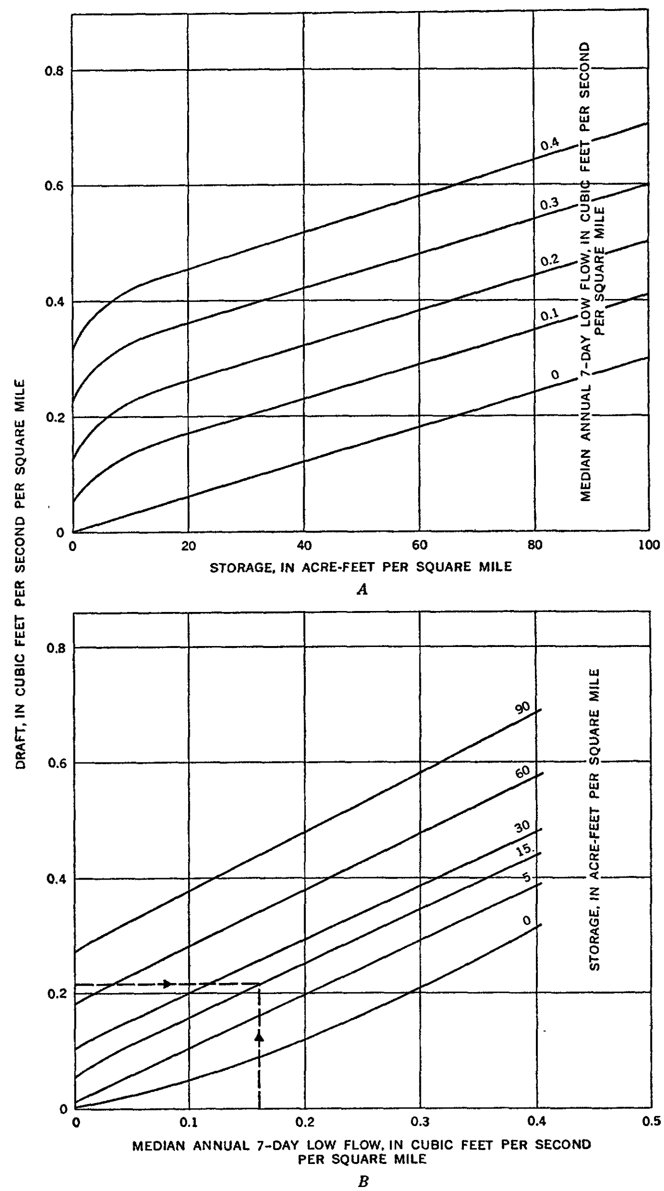

Figure 8.—Areal draft-storage relations for a 20-year recurrence interval as a function of the median annual 7-day low flow, for storage of 0, 5, 15, 30, 60, and 90 acre-ft per sq mi.

draft-storage analysis on a frequency basis for streams with indices of zero.

Data available to define the curves in figures 7*B* and 8*B* in the area covered by this chapter are very limited because of the large number of low-flow indices that are zero. To improve the reliability of the curves, similar data for the embayment in northern Arkansas and Missouri are included, and a single set of curves is developed for the Mississippi embayment in Arkansas, Missouri, northern Louisiana, and northeastern Texas. The number of points available to define the curves ranges from 4 for the 90 acre-ft per sq mi (acre-feet per square mile) at the 20-year recurrence interval to 66 for 0 acre-ft per sq mi at the 10- and 20-year recurrence intervals and for 5 acre-ft per sq mi at the 10-year recurrence interval. The scatter of the circles in figure 7*B* for a storage of 15 acre-ft per sq mi is typical of the scatter of the points that define other curves in the two lower graphs. The curves in figures 7*A* and 8*A* are based on the curves in 7*B* and 8*B*.

The curves of zero storage in figures 7 and 8 represent the 7-day low flow for the 10-year or 20-year recurrence interval and thus neglect the small amount of storage that will be required to regulate the 7-day flow within the minimum. None of the curves include reservoir losses or losses in conveyance of water from the storage facility to the point of utilization. Furthermore, a bias of about 10 percent that results from using low-flow frequency curves to compute storage requirements also has been neglected. As the losses and the bias both tend to make the computed amount of storage smaller than it should be, allowance for these must be included in project design. The areal draft-storage relations, therefore, should be used only for obtaining preliminary estimates of draft-storage requirements at partial-record sites and for making comparisons between stations. More detailed studies, using the data in table 3 if available for the location, should be made in connection with design of specific projects.

The curves should not be extrapolated beyond the limits to which they are shown.

The procedure used to estimate the draft-storage requirements is described by Speer, Golden, Patterson, and others (1964, p. I35–I36).

The storage required for a specified draft with a chance of its being insufficient on an average of once in 10 or once in 20 years can be estimated by using figures 7 and 8 and the median annual 7-day low flow (7-day 2-year low flow) for the stream at the point of utilization. By using the median annual 7-day low flow as abscissa and the storage to be provided as a parameter, the diagrams in figures 7*A* and 8*A* give the specified draft. If the required draft is known, the amount of storage required can be estimated from the diagrams in figures 7*B* and 8*B*.

Illustrative problem 1.—Let it be assumed that a proposal is made to build a manufacturing plant on Castor Creek at Castor, La., which will require a minimum flow of 6.0 cfs for operation; for economic reasons, the flow should not drop below this discharge more often than once in 20 years on a long-term average. How much storage will be required to maintain this flow for this frequency?

1. From table 2, for Castor Creek at Castor, La. (7–3527), obtain the median annual 7-day low flow (7-day 2-year low flow), which is 0.16 cfs per sq mi, and the drainage area, which is 27.9 sq mi.
2. Divide 6.0 cfs by 27.9 sq mi to obtain a required draft of 0.215 cfs per sq mi.
3. Use figure 8*B*. The abscissa being 0.16 cfs per sq mi and the ordinate being 0.215 cfs per sq mi, the estimated storage required is 15 acre-ft per sq mi or 418 acre-ft. This amount plus 10 percent for bias and plus an additional amount for reservoir and conveyance losses would be required to provide the desired draft and would be insufficient at average intervals of 20 years.

If it is desired to estimate the maximum draft that may be made from a specified amount of available storage, the available storage must first be adjusted by estimates of reservoir and conveyance losses, and then the drafts that may be expected at the point of utilization can be determined.

Illustrative problem 2.—Let it be assumed that demands for water are such that they greatly exceed the natural flow of Castor Creek at Castor, La., and let it be assumed also that upstream from Castor a total storage of 786 acre-ft could be developed or made available for supplementing low flows. What draft at Castor can be maintained by this storage if a deficiency once in 10 years can be tolerated?

1. From table 2, for Castor Creek at Castor, La. (7–3527), obtain the drainage area, which is 27.9 sq mi, and the median annual 7-day low flow (7-day 2-year low flow), which is 0.16 cfs per sq mi.
2. Estimate the annual reservoir and conveyance losses and deduct these amounts from the total storage. For this problem, the total of reservoir and conveyance losses during a dry year and 10 percent bias are estimated as 200 acre-ft. The net storage available for use at Castor is 786 acre-ft minus 200 acre-ft, or 586 acre-ft.
3. Divide the net storage by the drainage area to obtain the net acre-feet per square mile available at Castor:

$$\frac{586}{27.9}=21 \text{ acre-ft per sq mi}$$

4. Use figure 7*A*. The abscissa being 21 acre-ft per sq mi, and the parameter being 0.16 cfs per sq mi, interpolate between median annual 7-day low-flow curves of 0.1 and 0.2 cfs per sq mi, and read as ordinate the draft of 0.24 cfs per sq mi. For 27.9 square miles, this would give 6.7 cfs as the allowable draft that would deplete the storage once in 10 years on a long-term average. As soon as the storage was depleted, the available flow would drop to the natural inflow, which for this stream is 0.12 cfs per sq mi or 3.3 cfs at a 10-year recurrence interval, unless the allowable draft were curtailed to less than 6.7 cfs as the drought developed and as the amount of water in storage became dangerously low.

Storage and draft data in figure 7 and 8 may be converted to other units by using the following conversion equivalents:

1 acre-ft = 0.326 million gal = 0.504 cfs-day
1 cfs = 1.983 acre-ft per day = 0.646 million gal per day
1 million gal per sq mi = 1.548 cfs-days per sq mi = 3.070 acre-ft per sq mi

QUALITY OF THE WATER

By H. G. Jeffery

During periods of low flow, the chemical quality of water in streams sampled in the study area is controlled by the composition of the geologic units in the drainage basins unless altered by the addition of oil-field wastes. Because of these influences, surface waters in the area are extremely variable in the character and amounts of dissolved solids. In streams where the composition of the geologic units is the principal controlling factor on water quality, the character and amount of dissolved solids depend primarily on the solubility of the aquifer materials and the length of time the water is in contact with these materials. In these streams the dissolved-solids content usually is low, and the chemical characteristics of the water from each stream are fairly uniform. The dissolved-solids content of water in streams that receive oil-field wastes is variable, depending upon the relative rates of streamflow and the release of wastes.

The dissolved-solids content of water in the streams sampled (table 5) ranges from 12 to 12,900 ppm (parts per million), hardness from 6 to 1,010 ppm, iron from 0.00 to 1.2 ppm, fluoride from 0.0 to 2.0 ppm, nitrate from 0.0 to 4.0 ppm, and silica from 0.0 to 34 ppm. The higher concentrations of dissolved solids and hardness are from streams that contain oil-field wastes. Water that shows the higher concentrations of iron is also highly colored. The maximum concentration of fluoride is much higher than would normally be expected, and the source of the fluoride is not known. The source and significance of dissolved mineral constituents and properties of water are shown in table 6.

The suitability of water for most uses depends on the chemical, biological, and physical characteristics of the water. For most industrial and municipal uses, water requires some treatment, the degree and type of which depend on the quality and intended use of the water. In many of the unpolluted streams in this area, the water would be suitable for some uses, such as cooling, with little or no treatment. However, for municipal and most industrial uses, the water would require, as a minimum treatment, pH adjustment for corrosion control, and for some water, color and iron removal. Much of the water also would require silica removal if it was to be used in high-pressure boilers. Because of the present and potential variations in the chemical quality of water in streams receiving oil-field wastes, these streams generally are not suitable as sources of municipal or industrial water supplies.

The chemical characteristics of water in the streams sampled are shown graphically on plate 2. The single diagram or pattern represents the average of two analyses (table 5) of the water at each site sampled, except for Two Prairie Bayou at Carlisle, Ark. (7–2642), Big Cypress Creek at Turner, Ark. (7–0779.7), and Black Bayou at Benton, La. (7–3498.4), where only one analysis is available at each site. Double patterns are shown for Wattensaw Bayou near Hazen, Ark. (7–0769.5), and Kelly Creek near Marietta, Tex. (7–3460.2), where the water has a more variable composition.

The geologic units contributing water to Ozan Creek near McCaskill, Ark. (7–3612), are the Tokio Formation of Cretaceous age and the alluvium of Quaternary age. The water is a calcium bicarbonate type (pl. 2); this composition indicates that the principal soluble constituent in the aquifer materials is calcium carbonate. The variation in dissolved solids of the two analyses, 56 and 91 ppm (table 5), probably is due to the relative amounts of water contributed from each formation. Water from Quaternary deposits generally has a higher calcium bicarbonate content than water from the outcrop of the Tokio Formation. Thus, the increase in calcium bicarbonate with the decrease in discharge (from 0.27 to 0.14 cfs) is indicative of a larger percentage of the flow coming from the Quaternary deposits. The water in Ozan Creek near McCaskill, Ark., is similar in chemical characteristics to water in the Little Missouri River near Boughton, Ark. (U.S. Geol. Survey, 1959b, p. 227–229), and its quality is representative of the quality of water in other streams draining areas of similar geology.

Walnut Bayou near Foreman, Ark. (7–3369), drains the Ozan Formation and alluvium. The water in this stream generally is high in dissolved solids and the large amounts of sulfate and chloride indicate that most of the dissolved solids in the water are from the Ozan Formation.

Low-flow water in the streams that drain Eocene formations, or various combinations of Eocene and Quaternary formations, is variable in dissolved-solids content and in chemical characteristics. Water in these streams is slightly acid, and where the activities of man have not affected the water quality, the water is generally soft (0–60 ppm hardness) but has a dissolved-solids content of as much as 100 ppm. In many of the streams a large part of the variation in dissolved solids is caused by the variation in the silica content. Such water does not seem to have any chemical characteristic peculiar to one formation or a combination of formations. For instance, Francois Creek near Poyen, Ark. (7–3631), and Prewitt Creek near Karnack, Tex. (7–3460.8), both drain the Wilcox and the lower part of the Claiborne Group, but the patterns of the chemical analyses for

TABLE 5.—*Chemical analyses of low-flow surface waters in the study area*

Aquifers in drainage basin above sampling station	Date of collection	Discharge (cfs)	Parts per million: Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (calculated from determined constituents)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color
	7-3612. Ozan Creek near McCaskill, Ark. (drainage area, 148 sq mi)																		
Tokio Formation and alluvium	9- 8-60	0.27	0.7	0.00	17	0.8	2.0	1.6	51	6.0	3.0	0.0	0.1	56	46	4	101	6.8	6
	8-15-62	.14	5.5	.01	28	1.7	2.0	1.8	84	5.4	5.0	.2	.5	91	77	8	165	6.4	10
	7-3369. Walnut Bayou near Foreman, Ark. (drainage area, 83.6 sq mi)																		
Ozan Formation and alluvium	9-23-60	0.21	6.5	0.00	124	30	145	5.2	336	167	210	0.5	0.6	855	433	158	1,480	6.9	5
	8-16-62	.10	9.8	.00	91	19	147	3.6	273	117	205	.1	.2	727	305	82	1,260	8.1	4
	7-3369.5. Barkman Creek near Leary, Tex. (drainage area, 31.5 sq mi)																		
Midway Group	5-23-61	2.34	5.7	0.00	6.4	2.4	11	2.1	35	3.8	9.0	0.3	1.0	59	26	0	108	6.2	45
	9-18-62	.90	12	.03	7.2	1.8	13	2.6	36	6.8	10	2.0	.2	74	25	0	129	6.3	30
	7-3631. Francois Creek near Poyen, Ark. (drainage area, 84.1 sq mi)																		
Wilcox Group and lower part of Claiborne Group	9-20-60	0.05	1.6	--------	6.4	1.3	9.0	2.0	16	23	3.0	0.1	0.3	54	22	8	109	6.3	7
	6-27-61	5.24	5.9	--------	6.4	1.9	9.4	1.1	10	36	1.0	.0	.6	67	24	16	107	6.4	5
	7-3460.8. Prewitt Creek near Karnack, Tex. (drainage area, 29.5 sq mi)																		
Wilcox Formation, Carrizo Sand, and Reklaw Member of Mount Selman Formation	5-23-61	3.18	12	0.00	2.7	1.5	3.7	0.7	12	5.2	4.0	0.2	1.3	37	12	2	47	6.2	20
	9-19-62	.49	18	.04	3.0	1.9	3.3	1.2	13	4.8	5.5	.1	.0	44	15	5	48	6.2	15
	7-3617. Caney Creek near Bluff City, Ark. (drainage area, 167 sq mi)																		
Wilcox Group, Carrizo Sand, and Sparta Sand	9- 8-60	0.66	0.0	0.00	58	16	580	9.5	30	18	1,040	0.9	0.7	1,740	210	186	3,400	6.5	7
	8-15-62	.30	2.9	.00	69	19	561	12	2	14	1,050	.3	.4	1,730	250	249	3,350	5.4	4
	7-3482. Paw Paw Bayou near Greenwood, La. (drainage area, 78 sq mi)																		
Wilcox Group and terrace deposits	5-16-61	2.56	6.7	--------	28	13	100	3.5	86	37	165	0.2	1.0	396	124	53	741	7.0	15
	3- 7-63	10.6	4.7	0.11	31	17	113	5.3	40	64	205	.0	1.0	461	148	115	890	6.6	50
	7-3516.7. Rambin Bayou near Frierson, La. (drainage area, 59.6 sq mi)																		
	5-16-61	10.5	7.7	--------	25	13	61	3.6	100	70	70	0.1	1.2	301	116	34	511	7.2	10
	3- 8-63	4.79	4.9	0.04	22	12	37	4.8	66	61	51	.0	1.2	226	105	50	394	6.9	40
	7-3441. Caney Creek near Redwater, Tex. (drainage area, 18 sq mi)																		
Wilcox Formation and alluvium	5-23-61	3.90	17	0.00	5.2	3.0	13.	1.2	40	4.0	12	0.2	0.9	76	26	0	113	6.5	40
	9-18-62	.57	22	.03	9.0	2.9	9.4	1.9	45	5.4	10	.2	.0	83	34	0	114	6.3	15

	7-3601. L'Eau Frais Creek at Joan, Ark. (drainage area, 79.4 sq mi)																		
Lower part of Claiborne Group	9- 6-60	2.73	0.5	0.00	1.7	0.5	1.3	0.8	7	1.2	2.0	0.3	0.6	12	6	0	23	6.3	15
	8-13-62	3.94	6.3	.04	1.9	.6	1.7	1.0	6	2.8	3.0	.2	.6	21	7	2	26	6.4	5
	7-3460.2. Kelly Creek near Marietta, Tex. (drainage area, 50.5 sq mi)																		
Carrizo Sand and Reklaw and Queen City Sand Members of Mount Selman Formation	5-23-61	6.21	14	0.00	2.9	1.6	3.7	1.3	12	5.6	3.5	0.2	2.6	41	14	4	49	6.1	15
	9-18-62	.39	29	.01	6.2	2.5	4.9	2.8	2	28	6.0	.1	.0	81	26	24	93	5.4	5
	7-3460.4. Hughes Creek near Avinger, Tex. (drainage area, 48.6 sq mi)																		
Queen City Sand Member of Mount Selman Formation	5-23-61	9.86	10	0.00	2.5	1.5	3.7	1.2	10	5.0	5.0	0.0	1.5	35	12	4	47	5.8	7
	9-18-62	7.99	22	.02	2.5	2.0	5.3	2.3	15	6.4	7.2	.1	.0	55	14	2	62	5.8	15
	7-3460.6. Moccasin Creek near Harleton, Tex. (drainage area, 30.5 sq mi)																		
	5-23-61	1.38	19	0.00	3.8	1.8	8.8	1.4	10	7.2	14	0.1	1.3	62	17	9	87	5.8	12
	9-19-62	.56	34	.02	4.5	2.2	7.3	3.7	10	17	10	.2	.2	84	20	12	95	5.7	15
	7-3463.2. Black Bayou near Atlanta, Tex. (drainage area, 52.1 sq mi)																		
Queen City Sand and Weches Greensand Members of Mount Selman Formation and Sparta Sand	5-23-61	8.06	10	0.00	3.0	1.9	19	1.7	36	3.8	15	0.3	2.9	76	16	0	121	6.7	30
	9-18-62	4.90	19	.05	4.2	1.8	31	2.9	53	3.4	27	.2	4.0	120	18	0	189	6.2	25
	7-3464. Black Bayou near Rodessa, La. (drainage area, 113 sq mi)																		
Queen City Sand and Weches Greensand Members of Mount Selman Formation, Sparta Sand, and terrace deposits	11-18-60	3.57	4.1	0.96	3.5	0.8	6.1	2.0	12	6.0	7.8	0.4	1.3	39	12	2	60	6.1	80
	5-15-61	2.08	8.6	--------	4.0	1.2	5.4	1.0	20	2.0	7.0	.0	.7	40	15	0	59	6.5	40
	7-3520. Saline Bayou near Lucky, La. (drainage area, 154 sq mi)																		
Sparta Sand	11-17-60	24.7	3.8	0.22	3.6	0.4	14	1.1	10	0.0	23	0.5	1.0	52	10	2	101	6.0	45
	8-15-62	12.2	14	.01	3.5	1.6	22	.8	7	.2	41	.0	.0	86	15	10	159	5.5	5
	7-3708.2. Dugdemona River near Quitman, La. (drainage area, 117 sq mi)																		
	11-13-60	3.50	5.0	1.2	3.2	0.7	3.2	2.1	14	4.2	2.8	0.2	1.4	31	11	0	40	6.3	150
	8-15-62	.284	20	.05	7.2	3.4	5.7	2.6	41	3.0	7.1	.1	.2	69	32	0	92	6.0	25
	7-3491. Brushy Creek near Sibley, La. (drainage area, 43.6 sq mi)																		
	11-11-60	5.91	5.9	0.06	4.1	1.4	11	4.0	9	3.4	22	0.3	0.9	58	16	8	96	6.3	25
	5-23-61	9.46	9.8	--------	3.8	1.6	8.9	1.2	13	1.6	18	.0	.9	52	16	6	84	6.3	15
	7-3619. Bayou Freeo near Eagle Mills, Ark. (drainage area, 94.8 sq mi)																		
Sparta Sand and terrace deposits	9- 6-60	1.68	5.0	0.00	4.9	0.7	3.7	1.8	18	3.2	3.8	0.0	0.3	32	15	0	51	6.7	6
	8-13-62	.43	14	.22	4.5	2.4	5.3	2.4	30	4.8	3.2	.3	.6	52	21	0	75	7.1	30
	7-3618.5. Tulip Creek near Pine Grove, Ark. (drainage area, 152 sq mi)																		
Sparta Sand and alluvium	9- 6-60	2.64	5.7	0.06	3.2	0.5	1.4	1.1	12	2.6	1.8	0.1	0.8	23	10	0	31	6.4	20
	8-13-62	4.17	7.3	.02	3.2	1.0	2.2	1.4	14	3.2	2.2	.3	.3	28	12	0	37	6.6	10

TABLE 5.—*Chemical analyses of low-flow surface waters in the study area*—Continued

Aquifers in drainage basin above sampling station	Date of collection	Discharge (cfs)	Parts per million: Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (calculated from determined constituents)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color
	7-3651. Cypress Creek near Unionville, La. (drainage area, 63.3 sq mi)																		
Cook Mountain Formation	11-18-60	0.203	1.4	0.58	5.1	1.9	27	4.8	50	22	14	0.3	1.7	104	20	0	177	6.8	65
	8-17-62	.53	11	.03	5.2	2.6	43	3.8	71	15	32	.4	.2	148	24	0	253	6.2	10
	7-3649. Big Creek near Vienna, La. (drainage area, 68.9 sq mi)																		
	10-18-60	0.193	1.8	1.2	3.6	0.9	2.5	2.2	11	7.2	2.8	0.1	1.7	29	12	4	43	6.7	250
	4-19-63	10.7	5.4	.14	4.9	1.8	3.3	1.6	16	8.0	5.8	.0	.6	39	20	6	62	6.8	45
	7-3648. Bayou D'Arbonue at Homer, La. (drainage area, 30 sq mi)																		
	10-13-60	1.57	4.2	0.24	2.2	1.1	3.8	2.2	11	4.8	4.8	0.1	0.9	30	10	0	46	6.5	60
	9-21-62	1.49	19	.06	1.5	1.4	3.0	1.7	8	2.4	6.1	.1	.5	40	10	3	38	5.4	25
	7-3653. Middle Fork Bayou D'Arbonne near Colquitt, La. (drainage area, 43.9 sq mi)																		
	10-13-60	0.866	6.4	0.00	26	6.5	58	5.0	14	9.2	142	0.2	1.3	262	92	80	527	6.0	10
	9-21-62	3.71	18	.10	15	4.1	46	2.8	10	6.0	103	.2	.0	200	54	46	369	5.7	5
	7-3647.5. Bayou de Loutre at De Loutre, La. (drainage area, 302 sq mi)																		
Cook Mountain and Cockfield Formations	11-4-60	34.1	1.4	0.00	307	42	939	33	68	55	2,050	0.9	0.3	3,460	938	883	6,330	6.6	22
	8-14-62	10.3	7.3	.01	249	34	866	16	47	60	1,830	1.0	1.5	3,090	762	723	5,660	6.5	15
	7-3664. Bayou Choudrant at Tremont, La. (drainage area, 87.5 sq mi)																		
	10-14-60	1.69	6.8	0.15	2.4	0.6	2.7	1.5	11	1.0	3.5	0.2	0.9	25	14	4	35	6.3	35
	8-14-62	4.64	15	.04	2.0	1.3	2.6	1.3	11	1.2	4.8	.0	1.0	34	10	1	34	5.9	15
	7-3658.5. Little Corney Bayou near Summerfield, La. (drainage area, 54 sq mi)																		
Cockfield Formation	11-17-60	6.18	7.3	0.04	12	2.3	22	3.2	10	5.2	54	0.2	0.8	112	40	32	213	6.0	25
	8-15-62	.17	16	.09	13	2.6	12	2.4	34	2.6	29	.1	.0	95	43	15	164	6.0	10
	7-3673. North Cheniere Creek at Cheniere, La. (drainage area, 38 sq mi)																		
Cockfield Formation and alluvium	10-11-60	4.51	7.1	0.13	5.6	0.1	8.3	1.5	9	4.4	16	0.2	0.8	48	14	7	112	6.5	40
	8-14-62	2.32	15	.01	2.5	1.4	3.0	1.5	11	.2	7.0	.1	1.0	37	12	3	41	5.5	10

	7-2642. Two Prairie Bayou at Carlisle, Ark. (drainage area, 149 sq mi)																		
Terrace deposits	7-11-61	13.6	8.3	--------	19	7.1	18	3.2	108	11	14	0.3	1.4	135	76	0	229	7.3	10
	7-3498.4. Black Bayou at Benton, La. (drainage area, 17.2 sq mi)																		
	5-23-61	0	2.4	--------	19	8.8	29	3.5	96	12	40	0.2	1.4	163	84	5	295	7.1	20
	7-3492. Clarke Bayou near Haughton, La. (drainage area, 35.1 sq mi)																		
	5-23-61	0.52	0.9	--------	220	113	4,620	79	300	141	7,540	0.4	--------	12,900	1,010	768	21,600	7.5	10
	8-17-62	.16	8.1	0.02	76	47	2,440	20	204	4.9	3,860	--------	--------	6,560	383	216	11,200	6.8	20
	7-0779.7. Big Cypress Creek at Turner, Ark. (drainage area, 125 sq mi)																		
Terrace deposits and alluvium	10-26-60	--------	5.0	0.00	15	6.8	14	5.1	80	11	18	0.3	1.2	115	66	0	210	6.7	5
	7-0769.5. Wattensaw Bayou near Hazen, Ark. (drainage area, 195 sq mi)																		
	9-12-61	17.1	10	--------	20	7.8	18	3.1	124	4.2	13	0.3	0.9	138	82	0	227	7.2	10
	4-18-63	18.9	2.4	0.36	5.9	2.6	4.8	3.9	28	3.4	5.5	.0	2.1	45	25	2	72	7.0	90
	7-3642.5. Chemin-a-Haut Creek near Berlin, Ark. (drainage area, 216 sq mi)																		
	9-20-60	4.11	4.5	0.00	30	7.0	22	3.6	146	2.6	21	0.2	0.6	164	104	0	278	7.3	20
	8-13-62	1.61	4.9	.02	25	8.6	20	3.8	139	4.2	20	.2	.6	156	98	0	278	7.8	10
	7-3643. Chemin-a-Haut Bayou (Creek) near Beekman, La. (drainage area, 271 sq mi)																		
	11-14-60	20.3	0.9	0.00	19	5.8	17	4.3	100	1.4	20	0.4	1.0	119	72	0	219	7.1	17
	8-14-62	3.82	11	.12	24	7.6	23	3.4	132	2.8	23	.2	.2	160	91	0	289	6.4	5
	7-3685.2. Big Creek at Holly Ridge, La. (drainage area, 71 sq mi)																		
Alluvium	10-11-60	0.23	0.9	0.15	5.4	1.3	2.0	4.3	23	3.4	2.5	0.2	2.0	33	19	0	55	6.7	100
	8-16-62	2.16	6.5	.20	4.8	1.8	2.1	4.1	24	4.2	2.8	.2	.8	40	19	0	65	6.1	80

TABLE 6.—*Source and significance of dissolved mineral constituents and properties of water*

Constituent or property	Source or cause	Significance
Silica (SiO_2)	Dissolved from practically all rocks and soils, commonly less than 30 ppm. High concentrations, as much as 100 ppm, generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam of high-pressure boilers to form deposits on blades of turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps, and other equipment. More than 1 or 2 ppm of soluble iron in surface waters generally indicates acid wastes from mine drainage or other sources.	More than about 0.3 ppm stains laundry and utensils reddish brown. Objectionable for food processing, textile processing, beverages, ice manufacture, brewing, and other processes. USPHS (1962) [1] drinking-water standards state that iron should not exceed 0.3 ppm. Larger quantities cause unpleasant taste and favor growth or iron bacteria.
Manganese (Mn)	Dissolved from some rocks and soils. Not so common as iron. Large quantities often associated with high iron content and acid waters.	Same objectionable features as iron. Causes dark brown or black stain. USPHS (1962) drinking-water standards state that manganese should not exceed 0.05 ppm.
Calcium (Ca) and magnesium (Mg).	Dissolved from practically all rocks and soils, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Cause most of the hardness and scale-forming properties of water; soap consuming (see Hardness). Waters low in calcium and magnesium desired in electroplating, tanning, and dyeing and in textile manufacturing.
Sodium (Na) and potassium (K).	Dissolved from practically all rocks and soils. Found also in ancient brines, sea water, industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers, and a high sodium content may limit the use of water for irrigation.
Bicarbonate (HCO_3) and carbonate (CO_3).	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot-water facilities to form scale and release corrosive carbon dioxide gas. In combination with calcium and magnesium they cause carbonate hardness.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Commonly present in mine waters and some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives a bitter taste to water. Some calcium sulfate is considered beneficial in the brewing process. USPHS (1962) drinking-water standards recommend that the sulfate content should not exceed 250 ppm.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in ancient brines, sea water, and industrial wastes.	In large amounts in combination with sodium gives salty taste to water. In large quantities increases the corrosiveness of water. USPHS (1962) drinking-water standards recommend that the chloride content not exceed 250 ppm.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils. Added to many waters by fluoridation of municipal supplies.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth depending on the concentration of fluoride, the age of the child, the amount of water consumed, and the susceptibility of the individual. The maximum concentration of fluoride recommended by the USPHS (1962) varies with the annual average of maximum daily air temperatures and ranges downward from 1.7 ppm for an average maximum daily temperature of 50.0°F to 0.8 ppm for an average maximum daily temperature of 90.5°F. Optimum concentrations for these ranges are from 1.2 to 0.7 ppm.

TABLE 6.—*Source and significance of dissolved mineral constituents and properties of water*—Continued

Constituent or property	Source or cause	Significance
Nitrate (NO_3)	Decaying organic matter, legume plants, sewage, nitrate fertilizers, and nitrates in soils.	Concentration much greater than the local average may suggest pollution. USPHS (1962) drinking-water standards suggest a limit of 45 ppm. Waters of high nitrate content have been reported to be the cause of methemoglobinemia (an often fatal disease in infants) and therefore should not be used in infant feeding. Nitrate has been shown to be helpful in reducing the intercrystalline cracking of boiler steel. It encourages the growth of algae and other organisms which may cause odor problems in water supplies.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils.	USPHS (1962) drinking-water standards recommend that the dissolved solids should not exceed 500 ppm. However, 1,000 ppm is permitted under certain circumstances. Waters containing more than 1,000 ppm of dissolved solids are unsuitable for many purposes.
Hardness as $CaCO_3$	In most waters, nearly all the hardness is due to calcium and magnesium. All the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called noncarbonate hardness. Waters of hardness up to 60 ppm are considered soft; 61–120 ppm, moderately hard; 121–180 ppm, hard; more than 180 ppm, very hard.
Specific conductance (micromhos at 25°C).	Mineral content of the water	Indicates degree of mineralization. Specific conductance is a measure of the capacity of the water to conduct an electric current. It varies with the concentration and degree of ionization of the constituents, and with temperature.
Hydrogen-ion concentration (pH).	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 denote increasing acidity. pH is a measure of the activity of hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline water may also attack metals.
Color	Yellow-to-brown color of some water usually is caused by organic matter extracted from leaves, roots, and other organic substances. Color in water also results from industrial wastes and sewage.	Water for domestic and some industrial uses should be free from preceptible color. Color in water is objectionable in food and beverage processing and many manufacturing processes.
Temperature	Climatic conditions, use of water as a cooling agent, industrial pollution.	Affects usefulness of water for many purposes. Most users desire water of uniformly low temperature. Seasonal fluctuations in temperatures of surface waters are comparatively large depending on the volume of water.
Suspended sediment	Erosion of land and stream channels. Quantity and particle-size gradation affected by many factors such as form and intensity of precipitation, rate of runoff, stream channel and flow characteristics, vegetal cover, topography, type and characteristics of soils in drainage basin, agricultural practices, and some industrial and mining activities. Largest concentrations and loads occur during periods of storm runoff.	Sediment must generally be removed by flocculation and filtration before water is used by industry or municipalities. Sediment deposits reduce the storage capacity of reservoirs and lakes and clog navigable stream channels and harbors. Particle-size distribution is a factor controlling the density of deposited sediment and is considered in the design of filtration plants. Sediment data are of value in designing river-development projects, in the study of biological conditions and fish propagation, and in programs of soil conservation and watershed management.

[1] "Public Health Service Drinking Water Standards," revised 1962, apply to drinking water and water-supply systems used by carriers and others subject to Federal quarantine regulations.

these two streams (pl. 2) show no resemblance to each other. Calcium, sodium, and sulfate are the predominant constituents in water from Francois Creek, whereas no constituent predominates in water from Prewitt Creek. One of the patterns shown for Kelly Creek near Marietta, Tex. (7–3460.2), resembles the pattern shown for Francois Creek near Poyen, Ark., in that sulfate is the predominant anion. Kelly Creek drains the Carrizo Sand and the Reklaw and the Queen City Sand Members of the Mount Selman Formation.

Variability in the type of water in streams receiving their base flow from the same formation is also shown in the patterns for Saline Bayou near Lucky, La. (7–3520), Brushy Creek near Sibley, La. (7–3491), and Dugdemona River near Quitman, La. (7–3708.2). These three streams drain the Sparta Sand, but the pattern for Dugdemona River shows the water to be more like water from Big Creek at Holly Ridge, La. (7–3685.2), which drains the alluvium.

Except where oil-field wastes are present, water in streams draining alluvium and terrace deposits generally is a calcium-magnesium bicarbonate type. The dissolved-solids content of water in these streams ranges from 33 to 164 ppm. The dissolved-solids content of water in streams draining terrace deposits or a combination of terrace deposits and alluvium generally is higher than that of water in streams draining only the alluvium. Except for one sample from Wattensaw Bayou near Hazen, Ark. (7–0769.5), the dissolved-solids content of water from streams draining the terrace deposits and alluvium ranges from 115 to 164 ppm, whereas the maximum dissolved-solids content of water from the stream that drains only alluvium is 40 ppm. One sample from Wattensaw Bayou near Hazen, Ark., has a dissolved-solids content of 45 ppm. This value does not seem representative of the dissolved-solids content of water in this stream during low flow, and it is likely that the dissolved-solids content on this day (Apr. 18, 1963) was affected by rain that fell a few days prior to the sampling date.

The chemical quality of water in Caney Creek near Bluff City, Ark. (7–3617), Clarke Bayou near Haughton, La. (7–3492), Paw Paw Bayou near Greenwood, La. (7–3482), Rambin Bayou near Frierson, La. (7–3516.7), Bayou de Loutre at De Loutre, La. (7–3647.5), and Middle Fork Bayou D'Arbonne near Colquitt, La. (7–3653), is affected by the addition of oil-field wastes. The dissolved-solids content of water in these streams ranges from 226 to 12,900 ppm. Sodium and chloride are the principal constituents, but when the dissolved solids are low, the chemical characteristics are variable. Because of numerous active oil fields in southern Arkansas and northern Louisiana, many streams other than those listed may contain wastes, but it is beyond the scope of this study to determine the degree of contamination of streams in the area.

CONCLUSIONS AND RECOMMENDATIONS

1. Knowledge of the low-flow characteristics of streams in the Mississippi embayment in southern Arkansas, northern Louisiana, and northeastern Texas is useful in the solving of water problems and for the economic development of surface-water supplies in the area. The need for further development of water resources was accentuated by the drought of the 1950's and has increased rapidly in recent years. In some areas the use of surface water and the creation of numerous reservoirs have greatly altered the low-flow characteristics of the streams. As agriculture and industry continue to expand, the affected areas may be expected to increase in number and become more widespread. The total water resources of the area are sufficient to meet the needs for many years in the future, and the anticipated problems of water supply will be those of distribution and providing storage to meet the demands during periods of low flow. The data presented in this chapter provide a suitable basis for planned development of the water resources and for water management, but further investigations may be needed for detailed design. Estimates of future events based on the data in this report will be reasonably reliable provided there are no appreciable changes in the hydrologic regime.

2. Comparison of the low-flow characteristics of the streams is made on the basis of unit runoff per square mile. Because of the wide variation in the yield of the streams, and even of the same stream, it is not possible to generalize that in an area where one stream shows an index of a given yield, all streams in the area have the same index. Interpolation of low-flow data presented in this chapter should not be made to estimate the low flow at ungaged sites on the basis of drainage area without the aid of low-flow discharge measurements at the sites and without a knowledge of the geology, physiography, manmade changes, and other factors affecting the low flow.

3. The wide variations in the low-flow indices of the streams in the area may be largely attributed to the depth to which the streams are incised, the relation of the water table to the bed of the stream, and the porosity and permeability of the aquifers in the immediate area.

4. As indicated by the data in this chapter, the geologic units that contribute appreciable water to the low flow of streams in the study area are (in order of

decreasing volume contributed): Paleozoic rocks, sand units in the Claiborne Group, and Quaternary alluvium.

Streams that head in the Paleozoic rocks, particularly in the Ouachita Mountains, have high low-flow indices. The decrease in the low flow of some streams as they enter the broad alluvial valleys in the embayment may in part be due to flow entering the unconsolidated materials in the streambed. Studies to determine the magnitude of such underflow may reveal additional flows suitable for utilization.

The terrace deposits west of Crowleys Ridge in the northern part of the study area have indices of zero. In general, the streams receiving ther base flow from the alluvium and terrace deposits have low indices of low flow, but the indices are slightly higher for streams south of lat 32°30′ N. in the southeast corner of the study area.

Overdevelopment of ground-water supplies in the Grand Prairie region is shifting the emphasis on water supply to surface-water sources. The low-flow characteristics of the small streams in the region, however, indicate that surface storage will be required if the streams are to supply water during droughts.

In most other sections of the embayment, ground water has not been overdeveloped and the demands on surface supplies are not so pronounced. Surface water is utilized where a dependable supply is readily available. In many places, a combination of ground-water and surface-water supplies is used.

Streams in Louisiana lying between the Mississippi River and Bayou La Fourche have high low-flow indices because these streams are incised into aquifers in the alluvium.

Streams in the southwestern part of the study area generally have very low indices of low flow. Most of these streams are not incised sufficiently deep to be in contact with the water-yielding deposits.

5. The median annual 7-day low flow serving as an index, areal draft-storage relations for 10- and 20-year recurrence intervals provide a convenient means for estimating the storage required to maintain a given minimum flow. The relations are valid for median annual 7-day low flow of as much as 0.40 cfs per sq mi and for storage of as much as 90 acre-ft per sq mi. Application of these relations is not recommended for intermittent streams or for daily-record gaging sites.

6. The chemical quality of water in streams in the study area is controlled by the composition of the geologic units in the drainage basins unless altered by the addition of oil-field wastes.

In streams where the composition of the geologic units is the controlling factor, the dissolved-solids content of the water usually is low and the chemical characteristics of individual streams are fairly uniform. Water in streams draining the Tokio Formation and the alluvium is low in dissolved solids and is a calcium bicarbonate type. Where the activities of man have not affected water quality, water in streams draining formations of Eocene age generally is low in dissolved solids. Variations in dissolved solids are caused, to a large extent, by variations in the silica content. Streams draining Eocene formations do not seem to have any characteristics peculiar to one formation or a combination of formations. The chemical characteristics of water in streams draining deposits of Quaternary age are fairly uniform, but as the dissolved-solids content increases, calcium and bicarbonate become the principal constitutents.

The addition of oil-field wastes has adversely affected the quality of water in many streams that drain areas in southern Arkansas and northern Louisiana.

7. Data are needed to define additional causative phases of the hydrologic systems and to forecast the effect that future changes in the stream systems may have upon the low-flow regimen of the streams. These phases include the effect of floods upon the water table adjacent to the streams, the effect of swamp environment on the yield from or recharge to the aquifers, the effect of deepening or widening of stream channels upon the regimen of low flow of the streams and upon the ground-water table adjacent to the streams, the magnitude of underflow in the alluvial valleys, the interrelations between the ground-water fluctuations and the low flow of streams, and the effect of impoundment of water in ponds and reservoirs upon the low flow of the streams. The results of the study reported in this chapter indicate that increases or decreases in low flow probably have resulted from manmade changes. More detailed knowledge of the geology is needed to define the aquifers or water-bearing geologic units that underlie the drainage basins in much of the area.

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