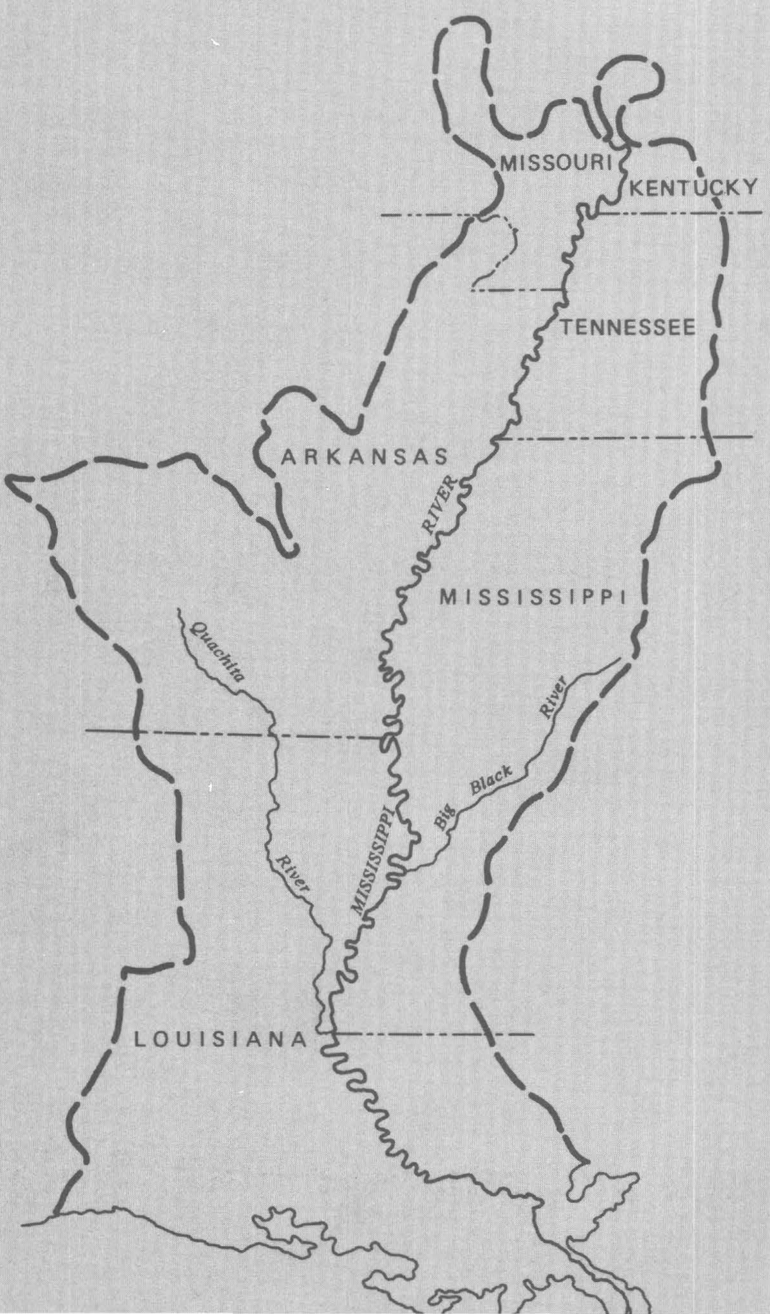
Summary Appraisals of the Nation's Ground-Water Resources— Lower Mississippi Region

GEOLOGICAL SURVEY PROFESSIONAL PAPER 813-N



SUMMARY APPRAISALS OF THE NATION'S
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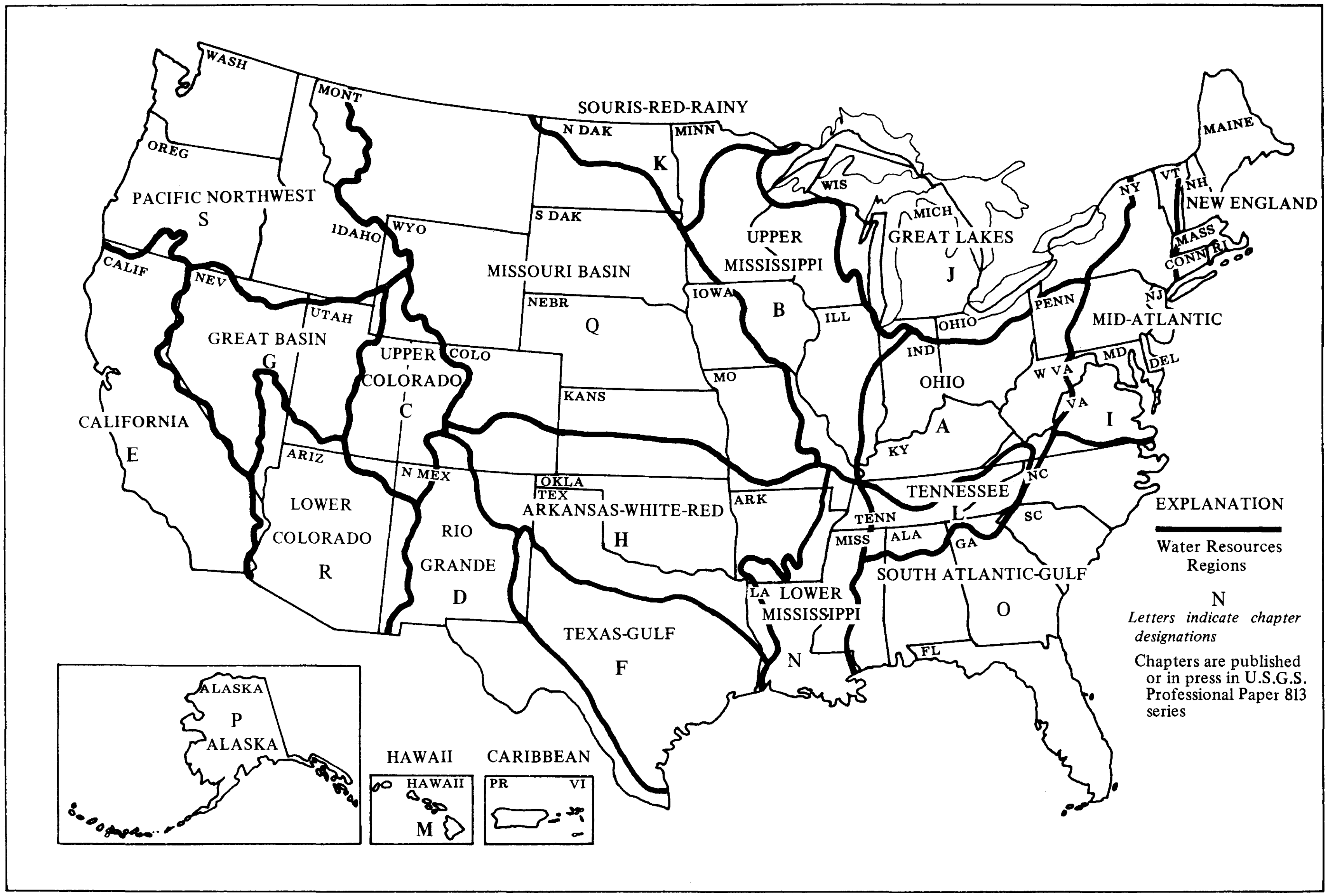
LOWER MISSISSIPPI REGION



Geographic Index to the Series, U.S. Geological Survey Professional Paper 813, *Summary Appraisals of the Nations Ground-Water Resources.*

Boundaries shown are those established by the United States Water-Resources Council for Water-Resources Regions in the United States.

Summary Appraisals of the Nation's Ground-Water Resources—Lower Mississippi Region

By J. E. TERRY, R. L. HOSMAN, *and* C. T. BRYANT

GEOLOGICAL SURVEY PROFESSIONAL PAPER 813-N

An emphasis on the region's large available supply of ground water and on the water-resource management practices directed toward deriving the maximum benefit from this large water supply

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, *Secretary*

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SUMMARY APPRAISALS OF THE NATION'S GROUND-WATER RESOURCES—LOWER MISSISSIPPI REGION

By J. E. Terry, R. L. Hosman, and C. T. Bryant

ABSTRACT

The Lower Mississippi Region comprises an area of 102,400 square miles (265,200 square kilometers). Almost all this area is in the physiographic province known as the Gulf Coastal Plain. Three small areas on the northwest boundary of the region are in the Interior Highlands.

The Lower Mississippi Region has an abundance of ground water. The geologic structure in that part of the region within the Coastal Plain is an elongated trough which has been filled with permeable materials, resulting in vast subsurface reservoirs. Except in local areas where continued large withdrawals have caused significant water-level declines, these reservoirs are full.

Recharge to the region's aquifers is primarily from rainfall. Annual rainfall in most of the region is well distributed throughout the year and is sufficient to satisfy evapotranspiration requirements and still provide recharge to the aquifers.

An estimated 844 billion cubic feet (24 billion cubic meters) of fresh ground water is available for withdrawal annually in the region. Only about one-third of this quantity is being utilized. Therefore, on this basis alone, the region still has much potential for ground-water development.

The Coastal Plain aquifers within the Lower Mississippi Region contain large reserves of saltwater in the downdip limits of the aquifers. The quantity of saltwater in the region is several times that of freshwater. As desalinization techniques are developed and as more uses are found for saltwater, this reserve could become an important source of water for the region.

At present (1976), the most productive and potentially productive aquifers or aquifer systems in the region are the Mississippi River valley alluvial aquifer of Quaternary age and the Sparta Sand and the Memphis aquifer (Memphis Sand in Tennessee) of Tertiary age. The Sparta Sand and the Memphis aquifer are heavily utilized and have shown significant water-level declines. However, selected well hydrographs indicate that water levels may be stabilizing under present pumping conditions. The Mississippi River valley alluvial aquifer is the most extensive high-yielding aquifer in the region; yields of several thousand gallons per minute may be obtained at depths of less than 200 feet (61 meters).

To obtain maximum benefit from the vast quantities of ground water in the region, adequate attention must be given to the effects of proposed development upon the ground-water regime. Knowledge of the geologic structure and hydraulic properties of the aquifer systems is essential to an evaluation of the effects of such development. Some studies have been made in sufficient detail to provide this knowledge, but additional studies are needed.

Activities that could cause significant changes in the ground-water regime should be undertaken only after all available information has been considered. Failure to seek out and use such information may result in inefficient development of the ground-water resource and, in some instances, degradation of the quality of the resource.

Some changes always result from ground-water development. The possible changes can be grouped into three categories: hydraulic, water quality, and those affecting the physical framework of the aquifers. Generally, they are small in magnitude and areal extent. Because these changes occur below the ground surface, they are unknown to the ground-water user unless they noticeably affect the quantity or quality of water produced or cause obvious physical effects, such as land subsidence.

Great advances have been made in hydrologic technology in recent years. Predictive models have been developed that make it possible for the hydrologist to simulate aquifer responses to proposed development or other stresses. These models would be invaluable tools in progressive water-resources planning and management.

INTRODUCTION

LOCATION AND SIZE OF AREA

The Lower Mississippi Region, as defined by the Water Resources Council, 1970, includes all the drainage basin of the Mississippi River downstream from its confluence with the Ohio River, except those parts of drainage basins of the Arkansas, Red, and White Rivers upstream from the backwater limits of the Mississippi River. It also includes the flood-protected areas at Cairo, Ill., and the Louisiana coastal area. The region comprises parts of Arkansas, Illinois, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee, and encompasses about 102,400 mi^2 (265,200 km^2). Drainage from almost half of the conterminous United States culminates in the Lower Mississippi Region (fig. 1). The Mississippi River terminates at the lower end of the region, completing a river course totaling 2,348 mi (3,778 km) (U.S. Geological Survey, 1970).

THE NEW LAND

Explorers, traders, and hunters who sought adventure and fortune were the first to travel the valley of the Mississippi River. Following the trails they blazed, immigrants came to farm the river soil and to settle the wilderness. These early settlers in the Lower Mississippi Region found the Mississippi River to be both friend and foe. The river provided a mode of transportation and fertile soil for farming, yet it be-

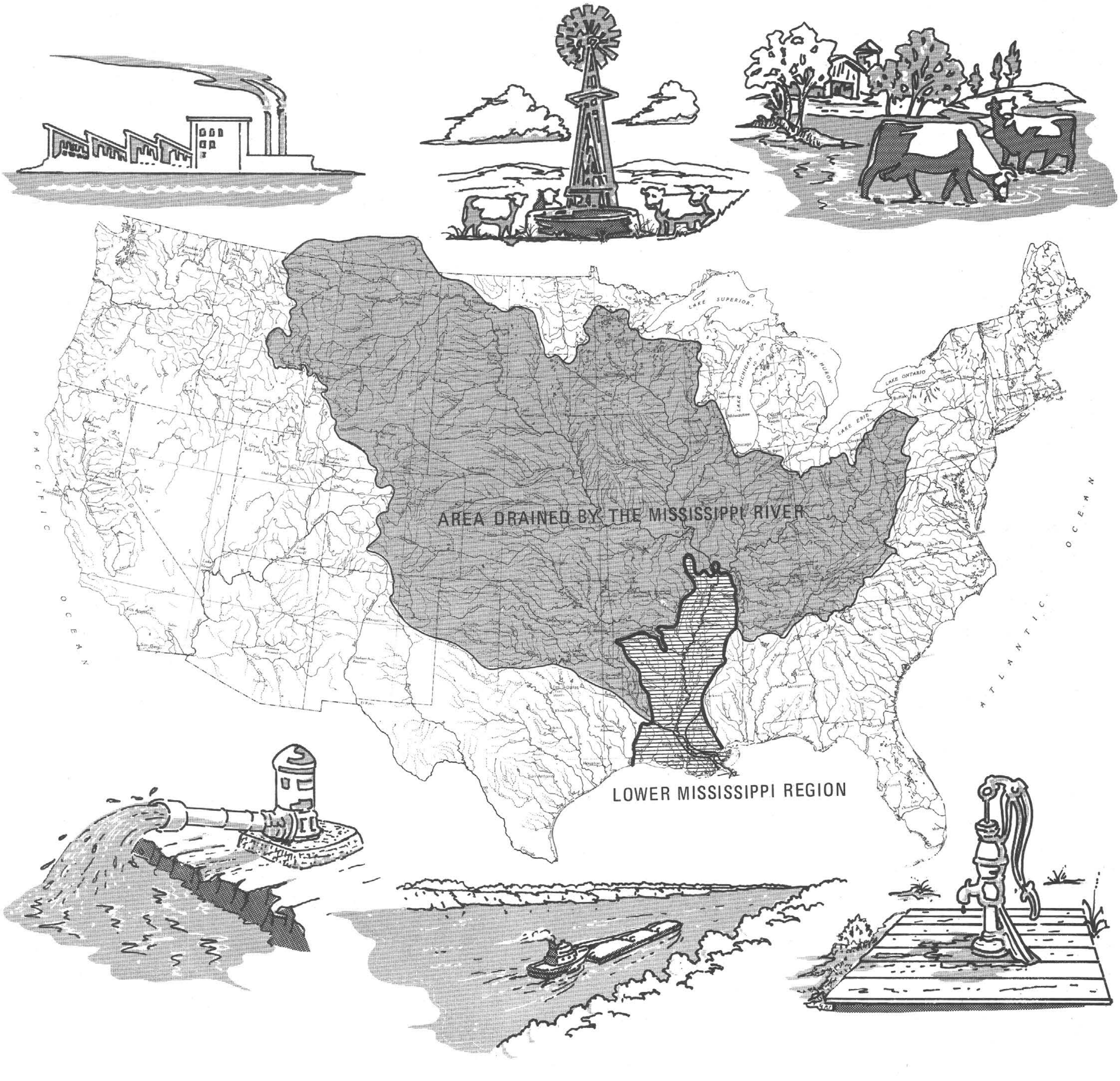


FIGURE 1.—The Lower Mississippi Region.

came a destructive force during floods. Since the time when the first plots of land were cleared for farming, agriculture has played a major role in both the economic and the cultural development of the region, and because the most productive land for farming lies along the Mississippi and its major tributaries, flood control has been the object of much concern and effort.

In more recent years, industry has greatly increased in the region. From Cairo, Ill., to the Gulf of Mexico, and between New Orleans and Lake Charles, La., are found petroleum refineries and related facilities, industrial and agricultural chemical plants, grain elevators, processing plants for food and kindred products, shipyards, textile mills, manufacturers of paper and related products, powerplants, cement plants, and aluminum-producing complexes. The reliance of many of these industries upon the river for movement of raw materials and finished products continues to focus regional attention upon the surface-water resource.

PURPOSE AND SCOPE

In contrast to the recognition given to surface water, only minor attention has been given to ground water in the Lower Mississippi Region since the early 1900's. The purpose of this report is to direct attention to the region's large ground-water resource so that it will not be overlooked when plans for water-resource-related changes within the region are devised and implemented. The pertinent questions about ground water that should be considered in developing and implementing water-management plans are:

1. Where is the ground water?
2. How much ground water is available?
3. What is the quality of the ground water?
4. What effects will development and use of ground water have on the total water resources and environment in the region?

And, inasmuch as ground water is such an important part of the total water resources of the region and should be considered in planning—

5. What kinds of data are needed, and where are data insufficient, to permit full consideration of ground water in water-resource planning?

This report supplies answers to these questions by presenting a regional assessment of the ground-water resource with emphasis on its significance. The scope is intended to be sufficient to permit evaluation of broad concepts of water planning for the region and to determine whether ground water has been adequately considered. This report is also intended to provide sufficient detail to serve as a basis for planning and program development.

All unreferenced quantitative values in this report were taken from either the "Lower Mississippi Region Comprehensive Study," by the Lower Mississippi Region Comprehensive Study Coordinating Committee (1974), or the "1975 National Water Assessment: Ground Water in the Lower Mississippi Region," by Boswell (1979).

Most numbers in this report are given in inch-pound units followed by metric units in parentheses. The conversions to metric units were made as follows:

Multiply		*By*	*To obtain*	
Inch-pound unit	*Inch-pound abbreviation*	*Conversion factor*	*Metric unit*	*Metric abbreviation*
Acre	acre	0.4047	Hectare	ha
Acre-foot	acre-ft	.0012335	Cubic hectometer	hm^3
Cubic foot	ft^3	.02832	Cubic meter	m^3
Cubic foot per second	ft^3/s	.02832	Cubic meter per second	m^3/s
Foot	ft	.3048	Meter	m
Gallon	gal	3.7854	Liter	L
Gallon	gal	.0037854	Cubic meter	m^3
Gallon per minute	gal/min	.06309	Liter per second	L/s
Inch	in.	25.4	Millimeter	mm
Mile	mi	1.6093	Kilometer	km
Square mile	mi^2	2.59	Square kilometer	km^2

Chemical concentrations are given only in metric units—milligrams per liter (mg/L). For concentrations less than 7,000 mg/L, the numerical value is about the same as for concentrations in the inch-pound unit, parts per million.

Throughout this report references to small, moderate, and large quantities of water in relation to aquifer yields have the following meaning: small, 0–50 gal/min (0–30 L/s); moderate, 50–500 gal/min (3–30 L/s); large, greater than 500 gal/min (30 L/s).

THE WATER-RESOURCES SCENE

The Lower Mississippi Region is indeed water rich. Precipitation throughout the region is generally abundant and well distributed areally. The normal annual precipitation ranges from 44 in. (1,100 mm) in the northern part of the region to 64 in. (1,600 mm) in the southeastern part (fig. 2). Seasonally, precipitation maximums occur in the winter in the northern part and in the summer in the southern part. A part of this precipitation is returned to the atmosphere by evapotranspiration, part infiltrates to the aquifers, and part becomes runoff.

Potential evaportranspiration is the combination of evaporation from the ground surface and transpiration from plants that would occur if there were complete vegetation coverage and adequate soil moisture. In the Lower Mississippi Region, average annual potential evapotranspiration ranges from 30 in. (760 mm) in the north to 44 in. (1,100 mm) in the south (fig. 3). Because periods of limited soil-moisture availability occur from time to time and vegetation coverage is not complete in many areas, actual evapotranspiration throughout a long period averages only about 70 to 90 percent of the potential value.

Runoff, including base runoff and direct runoff, combines with surface inflow to the region to make up streamflow and maintain water levels in surface-water impoundments. Runoff ranges from 18 in. (460 mm) in the north to 26 in. (660 mm) in the south (fig. 4).

Recharge to the confined aquifers occurs primarily in the outcrop areas. In the alluvial unconfined aquifers, recharge occurs in areas where the vertical hydraulic conductivity of the overlying material is sufficient to allow downward movement of water. When evapotranspiration requirements are met and soil-moisture storage maximums are exceeded, water infiltrates to the aquifers. An estimate of available recharge can be expressed by:

$$\text{Recharge} = \text{precip} - (\text{ET} + \text{direct runoff}),$$

where

precip = precipitation,
ET = evapotranspiration, and
direct runoff = direct surface runoff.

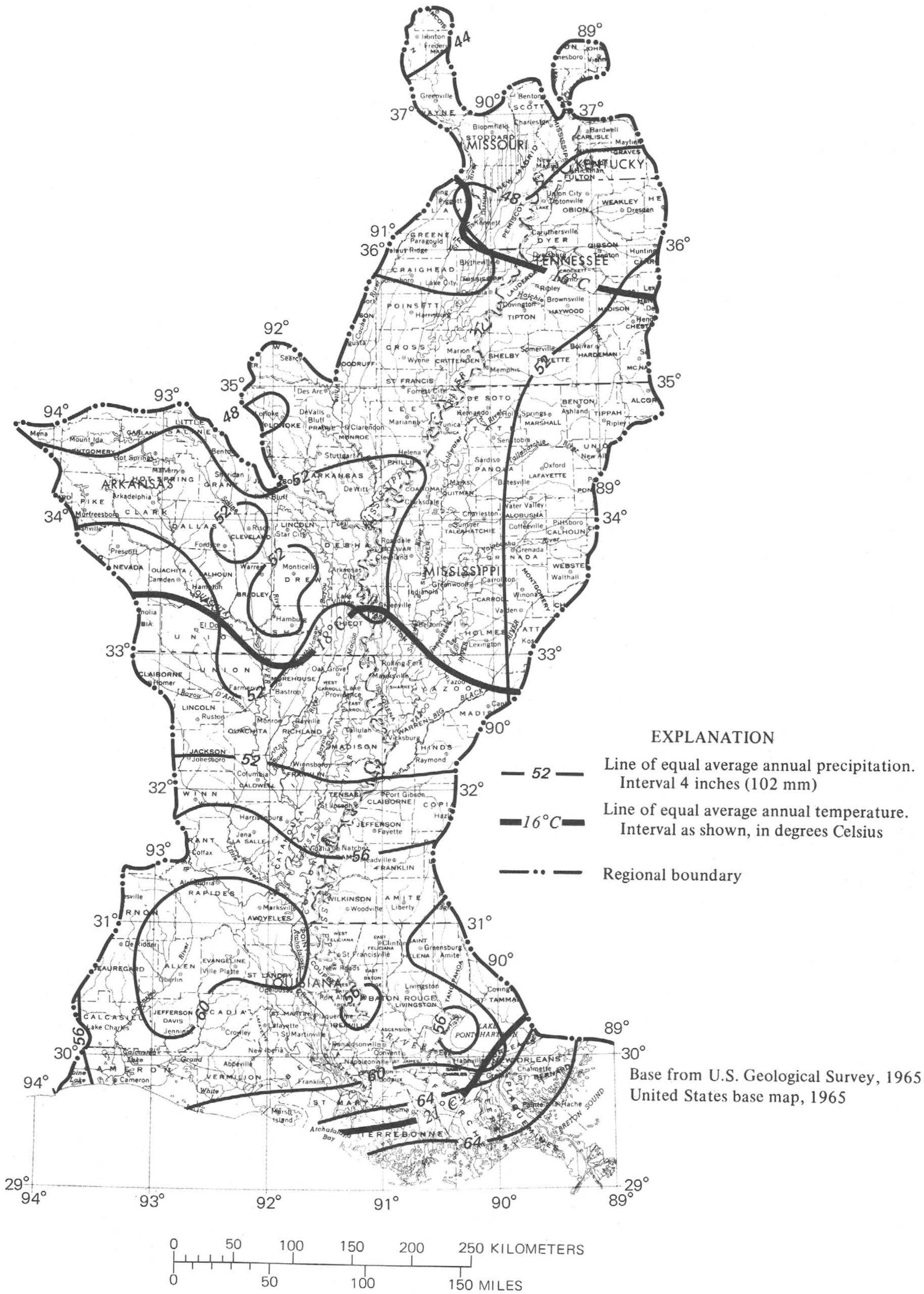
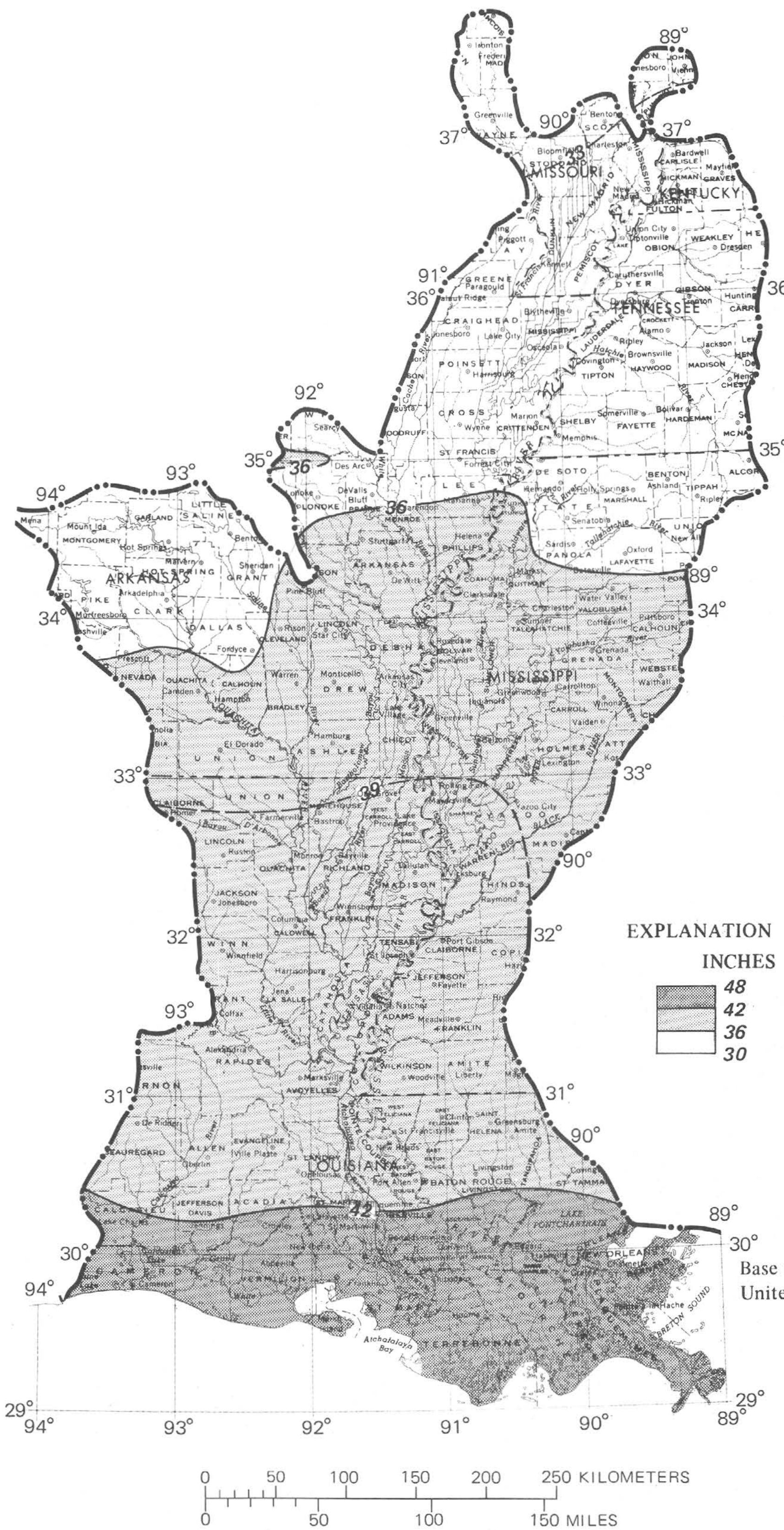


FIGURE 2.—Normal annual precipitation and temperature (modified from Lower Mississippi Region Comprehensive Study, 1974, v. 1, app. C).



Base from U.S. Geological Survey, 1965
United States base map, 1965

FIGURE 3.—Average annual potential evapotranspiration (from Thornthwaite, 1948).

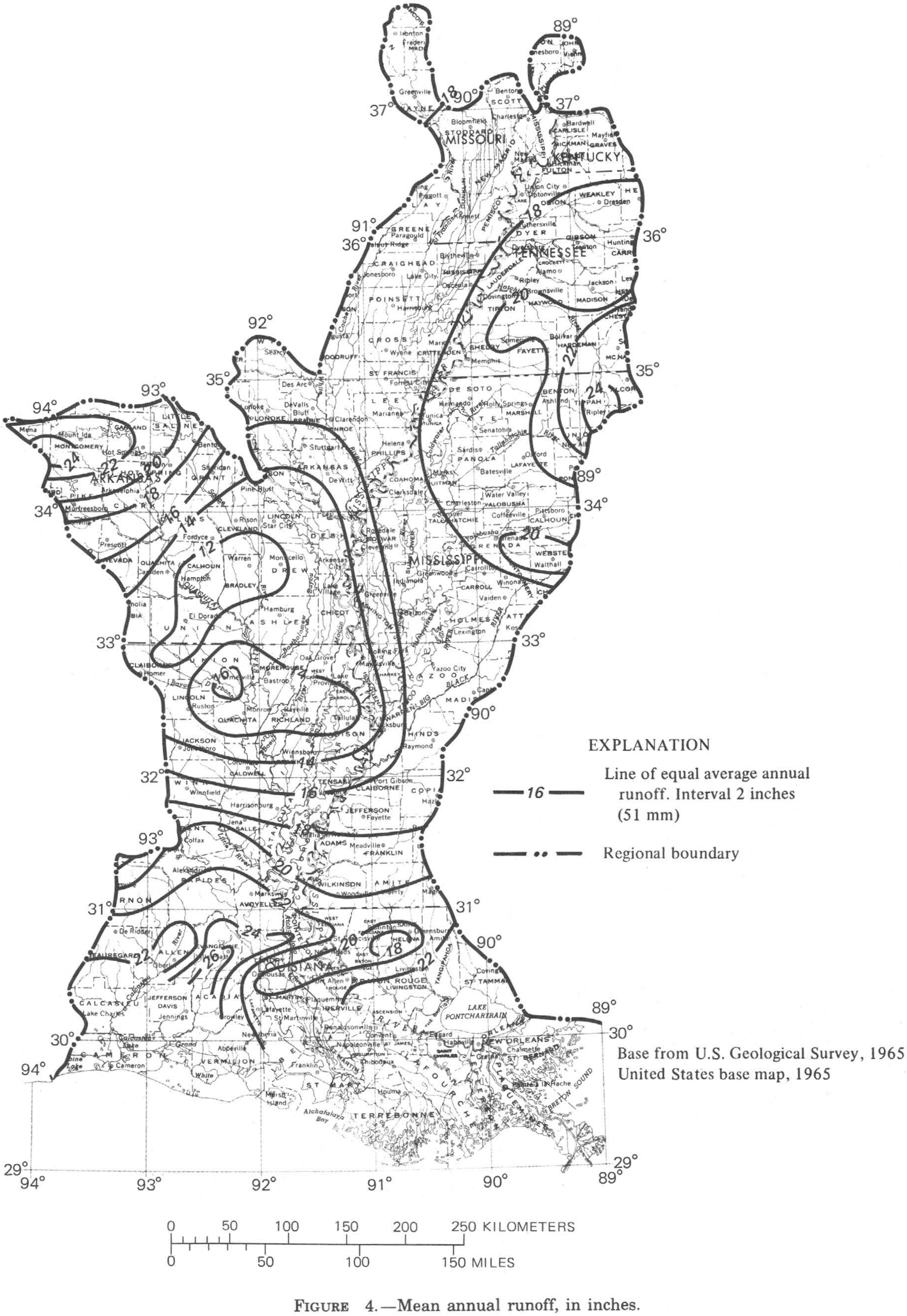


FIGURE 4.—Mean annual runoff, in inches.

HYDROLOGIC BOUNDARIES

The Lower Mississippi Region does not constitute a single or discrete hydrologic system. Although the regional boundaries are located primarily on drainage-basin divides, three major streams in addition to the Mississippi River bring substantial quantities of water across the regional boundary. In addition, and of even more significance in this region, underlying aquifers extend into adjacent areas and ground water moves into and out of the region. Because the regional boundaries are not completely hydrologically restrictive, the water resources of the region are affected by hydrologic events outside the region.

SURFACE WATER

The Lower Mississippi Region's surface-water supply is derived from precipitation and runoff within the region, streamflow including ground-water discharge entering the region from adjacent areas, and ground-water discharge to streams within the region.

The total mean annual inflow in major streams entering the region is nearly 550,000 ft^3/s (15,600 m^3/s). The mean annual stream discharge generated within the region is about 120,000 ft^3/s (3,400 m^3/s).

Each of the 29 controlled surface-water reservoirs within the region has a capacity of 5,000 acre-ft (6 hm^3) or more. The reservoirs have a combined storage of about 10 million acre-ft (12,300 hm^3).

Mean-annual stream outflow from the region is about 670,000 ft^3/s (19,000 m^3/s). Theroretically, this is the ultimate quantity of surface water available for use. However, because of the small number of available storage sites and the increased evaporative losses of surface water that occur with development, this quantity is not realistically obtainable. The dependable surface-water yield must therefore be defined on the basis of the percentage of time a given flow is available. For the Lower Mississippi Region, the 95-percent-duration flow (the flow that will be equaled or exceeded 95 percent of the time) is 216,400 ft^3/s (6,100 m^3/s), or 160 million acre-ft (197,000 hm^3) per year.

In 1970, regional surface-water withdrawals averaged 22,000 ft^3/s (620 m^3/s) or 16 million acre-ft (20,000 hm^3) per year. The total water returned to streams, including ground water withdrawn and not consumed, was 18,000 ft^3/s (510 m^3/s). The result was a net streamflow loss of 4,000 ft^3/s (113 m^3/s).

GROUND WATER

Ground water occurs in large quantities in the Lower Mississippi Region and is readily accessible because of the regional geological framework. Almost all the region is within the Gulf Coastal Plain physiographic province; three small areas along the northwest boundary are in the Interior Highlands (fig. 5). The Lower Mississippi Region includes most of the Mississippi embayment, a northeast-trending structural trough underlying part of the Coastal Plain. The Coastal Plain and the embayment received sediment during the Cretaceous, Tertiary, and Quaternary Periods. The older deposits generally consist of alternating layers of sand and clay; the Quaternary beds contain considerable gravel. The more permeable sand and gravel deposits now form the extensive and productive aquifers that underlie the Lower Mississippi Region.

The Cretaceous and older Tertiary units in the northern or embayment part of the area dip toward the axis of the Mississippi embayment, which coincides approximately with the present course of the Mississippi River. In the southern part of the area, the younger Tertiary deposits dip gulfward. Quaternary alluvium blankets most of the area and forms a gulfward-thickening wedge in the southern part (fig. 6).

Except in areas of outcrop and where local dewatering has taken place, water in the Cretaceous and Tertiary aquifers is confined under pressure; that is, water levels in wells tapping these aquifers rise above the top of the aquifer. Most of the Quaternary aquifers are also confined. In some areas, hydrostatic pressures are sufficient to produce natural flows from wells; in some areas, wells that once flowed no longer flow due to pressure declines. Although most of the declines have been caused by heavy pumping, a contributing and in places critical factor has been the practice of allowing uncapped wells to flow unregulated.

Recharge to the aquifers is primarily from rainfall. The movement of water in the confined aquifers generally is downdip unless affected by large withdrawals. In the alluvial aquifers, movement is toward points of discharge. The base of freshwater in the Coastal Plain aquifers is shown in figure 7. All aquifers locally contain some saltwater: Quaternary aquifers in coastal areas and the older aquifers in their downdip areas.

The vast reserves of saltwater in the Coastal Plain aquifers may prove to be an asset to the area as desalinization technology advances. The quantity of saltwater available is several times that of freshwater. Some saltwater is now used for purposes such as industrial cooling. Similar uses that can tolerate water of this quality will further enhance the value of the resource.

Aquifers in the parts of the Lower Mississippi Region that lie in the Interior Highlands do not repre-

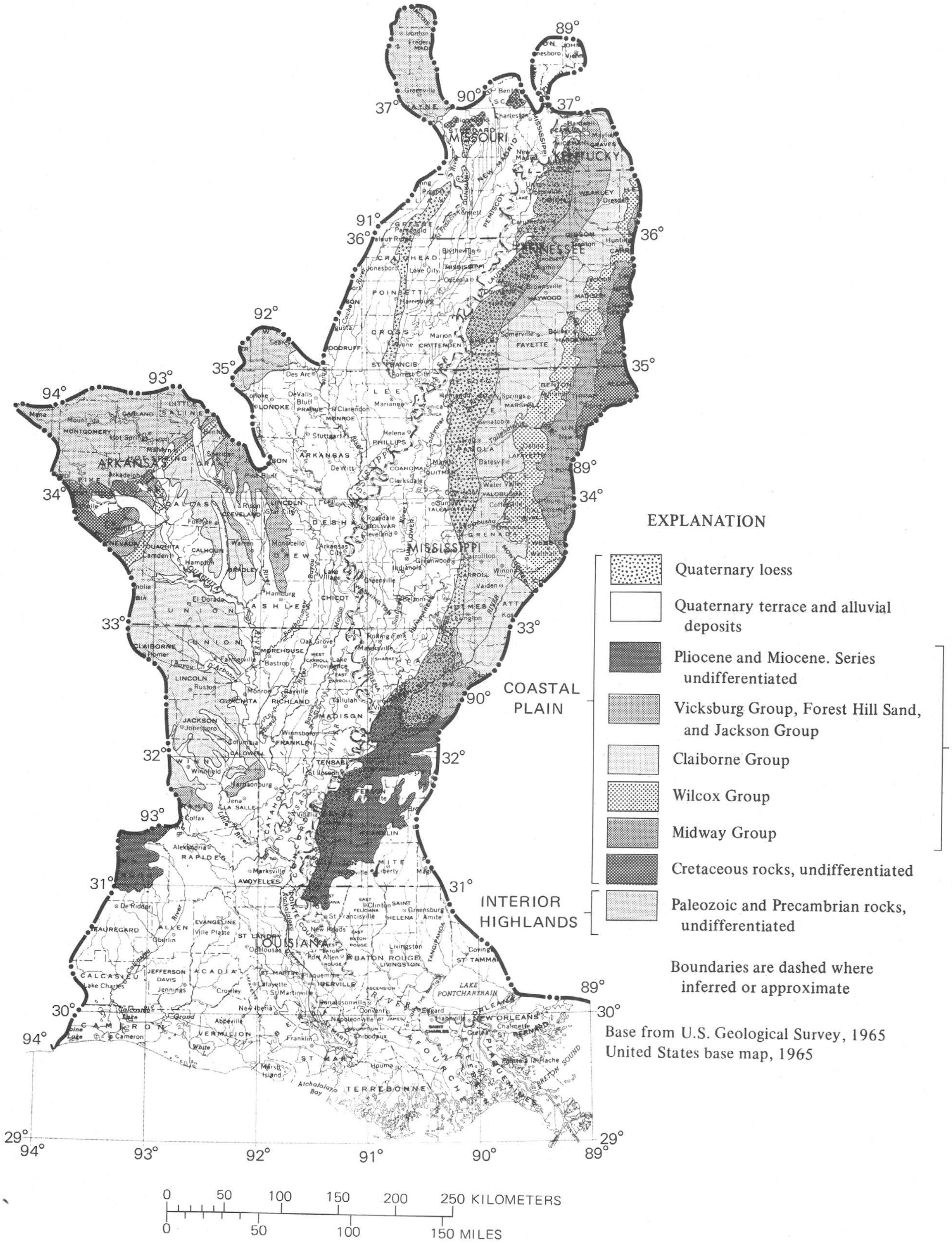


FIGURE 5.—Geologic map (modified from Lower Mississippi River Comprehensive Study, 1974, v. 1, app. C).

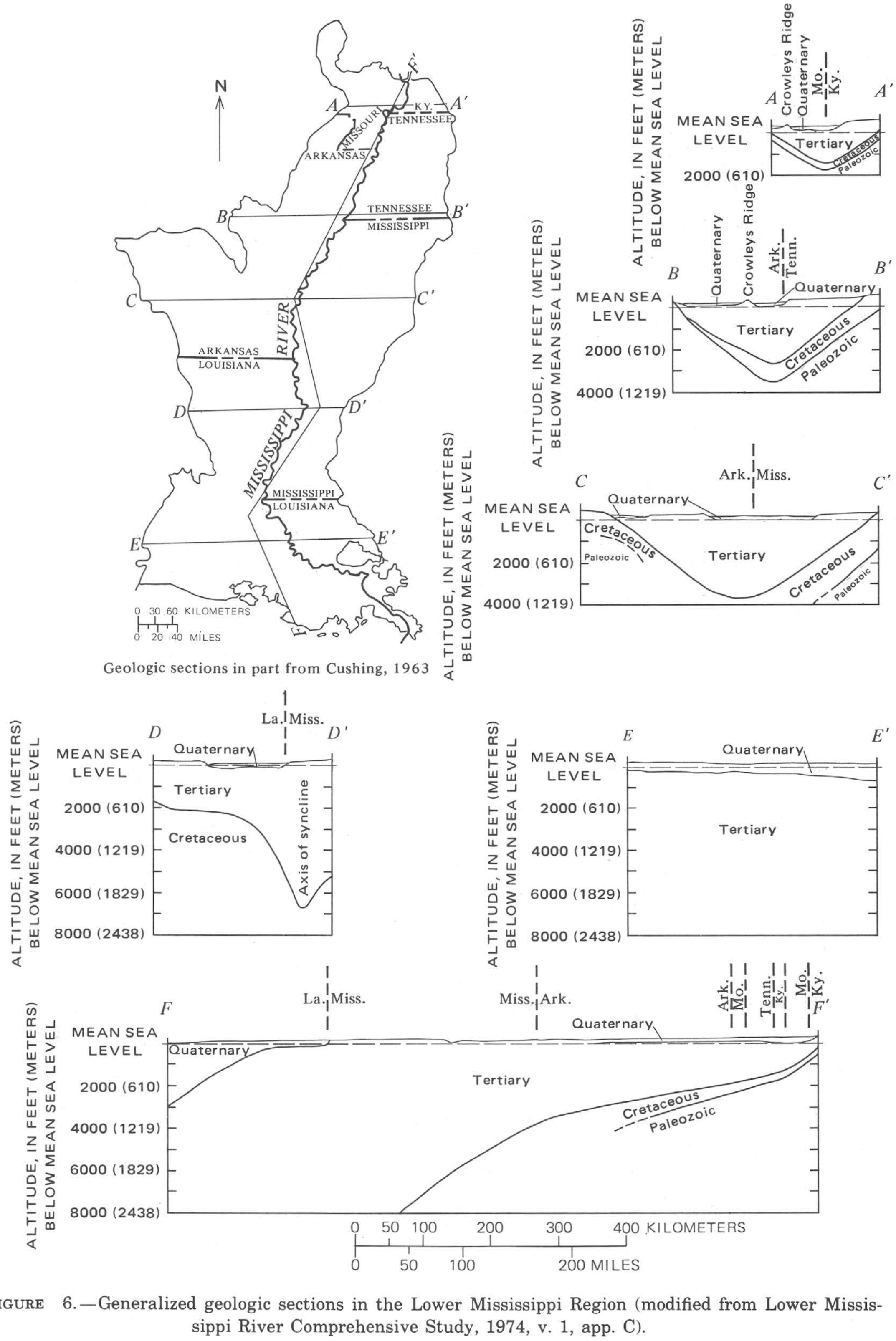


FIGURE 6.—Generalized geologic sections in the Lower Mississippi Region (modified from Lower Mississippi River Comprehensive Study, 1974, v. 1, app. C).

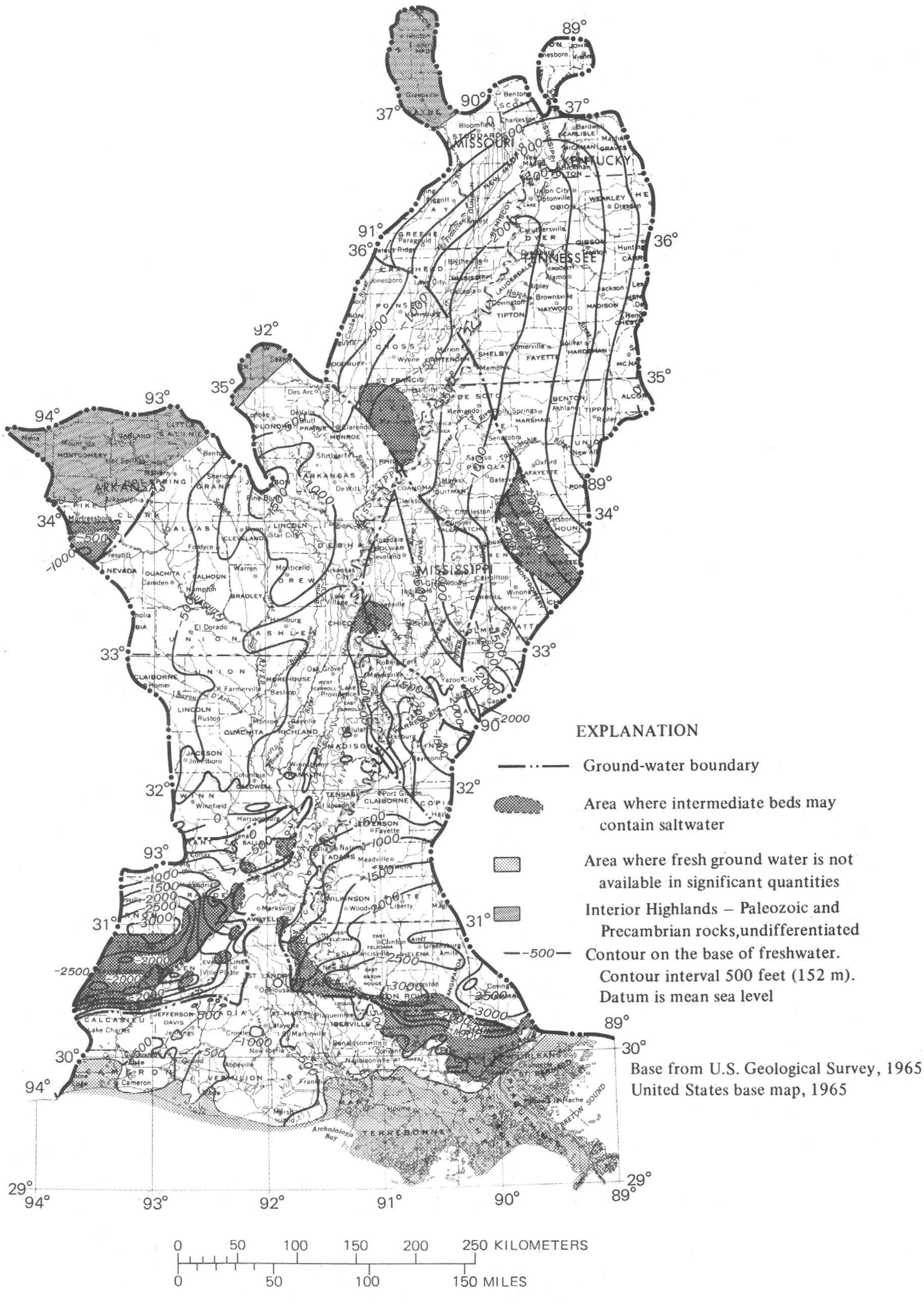


FIGURE 7.—Base of freshwater in Coastal Plain aquifers (modified from Lower Mississippi River Comprehensive Study, 1974, v. 1, app. C).

sent a significant resource to the region. Rocks in these areas are of Paleozoic age, mostly hard sandstone and shale, and the ground water they contain occurs in openings along fractures and bedding planes. The interstitial porosity and permeability that make the unconsolidated aquifers of the Coastal Plain so productive do not exist in the Interior Highlands.

An estimated 347,000 billion ft^3 (9,800 billion m^3) or 7,900 million acre-ft (10 million hm^3) of freshwater underlies the Lower Mississippi Region. Of this total, about 844 billion ft^3 (24 billion m^3) or 19 million acre-ft (23,900 hm^3) is available annually for development, using conventional methods. In 1970, regional groundwater withdrawals averaged about 8,300 ft^3/s (240 m^3/s) or 6 million acre-ft (7,400 hm^3) per year.

About 65 percent of the ground water withdrawn in the region is used for irrigation, about 15 percent by industry, and about 8 percent for municipal supply. The remaining 12 percent is used for domestic supply, livestock watering, and other uses.

WHY IS GROUND WATER OF IMPORTANCE IN THE LOWER MISSISSIPPI REGION?

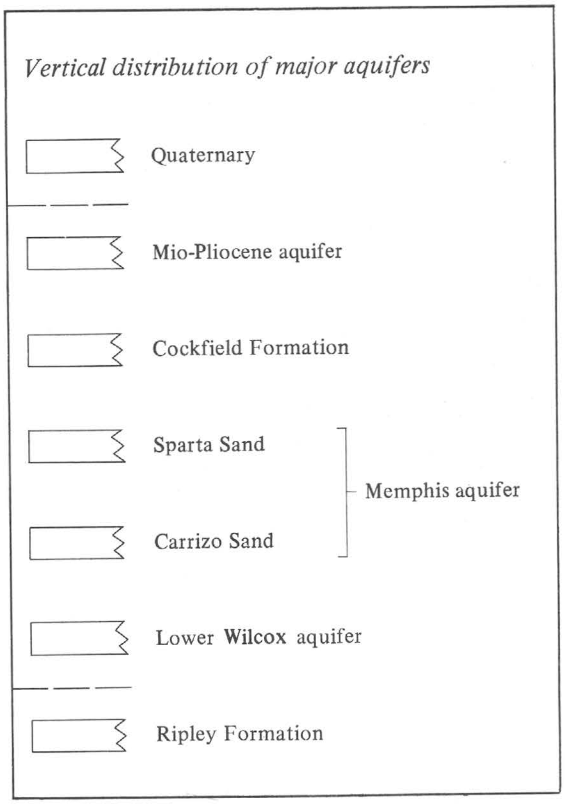
WIDESPREAD ACCESSIBILITY

Ground water is available beneath the entire Lower Mississippi Region. Except for small areas in the Interior Highlands and the coastal area of Louisiana, one or more major aquifers (fig. 8) make moderate to large quantitites of freshwater available throughout the region (fig. 9, 10).

The three areas in the region that are in the Interior Highlands are the Arkansas Valley and the Ouachita Mountains in west-central Arkansas and the Ozark Plateaus in southeast Missouri. In these areas, small quantities of ground water are available from Paleozoic rocks (figs. 9, 10).

Aquifers of Cretaceous age underlie the northern part of the region. Except for relatively small areas in Arkansas, Tennessee, Mississippi, and Missouri, the Cretaceous material is overlain by Tertiary and (or) Quaternary aquifers (fig. 6) that can yield moderate to large quantitites of water to individual wells. For this reason, the deeper Cretaceous aquifers are not utilized extensively.

The major Cretaceous aquifer is the McNairy Sand Member of the Ripley Formation in Mississippi (equivalent to the McNairy Sand in Tennessee, Missouri, Illinois, and Kentucky, and the Nacatoch Sand in Arkansas). These aquifers are present throughout the northern one-fifth of the region within the Coastal Plain and in a small area in southwest Arkansas, a total area of nearly 20,000 mi^2 (52,000 km^2). Withdrawals have been restricted to areas where the



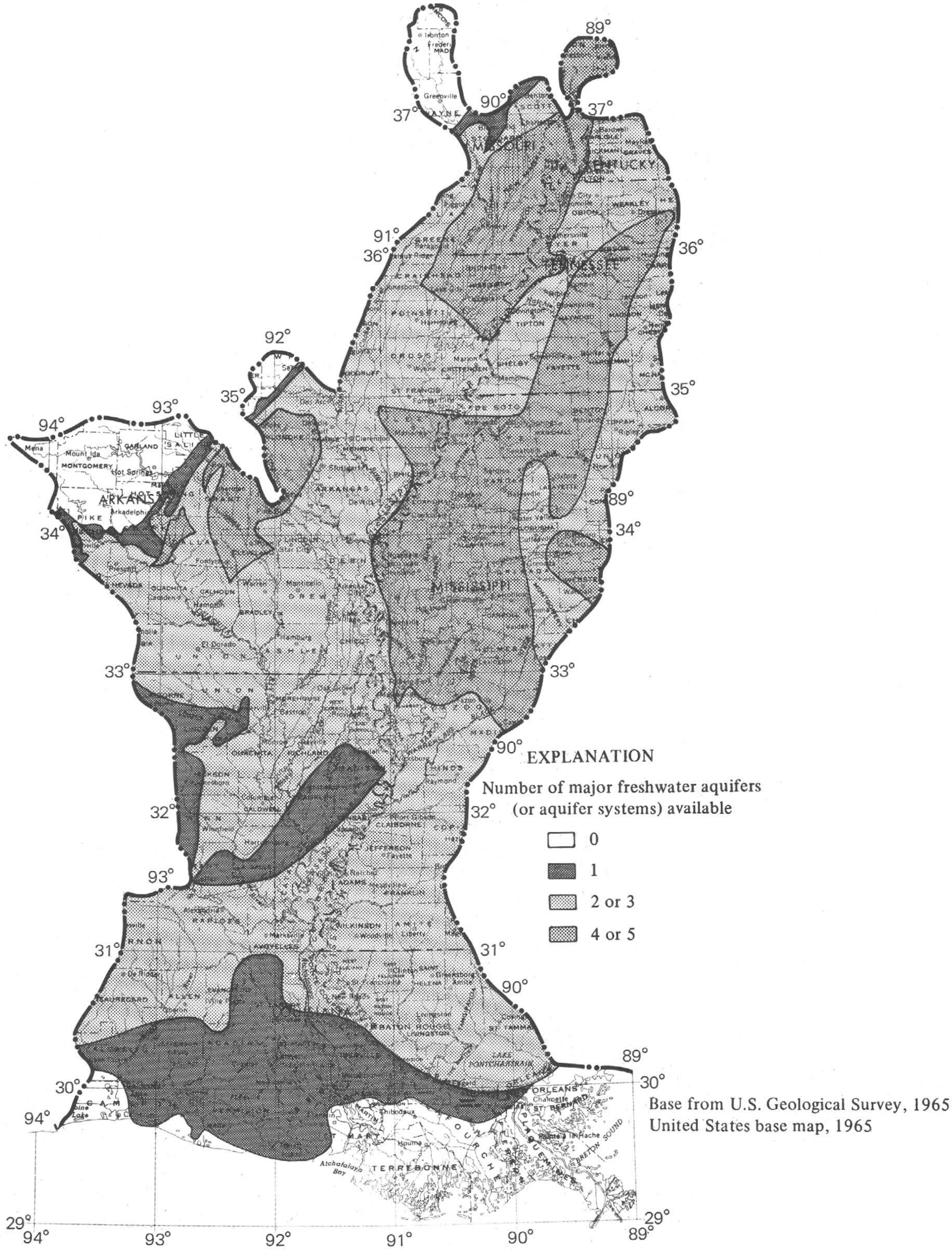


FIGURE 8.—Multiple freshwater aquifers underlie 90 percent of the Lower Mississippi Region.

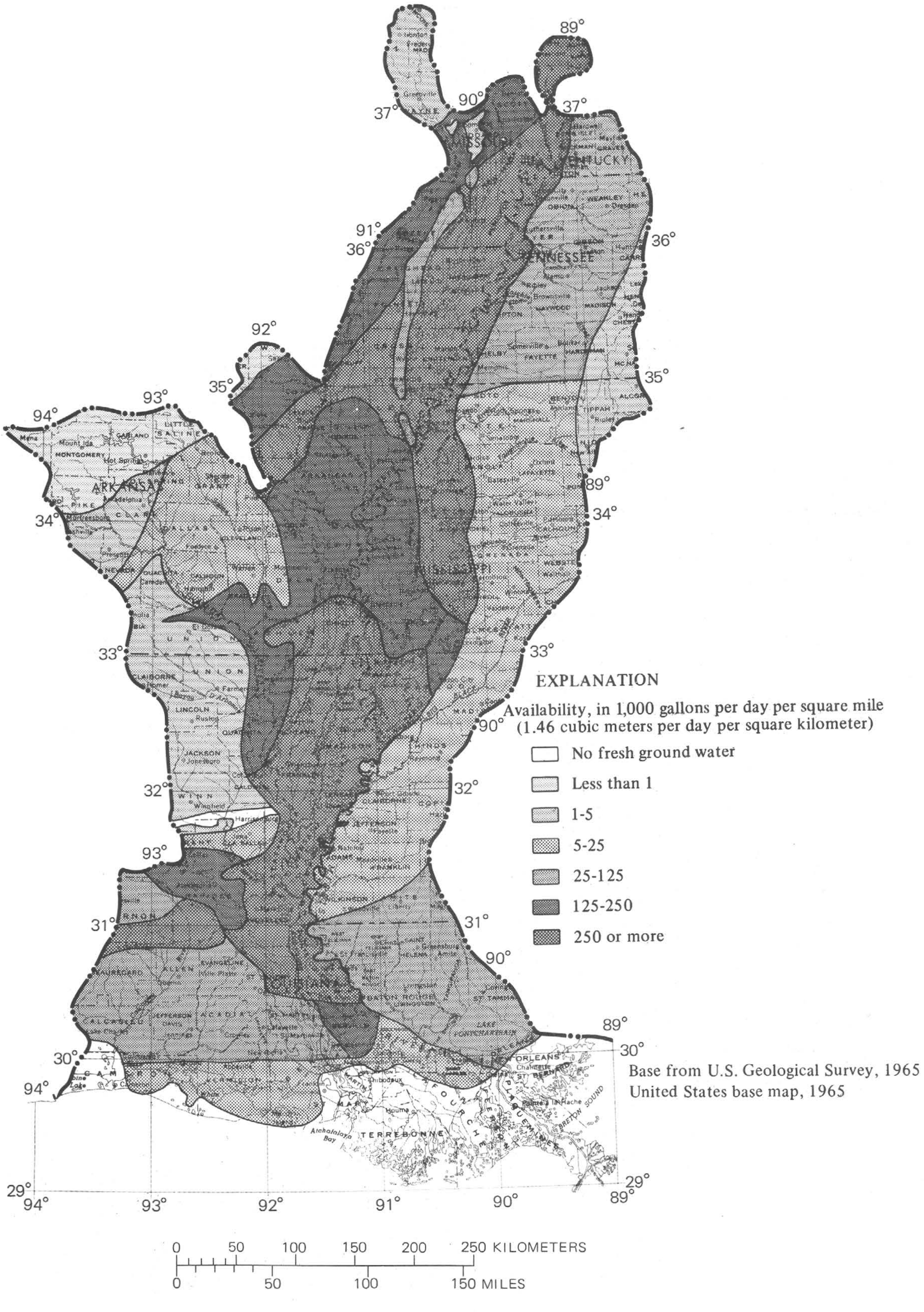


FIGURE 9.—Availability of fresh ground water.

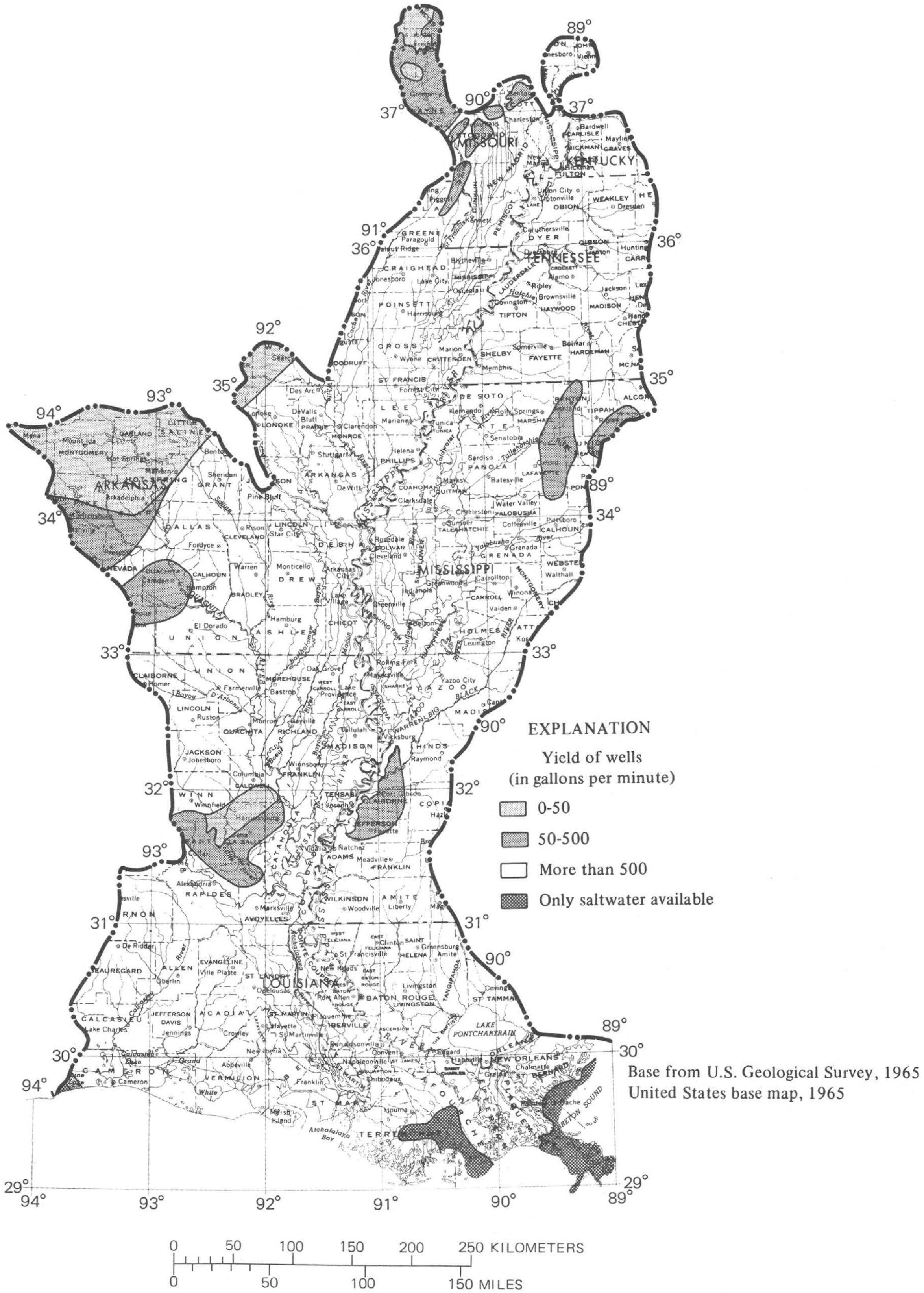


FIGURE 10.—Ranges in well yields throughout the region; only in small areas do wells yield less than 500 gallons per minute (modified from Boswell, 1975).

aquifers are present at moderate depths and water levels have been practically unaffected by pumping.

Other Cretaceous aquifers are important in some areas where they are the best or only sources of ground water available. In north-central Mississippi and parts of west Tennessee, the Coffee Sand is utilized. It is the best or only source of ground water in many places in this area where the underlying Eutaw Formation is too thin or yields highly mineralized water, or where Paleozoic rocks do not contain aquifers. The Gordo Formation underlies the Eutaw Formation in north-central Mississippi, primarily south of the downdip limit of the Coffee Sand. Water in the Gordo Formation generally is good quality and is the best available in this area.

Tertiary aquifers underlie virtually the entire Lower Mississippi Region, except for three small areas on the western border, two in Arkansas and one in Missouri, and a small strip on the eastern border in Tennessee and Mississippi. The Tertiary aquifers north of a line approximately through Vicksburg, Miss., to Colfax, La., are of Eocene age. South of this line, Miocene aquifers overlie the Eocene deposits. These beds dip southward and are, in turn, overlain by Pliocene deposits south of the 31st parallel.

The significant Eocene aquifers, in ascending order of their occurrence, are: the lower Wilcox aquifer, the Carrizo Sand (and its stratigraphic equivalent, the Meridian Sand Member of the Tallahatta Formation), the Sparta Sand, and the Cockfield Formation.

The lower Wilcox aquifer, the basal unit of the Wilcox Group, occurs throughout the northern one-third of the Lower Mississippi Region and in a strip across central Arkansas. It crops out in a narrow belt in north Mississippi and west Tennessee (Fort Pillow Sand in the subsurface of west Tennessee) and occurs as a subcrop beneath the Quaternary alluvium in Arkansas and Missouri. The lower Wilcox aquifer is a source of water for several cities in northeast Arkansas and northwest Mississippi.

Except for the lower Wilcox aquifer, the Tertiary aquifers mentioned previously are in the Claiborne Group. The basal unit of the Claiborne is the Carrizo Sand in Arkansas and Louisiana and its equivalent in Mississippi, the Meridian Sand Member of the Tallahatta Formation. This unit crops out in a narrow band in central Mississippi and southwest Arkansas and is a relatively minor aquifer in central Arkansas and in west Mississippi north of the latitude of Vicksburg. Separating the Carrizo from the overlying Sparta Sand is the Cane River Formation and its equivalents, composed mostly of clay and a few thin beds of fine, almost impermeable sand. The Cane River and its equivalents contain only very minor aquifers in south-central and southwest Arkansas and in west-central Mississippi. In northwest Mississippi, the Winona Sand (equivalent to the Cane River Formation) becomes more significant and merges into the Memphis aquifer. The Sparta Sand underlies the entire central part of the region. It crops out on the eastern side in a wide belt, from southwest Kentucky through Tennessee and Mississippi, and on the west side in northeast and south-central Arkansas. The Sparta occurs as subcrops beneath the Quaternary alluvium in some areas in Arkansas and Mississippi. The Sparta is a very productive aquifer throughout the northern three-fourths of the region. The Cook Mountain Formation, which is not an aquifer, overlies the Sparta Sand and separates it from the uppermost unit of the Claiborne Group, the Cockfield Formation. The Cockfield Formation directly underlies the Quaternary alluvium in most of the central part of the region. It includes productive aquifers in Arkansas, Louisiana, and Mississippi. The Cockfield crops out in small areas in southeast Arkansas, along the Arkansas-Louisiana State boundary, in northwest Louisiana, and in central Mississippi.

North of approximately the 35th parallel, the Memphis aquifer (Memphis Sand in Tennessee) comprises all Claiborne units from the base of the Carrizo Sand to the top of the Sparta Sand. This part of the Claiborne section is a massive sand several hundred feet thick which constitutes a vast ground-water reservoir. As such, the Memphis aquifer is second only to the Mississippi River valley alluvial aquifer as a potential source of large quantities of ground water.

Aquifers of Oligocene age in the Forest Hill Sand and the overlying Vicksburg Group occur in a small area in the southern half of the Lower Mississippi Region. These aquifers, although they are not extensive, are the only sources of fresh ground water in the 500 ft (150 m) or more of sediments between the top of the Claiborne Group and the base of the Miocene Series.

Aquifers of Miocene age occur south of a line approximately through Vicksburg, Miss., to Colfax, La. South of approximately the 31st parallel, the Miocene deposits are overlain by the Pliocene Series. These two series are lithologically similar and are referred to in Louisiana, where they occur together, as the Mio-Pliocene aquifer. In Mississippi, the Miocene deposits are divided into the undifferentiated upper Miocene aquifer and the Catahoula Sandstone. Both the Miocene and Pliocene Series are overlain by Quaternary deposits and, except for Miocene outcrops in west-central and southwest Louisiana, are not exposed at the surface. Both of these series are good present and potential sources of moderate to large quantities of fresh ground water. Near the Louisiana coast, water in both series becomes salty gulfward.

Deposits of Quaternary age cover most of the Lower Mississippi Region. Sediments of Pleistocene and Holocene age compose the Mississippi River valley alluvial aquifer, the most extensive source of ground water in the region. The Pleistocene deposits contain gravel at the base, grading upward to finer sand, and are the most productive parts of the aquifer. The overlying Holocene material is composed of very fine sand, silt, and clay. In many areas it forms a confining layer, although it is permeable to varying degrees.

Large quantities of water are available from the Mississippi River valley alluvial aquifer throughout most of the region. The aquifer's value is enhanced in that, generally, only shallow well depths are required, pumping lifts are small, and recharge conditions are favorable. Throughout most of the Lower Mississippi Region, recharge to the alluvial aquifer is by precipitation. In some areas, where overlying fine-grained materials are nearly impermeable, the aquifers are recharged by underflow. Along the coast in Louisiana, especially in the southeastern part of the State, the alluvial aquifer contains saltwater.

Ground water can be obtained with relative ease almost everywhere in the Lower Mississippi Region. For this reason, most public, industrial, and agricultural supplies are from wells. In most areas within the region, obtaining adequate quantities of water from surface-water supplies would be economically unfeasible. Of the total 102,400 mi^2 (265,200 km^2) within the Lower Mississippi Region, about 5 percent is covered by surface water. In contrast, 90 percent of tbe region is underlain by two or more aquifers that can yield 100 gal/min (6L/s) or more to individual wells.

In contrast to surface reservoirs that inundate many acres of land, large quantities of water are stored in subsurface reservoirs without loss of surface area. Some disadvantages of surface reservoirs are high construction costs, cost of land purchase, loss of land use, and maintenance. Another consideration is that some terrain is not suited for large reservoir construction. Much of the area within the southern half of the Lower Mississippi Region could be classified as unsuitable because of the absence of deep, broad stream valleys that could be dammed. For these reasons, much dependence is placed on the region's subsurface reservoirs.

LARGE AMOUNT AVAILABLE

Approximately 347,000 billion ft^3 (9,800 billion m^3) of water, containing less than 3,000 mg/L dissolved solids, is stored in the subsurface of the Lower Mississippi Region. This quantity of water is more than 16 times the average annual surface-water outflow from the region, and if contained in a reservoir it would cover an area the size of the entire region to a depth of 120 ft (37 m). Of this total, about 844 billion ft^3 (24 billion m^3) is available annually for development, based on withdrawals consistent with economically and environmentally acceptable water-level declines.

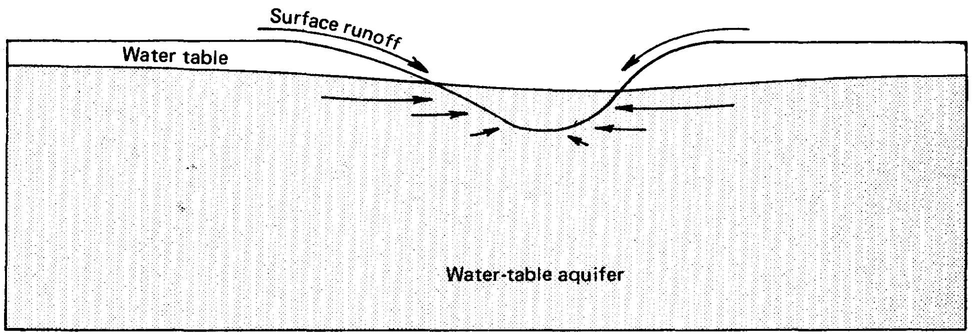
The primary containers of ground water in the lower Mississippi Region are the extensive unconsolidated sand-and-gravel aquifers of Tertiary and Quaternary age. The ability of these aquifers to store and transmit water varies due to differences in thickness and hydraulic conductivity. However, single aquifers that can yield 500 gal/min (32 L/s) or more to individual wells underlie about 90 percent of the region (fig. 10). The highest yields, often several thousand gallons per minute, are from wells screened in sand and gravel of the Quaternary alluvial-terrace deposits. The alluvial and terrace deposits account for two-thirds of the potential ground-water supply in the region.

Within most of the Lower Mississippi Region, water-table aquifers commonly discharge water to streams that are connected with them (fig. 11A). Also, some streams that have sufficient hydraulic connection with a confined aquifer may receive contributions from the aquifer. Such a condition occurs when the altitude of the water surface in the stream is less than the head (potentiometric surface) in the aquifer (fig. 11B). Under dry, low-flow conditions, perennial streams are sustained completely by discharged ground water. The lowest flow that occurs in a stream for 7 consecutive days once every 10 years is commonly accepted to be composed of discharged ground water. U.S. Geological Survey stream-gaging stations, within the region, where the 7-day, 10-year low-flow has been defined, are shown in figure 12. Table 1 contains the 7-day, 10-year low-flows for the stations plotted in figure 12.

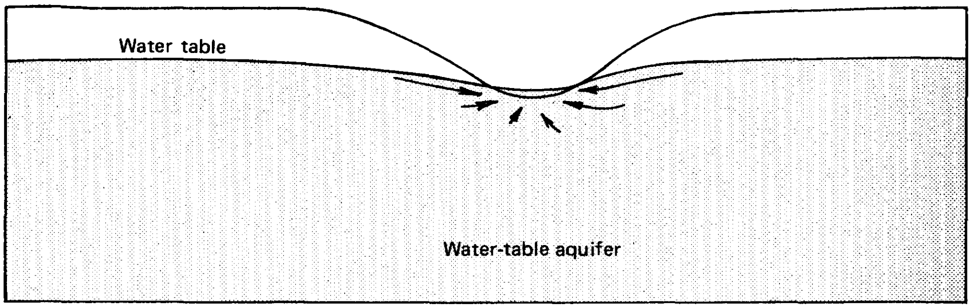
Where there is good connection between a major stream and an aquifer, advantage can be taken of the relationship by locating wells near the stream. When a well is pumped, one of two things will occur. If movement has been from the aquifer to the stream, gradients will flatten and may reverse in the vicinity of the well, utilizing water normally discharged to the stream and even taking water from the stream if the gradient reverses. If movement has been from the stream to the aquifer, the gradient will become steeper as the head in the aquifer near the well is reduced by pumping. In either instance, some water is diverted from the stream, thereby reducing the stress on the aquifer (fig. 13).

Most aquifers in the Lower Mississippi Region are full; consequently much potential recharge is rejected

A

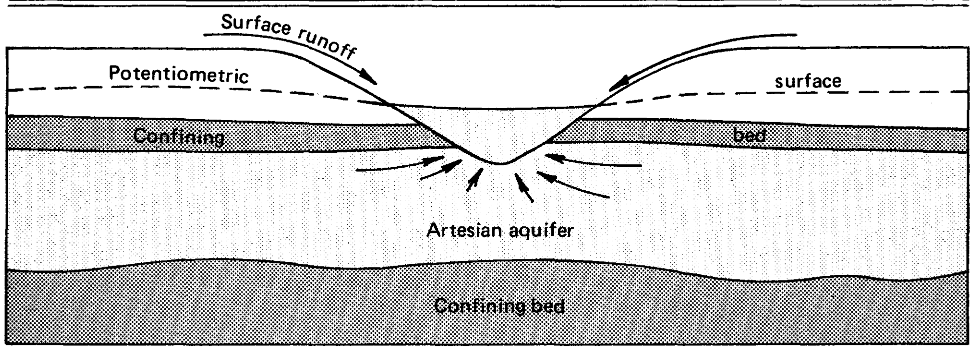


Stream in hydraulic connection with a water-table aquifer. Under normal conditions the stream receives some water from the aquifer.

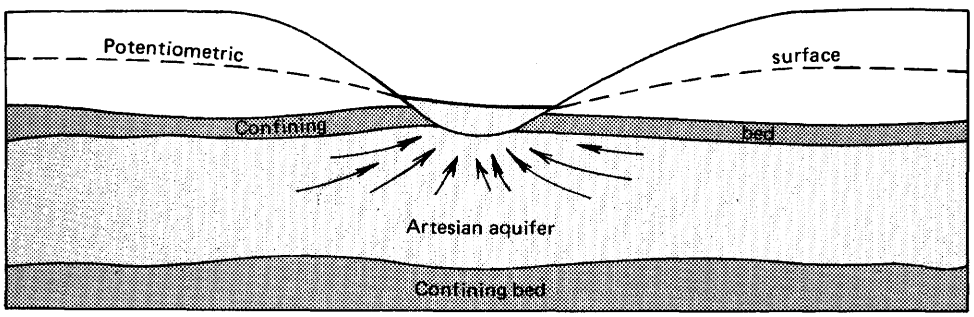


The same stream during low-flow conditions. The only flow in the stream is ground-water discharge.

B



Stream in hydraulic connection with an artesian aquifer. Under normal conditions the stream is receiving some water from the aquifer.



The same stream during low-flow conditions. The only flow in the stream is ground-water discharge.

FIGURE 11.—Ground water-surface water relations during normal and dry conditions.

and evapotranspired or discharged to streams. When an aquifer is tapped and water is withdrawn, changing head relations can cause the aquifer to become receptive to recharge (fig. 14). Under the most favorable

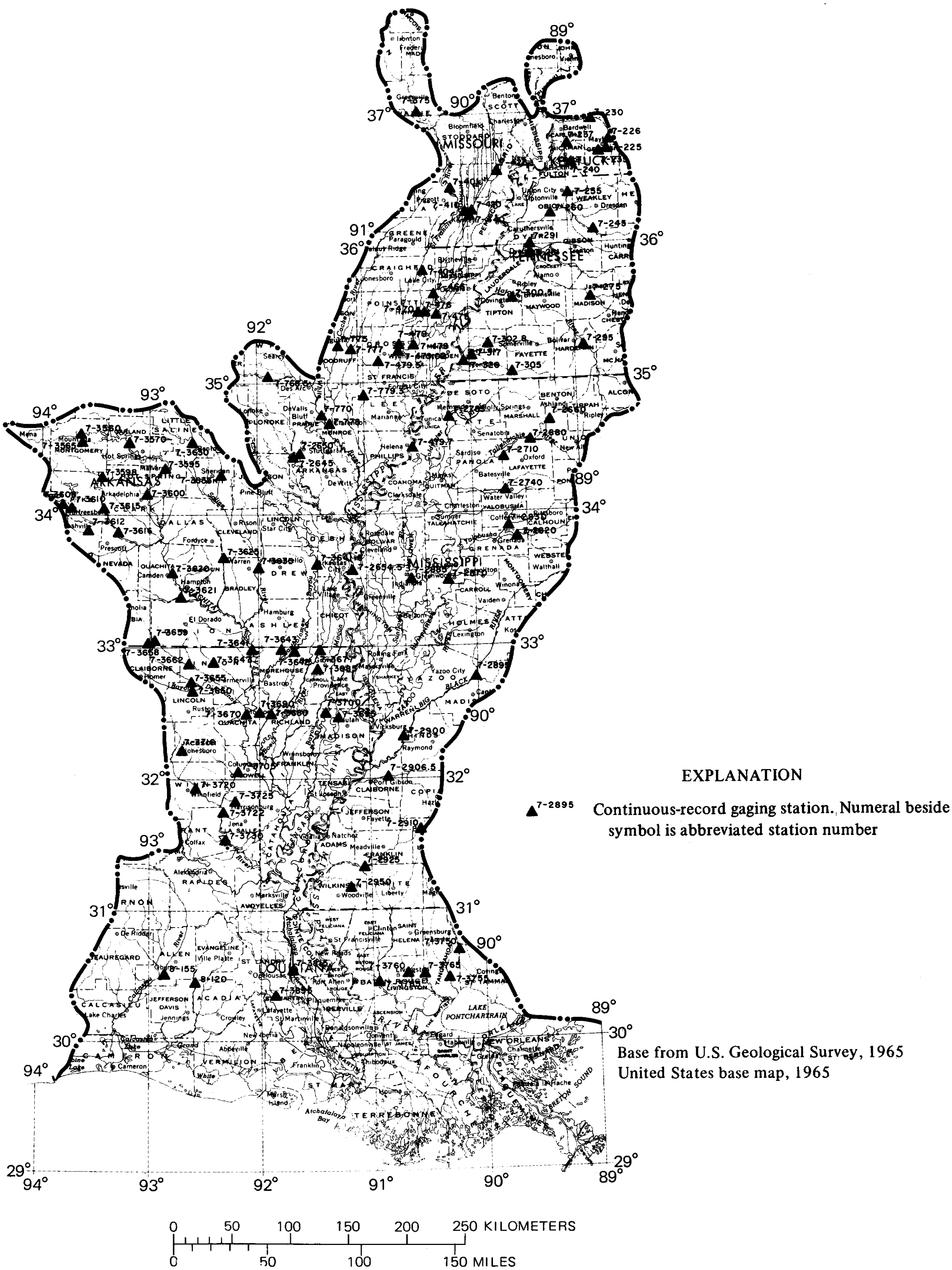


FIGURE 12.—Selected 7-day, 10-year low-flow sites.

TABLE 1.—*The 7-day, 10-year low flow at selected stream-gaging stations plotted in figure 12*

Station		7-day, 10-yr low flow
Number	Name	(ft^3/s)
07022500	Perry Creek near Mayfield, Ky	0.0
07022600	Mayfield Creek at Mayfield, Ky	0
07023000	Mayfield Creek at Lovelaceville, Ky	7.7
07023500	Obion Creek at Pryorsburg, Ky	0
07023700	Obion Creek near Arlington, Ky	3.3
07024000	Bayou du (de) Chien near Clinton, Ky	6.3
07024500	South Fork Obion River near Como, Tenn	79
07025500	North Fork Obion River near Union City, Tenn	90
07026000	Obion River at Obion, Tenn	260
07027500	South Fork Forked Deer River at Jackson, Tenn	80
07028100	South Fork Forked Deer River near Halls, Tenn	145
07029100	North Fork Forked Deer River at Dyersburg, Tenn	93
07029500	Hatchie River at Bolivar, Tenn	122
07030050	Hatchie River at Rialto, Tenn	284
07030280	Loosahatchie River at Brunswick, Tenn	58
07030500	Wolf River at Rossville, Tenn	124
07031700	Wolf River at Raleigh, Tenn	158
07032000	Mississippi River at Memphis, Tenn	99,000
07037500	St. Francis River near Patterson, Tenn	14.7
07040100	St. Francis River at St. Francis, Ark	76
07040450	St. Francis River at Lake City, Ark	97
07041000	Little River Ditch 81 near Kennett, Mo	15
07042000	Little River Ditch 1 near Kennett, Mo	17
07042500	Little River Ditch 251 near Lilbourn, Mo	30
07044000	Little River Ditch 251 near Kennett, Mo	69
07046600	Right Hand Chute of Little River at Rivervale, Ark	146
07047000	St. Francis River floodway near Marked Tree, Ark	0
07047500	St. Francis River at Marked Tree, Ark	97
07047600	Tyronza River near Tyronza, Ark	27
07047800	St. Francis River at Parkin, Ark	284
07047900	St. Francis Bay at Riverfront, Ark	38
07047902	St. Francis River at latitude of Wittsburg, Ark	405
07047950	L'Anguille River at Palestine, Ark	<.1
07047970	Mississippi River at Helena, Ark	102,000
07076850	Cypress Bayou near Beebe, Ark	0
07077000	White River at DeValls Bluff, Ark	4,830
07077500	Cache River at Patterson, Ark	33
07077700	Bayou DeView at Morton, Ark	<.1
07077800	White River at Clarendon, Ark	3,530
07077930	Big Creek near Moro, Ark	0
07264500	Bayou Meto near Stuttgart, Ark	0
07265000	Crooked Creek near Humphrey, Ark	0
07265450	Mississippi River near Arkansas City, Ark	115,000
07266000	Cane Creek near New Albany, Miss	.4
07268000	Tallahatchie River at Etta, Miss	8.6
07271000	Clear Creek near Oxford, Miss	4.2
07274000	Yocona River near Oxford, Miss	7.2
07282000	Yalobusha River at Calhoun City, Miss	<.1
07283000	Skuna River at Bruce, Miss	2.0
07287000	Yazoo River at Greenwood, Miss	720
07288500	Sunflower River at Sunflower, Miss	94
07289500	Big Black River at Pickens, Miss	41
07290000	Big Black River near Bovina, Miss	75
07290650	Bayou Pierre near Willows, Miss	19
07291000	Homochitto River at Eddiceton, Miss	31
07292500	Homochitto River at Rosetta, Miss	140
07295000	Buffalo River (Bayou) near Woodville, Miss	20
07356000	Ouachita River near Mount Ida, Ark	6.0
07356500	South Fork Ouachita River at Mount Ida, Ark	0
07357000	Ouachita River near Mountain Pine, Ark	19
07359500	Ouachita River near Malvern, Ark	73
07359800	Caddo River near Alpine, Ark	13
07360000	Ouachita River at Arkadelphia, Ark	110
07360800	Muddy Fork Creek near Murfreesboro, Ark	0
07361000	Little Missouri River near Murfreesboro, Ark	3.6
07361200	Ozan Creek near McCaskill, Ark	0
07361500	Antoine River at Antoine, Ark	0
07361600	Little Missouri River near Boughton, Ark	27
07362000	Ouachita River at Camden, Ark	175
07362100	Smackover Creek near Smackover, Ark	.1
07362500	Moro Creek near Fordyce, Ark	0
07363000	Saline River at Benton, Ark	1.1
07363300	Hurricane Creek near Sheridan, Ark	.1
07363500	Saline River near Rye, Ark	11
07364100	Ouachita River near Arkansas-Louisiana State Line	780
07364150	Bayou Bartholomew near McGee, Ark	4.5
07364200	Bayou Bartholomew near Jones, La	39
07364300	Chemin-a-Haut Bayou near Beekman, La	<.1
07364700	Bayou de Loutre near Laran, La	2.4
07365000	Bayou D'Arbonne near Dubach, La	.1
07365500	Middle Fork Bayou D'Arbonne near Bernice, La	.1
07365800	Cornie Bayou near Three Creeks, Ark	<.1
07365900	Three Creeks near Three Creeks, Ark	<.1
07366200	Little Corney Bayou near Lillie, La	.1
07367000	Ouachita River at Monroe, La	780
07367700	Boeuf River near Arkansas-Louisiana State line	21
07368000	Boeuf River near Girard, La	17
07368500	Big Colewa Bayou near Oak Grove, La	0
07369000	Bayou Lafourche near Crew Lake, La	4.6
07369500	Tensas Bayou at Tendal, La	4.0
07370000	Bayou Macon near Delhi, La	33
07370500	Castor Creek near Grayson, La	<.5
07371000	Garrett Creek at Jonesboro, La	0
07372000	Dugdemona River near Winnfield, La	.2
07372200	Little River near Rochelle, La	16
07372500	Bayou Funny Louis near Trout, La	<.1
07373000	Big Creek at Pollock, La	6.9
07375000	Tchefuncta River near Folsom, La	35
07375500	Tangipahoa River at Robert, La	270
07376000	Tickfaw River at Holden, La	23
07376500	Natalbany River at Baptist, La	2.5
07378500	Amite River near Denham Springs, La	290
07381500	Atchafalaya River at Krotz Springs, La	24,000
07385500	Bayou Teche at Arnaudville, La	90
08012000	Bayou Nezpique near Basile, La	.4
08015500	Calcasieu River near Kinder, La	200

management conditions, withdrawal should not be greater than average annual recharge.

Ground water has a low evaporation loss compared with surface water. Evaporation loss varies with the hydraulic conductivities of materials overlying the water-bearing zone and approaches zero as water levels deepen.

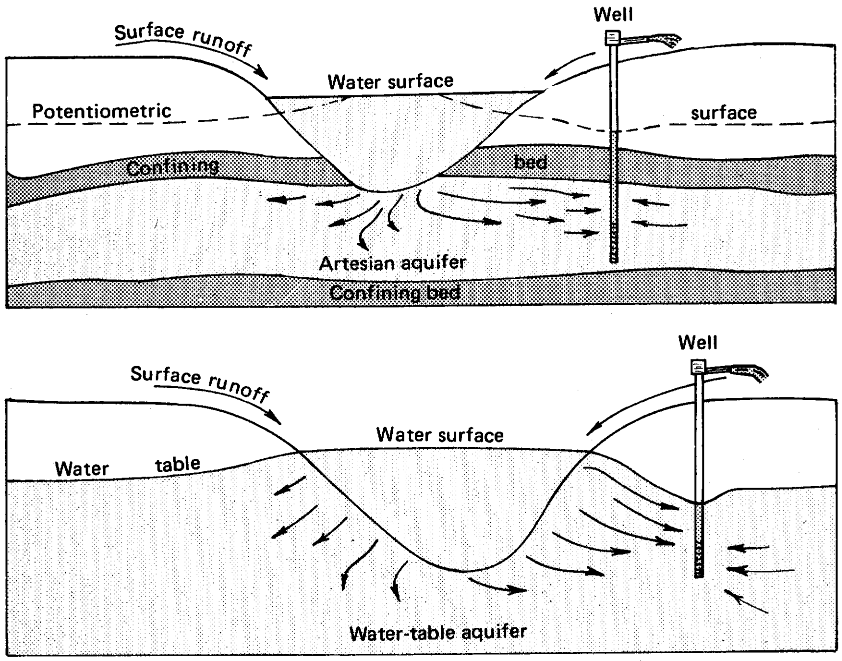
The same protective covering that minimizes evaporation losses from ground water also tends to filter the water and protect it from contamination under natural conditions. However, this attribute should not be taken too much for granted. For example, the dumping of concentrated pollutants in or near recharge areas, or the discharge of such pollutants into streams that may be recharging an aquifer, could have drastic effects on the quality of water in the aquifer.

Water-well development, operation, and maintenance are relatively economical in most of the Lower Mississippi Region. With two or more freshwater aquifers underlying most of the region, good-quality water in adequate amounts generally can be obtained at moderate depths. Thus, construction and pumping costs tend to be moderate.

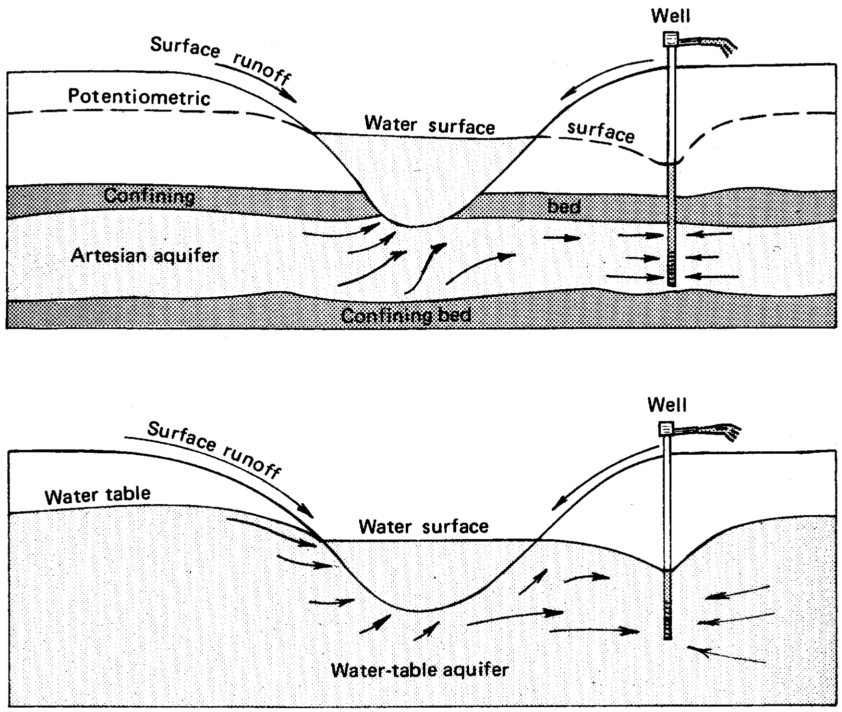
ACCEPTABLE FOR MANY USES

The quality of ground water in the Lower Mississippi Region varies from aquifer to aquifer and in some instances with geographic or vertical location within the aquifer. However, at almost any location within the region, ground water that has a total dissolved-solids concentration of less than 1,000 mg/L can be obtained (fig. 15). The exceptions are areas along the Louisiana coast and a small area in west-central Louisiana, where all the ground water is saline to varying degrees. The prevalent chemical types and dissolved-solids concentrations of water in the shallow aquifers control the quality of water in streams at low flow (figs. 16, 17).

Under most conditions, the quality of water in an aquifer will remain unchanged. If the ground water being withdrawn is of good quality, with proper man-

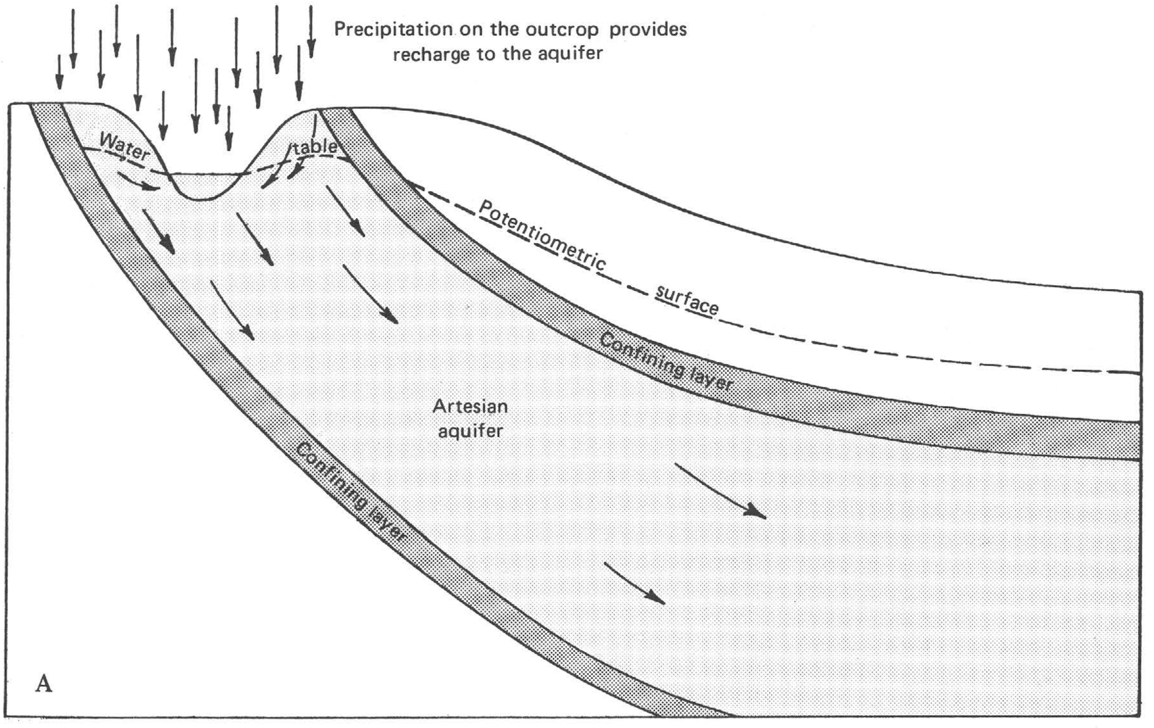


If a pumping well is located near a losing stream, increased quantities of water will move from the stream to the aquifer in the vicinity of the well.

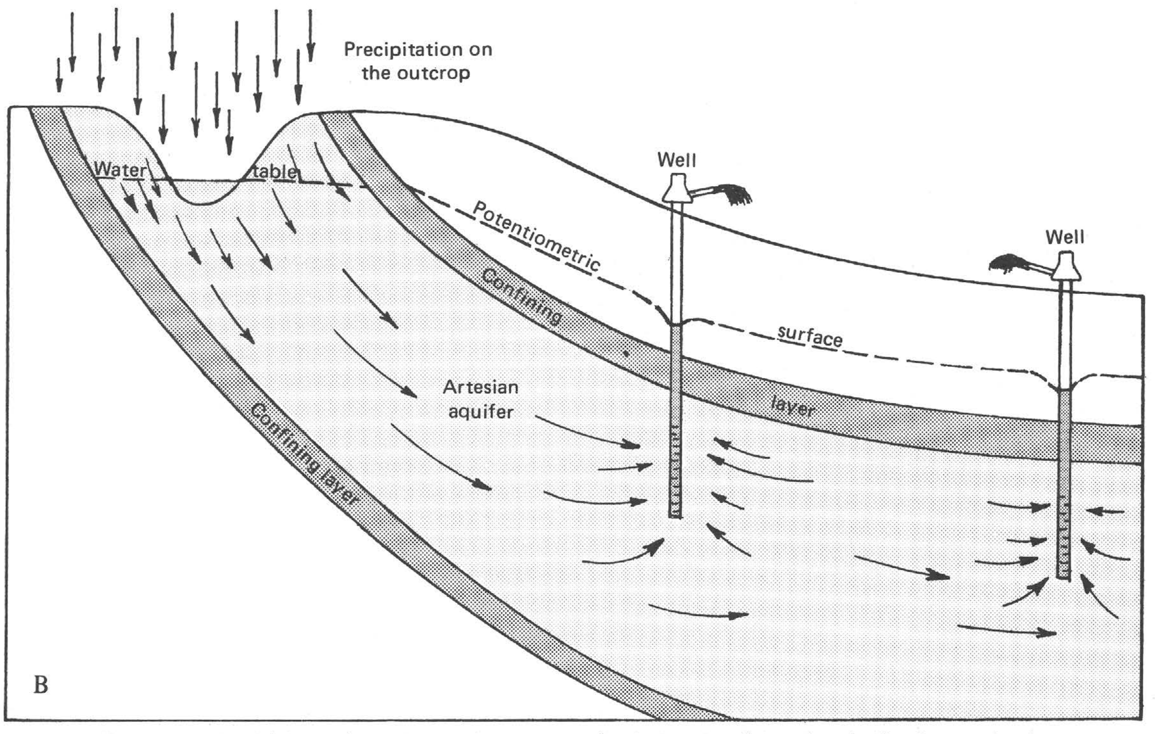


If a pumping well is located near a gaining stream, the direction of movement of water in the vicinity of the well may change and water normally discharged to the stream will be utilized by the well.

FIGURE 13.—Utilization of streamflow by nearby wells.



Pressure in the aquifer is great enough to maintain a head above the water-surface altitude in streams connected with the aquifer; therefore most potential recharge is discharged to the streams before it can move downdip.



When water is withdrawn from the aquifer, pressure (and, thus, head) is reduced, allowing previously rejected potential recharge to move downdip.

FIGURE 14.—Full aquifers reject recharge; movement of water downdip increases with utilization of the aquifer.

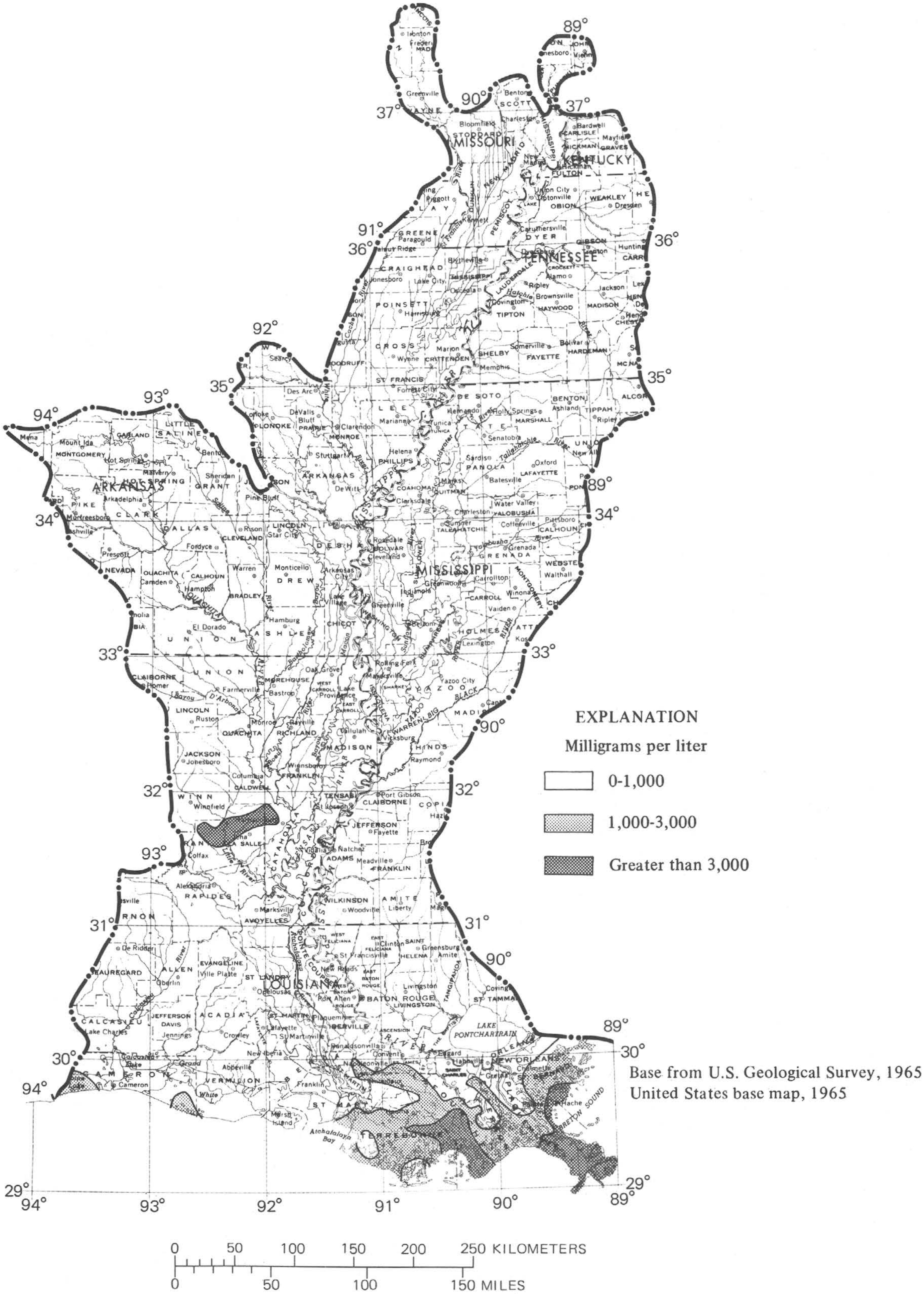


FIGURE 15.—Dissolved-solids concentration of available ground water (from Boswell, 1975).

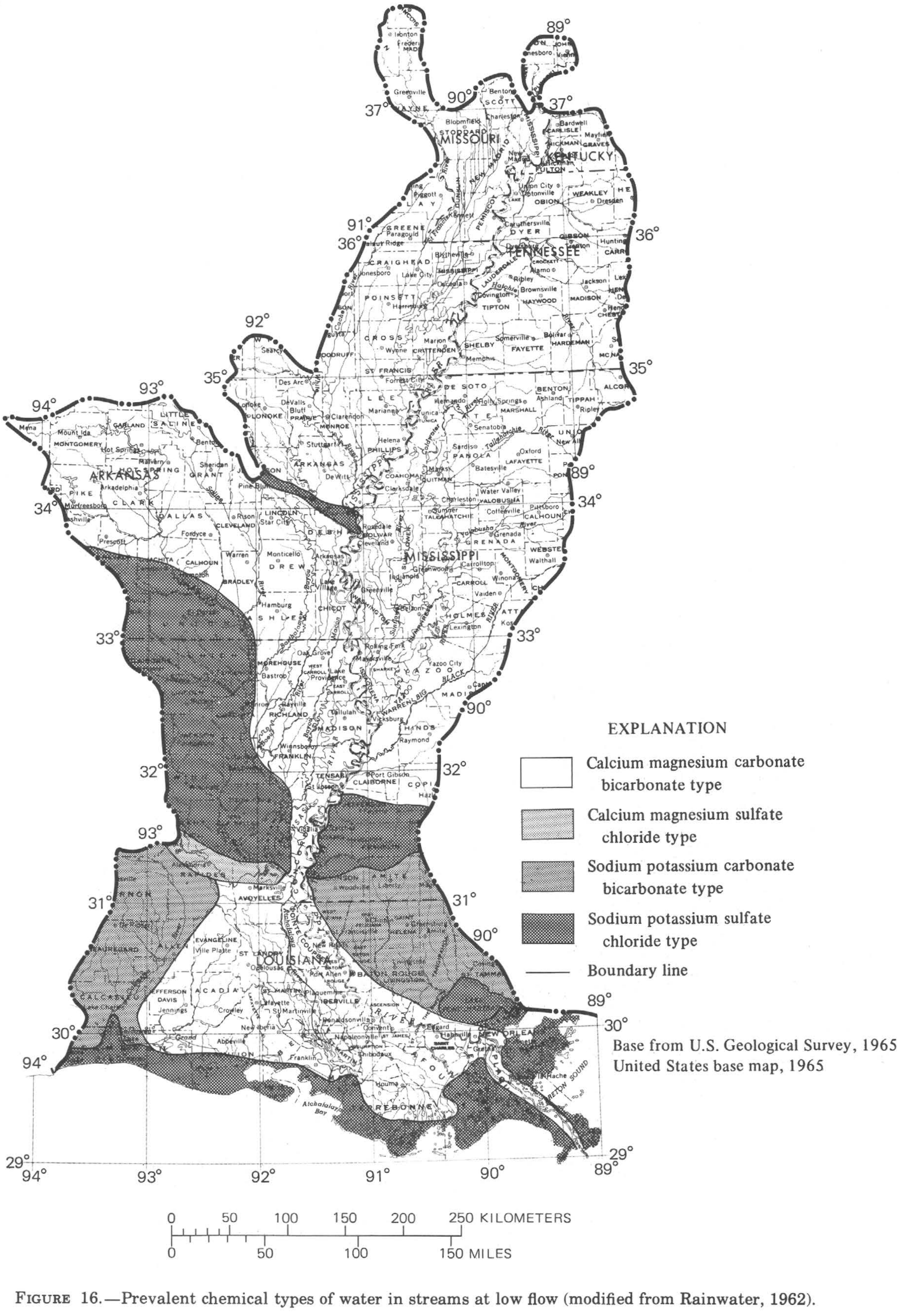


FIGURE 16.—Prevalent chemical types of water in streams at low flow (modified from Rainwater, 1962).

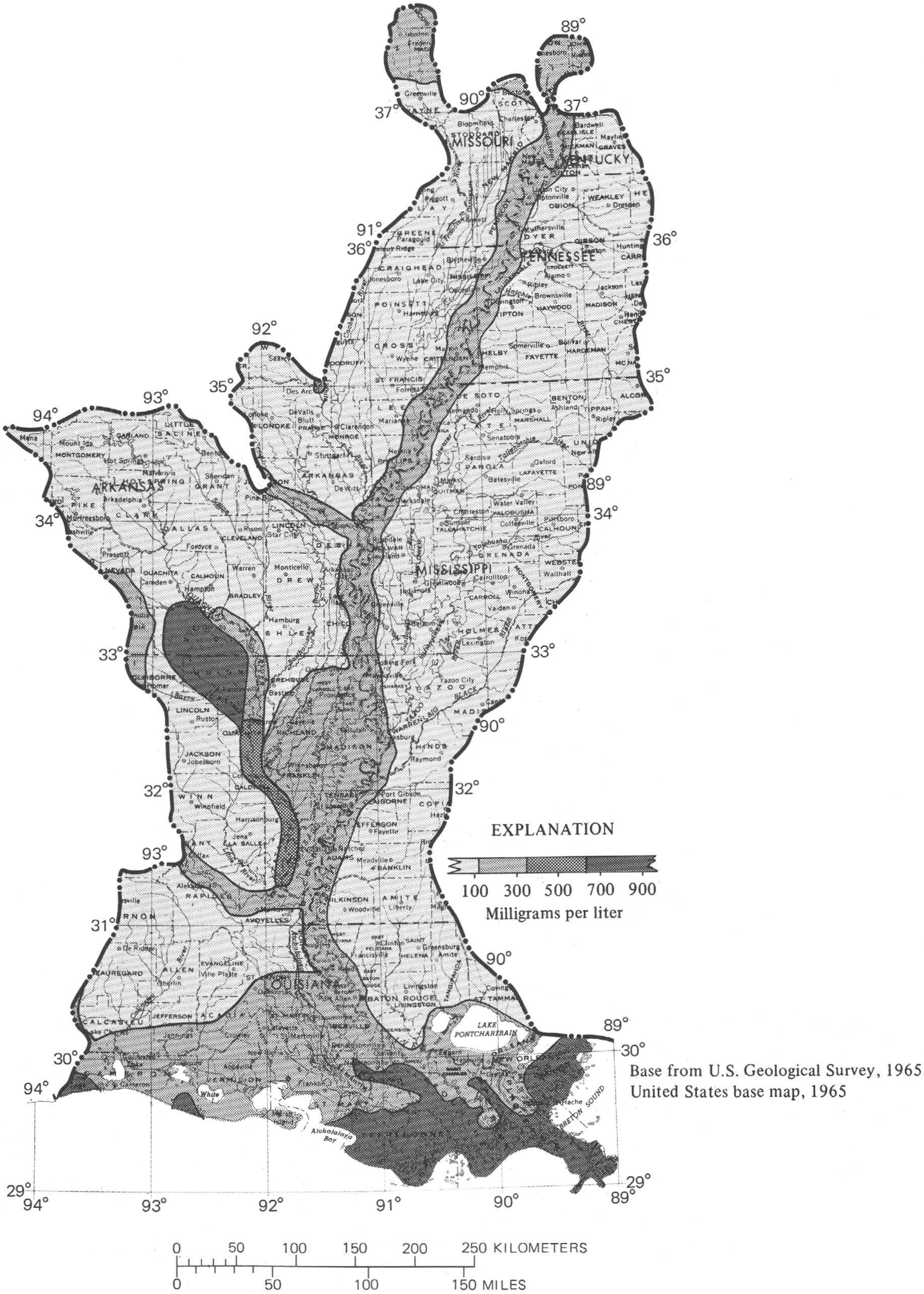


FIGURE 17.—Prevalent dissolved-solids concentration of water in streams at low flow (modified from Rainwater, 1962).

agement it is quite likely to remain so; if the ground water being withdrawn requires treatment, it is not likely that, with proper management, treatment facilities will have to be changed significantly due to changes in the ground-water quality.

Ground water is believed to be generally free of bacteria and chemical pollution. This belief is generally valid because ground water moves through natural soil and rock filtering media which can reduce natural bacterial pollution to almost zero. No widespread occurrence of bacterial pollution of ground water in the Lower Mississippi Region has been observed. However, locally, individual wells may yield bacterially contaminated water due to faulty well construction or location.

By definition, ground water is considered to be naturally "polluted" when natural mineral concentrations exceed established criteria for various uses; so, whether water from a particular aquifer is considered to be polluted depends upon the intended use. If a use problem arises, it can generally be solved by treatment of the water or, in some places, by tapping another available aquifer containing water that is more suitable.

WHY ARE WE NOT GETTING MAXIMUM BENEFIT FROM GROUND WATER?

INADEQUATE CONSIDERATION

Although ground water is being widely utilized, regionally much of its potential is not fully realized. Because of flooding problems and the need for navigation, high priority has generally been given to detailed studies of the region's surface-water systems. As a result, steps have been taken to alleviate most of the severe flooding problems, and good water-transportation systems have been developed. The characteristics of most of the major streams in the region are well defined, and consequently the behavior of these streams during periods of flood and drought is reasonably predictable.

Knowledge of the behavior of the region's subsurface water systems (aquifers) under natural or imposed stresses is also important in water resources management. The ability to predict with some precision the effects of additional ground-water development is needed. Data such as aquifer characteristics, interaquifer relations, and stream-aquifer relations must be available in order to make such predictions. At least as much effort should be made to define and control our subsurface waters as has been made to control our surface waters. Detailed ground-water studies, whose end results are predictive models, cover only small parts of the Lower Mississippi Region (fig. 18).

There is a general lack of public awareness of the overall significance of ground water and the possible widespread effects of ground-water development. Many times the proper information is not sought or is not properly analyzed before a ground-water-related development is started. There is also a lack of public awareness concerning specific problems, such as the possible impact upon the local ground-water regime of certain seemingly unrelated activities, such as land clearing, excavations, and the proximity of sewage facilities to shallow wells.

IMPROPER DEVELOPMENT

Improper ground-water development may entail one or any combination of the following:

1. Drilling below the base of freshwater.
2. Finishing a well above the most suitable aquifer.
3. Locating a well too near other pumping wells.
4. Locating a well too near a source of contamination.
5. Overdevelopment.

Some of these development problems may be due to an information deficit, as mentioned in the preceding section, but often available information is adequate but it is not given due consideration.

Sometimes when a new well is drilled, available information is not considered to determine the depth of the water best suited to the need. Drilling below the base of freshwater, for example, is generally a waste of time and money (fig. 19A) and will increase the chances of well contamination, as head is reduced by pumping (fig. 19B). Of course, the reverse is also true; when a driller does not have adequate knowledge of the section he is drilling, he may stop short of the best water-bearing zone.

Deep test holes, such as those drilled by oil companies, commonly pass through both freshwater aquifers and aquifers containing undesirable water (fig. 20A). If these holes are not properly plugged, they may become conduits through which undesirable water may leak into the freshwater zones that have lower hydrostatic heads (fig. 20B). Such leakage has caused saltwater pollution in local areas in the Lower Mississippi Region. The Mississippi River valley alluvial aquifer in northeast Louisiana has experienced some saltwater pollution due to leaky abandoned wells (Whitfield, 1975).

Interference between wells occurs when they are located too near each other and are screened in the same aquifer. The cones of depression, sometimes termed "zones of influence," created by continued withdrawal from the wells, may coalesce. This condi-

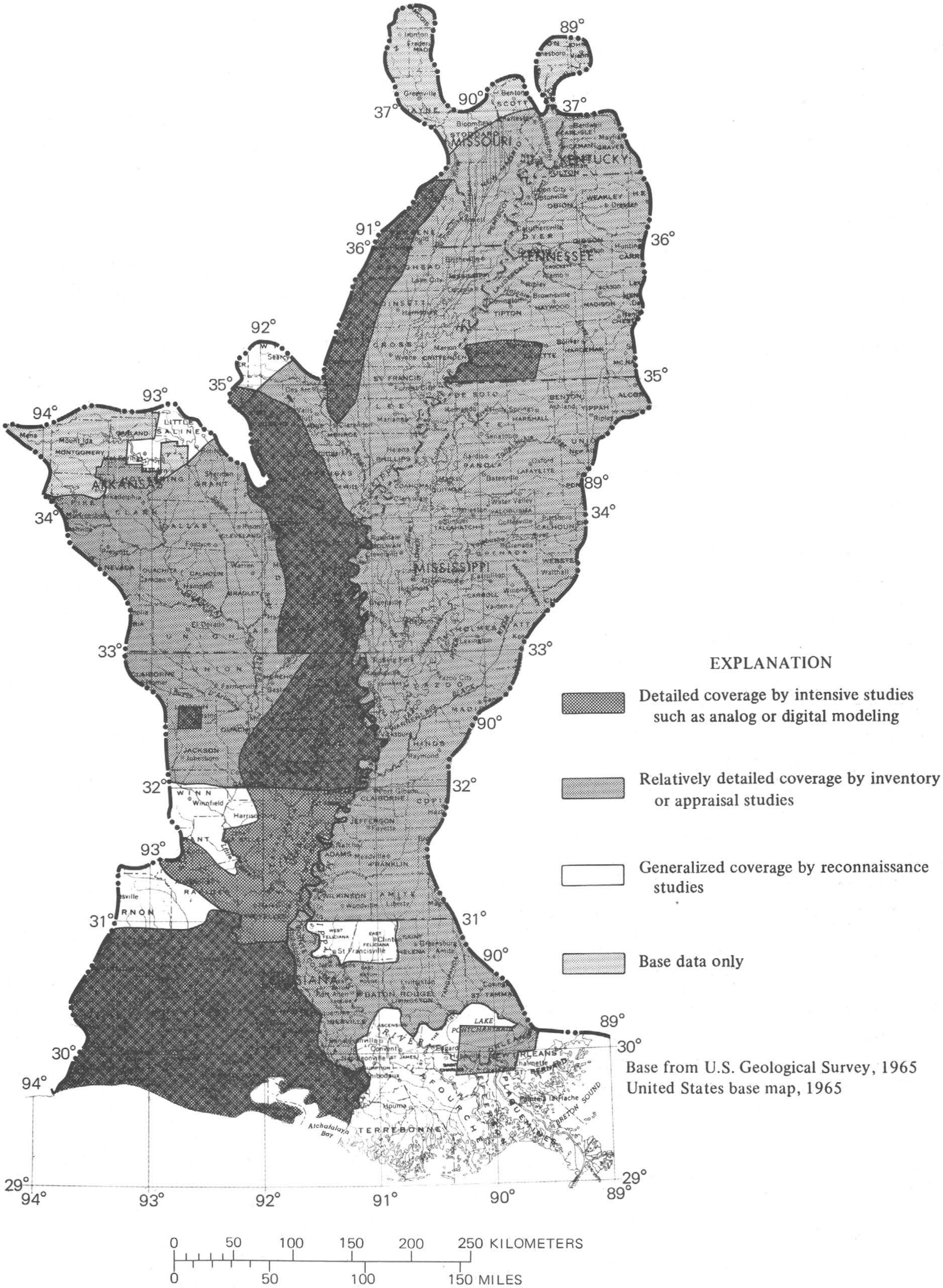


FIGURE 18.—Delineation of areas covered in ground-water-related reports.

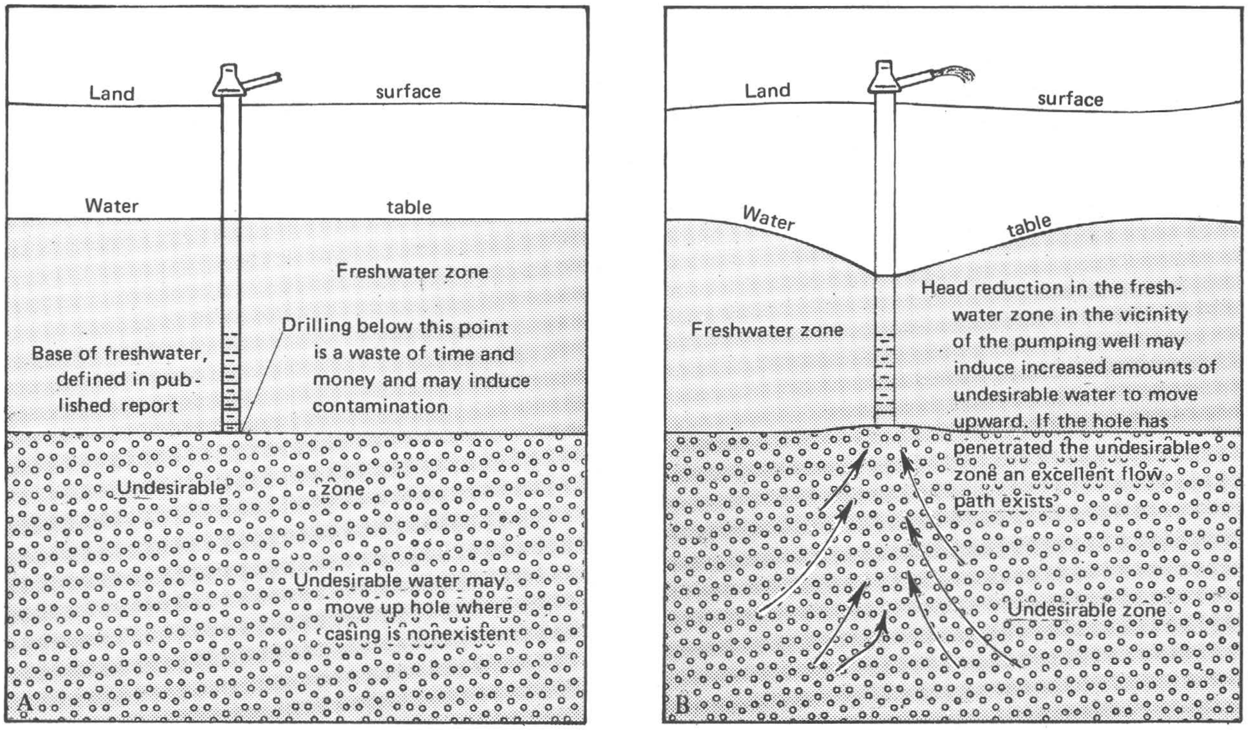


FIGURE 19.—Disregard of available information can be expensive economically and ecologically.

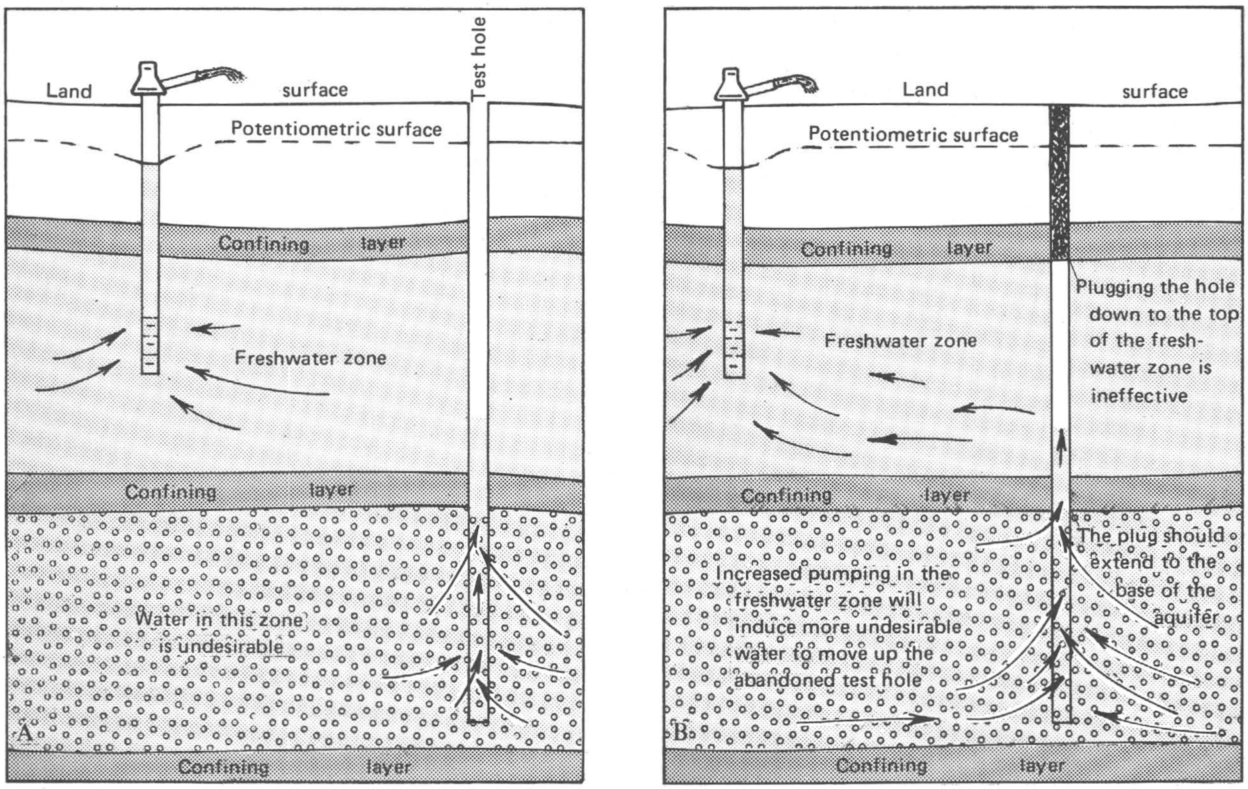


FIGURE 20.—Abandoned, deep test holes cause contamination by interaquifer water exchange if not properly plugged.

tion will significantly reduce the amount of water the aquifer will yield to these wells. Observe wells A, B, and C shown in figure 21. Well A depicts a very poor location for a new well; well B depicts a fair location, if pumping is not increased significantly from either the new or the existing well; well C depicts the best location of the three for the conditions indicated.

The development of a new water-supply well for a city within the region provides an example of both poor well spacing and disregard of information about the depth of the best water-bearing zone available. The city's existing water supply is from two wells screened at depth intervals of 365 ft (111 m) to 405 ft (123 m) and 370 ft (113 m) to 410 ft (125 m), in the upper part of the Claiborne Group. These wells each produce about 600 gal/min (38 L/s). About 300 ft (91 m) from one of these existing wells, the new supply well has been drilled to a depth of 575 ft (175 m). This well is screened in the 364-ft (111-m) to 398-ft (121-m) interval, the same water-bearing zone as the existing wells. It is intended that the well produce 1,000 gal/min (63 L/s), which is the capacity of a new water-treatment plant that the city is now building. Before the well was screened, a gamma-ray log, run by the Geological Survey on the pilot hole, indicated the presence of a possible aquifer 120 ft (37 m) thick below the lower confining layer of the thin (35 ft to 45 ft or 11 m to 14 m) aquifer now being used. Based on the piezometric surface in other wells tapping this aquifer, the pressure in this lower aquifer would have been sufficient to cause flow at ground surface. Further testing could have determined the potential of this lower sand.

Some wells are located too near freshwater-saltwater interfaces. When withdrawals are made from such wells, head(pressure) in the vicinity of the well is reduced, allowing saltwater to move toward the well. This problem can be avoided or possibly solved if adequate information about the aquifer is available. Although saltwater is the most common pollutant associated with ground water in the Lower Mississippi Region, the proximity of proposed well sites to other sources of contamination should be carefully considered before locating a well.

"Overdevelopment" of an aquifer is a relative term. In local areas where water levels have been lowered enough to significantly increase pumping lifts and costs, the term "overdevelopment" is often applied (fig.

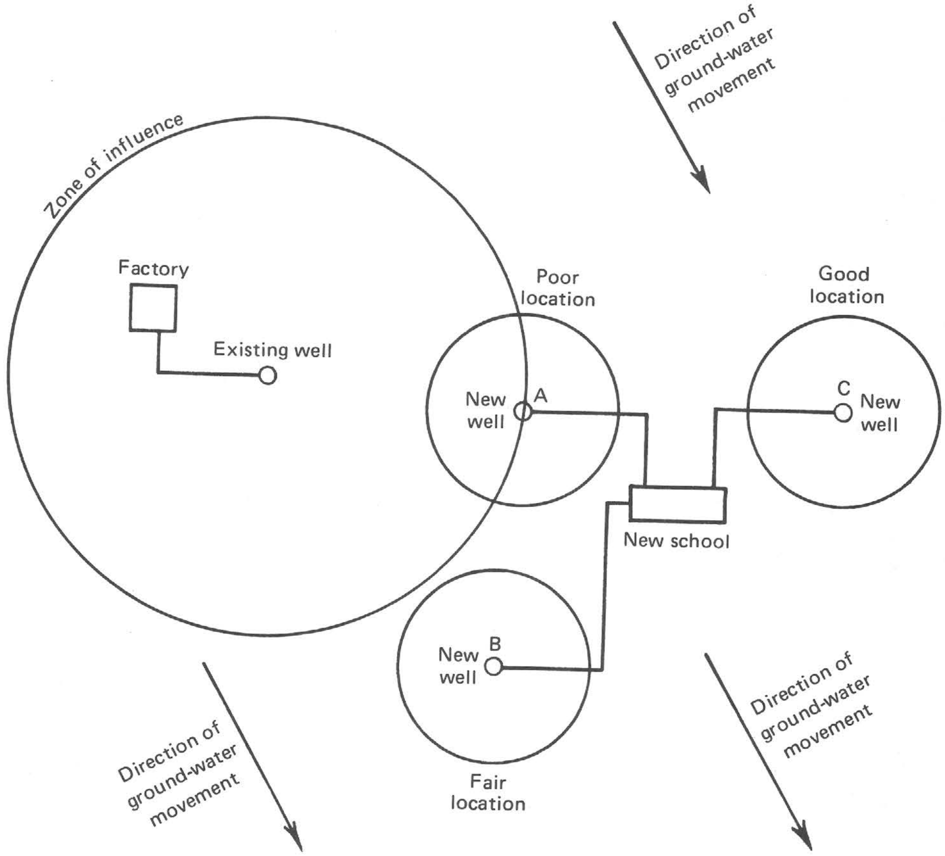


FIGURE 21.—A simplified sketch of how a well location should be selected.

22). If water levels around such pumping centers continue to decline, the zone of influence will spread, resulting in increased pumping costs for users in the area even though they do not significantly contribute to the cause of the decline.

Another cause of some loss in artesian pressure in aquifers within the region is the practice of allowing some naturally flowing wells to flow to waste. In southwest Arkansas, many wells that tap Cretaceous aquifers originally flowed at and above the land surface. Very few of these wells were capped and today, due at least in part to this waste, heads in these wells have dropped considerably and many of them have ceased to flow.

FRACTIONAL USE OF AVAILABLE SUPPLY

The availability of fresh ground water varies throughout the Lower Mississippi Region (fig. 9). Because annual ground-water withdrawal in the region is about one-third of the annual amount available (fig. 23), rejected potential recharge constitutes a loss of water that would have entered the subsurface (fig. 14) if storage space were available. A maximum continuous withdrawal that could be sustained from an aquifer would be that quantity of water necessary to reduce the hydrostatic pressure and maintain it at such a level that the controlling factor on recharge to the aquifer becomes either the amount of recharge available or the ability of the aquifer to transmit water.

As desalinization technology advances and as more uses are found for saltwater, the amount of usable ground water that is available in the region will increase several times. Utilization of saltwater will have a twofold effect—a reduction in demands placed upon freshwater aquifers, making more freshwater available for uses requiring better quality water, and a reduction of pressure in saltwater zones, thus allowing more freshwater to be withdrawn near saltwater interfaces without inducing coning or encroachment problems.

HOW CAN WE OBTAIN MAXIMUM BENEFIT FROM GROUND WATER?

Merely increasing the usage of ground water does not assure that the most benefit will be obtained from the available supply; in fact, unwise development could result in the opposite effect. The determination to protect, as well as utilize, ground water can prevent the waste that has resulted from misuse and mismanagement of some of our other natural resources.

EXPAND INFORMATION BASE, AND USE IT

Ground-water management in the future should consider not only the local aspects of a planned development but also the regional framework into which the development must fit. To do this there should be an adequate information base containing at least the following kinds of data: physical and hydraulic conditions within the aquifers, the quality of water in the aquifers, and interaquifer hydraulic relations.

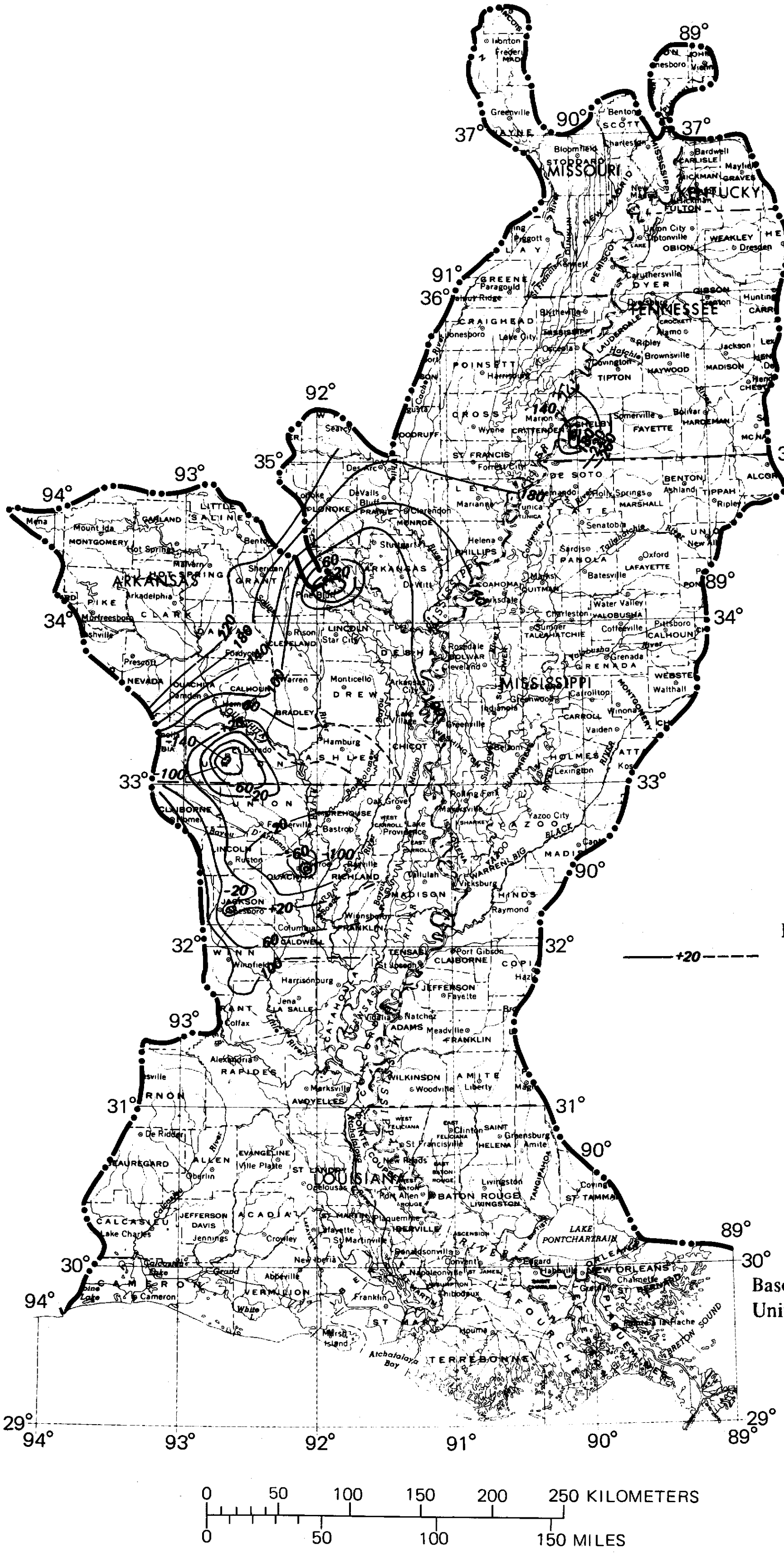
Comprehensive planning or the development of proper planning tools cannot be done without knowing the size and properties of the ground-water container involved. The vital statistics of an aquifer that must be determined are its thickness, areal extent, configuration, and texture. Also, the quality of water, and any areal or vertical changes in quality within an aquifer, should be known. In addition to the physical features, the hydraulic conditions within the aquifer must be understood, that is, the movement of water as influenced by recharge and discharge.

The hydraulic characteristics of an aquifer are those properties that determine its ability to store and transmit water. Aquifer characteristics, such as hydraulic conductivity and transmissivity, control the well yields, the amount of drawdown incurred to produce a specified yield, and the magnitude of water-level declines produced by pumping. With this information, the probable effects of a planned development can be predetermined, and well fields can be designed to minimize well interference. In addition, these aquifer characteristics can be used to estimate the gross yield available from an aquifer throughout a large area under a prescribed set of conditions.

Interaquifer relations—the way aquifers interact hydraulically with one another—must also be determined regionally and locally. Some aquifers receive recharge through or from other aquifers. Confining beds may be sufficiently permeable to permit exchange of water between aquifers. The movement of water into an aquifer that is being pumped can significantly affect water levels and water quality. In fact, in some areas where such conditions exist, the quality of water in an aquifer may be manipulated by carefully planned pumping patterns and schedules.

The extent of hydraulic connection between aquifers must be known for other reasons, too. For example, if poor-quality water or waste were to be injected into an aquifer for storage, a hydraulic connection with another aquifer could induce contamination of the second aquifer. Because of interaquifer hydraulic connections, aquifers considered to be separate entities locally may actually be part of a large system when considered regionally.

Much of the information base needed for planning can be provided by regional aquifer studies. Such studies have been made in most of the Lower Missis-



EXPLANATION

——— +20 - - - - POTENTIOMETRIC CONTOUR – Dashed where approximately located. Contour interval 40 feet (12 m). Datum is mean sea level.

Base from U.S. Geological Survey, 1965
United States base map, 1965

FIGURE 22.—Areas where extensive lowering of water levels has occurred in the Sparta Sand in Arkansas and Louisiana (contours based on 1974–75 data) and in the Memphis Sand in the area of Memphis, Tenn. (contours based on 1973 data).

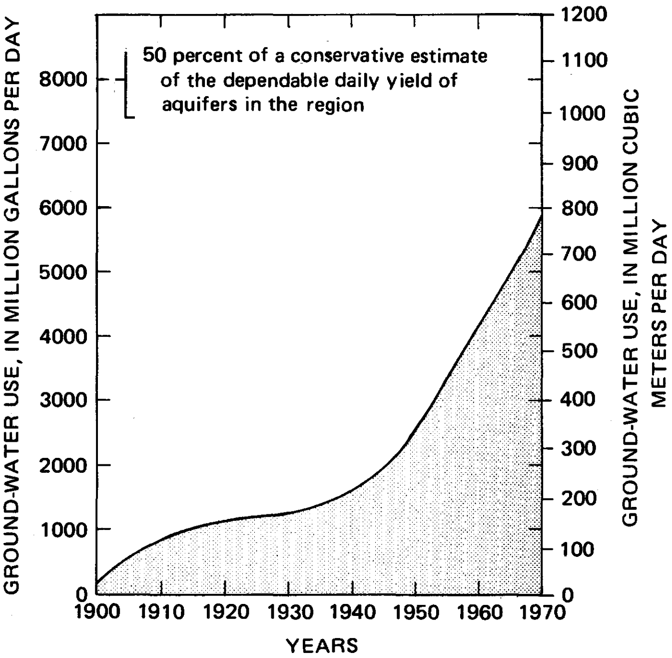


FIGURE 23.—Estimated ground-water use.

sippi Region. Most of the area north of the 32d parallel is included in studies of the water resources of the Mississippi embayment (Cushing and others, 1963, 1964; Boswell and others, 1965, 1968; Hosman and others, 1968). The reports describe the Cretaceous, Tertiary, and Quaternary aquifer systems. Further studies by Payne (1968, 1970, 1972, 1975) describe the hydrologic significance of lithofacies of aquifers of the Claiborne Group in Arkansas, Louisiana, Mississippi, and Texas. Much of the information necessary for the development of predictive aquifer models is provided by these studies. The only major aquifer systems in the Lower Mississippi Region that have not been studied regionally are the vast coastal aquifers of Miocene, Pliocene, and Pleistocene age.

A large amount of water-quality information is available in the Lower Mississippi Region, and regionally the water quality in the different aquifers is well known. Consideration of this information by water managers would help them in choosing a suitable source of water. However, the quality of the water in some aquifers varies in short distances, and substantial additional testing may be necessary at these localities. Water-quality testing is also advisable in the proximity of saltwater interfaces. Monitoring networks can be used to detect anticipated water-quality changes, such as an advancing saltwater front, before the change affects the pumping center. Information on water quality will become increasingly important as concerned management organizations seek measures to conserve and protect the resource.

In addition to the regional aquifer studies mentioned previously, local ground-water studies have been, and are being, made throughout the region. The areas investigated range in size from a few square miles to one or more counties (or parishes) or a river basin. Most of these studies are conducted by the Geological Survey in cooperation with State agencies. Reports based on these studies, plus abundant data in Geological Survey and State agency files, represent a sizable background of ground-water information for the region. Additional investigations should be undertaken in areas within the region where information is insufficient, especially where only reconnaissance studies or basic data are available (fig. 18). These investigations should provide information concerning aquifer properties sufficient for the development of predictive aquifer models.

USE MODERN TECHNOLOGY

In the past, ground-water technology was almost entirely oriented toward locating and developing supplies of potable water. Little attention was given to the possible consequences of such developments. As the science evolved, techniques were developed (and are still being developed) that meant to our ground-water resource and its users what reforestation technology meant to our timberlands and the lumber industry. With proper use and coordination of these techniques and the continued development of new techniques, benefits from use of ground water will approach a maximum, and our ground-water resource will be protected for future users.

AQUIFER MODELING

Aquifer models are the best-available predictive tool for ground-water planners and managers. Among the early models was the analog type: using a network of resistors and capacitors to simulate hydraulic properties, it simulated electrically the effects of pumping stresses on an aquifer. The early analog model was the predecessor of the digital model. Construction of the digital model has been made possible by the sophistication of the digital computer and the development of numerical methods for the solution of the equations of ground-water flow. Use of the digital model requires adequate knowledge of the physical and hydraulic properties of the aquifers, pumping information, and a history of water-level fluctuation for calibration of the model. After the model has been calibrated to reproduce verifiable results, the planner and manager can use it to predict the effect of proposed development upon the ground-water system. Models can also be used to predict the movement of a saltwater front or fluids injected into the aquifer.

Aquifer modeling is still in a relatively early stage of development, and the degree of sophistication of the technology is steadily increasing.

Within the Lower Mississippi Region, four ground-water studies that utilized either analog or digital modeling techniques have been completed. Two additional studies are currently underway. Each of these studies was, or is being, conducted by the Geological Survey in cooperation with another Federal, or a State, agency. Two of the completed studies used only analog models. One of these completed studies predicted the effects that the imposition of navigation structures on the Arkansas River would have on the ground-water regime (Bedinger, 1970), and the other simulated water-level declines in the Sparta Sand in the Mississippi embayment (Reed, 1972). Two of the completed studies used only digital models. In the Ruston, La., area a digital model was used to predict the effects of projected pumping upon water levels in the Sparta Sand (Sanford, 1973). Digital models were used to predict the effects that the construction of locks and dams on the Red River in Louisiana would have upon ground-water levels in the Red River alluvial aquifer (A. H. Ludwig, oral comm., 1976). One of the ongoing studies will model the hydrology of the Bayou Bartholomew alluvial aquifer-stream system in Arkansas. Originally, an analog model was constructed (Broom and Reed, 1973); however, adequate controlling parameters could not be incorporated into the analysis by analog methods. Today, development of a more versatile digital model is underway. The other ongoing study will determine, with the aid of a digital model, the effects of pumping stress upon ground-water levels in the Memphis Sand in the area of Memphis, Tenn.

ARTIFICIAL RECHARGE

Artificial recharge may be used to augment natural recharge. It has been used to salvage excess streamflow and has also been applied to problems associated with ground-water development, such as overdevelopment and subsidence. Artificial recharge is done by two basic methods: (1) impounding surface water where it can infiltrate a permeable part of the aquifer that is exposed at land surface and (2) injecting water into the aquifer through a well.

A method that combines injection with surface-water impoundment has been tried in some areas outside the Lower Mississippi Region, primarily in the West, with only limited success. In such experiments, playa lakes with relatively impermeable beds were used as catch basins. Wells drilled through the lake bottom and into the aquifer were intended to allow the accumulated water that otherwise would be lost to evaporation to drain by gravity into the aquifer. Problems with well plugging, both at the intake and in the screened interval, reduced the efficiency of this method to an unacceptable level. Whether or not this hybrid technique could be made feasible in the Lower Mississippi Region might be worth investigating.

Extensive experiments in which treated surface water was injected into the Quaternary aquifer in the Grand Prairie region of Arkansas were conducted by Sniegocki and others (1963). Heavy pumping for rice irrigation had depleted the ground-water supply in the shallow aquifer, and natural recharge to the aquifer was impeded by an extensive overlying clay layer. The conclusions of the experimental study were that the costs of the extensive treatment necessary to render raw surface water suitable for injection, without plugging the well screen or the aquifer, are economically prohibitive with present technology. However, well injection may become feasible in the Lower Mississippi Region, either through some technological advance or by locating a compatible combination of aquifer conditions and a surface-water recharge source of such quality that the cost of treatment to prevent well-screen and aquifer plugging would be acceptable.

At present, water spreading seems to offer the best hope for artificial recharge at places where water levels have been drawn down in the recharge area and where excess surface water is readily available. Aside from possible technical problems, a major consideration may be the high cost or unavailability of adequate land for water spreading. However, recharge by water spreading should be given consideration as a management option, wherever additional replenishment to the aquifer would be beneficial.

BLENDING OF WATER

The blending of waters from more than one source can enable the use of water that would require treatment if used by itself. The waters to be blended could come from different aquifers or from ground and surface sources if the waters are chemically compatible. The resulting concentration of chemical constituents in the blend will be in direct proportion to the quantity of each of the contributed waters. For example, a blend containing equal amounts of two types of water would have an average chemical composition of the two.

Considering the types of ground water in the Lower Mississippi Region, water blending could prove to be an extremely beneficial practice. The hard, high-iron, low-chloride water in the Quaternary aquifers is plentiful in most of the region; however, the water generally requires treatment for iron removal and softening. A soft, high-chloride, low-iron water occurs at depth in most aquifers; this water generally remains unused because of the difficulty in lowering the chloride concentration to acceptable levels. A blending of these two waters would dilute the iron concentration of one, the chloride concentration of the other, and produce an intermediate hardness. Blends could be designed that would require little or no treatment for most uses. Excesses in iron, chloride, and hardness represent the most common chemical-quality problems with ground water in the Lower Mississippi Region. Before considering a water blend, competent professional advice should be sought to determine the chemical compatibility of the different waters.

CONTROL AND USE OF SALTWATER

The potential for saltwater encroachment exists where withdrawals are large in the proximity of saltwater interfaces. However, if it is necessary to plan a large development of wells near an interface, techniques are available for maintaining a dependable supply of freshwater at the pumping center.

Barrier wells, either discharge or recharge, have been the most successful means of arresting saltwater encroachment. In a discharge-well system, a line of pumping wells between the saltwater front and the pumping center intercepts the migrating saltwater and forms a low-pressure trough in the potentiometric surface beyond which the saltwater cannot pass. The water discharged by the barrier wells will become increasingly salty. If the saltwater cannot be used, it must be disposed of, possibly by injection into a deeper, saltwater-bearing aquifer. Recharge barrier wells, also located between the pumping center and the saltwater, require a supply of freshwater that is chemically compatible with water in the receiving aquifer. The injected water creates a high-pressure ridge in the potentiometric surface and retards the advancement of the saltwater.

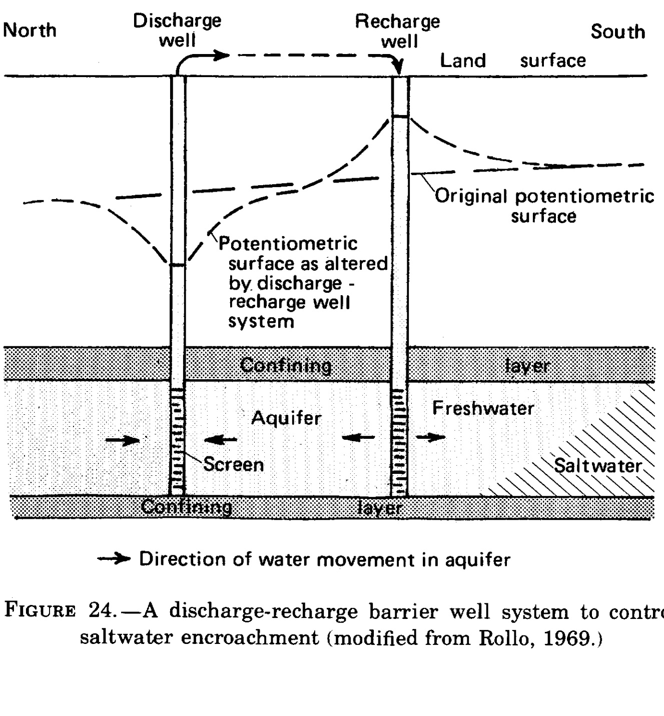


FIGURE 24.—A discharge-recharge barrier well system to control saltwater encroachment (modified from Rollo, 1969.)

A barrier-well system, combining both discharge and recharge wells, has many attractive features and solves most of the problems created by either of the separate systems. In such a system, the discharge wells pump into the recharge wells, which are located between the discharge wells and the interface (fig. 24). Thus, both a high-pressure ridge and a low-pressure trough are formed as an effective barrier to the saltwater. The problems of disposal of water from the discharge wells and a source of compatible water for the recharge wells solve each other, and there is no net loss of water from the aquifer. Although this combined discharge-recharge barrier system is not known to have been tried, its practical features may make it the most economic long-term technique for arresting saltwater encroachment.

Aside from functioning as a control tool, the combined barrier-disposal well system offers an additional application. Water from the discharge wells can be used elsewhere until it becomes too saline; then it can be diverted to the recharge wells. If the pressure ridge formed by the recharge wells effectively stops the progressive saltwater movement, water in the aquifer between the two lines of wells will gradually become fresh. When the chloride concentration in water from the discharge wells decreases to an acceptable level, the water can again be used elsewhere until it becomes too saline. The possibility that the combined barrier system could produce usable water cyclically is a distinct advantage over the discharge-well system that produces only saltwater.

Saltwater also presents problems in areas where it underlies freshwater in an aquifer. This condition exists mostly in coastal aquifers, as a result of the gentle gulfward dip of the aquifers and the low angle of the freshwater-saltwater interface. In a thick sand, the area in which freshwater overlies saltwater can be large. A well screened in the upper (freshwater-bearing) part of the aquifer will produce freshwater. The length of time it will continue to produce freshwater depends upon the rate and duration of pumping, the hydraulic characteristics of the aquifer, and the proximity of the saltwater. When the well is pumped, water in the aquifer moves toward the well. The underlying saltwater moves upward and can eventually reach the well if it is pumped hard enough and long enough. One method of producing freshwater under these conditions is to use several low-producing wells screened at the top of the aquifer. Although this method can be successful, it can also be expensive because of the number of wells and the amount of land required for proper well spacing.

A more economical way to withdraw large quantities of freshwater from a zone that is underlain by saltwater is through the use of a scavenger well (Long, 1965). The scavenger well is installed next to the supply well, but it is screened lower in the aquifer. The supply well can be pumped until the saltwater reaches it. At this time, the scavenger pump is turned on to intercept the saltwater, and the supply well will then produce freshwater. Of course, the saltwater from the scavenger well must be disposed of. It could be injected into a deeper aquifer or possibly into the basal part of the same aquifer. The basic scavenger-well technique offers interesting opportunities for innovative approaches.

RECYCLING

The possibilities for recycling water, or returning it to the subsurface for reuse, must be considered in order to derive maximum benefit from the ground-water resource. The water used for many processes is only slightly altered, sometimes only thermally, and could be reused, reclaimed for reuse, put to other uses, or returned to the same or another aquifer. Recycling should become a standard practice as far as is feasible for the sake of conservation. The advantages of recycling should be emphasized now, rather than at some future time when a shortage may force conservation measures.

GEOTHERMAL ENERGY

Harnessing geothermal energy is a newly developing technology, insofar as the United States is concerned. Whether or not development of geothermal-energy resources is feasible in the Lower Mississippi Region has not been determined. In this area, extremely deep strata contain hot water as a result of the natural geothermal gradient. Experiments with hot water from an abandoned, deep gas well in southern Louisiana are being planned to determine the feasibility of geothermal development. If results of the study are favorable, this would indicate similar possibilities in approximately the southern one-third of the region. The only other known source of hot ground water in the region is in the Hot Springs, Ark., area. The temperature of the water issuing from the hot springs is 145°F (62°C), which is sufficient only for space heating. The heat source for the springs does not seem to be large, and hotter water probably would not be available by drilling. Tapping the source of the water at depth probably would diminish the natural flow of the springs (Bedinger and others, 1974), and whether or not the energy that might be available would offset the loss to the tourist industry is questionable. The deep-seated, superheated water in the southern part of the region seems to offer the best potential for geothermal energy sources and may be more economically accessible where abandoned, deep oil and gas wells are available.

PLAN PROPERLY

Proper planning will be the key to maximizing benefits from the ground-water supply in the lower Mississippi Region. Planning must include provisions for management so as to prevent waste and assure conservation and protection of the resource. Plans must be coordinated within the region, as well as with adjacent regions, because most of the aquifers cross regional boundaries.

To coordinate work, planners should establish communications with all local, State, and Federal agencies that manage or investigate water resources (see following list). The main function of water-oriented agencies has been investigation. However, because of the need for planning and management, regulatory bodies are being formed and others are planned. Regulation should be based on cooperative planning by regions, States, and local districts in order to form workable management plans that account for hydrologic reality.

The underlying philosophy for planning and management efforts should be to promote wise use, conservation, and protection of the ground-water resource. Conservation measures, such as reuse or recycling, pumping controls, and blending, should be combined with measures to protect the ground-water supply, primarily from man's activities. One potentially harmful activity is the underground injection of liquid wastes. Saltwater-bearing aquifers are generally considered to be suitable receptacles for waste. However, as the result of advances that are being made in developing economical desalinization techniques, saline aquifers may eventually become important sources of water. Therefore, in addition to the other indirect hazards associated with waste injection, such as leakage through wells or confining beds, there is also the risk of directly contaminating a potential water supply. These practices should be of as much concern as is the dumping of waste into streams or the Gulf of Mexico.

Strip mining in the region is a possible future activity that should be evaluated for its potential effect on ground water. Most of the environmental concern with strip mining is about disturbance of the landscape; however, the geohydrologic effects could be far more serious. Mining companies now contemplate the

Selected agencies within the Lower Mississippi Region that manage or investigate ground-water resources

Arkansas

Arkansas Department of Pollution Control and Ecology
Arkansas Division of Soil and Water Resources
Arkansas Geological Commission
U.S. Geological Survey, Water Resources Division
U.S. Army Corps of Engineers

Louisiana

Capitol Area Water Conservation Commission
Capitol Region Planning Commission
Louisiana Department of Public Works
Louisiana Geological Survey
U.S. Geological Survey, Water Resources Division
U.S. Army Corps of Engineers

Mississippi

Mississippi Air and Water Pollution Commission
Mississippi Board of Water Commissioners
Mississippi Geological Economic and Topographical Survey
Mississippi Research and Development Center
Mississippi State Board of Health
Environmental Protection Agency
U.S. Geological Survey, Water Resources Division
U.S. Army Corps of Engineers

Tennessee

Chickasaw Basin Authority
Memphis, Arkansas, Tennessee Council of Governments, Memphis Delta Development District (MATCOG MDDD)
Memphis Department of Public Works
Memphis Light, Gas, and Water Development
Memphis Planning Commission
Memphis-Shelby County Health Commission
Shelby County Conservation Board
Utility Districts in cities in west Tennessee
Tennessee Department of Health
- Division of Water Quality Department
- Division of Solid Waste Management
- County Health Superintendents

Tennessee Division of Water Resources
U.S. Geological Survey, Water Resources Division
U.S. Army Corps of Engineers

Kentucky

Department for Natural Resources and Environmental Protection
Kentucky Geological Survey
U.S. Geological Survey, Water Resources Division
U.S. Army Corps of Engineers

Missouri

Missouri Department of Natural Resources
U.S. Geological Survey, Water Resources Division
U.S. Army Corps of Engineers

removal of as much as 200 ft (61 m) of overburden in order to mine small lignite layers. The current emphasis on locating new sources of energy has awakened interest in mining coal from deposits that heretofore have been considered uneconomical to develop. The Wilcox Group is such a deposit; it consists of complexly interbedded sands, silts, clays, and thin lignite beds. The sands are water bearing and are interconnected to varying degrees. Large, deep excavations in Wilcox deposits would act as sumps and would drain the sands. Such draining could have widespread effects, which would be difficult to predict, depending upon the size of the excavation and the extent and degree of hydraulic connection between the sands. The effects of such drainage would range from lowering the water level in aquifers to the removal of ground water from a sizable part of the aquifer system, thus endangering many existing wells, as well as future well development. Drainage of freshwater-bearing sands into excavation sites could also adversely affect the quality of the ground water downdip from the excavation by introducing contaminated water into the aquifer or by inducing the advance of saltwater into freshwater zones. Much of the damage to the ground-water regime caused by strip mining may be irreversible. Although refilling the excavations would help to restore the esthetic quality of the area, the continuity and interconnection of aquifers necessary to conduct recharge downdip probably could not be reestablished.

Conservation of ground water should go beyond eliminating the more obvious forms of waste, such as disposing of usable water once it has served a purpose. Water is also wasted when a superior-quality water is used where an inferior-quality water would suffice—for example, using potable water for industrial cooling. Obviously, if only one or two aquifers are available for supply in an area, there may be little or no choice as to which aquifer is to be used for which purpose. However, at most locations in the Lower Mississippi Region, several aquifers (fig. 8) that contain water of differing chemical quality are available. Under such conditions, water-use priorities keyed to water quality should be established for different-use categories. Each category would be assigned water of the lowest acceptable quality; however, drinking water would be assigned the top priority.

It is apparent that there is a need to plan carefully for the use of ground water. The resource is of no value unless used, and it should receive its due consideration. However, while use of ground water is to be encouraged, care must be taken to prevent its abuse. Development should be guided by sound precepts. The consequences of other planned activities that could affect the ground-water regime should be weighed carefully as are the more commonly recognized environmental consequences. Ground water is an unseen part of the environment but, like the visible part, it must not be neglected.

WHAT ARE THE POSSIBLE CONSEQUENCES OF INCREASED GROUND-WATER USE?

When considering the development of ground-water supplies, managers should not overlook possible consequences to the resource. Development of large-producing wells without an adequate knowledge of the aquifer system could result in undesirable changes in the system. These changes may be in the hydraulics of the system, in the quality of water in the aquifer, and (or) in the framework of the water-bearing unit.

HYDRAULIC CHANGES

When a well is pumped, the water level in the vicinity of the well is lowered. The lowering of the water level may be temporary if the pumping is cyclical or seasonal, or it may be permanent if the pumping is continuous. If recharge to the aquifer is increased or discharge is decreased to compensate for the water discharged from the well, the water level in the vicinity of the well should stabilize. Otherwise, the water level will continue to decline, and pumping lifts and pumping costs will increase.

Water levels in several aquifers have been lowered in sizable areas of the Lower Mississippi Region. The aquifers most affected are the Sparta Sand and the Memphis aquifer in Louisiana, Arkansas, and Tennessee (fig. 25). Other affected aquifers include the upper Wilcox in northwest Mississippi, the lower Wilcox at Memphis, Tenn., the Chicot-Atchafalaya aquifer near Lake Charles, La., and alluvial deposits of Quaternary age in the Grand Prairie region in Arkansas.

Normally, aquifers in the Lower Mississippi Region are recharged by streams only during high flows. Ground water discharges to streams during normal and low flows. However, continuous pumping from an aquifer in the vicinity of a stream may reverse the hydraulic gradient so that water is demanded from the stream (fig. 13). Inducing the flow of water from a stream to the aquifer can be of benefit if the stream carries sufficient quantities of water to meet both the normal surface-water demands and the demands of aquifer recharge.

Where an aquifer overlies another and the two are separated by a confining layer, movement of water from one aquifer to the other is minimal if a near balance of pressure (head) exists in the aquifers. When water is pumped from one of these aquifers, the head imbalance between the aquifers may induce flow through the confining layer. After continuous pumping, a stable pumping level will be reached in the receiving aquifer at a higher level than would be reached in the absence of recharge from the adjacent aquifer. Also, the head will be reduced in the contributing aquifer even if this aquifer is not being pumped directly. Reports by Hosman and others (1968), Whitfield (1975), and Boswell (1979) have pointed out several areas in the Lower Mississippi Region where water moves from one aquifer to another through a confining layer.

WATER QUALITY CHANGES

Where aquifers are hydraulically connected, as discussed previously, and where pumping of one aquifer has induced a change in the flow system, water-quality changes may occur. Inducing flow from a stream to an aquifer may also cause changes in the quality of water in the aquifer. Because the ground water generally will be of better quality than water in the stream, any significant change will probably be detrimental. However, an improvement in quality could result if water in the stream is of exceptionally good quality. Changes in quality should be carefully considered before inducing recharge from streams or from other aquifers.

Saltwater encroachment could occur in many places in the Lower Mississippi Region. Northward saltwater migration has been occurring for several years in the Chicot aquifer in southwest Louisiana due to pumpage in the Lake Charles area (Zack, 1971). However, the movement of saltwater thus far observed is small.

Many aquifers in the interior of the Lower Mississippi Region contain saltwater downdip. Under natural conditions, the saltwater is either virtually static or is moving very slowly downdip. However, heavy pumping of these aquifers near the saltwater-freshwater interface can reverse the hydraulic gradient and cause saltwater to move toward the point of withdrawal. This condition has occurred in the vicinity of Baton Rouge, where heavy industrial pumping has caused northward movement of saltwater in several aquifers (Rollo, 1969). In at least one place, the saltwater is moving across a fault south of the area of pumping. Conversely, the same fault acts as a barrier and protects some other aquifers from saltwater encroachment (fig. 26). Although saltwater has been moving toward the withdrawal point, no saltwater has yet migrated into the zone affected by pumping. The dense saltwater in the basal part of the aquifer appears to take a circuitous route because of irregularities in the base of the aquifer. Because the nature of these irregularities is not known, the time required for the saltwater to reach pumping centers is not predictable with any degree of accuracy.

AQUIFER-FRAMEWORK CHANGES

Large water-level declines caused by withdrawals of ground water may result in major changes in the framework of an aquifer. Major aquifers in the Lower Mississippi Region are composed principally of sand and gravel interbedded with clays and silts, and when large amounts of water are withdrawn, the fine-grained materials can become compacted.

Land-surface subsidence is the most visible effect of compaction due to pumping. In areas outside the region, land surfaces have been lowered in amounts ranging from a few feet to a few tens of feet. In the

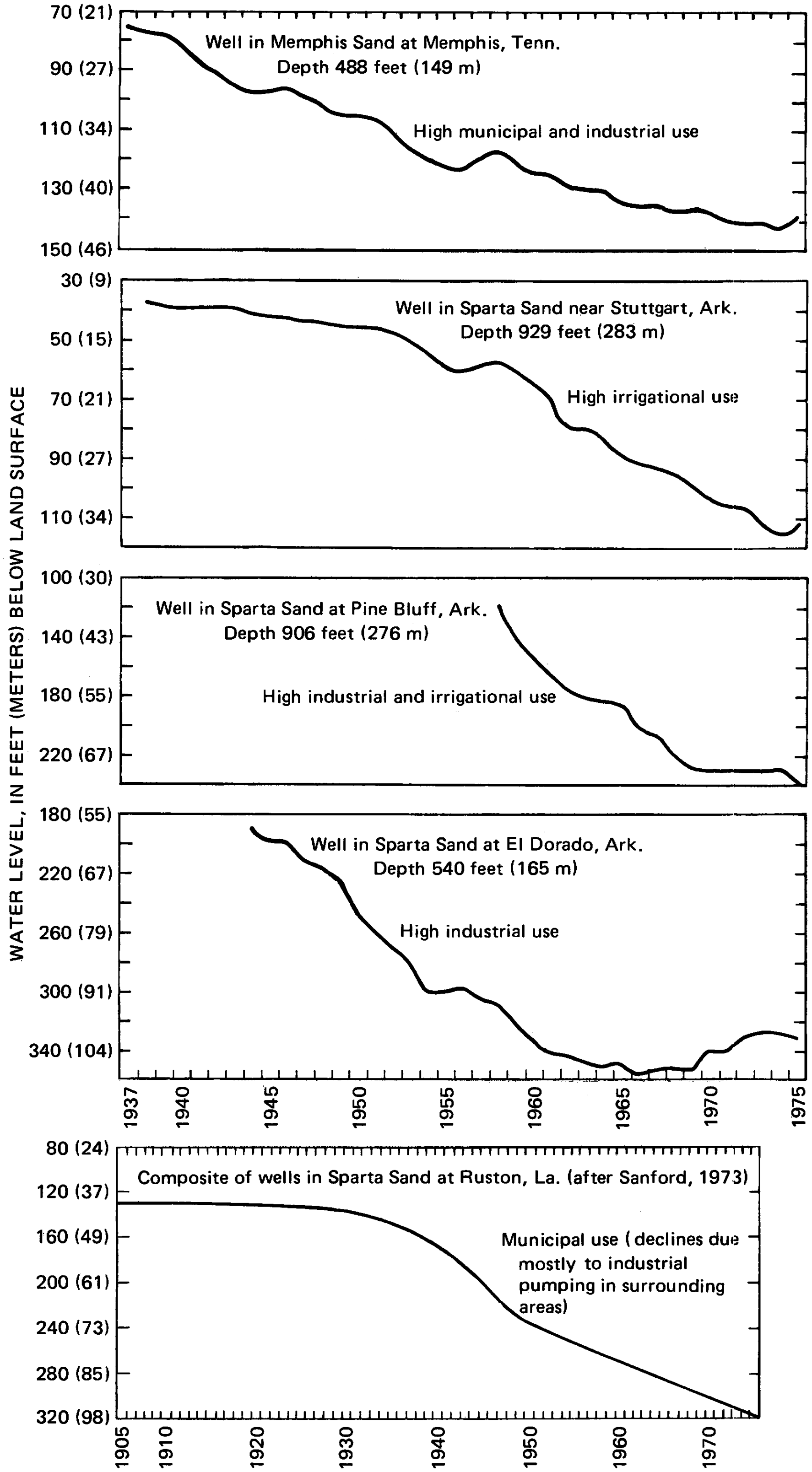


FIGURE 25.—Water-level declines in observation wells in the Memphis Sand and Sparta Sand.

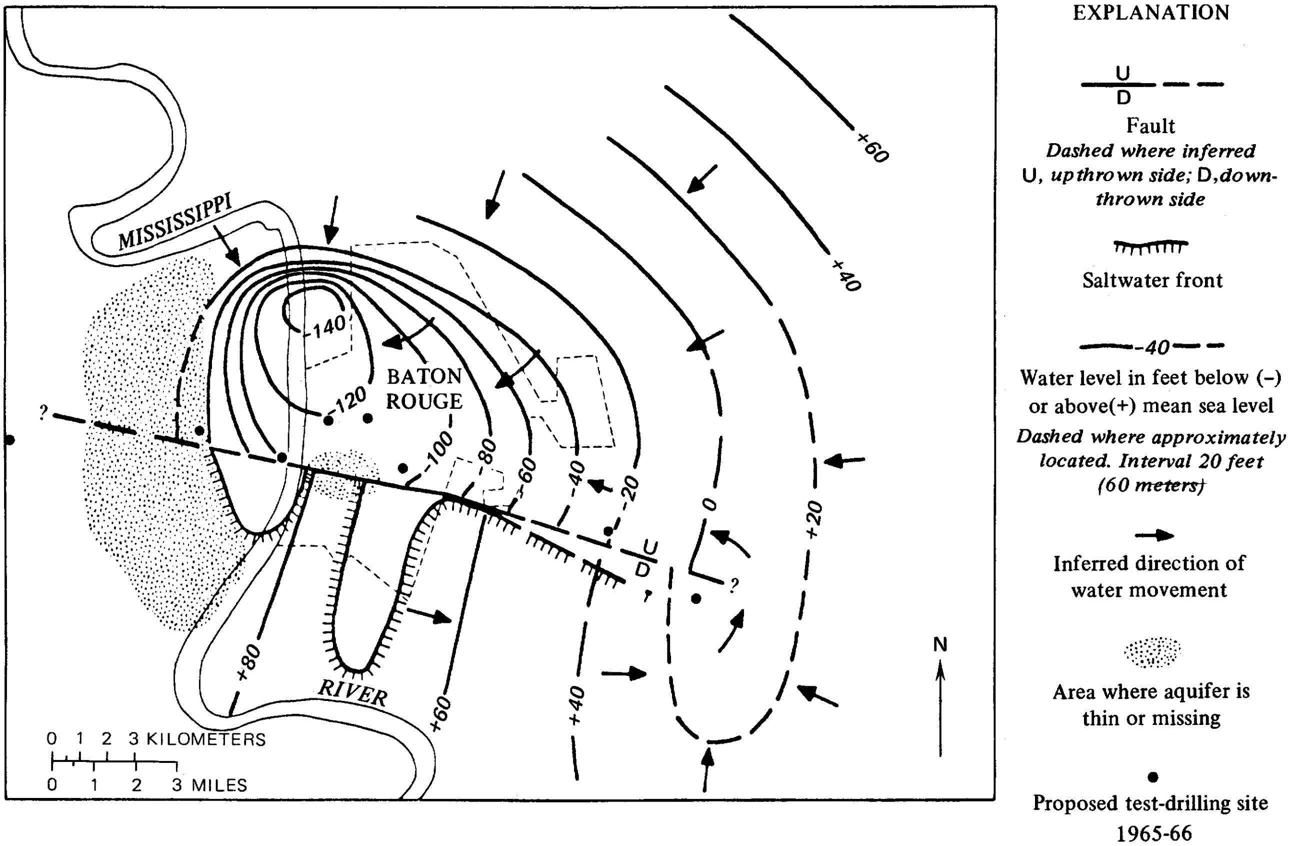


FIGURE 26.—Saltwater front, water-level contours, and location of fault in the "2,000-foot" sand as determined during the 1965 test-drilling program in the Baton Rouge, La., area (from Meyer and Rollo, 1965).

San Joaquin Valley of California, for example, withdrawals of water for irrigation have allowed compaction of fine-grained materials to the extent that by 1972 the land surface had subsided as much as 29 ft (9 m). More than 5,000 mi^2 (13,000 km^2) in the valley have been affected (Poland and others, 1975). Subsidence can cause damage to roadways and structures and allow innundation of low-lying coastal areas.

Known subsidence in the Lower Mississippi Region has been confined to Baton Rouge, La., where large withdrawals of ground water have caused the land surface to subside a maximum of about 1.5 ft (0.5 m). In other areas in the Lower Mississippi Region, where hydrostatic pressures have been significantly lowered in sand-and-gravel aquifers, compaction probably has occurred as a result of drainage from underlying, overlying, and interbedded fine-grained materials. Although noticeable subsidence may not have been produced, deformation generally is accompanied by a permanent reduction in storage of water in the fine-grained materials. Therefore, although subsidence is not a major problem in the Lower Mississippi Region at present, it should be regarded as a serious potential problem.

IN SUMMARY— IS THE OUTLOOK OPTIMISTIC?

The outlook for additional ground-water use in the Lower Mississippi Region is bright. Multiple freshwater aquifers are available throughout most of the region. By conservative estimate, 844 billion ft^3 (24 billion m^3) of fresh ground water is available annually in the region. Today, nearly two-thirds of this available supply is not being utilized, and an additional large quantity of water is being lost—water that might have infiltrated the surface to become ground water if storage space were available. In other words, increased ground-water usage would not only allow ground-water benefits to more nearly approach a maximum but would also save some water that today cannot recharge the aquifers.

Much of the ground water withdrawn and commonly termed "ground water used" could be used more than once or put to other uses. As existing water-oriented conservation techniques become more widely implemented and as new ones are developed, 1 gallon of water withdrawn may become several gallons used. It is quite conceivable that in the future, with the implementation of such practices are recycling, reuse, injection of unaltered ground water back into the aquifer, and induced aquifer recharge from streams, annual ground-water use (including reuse) could exceed the quantity now estimated to be available annually.

The quantity of subsurface saltwater available in the Lower Mississippi Region is several times that of freshwater. Further development and utilization of desalinization techniques would multiply the region's fresh ground-water supply several times. Furthermore, untreated saltwater may be used in some applications instead of freshwater; for example, at places, such as some areas of Louisiana, where saltwater occurs at shallow depths and is not too warm, it can be used for cooling purposes.

To make maximum use of this vast quantity of ground water, adequate information about the subsurface reservoirs and the hydraulics of the system must be available. This information, as well as adequate legislation, is necessary in order to properly protect the quality of the ground water and the physical integrity of the aquifers.

Today, there is an increasing awareness of the vital role that ground water plays in the total water-resources scene in the Lower Mississippi Region. Planning and management efforts are beginning to reflect this awareness. Interpretive and predictive investigations required by the water manager in order to make sound decisions have been, and are being, made in the region. Each State in the region maintains active water-resources-study programs of its own, as well as cooperative programs with other water-oriented agencies, including support of programs with the Geological Survey. All these agencies give considerable attention to ground-water resources. Increased cooperation between water-oriented agencies not only broadens the information base and helps prevent duplication of effort, but also stimulates new approaches to old problems and the recognition of areas where attention is needed.

The technology and methodology for creating useful management tools for the water-resource manager have greatly advanced in the last 10 years. The sophistication of the digital computer and the development of digital-modeling techniques have made it possible, with adequate data, to make long-term stress-response predictions for a large area in a very short time. Also, methods are available for dealing with problems that may be encountered when utilizing the ground-water resource; for example, selective use based on water quality where multiple aquifers are available, barrier-well systems, scavenger wells, and artificial recharge.

In the past, ground water and surface water were considered by many people to be separate entities that act and react independently. Today, such false ideas have been discarded, and the close and dependent relationship of the two resources is accepted. Total water-resource planning considers this relationship and the ways in which changes in one regime may affect the other.

Each State in the Lower Mississippi Region has water laws that directly and indirectly concern ground water. These laws are changed and improved as legislators are made more aware of the immediate need for enforceable guidelines in ground-water development and protection. Each State has an agency that is responsible for the identification and control of environmental pollution, including ground-water pollution. Some water-resources groups or agencies function on the local, county, or parish level. For example, in Louisiana, the Capital Area Ground-Water Conservation District encompasses a multiparish area in the Baton Rouge vicinity. The findings of the Louisiana Legislature that precipitated the organization of this conservation district are expressed in Article A of Section 3071, Part XIII, Chapter 13, Title 38, of the Louisiana Revised Statutes. The article states: "The orderly utilization of groundwater resources is hereby found and declared to be a matter of public interest." The purpose of the conservation district is, as stated in Article B of the same section "to provide for the efficient administration, conservation, orderly development and supplementation of groundwater resources***." The existence and resolve of such local groups is good; the extension of these concepts to a regional conservation organization concerned with ground-water planning and management would be even more compatible with the regional nature of ground-water occurrence.

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