WATER RESOURCES OF THE SOUTHEAST LOWLANDS, MISSOURI

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With a section on
WATER QUALITY, by Dale L. Fuller,
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CONVERSION FACTORS

For readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
foot	0.3048	meter
mile	1.609	kilometer
square mile	2.590	square kilometer
inch	25.40	millimeter
cubic foot per second	0.02832	cubic meter per second
cubic foot per second per square mile	0.01093	cubic meter per second per square kilometer
gallon per minute	0.06308	liter per second
acre-foot	0.001233	cubic hectometer

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

$$°F = 1.8\ °C + 32$$

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ABSTRACT

The Southeast Lowlands of Missouri occupies 4,000 square miles of prime agricultural land of the Coastal Plain in the extreme southeastern corner of Missouri. Even though this area receives about 4 feet of rainfall per year, there is a rapidly increasing demand for water for irrigation. The purpose of this study was to evaluate the water resources of this area with particular emphasis on the extent of irrigation and the potential of the ground-water system to support further irrigation development.

The area is underlain by consolidated aquifers of Paleozoic age and unconsolidated aquifers of Mesozoic and Cenozoic age. The consolidated aquifers, although possessing the potential to yield large quantities of water, generally are not used throughout much of the area because they lie at considerable depth and alternate supplies are readily available. In this report, the unconsolidated aquifers are divided into three systems; the McNairy aquifer of Cretaceous age, the Wilcox aquifer of Tertiary age, and the alluvial aquifer of Quaternary age. However, the alluvium and the Wilcox aquifer are often interconnected and the Wilcox Group (undivided) may contain more than one aquifer.

The McNairy aquifer, which underlies about three-fourths of the area, ranges from 0 to 600 feet in thickness with the top lying from 0 to more than 2,200 feet below land surface. This system is attractive as a municipal water supply because of its large artesian head and the small iron and hardness concentrations of the water. Although this system is now used exclusively for municipal water supplies, the McNairy may become more important in the future as a heat source.

The Wilcox Group (undivided), which underlies more than one-half of the area and almost always lies less than 300 feet below land surface, is as much as 1,400 feet thick. However, usually only the basal 250 to 500 feet of this group is used as an aquifer. This aquifer is recharged from the overlying alluvial aquifer near the subcrop of the Wilcox Group. This water then either flows into Arkansas or is withdrawn by municipal wells. This system, which in some areas is capable of yielding as much as 1,500 gallons per minute to properly constructed wells, is now primarily used for municipal supplies.

The alluvial aquifer underlies most of the area and is locally capable of yielding more than 3,000 gallons per minute. This aquifer generally is 100 to 200 feet thick, but in several places more than 250 feet of alluvium has been reported. This system, which supplies water to several thousand irrigation wells, plus many municipal and industrial wells, is recharged from local precipitation and discharges by evapotranspiration and to the surface-water

system. Irrigation wells withdraw an estimated 95,000 acre-feet per year from this aquifer, whereas municipal, industrial, and domestic wells withdraw an estimated additional 17,000 acre-feet per year. This compares to nearly 6 million acre-feet per year natural discharge and a total storage of 60 million acre feet.

The surface-water system in the area consists of a few natural rivers and many manmade ditches. The ditch system transformed much of the area from swamp to cropland. Even with this ditch system, the area still experiences periodic flooding that inundates tens-of-thousands of acres. Although a considerable quantity of water is available from the surface-water system, this system is not extensively used because attractive alternative sources are readily available.

Further study of the water resources of the area is needed. Monitoring of water levels in the alluvium needs to be continued, and the water-level network needs to be expanded to include the deeper aquifers. Much more additional data on water use needs to be collected. The mechanisms of recharge and the effect of concentrated rice irrigation west of Crowleys Ridge need to be investigated. And finally, a comprehensive study needs to be made of future water-management alternatives for the area.

INTRODUCTION

Description of the Area

The Southeast Lowlands, locally called "The Bootheel," comprises approximately 4,000 square miles of low-lying land in the Mississippi embayment in the extreme southeastern corner of Missouri (fig. 1). The Mississippi embayment is only a part of the vast geologic and hydrologic Coastal Plain province and only a small percentage of the area of the Mississippi embayment is in Missouri. A visitor traveling from the Ozark Plateaus into the Southeast Lowlands will notice extreme differences in elevation, topographic features, flora, land use, and even the life style of the people.

Although this area was once commonly referred to as "Swampeast Missouri," the Southeast Lowlands is presently (1978) an intensely developed agricultural area that provides 15 percent of the agricultural crop output for the entire State of Missouri. A wide variety of crops can be grown in the area. Soybeans, corn, cotton, wheat, and other small grains are the major crops, but numerous other crops, such as rice, watermelons, truck crops, sunflower seeds, and catfish also are grown in this area.

Purpose and Scope of the Study

Previous studies in Missouri have described the water resources of four large areas of the State (Gann and others, 1971, 1973, 1974, 1976). With the completion of these studies, that part of the Mississippi embayment in southeastern Missouri was the only major area in the State without a recent description of the water resources. This, coupled with the increasing demand for water for irrigation in southeastern Missouri, prompted the Missouri Department of Natural Resources, Division of Geology and Land Survey, and the U.S. Geological Survey to enter into a cooperative study to evaluate the water

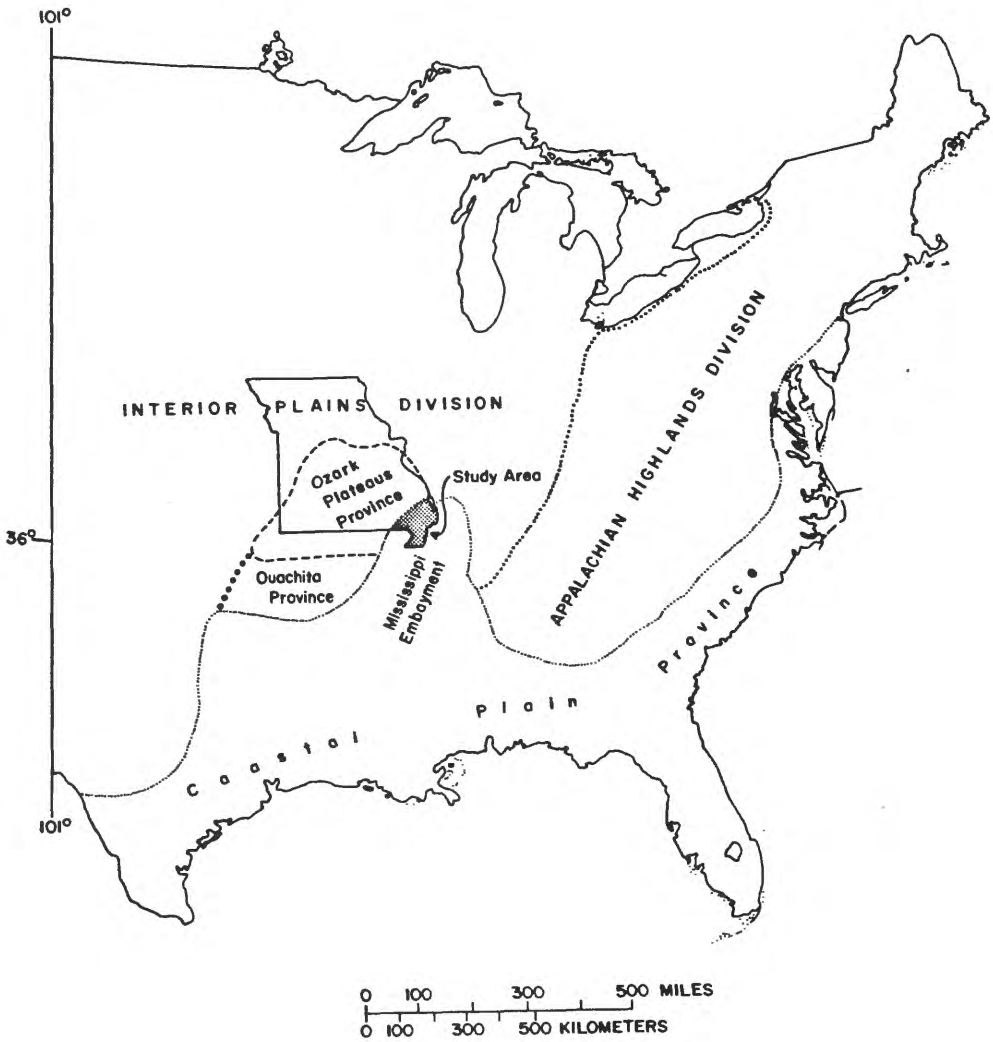


Figure 1.--The part of southeastern Missouri lying within the Mississippi embayment.

resources of this important area. Although the primary purposes of the study were to evaluate the extent of irrigation and the potential of the ground-water system in the area to support further development for irrigation, this study also was to evaluate the total water resource of the area.

The major objectives of the study were to (1) collect quantitative data to describe the characteristics of the ground-water system; (2) define the present level of development of the ground-water system for irrigation; (3) evaluate the surface-water system; (4) compute the quantity of water that may be developed for future use; and (5) evaluate the present water quality within the hydrologic system to provide a baseline from which future changes may be measured. The primary products of the study are a report containing hydrologic data (Luckey and Fuller, 1980) and this report.

Acknowledgments

The assistance and information provided by residents of the area are gratefully acknowledged. The landowners and irrigators were extremely helpful and friendly to all field personnel collecting data in the area. Particular thanks are extended to those landowners who permitted the drilling of test holes on their property, or allowed extensive tests to be made on their wells. Several offices of the U.S. Department of Agriculture, Soil Conservation Service, provided information on irrigation and well locations; and personnel of the University of Missouri-Columbia Delta Center Experimental Farm at Portageville were extremely helpful in explaining irrigation practices and crop requirements in the area, as well as allowing the use of their experimental farm to perform several tests. The electric utility companies in the area provided data that allowed the author to estimate water use for some of the principal crops in the area.

PHYSICAL AND CULTURAL ENVIRONMENT

Physiography

The Mississippi embayment is a northern extension of the Coastal Plain province of Fenneman (1938). The embayment occupies a broad structural trough between the Appalachian Highlands on the east and the Ozark Plateaus on the west. The embayment reaches its northernmost point at Cape Girardeau, and extends south and merges with the main body of the Coastal Plain.

Within the Mississippi embayment of Missouri there are several important physiographic features (fig. 2). The oldest features in the area are Crowleys Ridge, Benton Hills, and Hickory Ridge (Grohskopf, 1955). Crowleys Ridge, the largest feature, extends as far north as northern Stoddard County and has a maximum width of about 20 miles. The ridge narrows to the south where the average width is about 8 miles. It extends through northern Dunklin County and then outside the study area as far south as Helena, Arkansas. This ridge, which is an erosional remnant of a plain that once existed in this area, is as much as 200 feet higher than the surrounding country. The north and east edges form distinctive bluffs, but the west edge usually is less distinctive and often merges nearly imperceptibly with the lowlands to the west.

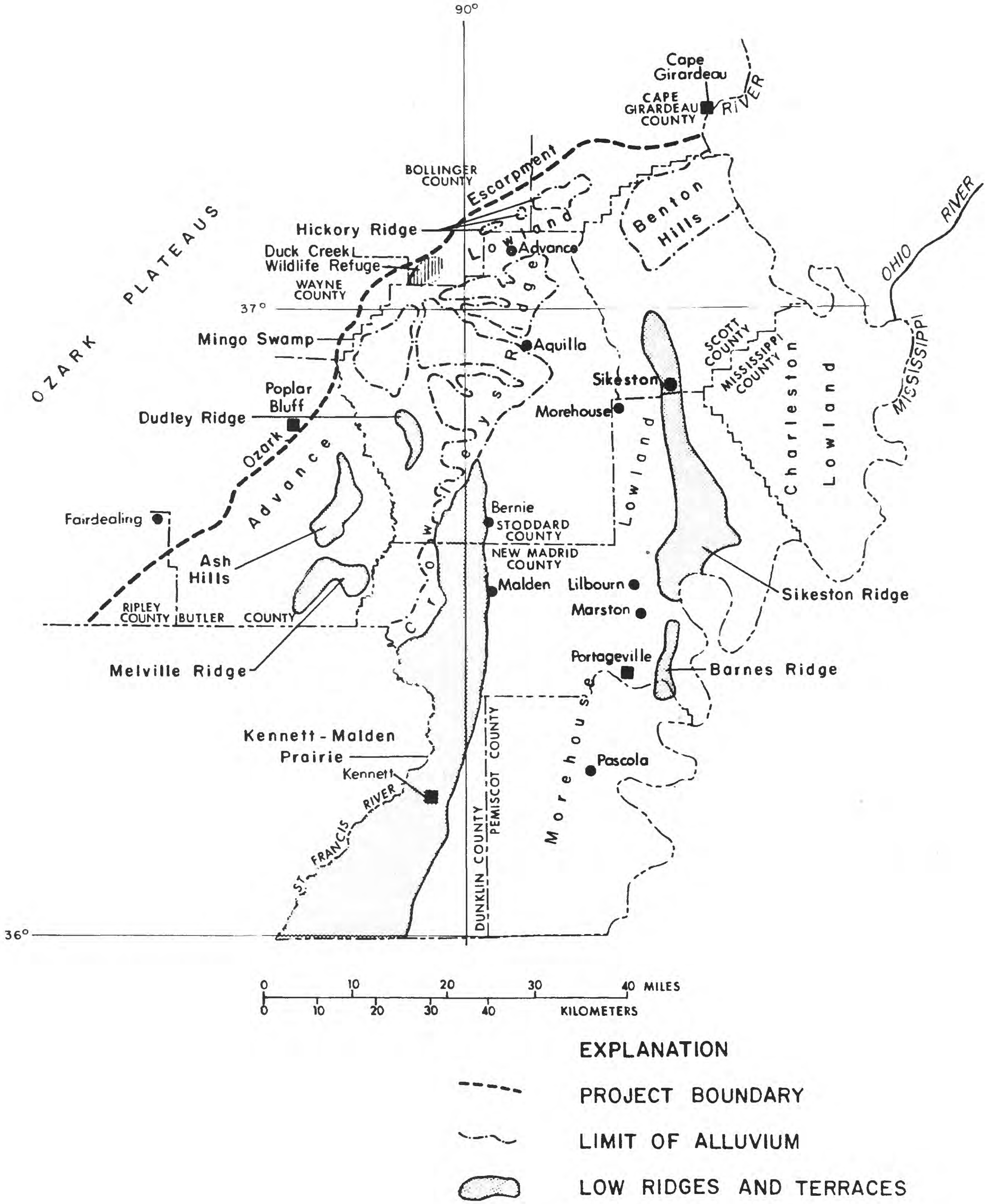


Figure 2.--Physiographic map of southeastern Missouri.

Benton Hills of northern Scott County is a physiographic feature similar to Crowleys Ridge. This upland area, which is about 12 miles long and 8 miles wide, is about 250 feet above the surrounding country and is bounded on all sides by steep bluffs. The southeast and northwest edges of Benton Hills are in line with the southeast and northwest edges of Crowleys Ridge and appear to be extensions of them. Benton Hills also has been referred to as "Scott County Hills" (Magill, 1958). Although parts of Benton Hills and Crowleys Ridge are topographically similar to the Ozark Plateaus to the north and west, much of these uplands are more closely related to the rolling hill country of western Tennessee and Kentucky.

A smaller upland area, Hickory Ridge, occurs in southern Cape Girardeau County. This ridge, which is an erosional remnant of the Ozark Plateaus, is similar to the northern parts of Crowleys Ridge and Benton Hills.

The prairies and other ridges are younger, slightly elevated sand features. Sikeston Ridge in Scott and New Madrid Counties is the most prominent younger ridge. It is a relatively flat terrace that is approximately 20 feet higher than the surrounding area and extends from about 5 miles north of Sikeston to New Madrid County. A smaller ridge to the south, called Barnes Ridge or Scrub Ridge, may be an extension of the same feature. Sikeston Ridge generally is about 1½ to 3 miles wide and is more than 25 miles long.

The Kennett-Malden Prairie is a major terrace on the east flank of Crowleys Ridge. This terrace, which is from a few feet to more than 15 feet above the lowlands to the east, extends from Dexter south through Dunklin County and into Arkansas. The Kennett-Malden Prairie in Missouri is more than 55 miles long and in places more than 10 miles wide.

Three smaller, named ridges exist west of Crowleys Ridge. These are called Dudley Ridge, Ash Hills, and Melville Ridge. All three are only from 1 to 3 miles wide, and from 5 to 15 miles long.

In southeastern Missouri there are three major, named lowland areas. The easternmost lowland, referred to as either the Charleston Lowland or the Mississippi Lowland, occupies the area between Sikeston Ridge and the Mississippi River. Some investigators (Grohskopf, 1955), extend this lowland area into Pemiscot County where it merges with the Morehouse Lowland. Between Sikeston Ridge and the Kennett-Malden Prairie or Crowleys Ridge, is the Morehouse Lowland. This lowland contains the lowest surface elevation in Missouri and extends from the northern part of Scott and Stoddard Counties into Arkansas. The westernmost lowland is called the Advance Lowland and occupies the area between the Ozark escarpment and the northern and western edges of the Benton Hills and Crowleys Ridge. This lowland is about 15 to 30 feet higher than the Morehouse Lowlands and the Charleston Lowlands to the east of Crowleys Ridge.

Before development of the drainage system, much of these three lowlands were vast swamps or poorly drained areas similar to the present Mingo Swamp in Stoddard and Wayne Counties. These areas originally were thought of only as a source of timber, but after clearing and draining, these lowlands have become major agricultural areas that are as productive as the prairies.

The area is drained by the Black River, St. Francis River, Little River ditch system, the Headwater diversion channel, and a number of smaller rivers (see fig. 31, p. 64). Some of the area also drains directly into the Mississippi River. The net outflow from the area is about 4 million acre-feet per year.

Much of the surface-water drainage is through a system of canals. This system of canals has changed much of southeastern Missouri from a formidable swamp into a major agricultural area by providing the needed avenue for runoff and sufficiently lowering ground-water levels so that the land may become more productive.

Climate

The lowlands of southeastern Missouri are warmer and receive more precipitation than the remainder of the State, especially during the winter. A summary of the climate of the area by McQuigg and Decker (1963) points out that during December, January, and February the lowlands may average nearly 3 inches more precipitation per month than northwest Missouri, and the average temperature is nearly 10 degrees warmer.

During 1956-75 mean annual precipitation in the area ranged from 45 to 49 inches per year (fig. 3). The average monthly precipitation at Sikeston (fig. 4) shows a fairly uniform distribution in time. This graph, based on 46 years of record (1930-75) shows that Sikeston receives about 4 inches of precipitation each month.

During 8 months of the year, precipitation exceeds potential evapotranspiration. Potential evapotranspiration is the quantity of water that could be lost from the soil by evaporation and transpiration by plants under a no-stress condition. During June through September the potential evapotranspiration is greater than precipitation and it exceeds precipitation by nearly 3 inches per month during July and August. The estimated annual potential evapotranspiration in the area is nearly 32 inches per year (McQuigg and Decker, 1963). The Weather Service Class A pan evaporation for 1946-55 averaged about 52 inches per year (Asheville, N.C., National Climatic Center, oral commun., May 26, 1978).

The average January temperature in the area is approximately 37 °F. The humidity is somewhat higher during the winter and lower during the summer and averages about 75 percent. Snowfall in the area is quite variable, but averages about 7 inches per year.

History

The first white men to enter what is now southeastern Missouri may have been a small contingent of DeSoto's army. Hernando DeSoto discovered the Mississippi River during 1541 and, although he crossed it near Memphis, Tennessee, some historians believe that a small contingent of his army may have explored southeastern Missouri (Larkin, 1975).

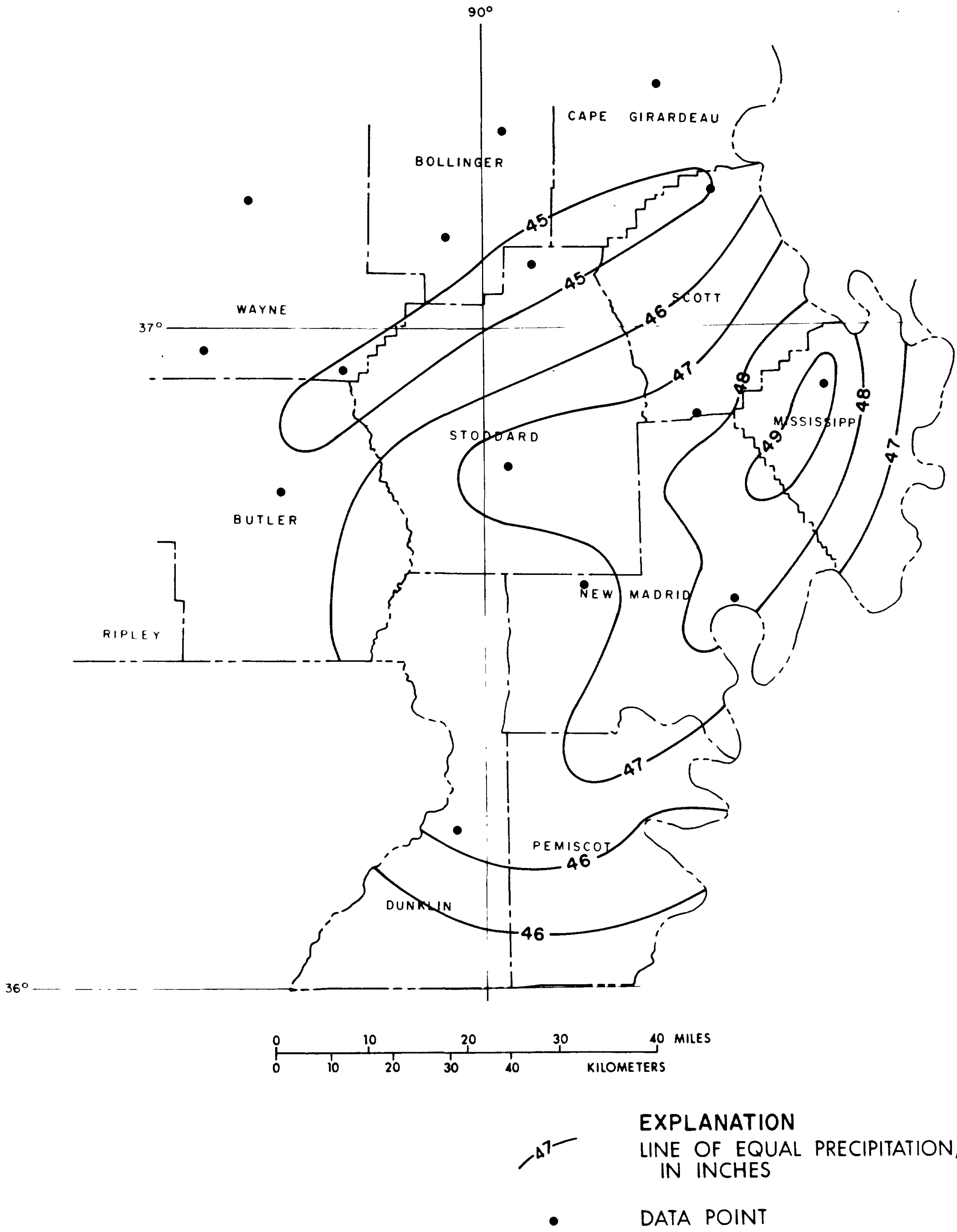


Figure 3.--Mean annual precipitation in southeastern Missouri, 1956-75.

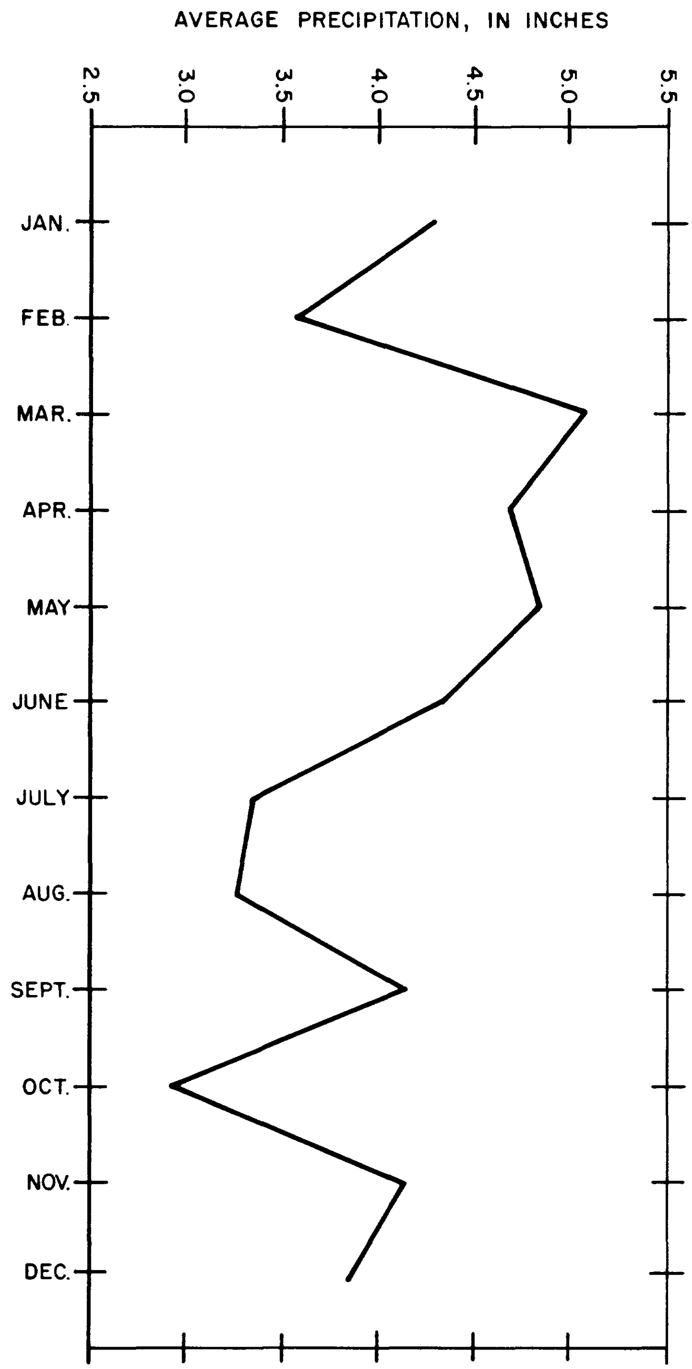


Figure 4.--Average monthly precipitation at Sikeston, 1930-75.

By the latter part of the 18th century, the French had settled on the terraces of southeastern Missouri and during 1789, Kingshighway was opened from New Madrid along Sikeston Ridge and north to Sainte Genevieve.

December 16, 1811, is a major date in the history of southeastern Missouri. It was on this date that the New Madrid earthquake series began and the devastating series of shocks lasted for more than a year. Fuller (1912) commented, "scientific literature in this country and in Europe has given it [New Madrid earthquake] a place among the great earthquakes of the world***." The first major shocks of the earthquake series occurred on December 16 and 17, 1811. A similar destructive earthquake occurred January 23, 1812, but perhaps the most destructive shock occurred on February 7, 1812. These quakes were so severe that the shocks could be felt throughout more than one-half of the United States without the aid of instruments. Various observers tabulated the number of shocks and all agree that a considerable number occurred. One observer tabulated 500 shocks before becoming tired of the task. Jared Brooks (Casseday, 1852) classified 1,874 shocks between December 16, 1811 and March 15, 1812. The total number of shocks involved in this series probably was more than 2,000.

Throughout the 19th century, population of southeastern Missouri continued to increase. The agricultural potential of the area, which had attracted many of the early French settlers, continued to be a major attraction. By about the time of the Civil War, railroads were beginning to be built in the area and late in the century logging operations were quite prevalent.

The dragline dredge was developed during the early 20th century. This development was to have a major impact on southeastern Missouri because it was now feasible to begin drainage of the lowland swamps. During 1907 the Little River Drainage District was formed to drain 560,000 acres of land in the Advance and Morehouse Lowlands. Nolen (1912) said, "The greatest drainage project in the United States is the Little River Drainage District in southeast Missouri." At the time of the district's formation only 6 percent of the land in the district was cleared and cultivated. During 1913 the drainage network was actually begun and by the 1930's much of the lowlands in southeastern Missouri had been drained. By the mid-1950's there were more than 2,000 miles of ditches in the area and even at present (1978) the drainage network is being improved and extended.

Population

The population of the study area during 1978 is estimated at about 155,000 and slightly more than one-half the population live in urban areas. There was a net migration out of the area of approximately 18 percent during 1960-70 and, in making the 1979 population estimate, it was assumed that this net outward migration has continued. The major population centers of the area are Cape Girardeau, Poplar Bluff, and Sikeston (see fig. 2).

Economy

The economy of southeastern Missouri is primarily based on agriculture. Agribusiness, composed of both agriculture and the related support functions, is by far the largest industry in the area. Along the Mississippi River there are several industries dependent on the river. There is a major ship-building industry in Pemiscot County and a large aluminum-processing plant and powerplant in New Madrid County. Although this is not a major industrial area, almost every city has some local industry.

GEOLOGIC ENVIRONMENT

Geologic History

A section on the geologic history of the area probably could start with the formation of the core of the Ozark uplift about 1.2 billion years ago. This history could continue through the Paleozoic Era when ancient seas repeatedly covered the area and thick sequences of marine sediments were deposited. However, such a history is beyond the scope of this report.

For the purpose of this report, the geologic history of the area started in Late Cretaceous time about 100 million years ago. It was about this time that a structural trough began to form. This synclinal trough, which Fisk (1944) referred to as the Mississippi structural trough, extends northward from the Coastal Plain to the northern limit of the Mississippi embayment. It continued to subside as it filled with sediment until about 40 million years ago (Thacker and Satterfield, 1977).

The formation and deepening of the Mississippi structural trough allowed Cretaceous and Tertiary seas to invade southeastern Missouri. For approximately 60 million years, various sediments were deposited in southeastern Missouri. These sediments range from deep-sea deposits of clay and limestone to near-shore deposits of sand and even small gravel.

The axis of the trough probably moved from west to east during this 60 million years (McCracken, 1971). This is in contrast to the southern part of the embayment where the axis probably moved from east to west. In Missouri the sediments thicken from west to east, and from north to south.

Approximately 40 million years ago at the close of Eocene time the seas retreated from the area and erosion began. The area has remained above sea level and has been subject to erosion since that time. Figure 5 is a pre-Quaternary geologic map that shows the various sediments that were deposited in the area. The last major chapter of geologic history in the area occurred during the last 1 million years when the ancestral and present-day Mississippi and Ohio rivers deposited a thick layer of alluvium in the area.

The present-day topography of the area is largely a result of erosion and deposition by two major rivers, the Mississippi and the Ohio. These two rivers did not always occupy their present position, but changed their courses through various parts of the area during different periods. Generally, the courses of these rivers have moved from west to east with time.

A review of the theories on the formation of the lowlands and a detailed explanation of the possible evolution of the river system is given in Magill (1968). The brief outline given here generally follows the explanation of Magill.

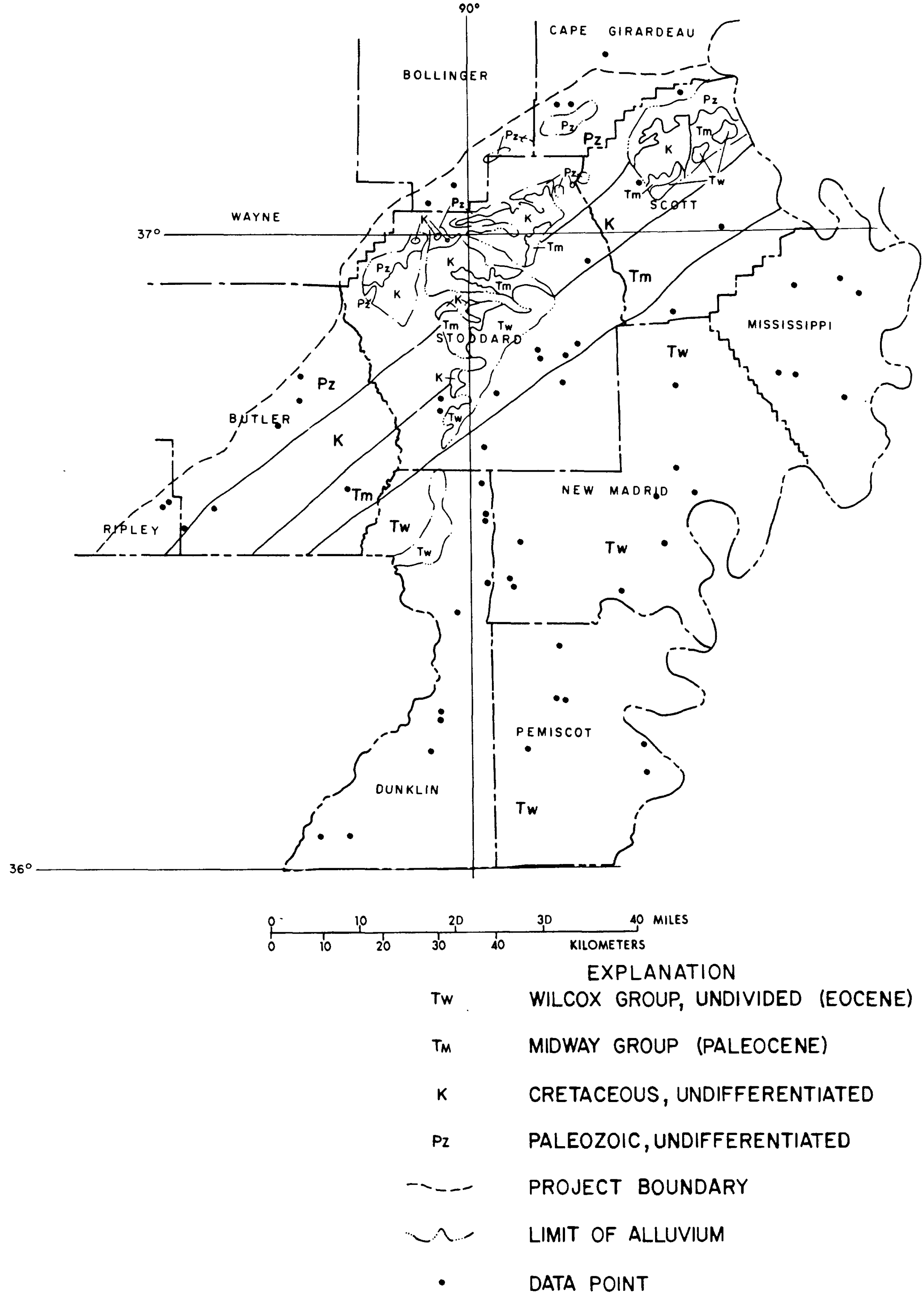


Figure 5.--Pre-Quaternary geologic map of southeastern Missouri.

The Mississippi River originally turned west just south of Cape Girardeau and flowed through the area now occupied by the Advance Lowlands (see fig. 2). The Ozark escarpment was at one time the west bank of the river. The boundary between the Ozarks and the Lowlands consists of long, graceful arcs that are typical of erosion by a major river. At the same time the Ohio River probably flowed through an area of Illinois north of its present course and along the southeastern edge of Benton Hills and Crowleys Ridge. The western limit of this river probably was at least partially controlled by several faults in the area. At this time, the Ohio River was lower than the Mississippi River. The Ohio River then captured the Mississippi River through the process of stream piracy, and the Mississippi River eroded the gap between Crowleys Ridge and Benton Hills. At this time, the Ohio River may have been further east and may have occupied the Charleston Lowlands instead of the Morehouse Lowlands. If this were the case, the two rivers probably joined somewhere south of New Madrid between the Little River and the present course of the Mississippi River. Later, the Ohio River again captured the Mississippi River through a tributary on the east side of Benton Hills. The rivers then joined at Cairo, Illinois, and the present drainage pattern was set.

Stratigraphy

A generalized stratigraphic section is given in table 1, which gives a general description of the sediments that have been deposited in the area during the last 100 million years. A geologic section that illustrates the stratigraphy of the area is shown in figure 6.

The McNairy Formation of Cretaceous age is the oldest formation of importance in terms of this water-resources study. This formation, which locally is referred to as the "Ripley Sand," is a widespread aquifer primarily used for municipal supply. Overlying the McNairy Formation are several formations that are significant to this report only in that they impede the movement of ground water. Overlying these is the Wilcox Group (undivided) of Tertiary age, which is a major source of water throughout much of the southeastern part of the area. This group may actually contain two or more aquifers and these aquifers generally are described separately in reports covering areas further south. The Quaternary alluvium, the youngest unit, is an aquifer throughout most of the area. In terms of water-use and water-yielding ability, the alluvium is the major aquifer in the area.

For a description of the stratigraphy of the Paleozoic units that are not covered in this report and much more detailed description of the formations of Mesozoic and Cenozoic age, the reader is referred to Koenig (1961) and Grohskopf (1955).

GROUND-WATER SYSTEM

The embayment part of southeastern Missouri is fortunate to have a large and renewable ground-water supply. Much of the area has at least several hundred feet of unconsolidated saturated sediments and, in some areas, this saturated material is more than 2,000 feet thick. For convenience in discussing

Table 1.--Generalized stratigraphic section for the Mississippi embayment of southeastern Missouri

[The stratigraphic nomenclature used in this report is that of the Missouri Division of Geology and Land Survey and differs somewhat from the current usage of the U.S. Geological Survey]

Era	System	Group	Formation	Maximum thickness expected (ft)	Est. age of time boundaries (m.y.)	Extent	Lithologic character	Hydrologic character
Cenozoic	Quaternary		Alluvium	250	0	Underlies entire lowland area.	Gravel, sand, silt, and clay.	Chief aquifer in the area. May yield 3,000 gal/min to wells in some localities.
			Loess	35	2	Covers Crowleys Ridge, Benton Hills, and uplands.	Tan to brown silt. May contain some clay.	Occurs above the water table.
	Tertiary		Terrace Gravel	60	(?)		Gravel, cobbles, some clay.	
		Wilcox		1,400	40 54	Crops out on Crowleys Ridge and Benton Hills. Underlies all of area south and east of line from Campbell to Charter Oak to Sikeston to Lusk.	Sand, some clay. Contains thin beds of lignite.	A major aquifer used chiefly for municipal supply. Known to yield 1,500 gal/min in favorable localities. May contain at least two aquifers with separate potentiometric surfaces.
		Midway	Porters Creek Clay	650	54	Crops out on Crowleys Ridge and Benton Hills. Underlies all of area south and east of a line from Neelyville to Bloomfield to Commerce.	Clay, light grey when dry, but dark grey when wet.	Does not yield significant quantities of water to wells. Acts as barriers to ground-water movement.
			Clayton Formation	30	65		Calcareous, glauconitic sand and clay to fossiliferous limestone.	
Mesozoic	Cretaceous		Owl Creek Formation	100	65	Crops out on Crowleys Ridge and Benton Hills. Underlies entire area except within about 10 mi of Ozarks.	Bluish-gray to brown sandy clay.	Generally impedes the flow of ground water.
			McNairy Formation	600 (combined thickness)			Sand, sandy clay, and clay; Nonmarine at outcrop, but marine in deep part of the embayment.	A significant aquifer widely used for municipal supplies. High heads make this aquifer attractive but excessive mineralization and high temperatures limit its use in some areas.
			Pre-McNairy Cretaceous Beds		100	Present only in deeper parts of the embayment.	Sand, chalk, marl, clay, and limestone.	
Paleozoic	Numerous formations. For description, see Koenig, J. W. (ed), 1961, The stratigraphic succession in Missouri.			>2,680	375 570	Crops out on Crowleys Ridge, Hickory Ridge, and Benton Hills. Underlies entire area.	Limestone, sandstone, and dolomite	Used for municipal supplies close to the Ozarks. Would probably yield large amounts of water in other areas but this water may be highly mineralized in some areas.

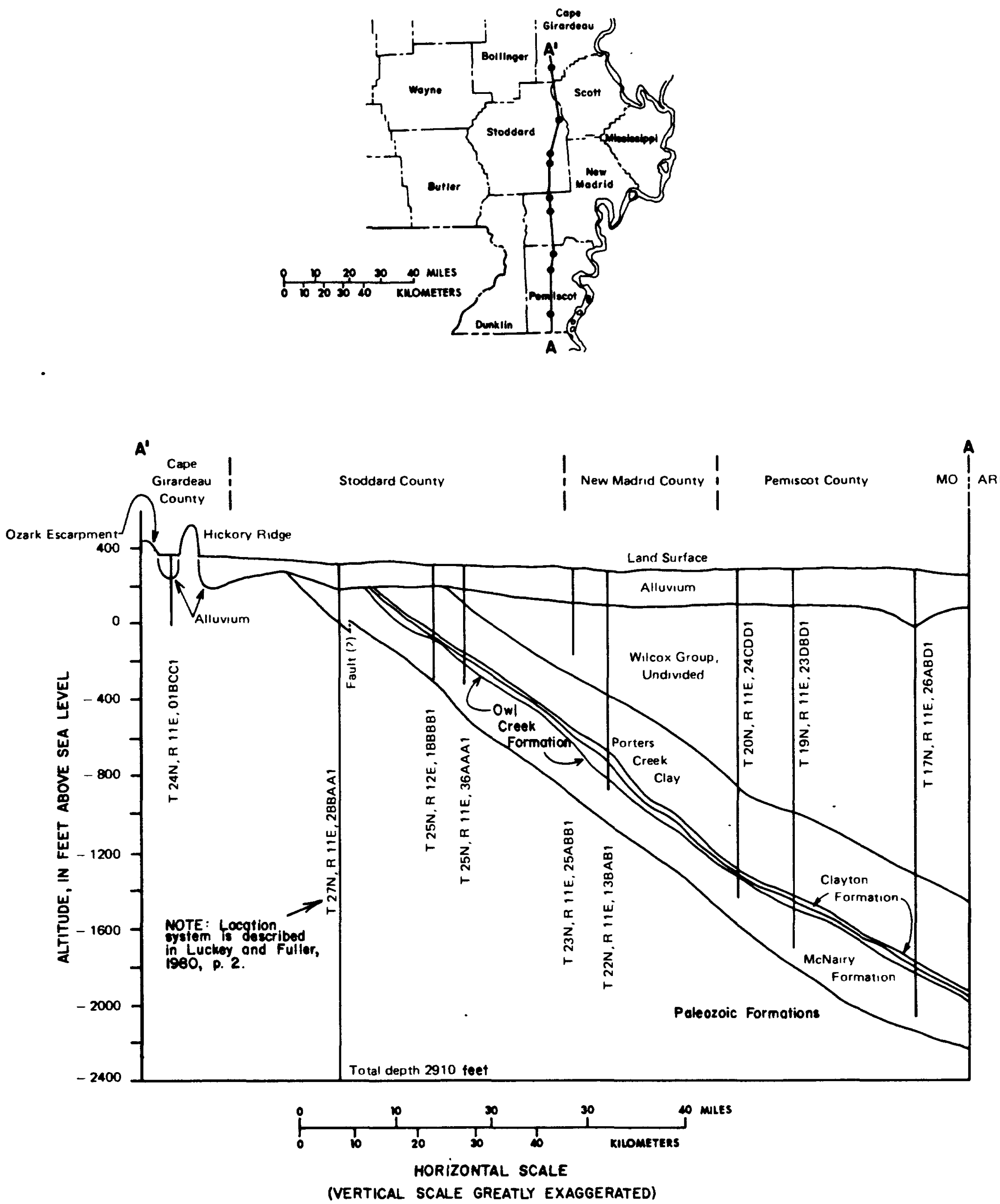


Figure 6.--Geologic section through southeastern Missouri.

the ground-water system, the unconsolidated sediments are divided into three units; the alluvium, the Wilcox Group (undivided), and the McNairy Formation. However, the alluvium and Wilcox Group are often interconnected and the Wilcox Group may contain more than one aquifer. A number of Paleozoic formations also may be aquifers, although throughout much of the area they are too deep to be of practical importance.

Alluvium

The alluvium consists of unconsolidated sand, gravel, silt, and clay that were laid down during the last 1 million years by the Mississippi and Ohio rivers and their tributaries. The alluvium covers about 3,600 square miles, or 90 percent of the project area. Only Crowleys Ridge, Benton Hills, and Hickory Ridge are not covered with alluvium (see fig. 2).

The thickness of the alluvium is fairly uniform (fig. 7), except near the edge of the Ozark escarpment or near Crowleys Ridge where it is less than 50 feet thick. In several places drillers reported penetrating more than 250 feet of alluvium, and in one well in Mississippi County more than 300 feet of alluvium was reported. However, most of the area is underlain by 100 to 200 feet of alluvium with a few areas having more than 200 feet. The thickest sequence of alluvium is where it has filled trenches eroded in the pre-Quaternary surface. These trenches are likely to be fairly narrow and may be difficult to find without extensive test drilling.

Water-Level Fluctuations

The pore space in the alluvium is filled with water and this water is available to wells penetrating the alluvium. The saturated alluvium is referred to as the alluvial aquifer and the point at which the water is under atmospheric pressure is referred to as the water table or potentiometric surface. The water level in a well completed in the alluvial aquifer stands at the water table. The water table is not static, but changes with time in response to various stresses.

A plot of the water level in the McGuire well 4 miles south of Malden (see fig. 2) for 1957-77 is shown in figure 8. The Missouri Division of Geology and Land Survey has maintained a continuous water-level recorder on this well since late 1956. The water level in this well shows seasonal fluctuations, but no appreciable long-term trend (fig. 8), and was lower during dry weather, such as the early 1960's, than it was during wet weather. Although there is a considerable amount of irrigation in the Malden area, only a few irrigation wells have been drilled within 2 miles of this recorder.

The water level in a well in Sikeston (see fig. 2) that also is equipped with a continuous water-level recorder is shown in figure 8. The water level in this well varies more on a month-to-month basis than the McGuire well, but this well also does not show any long-term trends in water levels for 1957-77.

Semiannual water-level changes throughout the entire area were monitored during 1976 and 1977. The water-level change from spring to fall 1976 is shown in figure 9; the water-level change for the same period during 1977 is shown in figure 10. A generally declining water level during the summer due to decreased recharge, increased evapotranspiration, and declining stage in the major rivers, is shown in figures 9 and 10.

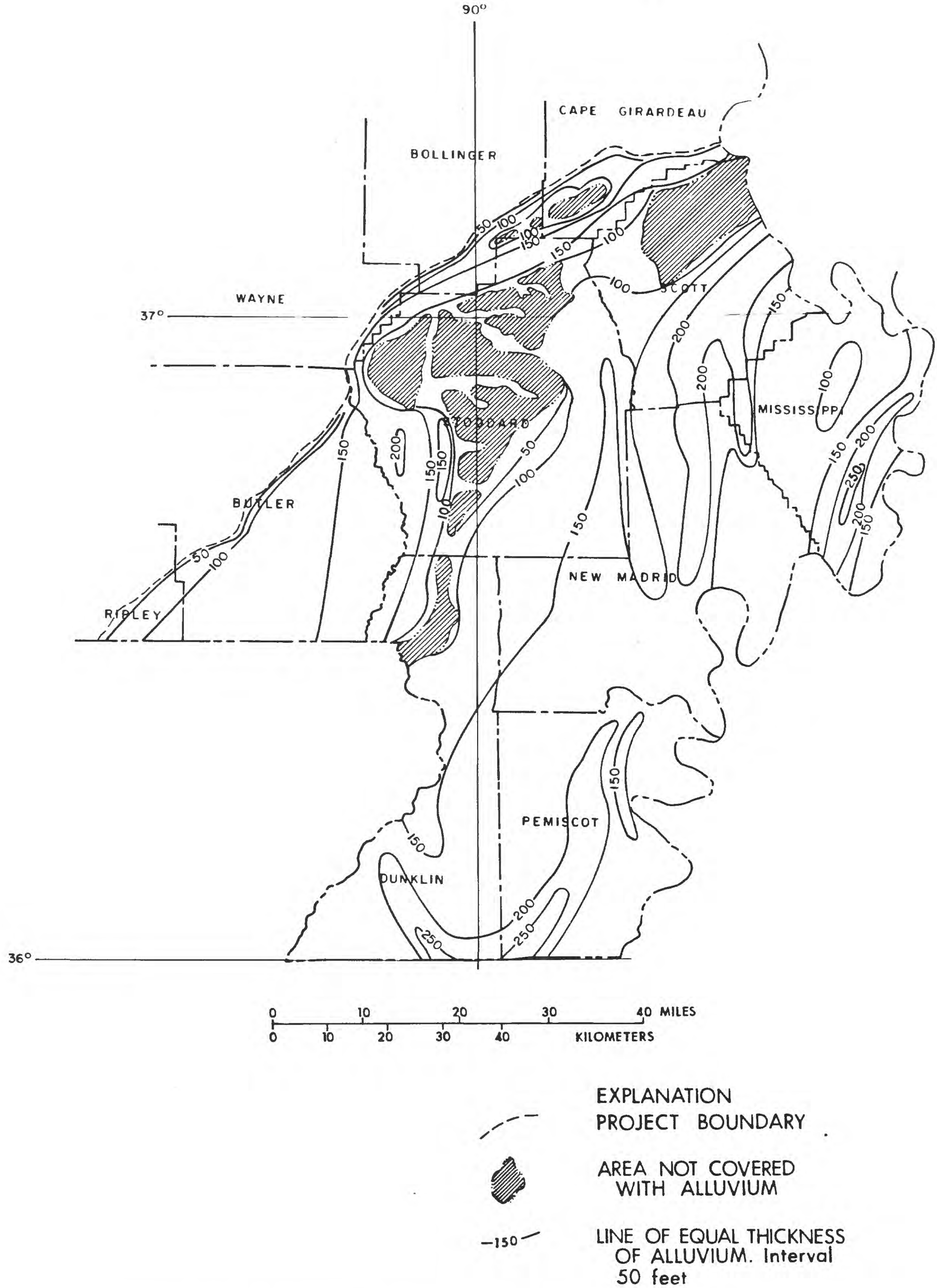


Figure 7.--Thickness of the alluvium in southeastern Missouri.

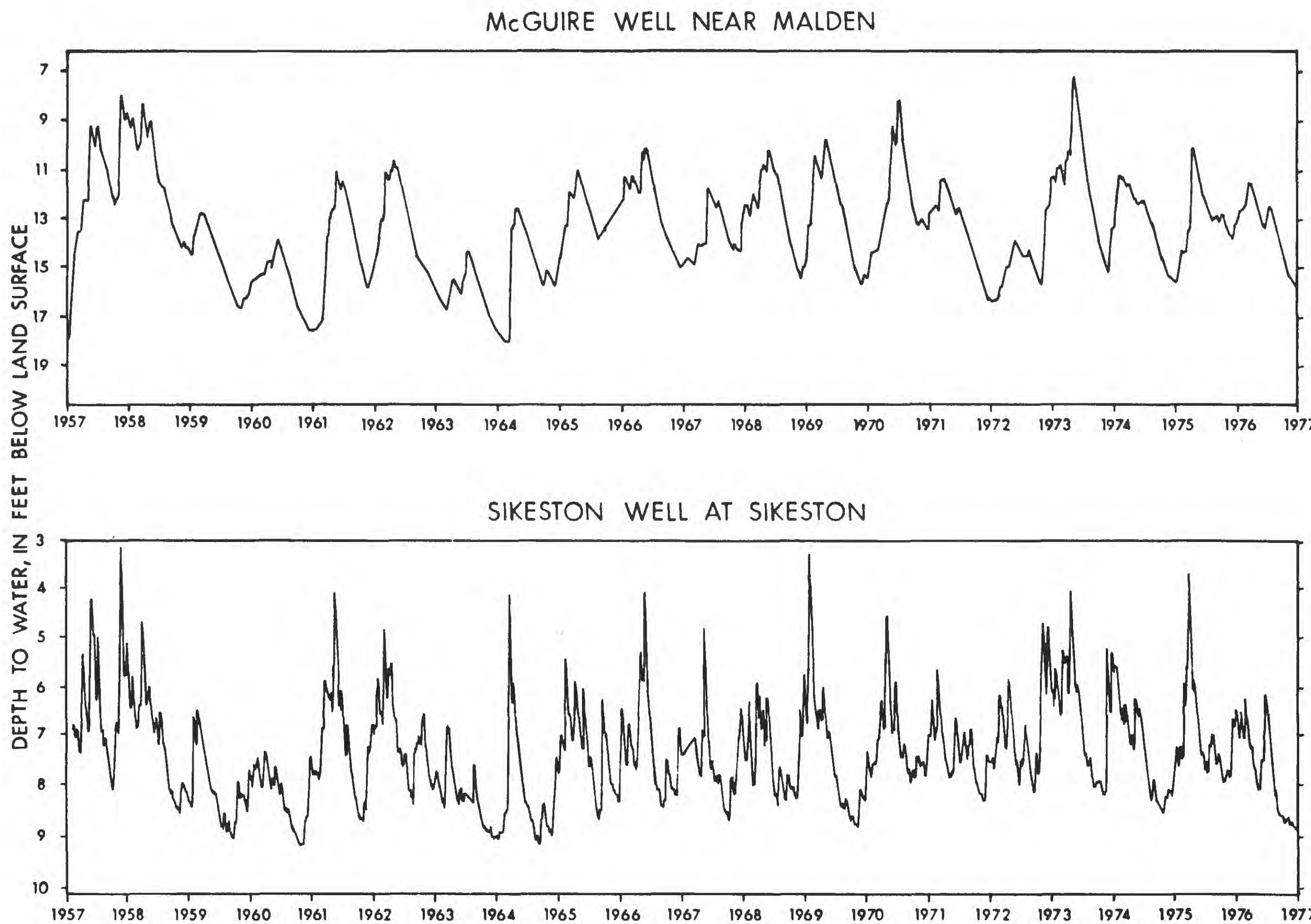


Figure 8.--Hydrographs for the McGuire and Sikeston wells, 1957-77.

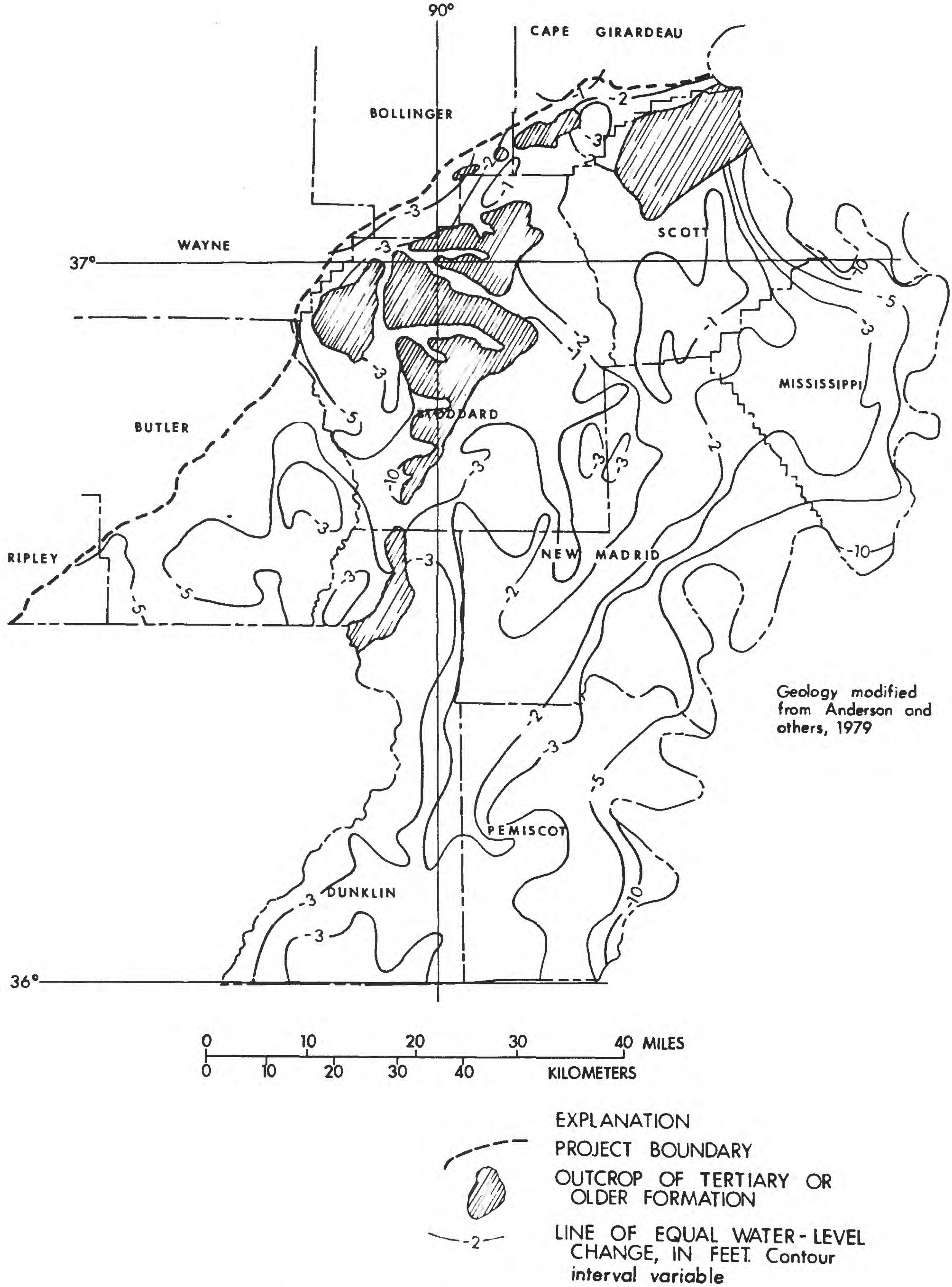


Figure 9.--Water-level changes in the alluvial aquifer in southeastern Missouri from spring to fall, 1976.

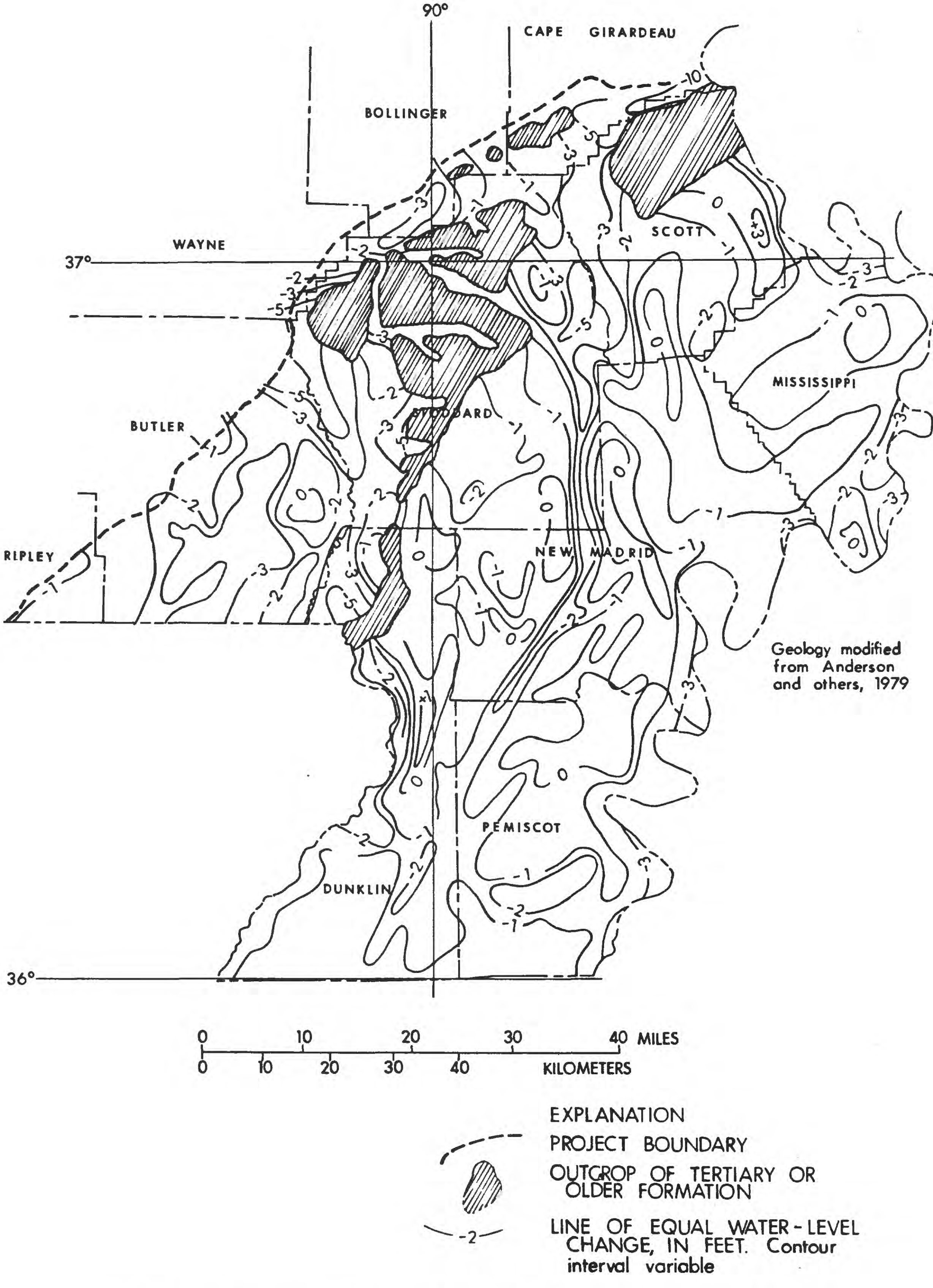


Figure 10.--Water-level changes in the alluvial aquifer in southeastern Missouri from spring to fall, 1977.

During 1976 the largest water-level declines were observed near the Mississippi River. These declines were due to the change in stage in the river from the springtime high to the fall low. Ground-water levels declined more than 10 feet in a few observation wells near the river and declines of more than 5 feet were observed several miles away from the river. During this period, the stage of the Mississippi River declined more than 15 feet. The area west of Crowleys Ridge had a larger average decline than the area to the east. The water-level decline on the west side of Crowleys Ridge averaged about 5 feet, whereas the water-level decline on the east side of the ridge averaged about 2½ feet. The larger declines to the west were due to the combined effects of a declining stage of the St. Francis River, tighter soils that retard recharge, and larger withdrawal to irrigate the rice crop in the area. All these water-level declines were temporary and the water levels recovered during the winter of 1976-77.

Water-level changes from spring to fall 1977 were much smaller. The water-level stage of the Mississippi and other major rivers declined a few feet from spring to fall 1977 and, hence, there were only small ground-water level declines near the rivers during 1977. The largest declines occurred along the lower reach of the Headwater Diversion Canal with water levels in three wells declining more than 10 feet and a larger area having water-level declines of more than 5 feet. A significant area near the St. Francis River west of Crowleys Ridge also had water-level declines of more than 5 feet.

Several areas of water-level rises are shown in figure 10. These water-level rises generally occur in the sandier, more permeable soils and probably are the result of recharge that occurred during the late summer or early fall of 1977. These rises are at most a few feet, but they are significant because water levels normally would be expected to decline several feet during this period.

The area west of Crowleys Ridge again had a larger average decline than the area east of the ridge. However, the decline in the area west of the ridge was much smaller during 1977 than it was during the same period in 1976.

Water levels in a well at the Duck Creek Wildlife Refuge in Bollinger County and the precipitation record at nearby Advance (see fig. 2) are shown in figure 11. The response of this well to precipitation can easily be seen. For example, the 8-inch rainfall during late November 1973, produced a rapid 3-foot rise in the water level. A similar intense rainfall during September 1972 produced a comparable rise. During the summer more of the rainfall usually replenishes depleted soil moisture than recharges the aquifer. This can be seen during mid-July 1972 and during late May 1973. The water level in this well declines rapidly during periods of limited rainfall. The dry summer of 1973 produced more than a 5-foot decline in water levels in this well.

Another rapid response to stress is shown by the water level in a well 8 miles south of Poplar Bluff in the rice-growing area. A hydrograph of the water level in the well during parts of May and August 1977 is shown in figure 12. This well is surrounded by large-capacity wells used to irrigate rice. The decline in water levels during May 12 through May 18, 1977, is in response to pumping an irrigation well 3,100 feet to the north. The well to the north

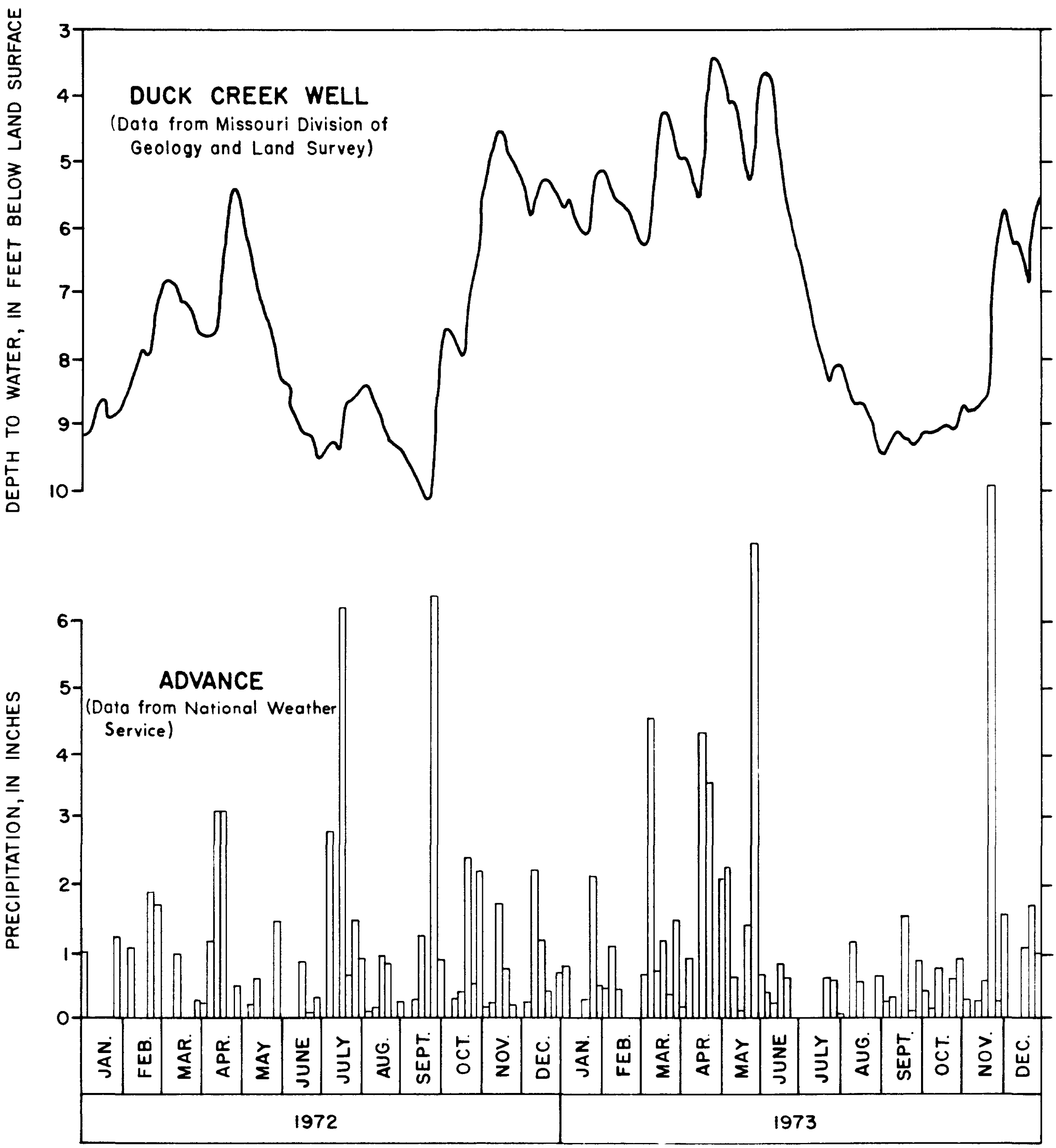


Figure 11.--Hydrograph for the Duck Creek well and precipitation at Advance, 1972-73.

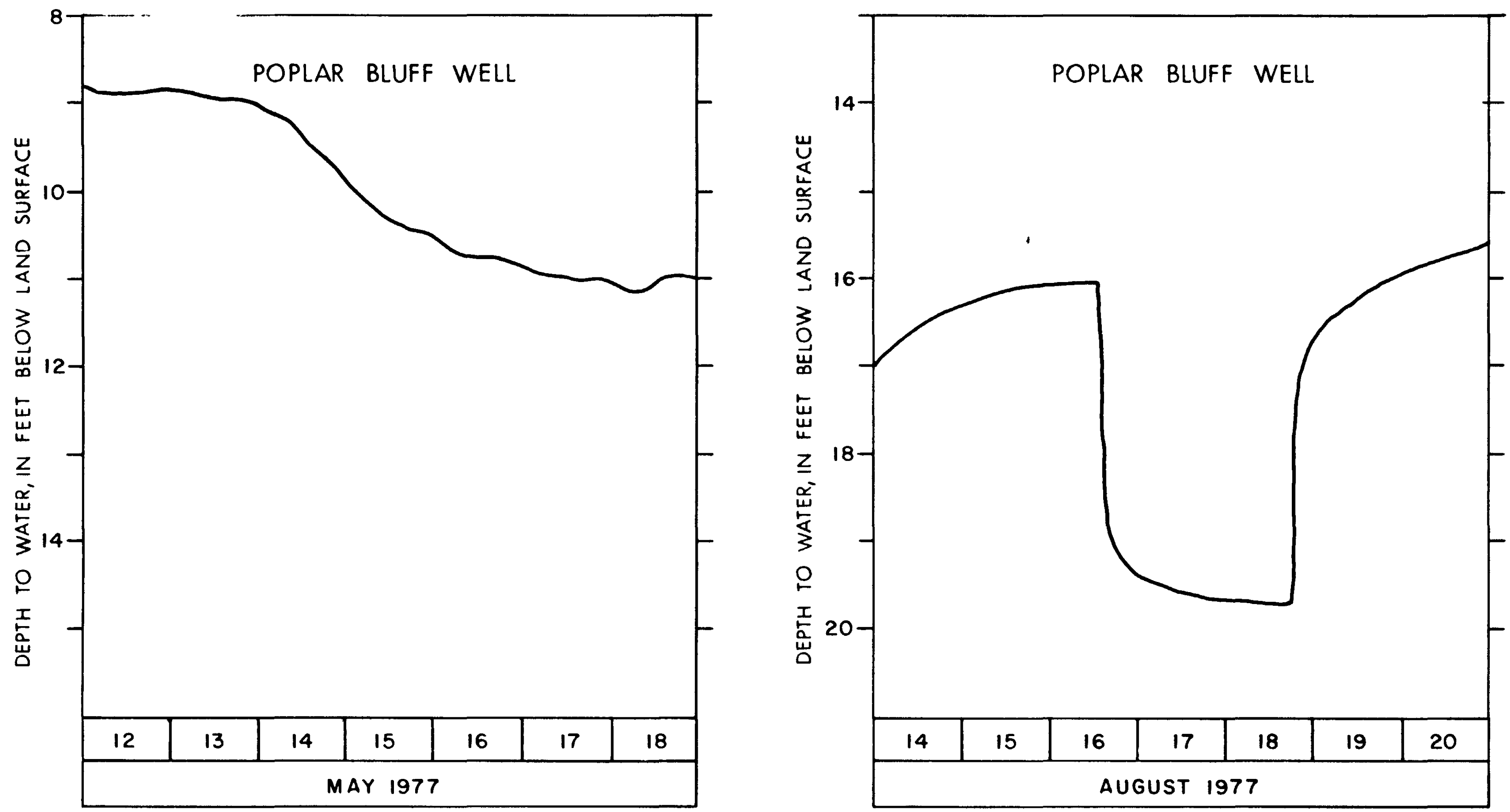


Figure 12.--Hydrograph for the Poplar Bluff well for selected periods during 1977.

produces about 1,550 gallons per minute. The decline and recovery of water levels during August 14 to 20 is caused by the pumping and cessation of pumping of an irrigation well only 75 feet from this well. Although this irrigation well produced about 2,060 gallons per minute during the 1976 season, the discharge was not measured during 1977. The effect of this irrigation well is much more significant because of its proximity to the recorder well.

Potentiometric Surface

The potentiometric surface of the alluvial aquifer during the spring of 1976 is shown in figure 13. The potentiometric surface (equivalent to the water table throughout much of the area) is the level at which water will stand in wells completed in the alluvial aquifer. Ground water moves perpendicular to the potentiometric contours from larger values to smaller values. The general direction of flow in southeastern Missouri is from north to south. The potentiometric surface has a maximum altitude of 345 feet above sea level north of the gap between Benton Hills and Crowleys Ridge and has a minimum altitude of less than 235 feet above sea level at the State line near the Little River ditches.

The potentiometric surface is affected by a number of things, but the major factors are the recharge and discharge conditions. Many of the potentiometric highs on the map correspond to sandy ridges. For example, a major high exists in the Charleston-East Prairie area, and another major high shows on the lower part of Sikeston Ridge. These areas receive more recharge from precipitation than the surrounding areas. The Kennett-Malden Prairie is another large recharge area. The nearly north-south orientation of the potentiometric contours in the area from Dexter to south of Malden indicates that this prairie is a recharge area. The sandy areas west of Crowleys Ridge also are significant recharge areas.

The ditch system in the area, along with the natural rivers, is the major drain on the ground-water system, as shown on the potentiometric-surface map. A pronounced low in the potentiometric surface indicating a discharge area conforms to the general course of the Whitewater-Castor-Little River system (see fig. 31, p. 64). This potentiometric low sometimes is aligned along the old natural system, and sometimes along the newer manmade drainage system. This trough in the potentiometric surface is most noticeable in the south one-half of the area.

The St. Francis River is a drain to the alluvial aquifer on the west side of Crowleys Ridge. However, on the east side of Crowleys Ridge it appears to be a source of water for the alluvial aquifer north of Kennett, but it appears to have little effect on the aquifer south of Kennett.

The Mississippi River is a significant drain to the ground-water system, particularly north of the Ohio River (see fig. 2). During times of large rises in river stage, the Mississippi and Little rivers can become a source of water for the aquifer. However, during the spring of 1976, the rise in stage on these rivers was relatively small. As shown on the map, the Mississippi River affects a relatively small part of the study area compared to the effect of the Whitewater-Castor-Little River system.

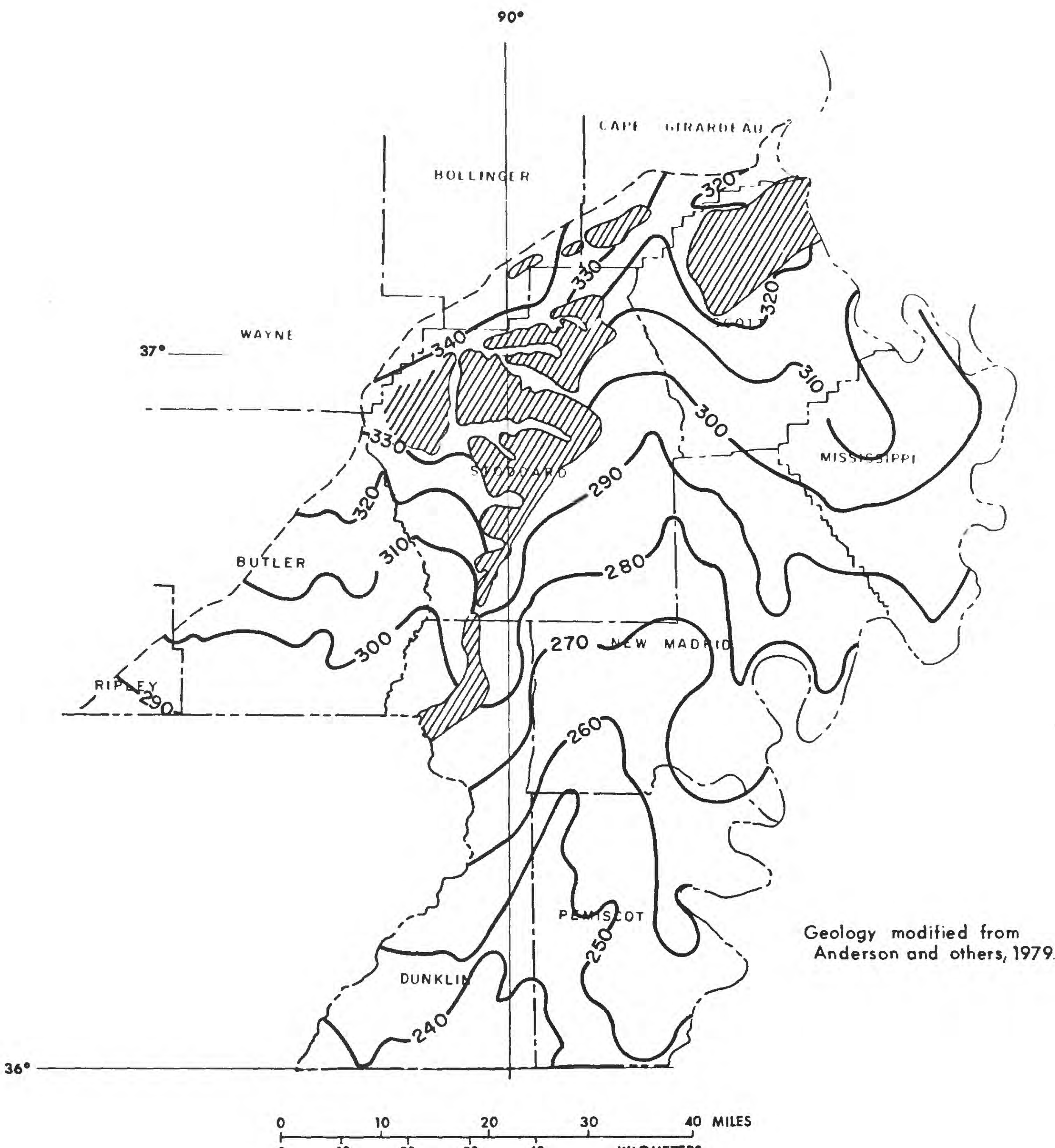


Figure 13.--Generalized potentiometric surface of the alluvial aquifer in southeastern Missouri during the spring of 1976.

EXPLANATION

PROJECT BOUNDARY

OUTCROP OF TERTIARY OR OLDER FORMATION

—250— POTENTIOMETRIC CONTOUR SHOWS APPROXIMATE ALTITUDE, IN FEET, OF THE POTENTIOMETRIC SURFACE
Contour interval 10 feet. Datum is sea level

Near the Stoddard-Dunklin County line, immediately west of Bernie (see fig. 2), is an area where Crowleys Ridge has been breached. The potentiometric-surface map shows that ground water moves from the Advance Lowlands on the west of Crowleys Ridge through this gap to the Malden Prairie. A cross section through this area is shown in figure 14. This cross section shows the land surface and the potentiometric surface during May 1977. The potentiometric surface through this section was drawn using considerably more data points than were used in drawing the previously shown potentiometric-surface map. This cross section indicates a continuous potentiometric surface from west of the gap to the east of the gap. The nature of the subsurface material near the gap could not be determined from the available data.

The configuration of the potentiometric surface during the fall of 1976 basically was the same as during the spring with only a few minor exceptions, as shown in figure 15. The entire surface declined slightly during the summer of 1976. Perhaps the greatest difference in the potentiometric surface between the spring and fall of 1976 is along the Mississippi River. By the fall of 1976 the Mississippi River had become a much more significant drain to the system. This was because the river stage declined about 15 feet during the summer of 1976, and water in the aquifer a considerable distance from the river was moving toward the river. The effects of the other recharge and discharge areas were similar to what they had been during the spring.

A series of water-level measurements were made in the area beginning during 1956. Maps of the potentiometric surface during the spring of 1956, 1965, and 1976 are shown in figures 13, 16, and 17. The 1956 map (fig. 16) was prepared by the Missouri Division of Geology and Land Survey (D. L. Fuller, written commun., 1978), and the 1965 map (fig. 17) was prepared by the U.S. Geological Survey (E. J. Harvey, written commun., 1978). The three maps show that there have been no large changes in the potentiometric surface in the area during the last 20 years. The differences between the three maps are mostly due to differences in interpretation of the water-level data by investigators rather than any actual difference in the potentiometric surface. The one area of significant difference is in northern Dunklin County on the west side of Crowleys Ridge. Channelizing the St. Francis River in this area has caused the river to become a stronger drain and locally lower water levels. The conclusion reached using these maps corresponds with the conclusion reached by examining the water-level data, which also indicates that no significant change has taken place in the potentiometric surface during the last 20 years.

Hydraulic Characteristics

Other major factors that affect the configuration of the potentiometric surface and the flow system are the hydraulic characteristics of the formation. Two characteristics are important: the permeability (or transmissivity) and the storage coefficient. According to Lohman (1972), the permeability of a material is "a measure of its ability to transmit fluid, such as water, under a hydropotential gradient." The coarser alluvial material has a high permeability, whereas the finer materials, such as silt and clay, have a lower permeability. The permeability of the material also is affected by such things as its sorting and cleanness. For example, a gravel in which most of the pore

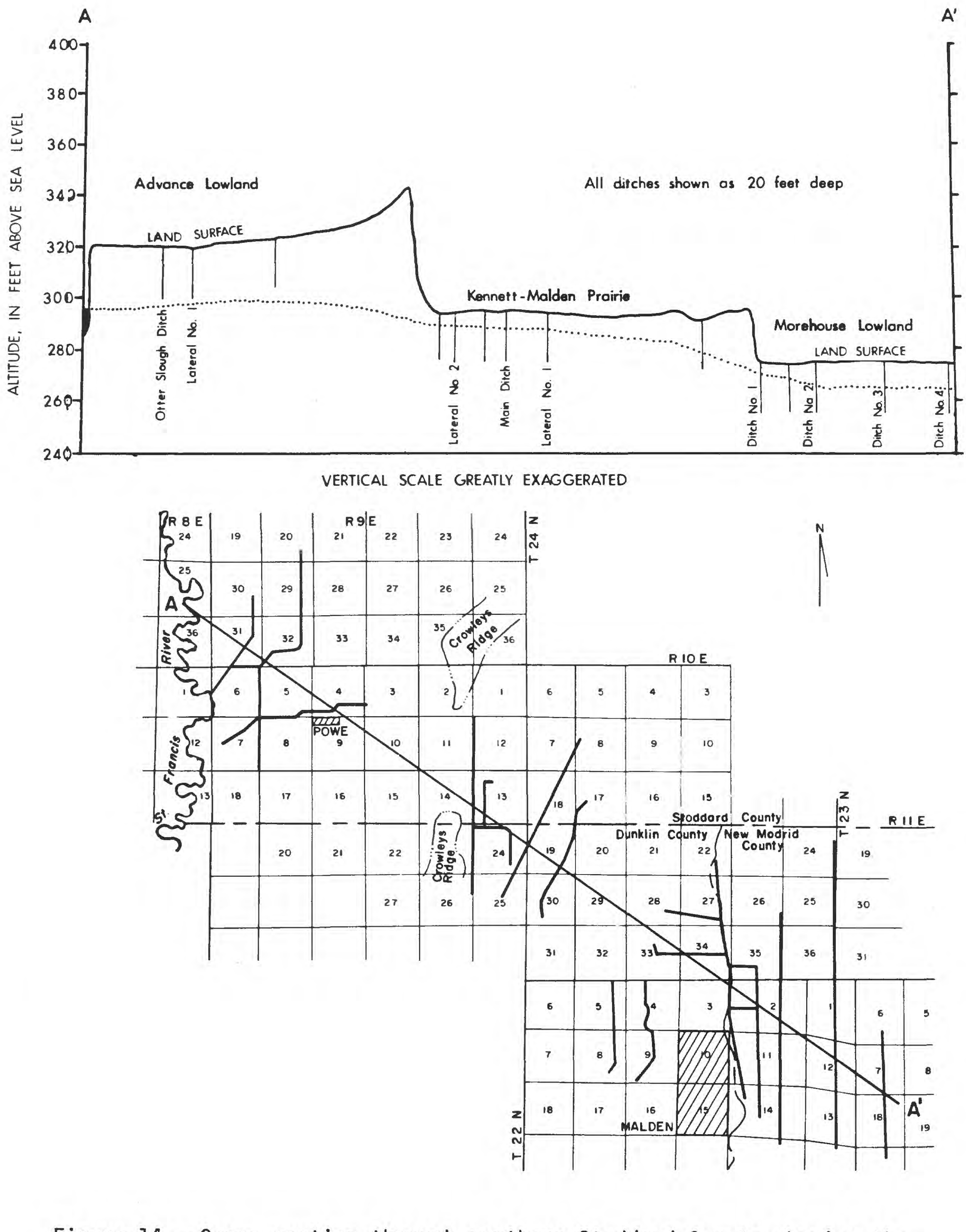


Figure 14.--Cross section through southern Stoddard County showing the potentiometric surface of the alluvial aquifer in southeastern Missouri during May 1977.

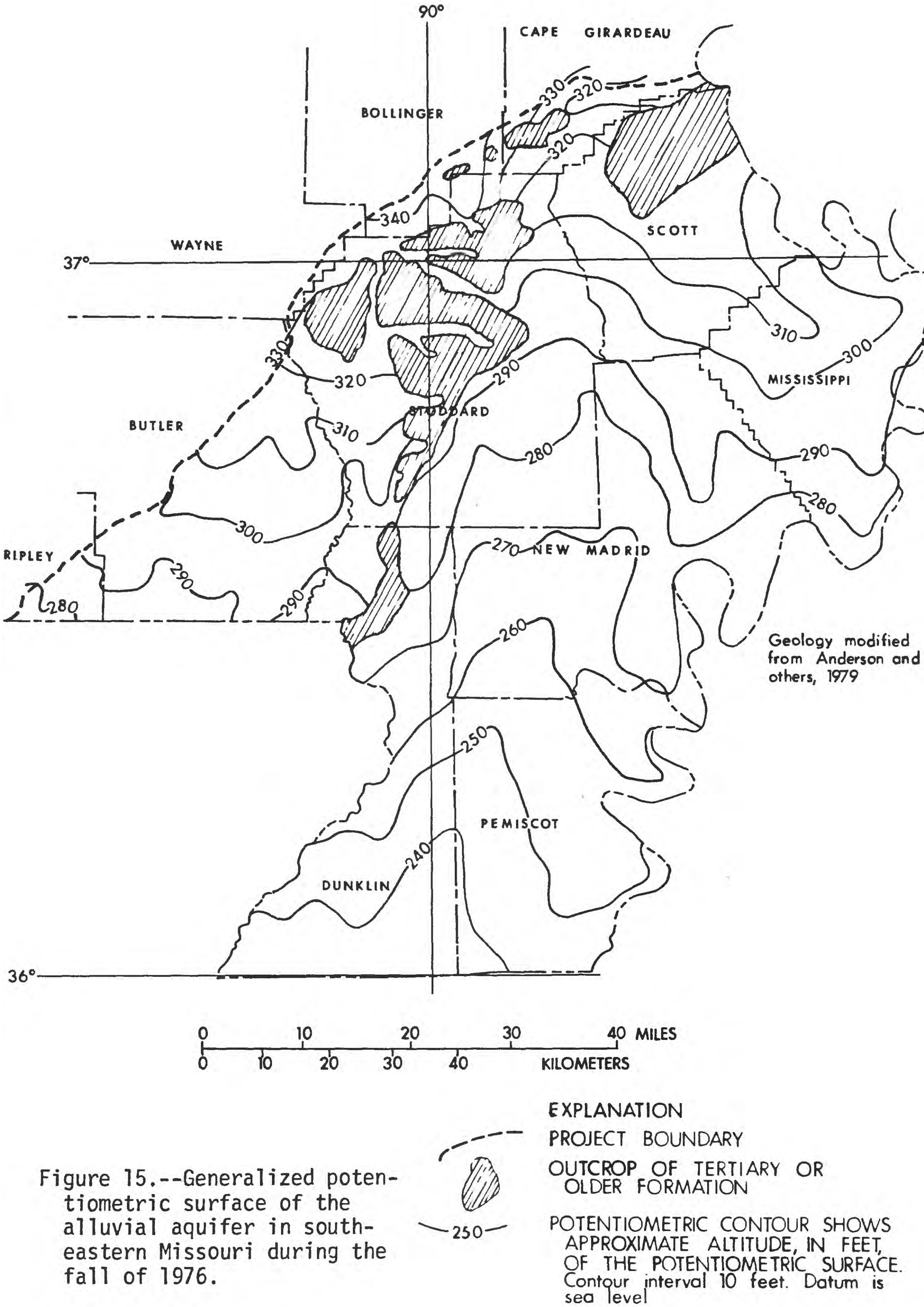
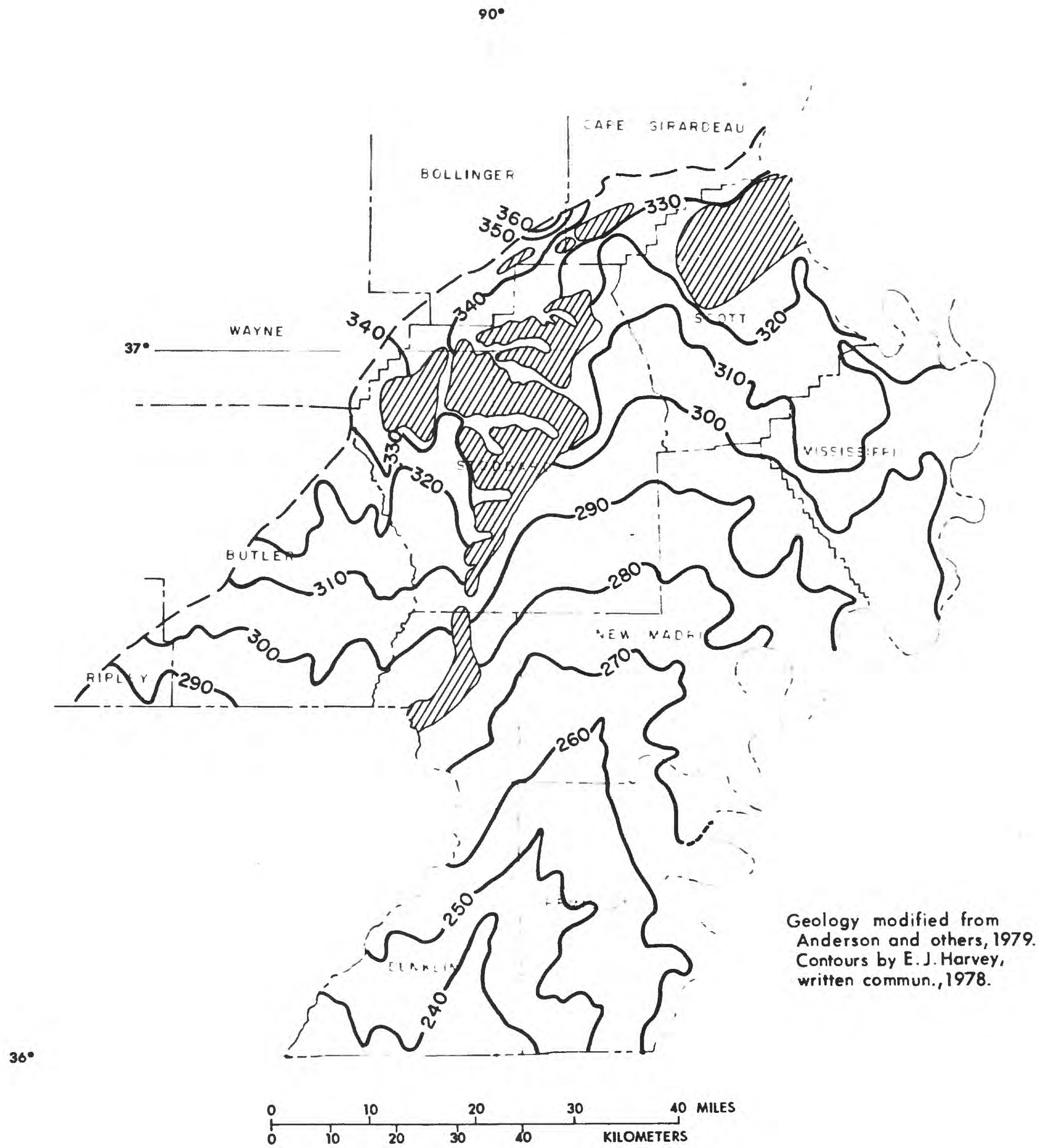


Figure 15.--Generalized potentiometric surface of the alluvial aquifer in southeastern Missouri during the fall of 1976.



EXPLANATION

PROJECT BOUNDARY

OUTCROP OF TERTIARY OR OLDER FORMATION

—250— POTENTIOMETRIC CONTOUR SHOWS APPROXIMATE ALTITUDE, IN FEET, OF THE POTENTIOMETRIC SURFACE. Contour interval 10 feet. Datum is sea level

Figure 16.--Generalized potentiometric surface of the alluvial aquifer in southeastern Missouri during the spring of 1956.

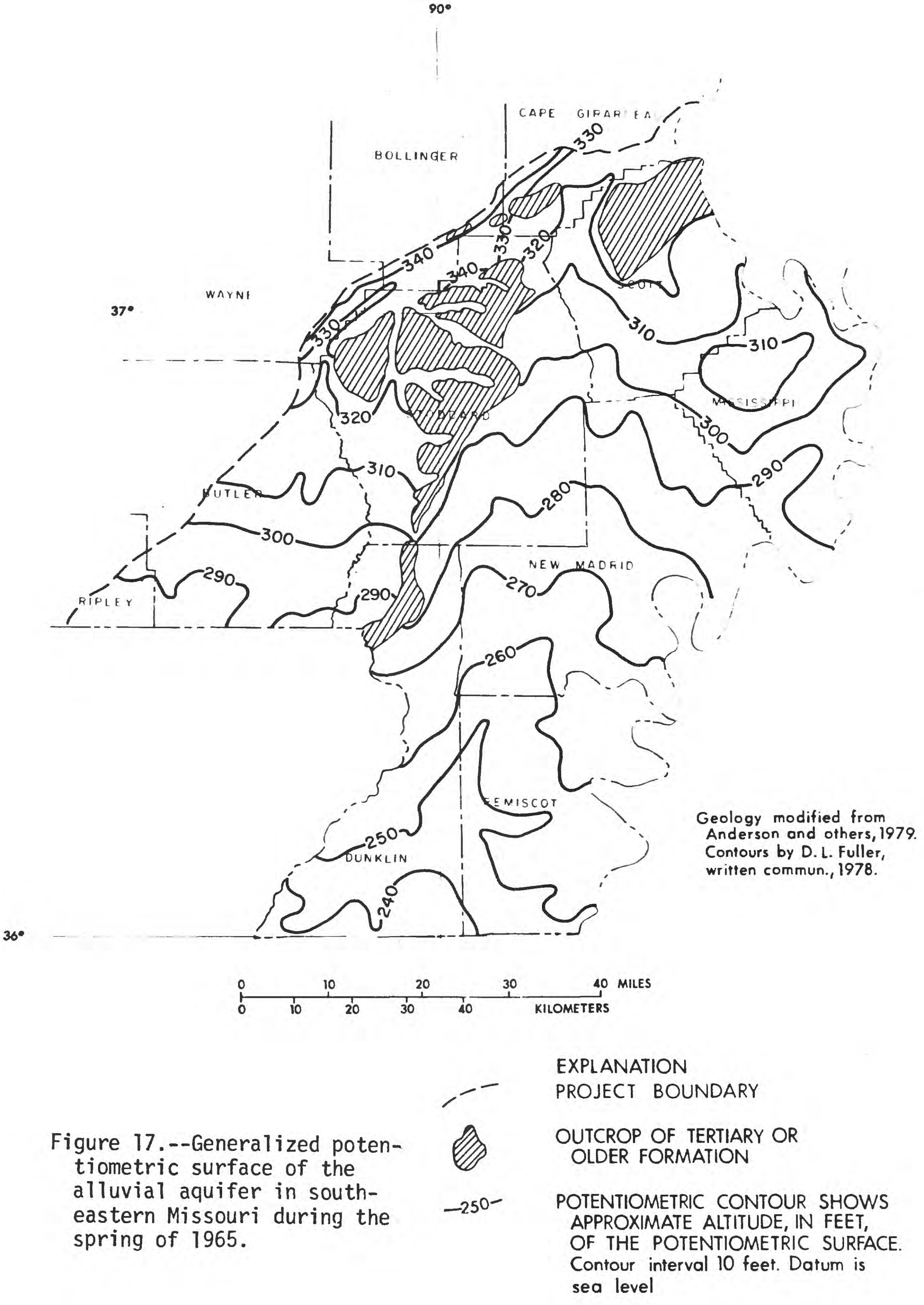


Figure 17.--Generalized potentiometric surface of the alluvial aquifer in southeastern Missouri during the spring of 1965.

space has been filled with clay will have low permeability, and a uniform, clean sand will have a higher permeability. The transmissivity, which is simply the sum of the permeabilities for each individual layer throughout the entire thickness of the formation, was measured in this study.

The storage coefficient is a measure of the ability of the aquifer to release water from storage or take water into storage. Under water-table conditions the storage coefficient is equal to the specific yield or the drainable pore space of the formation. Under confined conditions, water is released from storage by compaction of the aquifer and expansion of the water. Under these conditions, the storage coefficient is a measure of this compaction and expansion.

Aquifer tests were made at nine sites in the study area to determine the hydraulic characteristics of the alluvial aquifer. These sites are shown in figure 18, and table 2 lists the transmissivity and storage coefficient determined at each site. As shown in the table, there is minimal variation in transmissivity among the sites. All storage coefficients were determined from short-term tests. In a long-term test these coefficients probably would be much larger. In performing an aquifer test, one well is pumped and the response of the aquifer to the stress is measured in a number of nearby wells. The change in water level in the aquifer with time is shown in figure 19, and the change in water level (drawdown) with distance from the pumped well is shown in figure 20. This site, which is near Pascola (see fig. 2), shows a typical response in that the effect of pumping quickly diminished with distance and the rate of change of the water level decreased with time. A logarithmic plot of aquifer-test data at the University of Missouri-Columbia Delta Center Experimental Farm near Portageville is shown in figure 21. Numerous observation wells were used in this test. The hydraulic characteristics of the aquifer were determined from the shape of the curve obtained from this plot.

An attempt was made to use another method to estimate the hydraulic characteristics of the aquifer. This method uses the river rather than a pumping well as the stress on the ground-water system. Water-level recorders are placed fairly close to the Mississippi River and the change in water level in the well is compared with the change in river stage. Two such water-level records are shown in figures 22 and 23. A plot of the water level in a well near Marston (see fig. 2) and the river stage at nearby New Madrid are shown in figure 22. This well is approximately 1.1 miles from the edge of the Mississippi River. Although there is a response to change in river stage, this well probably is too far from the river to provide an adequate measure of the hydraulic characteristics of the alluvial aquifer. The water level at the University of Missouri-Columbia Delta Center Experimental Farm well and the river stage at nearby Tiptonville, Tennessee, are shown in figure 23. The response here is fairly similar to that at Marston and, again, the well probably is too far from the river to be useful in measuring hydraulic characteristics of the aquifer.

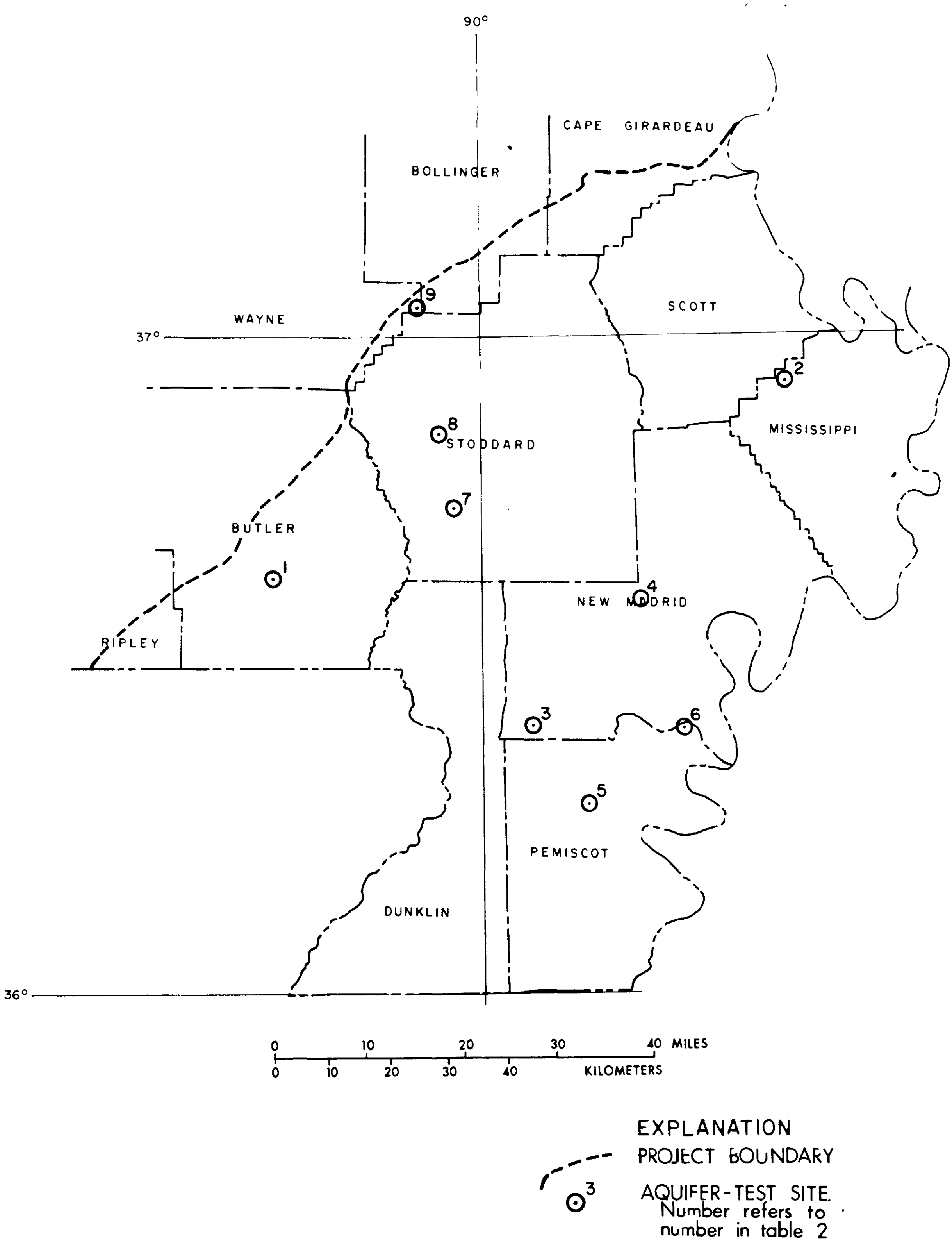


Figure 18.--Aquifer-test sites in southeastern Missouri.

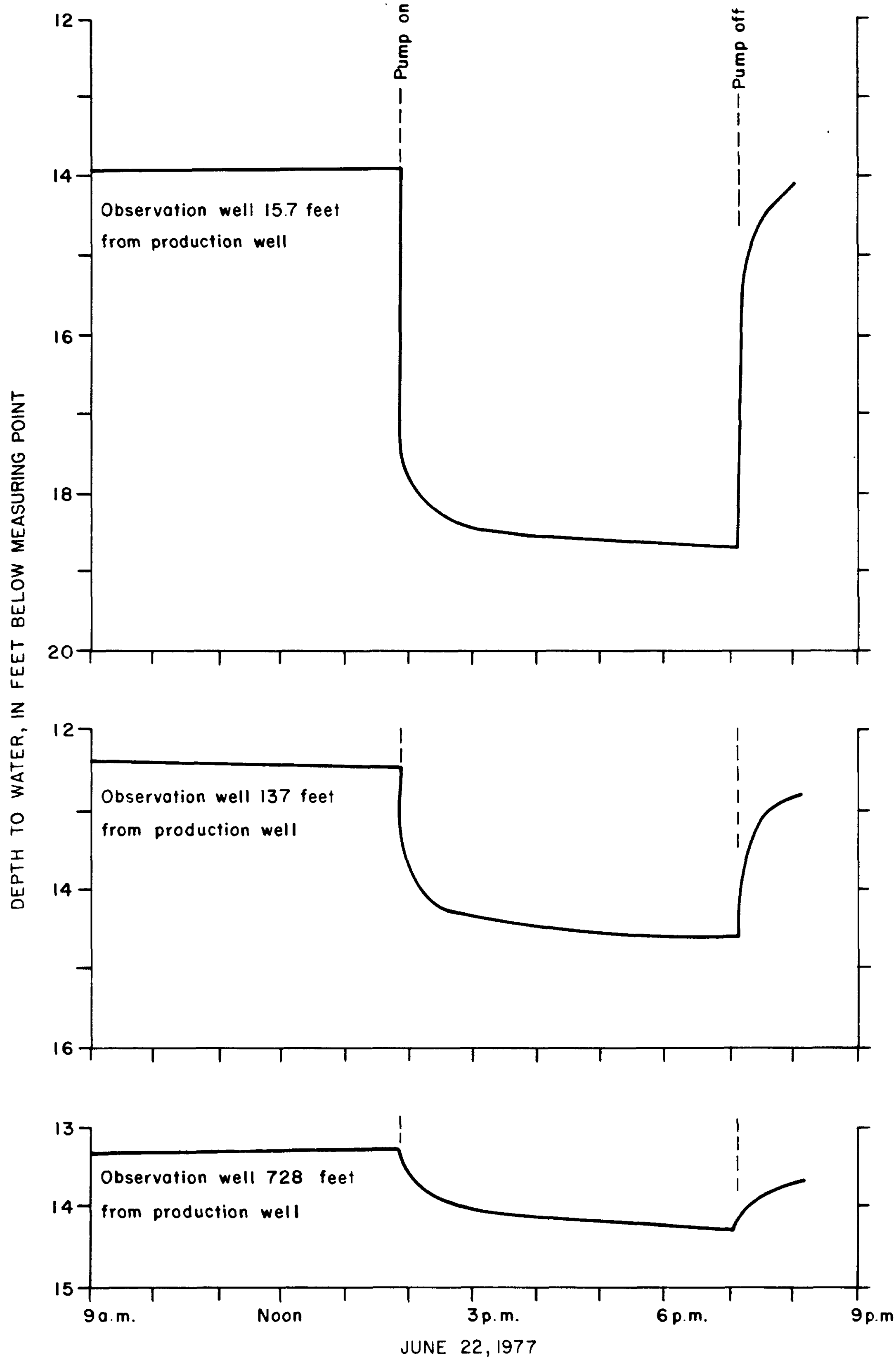


Figure 19.--Water-level changes versus time for aquifer test at site 5 near Pascola.

Table 2.--Summary of aquifer tests of the alluvial aquifer in southeastern Missouri

[ft^2/d, feet squared per day; --, no data]

County	Production well no.[1]	Owner	Map number (fig. 18)	Number of observation wells	Transmissivity (ft^2/d)	Storage coefficient (dimensionless)[2]	Remarks
Butler	T23N R06E 22ABB1	Duncan-Norwood	1	1	50,000	0.0010	None.
Mississippi	T27N R15E 34DDA1	Paul Hulshof	2	2	--	--	Too much interference from other wells to determine coefficients.
New Madrid	T21N R11E 31DAC1	Gideon-Anderson Company	3	4	50,000	.0010	Results poor.
New Madrid	T23N R13E 30CBB2	Paul Crouthers	4	1	54,000	.0010	None.
Pemiscot	T19N R12E 18ACA1	Lloyd Massey	5	6	48,000	.0020	See figures 19 and 20.
Pemiscot	T20N R13E 02DAA1	University of Missouri-Columbia Delta Center Experimental Farm	6	16	32,000	.0001	See figure 21.
Stoddard	T24N R09E 11ACB1	Harold Snider	7	1	20,000	.0010	Close to Crowleys Ridge.
Stoddard	T26N R09E 33ACC1	Bayless Taylor	8	3	15,000	.0020	Alluvium in this area may not be associated with Mississippi River.
Wayne	T28N R08E 36BCD1	Duck Creek Wildlife Area	9	5	47,000	.0009	None.

[1]Location system is described in Luckey and Fuller, 1980, p. 2.
[2]All tests were of 25 hours or less duration.

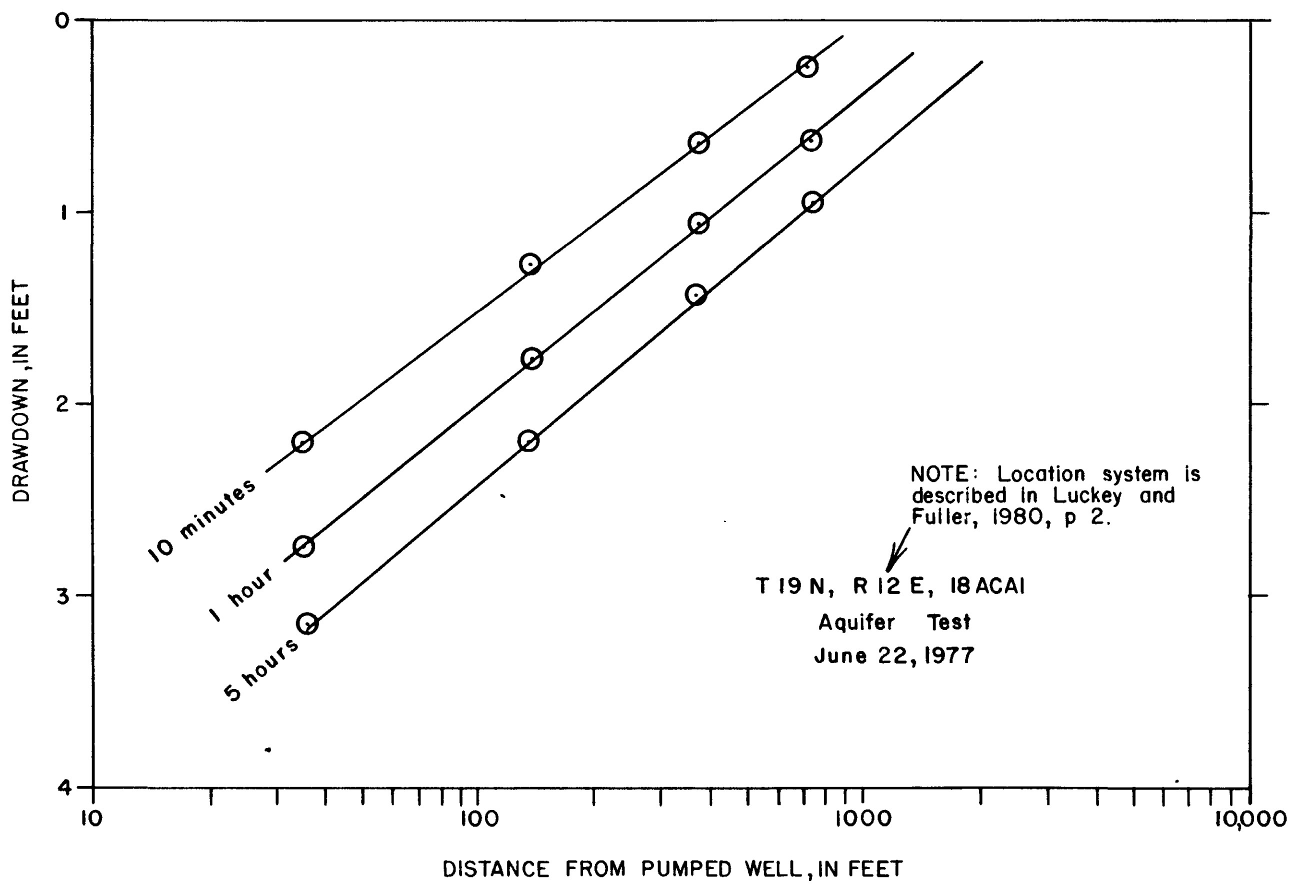


Figure 20.--Water-level changes versus distance for aquifer test at site 5 near Pascola.

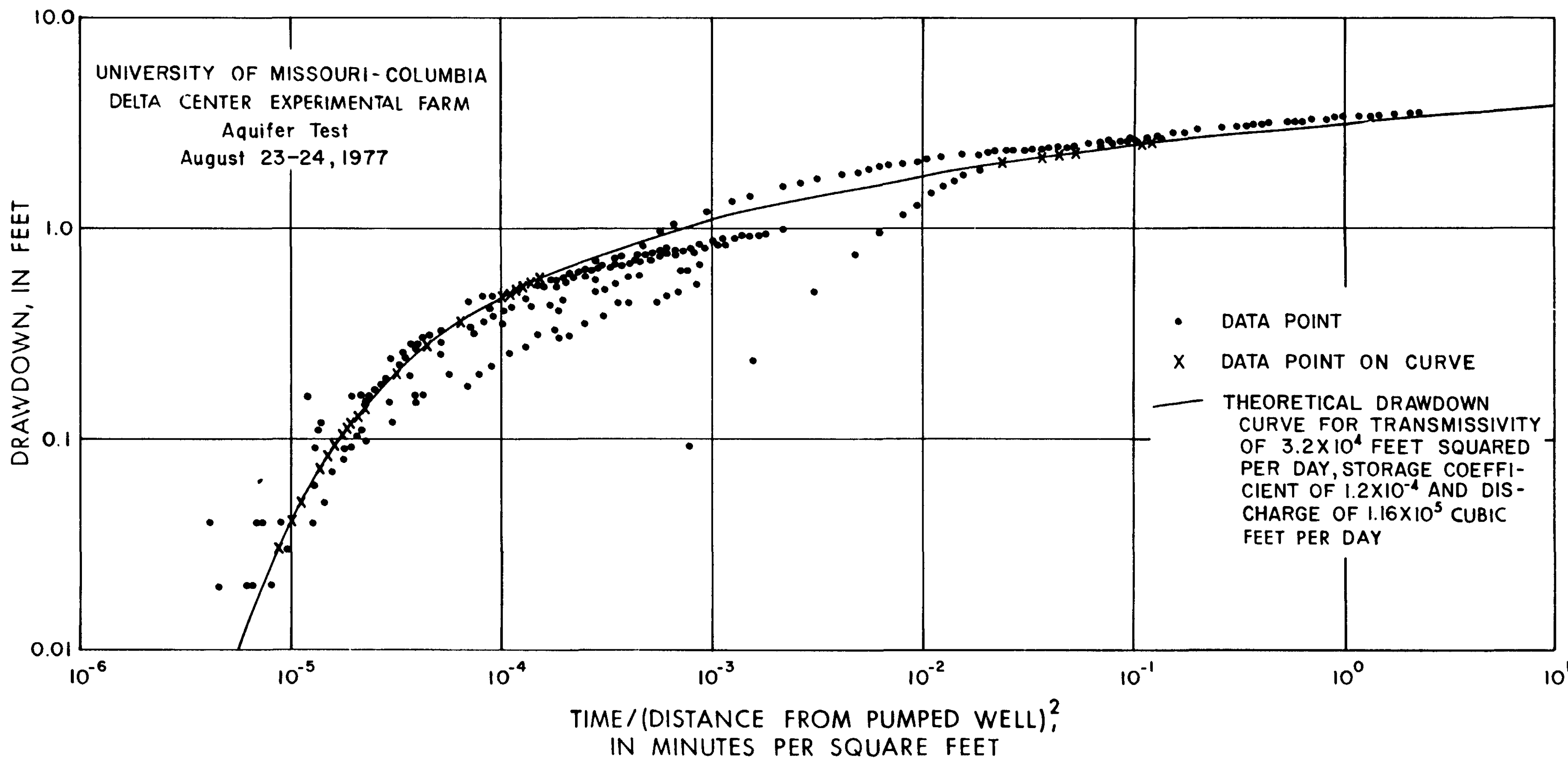


Figure 21.--Data for an aquifer test at site 6 at the University of Missouri-Columbia Delta Center Experimental Farm near Portageville.

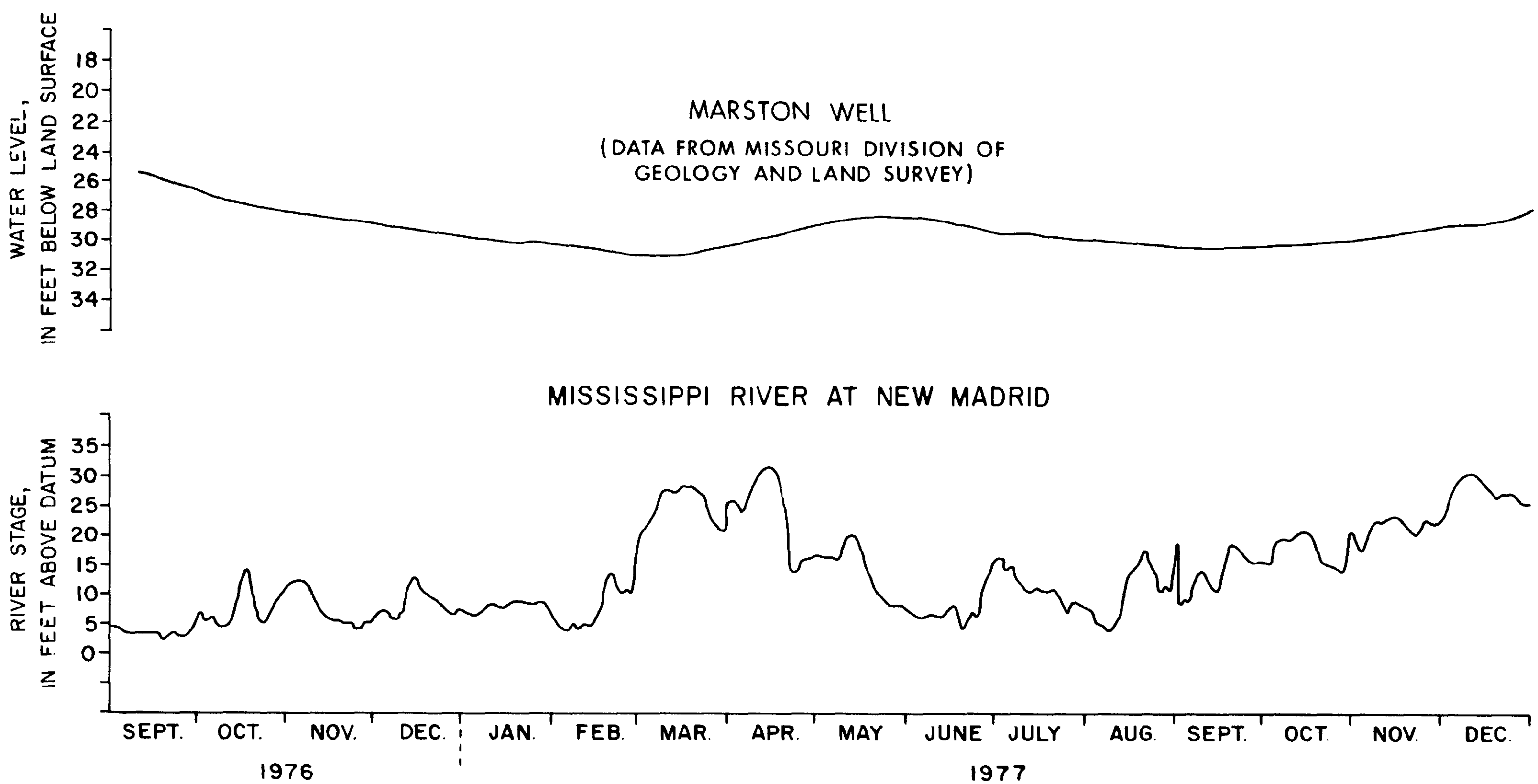


Figure 22.--River stage at New Madrid and hydrograph for the Marston well, September 1976 through December 1977.

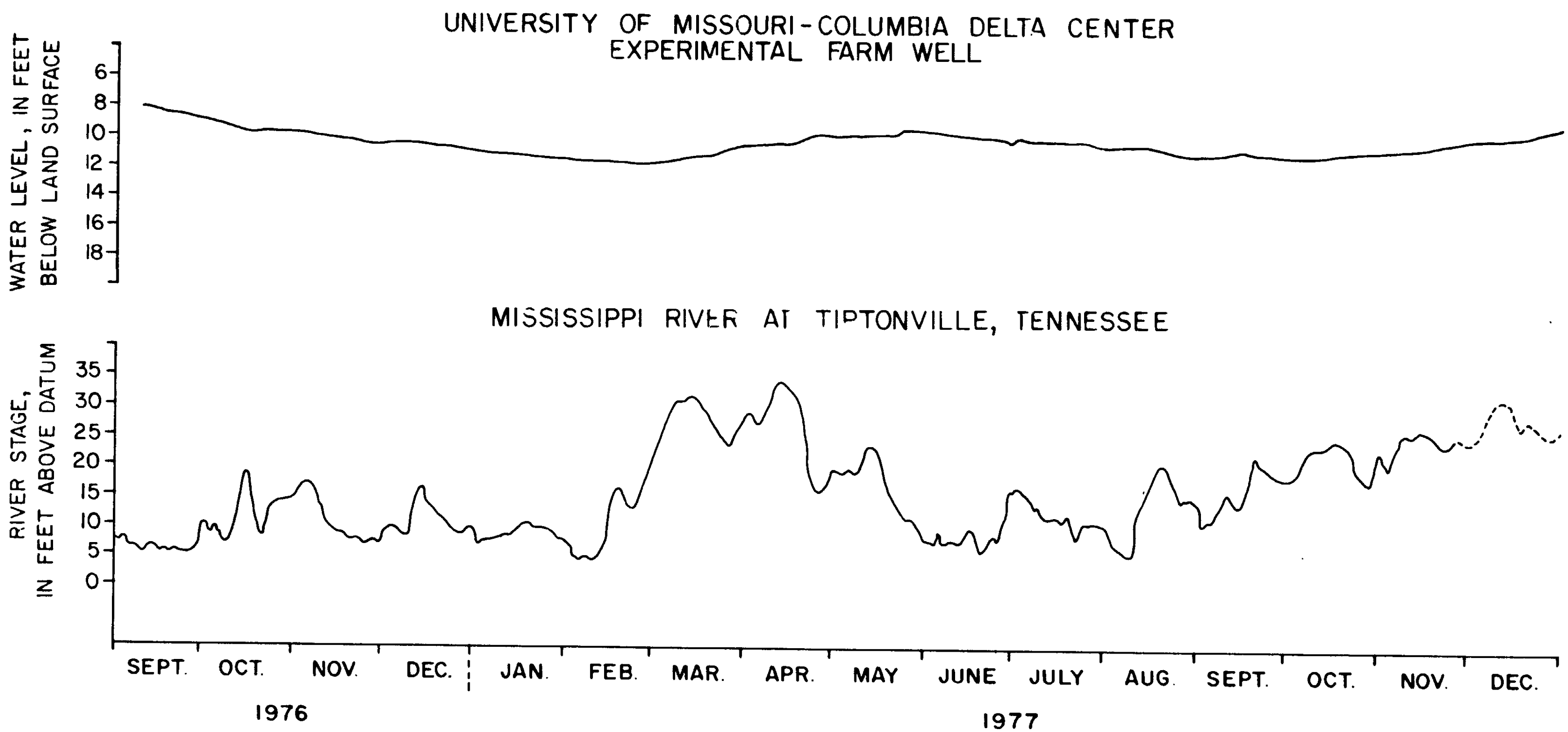


Figure 23.--River stage at Tiptonville, Tennessee, and hydrograph for the University of Missouri-Columbia Delta Center Experimental Farm well at Portageville, September 1976 through December 1977.

Water Use

Natural and artificial withdrawal from the aquifer are major stresses on the system. Natural withdrawal, or evapotranspiration where the water table is shallow, probably is considerable in the area. The total evapotranspiration in the area probably ranges from less than 24 inches per year to more than 30 inches per year. Although much of this evapotranspiration probably comes from soil moisture rather than the aquifer, it is impossible with data currently available to estimate the relative quantities that come from precipitation, soil moisture, and the ground-water system.

Withdrawal of water for irrigation is becoming increasingly common in the area. Although most of the area is flood irrigated, the use of sprinklers is increasing, particularly in Scott and Mississippi Counties. As practiced in the Southeast Lowlands, irrigation is a fairly low-cost operation after the land has been leveled. A well between 70 and 100 feet deep is drilled and cased with 8-inch pipe casing, although most older wells were cased with 6-inch casing. A mobile trailer-mounted centrifugal pump is commonly used on these wells with either a tractor or other mobile engine normally supplying the power. In this manner, one pumping plant may be used for a number of wells. Where larger quantities of water are needed, or where a deeper water table is present, a permanently installed lineshaft turbine pump with either a large stationary engine or an electric motor may be used. Water normally is delivered to the fields through gated pipe, except in rice fields where it is delivered through a system of canals.

One of the purposes of this study was to estimate the quantity of water that is being used for irrigation. This was accomplished by collecting more extensive pumpage data for selected wells in the area. The quantity of water used to irrigate rice, corn, and soybeans with these wells was determined. Although milo also is beginning to be an important irrigated crop in the area, no data were collected for milo irrigation. Other crops, such as watermelons, which occupied only a small percentage of the acreage in the area, and cotton, which is seldom irrigated, were not included in this study because water use by these crops is not considered significant.

A histogram showing water application on 28 rice fields during 1977 is shown in figure 24. The extremely small values may represent rice crops that were irrigated for only a part of the year and then abandoned for one reason or another. The extremely large water-use figure may represent a field with perpetual levee problems. However, the large quantity of data in the center of the histogram indicates a withdrawal for rice irrigation in excess of 3 feet of water per year. Not all the water was actually consumed by evaporation and transpiration, but some of it was released at the lower end of the rice field and some may have recharged the aquifer.

Estimated water use for rice, corn, and soybeans for 1975-77, along with the number of fields sampled, is shown in table 3. All values of water use are dependent on the weather, but the irrigators in the area report that the quantity of water supplied to soybeans is considerably more variable than the quantity of water applied to either corn or rice. Reliable figures on the irrigated acreage for corn and soybeans are not available, but much of the corn acreage is irrigated, and a much smaller part of the soybean acreage is irrigated. Milo is included in table 3 to indicate that it is a significant user of water even though no water-use data are available for this crop.

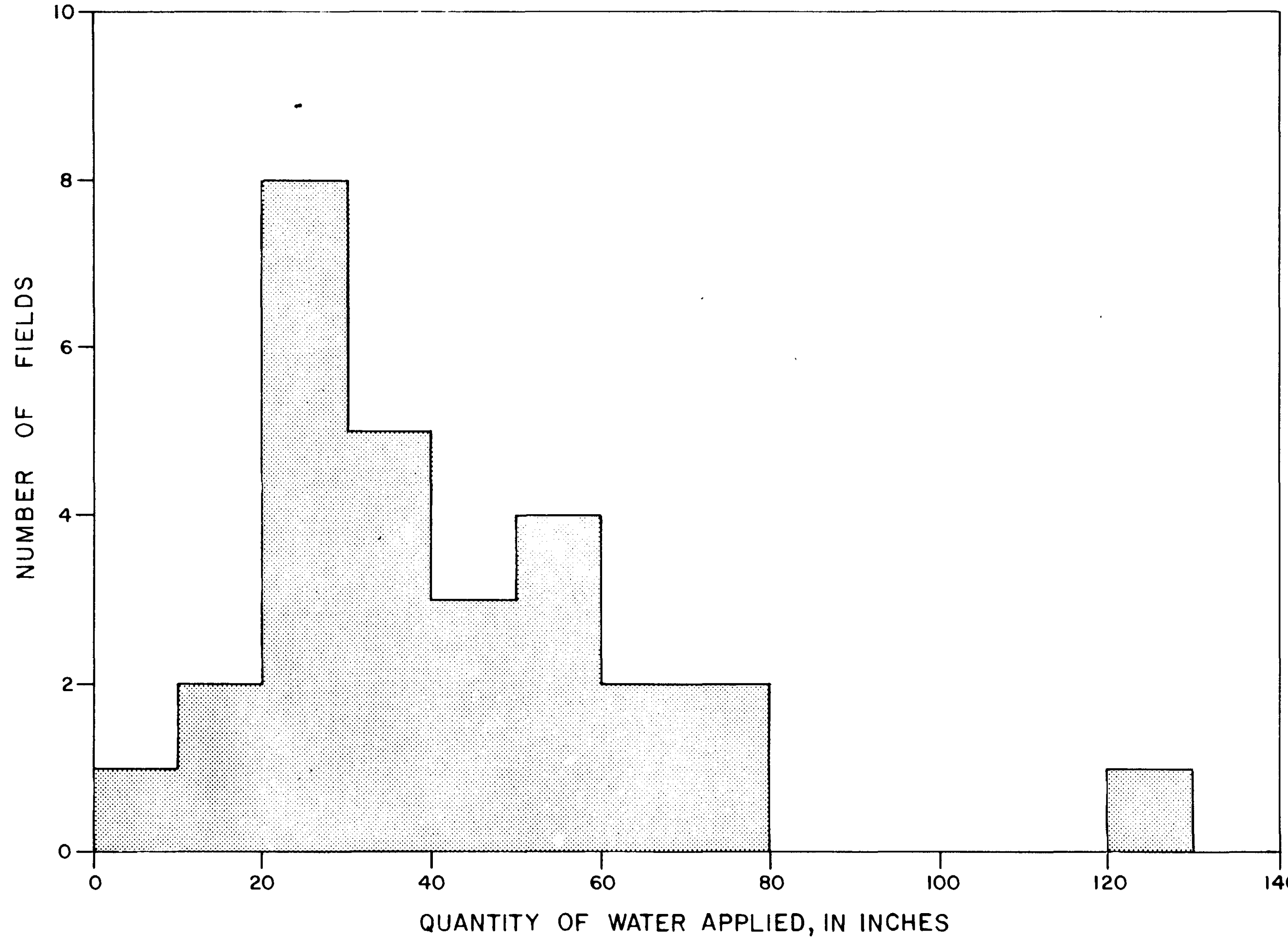
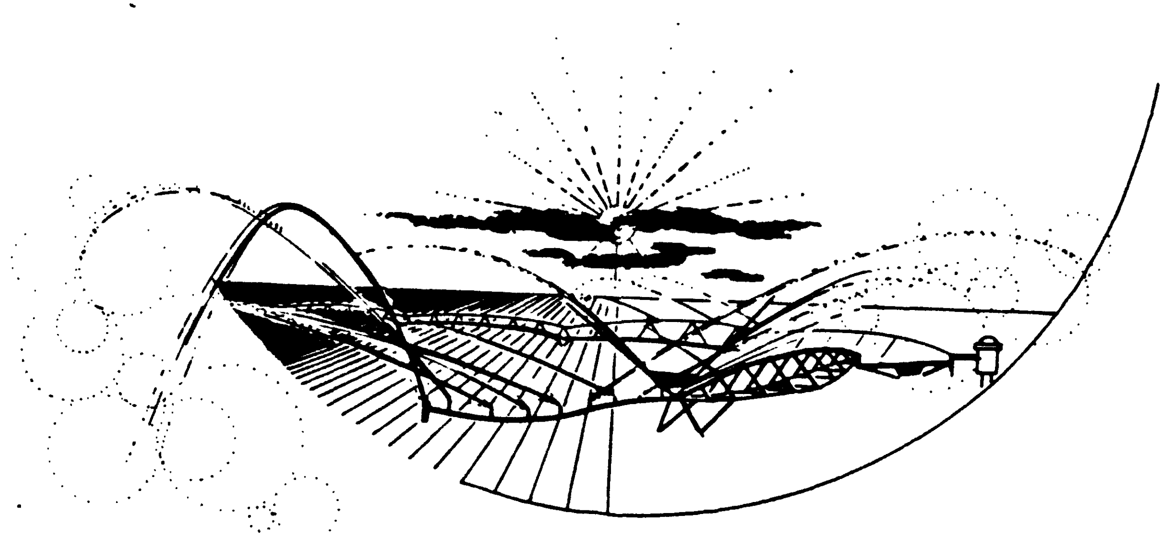


Figure 24.--Water applied to 28 rice fields during 1977 in southeastern Missouri.

Table 3.--Depth of water used to irrigate various crops in southeastern Missouri

[--, no data available]

Crop	1975 Median application, in inches	1975 Number of fields sampled	1976 Median application, in inches	1976 Number of fields sampled	1977 Median application, in inches	1977 Number of fields sampled
Rice	36.4	30	41.5	23	37.0	28
Corn	5.4	7	7.1	15	5.1	22
Soybeans	4.4	12	9.2	16	4.1	9
Milo	--	0	--	0	--	0



Location of irrigation wells inventoried during the project is shown in a report by Luckey and Fuller (1980, fig. 3). More irrigation wells are needed in areas with sandy soils, and the wells are particularly prevalent in the sandy Kennett-Malden Prairie (see fig. 2). Soil type is one of the major factors that determines if irrigation will be profitable in an area.

Major rice-growing areas of southeastern Missouri are shown in figure 25. Although the amount of acreage involved is not large, these areas are quite significant in terms of water use because of the large water requirement of rice. About 30,000 to 40,000 acre-feet of water are used annually to irrigate rice in the area.

A few larger towns and many of the smaller towns and municipalities use the alluvium to supply their municipal water. The alluvium provides a relatively inexpensive source of water. In most places the water quality is adequate and in some places exceptional.

Although major industries are not numerous in southeastern Missouri, these industries do use the alluvium for their water supply. A large water supply available at low cost is one of the factors that can enter into an industry's decision to locate in southeastern Missouri.

Essentially, all the self-supplied domestic water in the area is obtained from the alluvium. Only on uplands, such as Crowleys Ridge and Benton Hills where the alluvium is not available, are other sources commonly used for domestic water supply. The quality of the water is a major consideration for domestic use, but water-quality problems for domestic supply frequently can be corrected by drilling a new well a short distance away.

Water Budget

The water budget (table 4) summarizes the major components of the interconnected alluvial ground-water system and the surface-water system. The primary input to the system is the precipitation that falls on the area. Precipitation provides nearly 10 million acre-feet of water per year, or nearly 4 feet throughout the area. Rivers enter the area and add to the water supplied by precipitation. In Bollinger and Cape Girardeau Counties, these rivers are immediately diverted to the Mississippi River and leave the area. The St. Francis River and the Black River, as well as a number of smaller rivers, flow through the area. These rivers, except the Black River that supplies municipal water to the city of Poplar Bluff, generally are not used as a water supply. A small quantity of ground water also enters the system from the Ozark Plateaus to the north and west. With the available data this quantity of water can be only poorly estimated, but it apparently is not a significant part of the total supply available.

Water in the area leaves the system in a number of ways. The two largest outputs are evapotranspiration and surface-water outflow. The quantity of surface water that leaves the area is nearly 4 million acre-feet per year more than the quantity of surface water that has entered the area. This is nearly 40 percent of the precipitation that falls on the area. Most of the other 60 percent leaves the area as evapotranspiration. Nearly 6 million acre-feet of

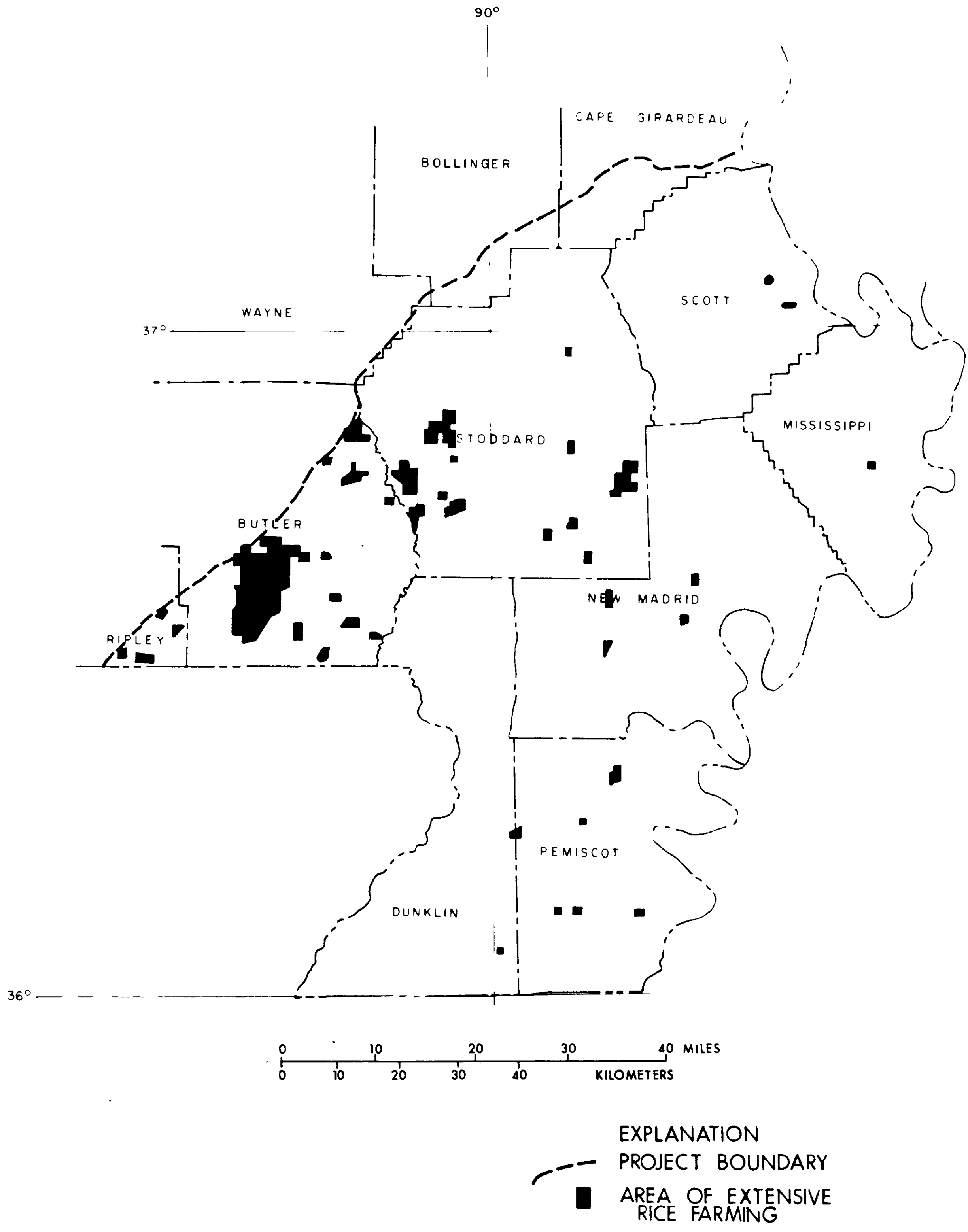


Figure 25.--Areas where rice was grown during 1977 in southeastern Missouri.

Table 4.--Water budget showing major components of the interconnected alluvial ground-water system and the surface-water system

[All units are in thousands of acre-feet per year)

INPUT	
Precipitation	9,390
Surface-water inflow	(a)
Ground-water inflow	10[b]
Total	9,940
OUTPUT	
Net surface-water outflow	4,000[c]
Evapotranspiration	5,814
Ground-water outflow (flow in alluvium across State line)	12
Net ground-water outflow (to deeper aquifers)	2
Ground-water pumpage:	
Irrigation	95
Municipal-domestic-industrial	17
Total	9,940
Quantity of ground water in storage in the alluvial aquifer	60,000

[a]Surface water calculated only as a net outflow from system (outflow minus inflow).

[b]Estimate only; probably small, but magnitude cannot be determined from the present data.

[c]Calculated from records representing 56 percent of the area.

water per year is consumed in the area through evapotranspiration. All the other outputs from the system, such as ground-water outflow, recharge to deeper aquifers and pumpage, are minor components of the water budget. For example, pumpage is only about 1 percent of precipitation and 2 percent of the evapotranspiration.

By assuming that the total water supply that could ultimately be developed in the area is equal to the precipitation on the area plus the surface-water and ground-water inflow, the size of the available water supply almost staggers the imagination. Only a part of the total water supply is ever likely to be developed and, hence, a major water-supply problem probably will not occur because of the quantity of water available. Any problems that occur will be either fairly local in nature or dependent on quality considerations rather than quantity considerations.

The last line of the water budget (table 4) shows the quantity of ground water in storage in the alluvium. This quantity, 60 million acre-feet, would be thought of as an asset in the balance-sheet form of the budget. This estimated 60 million acre-feet of water in storage represents 6 years of precipitation, 10 years of evapotranspiration, and more than 500 years of pumpage at the present rates. This water is not in static storage but is continuously replenished by precipitation and is continuously discharged to the ditches, evapotranspiration, and to wells.

Development of the ground-water system will not necessarily significantly decrease the quantity of water that is in storage in the alluvial aquifer. As more water is pumped from the aquifer this water will be replenished from three sources: (1) decreased discharge to rivers and ditches, (2) decreased evapotranspiration because of lowered water levels, and (3) increased recharge or salvage of previously rejected recharge because the aquifer was full and could accept no more recharge. If in any area pumpage begins to approach natural discharge, plus previously rejected recharge, then significant changes in storage (declines in water levels) in this area may become a problem.

Wilcox Group (Undivided)

In this report, the Wilcox Group (undivided) refers to all the Eocene sediments in southeastern Missouri. This group underlies about 2,200 square miles in the southern and eastern parts of the area and crops out throughout about 100 square miles on Crowleys Ridge and Benton Hills. It consists of unconsolidated or loosely consolidated sand and clay and contains one or more aquifers. In the outcrop areas the group can be divided into formations, but this usually is difficult in the subsurface. To the south and east in Arkansas and Tennessee, the Claiborne Group (undivided) generally is recognized, but in this report the Claiborne is included as part of the Wilcox Group (undivided).

Where present, the Wilcox Group generally immediately underlies the alluvium. Some well cuttings indicate the presence of a Pliocene terrace gravel between the alluvium and the Wilcox Group, although this frequently is not the case. The top of the Wilcox Group lies at an altitude ranging from 0 to 200 feet above sea level depending on the area, but generally only the basal 250 to 500 feet of this group is used for a water supply.

The Wilcox Group dips and thickens to the southeast at the rate of about 30 feet per mile. It has a maximum thickness in excess of 1,400 feet in the extreme southeast corner of the State (fig. 26). The entire thickness of the unit does not represent aquifer material. A part of the Wilcox may be clay; this is particularly true in the thicker sections.

A potentiometric-surface map of the lower Wilcox aquifer is shown in figure 27. The lower Wilcox aquifer refers to the basal sands generally found within the Wilcox Group that usually are used for a water supply. Water frequently is available in the upper part of the Wilcox, but these basal sands are reported to yield the largest quantity and the best quality water that is available in the group. The potentiometric surface generally slopes to the southwest in the northern part of the area and to the southeast in the southern part of the area. The altitude of the potentiometric surface ranges from more than 310 feet in Scott and Mississippi Counties to less than 250 feet in Pemiscot County. Not enough data are presently available to determine the characteristics of this aquifer on Crowleys Ridge.

The most likely place for recharge to occur in the lower Wilcox aquifer is near the subcrop (see fig. 27). In this area the basal sands generally are in direct contact with the overlying saturated alluvium. The effect of precipitation on the outcrop area probably is minimal, except in Dunklin County. The concept of the recharge area (see fig. 27) is further supported by comparing this figure with the potentiometric surface of the alluvium (see fig. 13). These two potentiometric surfaces correspond fairly well in the probable recharge area. This should be the case because there are no confining beds between the alluvium and the lower Wilcox aquifer.

Water that enters the lower Wilcox aquifer either flows into Arkansas and out of the area or is withdrawn by wells. Approximately 2,000 acre-feet per year of water from the Wilcox aquifer flows out of the State, whereas two to three times this much may be pumped in Missouri.

Because there are no apparent significant water-level declines in the lower Wilcox aquifer, recharge and discharge must be in equilibrium and probably are less than 10,000 acre-feet per year. Additional recharge from the alluvial aquifer to the lower Wilcox aquifer would be induced if the water level in the lower Wilcox aquifer were lowered.

It is not possible to accurately estimate the quantity of water that is in storage in the entire Wilcox Group (undivided), but there may be as much as 100 million acre-feet of water in storage in this group. This is nearly twice the quantity that is in storage in the alluvium.

No aquifer tests were made on wells completed in the lower Wilcox aquifer, but Hosman and others (1968) indicate that a transmissivity of 15,000 feet squared per day and a storage coefficient of $1.0X10^{-4}$ might be expected for this aquifer. The value of transmissivity is consistent with reported well yields and specific capacities of municipal wells completed in this aquifer.

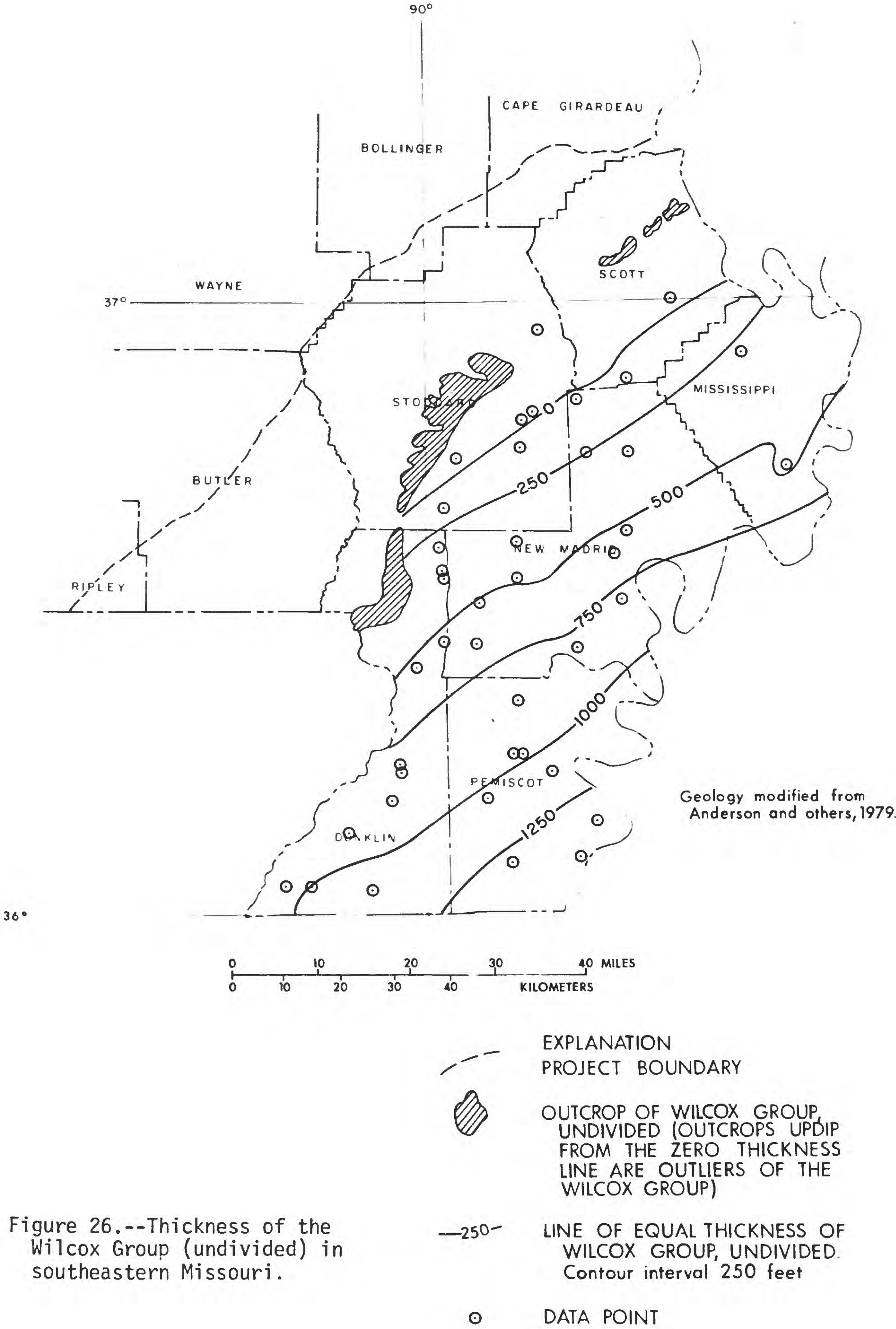
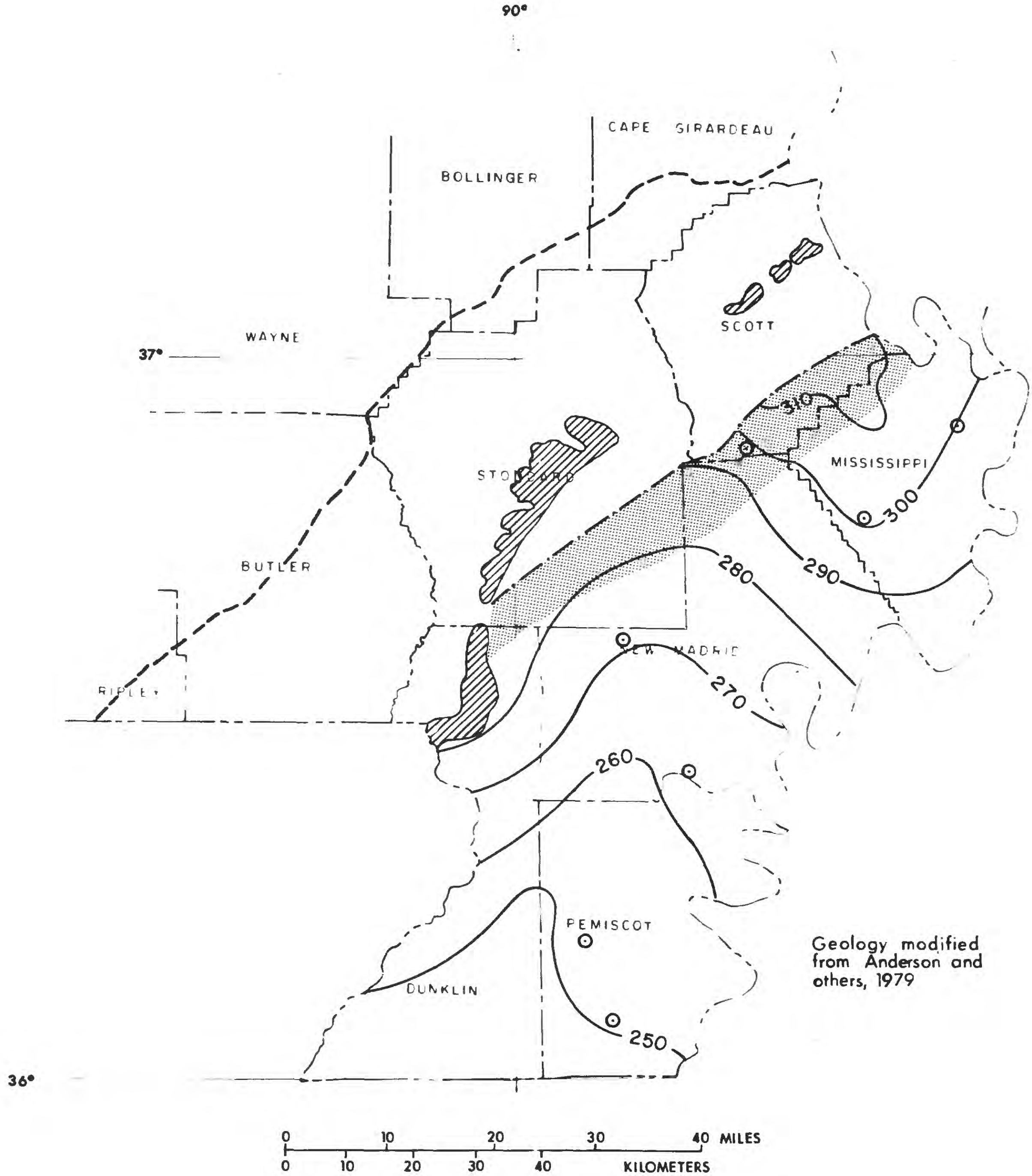


Figure 26.--Thickness of the Wilcox Group (undivided) in southeastern Missouri.



EXPLANATION

- PROJECT BOUNDARY
- OUTCROP OF WILCOX GROUP, UNDIVIDED
- LIMIT OF SUBCROP OF WILCOX GROUP (UPDIP LIMIT OF THE WILCOX GROUP EXCEPT FOR OUTLIERS)
- 250 POTENTIOMETRIC CONTOUR SHOWS APPROXIMATE ALTITUDE, IN FEET, OF THE POTENTIOMETRIC SURFACE. Contour interval 10 feet. Datum is sea level
- SUSPECTED RECHARGE AREA
- ⊙ DATA POINT

Figure 27.--Potentiometric surface of the lower Wilcox aquifer in southeastern Missouri.

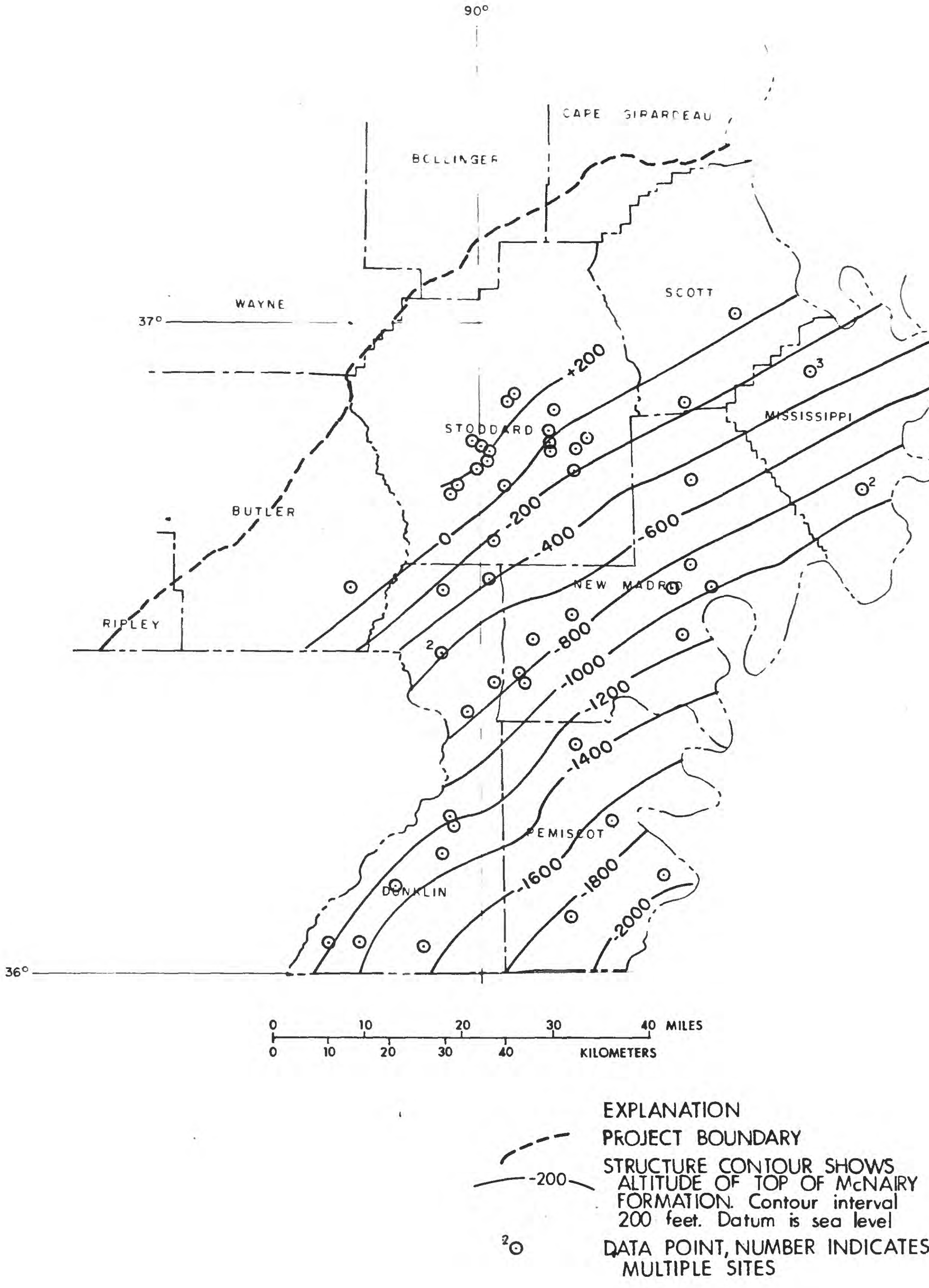


Figure 28.--Altitude of the top of the McNairy Formation in southeastern Missouri.

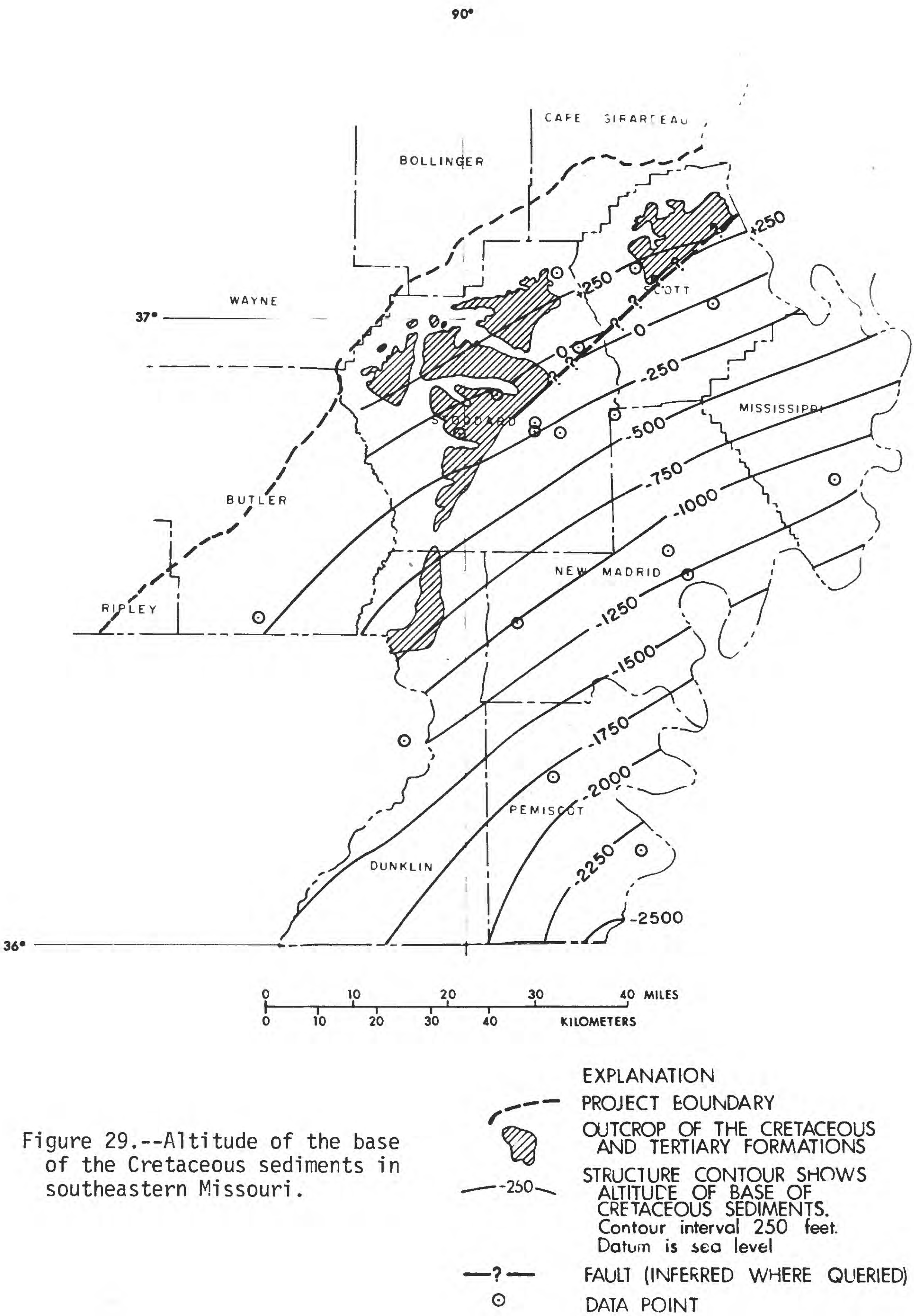


Figure 29.--Altitude of the base of the Cretaceous sediments in southeastern Missouri.

This aquifer currently is used only for municipal supplies. The city of Sikeston is the largest user, but other municipalities also use it (Luckey and Fuller, 1980). In the southeast part of the area, particularly in Pemiscot County, this aquifer is the preferred source for a municipal supply.

Midway Group

The Midway Group is composed of the green Clayton Formation and the thick Porters Creek Clay. The Clayton Formation is easily recognized as a marker bed by geologists. Above the Clayton is as much as 650 feet of extremely uniform, dark clay called the Porters Creek Clay. Below the Clayton Formation is the Owl Creek Formation; this formation also primarily is composed of clay. The Owl Creek Formation, together with the Midway Group, forms a sequence of as much as 780 feet of clay. The major hydrologic characteristic of this sequence is that it is an effective confining layer separating the lower Wilcox aquifer from underlying aquifers. Nothing is known of the hydraulic characteristics of this sequence, except that it must have extremely low permeability.

McNairy Formation

The McNairy Formation, which is locally called the "Ripley Sand," underlies about three-fourths of the lowlands in southeastern Missouri and crops out throughout about 125 square miles on Crowleys Ridge and Benton Hills. This formation primarily consists of sand, sandy clay, and clay and is a significant aquifer that is used to supply water throughout southeastern Missouri. Cretaceous sediments older than the McNairy Formation exist in the deeper part of the embayment and these sediments are included with the McNairy Formation in the discussion of the McNairy aquifer. The McNairy aquifer lies at considerable depth throughout most of the area (fig. 28). Although the McNairy Formation crops out on Crowleys Ridge and Benton Hills, it lies more than 2,000 feet below sea level in the extreme southeastern part of the area. The McNairy Formation dips and thickens to the southeast and this formation and pre-McNairy Cretaceous beds have a maximum thickness of 600 feet in the extreme southeastern part of the area.

The altitude of the base of the Cretaceous sediments is shown in figure 29. Because the Cretaceous sediments are the oldest Mesozoic sediments in the area, this map also shows the altitude of the top of the Paleozoic formations. By using figures 28 and 29, the thickness of the McNairy aquifer can be estimated.

Not enough data are available to draw a potentiometric-surface map for the McNairy aquifer. Boswell and others (1965) show a potentiometric-surface map that indicates the primary direction of flow in this aquifer is from the east flank of the embayment with a lesser volume of flow from the west flank of the embayment toward the axis. The low in Boswell's potentiometric-surface map occurs along a band parallel to Crowleys Ridge and 10 to 20 miles south and east of the ridge. Presently available data do not dispute this concept of the flow system, and in nearly all the wells that penetrate the McNairy aquifer in southeastern Missouri the water levels stand at an altitude ranging from 310 to 330 feet above sea level.

Recharge to the McNairy aquifer most likely occurs where the McNairy Formation directly underlies the alluvium in Missouri and where the formation crops out in Kentucky and Tennessee. The primary discharge from this aquifer probably is by pumpage for municipal water supply, although some natural discharge by upward leakage to overlying aquifers must have occurred in the undisturbed system.

The McNairy aquifer is used exclusively for municipal water supply because of the large artesian head and small iron and hardness concentrations of the water. However, in the southeast part of the area use of water from this aquifer has declined because of larger sodium concentration and elevated water temperature. The total withdrawal from this aquifer in Missouri probably is less than a few thousand acre-feet per year.

The McNairy aquifer may become more important in the future not as a water source but as a heat source. Water temperatures in the McNairy aquifer are shown in figure 30. In the southern one-half of the area the water in this aquifer is quite warm and is reported to be as much as 95 °F in places. Although part of this increase in temperature is due to the natural geothermal gradient, other factors also may be involved. The future use of this aquifer as a heat source can only be surmised, but as technology advances and energy costs increase it appears likely that this aquifer eventually may be developed for this purpose.

Paleozoic Aquifers

In addition to the unconsolidated aquifers previously discussed, a number of Paleozoic formations that underlie the entire area also are aquifers. Close to the Ozark escarpment these aquifers are used to some extent, but throughout most of the area sufficient water of acceptable quality is available before reaching the Paleozoic rocks.

In the southeastern part of the area, there is evidence that the water in the Paleozoic aquifers is excessively mineralized (Luckey and Fuller, 1980). Generally, few data are available to indicate the quantity and quality of water available from Paleozoic formations.

WATER QUALITY

By Dale L. Fuller,
Missouri Division of Geology and Land Survey

Surface Water

The principal streams in the Southeast Lowlands are the Mississippi, Black, St. Francis, and Castor rivers, and the major drainage ditches (see fig. 31, p. 64). Water-quality data for these streams and some miscellaneous surface-water sites are listed in table 10 of the hydrologic-data report by Luckey and Fuller (1980).

Dissolved-solids concentrations for the surface-water sites ranged from 67 milligrams per liter in the Castor River to 584 milligrams per liter in one of the drainage ditches. Two of the streams with the smaller dissolved-solids concentrations, the Black and St. Francis rivers, have impoundments near the western edge of the lowlands area. The major dissolved constituents are calcium, magnesium, and bicarbonate. Calcium-to-magnesium ratios appear to be smaller during the summer, which may reflect flow contributions from irrigation water that has smaller calcium-to-magnesium ratios. Concentrations of sulfate were relatively small, except in the Mississippi River, which is affected by geologic characteristics of many areas upstream from the Southeast Lowlands of Missouri. Nitrate concentrations generally were less than 4 milligrams per liter, except for a maximum concentration of 9.1 milligrams per liter in a water sample from the Mississippi River.

On October 21, 1976, water samples and streambed-sediment samples were collected for analysis for pesticides. The sites at which the samples were collected represent most of the surface outflow from southeastern Missouri. Analyses were made for a wide variety of herbicides and insecticides in these samples, and the results of the analyses are shown in table 5. In addition to this sampling program, the Arkansas District of the U.S. Geological Survey routinely collects pesticide samples at Black River and St. Francis River streamflow-gaging stations (U.S. Geological Survey, 1975, 1976). Although the use of pesticides in southeastern Missouri is widespread, only small quantities of a few compounds were detected. The October 1976 sampling took place while herbicides were being applied by aerial spraying to defoliate cotton. Small concentrations of the insecticides dieldrin and diazinon, and the herbicide 2, 4-D were present in some water samples. The insecticides aldrin, chlordane, DDD, DDE, and DDT were present in some bottom-sediment samples because of their tendency to concentrate in the bottom sediments and stay there for long periods of time. This probably accounts for the presence of some pesticides in the bottom sediments that were not detectable in the water. In summary, although the use of pesticides is common in the area, the sampling programs did not detect any pesticides in large enough concentrations in either the water or the bottom sediments to be of concern.

Ground Water

Aquifers utilized in southeastern Missouri are the alluvium, the Wilcox Group (undivided), the McNairy, and the Paleozoic carbonate rocks. Water-quality data for these aquifers are included in table 10 of the hydrologic-data report by Luckey and Fuller (1980). Ground water from each aquifer has somewhat differing chemical characteristics; the alluvium and the Wilcox are the most similar.

Alluvium

Water in the alluvium may be categorized as a calcium magnesium bicarbonate type. Carbonate hardness ranges from 30 to 340 milligrams per liter, averaging about 170. The dissolved-solids concentrations range from 60 to 570 milligrams per liter, and the average dissolved-solids concentration is 240.

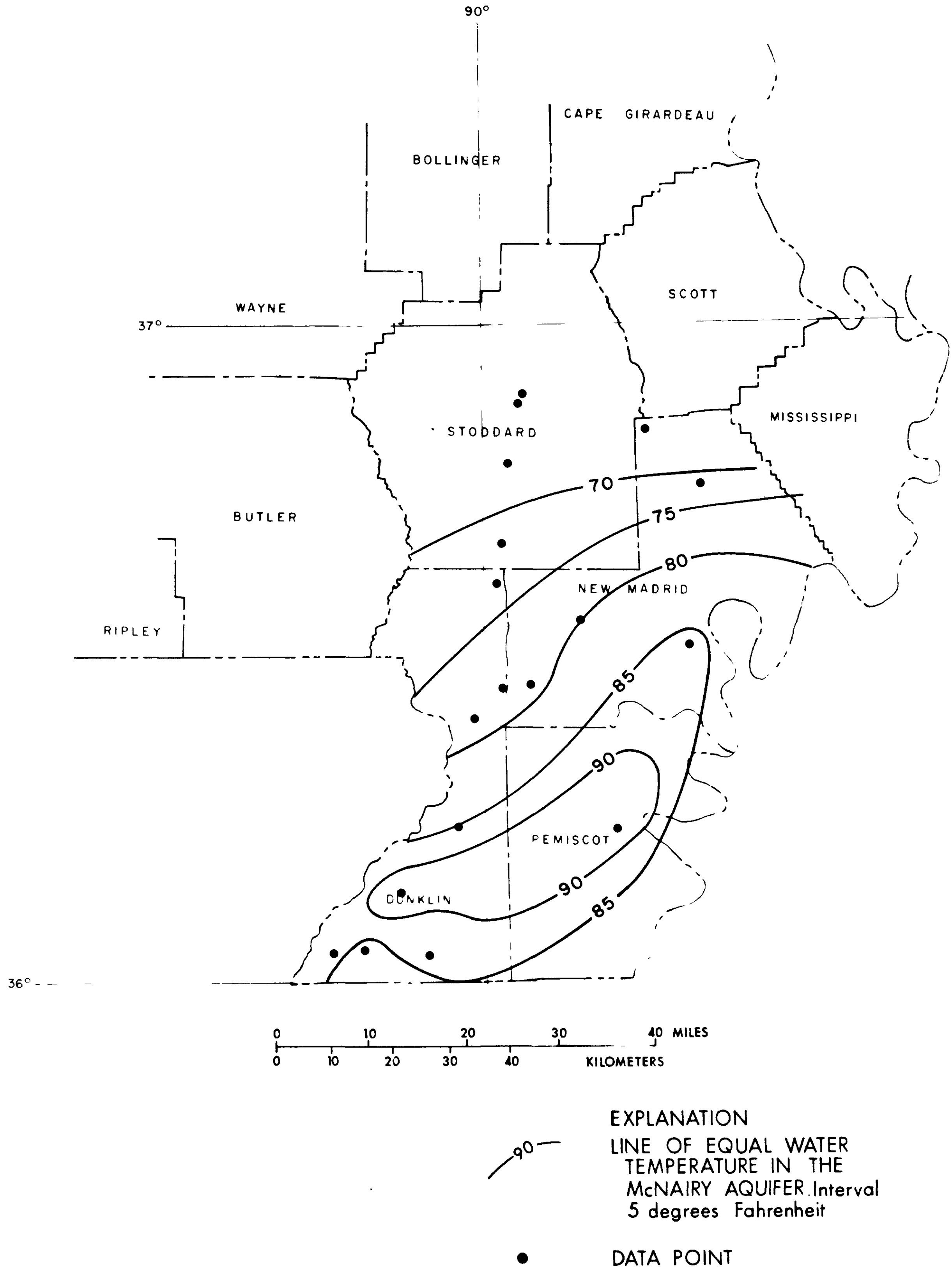


Figure 30.--Water temperature in the McNairy aquifer in southeastern Missouri.

Table 5.--Pesticides analyses of water and bottom sediments from selected ditches and rivers draining southeastern Missouri

[Water analyses are in micrograms per liter for unfiltered samples and bottom sediment analyses are in micrograms per kilogram; DDD, 1,1-Dichloro-2, 2-bis (p-chlorophenyl) ethane; DDE, Dichlorodiphenyldichloroethylene; <, less than; --, no data; DDT, Dichlorodiphenyltrichloroethane; PCB, Polychlorinated biphenyls; PCN, Polychlorinated naphthalenes; 2,4-D, 2,4-Dichlorophenoxy acetic acid; 2,4-DP, 2-(2,4-Dichlorophenoxy) propionic acid; 2,4,5-T, 2,4,5-Trichlorophenoxy acetic acid]

Station name	Material sampled	Date sampled	Aldrin	Chlordane	DDD	DDE
Little River ditches near Kennett, Missouri	Water	10/21/76	0.00	0.00	0.00	0.00
	Bottom sediments	10/21/76	.0	2	1.6	1.5
St. Johns Bayou near New Madrid, Missouri	Water	10/21/78	.00	.0	0.00	0.00
	Bottom sediments	10/21/78	.0	0	.0	.0
Black River near Corning, Arkansas	Water	01/21/74	<1.0	--	<1.0	<1.0
	--do--	11/04/75	.00	--	--	.00
	--do--	03/22/76	.00	--	--	.00
	--do--	10/21/76	.0	.00	.00	.00
	Bottom sediments	10/20/76	.0	0	.0	.0
St. Francis River at St. Francisville, Arkansas	Water	10/07/75	.00	--	--	.00
	--do--	03/22/76	.00	--	--	.00
	--do--	06/09/76	.00	--	--	.00
	--do--	07/13/76	.00	--	--	.00
	--do--	08/10/76	.00	--	--	.00
	--do--	09/14/76	.00	--	--	.00
	--do--	10/21/76	.00	.0	.00	.00
	Bottom sediments	10/21/76	.2	2	1.2	.6

Table 5.--Pesticides analyses of water and bottom sediments from selected ditches and rivers draining southeastern Missouri--Continued

Station name	Material sampled	Date sampled	DDT	Diazinon	Dieldrin	Endrin
Little River ditches near Kennett, Missouri	Water	10/21/76	0.00	0.00	0.00	0.00
	Bottom sediments	10/21/76	.0	--	.0	.0
St. Johns Bayou near New Madrid, Missouri	Water	10/21/78	.00	.02	.00	.00
	Bottom sediments	10/21/78	.0	--	.0	.00
Black River near Corning, Arkansas	Water	01/21/74	<1.0	--	<1.0	<1.0
	--do--	11/04/75	.00	--	.00	.00
	--do--	03/22/76	.00	--	.00	.00
	--do--	10/21/76	.00	.00	.00	.00
	Bottom sediments	10/20/76	.0	--	.0	.0
St. Francis River at St. Francisville, Arkansas	Water	10/07/75	.00	--	.00	.00
	--do--	03/22/76	.00	--	.00	.00
	--do--	06/09/76	.00	--	.00	.00
	--do--	07/13/76	.01	--	.01	.00
	--do--	08/10/76	.01	--	.01	.00
	--do--	09/14/76	.00	--	.00	.00
	--do--	10/21/76	.00	.00	.00	.00
	Bottom sediments	10/21/76	.0	--	.0	.0

Table 5.--Pesticides analyses of water and bottom sediments from selected ditches and rivers draining southeastern Missouri--Continued

Station name	Material sampled	Date sampled	Parathion	Trithion	Ethion	Heptachlor epoxide
Little River ditches near Kennett, Missouri	Water	10/21/76	0.00	0.00	0.00	0.00
	Bottom sediments	10/21/76	--	--	--	.0
St. Johns Bayou near New Madrid, Missouri	Water	10/21/78	.00	.00	.00	.00
	Bottom sediments	10/21/78	--	--	--	.0
Black River near Corning, Arkansas	Water	01/21/74	--	--	--	<1.0
	--do--	11/04/75	--	--	--	--
	--do--	03/22/76	--	--	--	--
	--do--	10/21/76	.00	.00	.00	.00
	Bottom sediments	10/20/76	--	--	--	.0
St. Francis River at St. Francisville, Arkansas	Water	10/07/75	--	--	--	--
	--do--	03/22/76	--	--	--	--
	--do--	06/09/76	--	--	--	--
	--do--	07/13/76	--	--	--	--
	--do--	08/10/76	--	--	--	--
	--do--	09/14/76	--	--	--	--
	--do--	10/21/76	.00	.00	.00	.00
	Bottom sediments	10/21/76	--	--	--	.0

Table 5.--Pesticides analyses of water and bottom sediments from selected ditches and rivers draining southeastern Missouri--Continued

Station name	Material sampled	Date sampled	Heptachlor	Lindane	Malathion	Methyl parathion
Little River ditches near Kennett, Missouri	Water	10/21/76	0.00	0.00	0.00	0.00
	Bottom sediments	10/21/76	.0	.0	--	--
St. Johns Bayou near New Madrid, Missouri	Water	10/21/78	.00	.00	0	0
	Bottom sediments	10/21/78	.0	.0	--	--
Black River near Corning, Arkansas	Water	01/21/74	<1.0	<1.0	--	--
	--do--	11/04/75	--	.00	--	--
	--do--	03/22/76	--	.00	--	--
	--do--	10/21/76	.00	.00	0	0
	Bottom sediments	10/20/76	.0	.0	--	--
St. Francis River at St. Francisville, Arkansas	Water	10/07/75	--	.00	--	--
	--do--	03/22/76	--	.00	--	--
	--do--	06/09/76	--	.00	--	--
	--do--	07/13/76	--	.00	--	--
	--do--	08/10/76	--	.00	--	--
	--do--	09/14/76	--	.00	--	--
	--do--	10/21/76	.00	.00	0	0
	Bottom sediments	10/21/76	.0	.0	--	--

Table 5.--Pesticides analyses of water and bottom sediments from selected ditches and rivers draining southeastern Missouri--Continued

Station name	Material sampled	Date sampled	Methyl trithion	PCB	PCN	Silvex
Little River ditches near Kennett, Missouri	Water	10/21/76	0.00	0.0	0.00	--
	Bottom sediments	10/21/76	--	0	0	--
St. Johns Bayou near New Madrid, Missouri	Water	10/21/78	0	0.0	.00	.00
	Bottom sediments	10/21/78	--	0	0	--
Black River near Corning, Arkansas	Water	01/21/74	--	--	--	--
	--do--	11/04/75	--	--	--	--
	--do--	03/22/76	--	--	--	--
	--do--	10/21/76	0	.0	.00	.00
	Bottom sediments	10/20/76	--	0	0	--
St. Francis River at St. Francisville, Arkansas	Water	10/07/75	--	--	--	--
	--do--	03/22/76	--	--	--	--
	--do--	06/09/76	--	--	--	--
	--do--	07/13/76	--	--	--	--
	--do--	08/10/76	--	--	--	--
	--do--	09/14/76	--	--	--	--
	--do--	10/21/76	0	.0	.00	.00
	Bottom sediments	10/21/76	--	0	0	--

Table 5.--Pesticides analyses of water and bottom sediments from selected ditches and rivers draining southeastern Missouri--Continued

Station name	Material sampled	Date sampled	Toxaphene	2,4-D	2,4-DP	2,4,5-T
Little River ditches	Water	10/21/76	0	--	--	--
near Kennett, Missouri	Bottom sediments	10/21/76	0	--	--	--
St. Johns Bayou near	Water	10/21/78	0	0.00	0.00	0.00
New Madrid, Missouri	Bottom sediments	10/21/78	0	--	--	--
Black River near	Water	01/21/74	0	--	--	--
Corning, Arkansas	--do--	11/04/75	<1	--	--	--
	--do--	03/22/76	--	--	--	--
	--do--	10/21/76	0	.01	.00	.00
	Bottom sediments	10/20/76	0	--	--	--
St. Francis River at	Water	10/07/75	<1	--	--	--
St. Francisville,	--do--	03/22/76	--	--	--	--
Arkansas	--do--	06/09/76	<1	--	--	--
	--do--	07/13/76	<1	--	--	--
	--do--	08/10/76	<1	--	--	--
	--do--	09/14/76	<1	--	--	--
	--do--	10/21/76	0	.00	.00	.00
	Bottom sediments	10/21/76	0	--	--	--

Except for iron and manganese, alluvial ground water meets public water-supply standards. Total-iron concentrations in all samples analyzed ranged from 0.03 to 35 milligrams per liter and averaged 4.30 milligrams per liter. Manganese ranged between 0 and 2.0 milligrams per liter and averaged 0.46 milligram per liter. The alluvial ground-water temperature generally ranged from 59 to 63 °F.

Principal water users are cities, industries, and irrigators. Some difficulties in treatment of water for domestic and industrial uses have been experienced, but problems of water quality for irrigation have been minimal. Those reported may be attributed to large iron concentrations. Some odor and taste problems exist.

The author believes that a significant quantity of recharge into the alluvium occurs from the Paleozoic dolomitic rocks in the area west of Crowleys Ridge. A difference in water quality was anticipated and some apparent differences were noted. The calcium-to-magnesium ratio in Butler County (west of Crowleys Ridge) is 3.88. For that area south of Benton Hills and east and south of Crowleys Ridge, the calcium-to-magnesium ratio averaged 5.18. The sulfate concentrations averaged 4.2 milligrams per liter for the west area and 15.5 milligrams per liter for the east and south areas.

East and south of Crowleys Ridge, wells penetrating 30 to 40 feet may yield water of better chemical quality compared to wells 70 to 100 feet deep. Commonly, the shallow-well water has smaller concentrations of dissolved solids, iron, manganese, and hardness.

Wilcox Group (Undivided)

The chemical characteristics of the ground water from the Wilcox Group (undivided) are similar to those of alluvial ground water, primarily differing only in smaller concentrations of chemical constituents in the Wilcox. Dissolved-solids concentrations averaged 166 milligrams per liter; carbonate hardness, 67 milligrams per liter; iron, 1.89 milligrams per liter; and manganese 0.20 milligrams per liter.

Because of the smaller concentrations of chemical constituents, many public water suppliers are utilizing the Wilcox as their water source, even though it requires a well depth 5 to 15 times deeper than in the alluvium. Water temperatures are depth-related and range from 59 to 68 °F.

McNairy Formation

Public water suppliers in areas having the water-productive McNairy aquifer have, historically, preferred to obtain their water from the McNairy. This choice is made because typically the ground water in the McNairy is less hard and iron usually is at a sufficiently minimal level that iron-removal treatment is not required.

The hardest water is along and near the outcrop of the McNairy aquifer in Stoddard County. The maximum carbonate hardness was 180 milligrams per liter; the maximum noncarbonate hardness was 210 milligrams per liter. Minimum for the two is 20 and 0 milligrams per liter, respectively. In contrast is the softness of water in the McNairy in Dunklin County where carbonate hardness ranged between 44 and 8 milligrams per liter and noncarbonate hardness was 0.

Total iron averaged 0.48 milligram per liter, including some anomalously large concentrations. Deleting the 4 of 50 concentrations that exceeded 1.0 milligrams per liter, the average total iron was 0.25 milligram per liter.

A negative aspect of the water quality from the McNairy is the larger concentrations of sodium and chloride as compared to the water in the alluvium and Wilcox. Sodium concentrations generally exceeded 100 milligrams per liter and not uncommonly exceeded 200 milligrams per liter. Chloride concentrations may be excessive, but for most wells does not exceed 250 milligrams per liter. Water temperatures ranged from 61 °F in Stoddard County to 95 °F in Pemiscot County.

Paleozoic Aquifers

Marginal to the southeast Missouri lowlands, ground water from the Paleozoic carbonate rocks is used to supply municipal needs. This water may be categorized as a calcium magnesium bicarbonate type. Dissolved-solids concentrations averaged about 300 milligrams per liter. The calcium-to magnesium ratio is 1.7. Carbonate hardness averaged about 250 milligrams per liter. Deep weathering involving carbonate removal and red clay filling of solution openings frequently causes excessive turbidities. A companion problem is iron concentrations in excess of 0.03 milligram per liter.

Southward and eastward from the Ozarks hill country, ground water is progressively more saline. The largest salinity levels measured to date (in an oil test) were in Mississippi County. This test well in T. 24 N., R. 17 E., had a depth of 4,900 feet and produced water having 66,700 milligrams per liter dissolved-solids concentration (Luckey and Fuller, 1980, table 10). This saline-water occurrence is not considered anomalous.

Three areas of anomalous salinities are at sec. 25, T. 30 N., R. 13 E., Scott County; in the area of T. 27 N., along the border of R. 10 and 11 E, Stoddard County; and T. 24 N., along the south one-third of the border between R. 9 and 10 E., Stoddard County (Luckey and Fuller, 1980, table 10). Faulting in the Paleozoic rocks is believed to be the cause of these anomalous salinities. The Scott County occurrence probably involves a fault block in which recementation of the fault planes has created barriers to ground-water movement. This site has wells in Paleozoic rocks in all directions around it that have potable ground water. The anomalous sites in Stoddard County are believed to have open fault planes permissive of upward saline ground-water movement from the Paleozoic rocks into the McNairy, the Wilcox Group (undivided), and the alluvium.

Temperatures of the aquifers in the Paleozoic ground water ranged from 57 to 88 °F, the maximum being for a discharging test well drilled by the U.S. Geological Survey during 1978 to a depth of 2,316 feet.

SURFACE-WATER SYSTEM

The surface-water system dominated the historical development of southeastern Missouri and still has a major effect on the area. The Mississippi River is the largest component of the surface-water system. The river provided early access to the area and still is a major link in the transportation system of the entire country. However, during flooding the river can inundate tens-of-thousands of acres of prime farmland.

The surface-water system in the area parallels the Mississippi River and drains from north to south, as shown in figure 31. The major rivers in the area are the St. Francis River, the Little River, and the Black River. The only major east-west river is the manmade Headwater diversion channel.

As mentioned in the section on history, the earliest water-resources projects in the area were the development and enhancement of the drainage system. This development is continuing. One of the earlier projects, the Headwater diversion channel, significantly altered the drainage pattern of the Whitewater-Little River drainage system. Drainage development has progressed to the point that today there are many more miles of artificial drainage in the area than there are of natural drainage.

Despite the development of the drainage network, frequent flooding occurs throughout much of southeastern Missouri. However, only the major drainage systems contain significant quantities of water during a drought. Because of the topography of the area, it is not practical to build large storage reservoirs to supply surface water during droughts. This, coupled with the availability of ground water, has discouraged development of the surface-water system as a resource everywhere in the area, except along the Mississippi River and the Ozark escarpment.

A typical runoff pattern for a ditch in southeastern Missouri is shown in figure 32. Runoff is maximum during the winter, decreases to minimum during the summer, and again increases during the fall. The difference between precipitation and runoff is almost entirely evapotranspiration. Excessive summer evapotranspiration is the reason that runoff is minimum during the summer, even though precipitation is fairly constant with time.

Floods--Magnitude and Frequency

Floods are common in the Southeast Lowlands. Because of the low relief in the area, runoff is slow and any major precipitation usually causes considerable standing water. Although the prairies and ridges generally are above flood levels, the various lowlands frequently are flooded.

The largest recent flood in the area occurred during 1973 along the Mississippi River. This flood occurred from early March into June 1973, and was notable because of the length of time that the river remained above flood stage, the total volume of the flood, and the magnitude of the river stages. Hundreds of square miles in southeastern Missouri were inundated by this flood (fig. 33). The recurrence interval for the discharge of the flood in the

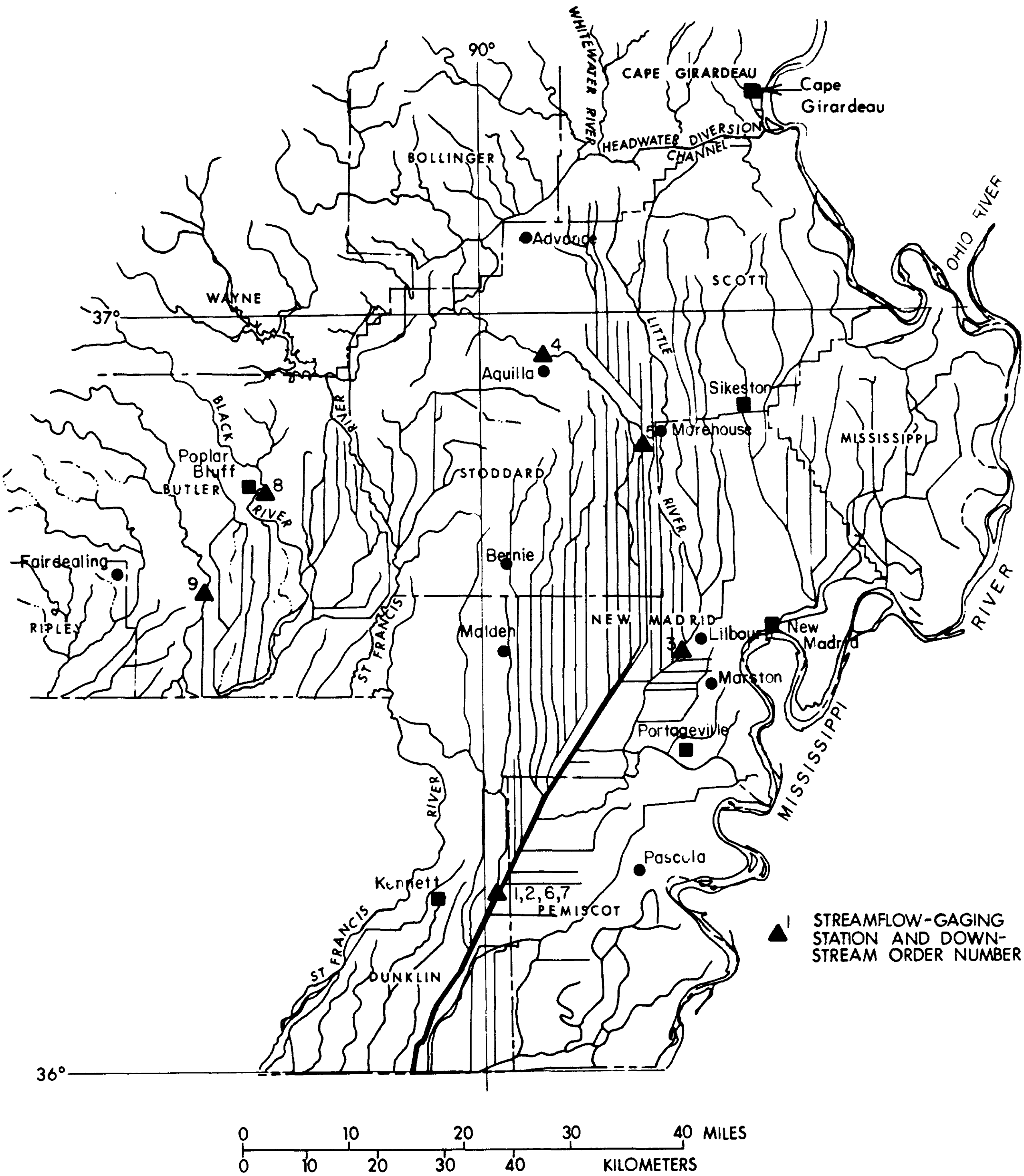


Figure 31.--Geographic features and streamflow-gaging station locations in southeastern Missouri.

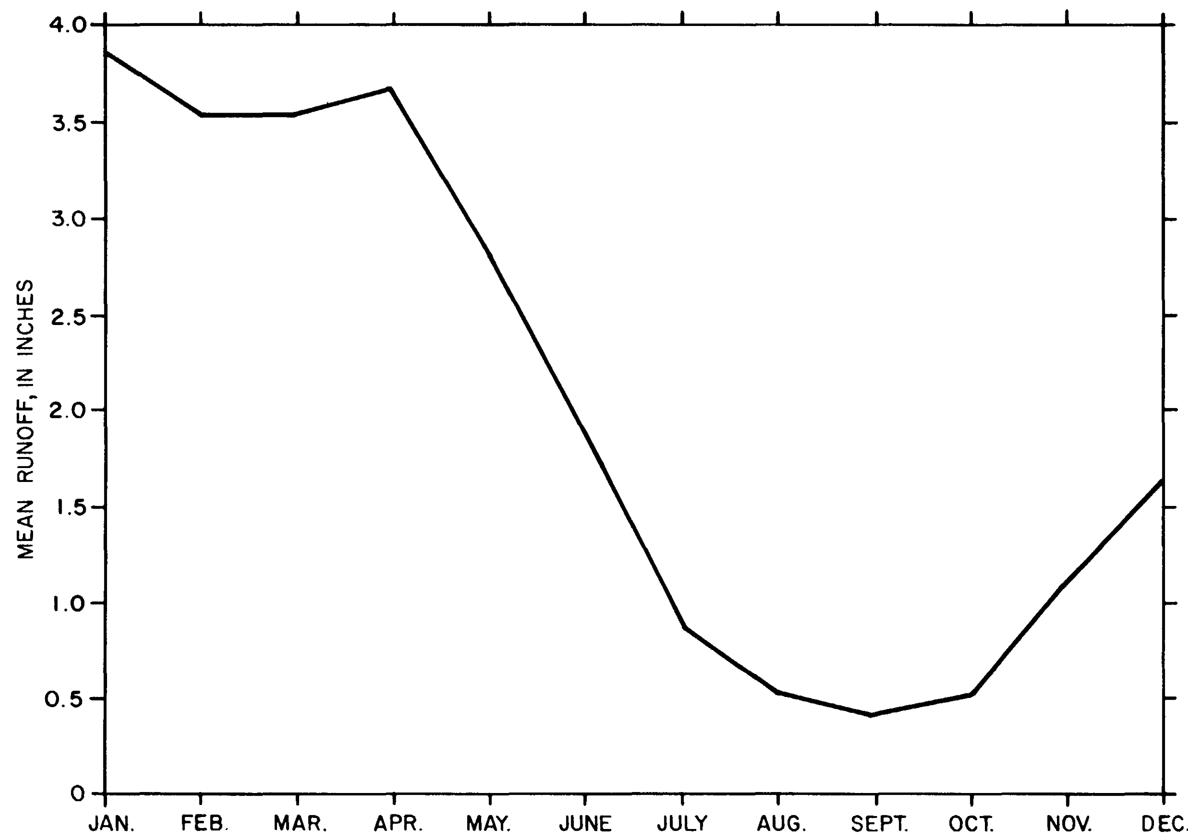


Figure 32.--Mean monthly runoff in Little River ditch 1 near Kennett, based on 1927-77 data.

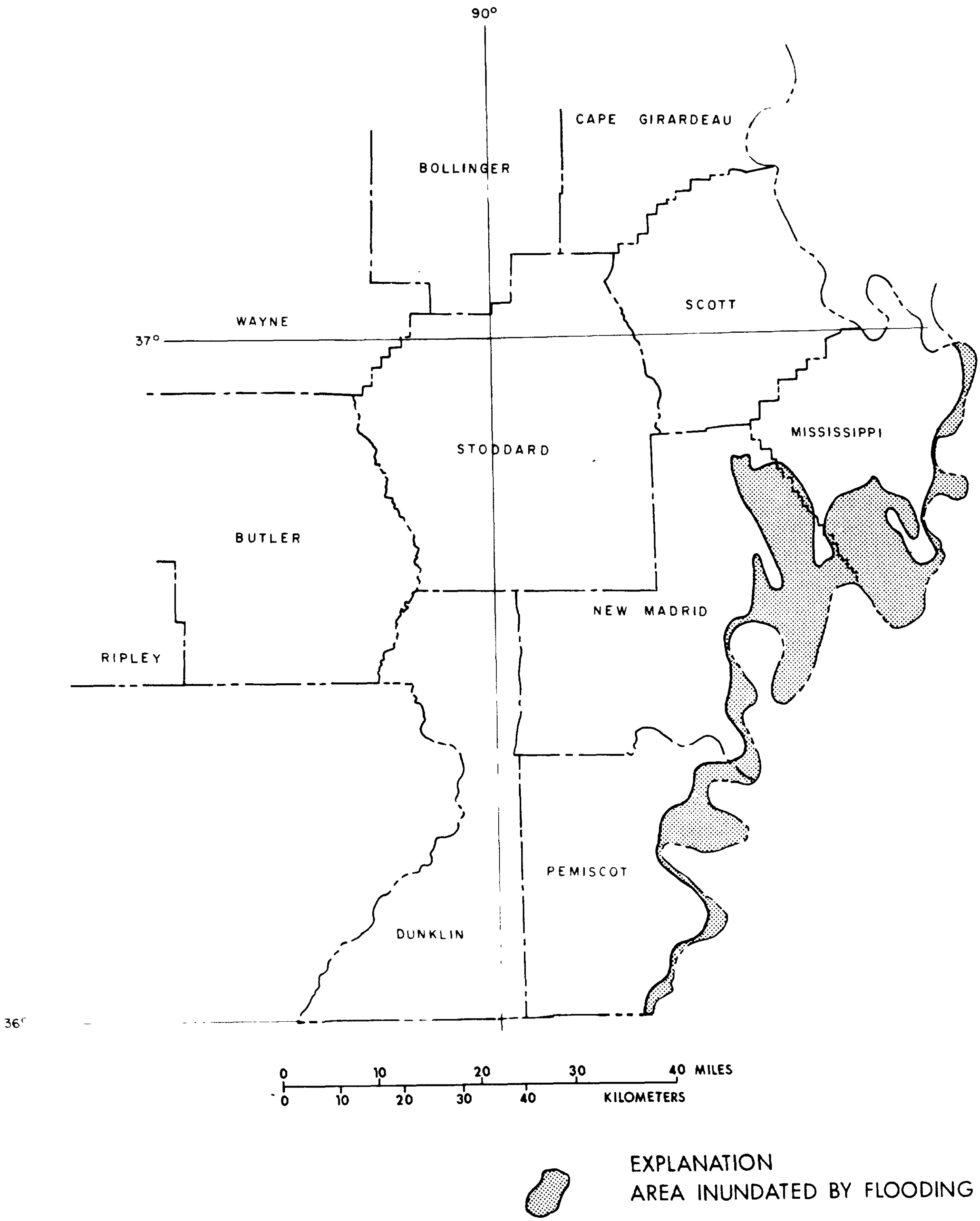


Figure 33.--Area of southeastern Missouri downstream from the Ohio River flooded by the Mississippi River during 1973.

study-area reach of the Mississippi River is estimated to be 20 years (Chin and others, 1975). A recurrence interval of 20 years means that a larger discharge could be expected on the average of once every 20 years. Downstream from the Ohio River, the stage of the 1973 flood was slightly lower than the stage of the all-time maximum 1937 flood. Upstream from the Ohio River, the Mississippi River reached the highest stages since at least 1785 because of modern levee systems and other activities of man on the flood plain that have caused a significant increase in stage for a given discharge (Chin and others, 1975).

During this study, significant floods occurred on the Black and Little Black rivers on March 27-29, 1977. The peak discharge of the Black River at Poplar Bluff (21,700 cubic feet per second) had an estimated recurrence interval of about 5 years; the peak discharge of the Little Black River at Fairdealing (52,800 cubic feet per second) had an estimated recurrence interval that was greater than 100 years. Large areas of Butler and Ripley Counties were inundated at this time from the combined overflow of the two rivers. This flood occurred at a time when ground-water levels in the area were being measured, and its effect on ground-water levels was documented (Luckey and Fuller, 1980).

Estimated flood frequencies for selected streamflow-gaging stations in the area are shown in table 6. Whereas this table only shows estimated flood magnitudes for selected streamflow-gaging stations, Hauth (1974) gives equations for estimating flood frequencies for ungaged sites that exceed 10 square miles drainage area.

Low-Flow Frequency and Flow Duration

The flow characteristics of the rivers and ditches in the area are affected by both man's regulation and ground-water storage in the area. A flow-duration curve for the Black River near Corning, Arkansas, just outside Missouri is shown in figure 34, and the flow-duration curve for Little River ditch 251 near Kennett is shown in figure 35. The Black River is typical of the area west of Crowleys Ridge, and the Little River ditch 251 represents the area east of Crowleys Ridge. The flow-duration curve for the Black River shows that during 1934-76, the discharge exceeded 300 cubic feet per second 95 percent of the time, and exceeded 5,500 cubic feet per second 5 percent of the time. The curve for Little River ditch 251 shows that during 1966-73, the discharge exceeded 90 cubic feet per second 95 percent of the time and exceeded 2,600 cubic feet per second 5 percent of the time. The discharge of the Black River is larger because of a larger drainage area. However, comparison of these two flow-duration curves shows that they have almost identical shapes, even though the Black River has slightly more discharge per square mile.

A flow-duration curve for the Mississippi River at Memphis, Tennessee, is shown in figure 36 for comparison. This figure shows that during 1934-73, the discharge exceeded 130,000 cubic feet per second 95 percent of the time and exceeded 1,100,000 cubic feet per second 5 percent of the time. The slope of this flow-duration curve is flatter than the flow-duration curves of the Black and Little Rivers, indicating a more sustained discharge.

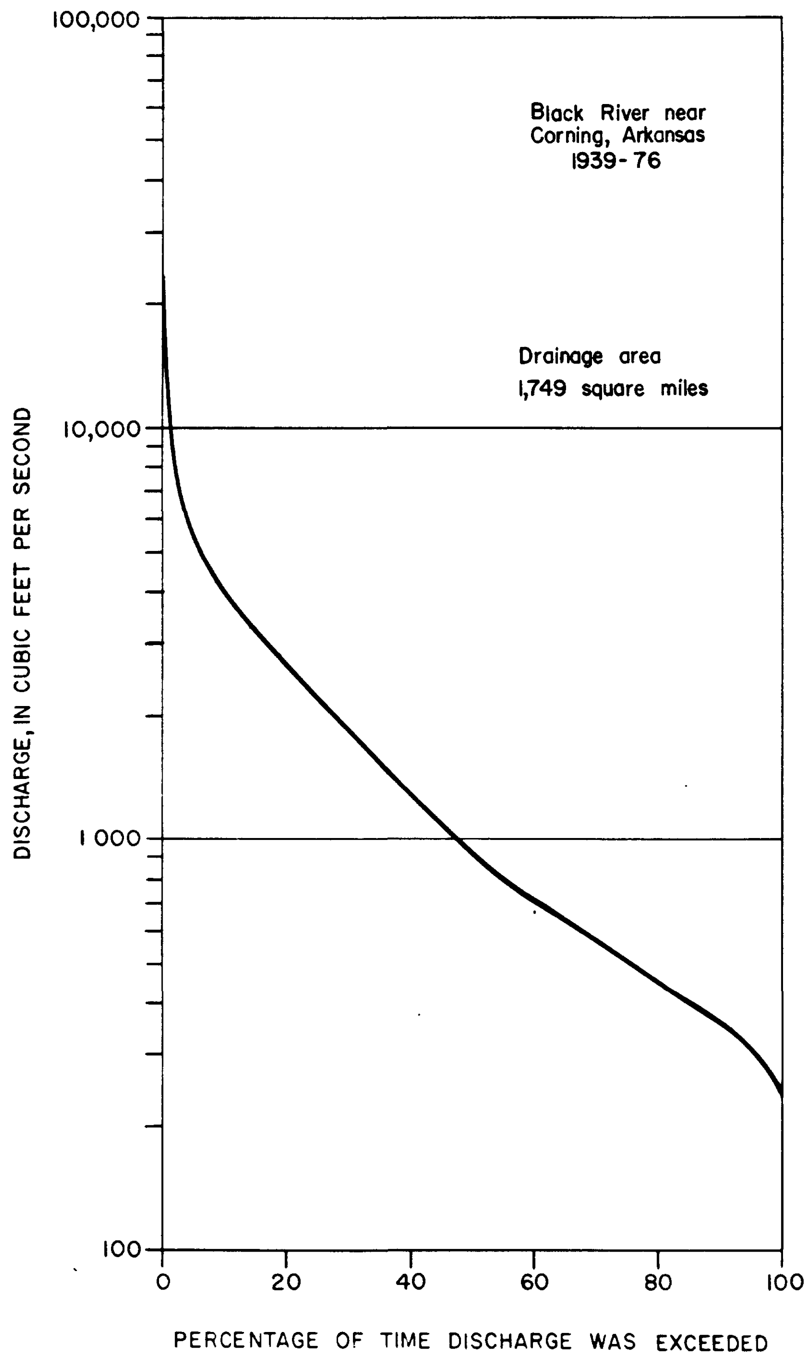


Figure 34.--Flow-duration curve for the Black River near Corning, Arkansas.

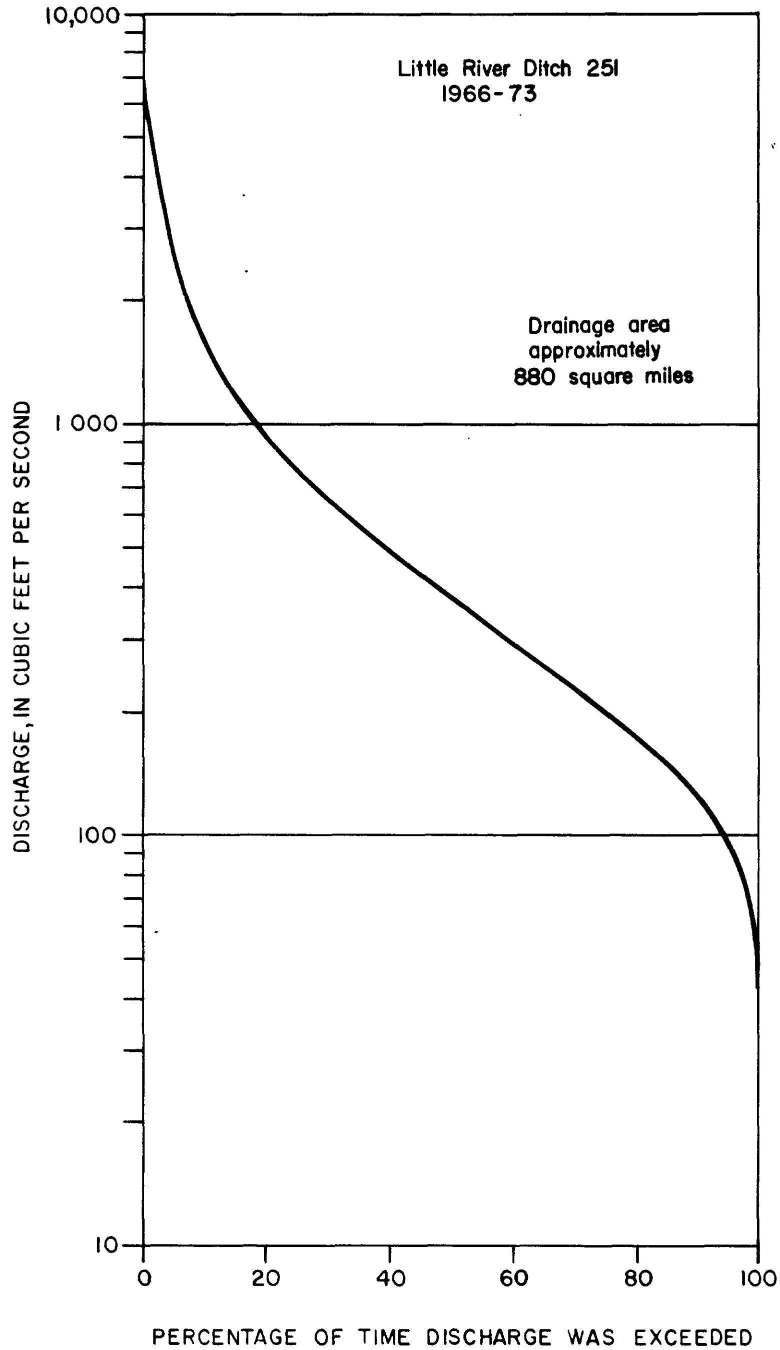


Figure 35.--Flow-duration curve for Little River ditch 251 near Kennett.

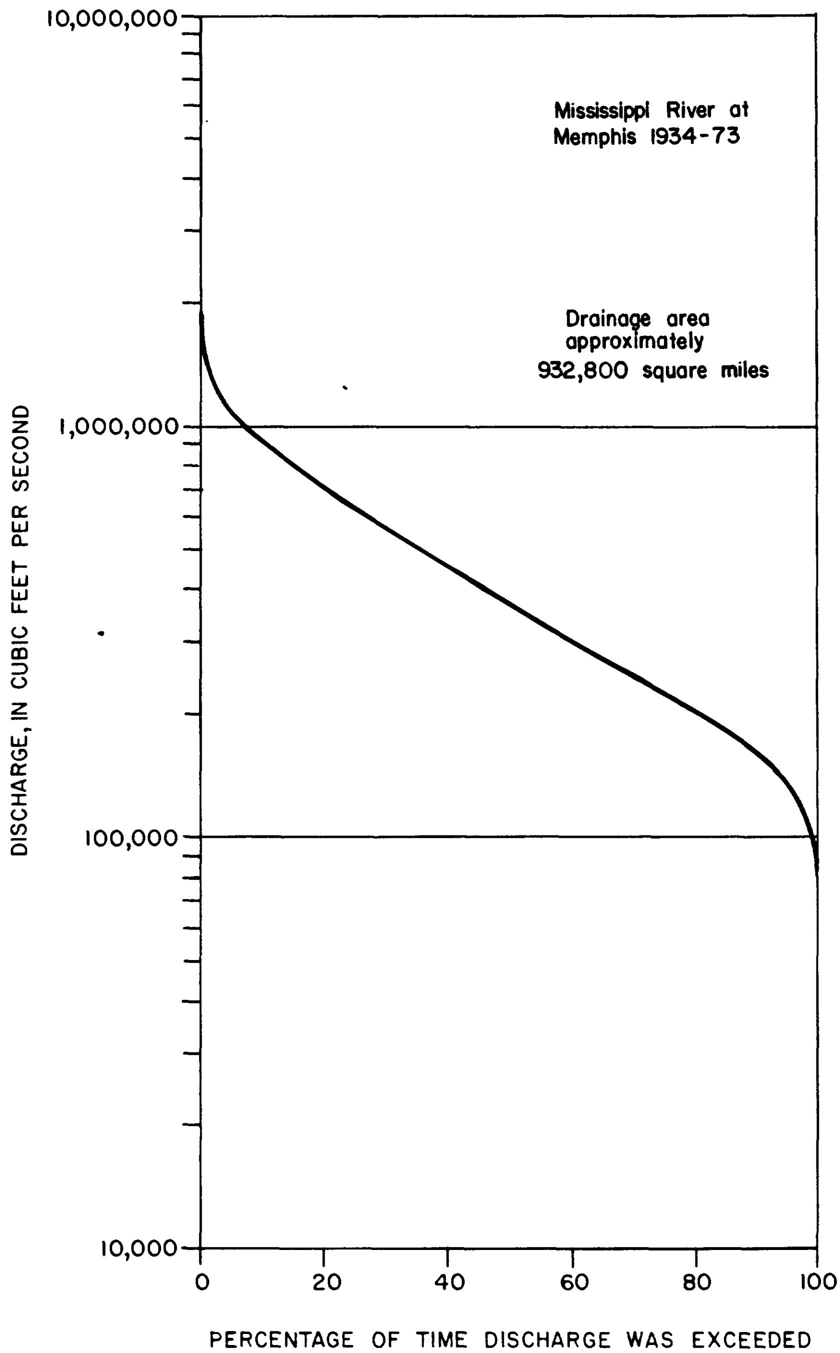


Figure 36.--Flow-duration curve for the Mississippi River at Memphis, Tennessee.

When development of a surface-water supply is being considered, the low-flow frequency data are of prime importance. A low-flow frequency analysis will determine if the surface-water system will deliver the required quantity of water during periods of drought. Low-flow frequency estimates for annual low flows at selected sites are shown in table 7 (Skelton, 1976). As can be computed from data in the table, the 7-day flow with recurrence interval of 2 years ranges from 0.4 cubic foot per second per square mile to 0.004 cubic foot per second per square mile at the sites shown. For longer recurrence intervals some of the stations show zero flow. Low-flow frequencies for many other sites in southeastern Missouri are shown by Skelton (1976).

When considering developing the surface-water system for irrigation supplies, additional analyses that consider flow frequencies only during the time of large irrigation demands are used (Skelton, 1970). However, because smallest surface-water flows usually occur during years with greatest irrigation demands and alternative sources are easily available, the surface-water system generally is not considered for an irrigation supply. However, there are a few isolated places in the lowlands where irrigators pump water directly from the ditches.

FUTURE TRENDS AND POSSIBLE CONCERNS

The continuing development and enhancement of the drainage network in southeastern Missouri will affect the water resources of the area. This development includes everything from leveling of individual fields to construction of major new drainage canals. The principal effect of an enhanced drainage network will be a lowering of ground-water levels in the alluvium. The drainage canals generally intersect the water table and are drains to the aquifer. The effect was observed during this study in the area around Charter Oak in Stoddard County where the drainage network was being improved. Improving the drainage system and leveling the land can decrease recharge to the aquifer because water runs off more quickly. However, in most areas this should not cause a serious problem as more water generally is available for recharge than the aquifer is able to accept.

Changing the drainage network also affects the surface-water system. The object of improving the drainage system is to move the water from the land more quickly and this means a change in the high-flow characteristics of the ditches. This may not create any serious problems, but it is an effect that needs to be monitored with time.

Irrigation probably will continue to expand and this will place an increased demand on the shallow alluvial aquifer. However, throughout most of the area the available water supply is large compared to the probable crop demands and no serious problems are anticipated even under full development for irrigation. There may be somewhat larger seasonal changes in water levels than there have been in the past, but there probably will not be any long-term declines throughout most of the area.

The use of centrifugal pumps for irrigation is quite common in much of southeastern Missouri. These pumps are limited in the depth from which they are able to lift water, usually less than 20 feet. In some areas continued

Table 6.--Flood-frequency data for selected streamflow-gaging stations in southeastern Missouri

[Data from Hauth, 1974; mi^2, square mile; ft/mi, foot per mile]

Station number (fig. 31)	Streamflow-gaging station name	Basin characteristics		Magnitude of flood, in cubic feet per second, for indicated recurrence interval					
		Area (mi^2)	Slope (ft/mi)	2-year	5-year	10-year	25-year	50-year	100-year
1	Little River ditch 81 near Kennett	111	1.0	1,730	2,660	3,240	3,940	4,420	4,880
2	Little River ditch 1 near Kennett	235	1.0	4,070	6,290	7,700	9,380	10,600	11,700
3	Little River ditch 251 near Lilbourn	235	2.0	2,520	3,160	3,520	3,900	4,160	4,380
4	Castor River at Aquilla	175	.8	2,230	3,220	3,810	4,500	4,960	5,400
5	Little River ditch 1 near Morehouse	450	2.0	5,210	7,080	8,170	9,390	10,200	11,000
6	Little River ditch 251 near Kennett	883	1.0	8,850	12,200	14,200	16,500	18,000	19,400
7	Little River ditch 259 near Kennett	89	1.0	1,760	2,780	3,430	4,210	4,760	5,290
8	Black River at Poplar Bluff	1,245	6.23	11,000	20,800	28,000	37,400	44,500	51,600
9	Little Black River near Fairdealing	187	10.8	6,600	13,400	18,400	25,800	31,200	37,700

Table 7.--Magnitude and frequency of annual low flows for selected streamflow-gaging stations in southeastern Missouri

[Data from Skelton, 1976; --, insufficient data for computations]

Station number (fig. 31)	Streamflow-gaging station name and period of record (years)	Drainage area (square miles)	Period (days)	Annual low-flow (in cubic feet per second) for indicated recurrence interval (in years)				
				2	5	10	20	50
1	Little River ditch 81 near Kennett 1927-72	111	7	45	25	18	13	9
			14	48	27	20	15	11
			30	54	30	22	17	13
			60	58	32	25	20	16
2	Little River ditch 1 near Kennett 1927-72	235	7	32	21	17	13	9.5
			14	35	23	20	16	12
			30	38	26	22	18	14
			60	45	28	24	21	18
3	Little River ditch 251 near Lilbourn 1946-72	235	7	87	52	40	33	26
			14	90	55	43	35	28
			30	96	58	46	37	30
			60	105	64	50	40	32
4	Castor River at Aquilla 1946-72	175	7	0.7	0.2	0.1	0.0	0.0
			14	1.0	.2	.1	0	0
			30	1.6	.6	.2	.1	--
			60	4.6	1.5	.5	.1	--
5	Little River ditch 1 near Morehouse 1946-72	450	7	68	42	33	27	22
			14	72	45	37	31	25
			30	76	50	41	35	30
			60	88	60	50	43	36
7	Little River ditch 259 near Kennett 1929-72	89	7	3.6	.3	.1	0	0
			14	4.5	.3	.1	0	0
			30	5	.4	.1	0	0
			60	5.6	.9	.2	.1	0

irrigation development may force a conversion to turbine pumps or other deep-well pumps because the larger seasonal fluctuation in water levels may preclude the use of centrifugal pumps at the season when the crops need the most water.

The continued increase of rice acreage in the area may have an effect on water levels in the alluvium in the major rice-growing areas. This effect probably would not extend more than a few miles beyond these areas. Rice requires large quantities of water and the best areas for growing rice are the areas with the tightest soils. These tight soils tend to limit the rate at which water can recharge the aquifer. In areas outside the study area, such as near Stuttgart, Arkansas, the combination of large ground-water withdrawal for irrigating rice and limited recharge because of tight soils has produced long-term water-level declines. A similar situation has not occurred in Missouri and may not develop because of the smaller extent of the prime rice-growing areas. However, if any long-term decline of the water level in the alluvial aquifer does occur it will most likely occur in the rice-growing areas.

The deeper aquifers, the lower Wilcox and the McNairy, are much more susceptible to overdevelopment (excessive withdrawal causing continuing long-term declines in water level) than the alluvial aquifer. These aquifers are primarily used for municipal supplies, so overdevelopment is most likely to occur in the major population centers. If overdevelopment does occur, it will probably be a fairly local problem that can easily be solved by withdrawing part of the needed water from another aquifer.

Both the surface-water and the ground-water systems are susceptible to contamination and, because the systems are interconnected, contamination of either system will ultimately lead to contamination of both systems. The water resource of the area is a tremendous resource that needs to be protected from contamination. Although major contamination has not occurred, the potential does exist because of the large quantity of agricultural and industrial chemicals used in the area.

SUGGESTIONS FOR FURTHER WORK

The purpose of this study was to evaluate the water resources of southeastern Missouri. The study was not designed to solve all water problems that might occur. Further work in this area is needed to better define the resource and to solve various special problems that may occur from time to time.

Monitoring of water levels in the area needs to be continued, and it is suggested that a water-level-monitoring network be established. This network should contain about 10 percent of the sites that were used to monitor the alluvial aquifer during this study (Luckey and Fuller, 1980, fig. 3). This would provide a data base for future studies in the area and alert water users to any problems that might be developing in the area. Water levels in this network need to be measured periodically (perhaps every 2 to 5 years) during the spring and fall.

Additional water-use information needs to be collected, including accurate recording of the quantity and source of water used by area municipalities and industries. Much more data also need to be collected on water use for agriculture. During this study an estimate of the quantity of water used for several crops was made, but these estimates need refining. Additional data are needed to estimate water use by crops not included in this report and to define the changing irrigation practices of the area. Because the major use for ground water in the area is irrigation, considerable effort needs to be expended to determine water needs for agriculture. Data on new irrigation wells need to be collected so that the extent and concentration of irrigation can be monitored. Updated irrigation well-location maps need to be periodically prepared.

Additional information needs to be collected to determine the mechanisms of recharge, particularly west of Crowleys Ridge. Such a study needs to include determining ditch and soil properties that might relate to recharge to the aquifer and the effect of nearby ditches on the cone of depression of a well. The study probably needs to include a model of the surface-water and ground-water systems west of Crowleys Ridge. One of the purposes would be to determine if any long-range water-level declines would occur in this area due to the concentration of rice irrigation.

After these additional data or information are collected, and if irrigation continues to expand, another project needs to be initiated for study of future water-management alternatives for the area. This project would include such things as energy requirements and irrigation, the feasibility of common distribution systems, delivery of water to areas where the aquifer is a limiting factor in development, increased utilization of surface-water supplies, and resolution of conflicts between irrigators and other water users. Such a study could lead to a local cooperative management of this valuable resource that would minimize future problems.

SUMMARY AND CONCLUSIONS

The purpose of this report was to describe the water resources of southeastern Missouri. The primary emphasis was an evaluation of the extent of irrigation in the area and the potential of the water resources to support further development.

In this report the ground-water system in the area is divided into three major systems. The alluvial aquifer, which is estimated to contain 60 million acre-feet of water, provides municipal, industrial, and irrigation water. Two deeper aquifers, the Wilcox aquifer and the McNairy aquifer, primarily are used for municipal water supplies. Although the quantity of water withdrawn from these three aquifers is considerable, it is small compared to the storage in the ground-water system and the annual rate of recharge.

More than 85 percent of the area is underlain by saturated alluvium. This alluvial aquifer will yield more than 1,000 gallons per minute to a properly constructed well in most places, and yields of more than 3,000 gallons per minute are possible. Wells of this capacity can be developed throughout most of the area with little chance of significant long-term declines in water levels. There has been no significant change in the potentiometric surface during the last 20 years (1956-76). The water in the alluvium is of adequate quality for irrigation, although it does have a larger iron and hardness concentration than is desirable for domestic use.

The Wilcox Group (undivided) contains an aquifer that will yield as much as 1,500 gallons per minute in favorable locations. This aquifer, which primarily is used for municipal water supplies, contains water that is generally of better quality than the water in the alluvium. The lower Wilcox aquifer is not used for irrigation because sufficient water exists in the alluvium above the lower Wilcox aquifer. The potential exists for local overdevelopment of the lower Wilcox aquifer, particularly in the major urban centers, but this problem can be remedied by transferring part of the water demand to other aquifers.

The McNairy aquifer is the deepest aquifer in general use in the area. This aquifer, which may be more than 2,000 feet below land surface, is used as a municipal supply because it contains soft water of small iron concentration. The McNairy aquifer has the potential for local overdevelopment as does the lower Wilcox aquifer. Throughout much of the area in the McNairy aquifer the temperature of the water is in excess of 80 °F. This high temperature combined with the high artesian pressure in the aquifer may make the McNairy an attractive heat source in the future.

The drainage network in the area is being expanded and enhanced. Making the drainage system in the area more efficient will affect both the surface-water and ground-water systems. The water levels in the alluvial aquifer will be lowered as the drainage system is improved, but this lowering probably will occur only where water levels are now at an undesirable high level.

The development of the ground-water system for irrigation probably will continue and accelerate in the future. Water use probably will increase greatly, but only minor problems are expected. Increased water use for irrigation may necessitate changing from centrifugal pumps to turbine pumps in some areas, and local water-level declines in the intensive rice-growing areas possibly could develop.

This study has outlined the water resources of the area, but additional work to better define the system still is necessary. A network of wells is needed to monitor water levels in all the aquifers. Much more data for water use need to be collected. This includes data for municipal water use as well as water for irrigation. The area west of Crowleys Ridge needs additional study. This area contains the tightest soils and much of the rice-growing area and would experience water-level declines if any are to occur due to irrigation.

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