Low-Flow Characteristics of Streams in the Mississippi Embayment in Tennessee, Kentucky, and Illinois

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With a section on QUALITY OF THE WATER

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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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By Paul R. Speer, W. J. Perry, John A. McCabe, O. G. Lara, and others

ABSTRACT

The low-flow characteristics of a stream largely govern the type and economics of its utilization. The magnitude, duration, and frequency of low flows are used to determine if a water-utilization project can be operated without storage or to compute the amount of storage required for its operation. The frequency of low flows affects the economics of both construction and operation of a water-utilization project.

The character and distribution of geologic formations within stream basins influence the quality and quantity of the low flows of streams. 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.

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

Limited low-flow data, in cubic feet per second per square mile, for 32 daily-record gaging stations and 57 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-year and 10-year intervals and gives the flow at the 95- and 90-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 32 daily-record gaging stations.

The 7-day low flow at the 2-year recurrence interval expressed on a per-square-mile basis is used to demonstrate areal variations of low flow in the study area. These indices range from 0 to 0.61 cubic foot per second per square mile.

Streams north of a low ridge that extends across the area north of the North Fork Obion River near the Tennessee-Kentucky line generally have relatively low indices of base flow, whereas streams immediately south of the ridge generally have higher indices of base flow. The reason for these marked differences in low-flow indices is not known, but displacements resulting from recent crustal movements in the area may affect the movement of ground water toward the streams. Ground water from the higher tract in Kentucky may drain toward the streams in Tennessee as underground flow.

Streams along the eastern margin of the embayment in Kentucky receive their base flow from the Cretaceous formations and Pliocene(?) deposits, and streams in the remainder of the State receive their base flow from the Eocene formations. Most headwater streams in Kentucky are above the ground-water table and are intermittent. At some downstream point the channels intersect the water table in the Paleozoic, Cretaceous, and Eocene deposits, and downstream from the point of intersection the streams are perennial. In some places, however, the amount of surface flow is lessened because of the amount of water moving out of the valley as underflow.

Streams north of the Ohio River in Illinois, and those in the embayment where the interstream areas are mantled by the relatively impervious loess, have fairly low indices of base flow.

Streams receiving their base flow from the "500-foot" sand member of the Claiborne Group or from the McNairy Sand Member of the Ripley Formation have the highest low-flow indices of streams in the study area. In the southeast corner of the area, the Paleozoic rocks, the Coffee Sand, and the Eutaw and Tuscaloosa Formations are good contributors to the base flow of the streams. Elsewhere, streams in the Paleozoic rocks and in the upper sands of the Claiborne Group have good low-flow indices. The Porters Creek Clay, the Coon Creek Tongue of the Ripley Formation, and the clays in the upper part of the Claiborne Group are poor contributors to the base flow of the streams.

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 composition of the surface water, as determined from samples collected at 30 sites during low-flow periods, shows the dissolved solids to range from 13 to 288 ppm (parts per million), hardness to range from 6 to 236 ppm, and the iron content to range from 0.00 to 0.51 ppm. The surface waters in the study area generally would be excellent sources for municipal and industrial supplies. The low-flow waters derived from the unconsolidated deposits above the Paleozoic rocks are soft (0–60 ppm hardness) and for most uses would require treatment for color, for iron removal, and for pH control. Waters from the Paleozoic rocks and terrace deposits are very hard (more than 180 ppm hardness), and softening would be desirable for many uses.

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

INTRODUCTION

In the Mississippi embayment in Tennessee, Kentucky, and Illinois, large supplies of fresh water are available from both surface and underground sources.

The area has a high average annual precipitation. In addition, four large rivers that originate outside the area pass immediately adjacent to or through it; they are the Mississippi River on the west side, the Tennessee and Cumberland Rivers on the east side, and the Ohio River near the north boundary. In the past, many parts of the area have been subjected to devastating floods and much attention has been centered on flood control, drainage, and improving the channel hydraulics of the streams systems. In recent years, however, increased use of water due to rapid economic development has resulted in shortages during periods of low streamflow. At present, the principal use of surface water in the area is for waste disposal, and the trend toward increased use for this purpose is likely to continue. Knowledge of the areal availability of water during critical periods of low flow is paramount to the orderly development of the area.

The overall flow characteristics of a stream and the chemical, physical, and biological properties of the water are the basis for the type of utilization of the stream, and these factors exert a major influence on the economics of the stream's development. These overall characteristics, as they change with time, are as important in determining utilization as are the flow characteristics at different locations. Equally as important as the characteristics resulting from natural controls are those resulting from manmade changes in water and its environment.

Streamflow records for this report were collected over a period of many years by the U.S. Geological Survey in cooperation with the Tennessee Department of Conservation, through the Division of Geology, the Division of Water Resources, and the Game and Fish Commission; the University of Kentucky, through the Kentucky Geological Survey; the Illinois Department of Registration and Education, Water Survey Division; and the Illinois Department of Public Works and Buildings, Division of Waterways. Other records were obtained through cooperation with Federal agencies—the Army Corps of Engineers, the Mississippi River Commission, the Bureau of Sport Fisheries and Wildlife, the Soil Conservation Service, and the Tennessee Valley Authority.

The records were analyzed and the manuscript describing the low-flow characteristics of the streams was prepared by the following: In Tennessee, W. J. Perry, assisted by G. H. Wood, under the general direction of J. S. Cragwall, Jr., district engineer; in Kentucky, John A. McCabe, assisted by C. H. Hannum, under the general direction of F. F. Schrader, district engineer; and in Illinois, O. G. Lara, assisted by V. D. Herreid, under the general direction of William D. Mitchell, 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 M. E. Schroeder, succeeded by J. H. Hubble, district chemist. Other parts of the report were prepared, the results of analyses were coordinated and reviewed, and the report was assembled by Paul 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, G. K. Moore, and L. M. MacCary. They 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 current phase of the investigations of the Mississippi embayment is to define the hydrologic systems. Because most of the area is underlain by aquifers which yield large quantities of water to wells, ground water is the most readily available source of fresh-water supply in the embayment. Surface waters are available to those users who have access to the streams. In defining the hydrologic systems of the area, ground water and the low flows of the surface water are essentially one water and cannot be separated. The results of the studies on surface water and the results of the studies on ground water, published as separate chapters of this Professional Paper series, complement each other in the definition of the hydrologic systems.

The purpose of this chapter is to present data to facilitate evaluation of the characteristics of low flow of streams within the embayment in Tennessee, Kentucky, and Illinois. It deals with surface water and with the relation of the underlying aquifers to low streamflow. The low-flow characteristics of streams at 89 sites in Tennessee, Kentucky, and Illinois are given in this chapter. Other chapters of this series contain similar data for other parts of the embayment (fig. 1).

Of particular interest to utilization of a stream are the magnitude of the low flow, the length of the period that a specific discharge continues or is not exceeded, the frequency at which this discharge recurs, and the quality of the water during the low-flow periods. The low-flow characteristics presented in this report show the amount of water available for utilization 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 streams during low flow.

Information on the interval at which low flows of a given magnitude may recur is a prerequisite to the orderly development and utilization of a stream. It is essential in the allocation of water, in the determination of the recurrence of the flow of water that is not chemically or physically suitable for specific uses, and in the determination of the economics of storage needed to produce certain minimum flows of acceptable minimum quality. The data in this report will enable designers to determine the magnitude and frequency of low flows at specific sites at the same time that they study the economics of development.

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

DEFINITION OF TERMS

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

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

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

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

Low-flow index. The median annual 7-day low flow, in cubic feet per second per square mile—that is, the average 7-day low flow having a recurrence interval (average return period) of 2 years.

Mean annual flood. The mean annual flood for a point on a stream is the flood having a recurrence interval (average return period) of 2.33 years.

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

DESCRIPTION OF THE AREA

The area of the embayment covered by this chapter (fig. 1) includes 10,600 square miles in Tennessee, 2,830 square miles in Kentucky, and 570 square miles in Illinois. It extends from Mississippi on the south to just beyond the Cache River sag north of the Ohio River in southern Illinois. The east boundary approximately follows the Tennessee River in Tennessee and the Cumberland River in Kentucky, and the west boundary follows the Mississippi River.

The major part of the drainage from the area is to the main stem of the Mississippi River. The principal streams draining to the Mississippi are the Cache River below the Post Creek cutoff, the Ohio River below the mouth of the Cumberland River, Mayfield Creek, and the Obion, Hatchie, Loosahatchie, and Wolf Rivers. Drainage from a strip along the east side of the area, ranging in width from about 10 to 40 miles, is to the Tennessee River in Tennessee and to the Tennessee and Cumberland Rivers in Kentucky. A small part in the north drains directly to the Ohio River.

The natural stream patterns are irregular and meandering. The channels have fairly flat slopes and the streams are sluggish. Many of the channels have been altered by man to facilitate drainage and to improve the hydraulics of the channels.

CLIMATE

The climate of the area is warm and humid. The average annual precipitation generally ranges from about 47 to 54 inches. Nearly all of the precipitation is rain; the annual snowfall in the area averages 4 to 6 inches across southern Tennessee and increases toward the north to an average of about 10 inches in southern Illinois. The area lies in the paths of the rain-producing low-pressure systems that move northeastward from the western gulf area and the dry continental airmasses that move west to east across the middle of the continent. These air masses, together with the position of the Atlantic high, exert the major influences on the climate. Temperatures range from an average low of about 28°F during January in southern Illinois to an average high of about 92°F during July in Tennessee and the western tip of Kentucky.

PHYSIOGRAPHY

The Mississippi embayment, a part of the Coastal Plain province, is a great structural trough between the Appalachian and Interior Highlands (Fenneman, 1938, p. 96). It has been formed by subsidence of the structural trough, aggradation, differential weathering, erosion, and crustal movement. During much of its

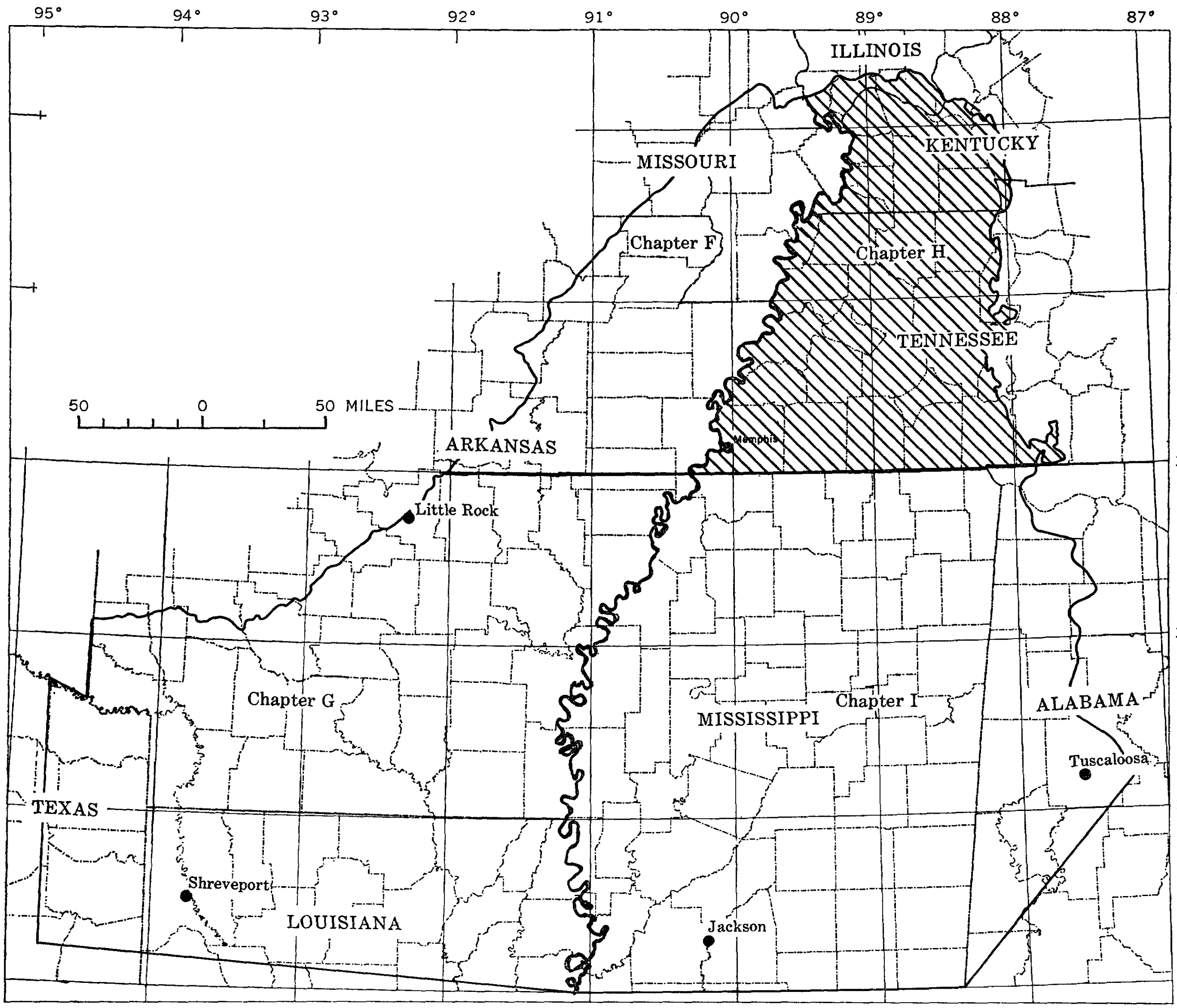

FIGURE 1.—The Mississippi embayment, showing areas covered by four chapters on low-flow characteristics of streams. The area covered by this chapter is shaded.

existence, the embayment has been submerged by the sea, and since the embayment last emerged the Mississippi River has followed close to the axis of the trough.

The Mississippi embayment can be divided into several large physiographic districts (fig. 2). From east to west in southern Tennessee, the features are similar to those found elsewhere in the East Gulf Coastal Plain. The Fall Line Hills, Black Belt, Pontotoc Ridge, Flatwoods, and North Central Plateau extend north from Mississippi into southern Tennessee, but they have been delimited only a few miles north of the Mississippi line. The demarcation of these belts (fig. 2) is only approximate.

The northern limit of the embayment is just north of the Cache River sag, which is an abandoned channel of the Ohio River in southern Illinois. The physiographic subdivisions that are recognized in southern Illinois are the coextensive alluvial plain of the Cache, Ohio, and Mississippi valleys and the Cretaceous hills between the Cache valley and the Ohio River (Leighton and others, 1948, p. 32). The elevations in this section range from about 300 feet above sea level near the Ohio River to about 660 feet in the uplands, and the average local relief is less than 100 feet.

Along the east side of the study area, the Cumberland and Tennessee Rivers have cut trenches through the Cretaceous sediments into the underlying pre-Cretaceous rocks. These pre-Cretaceous formations, the Paleozoic rocks, range in age from Mississippian to Ordovician. A few coastal-plain sediments are present on the east side of the Tennessee River.

Elevations in the southeast corner of the area exceed 1,000 feet, and the lowest elevation in the study area is about 200 feet in the Mississippi Alluvial Plain southwest of Memphis. The slope of the land surface is generally downward toward the west and northwest, but northwest of the Obion River the land rises again and forms a higher tract in the northwest corner of Tennessee and in southern Kentucky.

The valleys are filled with alluvium that forms flood plains as much as several miles wide, and in Kentucky there persist remnants of a higher flood plain, or second bottoms, not now subject to overflow. These second bottoms are separated from the present-day flood plains, or first bottoms, by a well-developed scarp, from 5 to 20 feet in height, along the larger streams (Davis, 1923).

The interstream areas are characterized by rolling to hilly uplands interspersed with relatively flat areas.

A distinctly different physical division, the Loess Hills, forms the western border of the North Central Plateau from the Ohio River southward. The Loess Hills are the result of an epoch of aggradation by wind. These hills are distinguished by the almost vertical bluffs left by erosion, and they overlie the steep slopes along the eastern side of the Mississippi Alluvial Plain. The Loess Hills rise to about 500 feet above sea level at the north end and decline in elevation toward the south.

A narrow strip of the Mississippi Alluvial Plain lies between the Loess Hills and the Mississippi River.

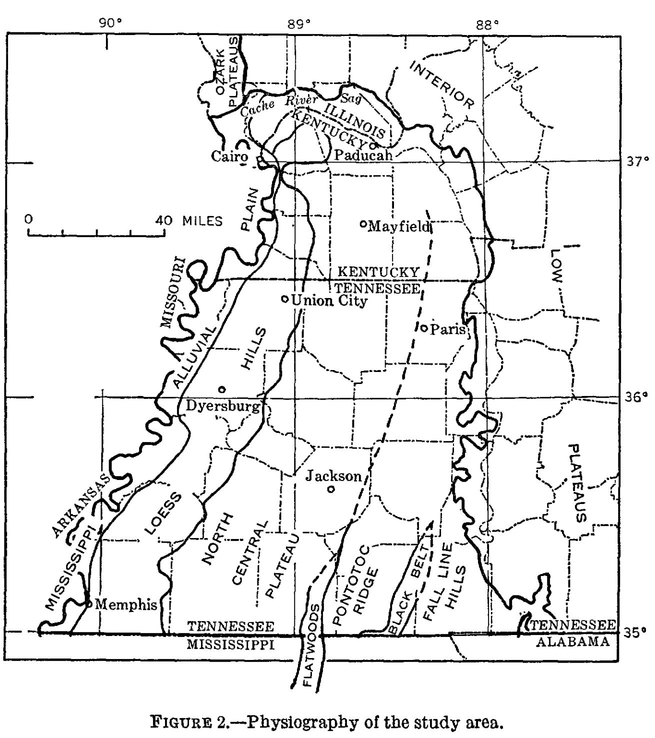

FIGURE 2.—Physiography of the study area.

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This belt is the result of aggradation by the Mississippi River and its tributaries. During the last stages of development of the Mississippi embayment, the Mississippi River cut a deep valley into the underlying rocks, mostly of Tertiary age; at that time the sea level was relatively much lower than it is at present. The general rise in sea level which followed the period of cutting was accompanied by aggradation of the valley which gradually assumed its present form. The alluvial plain is flat and follows the general slope of the Mississippi River. Various features, such as natural levees, oxbow lakes, abandoned meanders, and alluvial fans, occur in the plain. The Mississippi Alluvial Plain is divided into several basins; the St. Francis Basin includes all the alluvial plain north of Memphis, and the Yazoo Basin occupies a small area in Tennessee south of Memphis.

Crustal movement has played an important role in the northern end of the embayment and is mentioned here because of its possible influence over the years on the low-flow characteristics of streams in southern Illinois and western Kentucky as compared with those in western Tennessee and farther south. The area along the embayment trough above the mouth of the Arkansas River was subjected to extensive crustal movement in 1811–12 which was most intense around New Madrid, Mo. Early written records, geologic evidence, and Indian traditions are conclusive evidence that earth shocks have occurred earlier, and the 1811–12 occurrence was a continuation of the process (Fuller, 1912). The 1811–12 movement has been attributed to a subsidence of the embayment trough. Some land tracts rose while others sank to form channels and lakes. The most conspicuous remnant of the quake is Reelfoot Lake, which lies directly over a major fault in the basement rocks in the northwest corner of Tennessee.

GEOLOGY

The area in Tennessee, Kentucky, and Illinois covered by this report is a part of the Mississippi embayment and lies within the Gulf Coastal Plain. In the past the embayment was occupied periodically by the sea and has been filled gradually with sediments ranging in age from Jurassic to Quaternary. The thickness of these sediments ranges from zero at the edge of the embayment to several thousand feet near the axis at the southern end of the embayment. Within the area in Tennessee, Kentucky, and Illinois, units ranging in age from Cretaceous to Quaternary crop out (pl. 1). On the eastern end and northern periphery of the area, pre-Cretaceous rocks ranging in age from Ordovician to Mississippian crop out. Cushing, Boswell, and Hosman (1964) give a general description of the units of Cretaceous age and younger.

The major geologic units in the area of study are listed in table 1. The sand units contribute most of the water to the low flow of streams within the area. These units include the Tuscaloosa Formation, the Eutaw Formation, the Coffee Sand, the McNairy Sand Member of the Ripley Formation (the McNairy Sand in Kentucky and Illinois), the Wilcox Group, which includes the "1,400-foot" sand of the Memphis area, the Claiborne Group, which includes the "500-foot" sand of the Memphis area, the Pliocene(?) deposits, and the alluvium and terrace deposits.

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

ILLINOIS

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

KENTUCKY

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

TENNESSEE

- Quaternary System
  - Alluvium and terrace deposits
  - Loess
- Tertiary System
  - Eocene Series
    - Jackson(?) Formation
    - Claiborne Group undifferentiated
    - Wilcox Group undifferentiated
  - Paleocene Series
    - Midway Group
      - Porters Creek Clay
      - Clayton Formation

TENNESSEE—Continued

- Cretaceous System
  - Upper Cretaceous Series
    - Owl Creek Formation
    - Ripley Formation
      - McNairy Sand Member
      - Coon Creek Tongue
    - Demopolis Formation
    - Coffee Sand
    - Eutaw Formation
    - Tuscaloosa Formation
- Paleozoic rocks undifferentiated

MANMADE CHANGES

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

The earliest settlements were along the main rivers, which were the principal arteries of transportation. Accompanying the appreciable migration of new families into the area in the early 1800's, settlement spread out from the main rivers, and the forest cover was removed for homes, vegetable gardens, and, later, for farming. After the war years of 1861–65, increase in demand for cotton brought increases in cultivation. Rainfall on bare farmland during the winter months eroded soil from the fields and deposited it on flood plains and in stream channels. As the fertility of the hill land failed and fields became gullied, some of the uplands were permitted to return to forest, and agricultural encroachment on river flood plains began. In time, flood protection of these newly cleared fields on the flood plains was sought.

The Cache River Drainage District in Illinois and the first drainage districts in west Tennessee were formed in 1910. During the next 15 years many stream channels were dredged, many were straightened by relocation, and many levees were built. In Kentucky, ditching of bottom lands, clearing, and canalizing of stream channels became common practices. Much of this work was done prior to the start of collection of streamflow records.

The effects of most of the manmade changes on streamflow are difficult to evaluate quantitatively without collecting special data. Channel clearing is not a lasting change because of the regrowth of vegetation, and channel dredging is not a lasting change because of the redeposition of sediment in the channel or further degradation of the channel caused by the change in regime. Attempting to describe or define all the manmade changes that have affected the streamflow in the area is beyond the scope of this report, but some of the major changes made by man to the stream systems that may aid engineering interpretation of the low-flow characteristics are described briefly by river basins in the following paragraphs.

OHIO RIVER BASIN EXCEPT CUMBERLAND AND TENNESSEE RIVER BASINS

Parts of Humphrey and Massac Creek channels in Kentucky have been canalized.

Construction of navigation dams 52 and 53 on the Ohio River probably had no effect on low-flow characteristics of streams except those immediately adjacent to the Ohio River in the alluvial flood plain. Streamflow records are not available to evaluate these changes.

CACHE RIVER BASIN

Prior to 1910 the entire Cache River basin in Illinois drained into the Ohio River. During that year, construction of flood-control and diversion works was started by the Corps of Engineers. The Forman floodway, Post Creek cutoff (pl. 1), and channel work near Ullin, Ill., were completed in 1915. The Post Creek cutoff diverts water from the upper Cache valley directly to the Ohio River near the southeast corner of Pulaski County. The cutoff was further improved in 1925 to divert all the streamflow from the upper Cache watershed directly to the Ohio River, except that some floodwater spilled into the lower Cache valley when the stage exceeded elevation 334.1 feet. Further improvements to the Forman floodway and Post Creek cutoff, completed in 1951, provided a levee of sufficient height to divert all water from the upstream area directly to the Ohio River. Below this levee, most of the drainage to the lower Cache River is diverted to the Mississippi River through the Cache River diversion channel which was completed in 1950.

A small area, tributary to the lower Cache River downstream from the Cache River diversion, still drains into the Ohio River through the original Cache River mouth but is separated from the diversion channel by a levee across the old channel.

The flow of Cache River through the diversion channel is unregulated. A concrete control structure near the outlet into the Mississippi River regulates the stream gradient; however, the control does not restrict the floodflow of this stream.

The Bay Creek relief channel and levee constructed along the right bank of Bay Creek near Reevesville, Ill., prevent the Ohio River from flowing from the east, over the low natural divide in the Cache River sag, and into the Cache River basin. An earlier levee built by local interests at the Bay Creek divide provided little protection against Ohio River floods. The levee near Reevesville replaced this original levee and provides protection against Ohio River and Bay Creek floods 3 feet higher than the 1937 flood (maximum of record).

Big Creek near Wetaug, Ill., occupies a dredged channel. Levees have been built on both sides, and flow is confined to one channel.

TENNESSEE RIVER BASIN

Parts of Cypress Creek and West Fork Clarks River in Kentucky have been canalized.

Construction of Kentucky Dam on the Tennessee River, 22 miles upstream from the mouth, undoubtedly raised the ground-water level in the vicinity. There is a possibility that the base flow at the gaging station on the East Fork Clarks River near Benton, Ky. (3B6105), has been increased by this change.

BEECH RIVER BASIN

The Beech River channel, and channels of many of its tributaries in Henderson and Decatur Counties, Tenn., were dredged and straightened in the early 1920's. In 1944 a mosquito-control dam was built at Beech River adit into Kentucky Lake, and there is some small control of Beech River at this point.

The Beech River basin for several years has been a pilot watershed used by the Tennessee Valley Authority to study the effect of land use and treatment. In 1961 several sediment-detention ponds were recommended on tributaries in the watershed. TVA now has before Congress (1962) a plan for construction of multipurpose dams in the Beech River basin.

BIG SANDY RIVER BASIN

In 1918 the channel of the Big Sandy River was dredged and straightened from near Hollow Rock, Carroll County, Tenn., to the mouth. Tributaries, including West Sandy Creek, Holly Fork, and Bailey Fork, were dredged during 1918 and 1919. Later the dredging on the Big Sandy River was extended to the vicinity of Wildersville, Henderson County, Tenn. Impoundment of the water in Kentucky Lake in 1944 converted the lower 15 miles of Big Sandy River into a lake. West Sandy Creek was dammed below Holly Fork for mosquito control when Kentucky Lake was filled. There is, therefore, some degree of control of West Sandy Creek as it enters Kentucky Lake.

LOWER MISSISSIPPI RIVER BASIN

The Federal Flood Control Act of 1948 authorized channel work by the Corps of Engineers in the Obion and Forked Deer River basins in Tennessee. Some of this work has been completed and other work authorized (pl. 1) under this act is in progress (1962).

The small-watersheds program, authorized in 1954 by Public Law 566, was designed to produce beneficial agricultural effects in those watersheds that are included in the program. The Soil Conservation Service, U.S. Department of Agriculture, has thus far (1962) received 26 applications for planning assistance on small watersheds in West Tennessee. Operation has been authorized for 13 of these and the impoundments in 3 are complete or nearing completion. This program is discussed further under individual basins.

Parts of Mayfield Creek, West Fork Mayfield Creek, Obion Creek, and Bayou du Chien in Kentucky have been canalized.

OBION RIVER BASIN

Exclusive of the Forked Deer River, the Obion River system consists of the basins of the North, Middle, South, and Rutherford Forks, Reelfoot Lake drainage, and the main stem of the Obion River.

All the forks of Obion River and many tributaries were dredged and straightened during the period 1917–26. This work ended near the junction of the several forks and only two small ditches were dredged downstream from this point. These ditches were along the left flood plain of the Obion and extended downstream to near the mouth of Clover Creek.

Accumulation of drift in the channels of the forks of the Obion at the downstream end of the dredged channels caused backwater, slowed water velocities, and caused sedimentation in the channels of all the forks. By the middle 1930's, a lake covering several hundred acres had formed on the South Fork near Greenfield, Tenn., and by 1947, sedimentation from this ponding could be observed 20 miles upstream. About 1950, another such lake formed just upstream from U.S. Highway 79 northeast of Jarrell, Tenn. On the Middle Fork south of Dresden, Tenn., a similar lake was formed by drift about 1940. Although these lakes were not manmade, they were directly caused by activies of man.

Some channel dredging has been done at intervals since 1917 on Running Reelfoot Bayou and on Reelfoot Creek. The latest dredging of Running Reelfoot Bayou was completed in January 1959. Work on the channel of Reelfoot Creek in the past has been done on individual farms without coordination. Reelfoot Creek is now included in a small watershed project and channel work is planned for 1963.

Projects for areas ranging from 29 to 128 square miles have been proposed for eight small watersheds; four were authorized for operation as of October 1961.

The Forked Deer River, a tributary of the Obion River, has three principal forks—North, Middle, and South. All were dredged during the period 1917–26. Many tributaries were dredged during the same period, usually after the main-channel dredging. Drift racks have, over the years, caused the formation of several lakes on the forks. The more notable of these were on the South Fork near Fowlkes, Tenn., and on the North Fork immediately upstream from its junction with the Middle Fork.

Projects for areas ranging from 19 to 66 square miles have been proposed for five small watersheds in the Forked Deer River system; two have been authorized for operation (1962).

HATCHIE RIVER BASIN

The Hatchie River channel remains unchanged by man although his activities have made sediment and drift available for deposition in the channel. Many of the tributaries were dredged during 1917–26. Dredging on some tributary streams was extended across the Hatchie River flood plain. Without maintenance, the lower parts of the dredged ditches soon filled with sediment and recreated swamp conditions.

Projects for areas ranging from 12 to 126 square miles have been proposed for nine watersheds; five have been authorized for operation (1962).

LOOSAHATCHIE RIVER BASIN

The channel of the Loosahatchie River from Somerville, Tenn., to the Mississippi River backwater near Woodstock, Tenn., was dredged during 1922–23. Dredging upstream from Somerville was done later in the 1920's. Many tributary streams were dredged before and during the dredging of the river. These dredged ditches have deteriorated less than others in west Tennessee, and, in the upper reaches, they provide (1962) reasonably good drainage. At the lower end of the dredged reaches, however, the accumulation of drift has created lakes, and some remedial work was done in this section on two occasions between 1950 and 1962.

WOLF RIVER BASIN

The Wolf River has been affected only incidentally by the activities of man. Only short reaches of channel in the vicinity of road crossings have been dredged or changed. Some minor channel dredging and straightening has been done on a few of its tributaries.

Channel and drainage improvements have been authorized for Wolf River in Tennessee from Grays Creek, Shelby County (pl. 1), to the mouth.

Pilot watershed projects have been completed on Sand Creek and Marys Creek, and a project on Indian Creek is authorized for operation.

FARM-POND PROGRAM

The activities of the Civilian Conservation Corps in the 1930's introduced land-conservation measures and new farming practices. Building of farm ponds, terracing, contour plowing, tree planting, check damming, planting of winter cover crops, and rotation and balance of crops became familiar practices. More than 2,000 ponds are known to have been created in the study area.

LOW-FLOW CHARACTERISTICS

Streamflow data used in the study of the low-flow characteristics for this chapter include 32 continuous records of flow obtained at daily-record gaging stations, and limited streamflow data collected systematically over a period of years at 57 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. (See section on "Method of study" for discussion of the reference period.) Nine daily-record stations in the area have complete records for this selected reference period, and 13 others have 18 years or more of record during the reference period. Daily-record stations having less than 5 years of record during this period are used as partial-record stations in this report. Data extending through 1962 are used to define the low-flow characteristics at partial-record stations.

The average annual precipitation at Paducah, Ky., from 1882 to 1957 was 45.9 inches, and from 1929 to 1957 it was 46.8 inches. Thus, the average during the reference period was approximately equivalent to that since 1882. The within-the-year distribution of precipitation and many other factors, however, influence the quantity and rate of runoff, so that firm conclusions on the representativeness of streamflow patterns during the reference period cannot be drawn from the average precipitation alone.

The low-flow characteristics of all streams analyzed in the study are summarized in table 2. The stations are listed in downstream order by parts corresponding to those used by the U.S. Geological Survey (1953 b, c; 1954 a, b) in surface-water reports. The station number is the permanent nationwide number assigned to the station and is used for that station throughout this report. In assigning the numbers, no distinction is made between daily-record stations and partial-record stations. At several of the partial-record stations, three or more of the selected items of the data are zero; for these stations, additional flow data are given in footnotes. The last column of the table

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 cfs per sq mi) for indicated period of consecutive days and for indicated recurrence interval (in years)				Flow (in cfs per sq mi) which was equaled or exceeded for indicated percent of time		Daily-record station with which partial-record station is correlated
				7-day		30-day				
				2-yr	10-yr	2-yr	10-yr	90	95	
Part 3-A. Ohio River basin except Cumberland and Tennessee River basins										
	Bay Creek basin									
3A3850	Hayes Creek at Glendale, Ill	D	18.9	0.001	0	0.004	0.002	0.002	0.001	
	Massac Creek basin (Illinois)									
6112	Massac Creek at Metropolis, Ill	P	37.4	.002	0	.006	0	.004	.003	3A3850
	Massac Creek basin (Kentucky)									
6113	Massac Creek near Paducah, Ky	P	32.5	.003	.003	.006	.003	.004	.003	7-0230
	Cache River basin—Post Creek cutoff									
6120	Cache River at Forman, Ill	D	243	.003	0	.009	0	.006	.002	
	Humphrey Creek basin									
6130	Humphrey Creek near La Center, Ky	P	44.2	.002	.001	.005	.002	.004	.003	7-0230
	Hodges Bayou basin									
6135	Hodges Bayou tributary at Olmstead, Ill	P	4.67	0	0	.002	0	.001	0	3A3850

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

Station	Station name	Class of station	Drainage area (sq mi)	Annual low flow (in cfs per sq mi) for indicated period of consecutive days and for indicated recurrence interval (in years): 7-day, 2-yr	7-day, 10-yr	30-day, 2-yr	30-day, 10-yr	Flow (in cfs per sq mi) which was equaled or exceeded for indicated percent of time: 90	95	Daily-record station with which partial-record station is correlated
	Part 3-B. Cumberland and Tennessee River basins									
	Tennessee River basin									
3B5933	Snake Creek near Adamsville, Tenn	D	49.4	0.03	0.004	0.05	0.01	0.04	0.02	
5936	Horse Creek near Lowryville, Tenn	P	66.7	.30	.23	.34	.26	.36	.31	3B6040
5937	Holland Creek near Lowryville, Tenn	P	14.9	.30	.23	.34	.26	.36	.31	3B6040
5940	Horse Creek near Savannah, Tenn	D	104	.30	.23	.34	.26	.36	.31	
5940.4	Turkey Creek near Savannah, Tenn	P	53.7	.13	.07	.17	.09	.19	.14	3B6040
5941.2	Middleton Creek near Milledgeville, Tenn	D	45.5	.07	.02	.11	.04	.09	.06	
5941.4	Indian Creek near Martins Mills, Tenn	P	84.4	.13	.09	.15	.10	.15	.13	3B6040
5941.5	Weatherford Creek at Lutts, Tenn	P	25.8	.21	.07	.13	.09	.14	.11	3B6040
5941.6	Indian Creek near Cerro Gordo, Tenn	P	201	.13	.08	.17	.10	.18	.14	3B6040
5941.8	Hardin Creek at Clifton Junction, Tenn	P	50.7	.10	.07	.12	.09	.14	.12	3B6040
5942	Eagle Creek near Clifton Junction, Tenn	P	19.0	.008	.004	.01	.005	.01	.01	3B6040
5944.15	Beech River near Lexington, Tenn	D	15.9	.52	.43	.55	.45	.54	.50	
5944.3	Harmon Creek near Lexington, Tenn	D	6.87	.61	.42	.67	.48	.63	.57	
5944.45	Beech River near Chesterfield, Tenn	D	115	.28	.21	.33	.23	.31	.26	
5944.8	Turkey Creek near Decaturville, Tenn	D	8.40	.01	0	.02	0	.01	0	
6048	Birdsong Creek near Holladay, Tenn	D	44.9	.007	0	.02	0	.02	.007	
6065	Big Sandy River at Bruceton, Tenn	D	205	.22	.16	.25	.18	.24	.21	
6070	Big Sandy River at Big Sandy, Tenn	D	379	.17	.11	.20	.13	.19	.16	
6072	West Sandy Creek near Springville, Tenn	P	47.9	.31	.25	.33	.27	.33	.29	3B6065, 7-0245
6097	Cypress Swamp drainage ditch near Gilbertsville, Ky.[1]	P	27.6	0	0	0	0	0	0	3B6105
6098	East Fork Clarks River near Murray, Ky.[2]	P	45.6	0	0	0	0	0	0	3B6105, 7-0230
6100	East Fork Clarks River at Murray, Ky.[3]	P	89.7	0	0	0	0	0	0	3B6105, 7-0230
6105	East Fork Clarks River near Benton, Ky	D	227	.01	.01	.02	.01	.02	.02	
6106	West Fork Clarks River at Kaler, Ky	P	161	.05	.04	.06	.04	.06	.05	3B6105
	Part 5. Upper Mississippi River basin									
	Cache River basin—Cache River diversion channel									
5-6000	Big Creek near Wetaug, Ill	D	32.2	0.012	0.001	0.033	0.004	0.020	0.011	
6003	Boar Creek at Edith Chapel, Ill	P	11.7	.002	0	.008	0	.005	.003	3A6120
	Part 7. Lower Mississippi River basin									
	Mayfield Creek basin									
7-0225	Perry Creek near Mayfield, Ky.[4]	P	1.72	0	0	0	0	0	0	7-0230
227	Mayfield Creek at Mayfield, Ky.[5]	P	95.1	0	0	0	0	0	0	7-0230
230	Mayfield Creek at Lovelaceville, Ky	D	212	.05	.04	.06	.04	.05	.05	
231	West Fork Mayfield Creek near Bardwell, Ky	P	59.9	.01	.01	.01	.01	.01	.01	7-0230
	Obion Creek basin									
235	Obion Creek at Pryorsburg, Ky.[6]	P	36.8	0	0	0	0	0	0	7-0240
236	Obion Creek near Arlington, Ky	P	203	.02	.01	.03	.02	.04	.03	7-0240
	Bayou du Chien basin									
240	Bayou du Chien near Clinton, Ky	D	68.7	.11	.09	.13	.10	.15	.13	
	Obion River basin									
242	Crooked Creek near Huntingdon, Tenn	P	26.5	.30	.25	.33	.27	.32	.29	3B6065, 7-0245
242.5	Guins Creek near Huntingdon, Tenn	P	43.5	.16	.11	.19	.13	.18	.15	3B6065, 7-0245
243	Beaver Creek at Huntingdon, Tenn	P	55.5	.40	.32	.43	.38	.43	.40	3B6065, 7-0245
244	Reedy Creek near Trezevant, Tenn	P	57	.09	.06	.11	.07	.10	.09	3B6065, 7-0245
245	South Fork Obion River near Greenfield, Tenn	D	431	.22	.17	.24	.19	.23	.22	
247	Middle Fork Obion River near Como, Tenn	P	67.6	.40	.33	.43	.36	.41	.38	3B6065, 7-0245
249	Rutherford Fork Obion River near Milan, Tenn	P	107	.19	.15	.20	.17	.21	.19	7-0245, 7-0285
250	Rutherford Fork Obion River near Bradford, Tenn	D	203	.10	.07	.12	.09	.11	.10	
252	Mud Creek near Sidonia, Tenn	P	73.8	.02	.01	.02	.01	.02	.01	7-0245, 7-0255
253	North Fork Obion River at Jones Mill, Tenn	P	83.7	.32	.26	.35	.29	.33	.31	3B6065, 7-0255
253.5	Cypress Creek near Latham, Tenn	P	36.7	.005	.003	.008	.003	.008	.005	3B6065, 7-0255
255	North Fork Obion River near Union City, Tenn	D	480	.21	.18	.23	.19	.23	.21	
260	Obion River at Obion, Tenn	D	1,880	.17	.13	.19	.15	.19	.17	
260.3	Richland Creek near Obion, Tenn	P	17.7	.07	.07	.08	.07	.08	.07	7-0255, 7-0285
265	Reelfoot Creek near Samburg, Tenn [7]	D	110	.001	0	.001	0	0	0	
271	Pawpaw Creek at Push, Tenn	P	14.8	.02	.004	.03	.006	.02	.01	7-0255, 7-0290
273	Sonth Fork Forked Deer River near Henderson, Tenn	P	161	.22	.17	.25	.19	.25	.22	3B6065, 7-0275
274	Middle Fork Creek near Luray, Tenn	P	21.5	.56	.47	.60	.51	.60	.56	3B6065, 7-0275
275	South Fork Forked Deer River at Jackson, Tenn	D	574	.17	.13	.20	.15	.20	.17	
276	Johnson Creek near Jackson, Tenn	P	34	.02	.01	.03	.02	.03	.02	7-0275, 7-0290

See footnotes at end of table.

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

Station	Station name	Class of station	Drainage area (sq mi)	Annual low flow (in cfs per sq mi) for indicated period of consecutive days and for indicated recurrence interval (in years)				Flow (in cfs per sq mi) which was equaled or exceeded for indicated percent of time		Daily-record station with which partial-record station is correlated
				7-day		30-day				
				2-yr	10-yr	2-yr	10-yr	90	95	
	Part 7. Lower Mississippi River basin—Continued									
	Obion River Basin—Continued									
7-0277	Mud Creek near Bells, Tenn	P	27	0.01	0.007	0.01	0.007	0.01	0.01	7-0285, 7-0290
279	Black Creek near Chestnut Bluff, Tenn.[8]	P	26	0	0	.004	0	0	0	7-0290
280	South Fork Forked Deer River at Chestnut Bluff, Tenn	D	1,100	.16	.11	.18	.13	.18	.15	----------
285	North Fork Forked Deer River at Trenton, Tenn	D	73.4	.18	.15	.18	.16	.19	.18	----------
289	Middle Fork Forked Deer River near Spring Creek, Tenn	P	90	.08	.05	.11	.06	.10	.08	3B6065, 7-0290
290	Middle Fork Forked Deer River near Alamo, Tenn	D	410	.23	.19	.25	.20	.24	.22	----------
291	North Fork Forked Deer River at Dyersburg, Tenn	D	867	.13	.10	.15	.11	.14	.12	----------
	Cold Creek basin									
292	Cold Creek near Arp, Tenn	P	16.4	.04	.02	.06	.03	.05	.04	7-0290
	Hatchie River basin									
293.7	Cypress Creek at Selmer, Tenn	P	44	.30	.23	.32	.25	.32	.30	7-0275
293.9	Muddy Creek at Ramer, Tenn	P	48.3	.01	.004	.01	.006	.01	.008	7-0275, 7-0305
294	Hatchie River at Pocahontas, Tenn	D	837	.11	.06	.14	.08	.14	.11	----------
294.1	Mosses Creek near Pocahontas, Tenn	P	47.6	.29	.25	.34	.27	.34	.29	7-0275, 7-0305
294.4	Porters Creek near Middleton, Tenn	P	40.4	.05	.02	.07	.04	.07	.05	7-0275, 7-0305
294.8	Spring Creek at Bolivar, Tenn	P	121	.43	.39	.46	.38	.45	.41	7-0275, 7-0305
295	Hatchie River at Bolivar, Tenn	D	1,430	.13	.08	.16	.10	.16	.13	----------
297	Clover Creek at Cloverport, Tenn	P	86	.17	.13	.20	.15	.20	.16	7-0275
300	Hatchie River near Stanton, Tenn	D	1,940	.18	.13	.21	.15	.21	.18	----------
300.2	Big Muddy Creek near Stanton, Tenn	P	92.0	.10	.06	.12	.08	.11	.09	7-0275, 7-0290
300.3	Lagoon Creek near Orysa, Tenn	P	42	.002	.002	.005	.002	.005	.002	7-0290
301	Cane Creek at Ripley, Tenn	P	30	.01	.003	.02	.007	.02	.01	7-0290
301.4	Cane Creek near Cherry, Tenn	P	88	.001	0	.003	0	.002	.001	7-0290
	Loosahatchie River basin									
302	Loosahatchie River near Laconia, Tenn	P	26.2	.03	.02	.04	.02	.04	.03	7-0275
302.5	Beaver Creek near Arlington, Tenn	P	149	.001	0	.002	.001	.001	.001	7-0290, 7-0305
302.6	Cypress Creek near Eads, Tenn	P	36.2	0	0	0	0	0	0	7-0275
302.8	Loosahatchie River at Brunswick, Tenn	D	506	.15	.11	.17	.12	.15	.14	----------
303.5	Crooked Creek near Bolton, Tenn.[9]	P	17.3		0	0	0	0		----------
304	North Fork Wolf River near LaGrange, Tenn	P	71.8	.13	.09	.15	.11	.15	.13	7-0275, 7-0305
305	Wolf River at Rossville, Tenn	D	503	.30	.23	.33	.25	.32	.29	----------
317	Wolf River-Raleigh, Tenn	D	770	.25	.20	.28	.22	.28	.25	----------
	Nonconnah Creek basin									
322	Nonconnah Creek near Germantown, Tenn	P	70.8	.001	.001	.003	.001	.003	.001	7-0305

[1] 120-day Q_2=0.01 cfs per sq mi; flow equaled or exceeded 60 percent of time=0.03 cfs per sq mi.
[2] 120-day Q_2=0.03 cfs per sq mi; flow equaled or exceeded 60 percent of time=0.03 cfs per sq mi.
[3] 120-day Q_2=0.01 cfs per sq mi; flow equaled or exceeded 60 percent of time=0.02 cfs per sq mi.
[4] 120-day Q_2=0.03 cfs per sq mi; flow equaled or exceeded 60 percent of time=0.01 cfs per sq mi.
[5] 120-day Q_2=0.01 cfs per sq mi; flow equaled or exceeded 60 percent of time=0.01 cfs per sq mi.
[6] 120-day Q_2=0.02 cfs per sq mi; flow equaled or exceeded 60 perceut of time=0.007 cfs per sq mi.
[7] Flow equaled or exceeded 80 percent of time=0.2 cfs per sq mi.
[8] Flow equaled or exceeded 80 perceut of time=0.003 cfs per sq mi.
[9] Flow of this stream is negligible at base flow conditions.

enables the user of the data to develop the relation curve between the partial-record station and the daily-record station if he desires to interpolate additional data.

The low-flow data in table 2 are presented in cubic feet per second per square mile to facilitate comparison of flows of streams with different size drainage areas. It should not be inferred, however, that the yield is uniform throughout a drainage basin. To the contrary, the low-flow yields usually vary between tributary streams within a drainage basin and within reaches on a single stream.

The locations of the stations in table 2 are shown on plate 1. The station numbers shown on the plate are the same as those used in table 2.

LOW-FLOW FREQUENCY

Low-flow frequency data for 32 daily-record gaging stations are presented in table 3. Similar data for the partial-record stations have not been computed because of the limited basic information available at these sites. The data in table 3 can be plotted on graph paper similar to that used in figure 3*A* if a graphical presentation is desired. The data in table 3 can be used to estimate the probable future magnitude and

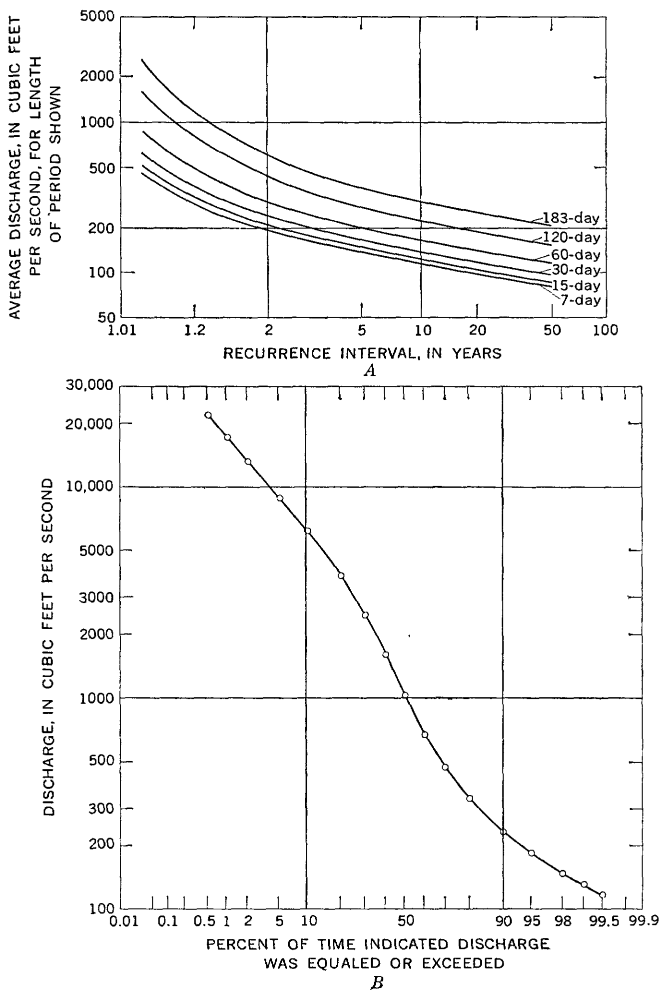

FIGURE 3.—Magnitude and frequency of annual low flow (*A*) and duration of daily flow (*B*) for Hatchie River at Bolivar, Tenn., 1929–57.

frequency of low flows at the indicated locations provided no appreciable climatological or manmade changes occur upstream. The probability of occurrence is given in terms of the average time interval between indicated low flows. For example, the lowest annual discharge for 7 consecutive days on the Hatchie River at Bolivar, Tenn. (7–0295), may be equal to or less than 114 cfs. (cubic feet per second) at average intervals of 10 years on a long-term basis. The chance of occurrence in any 1 year is 1 in 10, or 10 percent. These recurrence intervals are averages and do not imply any regularity of recurrence. During the period 1929–58, the 7-day minimum flow at Bolivar was less than 114 cfs (the 10-year event) in 1943 and 1956 and approached within 3 percent of the discharge in 1954. Thus, during the 30-year period, the 10-year event occurred or was approached three times; this recurrence is in close agreement with the probable frequency. The intervals between these occurrences, however, which are 11 and 2 years, demonstrate that there was not a regularity of recurrence.

FLOW DURATION

Flow-duration data for the 32 daily-record gaging stations are presented in table 4. As for the low-flow frequency data, no flow-duration data are shown for partial-record stations. The data in table 4 can be plotted on logarithmic-probability paper similar to that used in figure 3*B* if a graphical presentation is desired. The slope of the duration curve so plotted is a quantitative measure of variability of streamflow. The slopes of the flow-duration curves for the streams having large low-water yields are flatter than those for streams having small low-water yields. Thus, the flow-duration curves are excellent for comparing the flow characteristics.

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

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

Station	Station name	Drainage area (sq mi)	Period (consecutive days)	Annual low flow (in cfs) for indicated recurrence interval (in years)						
				1.03	1.2	2	5	10	20	50
Part 3-A. Ohio River basin except Cumberland and Tennessee River basins										
	Bay Creek basin									
3A3850	Hayes Creek at Glendale, Ill	18.8	7	0.37	0.10	0.017	0	0	0	0
			15	.57	.17	.033	.004	.001	----------	----------
			30	1.20	.38	.079	.012	.003	----------	----------
			60	3.65	1.22	.265	.043	.013	----------	----------
			120	13.5	4.30	.870	.130	.037	----------	----------
			183	28.5	9.80	2.17	.360	.110	----------	----------
	Cache River basin—Post Creek cutoff									
6120	Cache River at Forman, Ill	243	7	6.2	2.45	.66	.066	.015	.002	----------
			15	9.9	4.00	1.10	.165	.035	.006	----------
			30	18.5	7.50	2.15	.390	.100	.026	----------
			60	52.0	21.5	6.10	1.35	.620	.200	----------
			120	170	65.0	17.0	4.65	2.70	1.90	----------
			183	360	139	37.0	11.0	6.40	4.50	----------

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 cfs) for indicated recurrence interval (in years)						
				1.03	1.2	2	5	10	20	50
	Part 3-B. Cumberland and Tennessee River basins									
	Tennessee River basin									
3B5933	Snake Creek near Adamsville, Tenn	49.4	7	7.0	3.4	1.4	0.6	0.2	0	0
			15	9.2	4.2	1.8	.8	.4	.1	0
			30	11	5.4	2.3	1.1	.6	.2	.1
			60	19	8.2	3.2	1.7	1.0	.6	.2
			120	40	20	7.0	3.3	2.2	1.5	.8
			183	54	29	12	6.0	4.0	2.8	1.7
5940	Horse Creek near Savannah, Tenn	104	7	49	39	31	27	24	21	19
			15	52	42	33	28	25	23	20
			30	56	45	35	30	27	24	21
			60	72	50	38	33	30	27	24
			120	104	69	48	40	36	32	27
			183	131	87	58	47	42	37	32
5941.2	Middleton Creek near Milledgeville, Tenn	45.5	7	12	6.8	3.4	1.6	.7	.1	0
			15	15	8.1	4.2	2.0	1.1	.4	0
			30	17	9.6	4.9	2.6	1.6	.7	0
			60	26	13	6.3	3.8	2.7	1.7	.7
			120	42	23	11	6.4	4.6	3.3	1.8
			183	55	32	17	10	7.2	5.1	3.3
5944.15	Beech River near Lexington, Tenn	15.9	7	11	9.4	8.2	7.2	6.8	6.4	6.0
			15	12	9.8	8.4	7.4	7.0	6.6	6.2
			30	12	10	8.8	7.7	7.2	6.8	6.3
			60	15	11	9.3	8.2	7.8	7.4	6.8
			120	18	15	11	9.2	8.6	8.0	7.4
			183	22	16	12	10	9.4	8.7	8.1
5944.3	Harmon Creek near Lexington, Tenn	6.87	7	6.2	5.2	4.2	3.4	2.9	2.5	2.1
			15	6.7	5.4	4.4	3.6	3.1	2.7	2.2
			30	7.1	5.7	4.6	3.8	3.3	3.0	2.6
			60	8.3	6.4	5.0	4.2	3.7	3.4	2.9
			120	10	8.0	6.1	4.9	4.3	3.9	3.5
			183	12	9.1	7.0	5.6	5.0	4.6	4.2
5944.45	Beech River near Chesterfield, Tenn	115	7	73	48	32	26	24	22	20
			15	84	54	35	28	25	23	21
			30	93	62	38	29	26	24	22
			60	120	77	46	34	30	27	24
			120	158	112	68	46	37	32	27
			183	190	136	93	64	51	41	32
5944.8	Turkey Creek near Decaturville, Tenn	8.40	7	1.3	.3	.1	0	0	0	0
			15	2.0	.5	.1	0	0	0	0
			30	2.7	.8	.2	0	0	0	0
			60	4.9	1.5	.3	.1	0	0	0
			120	8.6	3.6	1.0	.2	.1	0	0
			183	12	6.0	2.2	.6	.3	.1	.1
6048	Birdsong Creek near Holladay, Tenn	44.9	7	4.7	1.6	.3	0	0	0	0
			15	6.4	2.2	.5	0	0	0	0
			30	8.4	3.0	.8	.1	0	0	0
			60	16	5.2	1.4	.4	.1	0	0
			120	36	14	4.0	1.4	.7	.2	0
			183	54	23	8.1	3.4	1.8	.8	.2
6065	Big Sandy River at Bruceton, Tenn	205	7	88	62	46	36	32	29	25
			15	102	69	50	38	34	31	26
			30	116	75	52	40	36	32	28
			60	155	92	60	46	41	36	32
			120	222	134	80	57	49	43	37
			183	297	174	106	72	58	50	44
6070	Big Sandy River at Big Sandy, Tenn	379	7	142	93	63	49	43	38	33
			15	166	106	68	52	46	41	35
			30	186	121	76	56	49	43	37
			60	257	153	94	64	56	49	42
			120	354	214	127	82	69	60	51
			183	492	290	169	110	88	75	63
6105	East Fork Clarks River near Benton, Ky	227	7	13	5.8	3.2	2.4	2.2	2.0	1.8
			15	17	7.6	3.8	2.8	2.4	2.1	1.9
			30	26	11	4.5	3.2	2.6	2.3	2.0
			60	49	18	6.3	3.7	3.0	2.6	2.3
			120	119	43	14	5.9	4.3	3.5	2.9
			183	228	89	29	10	6.6	5.0	3.8
	Part 5. Upper Mississippi River basin									
	Cache River basin—Cache River diversion channel									
5-6000	Big Creek near Wetaug, Ill	32.2	7	1.30	0.80	0.40	0.11	0.030	0.007	--------
			15	2.20	1.33	.66	.19	.060	.018	--------
			30	4.25	2.40	1.05	.34	.120	.042	--------
			60	9.20	4.90	2.10	.75	.380	.200	--------
			120	23.0	11.2	4.10	1.85	1.45	1.20	--------
			183	42.0	20.0	6.90	2.85	2.15	1.80	--------

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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 cfs) for indicated recurrence interval (in years)						
				1.03	1.2	2	5	10	20	50
	Part 7. Lower Mississippi River basin									
	Mayfield Creek basin									
7-0230	Mayfield Creek at Lovelaceville, Ky.	212	7	19	13	9.7	8.3	7.7	7.2	6.8
			15	22	15	10	8.7	7.9	7.5	7.0
			30	30	18	12	9.2	8.4	7.8	7.2
			60	48	24	14	10	9.2	8.5	7.8
			120	101	45	21	14	11	9.9	8.8
			183	182	80	32	18	14	12	10
	Bayou du Chien basin									
240	Bayou du Chieu near Clinton, Ky.	68.7	7	13	10	7.8	6.8	6.3	6.0	5.6
			15	16	11	8.3	7.1	6.6	6.3	5.8
			30	20	13	9.0	7.4	7.0	6.6	6.1
			60	30	17	10	8.1	7.6	7.1	6.6
			120	54	27	14	10	9.0	8.3	7.4
			183	90	42	21	14	11	9.7	8.5
	Obion River basin									
245	South Fork Obion River near Greenfield, Tenn.	431	7	155	116	94	82	75	70	64
			15	174	125	98	85	79	73	68
			30	196	136	104	90	82	77	70
			60	258	165	114	94	88	82	75
			120	340	206	137	109	100	93	85
			183	495	295	171	127	115	107	97
250	Rutherford Fork Obion River near Bradford, Tenn.	203	7	46	30	21	17	15	14	12
			15	56	32	24	19	17	15	13
			30	68	38	25	20	18	16	14
			60	114	53	29	23	21	19	17
			120	172	84	42	29	25	23	21
			183	256	128	60	36	31	28	25
255	North Fork Obion River near Union City, Tenn.	480	7	152	121	101	92	88	84	80
			15	166	130	105	95	90	86	82
			30	190	141	111	98	93	89	84
			60	245	162	120	105	99	94	90
			120	405	236	147	120	111	105	98
			183	695	352	190	137	124	116	108
260	Obion River at Obion, Tenn.	1,880	7	504	402	324	275	252	235	219
			15	578	440	348	290	259	242	229
			30	736	480	365	308	275	256	239
			60	1,030	600	404	336	308	281	260
			120	1,690	878	512	400	366	340	313
			183	2,840	1,300	658	468	420	390	362
265	Reelfoot Creek near Samburg, Tenn.	110	7	7.3	.4	.1	0	0	0	0
			15	10	1.2	.1	0	0	0	0
			30	16	3.9	.1	0	0	0	0
			60	32	9.4	.4	.1	0	0	0
			120	88	30	6.1	.4	.1	0	0
			183	158	73	16	2.4	.5	.2	.1
275	South Fork Forked Deer River at Jackson, Tenn.	574	7	186	128	98	83	76	70	63
			15	222	140	104	89	78	73	66
			30	260	162	114	93	84	78	69
			60	379	222	134	105	94	87	79
			120	656	347	199	133	114	103	91
			183	800	466	260	170	140	121	105
280	South Fork Forked Deer River at Chestnut Bluff, Tenn.	1,100	7	344	248	171	138	126	116	108
			15	385	260	180	144	131	122	112
			30	467	300	195	158	142	132	120
			60	660	386	235	178	161	148	133
			120	1,020	557	331	230	197	180	162
			183	1,340	780	434	290	246	218	191
285	North Fork Forked Deer River at Trenton, Tenn.	73.4	7	19	14	13	12	11	11	11
			15	25	15	13	12	12	11	11
			30	35	16	13	12	12	11	11
			60	52	22	14	13	12	12	11
			120	72	46	17	14	13	13	12
			183	100	60	30	16	14	13	13
290	Middle Fork Forked Deer River near Alamo, Tenn.	410	7	151	114	93	82	76	71	67
			15	172	124	98	85	78	74	70
			30	199	136	104	90	83	78	73
			60	254	168	113	96	89	83	77
			120	350	232	145	113	103	96	92
			183	496	310	188	133	118	109	100
291	North Fork Forked Deer River at Dyersburg, Tenn.	867	7	228	152	111	94	86	79	72
			15	270	171	120	98	88	82	76
			30	338	198	132	106	96	88	80
			60	485	260	150	118	106	97	88
			120	792	446	215	150	131	118	108
			183	1,300	685	324	190	158	141	124
	Hatchie River basin									
294	Hatchie River at Pocahontas, Tenn.	837	7	230	139	90	66	54	46	37
			15	262	157	99	71	58	49	40
			30	326	186	113	79	66	56	45
			60	468	250	143	96	80	67	54
			120	885	414	214	134	108	90	73
			183	1,450	630	303	181	147	124	100

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 cfs) for indicated recurrence interval (in years) 1.03	1.2	2	5	10	20	50
	Part 7. Lower Mississippi River basin—Continued									
	Hatchie River basin—Continued									
7-0295	Hatchie River at Bolivar, Tenn	1,430	7	447	278	184	135	114	98	80
			15	506	311	201	145	123	105	85
			30	621	366	228	163	138	118	96
			60	878	483	285	195	165	141	114
			120	1,590	782	417	267	219	187	152
			183	2,600	1,160	580	359	293	250	203
300	Hatchie River near Stanton, Tenn	1,940	7	676	471	340	285	255	232	210
			15	738	515	365	294	268	245	218
			30	856	581	402	316	286	262	232
			60	1,220	712	466	354	320	290	255
			120	1,880	1,060	642	455	394	347	300
			183	2,460	1,570	862	580	500	435	365
	Loosahatchie River basin									
302.8	Loosahatchie River at Brunswick, Tenn	506	7	122	96	74	62	54	48	41
			15	137	104	79	65	57	51	44
			30	160	112	84	69	61	54	47
			60	232	137	108	90	82	75	66
			120	380	240	130	106	97	89	79
			183	525	385	190	127	112	103	92
	Wolf River basin									
305	Wolf River at Rossville, Tenn	503	7	220	182	149	128	116	107	95
			15	238	194	156	134	122	112	100
			30	253	206	165	140	128	118	105
			60	292	231	179	151	137	126	113
			120	381	296	219	177	162	149	133
			183	520	385	270	207	188	173	154
317	Wolf River—Raleigh, Tenn	770	7	294	240	195	170	152	140	124
			15	318	249	202	176	160	146	130
			30	352	270	216	187	169	155	138
			60	454	310	232	200	182	168	150
			120	660	428	286	230	210	194	177
			183	894	615	364	270	242	224	202

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

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

Station	Station name	Drainage area (sq mi)	Flow (in cfs) 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 3-A. Ohio River basin except Cumberland and Tennessee River basins																		
	Bay Creek basin																		
3A3850	Hayes Creek at Glendale, Ill.	18.9	0	0	0.003	0.013	0.043	0.189	0.567	1.42	2.93	5.29	10.0	18.9	47.2	117	283	425	605
	Cache River basin—Post Creek cutoff																		
6120	Cache River at Forman, Ill.	243	0	.039	.136	.486	1.41	4.74	11.9	25.5	49.8	97.2	207	437	875	1,460	2,380	3,280	4,370
	Part 3-B. Cumberland and Tennessee River basins																		
	Tennessee River basin																		
3B5933	Snake Creek near Adamsville, Tenn.	49.4	0	0.4	0.7	1.2	1.9	3.6	5.8	9.2	14	22	36	68	153	300	625	1,000	1,530
5940	Horse Creek near Savannah, Tenn.	104	25	27	29	33	37	45	53	63	77	100	136	201	354	579	1,040	1,540	2,230
5941.2	Middleton Creek near Milledgeville, Tenn.	45.5	.8	1.4	2.0	2.9	4.3	7.0	10	14	19	28	41	65	132	264	596	940	1,580
5944.15	Beech River near Lexington, Tenn.	15.9	7.1	7.3	7.6	8.0	8.6	9.6	11	12	14	16	18	24	47	93	192	310	460
5944.3	Harmon Creek near Lexington, Tenn.	6.87	3.0	3.2	3.5	3.9	4.3	5.0	5.7	6.4	7.2	8.2	9.7	12	20	35	73	125	210
5944.45	Beech River near Chesterfield, Tenn.	115	24	26	27	30	36	50	66	80	96	116	144	203	408	762	1,210	1,670	2,740
5944.8	Turkey Creek near Decaturville, Tenn.	8.40	0	0	0	0	.1	.3	.7	1.5	2.7	4.4	6.6	11	27	50	92	205	485
6048	Birdsong Creek near Holladay, Tenn.	44.9	0	0	0	.3	.8	2.4	4.8	8.5	14	24	39	60	111	230	580	980	1,520
6065	Big Sandy River at Bruceton, Tenn.	205	34	36	38	43	49	62	76	93	116	147	194	298	710	1,220	1,900	2,760	4,100
6070	Big Sandy River at Big Sandy, Tenn.	379	44	46	50	60	71	94	121	156	200	262	347	558	1,310	2,070	3,060	4,280	6,170
6105	East Fork Clarks River near Benton, Ky.	227	2.6	2.8	3.0	3.6	4.6	7.0	11	19	32	56	99	185	564	1,360	2,880	4,850	7,280
	Part 5. Upper Mississippi River basin																		
	Cache River basin—Cache River diversion channel																		
5-6000	Big Creek near Wetaug, Ill.	32.2	0.033	0.050	0.072	0.131	0.234	0.480	0.819	1.31	2.05	3.22	5.15	9.13	19.7	46.8	129	222	345

	Mayfield Creek basin																		
7-0230	Mayfield Creek at Lovelaceville, Ky.	212	7.8	8.4	8.8	10	11	14	16	20	26	39	65	118	405	1,200	2,990	4,200	5,500
	Bayou du Chien basin																		
240	Bayou du Chien near Clinton, Ky.	68.7	6.8	7.5	8.0	9.2	10	11	12	14	17	22	30	53	166	412	1,020	1,440	1,880
	Obion River basin																		
245	South Fork Obion River near Greenfield, Tenn.	431	76	80	85	93	101	118	134	154	191	245	344	670	1,530	2,380	3,760	5,190	7,180
250	Rutherford Fork Obion River near Bradford, Tenn.	203	15	16	18	20	23	28	34	42	54	72	108	200	530	1,190	2,400	3,310	4,260
255	North Fork Obion River near Union City, Tenn.	480	91	94	97	103	111	126	139	156	181	225	304	512	1,510	2,950	5,250	7,200	9,300
260	Obion River at Obion, Tenn.	1,880	250	264	281	316	352	411	498	636	819	1,300	2,020	2,930	5,170	10,400	16,500	21,000	27,200
265	Reelfoot Creek near Samburg, Tenn.	110	0	0	0	0	0	.2	1.0	2.6	5.5	12	26	55	242	670	1,300	1,880	2,530
275	South Fork Forked Deer River at Jackson, Tenn.	574	76	81	87	97	114	142	178	220	278	374	520	850	2,040	3,350	4,790	6,080	8,300
280	South Fork Forked Deer River at Chestnut Bluff, Tenn.	1,100	127	135	147	168	196	246	300	371	493	702	1,190	2,100	3,980	5,540	8,100	10,800	14,600
285	North Fork Forked Deer River at Trenton, Tenn.	73.4	12	13	13	13	14	15	17	19	22	28	39	64	224	561	1,160	1,830	2,620
290	Middle Fork Forked Deer River near Alamo, Tenn.	410	76	79	82	90	99	114	130	146	171	212	286	502	1,340	2,480	4,790	5,920	7,190
291	North Fork Forked Deer River at Dyersburg, Tenn.	867	92	96	100	108	120	150	198	270	405	650	1,040	1,800	3,500	5,600	8,750	11,600	14,300
	Hatchie River basin																		
293.8	Cypress Creek—Ramer, Tenn.[1]	94.7	7.3	8.0	9.2	12	16	25	37	51	69	96	136	203	330	660	1,220	1,600	2,000
294	Hatchie River at Pocahontas, Tenn.	837	59	65	74	93	117	160	226	325	514	788	1,250	2,030	3,430	5,480	8,450	9,950	12,700
295	Hatchie River at Bolivar, Tenn.	1,430	118	130	148	184	233	334	470	670	1,030	1,600	2,460	3,780	6,190	8,800	13,100	17,000	21,800
300	Hatchie River near Stanton, Tenn.	1,940	263	274	299	346	412	557	738	982	1,440	2,120	3,060	4,400	7,280	10,400	14,600	18,500	27,600
	Loosahatchie River basin																		
302.8	Loosahatchie River at Brunswick, Tenn.	506	51	56	62	70	78	91	103	119	138	170	234	420	1,580	3,900	7,450	10,400	14,000
	Wolf River basin																		
305	Wolf River at Rossville, Tenn.	503	117	122	130	144	160	187	213	244	292	365	483	720	1,430	2,500	4,550	6,700	9,500
317	Wolf River—Raleigh, Tenn.	770	151	160	172	192	213	244	283	341	417	541	752	1,430	2,640	4,000	6,900	10,100	14,200

[1] Data are for periods 1941–58.

If it is assumed that no manmade or unusual climatological changes will occur, the adjusted data in table 4 may be used to predict the long-term distribution of future flows.

Duration data for any particular year can deviate from the adjusted data. For example, during 1943, a year of extremely low flow, the daily discharge for Hatchie River at Bolivar, Tenn. (7–0295), equaled or exceeded 100 cfs only 60 percent of the time, whereas during the reference period, the daily discharge equaled or exceeded 100 cfs more than 99.5 percent of the time. Thus, the flow-duration data in table 4 may be used in the preliminary planning of water projects, but detailed studies would require further analysis and use of the low-flow frequency data shown in table 3.

FACTORS AFFECTING LOW FLOW

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

The ability of geologic units to take water into storage depends on the lithology of the units, and movement of water through the units depends on the hydrologic character of the units and on the hydraulic gradient. The composition and configuration of geologic formations, as well as the topography, the vegetation, and the physical characteristics of the land surface, also influence the storage and discharge of ground water. The principal factors influencing the base flow of streams are: (1) the permeability and porosity of the geologic units, (2) the relation of the water surface in the streams to the elevation of the water table and to the base of the aquifers, (3) the slope of the water table, and (4) the rate of evapotranspiration.

The wide difference in the low-flow yields of the streams in the embayment in Tennessee, Kentucky, and Illinois may be attributed partly to the hydrologic properties of the geologic units and partly to the relation of the water table to the water surface in the streams.

Differences in hydrologic properties exist even within the same geologic unit. The McNairy Sand, for example, is not lithologically uniform but consists of interbedded sand and clay in varying proportions. These proportions, and the distribution of permeable beds within a geologic unit, determine its ability to transmit, store, and yield water.

Uncontrolled flowing artesian wells are found in limited numbers in the study area, usually on or near the flood plains of streams. Although these wells contribute to the streamflow, their effect on the flow is generally small.

A low ridge crosses the area north of the Obion River near the Tennessee-Kentucky line. This ridge trends in a southwest-northeast direction across Obion County, Tenn., almost to the Kentucky line, and near the Kentucky line it trends in a west-east direction across the embayment. The streams north of this ridge, except Bayou du Chien, show fairly low indices of low flow, whereas immediately south of the ridge, the streams in both the Tennessee and lower Mississippi River drainage basins have generally very high indices of low flow. These marked differences are probably due to one or both of the following factors: (1) A fault in the basement rocks in Lake and Obion Counties, Tenn., just northwest of the ridge, and other displacements may have affected the movement of ground water in the area; (2) much of the ground water in the higher land north of the ridge in Kentucky may be draining as underground flow southward across the surface divide and into the streams in Tennessee.

In Kentucky, the relation of the water table to the water surface in the stream is probably of primary importance to the low-flow characteristics. The headwaters of most streams in the Mississippi embayment in Kentucky lie above the elevation of the water table. At some downstream point the channels intersect the water table in the Paleozoic, Cretaceous, and Eocene deposits, and downstream from the point of intersection the streams are perennial. In some places, however, the low yield is due in part to water moving out of the basin as underflow. Gravel in the Pliocene(?) deposits, which overlie the Eocene and older units in places, yields significant amounts of water only in those areas where the gravel is underlain by impermeable clay. In areas where the Pliocene(?) is underlain by sandy deposits, the water drains rapidly out of the gravel into the underlying formations.

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

In Kentucky, the streams along the eastern margin of the Mississippi embayment receive their base flow from the Cretaceous formations and Pliocene(?) deposits, and the streams to the west receive their base flow from the Eocene deposits. The median annual 7-day low flows for these streams (pl. 1) range from

0 to 0.11 cfs per sq mi (cubic feet per second per square mile). Except for the East Fork Clarks River near Benton (3B6105), the streams that show more than zero flow receive ground water from the Eocene formations downstream from the point where the water table intersects the streambed.

OHIO RIVER BASIN EXCEPT CUMBERLAND AND TENNESSEE RIVER BASINS

Six streamflow stations north of the Ohio River in southern Illinois are included in the embayment studies. The entire drainage basins of three of these stations, Hayes Creek at Glendale (3A3850), Cache River at Forman (3A6120), and Big Creek at Wetaug (5-6000), are outside the embayment, and the other three, Massac Creek at Metropolis (3A6112), Hodges Bayou tributary at Olmstead (3A6135), and Boar Creek at Edith Chapel (5-6003), drain areas within the embayment. All these six stations have low-flow indices of 0.012 cfs per sq mi or less. These low yields are probably due to the fact that the uplands of southern Illinois are mantled by a relatively impervious brown loess of Quaternary age.

In Kentucky, Massac Creek near Paducah (3A6113) and Humphrey Creek near La Center (3A6130), which also have low indices of base flow, probably receive their base flow from aquifers in the Claiborne Group.

TENNESSEE RIVER BASIN

In the area east of the Tennessee River in Tennessee near the southeastern corner of the report area, gravel deep in the streambeds, particularly in the lower reaches of the streams, permits underflow in the valley. Inasmuch as the streamflow measurements do not include this underflow, the low-flow index does not represent all the down-valley flow and is therefore not a good index for the water-supply potential of the contributing aquifers in this area.

Horse Creek in Hardin County, Tenn., and its tributaries, Holland and Turkey Creeks, are incised through the Eutaw and Tuscaloosa Formations into Paleozoic rocks. The low-flow index of 0.30 cfs per sq mi for both Horse Creek near Savannah (3B5940) and Holland Creek near Lowryville (3B5937) is probably indicative of the base-flow potential of these formations. The lower index (0.13 cfs per sq mi) of Turkey Creek near Savannah (3B5940.4) may be due to subsurface flow below the stream channel. This hypothesis and the low-flow index of 0.30 cfs per sq mi for the Eutaw and Tuscaloosa Formations indicate that the subsurface flow of Turkey Creek at the gaging station could be as much as 8.5 cfs.

On the basis of a general estimate of ground-water contributions from the various formations in the Indian Creek basin, subsurface flow is indicated at the gaging station near Cerro Gordo, Tenn. Near Martins Mills, Tenn. (3B5941.4), the low-flow index is 0.13 cfs per sq mi, and downstream near Cerro Gordo, Tenn. (3B5941.6), the low-flow index is the same even though an intervening tributary, Smith Fork, flowing from the Eutaw and Tuscaloosa Formations, drains 10 percent of the basin above that point and should thus result in a higher index downstream.

Snake Creek, which lies west of the Tennessee River in McNairy County, flows southeastward from the basin divide near Leapwood, Tenn., through clay outcrops of the Demopolis Formation and the Coon Creek Tongue of the Ripley Formation. Its low index, 0.03 cfs per sq mi, near Adamsville, Tenn. (3B5933), is caused by the low yield of ground water from these clays. Middleton Creek, slightly to the north, flows through the same formations, but more of its drainage area is in the McNairy Sand Member of the Ripley Formation; its low-flow index, 0.07 cfs per sq mi, near Milledgeville, Tenn. (3B5941.2), is therefore slightly greater than that for Snake Creek.

The Beech River in Henderson County, Tenn., is in the McNairy Sand Member of the Ripley Formation from its source to Piney Creek. Beech River near Lexington, Tenn. (3B5944.15), and Harmon Creek near Lexington, Tenn. (3B5944.3), have two of the highest low-flow indices (0.52 and 0.61 cfs per sq mi, respectively) of any streams in the study area. Near Chesterfield, Tenn. (3B5944.45), after the Beech River has traversed several miles of the clay of the Coon Creek Tongue of the Ripley Formation, the low-flow index is 0.28 cfs per sq mi, which indicates a low-flow yield of about 0.2 cfs per sq mi from the intervening area.

Turkey Creek near Decaturville, Tenn. (3B5944.8), lies in the Coffee Sand, the Eutaw Formation, and Paleozoic rocks. Birdsong Creek near Holladay, Tenn. (3B6048), is in the Coon Creek Tongue, Coffee Sand, and Paleozoic rocks. The creeks at these points are poorly sustained, their low-flow indices being 0.01 and 0.007 cfs per sq mi, respectively.

The Big Sandy River heads in the McNairy Sand Member of the Ripley Formation and flows through it for about 30 miles to the Carroll-Benton County line. At Bruceton, Tenn. (3B6065), its low-flow index (0.22 cfs per sq mi) is the same as that for South Fork Forked Deer River near Henderson, Tenn. (7-0273), 30 miles to the south, which also receives its base flow from the McNairy Sand Member. At Big Sandy, Tenn. (3B6070), the low-flow index of the Big Sandy River drops to 0.17 cfs per sq mi because very little ground water is contributed by the Paleozoic rocks and by the Coon Creek Tongue along the eastern side of the lower reaches of the creek. West Sandy Creek flows for the most part through the McNairy Sand Member, although it originates in the eastern edge of sands of the Claiborne Group and its headwaters lie in the Porters Creek Clay. The flow index of 0.31 cfs per sq mi for West Sandy Creek near Springville, Tenn. (3B6072), compares well with that of other streams receiving their base flow from the McNairy Sand Member.

The McNairy Sand discharges water into the East Fork Clarks River and into the alluvium from near Almo, Ky., northward. Some of this water probably moves down the valley as underflow in the alluvium, but during dry weather most of it is probably lost through evapotranspiration. The base flow of East Fork Clarks River near Benton, Ky. (3B6105), may have been increased by the filling of Kentucky Lake in 1944–45, but available data are not conclusive.

Cypress Swamp receives ground water from the McNairy Sand. Much of the base flow in Cypress Swamp drainage ditch near Gilbertsville, Ky. (3B6097), is lost through evapotranspiration.

LOWER MISSISSIPPI RIVER BASIN

Streams in Kentucky which drain to the Mississippi River below the mouth of the Ohio River have low-flow indices of 0.01 to 0.05 cfs per sq mi except Bayou du Chien near Clinton (7–0240), which has an index of 0.11 cfs per sq mi, the highest index north of the ridge near the Tennessee-Kentucky line (p.H18). These streams receive their base flow from aquifers in the Claiborne Group.

The low-flow indices of streams which form the headwaters of the Obion River and its South Fork give a very good comparison of the relative ground-water yields of the McNairy Sand Member of the Ripley Formation, the "500-foot" sand (basal unit in the Claiborne Group), and the Porters Creek Clay of the Midway Group. Almost the entire basin above Beaver Creek at Huntingdon, Tenn. (7–0243), low-flow index 0.40 cfs per sq mi, lies in the McNairy Sand Member. Crooked Creek near Huntingdon, Tenn. (7–0242), low-flow index 0.30 cfs per sq mi, is mostly in the McNairy Sand Member. Guins Creek near Huntingdon, Tenn. (7–0242.5), low-flow index 0.16 cfs per sq mi, is partly in the "500-foot" sand, but the channel is almost completely shielded by Porters Creek Clay.

The South Fork Obion River, formed by the confluence of Beaver and Crooked Creeks, flows 10 miles through the "500-foot" sand and then almost an equal distance through clay and sand units in the upper part of the Claiborne Group. Near Greenfield, Tenn. (7–0245), the South Fork has a low-flow index of 0.22 cfs per sq mi. The North Fork Obion River near Union City, Tenn. (7–0255), and Middle Fork Forked Deer River near Alamo, Tenn. (7–0290), 40 miles to the south, have almost identical geologic settings and have low-flow indices of 0.21 and 0.23 cfs per sq mi, respectively.

The North Fork Obion River at Jones Mill, Tenn. (7–0253), low-flow index 0.32 cfs per sq mi, is a representative stream of the "500-foot" sand in the Claiborne Group. About 100 miles southwest of this station, a considerable part of Wolf River basin above Rossville, Tenn. (7–0305), low-flow index 0.30 cfs per sq mi, and all the drainage of Spring Creek at Bolivar, Tenn. (7–0294.8), low-flow index 0.43 cfs per sq mi, are also in the "500-foot" sand. The fact that Spring Creek parallels the strike of the "500-foot" sand and probably has a greater interception area may explain its higher low-flow index.

By using the low-flow indices of the Obion River and its forks, an index for the area between the gaging stations on the forks of the Obion River and the station on the main stem (7–0260) has been computed. Similarly, an index has been computed for the area on the South Fork Forked Deer River between Jackson (7–0275) and Chestnut Bluff (7–0280), Tenn., gaging stations. The computed index for each of these areas is 0.14 cfs per sq mi. Both are underlain predominantly by the upper sand and clay units of the Claiborne Group and by loess. These two areas and the area within the Forked Deer River basin include small parts in the "500-foot" sand. The Loosahatchie River at Brunswick, Tenn. (7–0302.8), in Shelby County, is incised into the same geologic units and has a low-flow index of 0.15 cfs per sq mi.

The computed low-flow index for the area between the gaging stations on Hatchie River at Bolivar, Tenn. (7–0295), and near Stanton, Tenn. (7–0300), is 0.31 cfs per sq mi. This index is in close agreement with indices for other streams that receive their base flow from the "500-foot" sand.

The low-flow index of Richland Creek near Obion, Tenn. (7–0260.3), is 0.07 cfs per sq mi; Reelfoot Creek near Samburg, Tenn. (7–0265), 0.001 cfs per sq mi; Pawpaw Creek at Push, Tenn. (7–0271), 0.02 cfs per sq mi; Black Creek near Chestnut Bluff, Tenn. (7–0279), 0.000 cfs per sq mi; Cold Creek near Arp, Tenn. (7–0292), 0.04 cfs per sq mi; Lagoon Creek near Orysa, Tenn. (7–0300.3), 0.002 cfs per sq mi; Cane Creek near Cherry, Tenn. (7–0301.4), 0.001 cfs per sq mi; Beaver Creek near Arlington, Tenn. (7–0302.5), 0.001 cfs per sq mi; Crooked Creek near Bolton, Tenn.

(7–0303.5), 0.000 cfs per sq mi; and Nonconnah Creek near Germantown, Tenn. (7–0322), 0.001 cfs per sq mi. Such indices indicate that the base flow of these streams is poorly sustained. These streams flow through the loess mantle and through terrace deposits. The water table probably is below the water surface in the streams, and the only sources of base flow therefore are probably channel storage and bank storage in the immediate vicinity of the channel.

For Mud Creek near Sidonia, Tenn. (7–0252), the low-flow index is 0.02 cfs per sq mi; Cypress Creek near Latham, Tenn. (7–0253.5), 0.005 cfs per sq mi; Mud Creek near Bells, Tenn. (7–0277), 0.01 cfs per sq mi; Big Muddy Creek near Stanton, Tenn. (7–0300.2), 0.10 cfs per sq mi; and Cypress Creek near Eads, Tenn. (7–0302.6), 0.000 cfs per sq mi. The streams at these points lie in the western part of the outcrop of the Claiborne Group, and their low-flow indices indicate that the sand and the clay overlying the "500-foot" sand do not contribute much water to the low flow of these streams.

MAJOR FLOODS AND GROUND-WATER RECHARGE

Floods react upon geologic units in the immediate area of the stream channels in two general ways: (1) By loading on shallow impermeable geologic units and thus transmitting the increased hydrostatic head to artesian aquifers with little or no recharge to the geologic units, and (2) by direct recharge of floodwater to the more permeable and porous aquifers exposed along the stream channels and overflow areas. Both of these flood reactions tend to bar the outflow of ground water during flood periods, and ground water which normally is discharging into the stream is thus held in storage in the aquifer.

The same properties of the geologic units along a stream that influence the movement of ground water into the stream may be expected 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 influence the amount of ground-water recharge. The deposition of sediment in the stream channel and over the flood plain may inhibit the movement of surface water into ground-water aquifers, and the use of the land on the flood plain affects floodwater infiltration.

The inundation curve (fig. 4) for Obion River in the vicinity of Lane, Tenn., is typical of large streams in the embayment. The maximum flood of record, the mean annual flood, and the 10-, 20-, and 30-percent duration points are shown on this curve. Although

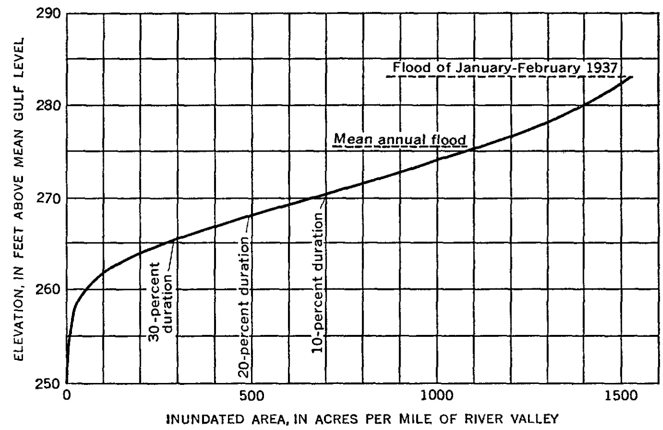

FIGURE 4.—Relation between water-surface elevation and inundated area, Obion River in the vicinity of Lane, Tenn.

the curve does not present sufficient data to permit prediction of the magnitude of ground-water recharge, it does show the relation for deriving the area flooded and the percent of time during which recharge could occur.

In the Mississippi embayment in Tennessee one of the most receptive geologic areas for ground-water recharge is the outcrop of the Eocene deposits. The "500-foot" sand (the basal unit of the Claiborne Group) crops out in the eastern part of these deposits. Lakes, formed by the accumulation of drift in the channel (p. H8) of South Fork of Obion River near Greenfield and near Jarrell, are in this area of outcrop, as is the lake on Middle Fork of Obion River south of Dresden. Each of these lakes may decrease the normal discharge from the ground-water aquifer to these rivers but may increase the discharge elsewhere.

The report on the floods of May 1943 in Illinois (Illinois State Water Survey Div. [1945], p. 148) contains a discussion of the influence of the flood on ground-water supplies at Cairo. The report also shows the effect of the flood on water-table wells less than 100 feet deep in the alluvial deposits and on artesian wells about 1,000 feet deep extending to the Paleozoic rocks.

At low river stages the water levels in the wells at Cairo are usually above the level of the Ohio river. When the river began to rise during the 1943 flood, the water in all the wells also began to rise but at a slower rate than the river. The average rise in the levels of the deep artesian wells during the flood was much less than the average rise in the shallow wells, and for the first time since observations were begun in 1937, the river peak was higher than the level in the artesian wells (fig. 5). The Illinois State Water Survey Division attributed this unusual condition to the rapid rise

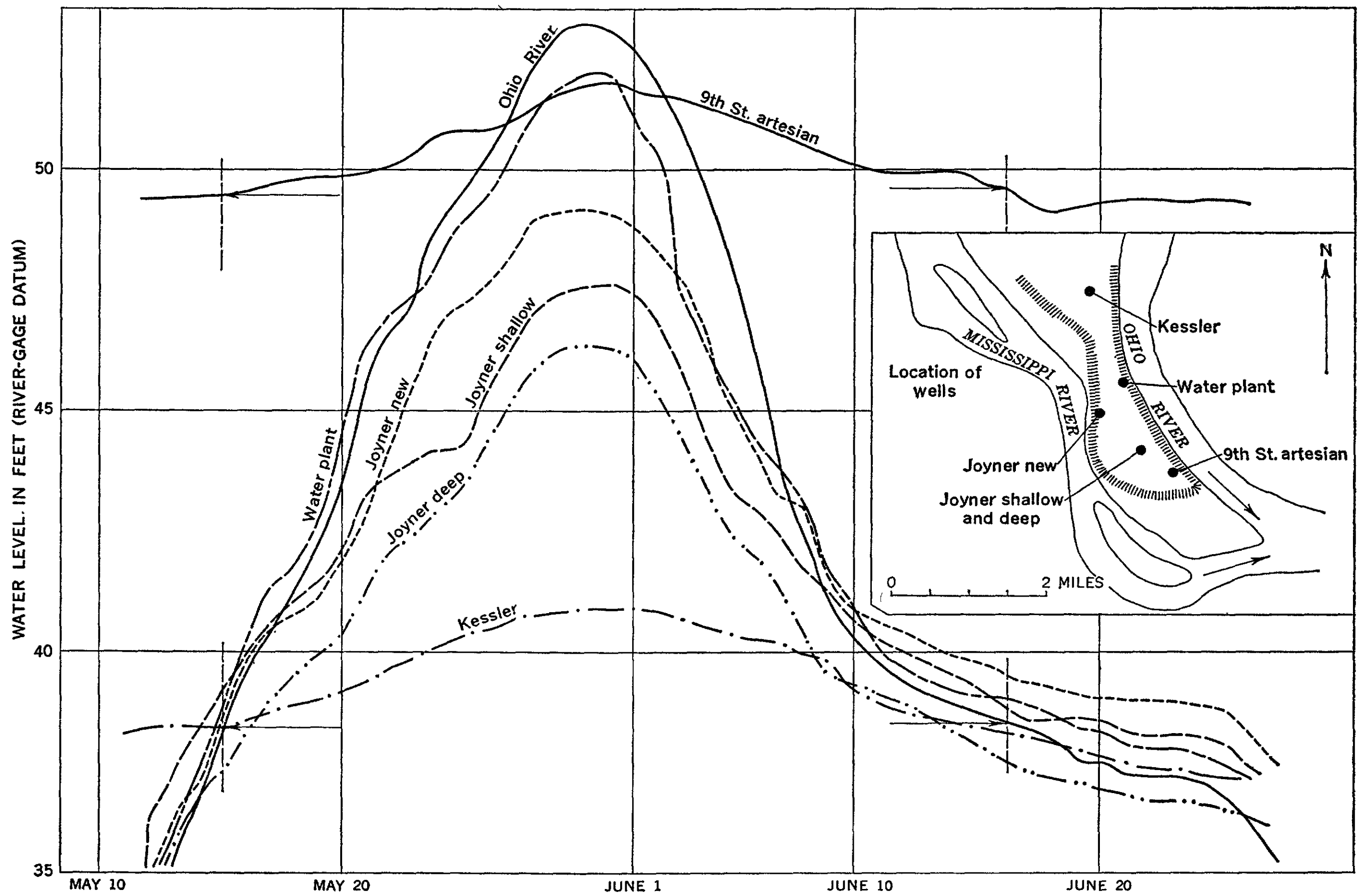

FIGURE 5.—Water levels in the Cairo, Ill., area during the 1943 flood. River stages, city datum; zero of gage, 270.61 feet above mean sea level, 1929 adjustment. After Illinois State Water Survey Division [1945].

and fall of the flood. Water levels in the wells closer to the river rose higher than water in wells farther away.

In figure 5, points, indicated by arrows, are shown on the rising and the receding limbs of the Ohio River flood graph at about a 38-foot stage. The time at each of these points is projected to intersect the graphs of the water levels in the 9th St. artesian, the Joyner deep, and the Kessler wells. During the period between these points on the river graph, the water levels in these wells had crested and receded to or below the same stage as the points on the rising limbs; these lower stages on the recession indicate that the rise and fall of the water level in these wells during the flood resulted from loading rather than recharge to the aquifer. On the other hand, the recession limb of the graph of the water level for the Joyner new well and possibly the recession limbs for the water-plant and Joyner shallow wells indicate that there was some recharge to the aquifers from which these wells receive their water.

Sand boils are regarded as a source of annoyance in protecting areas below flood level behind the levees, but investigations into their occurence reveal significant information on the interrelation between floodwaters and the movement of ground water in alluvial valleys. During the 1937 flood, the Illinois State Water Survey Division made several tests in the Cairo area to determine the origin of the water in sand boils. In these tests, certain properties of such water were determined and compared with the same properties of the river water and of water from wells near the sand boil. All samples for one set of tests were taken the same day. From these tests, it was concluded that the water in the sand boils is fundamentally ground water of the same character as the well water. The water in only one sand boil may have been diluted somewhat by Mississippi River water. These results indicate that the floodwater barred the discharge of ground water from the shallow aquifers.

LOW FLOWS AND GROUND-WATER FLUCTUATIONS

In the discussion of "Factors affecting low flow" (p. H18), the first factor expresses the influence of the fixed physical properties of the aquifer in contact with or adjacent to the stream, and the other three are variable factors that must be considered in relating the water level in the aquifers to the low flow. Because the geologic units are the natural storage reservoirs that sustain base flow, variation in elevations of the ground-water table (or of the water surface in the streams) and the resulting variation in the slope of the water table toward the stream influence the rate at which the aquifer yields water to the stream at low flow. A decline of the water table results in a decrease in the streamflow. Thus, the low-flow recession of a stream is generally related to the ground-water recession in the geologic units from which the stream receives its base flow.

Where a stream receives its base flow from a single aquifer, the ground-water recession in that aquifer is generally a direct index of the low-flow recession in the stream. Many streams, however, receive water from more than one aquifer, and the interrelation of these aquifers as they affect streamflow 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 thus result in a transfer of surface water to ground water. The stream then becomes the means by which ground water is transferred between aquifers, and the result is a decrease in flow in some reaches of the stream. Such a transfer probably occurs on Crooked Creek in Carroll County, Tenn.

Crooked Creek heads in the McNairy Sand Member of the Ripley Formation. About 7½ miles upstream from its mouth, it enters an area of the Porters Creek Clay of the Midway Group. After flowing about 5 miles through this formation, it flows the last 2½ miles to its mouth through the "500-foot" sand member of the Claiborne Group. The results of discharge measurements of Crooked Creek on September 29, 1954 (table 5), show an increase in flow down to a point 7.7 miles above its mouth; from that point the flow decreased slightly to and below Guins Creek. In the upper reach of Crooked Creek, between sites B and C, springs were observed in the streambed. The decrease in flow between site E and Guins Creek can probably be attributed to evapotranspiration losses and absorption in the Porters Creek Clay. On October 9, 1954, discharges of 19.5 and 18.6 cfs were measured at sites G and H, respectively. The difference of 0.9 cfs is presumed to represent evapotranspiration losses and water entering the "500-foot" sand. The differences between the measured discharges used in this discussion are far less reliable than the discharge measurements themselves, because subtraction magnifies the effect of small errors. An error of 3 percent in the measured discharge, for example, could explain the full amount of the indicated losses.

The volume of ground water available to support low flow is the amount of water in the aquifers that lie adjacent to the stream 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 ground-water aquifer that drain to the stream may not coincide with the surface drainage area and (2) there is great variation in the characteristics of the geologic units from which the base flow of a stream is derived. The variations in the runoff per square mile presented in table 2 demonstrate the effect of these ground-water factors and provide an index for

TABLE 5.—*Gains and losses of water in Crooked Creek, Carroll County, Tenn.*

Location and date of measurement	Distance above mouth (miles)	Geology	Discharge (cfs)				Length of reach (miles)
			Main stem	Tributary inflow	Main stem		
					Gain	Loss	
September 29, 1954							
At site A	12.5	McNairy Sand Member	0				
Above Vaughns Spring	10.4+	do	.69		0.69		2.1
Vaughns Spring at spring-branch mouth	10.4	do		0.14			
Below Vaughns Spring at site B	10.4−	do	.83		.14		0
Above Carver Creek st site C	9.2+	do	4.53		3.70		1.2
Carver Creek at mouth	9.2	do		3.54			
Below Carver Creek	9.2−	do	8.07		3.54		0
Unnamed tributary (Rosser Branch)	8.1	do		.09			
At site D	7.7+	do	8.90		.83		1.5
Unnamed tributary below site D	7.7	do		.10			
Below unnamed tributary	7.7−	do	9.00		.10		0
At State Highway 77, site E	5.7	Porters Creek Clay	8.92			0.08	2.0
Above Guins Creek at site F	3.9+	do	8.46			.46	1.8
Guins Creek at mouth	3.9	do		7.10			
Below Guins Creek	3.9−	do	15.56		7.10		0
October 9, 1954							
At State Highway 22, site G	2.6	do	19.5				
Unnamed tributary (Hico Branch)	1.1	"500-foot" sand		.02			
At mouth, site H	0	do	18.6			.9	2.6

further investigation into the physical basis for the variability in low-flow yields. As the index of low flow usually 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 comparing them with data from other long-term stations, and of then adjusting shorter records to the reference period through their relations with the long-term records. Statistical principles were used as a guide in evaluating the relations.

The following long-term stations served as a basis for the low-flow analyses in Tennessee, Kentucky, and Illinois:

Station	*Station name*
3B4355	Red River near Adams, Tenn.
3B6040	Buffalo River near Flatwoods, Tenn.
5-5970	Big Muddy River at Plumfield, Ill.
7-0295	Hatchie River at Bolivar, Tenn.
7-0305	Wolf River at Rossville, Tenn.

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

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

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

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

More detailed descriptions of the methods used in the study and the analyses of the records are given by Speer 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 32 daily-record and 57 partial-record stations in or adjacent to the Mississippi embayment in Tennessee, Kentucky, and Illinois. 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. Portions of 3 of the 14 parts into which the United States is divided to facilitate publication of the records are included in the area (fig. 6) covered by this report, as follows:

- 3–A, Ohio River basin except Cumberland and Tennessee River basins.
- 3–B, Cumberland and Tennessee River basins.
- 5, Hudson Bay and upper Mississippi River basins.
- 7, Lower Mississippi River basin.

Records of daily discharge for gaging stations having five or more complete consecutive water years not affected by regulation or diversion were processed by an electronic computer to obtain (1) the lowest mean discharge occurring during each year for selected numbers of consecutive days and (2) the number of daily flows each year between selected limits of discharge (Speer, 1960). If the natural flow of a station became regulated or affected by diversions as the result of manmade changes, the data for the record so affected were 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, 3, and 4 are indications of the natural flow of the streams. Storage must be provided for drafts greater than the natural flow. The amount of such storage and the frequency with which it is required provide a basis for obtaining an economic balance between the cost of the storage and

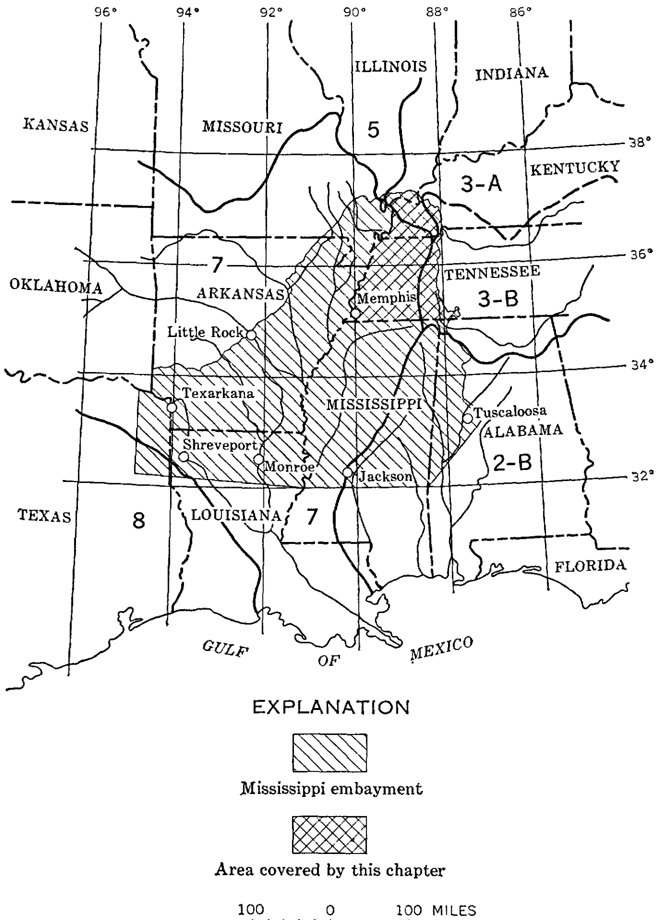

FIGURE 6.—The Mississippi embayment, showing areas covered, by numbered parts, for which streamflow records for respective parts shown are published in reports on surface-water supply.

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 from specific amounts of storage.

To provide a means for estimating the storage required for various drafts, the storage-required frequency data are related to the median annual 7-day (2-year) low flows in figures 7 and 8. This index of low flow, which is the same as that used in the section on "Factors affecting low flow," is given in table 2 for 89 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 (Searcy, 1959, p. 20).

The number of points available to define the curves in figures 7*B* and 8*B* range from 10 for the 90 acre-ft per sq mi (acre-feet per square mile) at the 10- and 20-year recurrence intervals to 31 for 0, 5, and 15 acre-ft per sq mi at the 10- and 20-year recurrence intervals. The scatter of the circles in figure 7*B* for a storage of 30 acre-ft per sq mi is typical of the scatter of the points that define other curves in 7*B* and 8*B*. The plottings show approximate standard errors of less than 10 percent. The curves in figures 7*A* and 8*A* are based on the curves in 7*B* and 8*B*.

The curves of zero storage in figures 7 and 8 represent the 7-day low flow for the indicated recurrence interval and thus neglect the small amount of storage that will be required to regulate the 7-day flow within the minimum. None of the curves include reservoir losses or losses in conveyance of water from the storage facility to the point of utilization. Furthermore, a bias of about 10 percent that results from using low-flow frequency curves to compute storage

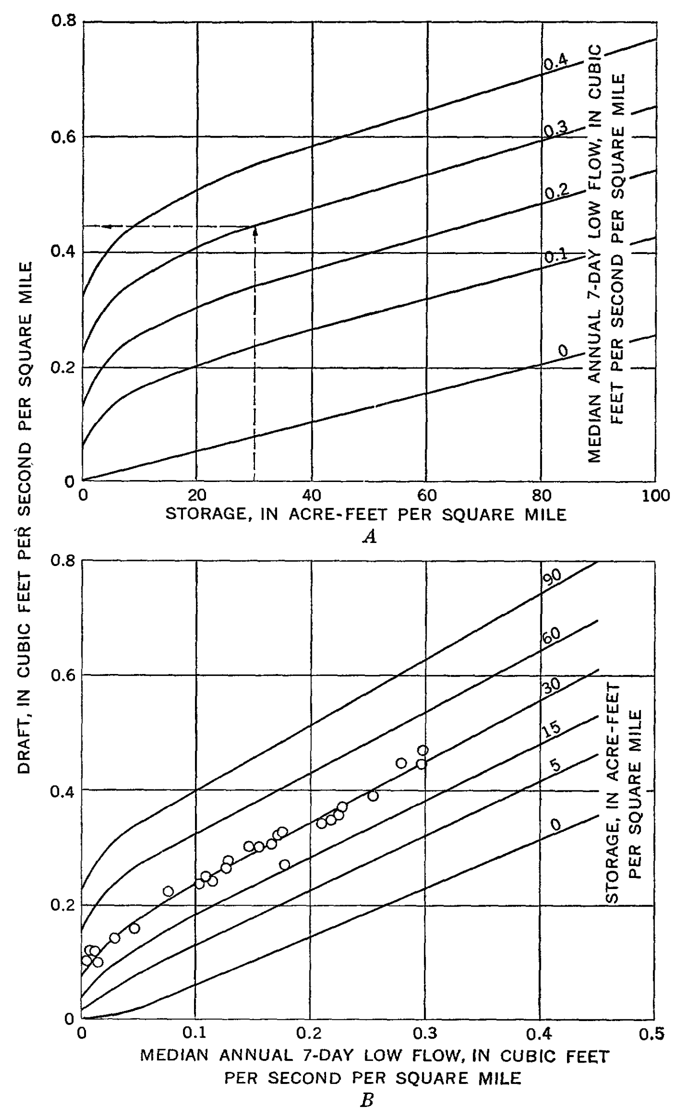

FIGURE 7.—Areal draft-storage relations for a 10-year recurrence interval as a function of the median annual 7-day low flow, for storage of 0, 5, 15, 30, 60, and 90 acre-ft per sq mi for the study area.

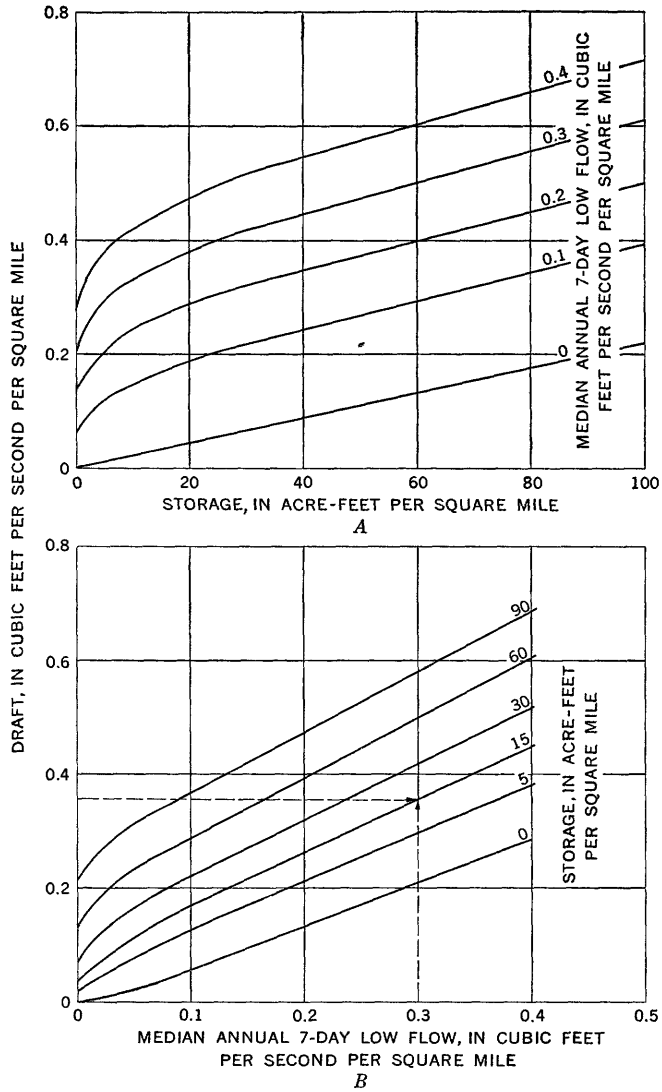

FIGURE 8.—Areal draft-storage relations for a 20-year recurrence interval as a function of the median annual 7-day low flow, for storage of 0, 5, 15, 30, 60, and 90 acre-ft per sq mi for the study area.

requirements also has been neglected. As the losses and the bias both tend to make the computed amount of storage smaller than it should be, allowance for these must be included in project design. The areal draft-storage relations, therefore, should be used only for obtaining preliminary estimates of draft-storage requirements at partial-record sites and for making comparisons between stations. More detailed studies, using the data in table 3 if available for the specific location, should be made in connection with design of specific projects.

Values for median annual 7-day low flow as high as 0.61 cfs per sq mi are shown in table 2. However, because of the limitations of the data on which the curves in figures 7 and 8 are based, 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 and others (1964).

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

Illustrative problem 1.—Let it be assumed that a proposal is made to build a manufacturing plant on Wolf River at Rossville, Tenn., which will require a minimum flow of 181 cfs for operation; for economic reasons, the flow should not drop below this discharge more often than once in 20 years on a long-term average. How much storage will be required to maintain this flow for this frequency?

1. From table 2, for Wolf River at Rossville, Tenn. (7–0305), obtain the 7-day 2-year low flow, which is 0.30 cfs per sq mi, and the drainage area, which is 503 square miles.
2. Divide 181 cfs by 503 square miles to obtain a required draft of 0.36 cfs per sq mi.
3. Use figure 8*B*. The abscissa being 0.30 cfs per sq mi and the ordinate being 0.36 cfs per sq mi, the estimated storage required is 15 acre-ft per sq mi or 7,540 acre-ft. This amount plus 10 percent for bias and an additional amount for reservoir and conveyance losses would be required to provide the desired draft and would be insufficient at average intervals of 20 years.

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

Illustrative problem 2.—Let it be assumed that demands for water at Rossville, Tenn., are such that they greatly exceed the natural flow of the Wolf River, and let it be assumed also that upstream from Rossville a total storage of 17,600 acre-ft could be developed or made available for supplementing low flows. What draft at Rossville can be maintained by this storage if a deficiency once in 10 years can be tolerated?

1. From table 2, for Wolf River at Rossville, Tenn. (7–0305), obtain the drainage area, which is 503

sq mi, and the 7-day 2-year low flow, which is 0.30 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 2,500 acre-ft. The net storage available for use at Rossville is 17,600 acre-ft minus 2,500 acre-ft, or 15,100 acre-ft.
3. Divide the net storage by the drainage area to obtain the net acre-ft per sq mi available at Rossville:

$$\frac{15{,}100}{503}=30 \text{ acre-ft per sq mi}$$

4. Use figure 7*A*. The abscissa being 30 acre-ft per sq mi and the parameter being 0.30 cfs per sq mi, read as ordinate the draft of 0.446 cfs per sq mi. For 503 sq mi, this would give 224 cfs as the allowable draft that would deplete the storage once in 10 years on a long-term average. As soon as the storage was depleted, the available flow would drop to the natural inflow, which for this stream is 0.23 cfs per sq mi or 116 cfs at a 10-year recurrence interval, unless the allowable draft were curtailed to less than 224 cfs as the drought developed and as the amount of water in storage became dangerously low.

Storage and draft data in figures 7 and 8 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

TABLE 6.—*Chemical analyses of low-flow surface waters in the study area*

Aquifers in drainage basin above sampling station	Date sampled	Discharge (cfs)	Parts per million														Specific conductance (micromhos at 25° C)	pH	Color
			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			
	5-6000. Big Creek near Wetaug, Ill. (drainage area, 32.2 sq mi)																		
Paleozoic rocks	6-27-61	6.31	4.4	0.05	40	6.0	5.4	3.1	130	19	6.0	0.2	3.5	152	124	18	257	7.3	5
	8-14-62	.89	4.9	.00	39	9.1	8.9	3.4	166	7.4	6.0	.3	.8	166	135	0	272	8.2	3
	3B5944.8. Turkey Creek at Decaturville, Tenn. (drainage area, 8.40 sq mi)																		
Paleozoic rocks, Eutaw Formation, and Coffee Sand	8-10-61	0.22	7.8	0.06	29	5.3	3.0	1.3	110	9.6	4.0	0.0	0.1	114	94	4	191	7.4	7
	10-9-62	.25	8.2	.00	37	3.8	2.8	2.4	127	9.8	2.6	.1	.2	129	108	4	205	7.4	2
	3B6048. Birdsong Creek near Holladay, Tenn. (drainage area, 44.9 sq mi)																		
Coffee Sand	8-10-61	2.07	5.9	0.05	4.9	2.1	1.9	0.7	26	4.4	2.0	0.0	0.2	35	20	0	52	7.3	5
	10-9-62	5.01	7.8	.07	4.4	1.6	2.2	1.4	23	4.0	1.2	.2	.8	35	18	0	46	7.2	7
	7-0242. Crooked Creek near Huntingdon, Tenn. (drainage area, 26.5 sq mi)																		
	10-18-60	9.00	8.5	0.13	2.2	1.0	2.7	0.5	12	4.4	1.2	0.1	0.8	27	10	0	31	6.5	12
	10-10-62	10.2	8.5	.00	2.1	.9	2.6	.4	14	2.4	1.0	.1	.7	26	8	0	32	7.2	2
	7-0243. Beaver Creek near Huntingdon, Tenn. (drainage area, 55.5 sq mi)																		
McNairy Sand Member of Ripley Formation	10-18-60	22.6	8.2	0.26	4.3	0.1	2.5	0.5	13	5.8	1.2	0.1	0.8	30	11	0	39	6.3	20
	10-10-62	25.5	8.7	.02	2.7	1.2	2.9	.6	16	5.2	1.0	.0	.7	31	12	0	37	7.1	1
	7-0273. South Fork Forked Deer River near Henderson, Tenn. (drainage area, 161 sq mi)																		
	8-10-61	57.8	3.5	0.04	2.5	0.5	1.9	1.1	12	3.0	1.5	0.0	0.1	20	8	0	30	6.7	5
	10-8-62	58.9	8.1	.00	1.9	1.1	2.1	1.0	14	1.6	1.2	.0	.2	24	9	0	29	6.5	1
	7-0274. Middle Fork Creek near Luray, Tenn. (drainage area, 21.5 sq mi)																		
	8-10-61	10.6	2.9	0.05	1.3	0.6	1.8	0.4	9	0.0	1.5	0.0	0.1	13	6	0	21	6.4	5
	10-8-62	13.1	8.2	.00	1.9	.8	1.8	.9	13	.8	.8	.0	.3	21	8	0	24	6.6	2

TABLE 6.—*Chemical analyses of low-flow surface waters in the study area*—Continued

Aquifers in drainage basin above sampling station	Date sampled	Discharge (cfs)	Parts per million														Specific conductance (micromhos at 25° C)	pH	Color
			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			
	7-0293.7. Cypress Creek at Selmer, Tenn. (drainage area, 44 sq mi, approx.)																		
McNairy Sand Member of Ripley Formation—Continued	10-19-60	16.8	8.6	0.30	2.1	0.6	1.7	0.6	12	0.2	1.2	0.1	1.1	20	8	0	26	6.4	26
	10- 8-62	20.9	8.0	.00	2.4	.7	1.7	.8	13	2.2	.6	.0	.2	23	9	0	27	6.6	3
	7-0294.1. Mosses Creek near Pocahontas, Tenn. (drainage area, 47.6 sq mi)																		
	10-19-60	21.9	7.5	0.33	1.8	1.3	1.8	0.8	12	2.4	2.0	0.1	0.8	25	10	0	30	6.4	37
	10- 9-62	19.3	7.8	.00	2.1	.8	1.6	.8	13	2.0	1.2	.0	.2	23	8	0	26	6.6	4
	3B6072. West Sandy Creek near Springville, Tenn. (drainage area, 47.9 sq mi)																		
McNairy Sand Member of Ripley Formation and Wilcox Group undifferentiated	10-18-60	17.4	8.3	0.51	2.9	1.1	2.4	0.7	16	3.2	0.2	0.1	1.1	28	12	0	38	6.3	32
	10- 8-62	22.3	9.1	.00	2.7	1.2	2.4	.9	18	1.2	1.4	.2	.9	29	12	0	36	7.0	2
	7-0289. Middle Fork Forked Deer River near Spring Creek, Tenn. (drainage area, 90 sq mi, approx.)																		
McNairy Sand Member of Ripley Formation and Claiborne Group undifferentiated	9-10-61	9.56	7.8	0.05	1.4	1.1	1.9	1.1	13	2.2	1.5	0.0	0.2	24	8	0	29	6.4	6
	10- 9-62	11.0	8.6	.02	2.5	1.4	2.1	1.3	18	1.6	1.0	.2	.8	28	12	0	36	7.3	3
	3A6112. Massac Creek at Metropolis, Ill. (drainage area, 37.4 sq mi)																		
McNairy Sand and Pliocene(?) deposits	6-26-61	5.87	5.6	0.06	7.2	3.1	4.7	1.6	40	0.2	5.5	0.0	0.2	48	30	0	95	6.5	5
	8-14-62	.14	7.2	.00	8.2	2.9	4.7	3.4	34	12	4.4	.2	.7	61	32	4	95	7.3	2
	7-0242.5. Guins Creek near Huntingdon, Tenn. (drainage area, 43.5 sq mi)																		
Wilcox Group undifferentiated	10-18-60	6.88	7.4	0.44	2.9	0.8	2.0	0.8	16	0.0	1.5	0.1	1.2	25	10	0	33	6.5	40
	10-10-62	11.2	8.8	.00	2.7	1.1	2.1	1.1	18	2.0	.8	.0	.4	28	11	0	33	6.7	3
	7-0244. Reedy Creek near Trezevant, Tenn. (drainage area, 57 sq mi, approx.)																		
Wilcox and Claiborne Groups undifferentiated	10-18-60	5.51	9.1	0.09	2.5	0.8	3.2	0.7	17	0.0	2.2	0.1	1.8	29	10	0	37	6.5	15
	10- 9-62	7.33	9.4	.00	2.7	1.2	3.0	1.1	19	2.0	1.0	.0	.4	30	12	0	37	6.5	1
	7-0253.5. Cypress Creek near Latham, Tenn. (drainage area, 36.7 sq mi)																		
Claiborne Group undifferentiated	10-18-60	0.61	8.6	0.07	3.0	0.8	4.0	0.8	21	0.2	2.0	0.1	0.6	30	11	0	43	6.7	15
	10- 8-62	.70	9.0	.00	2.2	1.2	4.1	.9	22	1.2	1.6	.1	.7	32	10	0	43	7.1	1
	7-0277. Mud Creek near Bells, Tenn. (drainage area, 27 sq mi, approx.)																		
	10-20-60	0.42	8.9	0.10	2.5	0.8	4.2	0.9	20	0.0	2.5	0.1	0.6	30	10	0	42	6.2	23
	10-10-62	.56	11	.00	2.5	.8	4.4	.8	22	1.4	1.0	.0	.2	33	9	0	38	7.1	1
	7-0276. Johnson Creek near Jackson, Tenn. (drainage area, 34 sq mi, approx.)																		
	10-19-60	0.91	8.9	0.00	2.9	1.0	3.3	0.8	21	0.2	1.0	0.1	0.9	29	11	0	40	6.4	3
	8-10-61	.77	7.8	.04	1.4	1.5	3.5	.8	18	.8	2.0	.0	.2	27	10	0	38	6.6	4
	10- 8-62	2.15	6.7	.02	3.2	1.9	2.8	2.3	25	2.4	1.4	.1	1.4	34	16	0	46	7.1	2
	7-0294.4. Porters Creek near Middleton, Tenn. (drainage area, 40.4 sq mi)																		
	10-19-60	10.5	7.4	0.18	2.6	1.6	2.1	1.0	16	2.4	1.8	0.1	0.5	28	13	0	37	6.6	25
	10- 9-62	7.15	8.0	.00	2.2	.9	1.7	1.2	14	1.6	1.2	.0	.2	24	9	0	27	6.6	4

TABLE 6.—*Chemical analyses of low-flow surface waters in the study area*—Continued

Aquifers in drainage basin above sampling station	Date sampled	Discharge (cfs)	Parts per million														Specific conductance (micromhos at 25° C)	pH	Color
			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			
	7-0302. Loosahatchie River near Laconia, Tenn. (drainage area, 26.2 sq mi)																		
Claiborne Group undifferentiated—Continued	10-19-60	1.65	7.9	0.07	1.9	0.6	2.9	0.8	16	0.0	1.5	0.1	0.7	24	7	0	30	6.5	12
	10- 9-62	.46	11	.00	2.6	1.0	3.8	1.0	22	1.0	1.2	.0	.3	33	10	0	38	6.9	2
	7-0305. Wolf River at Rossville, Tenn. (drainage area, 503 sq mi)																		
	8-16-61	177	6.8	0.04	1.6	1.0	2.5	0.5	15	0.6	1.5	0.0	0.2	22	8	0	30	6.6	5
	10- 9-62	241	8.5	.00	2.4	1.0	2.6	1.3	19	2.0	.8	.0	.1	28	10	0	33	6.6	2
	7-0235. Obion Creek at Pryorsburg, Ky. (drainage area, 36.8 sq mi)																		
Eocene deposits undifferentiated.	11-22-60	0.029	7.0	0.00	7.7	4.3	3.0	3.1	44	5.4	2.5	0.3	0.5	56	36	0	94	6.7	25
	8-24-62	.013	2.9	.24	3.6	2.0	1.1	6.7	22	6.8	1.8	.2	1.5	38	17	0	59	6.8	50
	7-0240.5. Cane Creek near Clinton, Ky. (drainage area, 16.9 sq mi)																		
	11-23-60	0.39	5.0	0.24	5.8	2.5	6.7	5.2	22	20	5.2	0.3	1.0	63	25	7	100	6.4	70
	8-24-62	.028	6.4	.00	11	5.0	9.3	3.4	80	2.0	3.0	.4	1.8	81	48	0	130	8.1	3
	3A6113. Massac Creek near Paducah, Ky. (drainage area, 32.5 sq mi)																		
Eocene deposits undifferentiated and Pliocene(?) deposits	11-23-60	2.38	6.8	0.18	7.8	2.5	14	3.1	28	12	20	0.2	1.7	82	30	7	148	6.6	40
	8-22-62	.009	6.9	.00	9.6	3.8	26	3.8	77	5.2	23	.3	1.7	118	40	0	204	7.9	2
	3A6130. Humphrey Creek near La Center, Ky. (drainage area, 44.2 sq mi)																		
	11-23-60	0.74	5.7	0.43	5.2	2.1	2.8	4.5	17	12	4.0	0.3	1.5	47	22	8	69	6.3	225
	8-24-62	.13	8.8	.00	5.1	2.8	12	2.5	44	8.0	5.8	.2	.8	68	24	0	105	7.3	1
	7-0231. West Fork Mayfield Creek near Bardwell, Ky. (drainage area, 59.9 sq mi)																		
	11-22-60	1.84	7.3	0.23	3.8	2.3	5.3	1.0	31	3.4	3.2	0.2	0.3	42	19	0	65	6.2	50
	3A6135. Hodges Bayou tributary at Olmstead, Ill. (drainage area, 4.67 sq mi)																		
Pliocene(?) deposits	6-27-61	0.22	4.9	0.06	13	6.4	8.7	2.2	52	27	7.0	0.0	1.0	96	59	16	156	7.0	5
	3B6100. East Fork Clarks River at Murray, Ky. (drainage area, 89.7 sq mi)																		
	11-23-60	3.16	4.7	0.15	4.3	2.0	5.6	2.2	28	3.2	3.2	0.2	0.5	40	18	0	75	6.5	17
	8-28-62	.186	4.6	.00	3.8	1.5	5.4	2.6	22	2.0	7.2	.2	1.0	39	16	0	64	7.1	3
	5-6003. Boar Creek at Edith Chapel, Ill. (drainage area, 11.7 sq mi)																		
Terrace deposits	6-27-61	0.20	4.4	0.05	42	19	19	3.1	214	33	8.0	0.0	0.2	234	183	8	386	7.5	6
	7-0293.9. Muddy Creek at Ramer, Tenn. (drainage area, 48.3 sq mi)																		
	10-19-60	0.06	3.6	0.10	20	1.5	2.4	4.0	59	11	3.0	0.2	0.7	76	56	8	129	6.9	40
	10- 9-62	.0005	3.8	.01	22	3.2	4.4	4.4	84	10	2.0	.1	.3	91	68	0	153	7.4	10
	7-0260.3. Richland Creek near Obion, Tenn. (drainage area, 17.7 sq mi)																		
Terrace deposits and loess	10-20-60	1.04	5.6	0.01	52	26	6.5	2.5	296	4.6	3.0	0.3	1.2	248	236	0	425	7.4	7
	11- 8-62	1.64	4.5	.02	40	28	6.8	2.4	[1] 273	4.6	2.0	.3	1.0	224	215	0	366	8.5	2

[1] Includes equivalent of 10 ppm of carbonate (CO_3).

QUALITY OF THE WATER

By H. G. Jeffery

During periods of low flow the chemical quality of water in streams is determined primarily by the lithology of the geologic units in the basins. The chemical analyses of samples (table 6) collected at 30 sites within the area do not indicate any pollution, and they are thus presumed to be representative of the dissolved constituents in the water from streams draining the various aquifers. The dissolved-solids content of surface waters in this area is low to moderate, ranging from 13 to 248 ppm (parts per million), and most of the samples have less than 50 ppm. Hardness of the waters ranges from 6 to 236 ppm, and the iron content ranges from 0.00 to 0.51 ppm. The source and significance of dissolved mineral constituents and properties of water are shown in table 7.

TABLE 7.—*Source and significance of dissolved mineral constituents and properties of water*

Constituent or property	Source or cause	Significance
Silica (SiO_2)	Dissolved from practically all rocks and soils, commonly less than 30 ppm. High concentrations, as much as 100 ppm, generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam of high-pressure boilers to form deposits on blades of turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps, and other equipment. More than 1 or 2 ppm of soluble iron in surface waters generally indicates acid wastes from mine drainage or other sources.	More than about 0.3 ppm stains laundry and utensils reddish brown. Objectionable for food processing, textile processing, beverages, ice manufacture, brewing, and other processes. USPHS (1962) [1] drinking-water standards state that iron should not exceed 0.3 ppm. Larger quantities cause unpleasant taste and favor growth 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 waters.	Same objectionable features as iron. Causes dark brown or black stain. USPHS (1962) drinking-water standards state that manganese should not exceed 0.05 ppm.
Calcium (Ca) and magnesium (Mg).	Dissolved from practically all rocks and soils, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Cause most of the hardness and scale-forming properties of water; soap consuming (see Hardness). Waters low in calcium and magnesium desired in electroplating, tanning, and dyeing and in textile manufacturing.
Sodium (Na) and potassium (K).	Dissolved from practically all rocks and soils. Found also in ancient brines, sea water, industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers, and a high sodium content may limit the use of water for irrigation.
Bicarbonate (HCO_3) and carbonate (CO_3).	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates o calcium and magnesium decompose in steam boilers and hot-water facilities to form scale and release corrosive carbon dioxide gas. In combination with calcium and magnesium they cause carbonate hardness.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Commonly present in mine waters and some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives a bitter taste to water. Some calcium sulfate is considered beneficial in the brewing process. USPHS (1962) drinking-water standards recommend that the sulfate content should not exceed 250 ppm.

See footnote at end of table.

TABLE 7.—*Source and significance of dissolved mineral constituents and properties of water*—Continued

Constituent or property	Source or cause	Significance
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in ancient brines, sea water, and industrial wastes.	In large amounts in combination with sodium gives salty taste to water. In large quantities increases the corrosiveness of water. USPHS (1962) drinking-water standards recommend that the chloride content not exceed 250 ppm.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils. Added to many waters by fluoridation of municipal supplies.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth depending on the concentration of fluoride, the age of the child, the amount of water consumed, and the susceptibility of the individual. The maximum concentration of fluoride recommended by the USPHS (1962) varies with the annual average of maximum daily air temperatures and ranges downward from 1.7 ppm for an average maximum daily temperature of 50.0° F to 0.8 ppm for an average maximum daily temperature of 90.5° F. Optimum concentrations for these ranges are from 1.2 to 0.7 ppm.
Nitrate (NO_3)	Decaying organic matter, legume plants, sewage, nitrate fertilizers, and nitrates in soils.	Concentration much greater than the local average may suggest pollution. USPHS (1962) drinking-water standards suggest a limit of 45 ppm. Waters of high nitrate content have been reported to be the cause of methemoglobinemia (an often fatal disease in infants) and therefore should not be used in infant feeding. Nitrate has been shown to be helpful in reducing the intercrystalline cracking of boiler steel. It encourages the growth of algae and other organisms which may cause odor problems in water supplies.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils.	USPHS (1962) drinking-water standards recommend that the dissolved solids should not exceed 500 ppm. However, 1,000 ppm is permitted under certain circumstances. Waters containing more than 1,000 ppm of dissolved solids are unsuitable for many purposes.
Hardness as $CaCO_3$	In most waters nearly all the hardness is due to calcium and magnesium. All the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called noncarbonate hardness. Waters of hardness up to 60 ppm are considered soft; 61–120 ppm, moderately hard; 121–180 ppm, hard; more than 180 ppm, very hard.
Specific conductance (micromhos at 25° C).	Mineral content of the water	Indicates degree of mineralization. Specific conductance is a measure of the capacity of the water to conduct an electric current. It varies with the concentration and degree of ionization of the constituents, and with temperature.
Hydrogen-ion concentration (pH).	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 denote increasing acidity. pH is a measure of the activity of hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline waters may also attack metals.
Color	Yellow-to-brown color of some water usually is caused by organic matter extracted from leaves, roots, and other organic substances. Color in water also results from industrial wastes and sewage,	Water for domestic and some industrial uses should be free from perceptible color. Color in water is objectionable in food and beverage processing and many manufacturing processes.

TABLE 7.—*Source and significance of dissolved mineral constituents and properties of water*—Continued

Constituent or property	Source or cause	Significance
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.

Surface waters in the study area generally would be excellent sources for municipal and industrial supplies. Water from streams draining most of the unconsolidated deposits is soft (0–60 ppm hardness). The water has a low dissolved-solids content and only small variations in the chemical characteristics. For most uses the water would require treatment for color, for iron removal, and for pH control. The dissolved-solids content of water from streams draining Paleozoic rocks and terrace deposits is the highest in the area but is not excessive. Water from these deposits is very hard (more than 180 ppm hardness) and for many uses softening would be desirable.

The chemical characteristics of water in the streams reflect the soluble mineral constituents in the various geologic units. These characteristics are shown graphically on plate 2. Two analyses are plotted for those sites where the water has a somewhat variable composition; otherwise, the diagrams or patterns represent the average of two analyses except for Hodges Bayou tributary at Olmstead, Ill. (3A6135), Boar Creek at Edith Chapel, Ill. (5–6003), and West Fork Mayfield Creek near Bardwell, Ky. (7–0231), where only one analysis for each site is available.

Some of the Paleozoic rocks contain large quantities of calcium carbonate, which is soluble in the slightly acidic ground water. Consequently, water in the streams originating in these rocks, such as Big Creek near Wetaug, Ill. (5–6000), is of the calcium bicarbonate type, and variations in the dissolved-solids content are primarily changes in these two constituents.

The chemical character of water from the Paleozoic rocks is evident in some of the chemical analyses of water from streams whose drainage basins are mostly in other geologic units. The drainage area of Birdsong Creek near Holladay, Tenn. (3B6048), is in Paleozoic rocks, the Coffee Sand, and the Coon Creek Tongue of the Ripley Formation. The drainage area of Turkey Creek at Decaturville, Tenn. (3B5944.8), is mostly in the Coffee Sand but includes some parts that are in Paleozoic rocks and the Eutaw Formation. A comparison of the patterns for Turkey Creek with those for Big Creek near Wetaug, Ill. (5–6000), and Birdsong Creek shows that the water from Turkey Creek is chemically similar to the Paleozoic water of Big Creek and that the water from Birdsong Creek is characteristic of water from the Coffee Sand. The dissolved-solids content of water from Turkey Creek indicates that the principal effect of the mixing of waters from the Paleozoic rocks, the Coffee Sand, and the Eutaw Formation is to dilute the characteristics of the water from the Paleozoic rocks.

The drainage area above Massac Creek at Metropolis, Ill. (3A6112), is in the McNairy Sand and Pliocene(?) deposits. The dissolved-solids content of water from this stream ranged from 48 to 61 ppm and is intermediate between the dissolved-solids content of water from Pliocene(?) deposits (39–96 ppm) and the McNairy Sand (13–31 ppm).

Water in streams receiving their base flow from the Coffee Sand, the McNairy Sand, the Wilcox Group, or the Claiborne Group are low in dissolved solids and are uniform in composition. These deposits apparently contain only small amounts of soluble material, and infiltration is sufficient to leach the soluble products of weathering from the deposits. The dissolved-solids content of water in streams draining these units ranges from 13 to 35 ppm, but the range in individual streams is usually small. The dissolved solids are mostly carbonate salts of calcium, magnesium, and sodium. The higher iron content in water from some of these streams apparently is related to the higher colors and possibly is of vegetal origin.

Water in streams draining undifferentiated Eocene deposits and in streams draining a combination of undifferentiated Eocene and Pliocene(?) deposits in Kentucky is variable in both chemical character and amount of dissolved solids. In these streams the dissolved solids generally increase with a decrease in discharge. However, the dissolved solids of Obion Creek at Pryorsburg (7–0235) decrease as the discharge decreases. The variations in the chemical characteristics of water in streams draining these units are shown by the double patterns for Obion Creek at Pryorsburg (7–0235), Cane Creek near Clinton (7–0240.5), Massac Creek near Paducah (3A6113), and Humphrey Creek near La Center (3A6130). These variations probably are related to changes in the amount of water contributed to the streams by the different aquifers in the drainage basins.

The dissolved-solids content of water from streams that drain Pliocene(?) deposits varies considerably from stream to stream, but the information for East Fork Clarks River at Murray, Ky. (3B6100), indicates that within each stream it remains fairly uniform during periods of low flow. Variation in the dissolved-solids content and chemical character probably are related to lithologic differeneces of the Pliocene(?) materials. The dissolved-solids content of water from Pliocene(?) deposits, such as water in the East Fork Clarks River, is only slightly higher than the dissolved-solids content of water in streams draining the McNairy Sand and the Wilcox and Claiborne Groups, and the chemical characteristics of these waters are similar. The dissolved-solids content of water from Hodges Bayou tributary at Olmstead, Ill. (3A6135), is more than twice that of water from East Fork Clarks River at Murray, Ky. (3B6100), and the chemical characteristics, except for a deficiency of calcium magnesium carbonate, are similar to those of water from the terrace deposits.

Water from streams draining terrace deposits is similar in character to water from Paleozoic rocks. The prinicpal constituents of water in the streams draining these units are calcium, magnesium, and bicarbonate. The water from Richland Creek near Obion, Tenn. (7–0260.3), has a smaller concentration of sodium and sulfate and a larger concentration of magnesium than does water from Boar Creek at Edith Chapel, Ill. (5–6003). The differences in the concentrations of these constituents possibly are related to overlying loess in the drainage area above Richland Creek, or to the lithologic differences of the material in the terrace deposits. Water in Muddy Creek at Ramer, Tenn. (7–0293.9), is chemically similar to water in streams draining Paleozoic rocks, but water in Muddy Creek contains less dissolved solids than water from Paleozoic rocks.

CONCLUSIONS AND RECOMMENDATIONS

1. The low-flow characteristics of streams in the Mississippi embayment in Tennessee, Kentucky, and Illinois are useful in the solution of water problems in the area. The need for further development of water resources, particularly for consumptive uses, was accentuated by the drought of the 1950's and has increased rapidly in recent years. In some areas the use of surface water has greatly altered the low-flow characteristics of the streams. As industry and agriculture continue to expand, the critical areas may be expected to increase in number and become more widespread. Planned development of the water resources and effective water management, guided by the results of this study and by future investigations, offer a basis for meeting the future needs for water in the area.

2. Comparison of the low-flow characteristics of the streams has been made on the basis of unit runoff per square mile. However, because of the wide variations in the yield of the streams, and even on the same stream, interpolation of low-flow data presented in this report should not be made at ungaged sites on basis of drainage area without the aid of low-flow discharge measurements at the sites and without a knowledge of the geology, physiography, and other factors affecting the low flow.

3. The wide differences in the low-flow indices of the streams may be attributed, in part, to the depth to which the streams are incised, the relation of the water table to the bed of the stream, the porosity and permeability of the aquifers in the immediate area, and the characteristics of the alluvial sediments in the stream valleys. Some of the lower yielding streams in the area suggest possible locations for investigating ways and means of increasing the low flow.

4. As indicated by the data in this report, the geologic units that contribute appreciable water to the

low flow of streams in the study area are (in order of amount contributed): The "500-foot" sand in the Claiborne Group, the McNairy Sand Member of the Ripley Formation (McNairy Sand in Kentucky and Illinois), the Coffee Sand, the Tuscaloosa Formation, the Eutaw Formation, Paleozoic rocks, sands in the upper part of the Claiborne Group, and terrace deposits and alluvium.

The "500-foot" sand contributes the most water because of its large area of outcrop. The McNairy Sand produces more water per unit area, but has a less extensive area of outcrop.

The poor producers of water to the low flow of streams are the Demopolis Formation, the Coon Creek Tongue of the Ripley Formation, the Porters Creek Clay, clay beds in the upper part of the Claiborne Group, and the loess.

Sands of the Wilcox Group and of the Jackson(?) Formation are of little importance as water producers in the Mississippi embayment in Tennessee, Kentucky, and Illinois because the areas of outcrop are small.

5. Areal draft-storage relations for 10-year and 20-year recurrence intervals provide a convenient means for estimating the storage required to maintain a given minimum flow, the median annual 7-day low flow being used as an index. 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.

6. The chemical characteristics of water in streams during periods of low flow depend on the lithology of the geologic units in the drainage basins, but the chemical analyses of the water generally are not a sufficient basis for the differentiation of the geologic units. Water from streams originating in Paleozoic rocks and the terrace deposits can be distinguished from water from other formations by the higher dissolved-solids content and the characteristic calcium bicarbonate or calcium magnesium bicarbonate type. Water from the terrace deposits has more dissolved solids and a higher magnesium content than water from Paleozoic rocks.

Water from the Coffee Sand and from the McNairy Sand of Cretaceous age and that from the Wilcox and Claiborne Groups of Tertiary age are low in dissolved solids and have similar chemical characteristics. Water samples from streams originating in these deposits cannot be distinguished from each other.

Water from streams draining undifferentiated Eocene deposits and from streams draining a combination of undifferentiated Eocene deposits and Pliocene(?) deposits can be recognized by the variability in both the chemical character and dissolved-solids content. This water generally is higher in dissolved solids than water from the Coffee Sand, the McNairy Sand, the Wilcox Group, or the Claiborne Group, and is lower in dissolved solids than is water from Paleozoic rocks and the terrace deposits.

Water from Pliocene(?) deposits probably cannot be recognized as such. At one location the chemical characteristics are similar to those of water from the McNairy Sand, and at another location they are more nearly like those of water from Paleozoic rocks.

Low-flow surface waters in the study area generally would be excellent sources for municipal and industrial supplies. Water from streams draining most of the unconsolidated deposits is soft and has a low dissolved-solids content. The variations in the chemical characteristics are small. For most uses the water would require treatment for color, for iron removal, and for pH control.

The dissolved-solids content of water from streams draining Paleozoic rocks and the terrace deposits is the highest in the area. Water from these deposits is very hard and, for many uses, softening would be desirable.

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

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