Low-Flow Characteristics of Streams in the Mississippi Embayment in Northern Arkansas and in Missouri

By PAUL R. SPEER, MARION S. HINES, M. E. JANSON, *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 NORTHERN ARKANSAS AND IN MISSOURI

By Paul R. Speer, Marion S. Hines, M. E. Janson, and others

ABSTRACT

The low-flow characteristics of a stream largely govern the type and the 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 estimate the amount of storage required to provide the minimum flows 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 influence 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. Heavy pumping of ground water near the streams may have lowered the water table, caused low flows to diminish or cease, and permitted the stream to recharge other aquifers with water derived from an adjacent aquifer.

Limited low-flow data, in cubic feet per second per square mile, for 23 daily-record gaging stations and 37 partial-record stations are summarized for ready comparison. The summary gives the minimum average 7-day and 30-day discharges that may be expected to recur at 2- and 10-year intervals and the flow at the 90- and 95-percent duration points. More detailed data on the magnitude and frequency of low flows and flow duration, in cubic feet per second, are given for the 23 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 this area. These indices range from 0 to 0.49 cubic foot per second per square mile.

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

Chemical analyses of surface-water samples collected at 12 sites during low-flow periods show the dissolved solids to range from 90 to 333 ppm (parts per million); the hardness to range from 57 to 275 ppm; and the iron content to range from 0.00 to 0.08 ppm. The surface waters in the study area generally are suitable for some uses with little or no treatment, but for municipal and industrial supplies, the waters would require softening, coagulation, filtration, and pH adjustment for corrosion control.

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

INTRODUCTION

In the Mississippi embayment in northern Arkansas and in Missouri, large supplies of fresh water are available from both surface and underground sources. The area has a high average annual precipitation, and, in addition, much water is available from the Mississippi River, which lies on the east side of the area, and from other large streams that originate outside. The water resources of the area, therefore, are more than ample to meet the needs for many years in the future, and the problems in surface-water supply will be those of distribution and of providing storage to meet the demands.

Because many parts of the area have been subjected to devastating floods, much attention in the past has been focused on flood control, on drainage, and on improving the channel hydraulics of the streams. In recent years, however, rapid economic development within the study area has so increased the consumptive use of water that serious localized shortages have occurred during periods of low streamflow. These shortages emphasize that 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 and the chemical, physical, and biological properties of the water, which form the basis for utilizing the flow of a stream, exert a major influence on the economics of the stream's development. These factors 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 specific discharge, and the quality of the water during the low-flow periods. The low-flow data included in this report show the amount of water available for use without storage and may be used to determine the storage required to provide the minimum flow needed; included also is an indication of the chemical quality of the waters in the streams during low flow.

Streamflow records used in the analyses for this report were collected over a period of many years by the U.S. Geological Survey in cooperation with the Arkansas Geological Commission and with the Missouri Division of Geological Survey and Water Resources. Other records were obtained through cooperation with Federal agencies such as the Corps of Engineers and the Mississippi River Commission. 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 manuscript describing the low-flow characteristics of the streams in northern Arkansas was prepared by M. S. Hines, assisted by L. D. Hauth and John Sullavan, under the general direction of J. L. Saunders, succeeded by I. D. Yost, district engineer, and in Missouri by M. E. Janson, under the general direction of H. C. Bolon, succeeded by Anthony Homyk, Jr., district engineer. Technical supervision of quality-of-water analyses and preparation of the section of the report on quality of the water was 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 P. R. Speer, staff engineer. Technical guidance on analytical procedure and format were 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 L. M. MacCary, who prepared the subsection on "Geology," participated in the determination of the geologic units that contribute 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 low-flow 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 waters are virtually one body of water and cannot be separated. The results of the studies on surface water and the results of the studies on ground water, which are published in chapters C–E of Professional Paper 448, 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 northern Arkansas and in Missouri. The chapter deals with surface water and with the relation of the aquifers to low streamflow; the low-flow characteristics of streams at 60 sites in the area are given. Other chapters (G–I) of the 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 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. The data also are useful in the allocation of water and in the determination (1) of the recurrence of flows that are qualitatively unsuitable for specific uses and (2) of the economic feasibility of designing storage capacity needed to produce certain minimum flows of acceptable minimum quality. The data contained herein will enable water managers and designers to determine the magnitude and frequency of low flows at specific sites at the same time that they study the economics of development and operation.

The data presented for specific sites in the area consist of (1) frequency data showing the average intervals, in years, between low 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 surface waters at various sites during low flows.

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 geologic 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)—that is, the mean flow for 7 consecutive days to be expected as the annual minimum 1 year out of 2, on the average.

Partial-record station. A particular site on a stream at which limited streamflow data, generally 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.

Reference period. The years 1929–57; for low-flow frequency data, it is the 29 climatic years, April 1, 1929, to March 31, 1958, and for flow-duration data, it is the 29 water years, October 1, 1928, to September 30, 1957.

DESCRIPTION OF THE AREA

The area of the embayment described in this chapter (fig. 1) includes 7,670 square miles in northern Arkansas and 3,950 square miles in southeastern Missouri.

Drainage from the area is to the Mississippi River and its tributaries. The principal tributary basins include that of the St. Francis River and its tributary, Little River; and that of the White River and its tributaries, the Black and the Cache Rivers. The natural channels are irregular and meandering, but some have been canalized, straightened, or otherwise altered to such an extent that they no longer resemble their natural state. Most channels have low hydraulic gradients due to the flat topography, and the flow is sluggish. The drainage

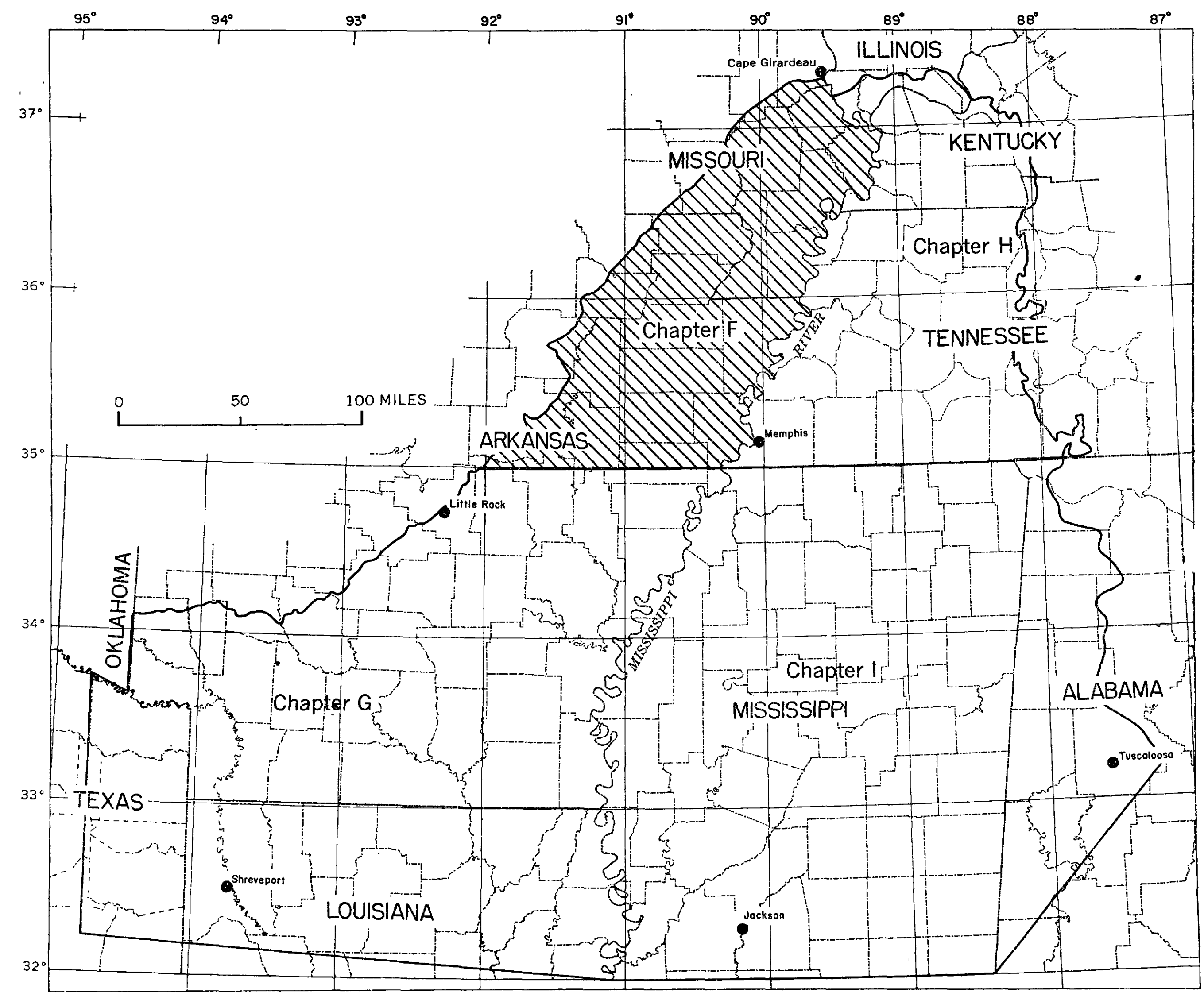

FIGURE 1.—Map of the Mississippi embayment showing the areas described in the four chapters F–I of Professional Paper 448 on low-flow characteristics of streams. The area described in this chapter is shaded.

patterns in the lower reaches of the Headwater diversion channel, in the Little River ditches, and in the lower reaches of the St. Francis River have been greatly altered by man to facilitate drainage of the land for cultivation and to improve the hydraulics of the channels.

CLIMATE

The climate of the area is warm and humid. The temperature ranges from an average daily low of about 26°F during Janaury in the northernmost part of the area to an average daily high of about 93°F during July in the southernmost part of the area. The average annual precipitation ranges from about 45 to about 48 inches. Most of the precipitation is rain, but snowfalls of 1 inch or more occur in the northern part of the area on an average of five or six times a year. The climate of the area is mainly continental and is the result of an interplay of the cold airmasses moving out of Canada, warm moist air moving northeastward from the Gulf of Mexico, and dry air from the west.

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 it last emerged, the Mississippi River has followed close to the axis of the trough. The Mississippi embayment in the area covered by this report lies in two physiographic districts, St. Francis Basin and Crowleys Ridge (fig. 2). The St. Francis Basin extends from the Mississippi River to the western boundary of the embayment except

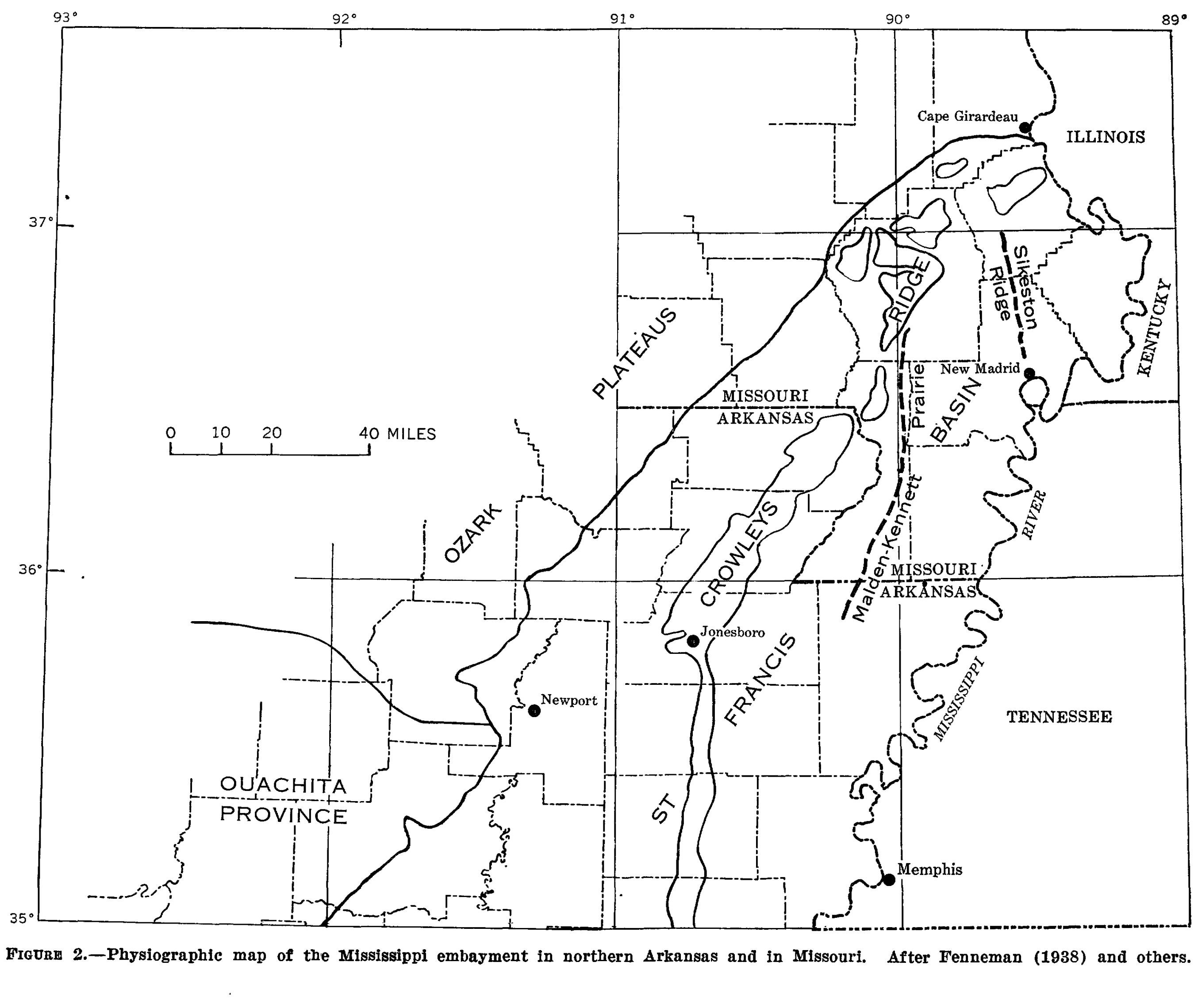

FIGURE 2.—Physiographic map of the Mississippi embayment in northern Arkansas and in Missouri. After Fenneman (1938) and others.

for the area occupied by Crowleys Ridge, which is about midway between the river and the boundary.

Most of the present physiography probably is the result of (1) crustal movements of which the New Madrid earthquake (Fuller, 1912) of 1811–13 is the most recent, (2) the last submergence of the area by an arm of the sea while the lowlands were in the process of sinking or downwarping, and (3) erosion.

The St. Francis Basin occupies nearly all of the area studied. It is an extensive flat lowland plain of aggradation of the Quaternary System and has only a few areas higher than 300 feet above mean sea level. Streams in the St. Francis Basin in their natural state are sluggish and meandering. Crowleys Ridge is a distinctive feature that extends lengthwise through and mainly in the middle of the St. Francis Basin. The ridge is composed of Tertiary and Cretaceous deposits capped by Quaternary deposits and rises from 100 to 250 feet above the alluvial plain of the St. Francis Basin. The eastern slopes of the ridge are rather steep, and they grade into the alluvial plains of the river valleys. A few thousand years ago, Crowleys Ridge was the divide between two great rivers that contributed to the alluvial plain of the embayment.

The Sikeston Ridge and Malden-Kennett Prairie are low terraces on the Quaternary alluvial plain; they lie east of Crowleys Ridge and rise 10–20 feet above the lowland plains. West of Crowleys Ridge, there are other small isolated terraces. The long, narrow low drainage basins of the streams and drainage ditches are alined parallel to these low terraces.

GEOLOGY

The area in northern Arkansas and southeastern Missouri described in this report is a part of the Mississippi embayment and lies within the Gulf Coastal Plain. The embayment in the past was periodically occupied by the sea and has been filled with sediments ranging in age from Jurassic to Quaternary. The thickness of the sedimentary rocks ranges from 0 at the edge of the embayment to many thousands of feet near the axis of the trough at the south end of the embayment, whereas in this area they range from 0 to about 3,000 feet. Within this area, units ranging in age from Cretaceous to Quaternary crop out (pl. 1). On the western and northern periphery of the area, Paleozoic rocks crop out. Cushing, Boswell, and Hosman (1964) give a general description of the units of Cretaceous age and younger.

The important geologic units that crop out within the area of this study are given in table 1. The sand units that contribute most of the water to the low flow of streams include the McNairy Sand, sands of the Wilcox Group (Wilcox Formation in Missouri) and the Claiborne Group, the Pliocene(?) deposits, and the alluvium and terrace deposits.

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

ARKANSAS	MISSOURI
Quaternary System	Quaternary System
Alluvium and terrace deposits	Alluvium and terrace deposits
Loess	Loess
Tertiary System	Tertiary System
Pliocene(?) deposits	Pliocene(?) deposits
Eocene Series	Eocene Series
Claiborne Group undifferentiated	Wilcox Formation
Wilcox Group undifferentiated	Paleocene Series
Paleocene Series	Midway Group
Midway Group undifferentiated	Porters Creek Clay
Cretaceous System	Clayton Formation
Upper Cretaceous Series	Cretaceous System
Nacatoch Sand	Upper Cretaceous Series
Paleozoic rocks undifferentiated	Owl Creek Formation
	McNairy Sand
	Paleozoic rocks undifferentiated

MANMADE CHANGES

Activities of man and nature combine to produce changes in the low flows of streams. In most instances, the effects of the changes are very difficult if not impossible to distinguish. This discussion will be confined to those manmade changes that probably have altered the regimen of flow of the streams. The changes can be grouped into (1) those applied to the land itself, such as irrigation, drainage, land utilization, changes in farm practices, and the intensity of cultivation, and (2) those applied to the stream systems, such as diversion of water, construction of drainage systems and levees, dredging of channels, and the creation of reservoirs for impoundment of water. Generally, the effects of these changes, many of which were begun prior to the collection of streamflow records, are interdependent and difficult to evaluate.

Most of the land in this area has been cultivated at one time or another. Some of the land was found to be submarginal for farming and was permitted to return to timber; other areas of previously uncultivated land have been drained and the land used for intensive farming by modern methods. During the growth of population centers, more wells are dug, more land is cleared of timber, farming operations are varied, industrial activity is changed, and the effects of these changes combine to produce an ever-changing demand on the supply of water available during periods of low flow in the streams. Most of these changes are gradual, and the effect on low flow would be difficult to evaluate without the extensive collection of data and a very thorough and detailed investigation.

Changes made directly to the stream systems involve the use or control of the water and are more noticeable.

The effects of some of these changes, however, are not permanent. Dredged channels may become partly filled with sediment or they may erode owing to increased velocity of flow. Channel clearing and snagging is a temporary improvement because of the regrowth of vegetation and reaccumulation of debris.

To define and describe all the manmade changes is beyond the scope of this report, but some of the major manmade changes to the river systems are described briefly by river basins in the following paragraphs.

HEADWATER DIVERSION CHANNEL BASIN

The upper part of the Castor River basin, which originally drained toward the Little River basin, was diverted in the early 1900's from its natural channel to the Headwater diversion channel. The flow in this manmade channel is eastward through low flat terrain. The Headwater diversion channel is joined by the Whitewater River before it enters the Mississippi River south of Cape Girardeau, Mo. (pl. 2). The diversion system comprises 50 miles of channel, 10 miles of floodways, 45 miles of levees, and 16,000 acres of detention basins which protect southeastern Missouri and northeastern Arkansas from flooding by the Mississippi River and by the streams that drain the Ozark foothills north of the embayment. The system diverts runoff from 1,130 square miles. During low-flow periods, the water in the system originates largely in the hilly areas north of the embayment. Without this manmade drainage system it would have been impossible to develop the low-lying areas of the embayment south of this system.

ST. JOHNS BAYOU BASIN

Maple Slough and St. James ditch have been channeled into the St. Johns Bayou. The levee of the New Madrid Floodway along the Mississippi River parallels the channels of St. James ditch, Maple Slough, and other ditches south and east of East Prairie, Mo. The drainage of Main ditch lateral 2 lies within the area of the floodway, and the lateral enters St. Johns Bayou through the floodway levee. These channels drain the area and allow storm runoff to flow rapidly from the low-lying, highly productive agricultural land.

ST. FRANCIS RIVER BASIN

Low flows of the St. Francis River have been affected by regulation at Wappapello Reservoir (capacity, 38,600 acre-ft at conservation pool level) since 1941, by operation of the locks and siphons at Marked Tree, Ark., since 1925, and by numerous drainage projects in the basin. Numerous cutoff channels have been dredged to straighten meanders in the natural channel, the banks have been leveed, and other channel improvements have been completed along the main stem of the St. Francis River from Marked Tree, Ark., to the mouth and at several locations along two of its tributaries, Little and Tyronza Rivers. Several manmade ditches, such as Kinnemore ditch, have been dug to drain sloughs and marshland near the river. Extensive additional improvements are proposed for the main stem of the lower St. Francis and the lower reaches of Little River. Plate 2, a map prepared by the Memphis District, Corps of Engineers, shows the completed and proposed levees and channel improvements along the St. Francis, Little, and Tyronza Rivers, as of February 26, 1964.

The drainage pattern of the upper end of the Little River basin, north of about lat 36° N., has been affected more by manmade changes than any other basin of comparable size in the area. The Little River Drainage District comprises a drainage system of 850 miles of ditches, 242 miles of low levees, and two detention basins. The system protects areas that previously were subject to frequent flooding; it drains about 1,760 square miles into Big Lake, which is in Arkansas just south of the Missouri line. A continuing program is carried on to maintain and improve the system.

The L'Anguille River channel has been cleared for a distance of 5 miles upstream from the mouth as part of the St. Francis River basin project of the Corps of Engineers. Clearing and enlargement are proposed for the channel of the L'Anguille River from the Poinsett-Craighead County line to the mouth and for two of its tributaries, Brushy Creek and First Creek, for a distance of about 7 miles upstream from the main stem.

Drainage districts and many other local organizations have been engaged in drainage projects in the St. Francis River basin, but detailed information on the nature and extent of the projects is not readily available.

The Soil Conservation Service, U.S. Department of Agriculture, is engaged in a few watershed improvement projects in the area. On Caney Creek in Cross County, Ark., six floodwater-retarding structures (total capacity, 3,263 acre-ft) had been completed by the end of 1961. Other projects are probably of such a nature that they have little, if any, effect on low flow.

WHITE RIVER BASIN

Regulation by several reservoirs in the White River basin affects low flows of the main stem and some of its tributaries. Construction was completed and storage began in Norfork Reservoir on North Fork River in 1943, in Clearwater Reservoir on Black River in 1948, in Bull Shoals Reservoir in 1951, in Table Rock Reservoir in 1956, and in Greers Ferry Reservoir on Little Red River in 1961. On rare occasions, unusual operations at locks and dams 1, 2, and 3, near Batesville, Earnharts, and Walls Ferry, Ark., respectively, may affect the daily discharge of the White River downstream from these locations.

Some levee- and channel-improvement work has been completed along the White and Black Rivers and their tributaries. Levees and tributary-channel improvements have been completed on the east bank of White River from about 8 miles northwest of Clarendon, Ark., to about 2 miles north of Newport, Ark. Prior to 1948, White River floodwaters sometimes topped the old levees in the vicinity of Augusta, Ark., flowed through the Cache River bottoms, and returned to the White River at Clarendon.

On the Black River, short sections of levees and limited channel improvement have been completed in the vicinity of Manson, Pocahontas, Knobel, and Corning, Ark. The low flows of Black River within the embayment have been partly regulated by Clearwater Reservoir (capacity, 21,920 acre-ft at conservation pool level) since 1948. Part of the low flow, however, is derived from springs below the dam, with the result that the low-flow discharge is high and quite constant.

On the main stem and tributaries of Flat Creek in Lawrence County, Ark., three floodwater-retarding structures (total capacity, about 13,200 acre-ft) were completed by the Soil Conservation Service in 1962.

FARM PONDS AND LAKES

The U.S. Department of Agriculture has assisted in the creation and improvement of many small ponds in the area. Many other impoundments have been created by other agencies, individuals, and private organizations. The Arkansas Conservation Needs Committee has estimated that there are 26,200 farm ponds and lakes, 40 acres or less in size, in the Mississippi embayment in Arkansas. Only the northern third of this area is included in this chapter.

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

LOW-FLOW CHARACTERISTICS

Streamflow data used in the study of the low-flow characteristics for this chapter include 23 continuous records of flow obtained at daily-record gaging stations, and limited streamflow data collected systematically over a period of years at 37 low-flow partial-record stations.

In order to compare the low-flow characteristics of one stream with those of another, all data were adjusted to the common reference period, 1929–57, except where noted. (See section on "Method of study" for discussion of the reference period.) Daily-discharge records at seven gaging stations are complete for the reference period, and seven others have 15 years or more of record during the period. Daily-record stations having less than 5 years of daily record during this period were used as partial-record stations. Data recorded through 1963 were used to define the low-flow characteristics at the partial-record stations.

The average annual precipitation in Arkansas from 1891 to 1957 was about 49 inches, and from 1929 to 1957, it was 48.6 inches. In Missouri, the average annual precipitation from 1929 to 1957 was 46.3 inches. Thus the average precipitation in Arkansas during the reference period is approximately equivalent to that since 1891; precipitation data in Missouri for 1891–1957 are not available to show this comparison. Droughts occurred in this area in 1930, 1936, and near the end of the reference period. Arkansas and Missouri both had new extremes in precipitation during 1929–57. The new annual statewide lows are 34.2 and 30.6 inches, respectively, and the annual statewide highs are 65.8 and 76.9 inches, respectively. However, precipitation data alone are not in themselves valid criteria on which to assess streamflow patterns because many other factors, among them spatial and within-the-year distributions of precipitation, influence the quantity and rate of runoff.

The low-flow characteristics for all streams analyzed in this study are summarized in table 2. The stations are all in Part 7 (fig. 5); they are listed in downstream order, and their numbers are referred to the nationwide station-numbering system—all these factors by current usage by the U.S. Geological Survey in its surface-water reports. In assigning the numbers, no distinction is made between daily-record and partial-record stations. For some stations for which the selected items are zero, additional flow data are given in parentheses with appropriate reference notes. The last column of the table enables the user of the data to reconstruct 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 to another partial-record station; for each such station the number of the other station is shown in parenthesis. The data shown are for natural unregulated conditions on the streams.

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									
	Headwater diversion channel basin									
7-210	Castor River at Zalma, Mo	D	423	0.09	0.06	0.11	0.07	0.12	0.10	-------------
219	Headwater diversion channel at Allenville, Mo	P	982	.07	.04	.08	.05	.09	.07	7-0210
	St. Johns Bayou basin									
241	Main ditch lateral 2 near East Prairie, Mo	P	97.3	.04	(2)	.05	(2)	.04	.03	7-0440
241.5	St. James ditch at East Prairie, Mo	P	17.5	.02	(2)	.03	.006	.03	.02	7-0435
241.7	Maple Slough near East Prairie, Mo	P	24.5	.07	(2)	.07	(2)	.07	.05	7-0440
	St. Francis River basin									
375	St. Francis River near Patterson, Mo	D	956	.03	.01	.04	.02	.05	.03	-------------
400	St. Francis River at Fisk, Mo. [3]	D	1,370	.10	.08	.11	.08	.11	.10	-------------
403	Big Slough ditch near Marmaduke, Ark	P	245	.28	.14	.37	.17	.29	.22	7-0410
404	Locust Creek ditch near Paragould, Ark	P	79.5	.017	.004	.030	.006	.019	.012	7-0410
404.7	Kinnemore ditch at Cardwell, Mo	P	11.5	.009	0	.009	0	.009	.009	7-0410
407	Ditch 9 near Gideon, Mo	P	59.6	.01	(2)	.02	(2)	.02	.01	7-0420
408	Main ditch 6 east of Malden, Mo	P	28.0	0	(2)	.004	(2)	.004	0	7-0435
408.5	Main ditch near Bernie, Mo	P	31.7	.03	(2)	.07	(2)	.06	.03	7-0430
409	Main ditch 2 near Malden, Mo	P	46.9	.38	.18	.49	.23	.41	.32	7-0410
410	Little River ditch 81 near Kennett, Mo	D	111	.33	.14	.45	.18	.35	.26	-------------
410.5	Main ditch near Malden, Mo	P	28.6	.21	.13	.26	.15	.22	.19	7-0410
411	Main ditch at Holcomb, Mo	P	96.1	.22	(2)	.27	.17	.22	.18	7-0425
420	Little River ditch 1 near Kennett, Mo	D	235	.14	.07	.17	.09	.16	.12	-------------
424	Main ditch 1 near Matthews, Mo	P	62.0	.37	(2)	.45	.29	.37	.31	7-0425
425	Little River ditch 251 near Lilbourn, Mo	D	235	.24	.15	.29	.18	.23	.20	-------------
430	Castor River at Aquilla, Mo	D	175	.004	.0006	.009	.001	.007	.003	-------------
430.5	Ditch 24 at Heagy, Mo	P	36.8	.49	(2)	.54	.43	.54	.49	7-0435
431	Old Channel ditch 1 near Chaffee, Mo	P	41.4	.02	(2)	.04	.01	.02	.02	7-0425
435	Little River ditch 1 near Morehouse, Mo	D	450	.11	.07	.13	.08	.13	.11	-------------
439	Meander Line ditch near Portageville, Mo	P	51.5	.01	(2)	.01	(2)	.01	.008	7-0425
440	Little River ditch 251 near Kennett, Mo	D	[4] 883	.15	.08	.16	.09	.15	.12	-------------
460	Little River ditch 259 near Kennett, Mo. [5]	D	89	.01	0	.02	.001	.01	.006	-------------
465.1	Pemiscot Bayou near Holland, Mo	P	144	.15	(2)	.17	(2)	.15	.12	7-0440
465.2	Main ditch 1 near Deering, Mo	P	66.4	.14	(2)	.17	(2)	.17	.12	7-0420
465.5	Buffalo ditch near Arbyrd, Mo	P	38.7	.26	(2)	.39	(2)	.28	.19	7-0410
466	Right Hand Chute of Little River at Rivervale, Ark	D	2,113	.13	.043	.18	.061	.15	.11	-------------
478.5	Little Bay ditch near Jonesboro, Ark	P	28.7	0	0	0	0	0	0	Observed.
479.2	Fifteen Mile Bayou near West Memphis, Ark	P	51.0	[6](.012)	0	.005	0	.008	0	7-0479.5
479.4	L'Anguille River near Wynne, Ark	P	503	[6](.032)	0	[6](.015)	0	.002	.001	7-0479.5
479.5	L'Anguille River at Palestine, Ark	D	807	[6](.029)	0	.012	0	.019	.001	-------------
	White River basin									
609	Polk Bayou at Batesville, Ark	P	165	.20	.18	.21	.18	.23	.21	7-0740
615	Black River near Annapolis, Mo	D	484	.20	.14	.23	.16	.23	.20	-------------
625	Black River at Leeper, Mo. [3]	D	957	.23	.17	.25	.19	.25	.22	-------------
630	Black River at Poplar Bluff, Mo. [3]	D	1,245	.24	.20	.29	.22	.28	.25	-------------
631	Lake Slough near Qulin, Mo	P	78.0	.03	(2)	.05	.01	.05	.03	7-0435
631.3	Menorkenut Slough near Qulin, Mo	P	33.5	.04	.006	.06	.009	.04	.02	7-0410
635	Cane Creek at Harviell, Mo	P	188	.05	.05	.06	.05	.06	.05	7-0375
640	Black River near Corning, Ark	D	1,749	.17	.14	.19	.15	.19	.17	-------------
689	Fourche Creek near Pocahontas, Ark	P	305	.033	.022	.039	.025	.052	.038	7-0740
690	Black River at Pocahontas, Ark	D	4,843	.31	.25	.35	.27	.34	.30	-------------
694	Janes Creek at Ravenden Springs, Ark	P	78.5	(2)	(2)	.002	(2)	.005	(2)	7-0740
695	Spring River near Imboden, Ark	D	1,162	.28	.23	.29	.24	.30	.27	-------------
720	Eleven Point River near Ravenden Springs, Ark	D	1,123	.31	.24	.37	.25	.32	.28	-------------
735	Piney Fork Strawberry River at Evening Shade, Ark	D	99	.012	[7](.005)	.022	.005	.028	.015	-------------
740	Strawberry River near Poughkeepsie, Ark	D	476	.10	.086	.11	.090	.12	.11	-------------
746	Village Creek at Walnut Ridge, Ark	P	34.3	[6](.001)	0	[6](.016)	0	.001	0	7-0740
747	Village Creek at Newport, Ark	P	270	(2)	(2)	.007	(2)	.006	(2)	7-0775
748	Departee Creek near Coffeyville, Ark	P	86.5	0	0	[6](.005)	0	[8](.003)	0	7-3630
760	Little Red River near Heber Springs, Ark	D	1,141	.001	0	.005	0	.005	0	-------------
768	Bayou Des Arc near Garner, Ark	P	97.1	[6](.017)	0	.004	0	.003	0	7-0760
768.5	Cypress Bayou near Bebee, Ark	P	163	0	0	[6](.002)	0	[9](.007)	0	7-0760
769.5	Wattensaw Bayou near Hazen, Ark	P	195	.001	0	.002	0	.002	.001	7-0775
773	Cache River near Stonewall, Ark	P	285	.004	.001	.006	.002	.006	.004	7-0775
775	Cache River near Patterson, Ark	D	1,041	.042	.014	.057	.027	.055	.041	-------------
776.5	Big Creek near Jonesboro, Ark	P	51.1	.008	.002	.013	.003	.009	.005	(7-0404)

[1] Station numbers shown in parentheses are partial-record stations.
[2] Relation curve not defined in this range.
[3] Data for natural conditions prior to operation of reservoir upstream.
[4] Includes that of Little River ditches 66 and 66–A.
[5] Data not to base period; based on observed data 1927–57 and records for nearby gaging stations.
[6] Figure is for 1.2-yr recurrence interval; 2-yr figure is 0.
[7] Figure is for 5-yr recurrence interval; 10-yr figure is 0.
[8] Figure is for 80 percent of time; figure for 90 percent is 0.
[9] Figure is for 70 percent of time; figures for 80 percent and 90 percent are 0.

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 drainage areas of different sizes. It should not be inferred, however, that the yield is uniform throughout each drainage basin. On the contrary, 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 7-day 2-year low flow as the index, the low-flow indices for streams in the Black River basin (7–0615 to 7–0740) range from 0.17 to 0.31 cfs per sq mi (cubic feet per second per square mile) on the main stem and from 0.012 to 0.31 cfs per sq mi on the tributaries. The differences in low-flow indices are primarily due to the differences in hydraulic characteristics of the aquifer supplying the 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 drainage areas given for most of the manmade ditches in the flat lowlands are subject to considerable error because the available maps do not permit accurate delineation of the drainage basins. The values for cubic feet per second per square mile for these ditches should, therefore, be used with caution.

The locations of the stations that are given in table 2 are 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 parentheses near the station symbol. The dash shown in parentheses for a few of the stations means that the relation with the daily-discharge station is not defined in this range.

LOW-FLOW FREQUENCY

Low-flow frequency data for 23 daily-record gaging stations are presented in table 3. Some of these stations are now regulated, but the data are based on unregulated flow for the period of record, adjusted to the reference period 1929–57. Similar data for the partial-record stations have not been computed because of the limited basic information available at these sites. The data in table 3 can be plotted on graph paper similar to that used in figure 3 if a graphical presentation is desired.

In table 3, the probability of occurrence is given in terms of the average time interval between indicated low flows. For example, the annual low discharge for 7 consecutive days on the Castor River at Zalma, Mo. (7–0210), may be equal to or less than 24 cfs (cubic feet per second) at average intervals of 10 years on a long-

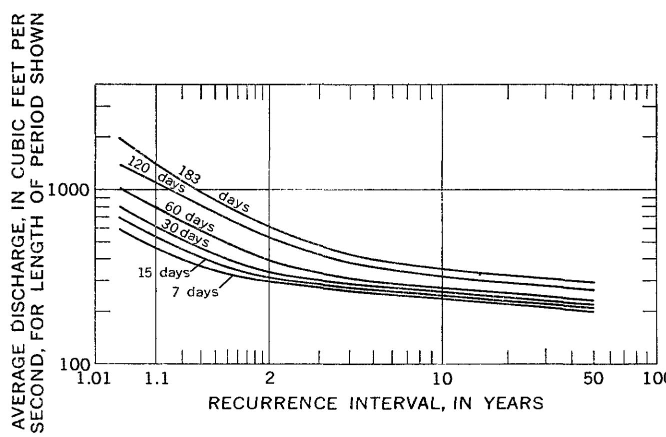

FIGURE 3.—Magnitude and frequency of annual low flow for Black River near Corning, Ark. (7–0640), 1929–57.

term basis. The chance of occurrence in any year is 1 in 10 or 10 percent. These recurrence intervals are averages and do not imply any regularity of recurrence. During the period 1929–57, the 7-day minimum flow was equal to or less than 24 cfs (the 10-year event) in 1936, 1937, and 1954. Thus, during the 29-year period, the 10-year event occurred three times, which is in close agreement with the probable frequency; however, the intervals between these occurrences, 1 and 17 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 provided that climatological conditions remain the same and that manmade changes are considered in the computations.

FLOW DURATION

Flow-duration data for the 23 daily-record gaging stations are presented in table 4. As with 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 graphical presentation is desired.

The slope of the flow-duration curve so plotted is a quantitative measure of the variability of streamflow. The slopes of the flow-duration curves of the streams having large low-flow yields are flatter than those for streams having small low-flow yields. For example, the duration curve for Black River near Corning, Ark. (fig. 4), shows a lower variability and a higher low-flow yield than the duration curve for Right Hand Chute of Little River at Rivervale, Ark. Thus, the

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 to 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									
	Headwater diversion channel basin									
7-210	Castor River at Zalma, Mo	423	7	82	57	39	29	24	21	17
			15	92	63	42	31	26	23	18
			30	114	75	48	34	29	25	20
			60	143	89	56	41	34	29	24
			120	246	145	83	55	46	39	32
			183	395	219	118	72	60	51	41
	St. Francis River basin									
375	St. Francis River near Patterson, Mo	956	7	96	56	30	18	13	10	6.9
			15	114	67	36	20	15	11	7.8
			30	146	84	43	24	18	13	9.4
			60	233	123	58	29	22	17	11
			120	476	249	112	54	40	30	21
			183	959	487	207	92	64	48	34
400	St. Francis River at Fisk, Mo.[1]	1,370	7	258	180	132	113	103	96	87
			15	287	203	140	117	108	100	90
			30	344	230	151	122	113	104	94
			60	436	289	180	131	123	112	102
			120	740	460	266	174	146	130	118
			183	1,330	700	388	239	190	160	138
410	Little River ditch 81 near Kennett, Mo	111	7	90	64	37	20	15	11	7.4
			15	99	70	41	23	16	12	8.5
			30	107	80	50	29	20	15	10
			60	123	88	54	32	23	18	12
			120	149	104	63	36	27	21	16
			183	204	134	74	43	33	27	21
420	Little River ditch 1 near Kennett, Mo	235	7	110	60	32	21	17	14	11
			15	125	69	36	22	18	15	12
			30	144	80	40	25	21	17	14
			60	180	94	46	29	25	21	16
			120	264	134	62	37	31	26	21
			183	366	178	82	47	38	32	26
425	Little River ditch 251 near Lilbourn, Mo	235	7	110	80	56	42	36	31	26
			15	123	88	61	45	38	33	28
			30	142	101	68	49	42	36	30
			60	176	122	80	56	48	42	34
			120	254	180	116	77	65	56	46
			183	352	246	160	102	84	72	59
430	Castor River at Aquilla, Mo	175	7	8.5	2.8	.7	.2	.1	.1	0
			15	11	4.0	.9	.3	.1	.1	0
			30	18	6.3	1.5	.4	.2	.1	0
			60	28	12	3.3	.7	.4	.2	.1
			120	44	25	10	2.3	1.2	.7	.3
			183	60	43	21	6.8	3.4	1.8	.8
435	Little River ditch 1 near Morehouse, Mo	450	7	96	71	50	36	30	26	21
			15	106	78	54	39	32	27	22
			30	123	90	60	43	36	30	24
			60	152	106	71	50	42	36	29
			120	228	156	101	68	58	49	40
			183	335	219	138	90	75	64	52
440	Little River ditch 251 near Kennett, Mo	883	7	321	207	129	86	71	60	48
			15	355	222	132	92	76	64	52
			30	410	249	142	97	82	69	55
			60	510	293	163	108	89	76	62
			120	690	378	201	134	113	97	80
			183	880	473	240	159	133	115	96
460	Little River ditch 259 near Kennett, Mo.[3]	89	7	14	6.3	1.3	.1	0	0	0
			15	17	7.4	1.5	.2	.1	0	0
			30	21	9.0	1.9	.3	.1	0	0
			60	27	10	2.7	.5	.2	.1	0
			120	33	15	4.5	1.2	.5	.4	.1
			183	67	24	7.4	2.5	1.4	1.0	.4
466	Right Hand Chute of Little River at Rivervale, Ark	2,113	7	970	550	268	128	90	72	56
			15	1,190	655	310	155	104	80	61
			30	1,440	765	380	194	128	92	69
			60	1,980	1,030	475	236	161	112	80
			120	3,100	1,700	740	335	230	167	112
			183	3,550	1,800	780	390	288	224	164
479.5	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	.
			120	790	375	143	57	36	24	13
			183	1,400	720	295	106	60	35	18
	White River basin									
615	Black River near Annapolis, Mo	484	7	160	126	97	78	70	62	54
			15	174	135	103	82	74	66	57
			30	196	150	113	88	78	70	61
			60	235	173	127	98	87	78	67
			120	327	236	169	124	109	97	84
			183	465	316	212	154	131	116	101
625	Black River at Leeper, Mo.[1]	957	7	330	272	218	175	158	147	132
			15	358	286	225	185	165	152	135
			30	400	315	240	200	180	162	145
			60	465	355	268	214	192	175	155
			120	625	464	342	265	237	214	190
			183	820	598	432	320	283	254	223

See footnotes at end of table.

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									
	White River basin—Continued									
7-630	Black River at Poplar Bluff, Mo.[1]	1,245	7	438	361	300	256	231	217	193
			15	465	373	315	264	242	223	200
			30	520	408	330	278	256	234	213
			60	608	460	355	302	275	254	226
			120	822	606	450	356	322	290	268
			183	1,180	779	570	420	380	348	311
640	Black River near Corning, Ark	1,749	7	590	400	295	258	240	224	205
			15	685	455	312	266	248	231	212
			30	800	522	336	278	258	240	221
			60	1,030	670	391	294	274	254	232
			120	1,370	900	540	358	320	290	266
			183	1,910	1,120	618	392	350	321	294
690	Black River at Pocahontas, Ark	4,843	7	2,420	1,900	1,520	1,310	1,210	1,120	1,020
			15	2,690	2,100	1,640	1,350	1,270	1,180	1,060
			30	3,020	2,250	1,710	1,430	1,330	1,240	1,110
			60	3,450	2,690	1,970	1,550	1,380	1,270	1,160
			120	4,220	3,170	2,210	1,650	1,480	1,370	1,300
			183	6,250	3,540	2,400	1,800	1,620	1,500	1,410
695	Spring River at Imboden, Ark	1,162	7	670	390	320	280	265	250	240
			15	840	420	330	290	270	260	250
			30	910	460	340	300	280	270	255
			60	1,080	540	365	305	290	275	270
			120	1,350	660	400	330	310	290	280
			183	1,630	860	510	380	340	320	310
720	Eleven Point River near Ravenden Springs, Ark	1,123	7	745	504	352	289	268	250	232
			15	860	550	376	305	276	256	238
			30	920	598	410	316	286	268	246
			60	1,020	658	450	331	300	279	260
			120	1,220	742	490	351	310	292	276
			183	1,420	840	530	385	339	316	300
735	Piney Fork Strawberry River at Evening Shade, Ark	99	7	12	5.0	1.2	.5	.2	0	0
			15	15	6.4	1.5	.7	.4	.1	0
			30	21	9.0	2.2	.9	.5	.2	0
			60	29	14	4.8	1.2	.7	.4	.1
			120	49	28	13	4.7	1.8	1.1	.7
			183	83	48	23	10	6.3	3.4	1.3
740	Strawberry River near Poughkeepsie, Ark	476	7	93	63	48	43	41	39	37
			15	108	70	49	44	42	40	38
			30	130	84	52	45	43	41	39
			60	171	106	62	47	45	42	40
			120	284	172	99	62	51	46	44
			183	465	275	146	87	68	57	48
760	Little Red River near Heber Springs, Ark	1,141	7	159	26	1.2	0	0	0	0
			15	270	46	2.2	0	0	0	0
			30	400	87	5.8	.1	0	0	0
			60	520	185	16	.6	0	0	0
			120	1,020	460	100	13	3.4	.9	.1
			183	1,540	770	270	73	31	13	3.6
775	Cache River near Patterson, Ark	1,041	7	173	70	44	29	15	4.9	1.2
			15	260	82	49	33	21	8.0	2.0
			30	394	125	59	37	28	15	3.4
			60	590	226	78	44	34	25	8.1
			120	910	450	117	61	52	43	32
			183	1,330	670	185	78	66	60	49

[1] Data for natural conditions prior to operation of reservoir upstream.
[2] Includes that of Little River ditches 66 and 66-A.
[3] Data not to base period; based on observed data 1927-57 and records for nearby stations.

flow-duration data in table 4 are excellent for comparing the flow characteristics of different streams and may be used for preliminary planning of projects, but detailed planning 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 may deviate considerably from the adjusted data. For example, during 1954, a year of extremely low flow on Castor River, the daily discharge for Castor River at Aquilla, Mo. (7–0430), equaled or exceeded 6.2 cfs only 41 percent of the time, whereas during the reference period, the daily discharge equaled or exceeded 5.8 cfs for 70 percent of the time.

The adjusted data in table 4 may be used to predict the long-term distribution of future flows at the indicated locations, provided that climatological conditions remain the same and that manmade changes are considered in the computation.

FACTORS AFFECTING LOW FLOW

Water that sustains the natural flow of streams during long periods of little or no precipitation comes from ground-water discharge. The natural storage of this water is in the geologic units, and the low-flow characteristics of streams are governed by the release of the stored water.

The important factors that influence the natural base flow of streams are: (1) the permeability and porosity of the geologic units, (2) the accessibility of ground water to the stream channels, (3) the elevation of the water surface in the streams with respect to the eleva-

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

[Data are adjusted to period October 1928 to 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																		
	Headwater diversion channel basin																		
7-210	Castor River at Zalma, Mo	423	27	30	34	42	52	69	91	121	166	233	341	540	1,070	2,000	4,120	6,060	8,000
	St. Francis River basin																		
375	St. Francis River near Patterson, Mo	956	.7	16.5	20.8	30.2	43.5	73.8	120	198	305	470	725	1,180	2,230	4,100	8,790	13,700	19,800
400	St. Francis River at Fisk; Mo.[1]	1,370	108	113	120	133	150	192	250	344	490	700	1,040	1,780	3,400	5,600	8,900	11,800	14,500
410	Little River ditch 81 near Kenuett, Mo	111	16	18	22	29	39	55	72	89	108	132	164	220	350	630	1,220	1,700	2,100
420	Little River ditch 1 near Kennett, Mo	235	18	21	24	29	37	54	78	109	150	210	300	475	920	1,690	3,800	4,100	4,700
425	Little River ditch 251 near Lilbourn, Mo	235	36	37	40	46	55	76	107	140	174	220	284	390	610	1,000	1,950	2,850	4,000
430	Castor River at Aquilla, Mo	175	.1	.2	.3	.6	1.2	2.8	5 8	11	19	34	63	134	360	870	1,530	2,000	2,370
435	Little River ditch 1 near Morehouse, Mo	450	30	34	38	48	59	77	101	130	166	220	306	482	980	1,980	3,860	5,880	8,100
440	Little River ditch 251 near Kennett, Mo	[2] 883	66	73	84	105	130	176	229	300	393	508	684	995	1,700	2,700	4,060	4,960	5,640
460	Little River ditch 259 near Kenuett, Mo.[3]	89	0	.1	.2	.5	1.3	3.2	5.9	10	18	30	53	100	245	510	1,050	1,500	1,950
466	Right Hand Chute of Little River at Rivervale. Ark	2,113	112	131	156	226	315	530	770	1,110	1,580	2,220	3,100	4,500	7,000	9,600	13,800	18,400	23,600
479.5	L'Anguille River at Palestine, Ark	807	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																		
615	Black River near Annapolis, Mo	484	77	81	86	97	113	137	169	212	263	329	433	620	1,090	1,880	3,560	5,150	6,800
625	Black River at Leeper, Mo.[1]	957	160	170	184	210	241	290	335	410	500	610	780	1,080	1,800	2,850	5,200	8,000	12,000
630	Black River at Poplar Bluff, Mo.[1]	1,245	238	248	262	289	323	382	448	540	670	860	1,150	1,640	2,770	4,400	7,400	10,100	13,600
640	Black River near Corning, Ark	1,749	252	262	272	298	333	410	510	665	880	1,180	1,660	2,500	3,960	5,700	9,200	12,500	16,600
690	Black River at Pocahontas, Ark	4,843	1,120	1,210	1,310	1,460	1,660	1,940	2,280	2,770	3,550	4,550	5,950	8,150	12,400	17,100	24,500	30,500	37,200
695	Spring River at Imboden. Ark	1,162	257	268	282	311	345	412	495	600	738	920	1,200	1,640	2,560	3,780	6,200	9,200	14,700
720	Eleven Point River near Ravenden Springs, Ark	1,123	255	266	282	316	361	445	538	641	770	920	1,120	1,440	2,060	2,830	4,350	6,100	9.250
735	Piuey Fork Strawberry River at Evening Shade, Ark	99	0	.2	.7	1.5	2.8	6.1	11	17	27	40	62	100	210	375	790	1,290	2,020
740	Strawberry River near Poughkeepsie, Ark	476	38	40	44	51	58	72	95	130	180	250	360	550	1,020	1,820	3,950	6,400	9,700
760	Little Red River near Heber Springs, Ark	1,141	0	0	0	.4	5.3	41	122	276	520	890	1,430	2,220	4,210	7,500	15,300	23,600	34,400
775	Cache River at Patterson, Ark	1,041	18	24	31	43	57	90	136	218	350	590	1,120	2,110	3,800	5,400	7,200	8,300	9,300

[1] Data for natural conditions prior to operation of reservoir upstream.
[2] Includes that of Little River ditches 66 and 66-A.
[1] Data not to base period; based on observed data 1927-57 and records for nearby stations.

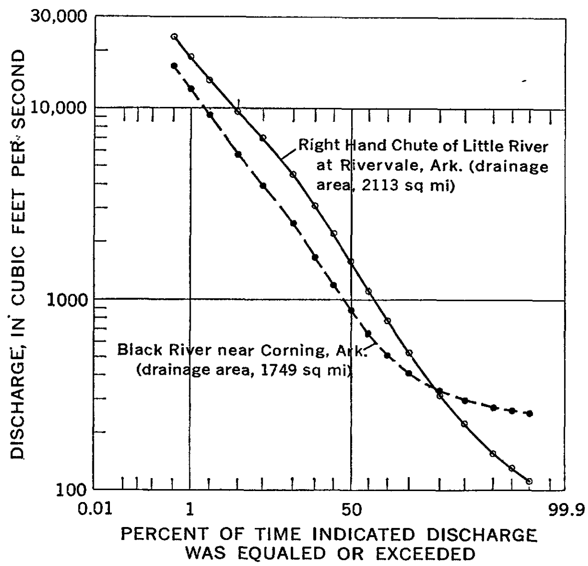

FIGURE 4.—Flow-duration curves for Right Hand Chute of Little River at Rivervale, Ark. (7–0466), and Black River near Corning, Ark. (7–0640), 1929–57.

tion of the water table and to the elevation of the base of the aquifers, (4) the slope of the water table, and (5) the rate of evapotranspiration.

Heavy pumping of ground water near the stream may lower the water table and permit the stream to yield some of its flow to the aquifers. The dredging of stream channels may increase or decrease the low flows of the streams. Water is withdrawn from the streams in many parts of this area. The low flows of some of the streams given in this report may have been so altered from their natural flows by manmade practices that caution should be exercised in interpretation of the low-flow data.

Three major river basins, the Headwater diversion channel, the St. Francis River with its large upstream tributary, Little River, and the White River, are in the area of study. The factors affecting low flow of the streams in each basin are discussed in the following sections. The low-flow characteristics of the streams are compared by using the 7-day flow for the 2-year recurrence interval (table 2) as the low-flow index. 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 emphasize the effects of basin geology.

A study of data in table 2 indicates a wide variation in low-flow yields of streams. This variation can be attributed mostly to the properties of the water-bearing geologic formations at elevations higher than the streambed, to the relation of streambed to water table, and to manmade changes in the drainage area. In the study area, some of these formations and aquifers are the alluvial sands and gravels, the sands of the Wilcox Group (Wilcox Formation in Missouri), the McNairy Sand, and the Paleozoic rocks. Permeable layers in these formations are good contributors to the low flow of streams where the streambed is below the water table, but inasmuch as the units are not homogenous no definite figure of yield can be assigned to each formation. The McNairy Sand, for example, consists of irregularly bedded sand with sandy clay and glauconitic layers, and the extent and distribution of the permeable sand layers determine the ability of the formation to transmit, store, and yield water. During long periods of annual low flow, such as 183 days, during which precipitation occurs, varying rates of direct runoff are likely to occur concurrently with flow from ground-water sources.

HEADWATER DIVERSION CHANNEL BASIN

The Castor River basin above the station at Zalma, Mo. (7–0210), drains uplands that lie in Paleozoic rocks outside the embayment. The low-flow index of 0.09 cfs per sq mi at this station is representative of the Paleozoic rocks in this area. Farther downstream, the Headwater diversion channel at Allenville, Mo. (7–0219), has an index of 0.07 cfs per sq mi. This lower yield is probably due in part to some loss of water into the alluvium from the manmade channel.

ST. JOHNS BAYOU BASIN

Maple Slough (7–0241.7), St. James ditch (7–0241.5), and Main ditch lateral 2 (7–0241) near East Prairie, Mo., have low-flow indices that range from 0.02 to 0.07 cfs per sq mi. This range is typical of streams in the alluvium where the water table is not much higher than the streambed and where the hydraulic gradients of both the water table and the stream are low.

ST. FRANCIS RIVER BASIN

The headwaters of the St. Francis River are outside the embayment in an area where the geologic formations yield very little base flow to the streams as indicated by the index of 0.03 cfs per sq mi for the station near Patterson, Mo. (7–0375). Downstream from Patterson, the low flows of the St. Francis River are regulated by Wappapello Reservoir, which is at the edge of the embayment. The low-flow index of 0.10 cfs per sq mi shown for the station at Fisk, Mo. (7–0400), is indicative of natural flow conditions before the reservoir was created. The increase in natural low-flow yield between Patterson and Fisk is attributed to several large springs that flow from Paleozoic dolomitic limestones.

The St. Francis River cuts through to the east side of Crowleys Ridge near Campbell, Mo. The western tributaries of the St. Francis River in Arkansas, above the mouth of L'Anguille River, head in the loess on Crowleys Ridge. As they leave the ridge, the streams cross outcrops of the Claiborne Group and terrace deposits and then cross the alluvium to reach the main channel. The alluvium is the primary source of base flow in this area, but the Claiborne Group also yields water to those streams that pass through its outcrop. The streams having the greater channel length in the alluvium have the higher low-flow indices. The low-flow index for Big Slough ditch near Marmaduke, Ark. (7–0403), is 0.28 cfs per sq mi. This high yield is caused by the dredging of the channel in the Quaternary alluvium for about 24 miles upstream from the station and also by the dredging of many tributaries that fan out over the valley from near Marmaduke to Piggott, Ark., and extend upstream into Crowleys Ridge on the west.

Locust Creek ditch near Paragould, Ark. (7–0404), which has a low-flow index of 0.017 cfs per sq mi, heads in the loess on Crowleys Ridge, crosses outcrops of Tertiary sand and gravel, and then enters the alluvium, where the main stem is dredged for a distance of about 6 miles upstream from the station. The ditch has many small natural and dredged tributaries and one large dredged tributary, some of which head in Crowleys Ridge. The fact that Locust Creek ditch crosses terrace deposits and has a shorter length of channel in the alluvium than does Big Slough ditch explains the lower yield of Locust Creek ditch. To the south, Little Bay ditch near Jonesboro (7–0478.5), which has an index of zero, is dredged a short distance through the alluvium and drains mostly terrace deposits and Tertiary sand and gravel.

Most of the eastern tributaries of the St. Francis River within the embayment are in alluvium or terrace deposits. A small part of the tributary drainage in the north end of the St. Francis River basin is in detached sections of Crowleys Ridge, which are underlain by Tertiary and Cretaceous deposits. The ground water in the alluvium is near the land surface and in some places is under temporary artesian conditions, as shown by the fact that some wells along the lower part of Little River in Arkansas flow for short periods following a general rain over the area. Kinnemore ditch at Cardwell, Mo. (7–0404.7), which has a low-flow index of 0.009 cfs per sq mi, is in the alluvium. The drainage area of this stream is small and the elevation of the water table at this point is near the elevation of the water surface in the stream. Fifteen Mile Bayou near West Memphis, Ark. (7–0479.2), has an index of zero, but this low index is believed to reflect the effects of withdrawals for irrigation in the vicinity of the station.

The Little River ditches are manmade; they lie in the alluvium east of the St. Francis River in Missouri. The number of tributary laterals, the properties of the geologic formations, the level of the adjacent water table, the amount of the drainage area that lies on higher ground upstream, the depth of the dredged channel—all these factors together cause the wide variations in the low flow of the ditches, and as a result, the low-flow indices range from 0 to 0.49 cfs per sq mi. Main ditch 6 east of Malden (7–0408) and ditch 9 near Gideon (7–0407), Mo., drain low-lying land that is within the sunken lands resulting from the New Madrid earthquate (Fuller, 1912), and have indices of 0 and 0.01 cfs per sq mi, respectively; these ditches have verv low channel slopes and the elevation of the adjacent water table is about the same as the elevation of the bottom of the ditches. The station on Main ditch near Bernie (7–0408.5), which has a low-flow index of 0.03 cfs per sq mi, probably receives some water from the Wilcox Formation in the upper part of the basin. Two points on Main ditch, near Malden (7–0410.5) and at Holcomb (7–0411), have about the same index of 0.22 cfs per sq mi. Most of the low flow of this ditch probably originates in aquifers of the Wilcox Formation which are near the surface or crop out along the east side of Crowleys Ridge.

Ditches in the Little River drainage system in Missouri lie along or are incised into the minor ridges in the alluvium, such as the Malden-Kennett Prairie and Sikeston Ridge; they have relatively high indices of low flow. Main ditch 2 near Malden (7–0409), which has an index 0.38 cfs per sq mi, intercepts the water table along the east side of the Malden-Kennett Prairie. Farther downstream, Little River ditch 81 near Kennett (7–0410), which has an index of 0.33 cfs per sq mi, includes the flow from several laterals that join the system below Main ditch 2. The interchange of surface and ground water in the ditches depends on the manner in which the flow is controlled upstream. Little River ditch 1 near Kennett (7–0420), which has an index of 0.14 cfs per sq mi, is influenced by flow in the laterals to tributary ditch 81 whose base flow is derived mostly from the upper reaches east of the Malden-Kennett Prairie.

Main ditch 1 near Matthews (7–0424) has a high low-flow index of 0.37 cfs per sq mi. This flow originates mostly in the alluvial sand and gravel of Sikeston Ridge, which lies along the east side of the channel, and in the Wilcox Formation and the McNairy Sand that are in the upper reaches of the ditch near Oran. Similarly, the base flow of Little River ditch 251 near Lilbourn (7–0425), which has a low-flow index of 0.24 cfs per sq mi, results mostly from high base flows along

Sikeston Ridge that are received through the tributary, Main ditch 1. Several diversions upstream from the Lilbourn station complicate the derivation of the low flow at this point.

Castor River at Aquilla (7–0430) has a low-flow index of 0.004 cfs per sq mi; it has a relatively short channel upstream to the point where it is cut off by the Headwater diversion channel. Much of the Castor River main stem lies between detached sections of Crowleys Ridge. The Castor River basin lies mostly in the alluvium, but its channels are not incised deep enough into the zone of saturation to derive much yield from the alluvium. The low-flow index of 0.02 cfs per sq mi for Old Channel ditch 1 near Chaffee (7–0431) is typical of stream channels in the alluvium in the north end of the Little River drainage district; these channels do not intercept flow from any large aquifers. Ditch 24 at Heagy (7–0430.5) has the highest low-flow index, 0.49 cfs per sq mi, of any stream or ditch within the study area. This ditch derives most of its base flow from the McNairy Sand that crops out at the base of the northeast corner of Crowleys Ridge. A small part of the base flow in ditch 24 is derived as underflow through the alluvium (p. F13) from the manmade Headwater diversion channel, which lies north of the basin. Little River ditch 1 near Morehouse (7–0435), which includes Castor River, Old Channel ditch 1, and ditch 24, has a low-flow index of 0.11 cfs per sq mi.

Meander Line ditch near Portageville (7–0439) is in the alluvium and has a low-flow index of 0.01 cfs per sq mi. Little River ditch 251 near Kennett (7–0440) has a low-flow index of 0.15 cfs per sq mi, which is higher than the indices for nearby ditches or streams. The ditch receives its base flow from the alluvium along the west edge of Sikeston Ridge and from the interchange of flow between tributary ditches. Little River ditch 259 near Kennett (7–0460) has a low-flow index of 0.01 cfs per sq mi based on observed values; it is affected by lateral diversions and by withdrawals and return of irrigation waters. The indices for Pemiscot Bayou near Holland (7–0465.1), Main ditch 1 near Deering (7–0465.2), and Buffalo ditch near Arbyrd (7–0465.5) are 0.15, 0.14, and 0.26 cfs per sq mi, respectively. These values are high as compared to other streams in the alluvium, but the channels are deeply entrenched and, therefore, intercept more ground water in their reaches than do the ditches or streams to the north. Furthermore, Buffalo ditch drains an area of the sunken lands that resulted from the New Madrid earthquake. The index for Right Hand Chute of Little River at Rivervale, Ark. (7–0466), is 0.13 cfs per sq mi; this index is probably representative of those for the larger streams in the lower part of the Little River basin.

WHITE RIVER BASIN

The White River enters the Mississippi embayment near Newport, Ark. Flow of the main stem is regulated by numerous reservoirs and diversions upstream from the embayment boundary.

Immediately after entering the embayment, the White River is joined by the Black River, which also rises outside and enters the embayment at Poplar Bluff, Mo. The main stem of the Black River and its tributaries have large low-flow indices. The Black River at Poplar Bluff, Mo. (7–0630), for example, has a natural unregulated low-flow index of 0.24 cfs per sq mi; this flow is derived principally from springs in the Paleozoic rocks.

The eastern tributaries to the Black between Poplar Bluff, Mo., and Corning, Ark., include Lake Slough (7–0631) and Menorkenut Slough (7–0631.3) near Qulin, Mo., which are in the alluvium and which have indices of 0.03 and 0.04 cfs per sq mi, respectively. Cane Creek at Harviell, Mo. (7–0635), a western tributary to the Black, rises in the Paleozoic rocks but has an index of only 0.05 cfs per sq mi because erosion has not exposed the high-producing Paleozoic aquifers to the Cane Creek channels. The low indices of these and other tributaries between Poplar Bluff and Corning are the reason for the smaller low-flow index of 0.17 cfs per sq mi for the Black River near Corning (7–0640).

The Current, Eleven Point, and Spring River basins include many large springs in south-central Missouri and north-central Arkansas that sustain very high base flows in the rivers. Eleven Point River near Ravenden Springs (7–0720), Ark., and Spring River near Imboden (7–0695), Ark., have low-flow indices of 0.31 and 0.28 cfs per sq mi, respectively. No station on the Current River is included in the study, but its low-flow index is comparable or possibly higher than those for the Eleven Point and the Spring Rivers. The fact that the Current River enters the Black a short distance above the Pocahontas station (7–0690) explains the high index of 0.31 cfs per sq mi at Pocahontas.

The other western tributaries of the Black River and the tributaries to the White River downstream from the Black have low-flow indices of 0.033 cfs per sq mi or less, except Strawberry River near Poughkeepsie, Ark. (7–0740), which has an index of 0.10 cfs per sq mi. The base flow at these stations, which are outside of the embayment, is derived mostly from Paleozoic rocks. After entering the embayment, the streams flow through alluvium and terrace deposits. Yield from the alluvium probably increases the base flow of these streams downstream from the gaging stations. Wattensaw Bayou near Hazen (7–0769.5) and Lagrue

Bayou near Stuttgart (7–0780), Ark., each of which has a low-flow index of 0.001 cfs per sq mi, receive their base flow almost entirely from Quaternary terrace deposits. Small parts of their lower basins, which are near the White River, are in the alluvium, and the headwaters of Wattensaw Bayou are in Tertiary deposits.

The eastern tributaries to the White River downstream from the Black River are low-yielding streams in narrow alluvial valleys within the Mississippi River alluvium. They are fed by smaller streams, many of which are in manmade channels that are incised into the terrace deposits. Cache River may be affected by diversions for irrigation in the extreme upper part of the basin, but at the station near Patterson, Ark. (7–0775), where the effect from irrigation, if any, is less significant, the low-flow index is 0.042 cfs per sq mi.

MAJOR FLOODS AND GROUND-WATER RECHARGE

The same properties of the geologic units along a stream that influence the movement of ground water into the stream may be expected also to influence the extent to which major floods may increase the ground-water storage. In addition, the elevation of the water table in the aquifer with respect to the stream, the height and duration of the flood, and the area inundated by the flood will influence the amount of ground-water recharge.

Most of the streams in this area are effluent streams that receive their base flow from ground-water sources, but some of the effluent streams or parts of them may become influent during periods of drought. During flood periods, also, an effluent stream may cease to be effluent, or may even become influent and contribute flow to the ground water. Ground-water recharge during times of flood stage in effluent streams is generally temporary. The recharged water, which is stored near the stream during the period of high river stage, is released soon after the flood has receded. Furthermore, the area of recharge due to flooding is generally limited to the flood plain of the stream. Recharge benefits derived during floods are similar to those from excess rainfall on the flood plain.

The deposition of sediment in the stream channel and on the flood plain may inhibit the interchange of surface and ground water. In some places, on the other hand, scouring action may increase the infiltration capacity of the stream channels and the flood plains.

The entire area east of Crowleys Ridge probably receives some recharge to the underlying aquifers during floods. East of Little River, however, much of the area is underlain by sandy clay, and the recharge through the sandy clay during flood periods is somewhat less than in the area between the Little River and the St. Francis River which is underlain by sand. In areas other than that east of Crowleys Ridge, recharge as the result of flooding is limited to the narrow alluvial valleys along the streams.

LOW FLOWS AND GROUND-WATER FLUCTUATIONS

In the discussion of the factors affecting low flow, five important factors that influence the base flow of a stream are enumerated (p. F11). The first two of these factors are fixed by the physical properties of the aquifers in contact with the stream, and the other three are variable factors that influence the rate at which the geologic units yield water to the stream.

Fluctuations in the base flow of a stream are generally related to fluctuations of the ground-water levels 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.

Where a stream receives its base flow from a single aquifer, the elevation of the ground water in that aquifer is generally an index of the base flow. Most streams, however, receive their base flow from more than one aquifer, and the interrelation between waters in the aquifers and the base flow of the stream becomes extremely complex. Ground water in one or more of the aquifers, for example, may recede sufficiently to cause a reversal of water movement, and a transfer of surface water to ground water and a decrease in flow in some reaches of the stream may thus result. Furthermore, evapotranspiration exerts a seasonal effect on streamflow, an effect that is difficult to evaluate.

The volume of ground water available to support low flow is the water in the aquifers that lies adjacent to and at a higher elevation than the elevation of the water surface in the stream. The size of the surface drainage area, then, is not always a dependable basis for estimating the low-flow characteristics of streams, because (1) the limits of the aquifer that drains to the stream may not coincide with the surface drainage area, (2) there is great variation in the water-bearing characteristics of the geologic units from which the base flow of a stream is derived, and (3) there is great variation in the depth of entrenchment. The variations in the runoff per square mile presented in table 2 demonstrate the effect of these underground factors and provide an index for further investigation into the physical basis for the areal variation in low-flow yields. Because the index of low flow generally differs from stream to stream and at different points on the same stream, estimates of low-flow characteristics at an ungaged site should be based on discharge measurements of low flow at the site and on consideration of 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 essentially graphical. The procedure consisted of smoothing the low-flow data for long-term records by comparison with data from other long-term stations and then adjusting the shorter records to the reference period by using 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 northern Arkansas and Missouri:

No.	*Name*
3B6040	Buffalo River near Flatwoods, Tenn.
7-0305	Wolf River at Rossville, Tenn.
7-0375	St. Francis River near Patterson, Mo.
7-0570	Buffalo River near Rush, Ark.
7-3635	Saline River near Rye, Ark.

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 observed data for the reference period, some consideration being given to the shape of the flow-duration curves at other long-term stations.

Index stations were selected from the remaining stations 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 were then used as a base to which to relate the flow at stations having records shorter than those at the index stations. Records from daily-record stations having less than 5 years of record and data from low-flow partial-record stations were related to records for one of the other 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 at the selected long-term and index stations was available. The annual minimum discharges used in the low-flow frequencies are the lowest in each climatic year (the year starting April 1); the periods of low flow, which generally occur in the summer and fall, are therefore 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 of a much lower order of accuracy than are similar results for the longer term stations, because the results are based on relations defined over a smaller range in discharge and for 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 23 daily-record and 37 partial-record stations in or adjacent to the Mississippi embayment in northern Arkansas and southeastern Missouri. Locations of the stations are 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. In order to facilitate the publication of streamflow records, the United States is divided into 14 parts. All the records for the area described in this chapter are in Part 7, the Lower Mississippi River basin (fig. 5).

Records of daily discharge for gaging stations having five or more complete consecutive water years not materially affected by regulation or diversion were processed by an electronic computer to obtain (1) the lowest mean discharge occurring during each climatic year for selected number of consecutive days and (2) the number of daily flows during each water year between selected limits of discharge (Speer, 1960). If the natural flow at a station became materially regulated or affected by diversions as the result of manmade changes, the part of the record so affected was not used. Records of 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 tables 2–4 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 economic balance between the cost and the loss resulting from an insufficient supply at periodic intervals. The low-flow frequency data in table 3 were used to estimate the draft that may be maintained with specified amounts of storage.

To provide a means for estimating the storage required 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 6 and 7. This index of low flow, which is the same as that used in the

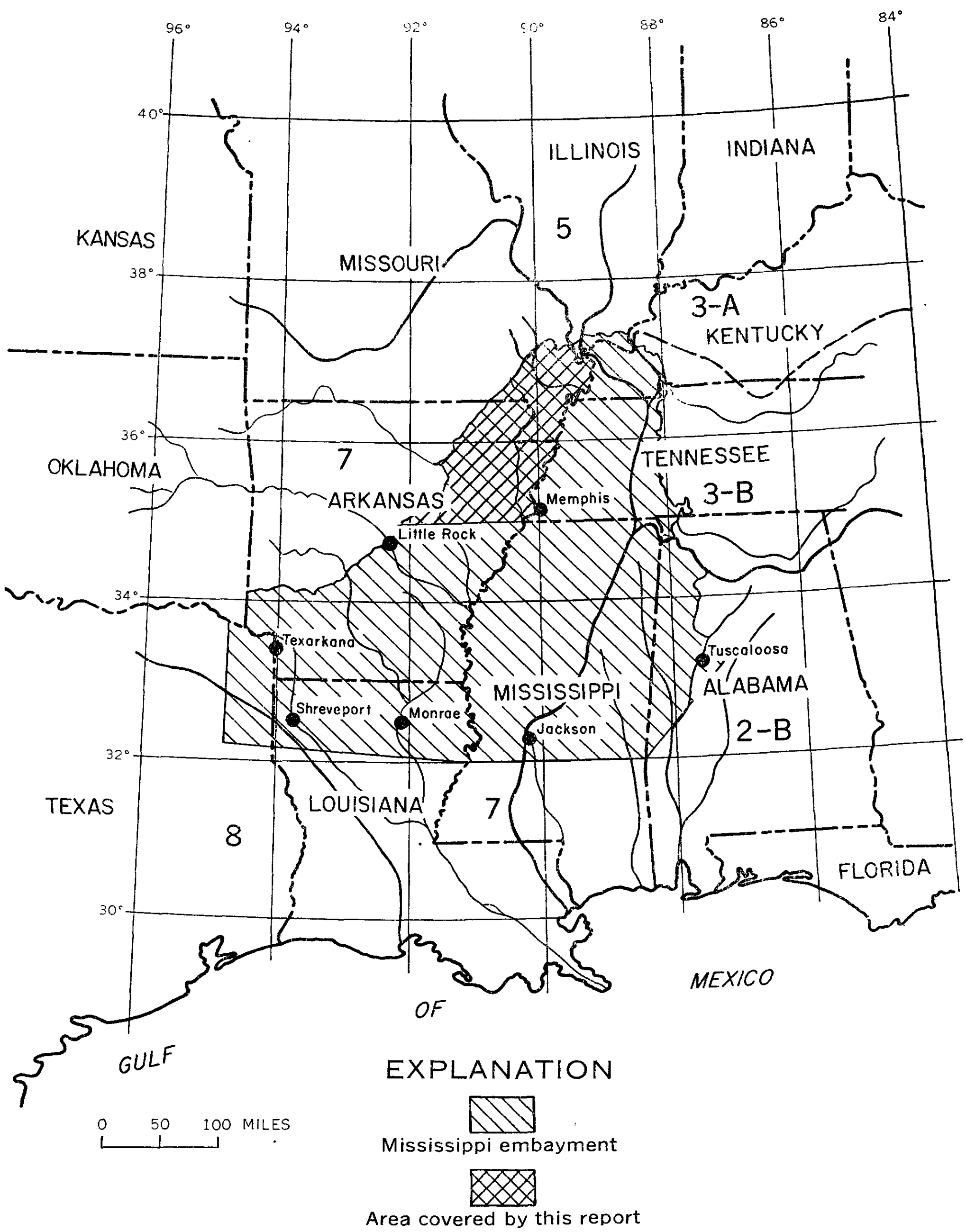

FIGURE 5.—Map of the Mississippi embayment showing numbered areal parts for which streamflow records are published in U.S. Geological Survey reports on surface-water supply.

section on "Factors affecting low flow," is given in table 2 for 58 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 where an acceptable correlation can be obtained (Searcy, 1959, p. 20). Application of frequency data for intermittent streams to storage problems is not recommended because techniques are not sufficiently well formulated at present to permit draft-storage analysis on a frequency basis for streams having indices of zero.

Data available to define the curves in figures 6*B* and 7*B* have been combined with similar data for the embayment in southern Arkansas, northern Louisiana, and northeastern Texas, and one set of curves developed for the Mississippi embayment area west of the Mississippi River in order to improve the reliability of the curves. The number of points available to define the curves range from 4 for the 90 acre-ft per sq mi at the 20-year

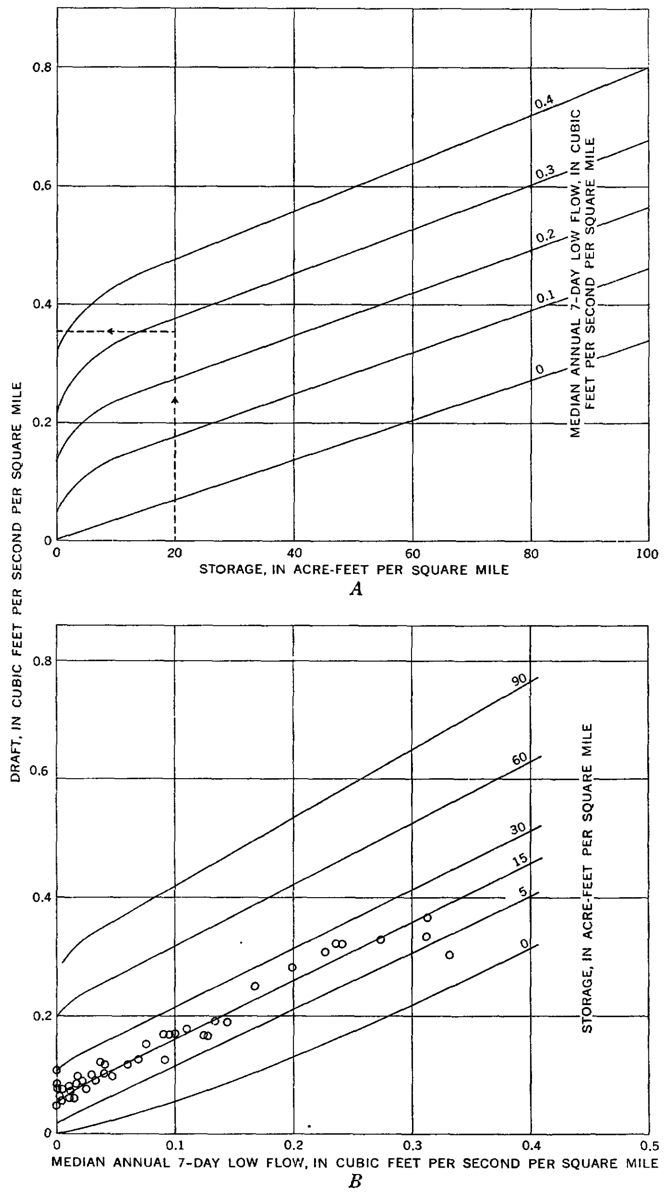

FIGURE 6.—Areal draft-storage relations for a 10-year recurrence interval as a function of the median annual 7-day low flow, for storage of 0, 5, 15, 30, 60, and 90 acre-ft per sq mi.

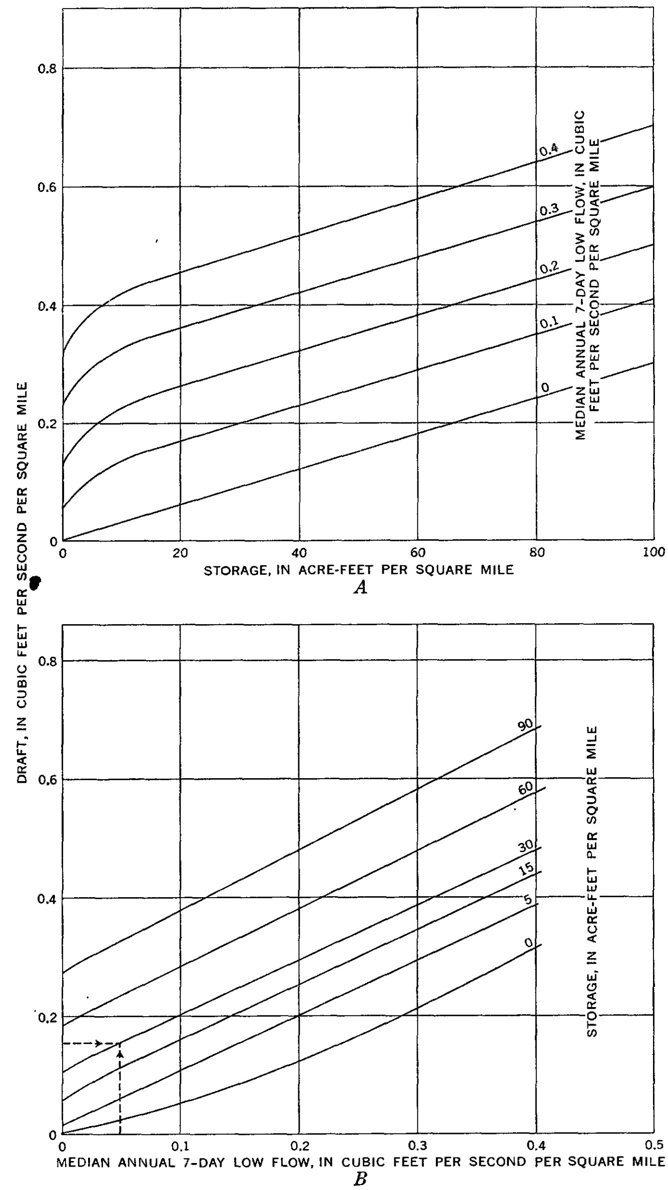

FIGURE 7.—Areal draft-storage relations for a 20-year recurrence interval as a function of the median annual 7-day low flow, for storage of 0, 5, 15, 30, 60, and 90 acre-ft per sq mi.

recurrence interval to 66 for 0 acre-ft per sq mi at the 10- and 20-year recurrence intervals and 5 acre-ft per sq mi at the 10-year recurrence interval. The scatter of the circles in figure 6*B* for a storage of 15 acre-ft per sq mi is typical of the scatter of the points that define other curves in figures 6*B* and 7*B*. The curves in figures 6*A* and 7*A* are based on the curves in 6*B* and 7*B*.

The curves of zero storage in figures 6 and 7 represent the 7-day low flow for the 10- and 20-year recurrence interval and thus neglect the small amount of storage that would be required to regulate the 7-day flow. None of the curves consider 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. Because 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. Furthermore, the scatter of the points in figure 6*B* indicates that the storage required at a given station may depart greatly from the average given by the curves. The areal draft-storage relations, therefore, should be used only for obtaining preliminary estimates of draft-storage requirements at partial-record stations and for making comparisons between stations. More detailed studies using the data in table 3, if available for the particular 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).

The storage required for a specified draft with a chance that it will be insufficient on an average of once in 10 and once in 20 years can be estimated by using figures 6 and 7 and the median annual 7-day low flow for the stream at the point of utilization. Using the median annual 7-day low flow as abscissa and the storage to be provided as a parameter; the curves in figures 6*A* and 7*A* give the expected draft. If the required draft is known, the curves in figures 6*B* and 7*B* can be used to estimate the amount of storage required.

Illustrative problem 1: Let it be assumed that a proposal is made to build a manufacturing plant on Cane Creek at Harviell, Mo., which will require a minimum flow of 29 cfs for operation; for economic reasons, the flow should not drop below this discharge more 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 Cane Creek at Harviell, Mo. (7–0635), obtain the median annual 7-day low flow (7-day 2-year), which is 0.05 cfs per sq mi, and the drainage area, which is 188 square miles.
2. Divide 29 cfs by 188 square miles to obtain a required draft of 0.154 cfs per sq mi.
3. Use figure 7B. The abscissa being 0.05 cfs per sq mi and the ordinate being 0.154 cfs per sq mi, the estimated storage required is 30 acre-ft per sq mi or 5,640 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 it would be insufficient at average intervals of 20 years.

Illustrative problem 2: Let it be assumed that demands for water are such that they greatly exceed the natural flow of Big Slough ditch near Marmaduke, Ark., and let it be assumed also that upstream from Marmaduke a total storage of 6,000 acre-ft could be developed or made available for supplementing low flows. What draft at Marmaduke can be maintained by this storage if a deficiency once in 10 years can be tolerated?

1. From table 2 for Big Slough ditch near Marmaduke, Ark. (7–0403), obtain the drainage area, which is 245 square miles, and the median annual 7-day low flow (7-day 2-year), which is 0.28 cfs per sq mi.
2. Estimate the annual reservoir and conveyance losses and deduct these amounts from the total storage. For the purpose of this problem, the total of reservoir and conveyance losses during a dry year and 10 percent bias are estimated as 1,100 acre-ft. Then, the net storage available for use at Marmaduke is 6,000 acre-ft minus 1,100 acre-ft, or 4,900 acre-ft.
3. Divide the net storage by the drainage area to obtain the net acre-feet per square mile available at Marmaduke:

$$\frac{4,900}{245} = 20 \text{ acre-ft per sq mi.}$$

4. Use figure 6*A*. The abscissa being 20 acre-ft per sq mi and the parameter being 0.28 cfs per sq mi, interpolate between median annual 7-day low-flow curves of 0.2 and 0.3 cfs per sq mi and read as ordinate the draft of 0.355 cfs per sq mi. On 245 square miles this unit draft would give 87 cfs as the allowable draft that may be made and 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 0.14 cfs per sq mi or 34 cfs at a 10-year recurrence interval (see table 2), unless the allowable draft were curtailed to less than 87 cfs as the drought developed and as the amount of water in storage became dangerously low.

Storage and draft data in figures 6 and 7 may be converted to other units by using the following conversion equivalents:

1 acre-ft = 0.326 million gallons = 0.504 cfs-day.

1 cfs = 1.983 acre-ft per day = 0.646 million gallons per day.

1 million gallons 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

Low-flow surface water in this area is generally a calcium magnesium bicarbonate type. The water is moderately mineralized, and most of it is hard. In 21 samples analyzed (table 5), the dissolved-solids content ranged from 90 to 333 ppm (parts per million), hardness from 57 to 275 ppm, iron from 0.00 to 0.08 ppm, fluoride from 0.0 to 0.5 ppm, nitrate from 0.0 to 1.4 ppm, and silica from 1.8 to 30 ppm. The source and significance of dissolved mineral constituents and properties of water are shown in table 6.

TABLE 5.—*Chemical analyses of low-flow surface waters in the Mississippi embayment in northern Arkansas and in Missouri*

Geologic units in drainage basin above sampling station	Date sampled	Discharge (cfs)	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
			Parts per million																
Paleozoic rocks and Cretaceous deposits	**7-0430.5. Ditch 24 at Heagy, Mo. (drainage area, 36.8 sq mi)**																		
	9-13-60	22.0	8.5	0.00	56	27	8.3	1.4	294	11	12	0.3	0.2	270	250	10	471	7.6	5
	11-14-62	30.8	18	.00	60	26	8.2	1.3	296	14	13	.2	.0	287	256	14	498	7.4	3
Cretaceous deposits, Tertiary deposits, and alluvium	**7-0424. Ditch 1 near Matthews, Mo. (drainage area, 62.0 sq mi)**																		
	6-27-61	107	12	0.06	40	14	9.0	1.1	164	35	7.0	0.0	0.0	199	158	23	316	7.6	5
Pliocene(?) deposits	**7-0776.5. Big Creek near Jonesboro, Ark. (drainage area, 51.1 sq mi)**																		
	9-28-60	1.06	6.8	0.01	13	6.0	9.6	2.7	87	5.0	4.0	0.3	0.5	91	57	0	151	7.4	15
	8-15-62	.52	9.3	.04	12	6.8	9.1	2.5	83	5.8	5.5	.1	.2	92	58	0	144	7.3	10
Quaternary terrace deposits and alluvium	**7-0746. Village Creek at Walnut Ridge, Ark. (drainage area, 34.3 sq mi)**																		
	8-14-62	2.64	17	0.00	36	14	7.5	4.2	182	9.2	3.5	0.1	0.4	182	148	0	274	7.9	8
	7-0747. Village Creek at Newport, Ark. (drainage area, 270 sq mi)																		
	9-28-60	------	1.8	0.01	20	4.8	7.2	4.0	93	6.2	5.0	0.2	0.9	96	70	0	164	7.2	22
	10-26-60	26.0	7.5	.01	18	4.3	6.0	3.8	78	6.6	4.5	.2	1.0	90	62	0	152	7.0	22
	7-0404. Locust Creek ditch near Paragould, Ark. (drainage area, 79.5 sq mi)																		
	9-28-60	2.67	6.4	0.00	41	9.9	12	2.6	170	20	9.5	0.3	0.5	186	143	4	309	7.8	10
	8-15-62	1.58	16	.00	63	15	11	1.5	[1]266	16	7.5	.1	.4	261	219	0	393	8.5	5
Quaternary alluvium	**7-0241. Lateral ditch 2 near East Prairie, Mo. (drainage area, 97.3 sq mi)**																		
	9-14-60	9.43	11	0.00	52	12	7.2	2.0	216	12	2.8	0.5	1.4	207	179	2	346	7.3	7
	7-0465.2. Main ditch 1 near Deering, Mo. (drainage area, 66.4 sq mi)																		
	9-15-60	22.3	13	0.00	67	19	13	2.9	302	23	5.5	0.4	0.4	293	245	0	480	7.7	7
	11-13-62	25.7	24	.00	79	19	15	2.8	328	25	6.0	.3	.8	333	275	6	550	7.1	5
	7-0409. Main ditch 2 near Malden, Mo. (drainage area, 15.2 sq mi)																		
	9-13-60	12.1	12	0.00	38	6.8	7.4	1.7	140	19	5.5	0.4	0.6	160	123	8	258	7.1	5
	6-26-61	50.2	13	.00	39	7.2	7.4	1.2	146	16	5.0	.0	.1	161	127	8	257	7.6	7
	11-12-62	37.8	26	.01	36	7.5	8.0	1.5	133	19	6.2	.2	.5	170	121	12	266	7.1	5
	7-0631. Lake Slough near Qulin, Mo. (drainage area, 78.0 sq mi)																		
	9-13-60	6.90	18	0.00	58	13	4.5	1.3	248	6.4	3.0	0.4	0.3	227	198	0	372	7.5	7
	11-12-62	9.33	30	------	56	14	4.4	1.3	236	7.2	2.8	.2	.2	232	197	4	375	7.0	5
	7-0465.5. Buffalo ditch near Arbyrd, Mo. (drainage area, 38.7 sq mi)																		
	9-15-60	16.6	14	0.00	53	10	8.0	1.5	204	18	5.0	0.5	0.7	211	173	6	346	7.3	7
	6-26-61	64.5	20	.08	40	16	6.6	1.3	186	23	6.0	.0	.4	204	166	14	317	7.7	5
	1-0479.2. Fifteen Mile Bayou near West Memphis, Ark. (drainage area, 51.0 sq mi)																		
	10-25-60	7.36	7.1	0.00	62	18	8.1	4.1	266	26	4.0	0.3	1.0	262	228	6	433	7.2	20

[1] Includes equivalent of 12 ppm of carbonate (CO_3).

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 water 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 of 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 water.	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"). Water 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 water and in 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 water systems 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.
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.

See footnote at end of table.

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

Constituent or property	Source or cause	Significance
Hardness as $CaCO_3$	In most water, 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 waters may also attack metals.
Color	Yellow-to-brown color of some water is generally 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.

The suitability of water for most uses depends on the chemical and biological characteristics and the physical properties 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 this area, the waters would be suitable for some uses with little or no treatment. However, for municipal and most industrial uses, most of the water would require softening, coagulation, filtration, and pH adjustment for corrosion control.

All the water in streams during periods of low flow is mainly ground-water discharge. Consequently, the chemical quality of low-flow surface water is similar to the chemical quality of the ground water. The chemical characteristics of this water are related to the chemical composition and solubility of the rocks in the drainage basins, and the length of time that the water has been in contact with the rocks.

The chemical characteristics of the water from the streams sampled are shown graphically on plate 3. The diagram, or pattern, at each site represents the average of the two or three analyses shown in table 5 for the site except for four sites for which only one analysis is available. The number above the pattern denotes the average dissolved-solids content, and the symbols beneath the pattern indicate the geologic units that contribute water to the stream.

The patterns (pl. 3) show that calcium, magnesium, and bicarbonate are the principal constituents in waters from streams draining all formations except the Pliocene(?) deposits. All the streams, except ditch 24 at Heagy, Mo. (7–0430.5), and Big Creek near Jonesboro, Ark. (7–0776.5), drain terrace or alluvial deposits of Quaternary age or they have alluvium present in the drainage basin. The chemical analyses of low-flow water (table 5 and pl. 3) from streams draining Quaternary deposits are similar to those given by Ryling (1960, p. 61) and Plebuch (1961, p. 54) for ground water from Quaternary deposits. This similarity indicates that during periods of low flow the flow for most streams in the area is mainly ground-water discharge from these deposits.

Ditch 24 at Heagy, Mo. (7–0430.5), drains Paleozoic rocks and Cretaceous deposits. The chemical characteristics of water in this stream are similar to those of water in streams draining Quaternary deposits. This similarity is to be expected because generally the principal soluble constituents in the Paleozoic rocks and in the outcrop of the Cretaceous deposits are the carbonate salts of calcium and magnesium.

The dissolved-solids content of water in streams draining Quaternary deposits or draining Paleozoic rocks and Cretaceous deposits ranged from 90 to 333 ppm. In each stream, however, the quality was fairly uniform during periods of low flow. The areal variation in dissolved solids is caused largely by differences in the composition of the deposits.

The dissolved-solids values of water from Village Creek at Newport, Ark. (7–0747), are much smaller than that for Village Creek at Walnut Ridge, Ark. (7–0746), or for other streams draining the alluvium or terrace deposits. The difference in the dissolved-solids content of water in Village Creek, however, is within the range observed during periods of fairly low flow in the daily samples on the Cache River at Patterson, Ark. (U.S. Geol. Survey, 1959, p. 47). Village Creek drains an area of similar geology that lies parallel to the Cache River drainage basin, and the differences in the dissolved-solids values shown for the two sites on Village Creek may be due to the fact the samples were taken on different dates.

Big Creek near Jonesboro, Ark. (7–0776.5), drains Pliocene(?) deposits. The analyses indicate that bicarbonate is the principal anion in water from these deposits and that calcium, magnesium, and sodium are present in about equal quantities. The dissolved-solids content of water from Big Creek near Jonesboro generally is less than that in streams draining other geologic units, probably because the Pliocene(?) deposits do not have as much soluble material as the other deposits.

CONCLUSIONS AND RECOMMENDATIONS

1. In the Mississippi embayment in northern Arkansas and in Missouri, the total water resources are sufficient to meet the needs for many years in the future; future problems in water supply are likely to be those of distribution and of providing storage to meet the demands during low flow. The use of water has increased rapidly in recent years, and in some areas, manmade changes probably have altered the low-flow characteristics of the streams. The data presented in this report provide a basis for planning development of the water resources and for water management, but further investigations may be needed for detailed design.

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 variations in the yields of the streams, and even of the same stream, the low-flow data presented in this report should not be extrapolated to ungaged sites without the aid of low-flow discharge measurements at the ungaged sites and without a knowledge of the geology, physiography, and other factors affecting the low flow.

3. The wide variations in the low-flow indices of the streams may be attributed, largely, 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. This study shows that some streams in this area have relatively low yields. If the need for additional low flow in these streams should arise, further investigations may suggest ways and means for increasing these low flows.

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

Alluvium.
Paleozoic rocks outside of the area.
Tertiary sands and gravels.
McNairy Sand of the Upper Cretaceous Series.

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 flows 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 analyses of water in streams in this area during periods of low flow show that the waters generally are a calcium magnesium bicarbonate type. The water is moderately mineralized and most of it is hard (more than 120 ppm). It would be suitable for some uses with no treatment, but for municipal and most industrial uses, water of most of the streams would require softening, coagulation, filtration, and pH adjustment for corrosion control.

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 features include the effect of floods upon the ground-water table adjacent to the streams, 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 interrelations between the ground-water fluctuations and the low flow of the streams, and the effect of impoundment of waters in ponds and reservoirs upon the low flow of the streams.

The results of this study indicate that increases or decreases in low flow have probably resulted from manmade changes. More detailed knowledge of the geology and more low-flow measurements at additional sites would be needed to evaluate the low-flow potential of streams in much of this area.

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