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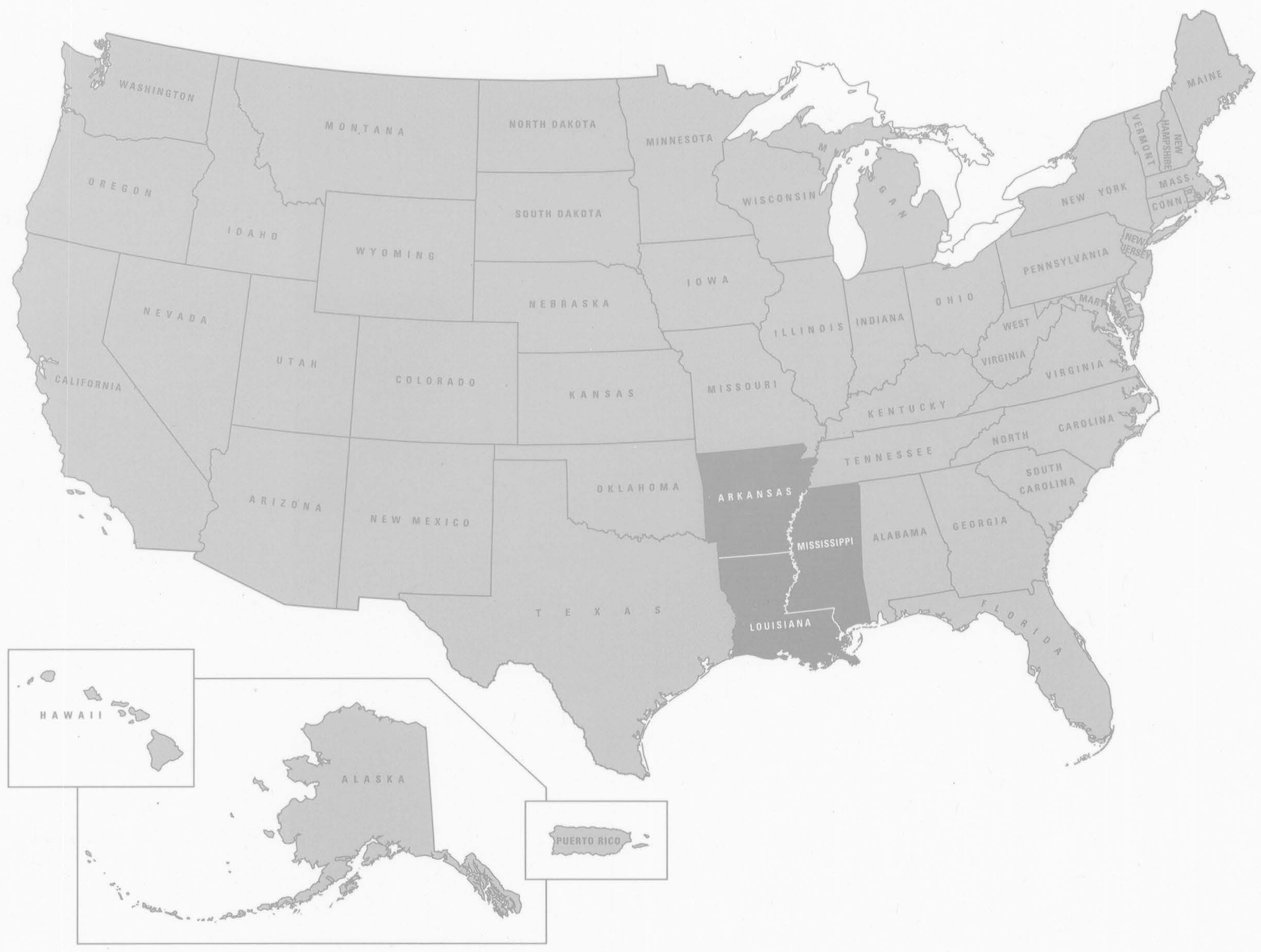
Ground Water Atlas of the United States

Segment 5

Arkansas
Louisiana
Mississippi



HYDROLOGIC INVESTIGATIONS ATLAS 730–F
U.S. Geological Survey

Reston, Virginia
1998

GROUND WATER ATLAS OF THE UNITED STATES
Hydrologic Investigations Atlas 730–F

FOREWORD

The Ground Water Atlas of the United States presents a comprehensive summary of the Nation's ground-water resources, and is a basic reference for the location, geography, geology, and hydrologic characteristics of the major aquifers in the Nation. The information was collected by the U.S. Geological Survey and other agencies during the course of many years of study. Results of the U.S. Geological Survey's Regional Aquifer-System Analysis Program, a systematic study of the Nation's major aquifers, were used as a major, but not exclusive, source of information for compilation of the Atlas.

The Atlas, which is designed in a graphical format that is supported by descriptive discussions, includes 13 chapters, each representing regional areas that collectively cover the 50 States and Puerto Rico. Each chapter of the Atlas presents and describes hydrogeologic and hydrologic conditions for the major aquifers in each regional area. The scale of the Atlas does not allow portrayal of minor features of the geology or hydrology of each aquifer presented, nor does it include discussion of minor aquifers. Those readers that seek detailed, local information for the aquifers will find extensive lists of references at the end of each chapter.

An introductory chapter presents an overview of ground-water conditions Nationwide and discusses the effects of human activities on water resources, including saltwater encroachment and land subsidence.

Thomas J. Casadevall
Acting Director

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, *Secretary*

U.S. GEOLOGICAL SURVEY
Thomas J. Casadevall, *Acting Director*

CONVERSION FACTORS

For readers who prefer to use the International System (SI) units, rather than the inch-pound terms used in this report, the following conversion factors may be used:

Multiply inch-pound units	*By*	*To obtain metric units*
	Length	
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
billion gallons per day (Bgal/d)	3.785	million cubic meters per day (Mm^3/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
acre-foot per year	0.00003909	cubic meter per second (m^3/s)
acre-foot	1,233	cubic meter (m^3)
	Transmissivity	
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
	Temperature	
degree Fahrenheit (°F)	5/9(°F–32)=°C	degree Celsius (°C)

Sea Level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

ATLAS ORGANIZATION

The Ground Water Atlas of the United States is divided into 14 chapters. Chapter A presents introductory material and nationwide summaries; chapters B through M describe all principal aquifers in a multistate segment of the conterminous United States; and chapter N describes all principal aquifers in Alaska, Hawaii, and Puerto Rico.

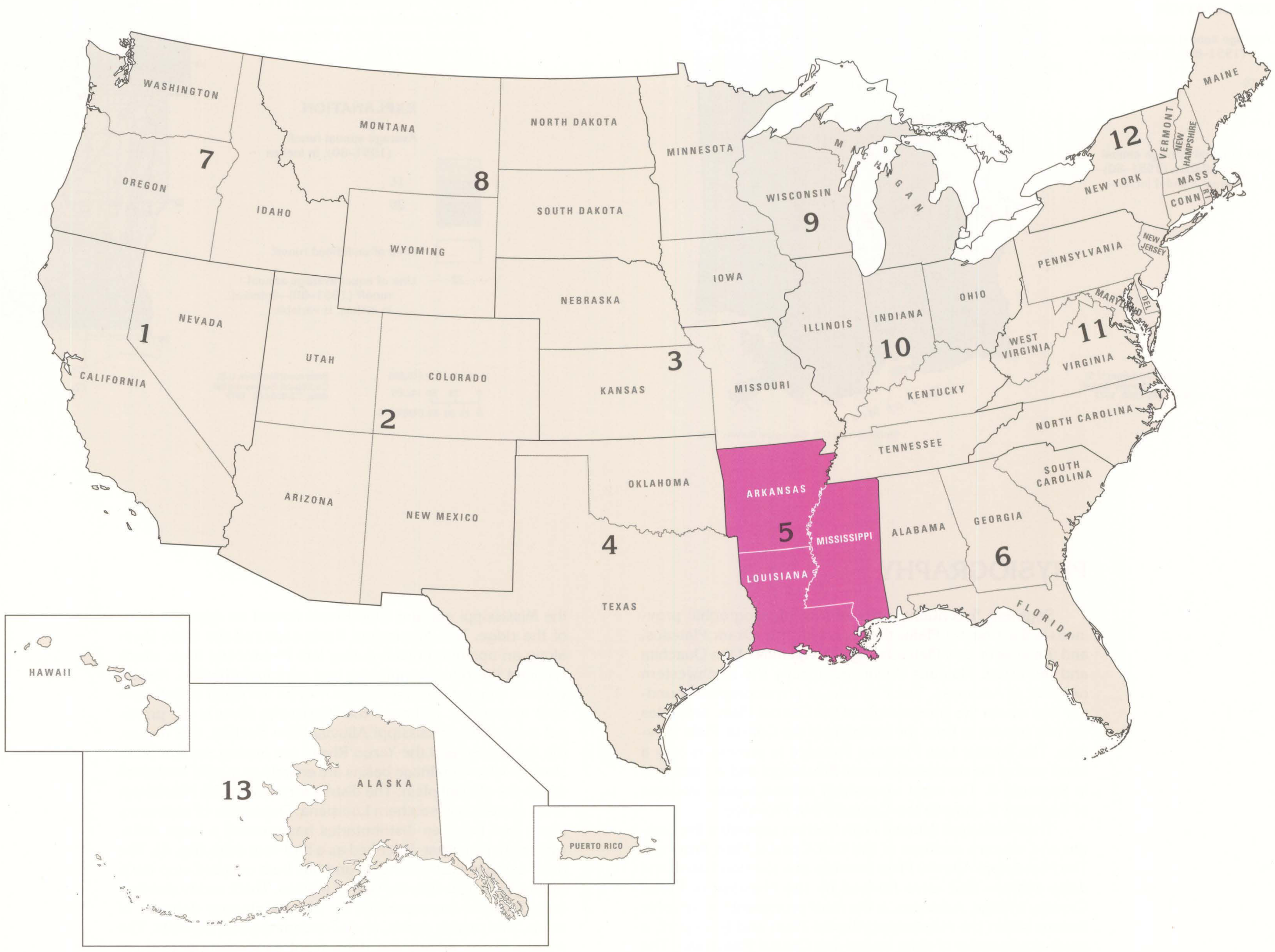
Segment Number	*Chapter content*	*Hydrologic Atlas Chapter*
—	Introductory material and nationwide summaries	730–A
1	California, Nevada	730–B
2	Arizona, Colorado, New Mexico, Utah	730–C
3	Kansas, Missouri, Nebraska	730–D
4	Oklahoma, Texas	730–E
5	Arkansas, Louisiana, Mississippi	730–F
6	Alabama, Florida, Georgia, South Carolina	730–G
7	Idaho, Oregon, Washington	730–H
8	Montana, North Dakota, South Dakota, Wyoming	730–I
9	Iowa, Michigan, Minnesota, Wisconsin	730–J
10	Illinois, Indiana, Kentucky, Ohio, Tennessee	730–K
11	Delaware, Maryland, New Jersey, North Carolina, Pennsylvania, Virginia, West Virginia	730–L
12	Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, Vermont	730–M
13	Alaska, Hawaii, Puerto Rico	730–N

GROUND WATER ATLAS OF THE UNITED STATES

SEGMENT 5

ARKANSAS, LOUISIANA, MISSISSIPPI

By R.A. Renken



CONTENTS

Cartographic design and production by Bruce R. Droster, Wendy A. Zareczny, and Gary D Latzke

INTRODUCTION

The States of Arkansas, Louisiana, and Mississippi, which are located adjacent to each other and north of the Gulf of Mexico, compose Segment 5 of this Atlas. The three-State area encompasses an area of nearly 149,000 square miles. These States are drained by numerous rivers and streams, such as the Atchafalaya, the Teche, the Vermilion, the Calcasieu, the Mermentau, the Sabine, the Tombigbee, the Pascagoula, the Wolf, and the Pearl Rivers, that drain directly to the Gulf of Mexico. The Yazoo, the Big Black, the Arkansas, the St. Francis, the Red, and the White Rivers are tributaries of the Mississippi River, which is the largest of the rivers that drain the three States. Although surface water is the largest source of freshwater to public supply, domestic and commercial, industrial, mining, thermoelectric power and agricultural users, ground water also is important and accounts for 38 percent of total water use in Arkansas, Louisiana, and Mississippi.

Precipitation is the ultimate source of water that recharges the ma-jor aquifers in Segment 5. Average annual rainfall (1951–80) amounts range from about 40 to about 68 inches (**fig. 1**). Temporal (seasonal) and spatial variations in precipitation are evident in the three-State area.

Average annual rainfall is greatest (60 inches per year or more) in southern Louisiana and southern Mississippi and diminishes in Arkansas and in northwestern Louisiana. Precipitation is greatest during January and May in Arkansas. May to September represent the wettest months in southeastern Louisiana and southern Mississippi. March and April are the wettest months in northern Mississippi. Average annual (1951–80) runoff ranges from less than 12 inches in western Louisiana and northwestern Arkansas to more than 20 inches in southern and northern Mississippi and in central and western Arkansas (**fig. 2**). Comparison of precipitation and runoff maps shows that less than one-half of the annual precipitation leaves the area as stream runoff. Much of the water that does not exit Segment 5 as runoff is returned to the atmosphere by evapotranspiration, which is the combination of transpiration by vegetation and evaporation from marshes, swamps, lakes and streams. A small amount of water recharges aquifers that are either exposed or buried to shallow depths, and an even smaller amount percolates downward and enters the deep flow system.

Regional summary

Figure 1. *Average annual precipitation (1951–80) ranges from about 40 to 68 inches.*

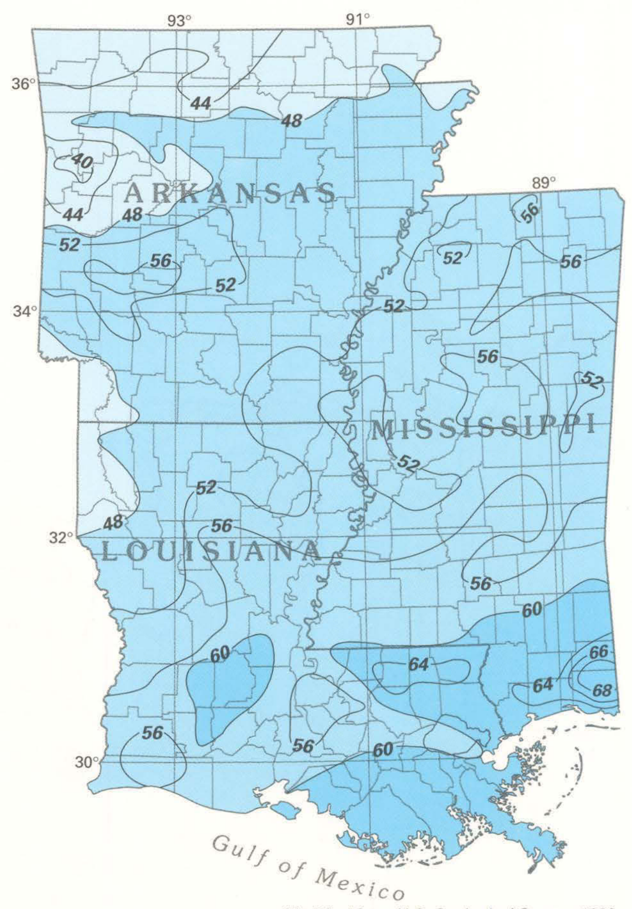
EXPLANATION

Average annual precipitation (1951–80), in inches

48

60

—52— **Line of equal average annual precipitation (1951–80)**—Interval 2 and 4 inches



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Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Modified from U.S. Geological Survey, 1986

Figure 2. *Average annual runoff (1951–80) reflects the similar distribution of average annual precipitation in that greater precipitation causes greater runoff. Runoff in southern Louisiana cannot be estimated owing to low stream gradients and extensive wetland areas that are influenced by wind and tide.*

EXPLANATION

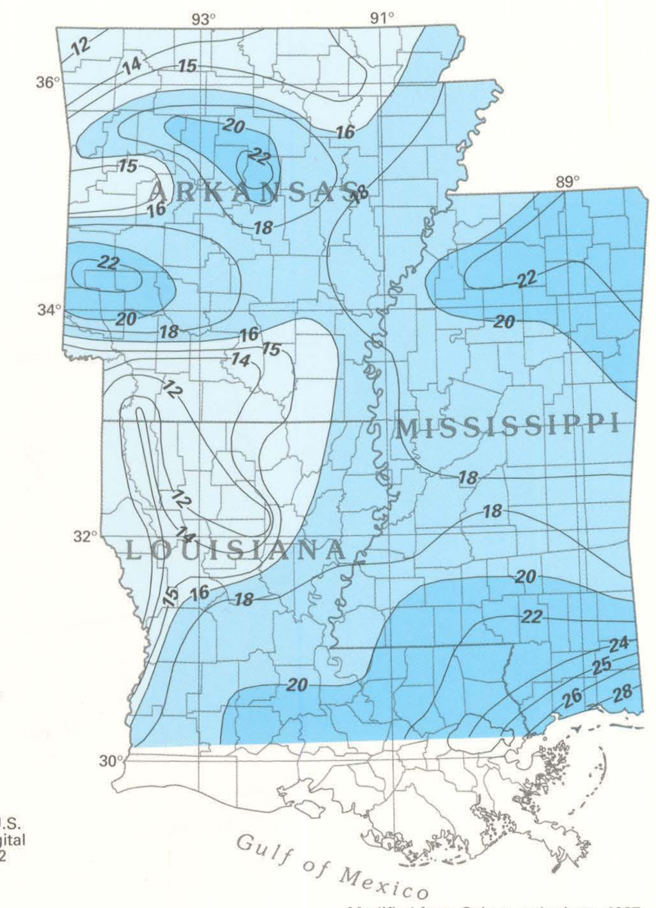
Average annual runoff (1951–80), in inches

16

20

Area of undefined runoff

—22— **Line of equal average annual runoff (1951–80)**—Interval, in inches, is variable



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Modified from Gebert and others, 1987

PHYSIOGRAPHY

Segment 5 contains parts of four physiographic provinces—the Coastal Plain, the Ouachita, the Ozark Plateaus, and the Interior Low Plateaus (**fig. 3**). Uplands of the Ouachita and the Ozark Plateaus Provinces occupy the northwestern one-half of Arkansas. The Fall Line, a physiographic boundary that marks the inner margin of the Coastal Plain, separates the two provinces from the lowlands of the Coastal Plain Province. The Interior Low Plateaus Province is present in only a small part of the northeasternmost Mississippi and is discussed in Segment 6. The most extensively utilized aquifer systems of Segment 5 underlie the Coastal Plain Province.

The Mississippi Alluvial Plain Section separates the eastern and western sections of the Gulf Coastal Plain Province. The Mississippi Alluvial Plain consists of a low flood plain and delta system that were formed by the Mississippi River. Crowley's Ridge, Arkansas, is the most prominent topographic feature within the Mississippi Alluvial Plain and is, in part, a north–south outlier of older, underlying Coastal Plain rocks. The southern portion of the ridge is covered with loess that is thought to have been deposited at the same time as the river terraces. The ridge cuts the northern part of the alluvial plain in half and is thought by some workers to have formed when the Mississippi and the Ohio Rivers flowed on opposite sides of the ridge. The Mississippi River captured the Ohio River along an upstream reach during late Pleistocene time, which reduced the river complex to one principal channel. Recent workers suggest Crowley's Ridge may be the result of Holocene fault movement. Although the Mississippi River is the principal river of the Mississippi Alluvial Plain Section, the Tensas, the Sunflower, and the Yazoo Rivers are among several other streams whose drainage basins are entirely or mostly contained within the alluvial plain. The distributary part of the Mississippi River system is in southern Louisiana. Deposition of sediments along and between distributaries has created a large delta, whose shape is best described as a bird-foot delta (**fig. 4**). The delta extends east-southeast and has built outward atop thick marine clay beds into the Gulf of Mexico. Thick sandy distributary channels are separated by interdistributary deposits of muds, thin muddy sands, and abundant organic deposits. The weight of the advancing delta front sand compacts thick underlying clays and forms depressions in which prograding channel sand or bar-finger sand facies are protected from erosion. As progradation continues, distributary channels extended further seaward, and the delta enlarges.

Figure 3. *Segment 5 lies within parts of four physiographic provinces. The low-lying, flat Coastal Plain Province is the most areally extensive physiographic province and incorporates the entire State of Louisiana, most of Mississippi, and a large part of Arkansas.*

EXPLANATION

Physiographic province or section

Coastal Plain Province
- East Gulf Coastal Plain Section
- Mississippi Alluvial Plain Section
- West Gulf Coastal Plain Section

Ozark Plateaus Province
- Springfield Plateau Section
- Salem Plateau Section
- Boston Mountains Section

Ouachita Province
- Arkansas Valley Section
- Ouachita Mountains Section

Interior Low Plateaus Province

Inner margin of Coastal Plain

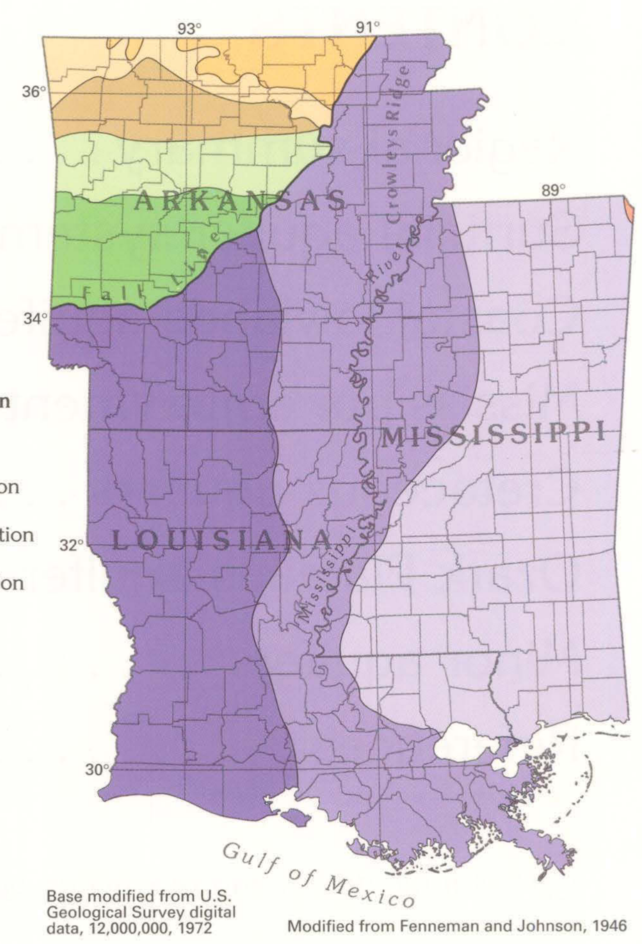

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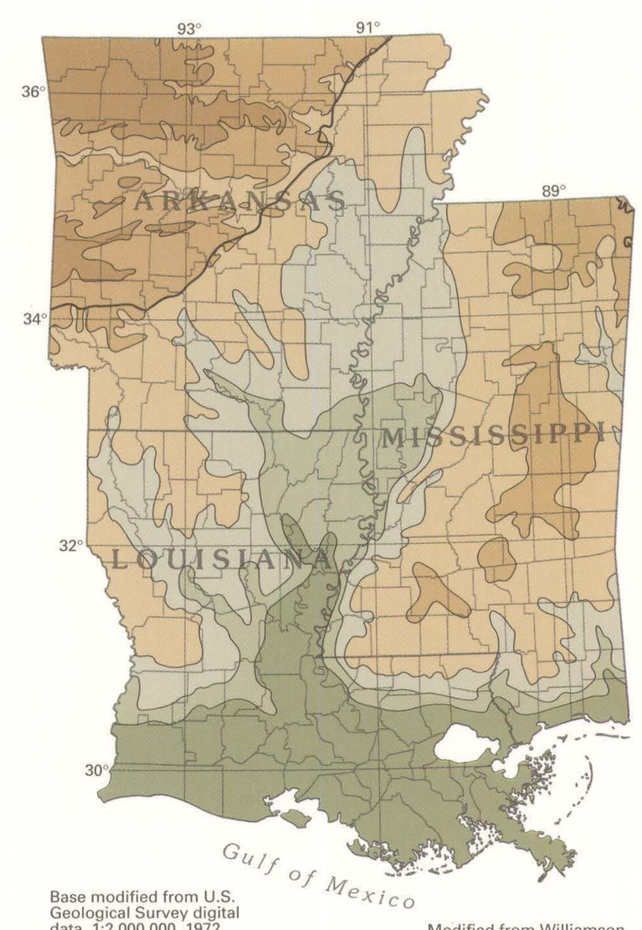
Figure 5. *Land-surface altitudes range from sea level to 200 feet above sea level in a large part of the central and southern Coastal Plain. Inland, Coastal Plain land-surface altitudes are higher on the eastern side of the Mississippi Embayment than on the western side. The highest land surface altitudes are greater than 2,000 feet above sea level in small areas in the Ouachita and the Ozark Provinces of Arkansas.*

EXPLANATION

Land-surface altitude, in feet above sea level

50
100
200
400
1,000

Inner margin of Coastal Plain



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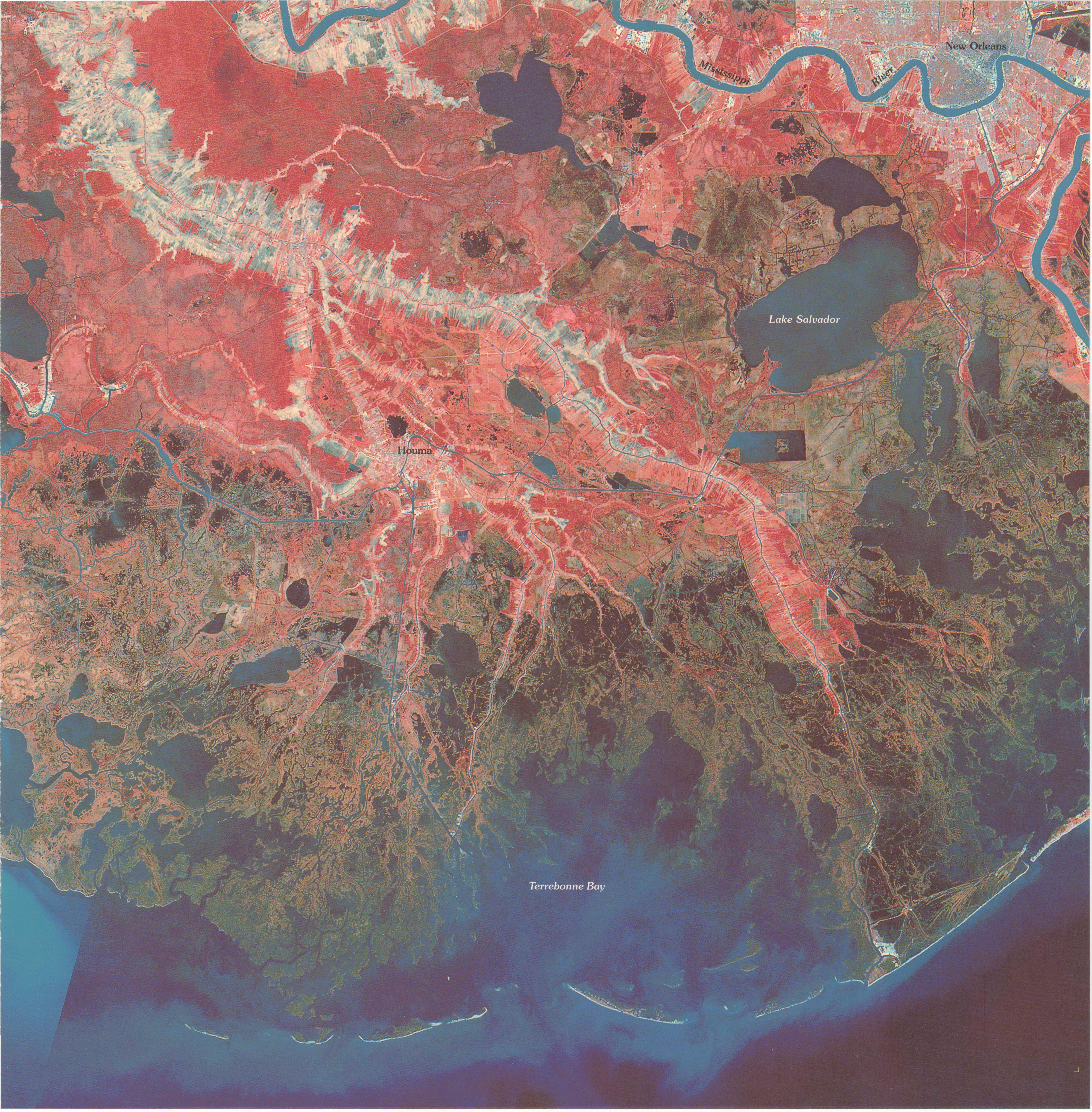

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From New Orleans Satellite image map, U.S. Geological Survey, 1986

Figure 4. *This National Aeronautics and Space Administration (NASA) LANDSAT satellite false-color composite image shows the present-day (1986) delta of the Mississippi River. The Mississippi River delta is called a bird-foot delta because the shape resembles the splayed toes of a bird's foot. Coarse-grained delta sediments that consist of bar-finger sand are deposited in the channels of passes, or distributaries, and interdistributary clay is deposited in swampy areas between the distributaries.*

The altitude of most of the inland part of the Coastal Plain Province ranges from 300 to 600 feet above sea level in Mississippi and from 200 to 400 feet above sea level in Arkansas and Louisiana (**fig. 5**). A 10- to 150-mile wide coastal zone immediately adjacent to the Gulf of Mexico lies no more than 50 feet above sea level. The eastern part of the Gulf Coastal Plain Province (**fig. 3**) is characterized by a coastal plain of low hills, low cuesta ridges, and gentle lowlands. Fine-grained strata of clay, chalk, and mudstone underlie the low-lying areas; coarse sand and gravel underlie low ridges and hills. The western part of the province is a southward-facing plain of low, rolling, slightly hilly terrain that becomes a flat plain to the south. A broad marshy zone is near the coast.

The Ouachita Province in Arkansas is north of the West Gulf Coastal Plain Section and can be separated into the Ouachita Mountains Section to the south and Arkansas Valley Section to the north (**fig. 3**). The Ouachita Mountains Section is distinguished by valley and ridge topography. The ridges form straight to zigzag patterns and increase in height westward. Some ridges rise to more than 2,000 feet above sea level. North of the Ouachita Mountains Section, the Arkansas Valley Section forms a low-lying plain with low ridges oriented east to west. Although much of the Arkansas Valley Section generally is only 300 to 600 feet above sea level (**fig. 5**), the altitudes of several ridges range from 1,000 to more than 2,000 feet.

The Ozark Plateaus Province is north of the Ouachita Province and can be separated into the Boston Mountains Section to the south and the Springfield and the Salem Plateaus Sections to the north. The Springfield Plateau lies west and south of the Salem Plateau. The 200-mile long by 35-mile wide Boston Mountains Section is a deeply dissected plateau region that generally ranges from more than 1,900 to more than 2,500 feet above sea level and is characterized by flat-crested ridges that rise from 300 to more than 1,000 feet above V-shaped valleys. The surface of the Western Springfield Plateau, which is the intermediate level plateau, varies from gently rolling prairies to dissected terrain that ranges from 1,000 to 2,000 feet above sea level along its northern and southern margins. Topographic relief within this plateau area ranges from less than 100 feet in the prairie areas to more than 400 feet where streams have incised a north-facing escarpment that borders the Salem Plateau. In some areas of the Springfield Plateau, straight solution valleys intersect one another at 90-degree angles. The Salem Plateau, which is located east and north of the Springfield Plateau, lies at altitudes of 1,000 feet or less above sea level, but its land surface forms an irregular topography and is cut deeply by streams. However, topographic relief between hill crests and valley bottoms usually does not exceed 100 feet.

MAJOR AQUIFERS

Major aquifers in Segment 5 are highly varied in composition, consolidation, and hydraulic character. The majority of Segment 5 aquifers consist of unconsolidated to poorly consolidated Coastal Plain strata of gravel, sand, clay, and minor limestone of Cretaceous to Holocene age. Other Segment 5 aquifers consist of indurated limestone, dolomite, shale, sandstone, chert, and novaculite of Paleozoic age that are either flatlying or gently to highly folded and contorted and that may be faulted and fractured. These aquifers are combined into eight aquifer systems, all of which extend beyond the Segment 5 study area (**fig. 6**). Only small parts of the Texas coastal uplands and the Floridan aquifer systems are in Segment 5; these aquifer systems are discussed in Chapters E and G of this Atlas, respectively.

An aquifer system consists of two or more aquifers that are hydraulically connected. The aquifers may be separated, in places, by confining units, but there is regional hydraulic continuity within the system—the flow systems of the aquifers function similarly, and a change in conditions within one aquifer commonly affects the other aquifer(s). Likewise, confining units that may contain local aquifers, but which function together to retard the vertical movement of water, are called confining systems. The outcrop extent of the principal aquifers, aquifer systems, and a confining system in the Segment 5 study area is shown in **figure 7**.

Figure 6. The aquifer systems, aquifers, and confining systems within Segment 5 extend beyond Arkansas, Louisiana, and Mississippi.

EXPLANATION

- Surficial aquifer system (Mississippi River Valley alluvial aquifer)
- Coastal lowlands aquifer system
- Mississippi embayment aquifer system
- Texas coastal uplands aquifer system
- Southeastern Coastal Plain aquifer system
- Floridan aquifer system
- Edwards–Trinity aquifer system
- Ozark Plateaus aquifer system
- Western Interior Plains confining system
- 5 Atlas segment number and boundary

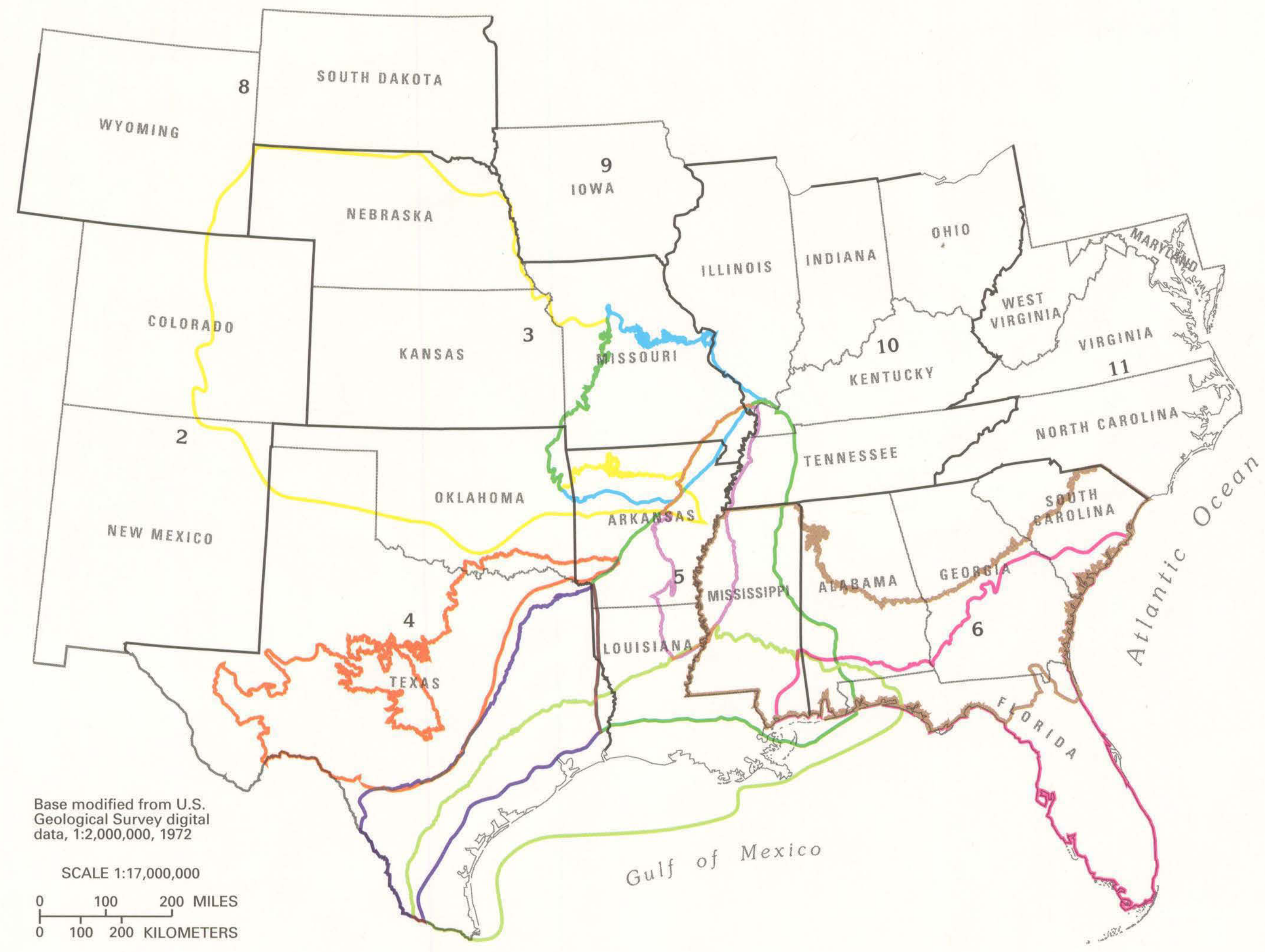
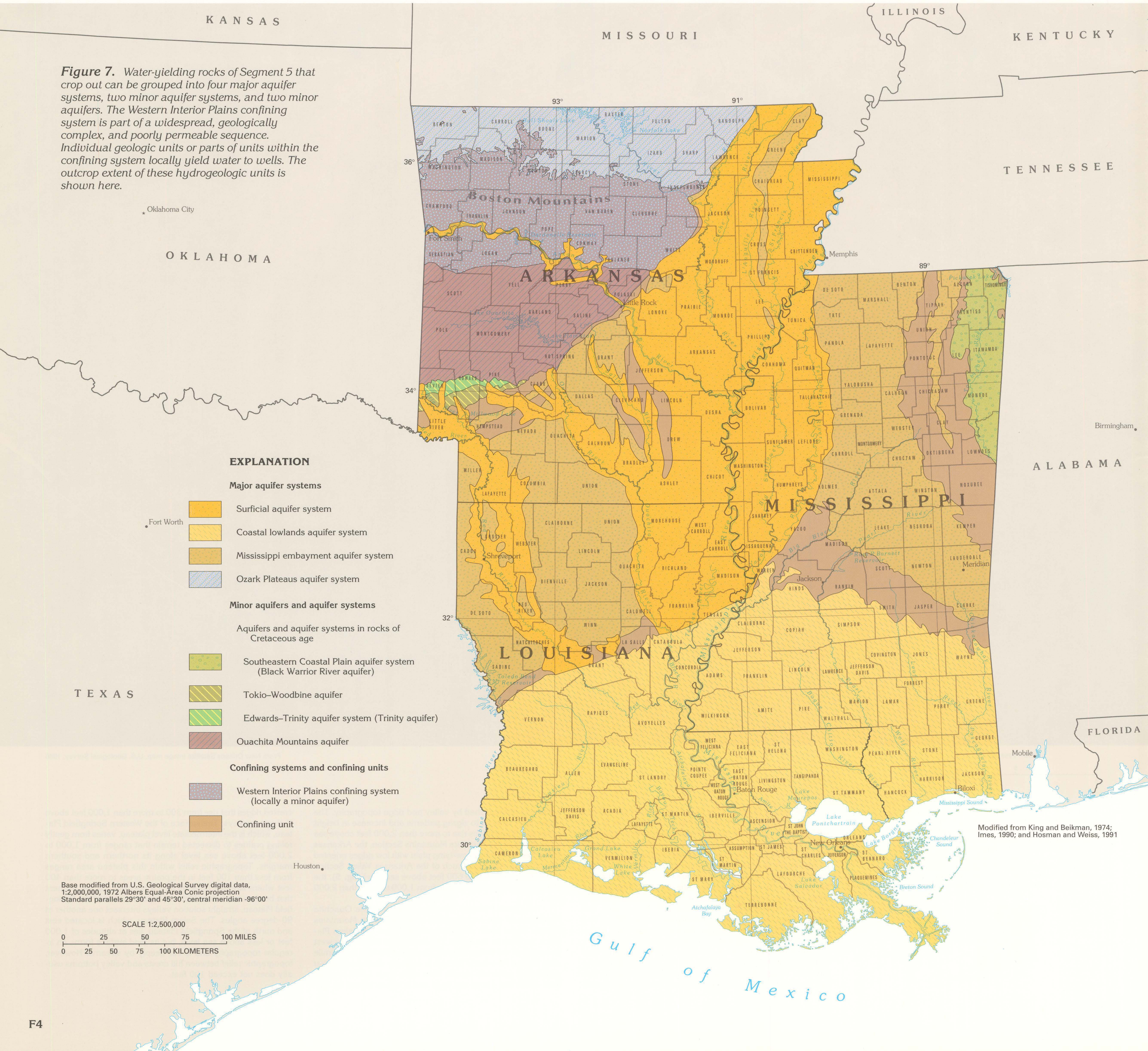


Figure 7. Water-yielding rocks of Segment 5 that crop out can be grouped into four major aquifer systems, two minor aquifer systems, and two minor aquifers. The Western Interior Plains confining system is part of a widespread, geologically complex, and poorly permeable sequence. Individual geologic units or parts of units within the confining system locally yield water to wells. The outcrop extent of these hydrogeologic units is shown here.



EXPLANATION

Major aquifer systems

- Surficial aquifer system
- Coastal lowlands aquifer system
- Mississippi embayment aquifer system
- Ozark Plateaus aquifer system

Minor aquifers and aquifer systems

Aquifers and aquifer systems in rocks of Cretaceous age

- Southeastern Coastal Plain aquifer system (Black Warrior River aquifer)
- Tokio–Woodbine aquifer
- Edwards–Trinity aquifer system (Trinity aquifer)
- Ouachita Mountains aquifer

Confining systems and confining units

- Western Interior Plains confining system (locally a minor aquifer)
- Confining unit

The surficial aquifer system consists of alluvial aquifers and includes one major and three minor aquifers (**fig. 8**). In terms of water use and areal extent, the most important aquifer is the highly productive Mississippi River Valley alluvial aquifer. The minor aquifers include the Arkansas River, the Ouachita–Saline Rivers, and the Red River alluvial aquifers. The Arkansas River alluvial aquifer is not as widespread as the other two aquifers, but locally is an important water source.

Parts of four Coastal Plain aquifer systems, the coastal lowlands (**fig. 9**), the Mississippi embayment (**fig. 10**), the Southeastern Coastal Plain (**fig. 11**), and the Edwards–Trinity, which are within rocks of Cretaceous to Quaternary age, are in the Segment 5 area. Coastal Plain rocks of Cretaceous age make up a locally important aquifer known as the Tokio-Woodbine aquifer. For purposes of this chapter, the Southeastern Coastal Plain and the Edwards–Trinity aquifer systems, and the Tokio–Woodbine aquifer are described in the section entitled, "Cretaceous Aquifers"; only parts of the aquifer systems are present (**fig. 11**). Aquifers and confining units within each of the four Coastal Plain aquifer systems thin landward to a featheredge and thicken with depth as they extend toward the Gulf of Mexico into the deep subsurface. Most Segment 5 Coastal Plain aquifers contain freshwater downgradient well beyond the extent of their outcrop. All of the Coastal Plain aquifers and aquifer systems are comprised predominantly of poorly consolidated to unconsolidated clastic sedimentary rocks. The distribution and pattern of permeability within the different Coastal Plain aquifer systems are a function of lithology and primary porosity. In general, the most permeable Coastal Plain aquifers consist of sand and some gravel and are separated by silt, clay, marl, or chalk confining units. As these aquifers extend downdip, most grade to less permeable facies, such as clay or marl, that are part of adjoining confining units. A geopressured zone truncates the gulfward limit of aquifers within the coastal lowlands aquifer system.

Flat-lying to southward-dipping limestone, dolomite, and sandstone comprise the principal aquifers of the Ozark Plateaus aquifer system (**fig. 12**). Permeability within this aquifer system is a function of regional and local tectonics, diagenesis, geochemistry, hydrology, and weathering.

The Western Interior Plains confining system underlies the rugged Boston Mountains and the rolling lowlands, synclinal mountains, and cuestas that characterize the northern flank of the Arkansas Valley. Although this confining system is poorly permeable, it contains sandstone, minor limestone, and highly jointed and fractured siltstone and shale that function as local aquifers. Geologic structure is a principal factor that controls the occurrence and movement of ground water within the unweathered part of the confining system. Another permeability control is associated with local faults, joints, and fractures. Ground-water movement within this system of secondary permeability depends on the intensity, aperture, orientation, connectivity, and filling of fracture systems.

Limited quantities of ground water can be obtained from sandstone, siltstone, shale, and chert-novaculite rocks of the Ouachita Mountains Section and the southern part of the Arkansas Valley Section. Primary porosity within the Paleozoic rocks of Segment 5 was destroyed by compaction during burial and structural deformation during uplift. Small amounts of ground water can be obtained from wells completed in rocks that contain joints and fractures or bedding planes.

Figure 8. *The surficial aquifer system is the uppermost aquifer system in Segment 5 and can be divided into the Mississippi River Valley, the Arkansas River, the Ouachita–Saline Rivers, and the Red River alluvial aquifers. The aquifers consist of gravel, sand, silt, and clay and are capable of yielding large quantities of water to wells.*

Figure 9. *The coastal lowlands aquifer system consists of permeable sedimentary rocks of late Oligocene to Holocene age that range from poorly consolidated to unconsolidated.*

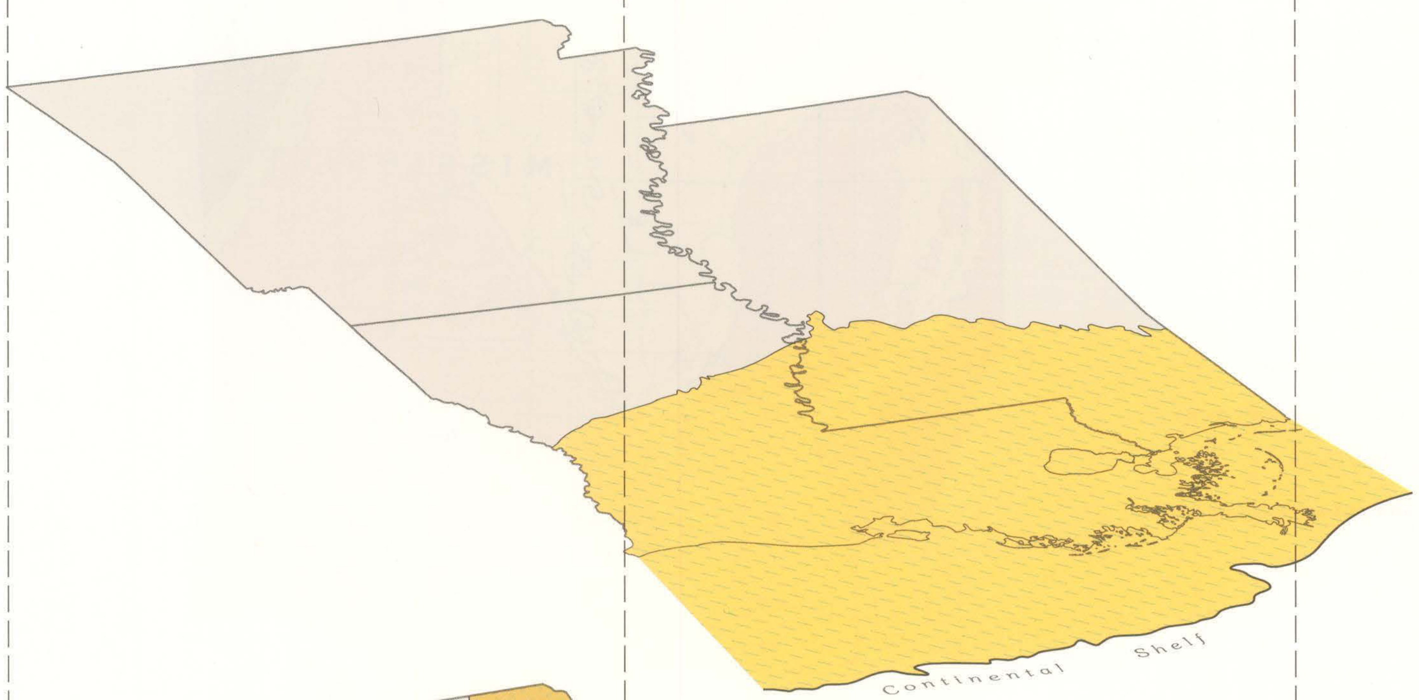


Figure 10. *The Mississippi embayment aquifer system, which is in poorly consolidated sedimentary rocks of Late Cretaceous to middle Eocene age, underlies the coastal lowlands aquifer system; the two systems are separated by a thick, effective confining unit. The Mississippi embayment aquifer system is the most widespread aquifer system in the Coastal Plain.*

Figure 11. *Cretaceous aquifers (Tokio–Woodbine) and aquifer systems (Southeastern Coastal Plain and Edwards–Trinity) consist mostly of poorly consolidated sedimentary rocks that are exposed at the northeastern and southwestern inner margins of the Coastal Plain. These aquifers and aquifer systems are overlain by a thick confining unit and extend under the Mississippi embayment aquifer system for short distances.*

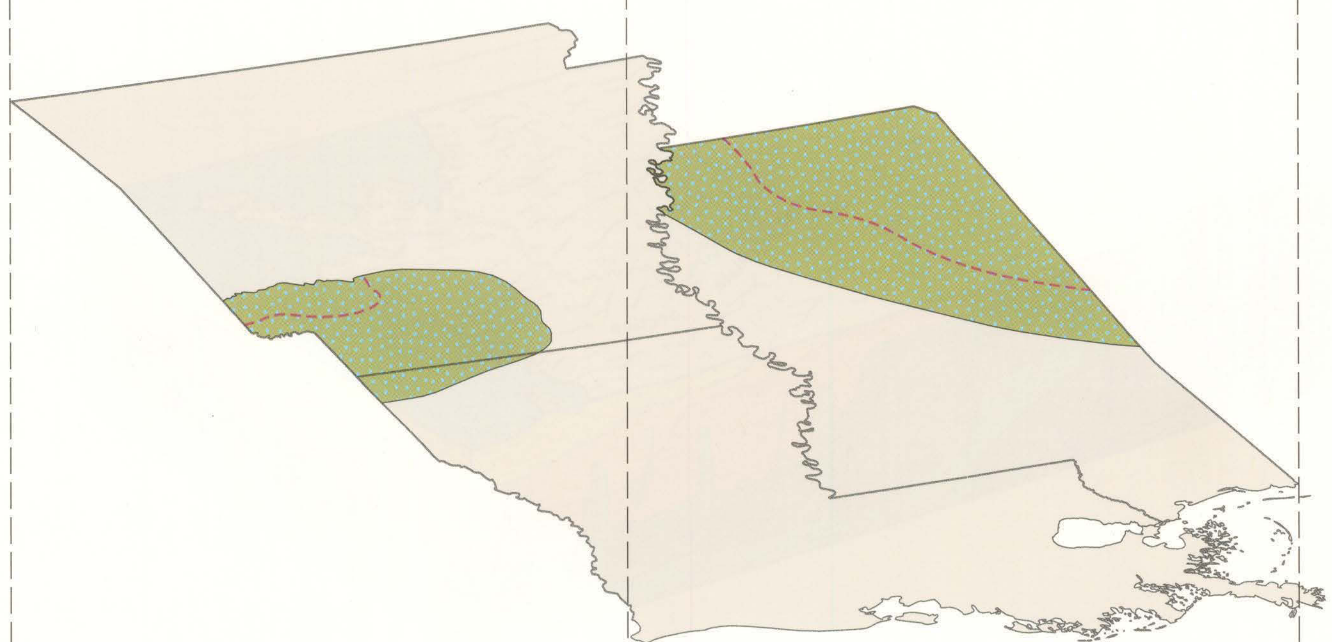
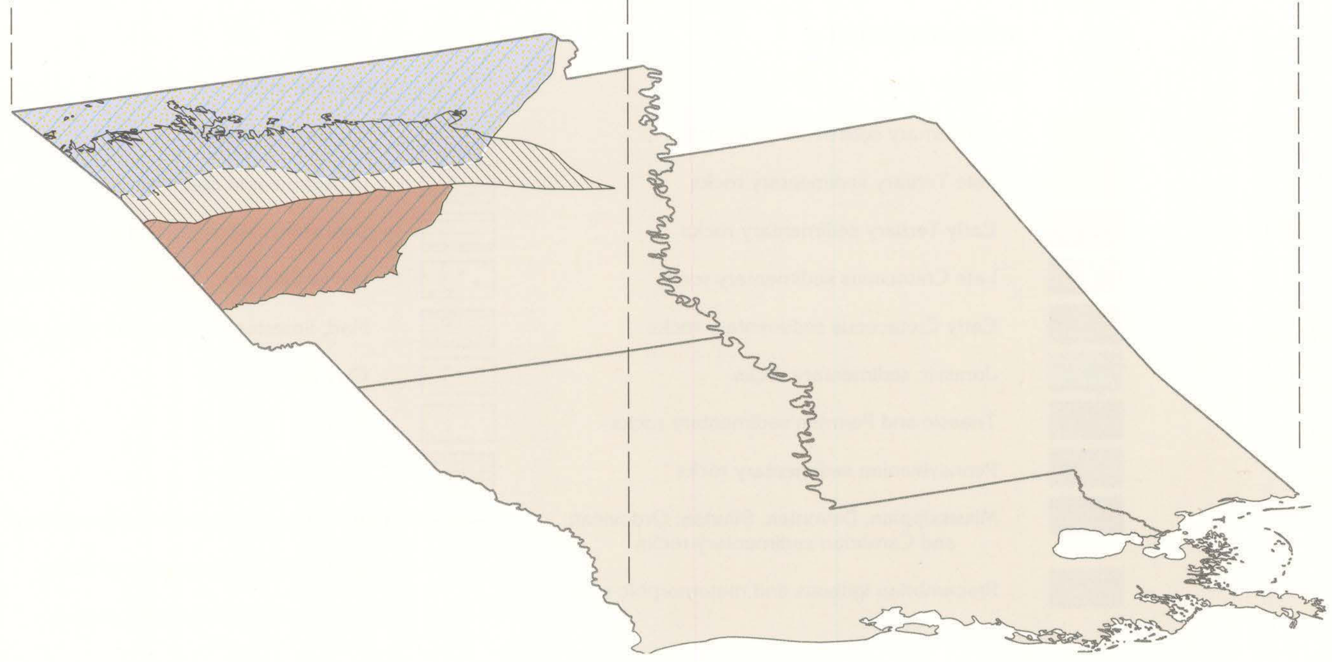


Figure 12. *The Ozark Plateaus aquifer system consists of limestone, dolomite, and sandstone. The Western Interior Plains confining system consists of shale, siltstone, sandstone, and minor limestone that may yield water locally, but regionally function as a confining unit. The Ouachita Mountains aquifer consists mostly of sandstone, shale, and chert-novaculite. Aquifers within these hydrologic units are well-lithified, and permeability is a function of tectonics, diagenesis, geochemistry, hydrology, and weathering.*



GEOLOGY

Segment 5 is underlain by sedimentary rocks that range from unconsolidated to poorly consolidated clastic rocks in the Coastal Plain Province and alluvial areas to well-consolidated, flat-lying to southward-dipping fractured carbonate and clastic rocks in the Ozark Province to fractured, faulted, and folded shale, sandstone, limestone and chert-novaculite rocks in the Ouachita Province. Coastal Plain Province rocks are Mesozoic and Cenozoic (Jurassic to Quaternary) in age; rocks that underlie the Ozark and Ouachita Provinces are Paleozoic (Cambrian to Pennsylvanian) in age (**figs. 13, 14**).

The geologic and hydrogeologic nomenclature used in this report differs from State to State because of independent geologic interpretations and varied distribution and lithology of rock units. A fairly consistent nomenclature, however, can be derived from the most commonly used rock names. Therefore, the nomenclature used in this report is basically a synthesis of that used by the U.S. Geological Survey, the Arkansas Geological Commission, the Louisiana Geological Survey, and the Mississippi State Geological Survey. Individual sources for nomenclature are listed with each correlation chart prepared for this report.

Rocks of Ordovician to Pennsylvanian age underlie the outcrop areas of the Ozark Plateaus Province, and are, in turn, underlain by dolomite and sandstone beds of Cambrian age. The rocks of Cambrian age form the basal part of the Paleozoic sedimentary sequence, but are not exposed in northern Arkansas. The Ozark Uplift is a structural high area that affects the attitude of rocks in northern Arkansas. In general, the rocks in northern Arkansas crop out as annular bands around the center of the Ozark Uplift, which is located in southern Missouri (**fig. 15**). Rocks of Ordovician to Mississippian age in the Ozark Plateaus Province that dip gently southward from northern Arkansas are dominated by shallow-water carbonate-shale sequences and contain some prograding deltaic sandstones, all of which were deposited on a cratonic shelf of Precambrian age. Sedimentary rocks that underlie the Boston Mountains Section consist mostly of Pennsylvanian sandstone and shale deposited in deltaic, open marine, coastal, and swamp environments.

Rocks that underlie the Ouachita Province consist mostly of a thick sequence of shale and sandstone that was deposited during Cambrian to early Pennsylvanian time within an elongate, subsiding Ouachita Trough. This trough formed by rifting along a late Precambrian–early Paleozoic continental margin. Down-to-the-south normal faulting and subsidence during Mississippian to Pennsylvanian time formed the shallower Arkoma Basin that lies north of the Ouachita Trough. Clastic, deep-water sediments were deposited within the Ouachita Trough and prograding deltaic, clastic shallow-marine, and some deep-marine deposits infilled the Arkoma Basin. Compressional tectonic forces closed the trough during late Pennsylvanian time and helped form the Ouachita Anticlinorium. The Ouachita Anticlinorium is an intensely folded structure of plunging synclines, anticlines, and north- and south-directed thrust faults; shale, chert, sandstone, conglomerate, novaculite, and volcanic tuff of this folded structure have been subject to widespread low-grade and low-temperature metamorphism. To the north, rocks of Pennsylvanian age within the Arkoma Basin were gently folded into an alternating series of synclines and anticlines in which anticlinal axes are separated by a distance from 5 to 8 miles. Normal faults are common in areas north of the Arkansas River, and thrust faults are present south of the river.

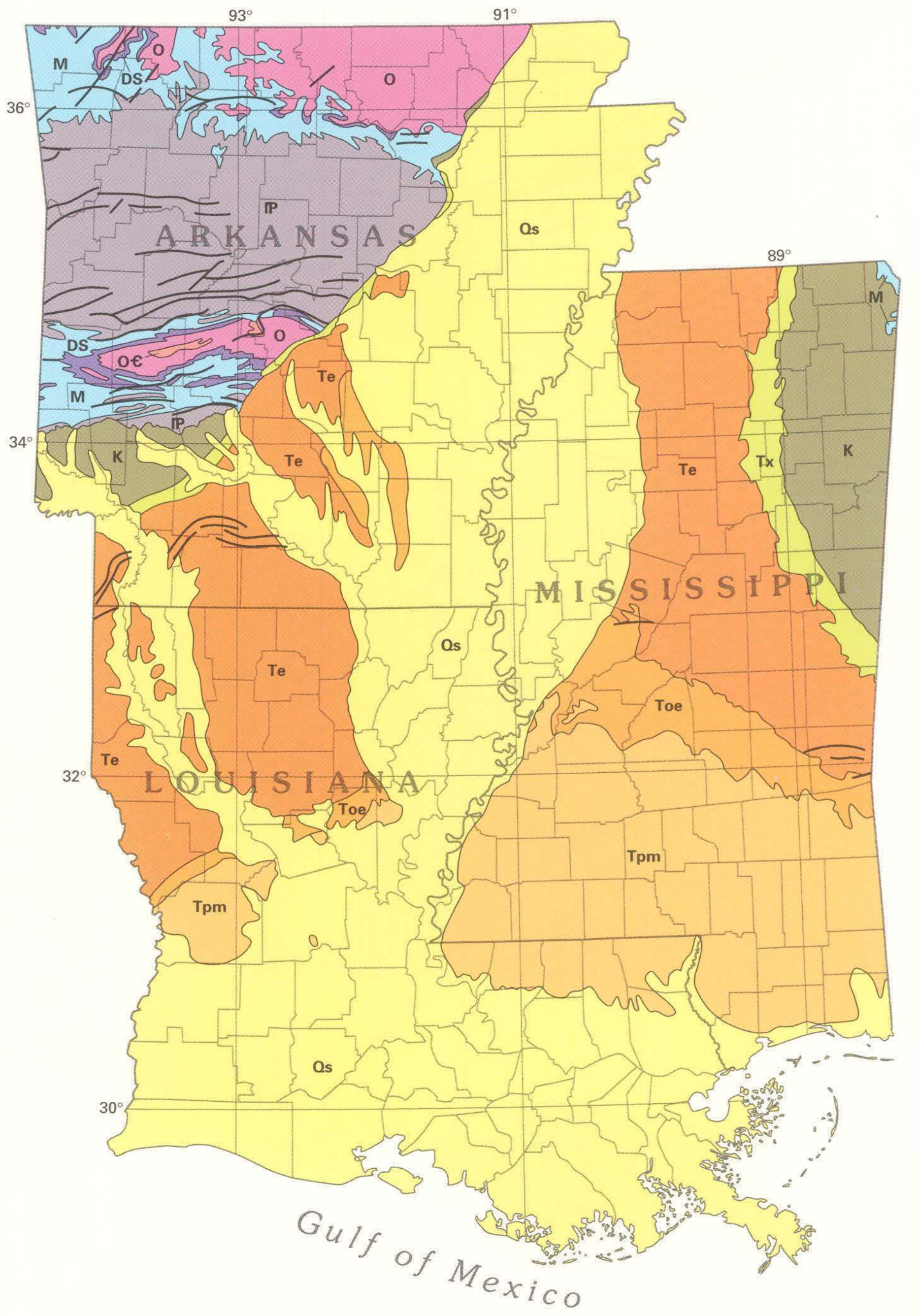
Postorogenic rocks of Permian and Triassic age rest unconformably on the eroded Ouachita folded rocks but lie buried beneath Coastal Plain deposits in northern Louisiana. These strata largely consist of continental red-bed sedimentary deposits derived from the erosion of the Ouachita Mountains.

The oldest Coastal Plain rocks of Segment 5 are Jurassic in age and are deeply buried in the subsurface. A thick and extensive salt layer of Jurassic age composes the lower part of the Coastal Plain sequence in the Gulf Coast Basin (Stage I, **fig. 16**). Collapse and the gulfward diapiric flow of salt occurred during crustal downwarping and infilling of the Gulf Coast Basin (Stage II, **fig. 16**). Coastal Plain sedimentary rocks of Cretaceous age were deposited across a broad shelf. Major Cretaceous depositional facies shifted landward or gulfward during transgressive or regressive cycles that were controlled by eustatic sea-level change and differential rates of subsidence. Rocks of early Tertiary age and younger were deposited during progradational depositional cycles of alluvial and deltaic infilling within the Gulf Coast Basin (Stages III, IV, **fig. 16**).

Salt-dome basins are in southern Mississippi and central and southern Louisiana (**fig. 15**). Although few occur near the land surface, salt domes penetrate most or all of the Tertiary rocks at isolated locations. The domes are usually only 1 to 3 miles in diameter, and their effect on ground-water flow and water quality is localized.

The Mississippi Embayment is a large reentrant that forms a southward-plunging syncline, which greatly influences the outcrop pattern of Coastal Plain rocks in Segment 5. The embayment axis is closely aligned with the present-day (1997) location of the Mississippi River (**fig. 15**). Except where they are covered by Holocene alluvial deposits of the ancestral Mississippi River, Coastal Plain sedimentary rocks of Cretaceous to early Tertiary age crop out mostly in offlapping bands that parallel the perimeter of the embayment and dip gently toward its axis. Younger outcropping Coastal Plain sediments of late Eocene to Pliocene age do not extend as far north into the embayment as do older strata, but crop out as a belt that parallels the coastline, dipping gently southward into the Gulf Coast geosynclinal basin. Late Quaternary alluvial and deltaic deposits of the Mississippi River and its tributaries form a wide band that extends southward from the northern part of the embayment into the Gulf of Mexico. From a landward, outcropping featheredge, the entire Coastal Plain sequence thickens greatly toward the axis of the Mississippi Embayment and the Gulf Coast Geosyncline. The general gulfward thickening is interrupted by uplifts, domes, anticlines, basins, synclines, and faults of subregional size, some of which are shown in **figure 15**.

Figure 13. A generalized geologic map shows the extent of major rock units that crop out within Segment 5.



EXPLANATION

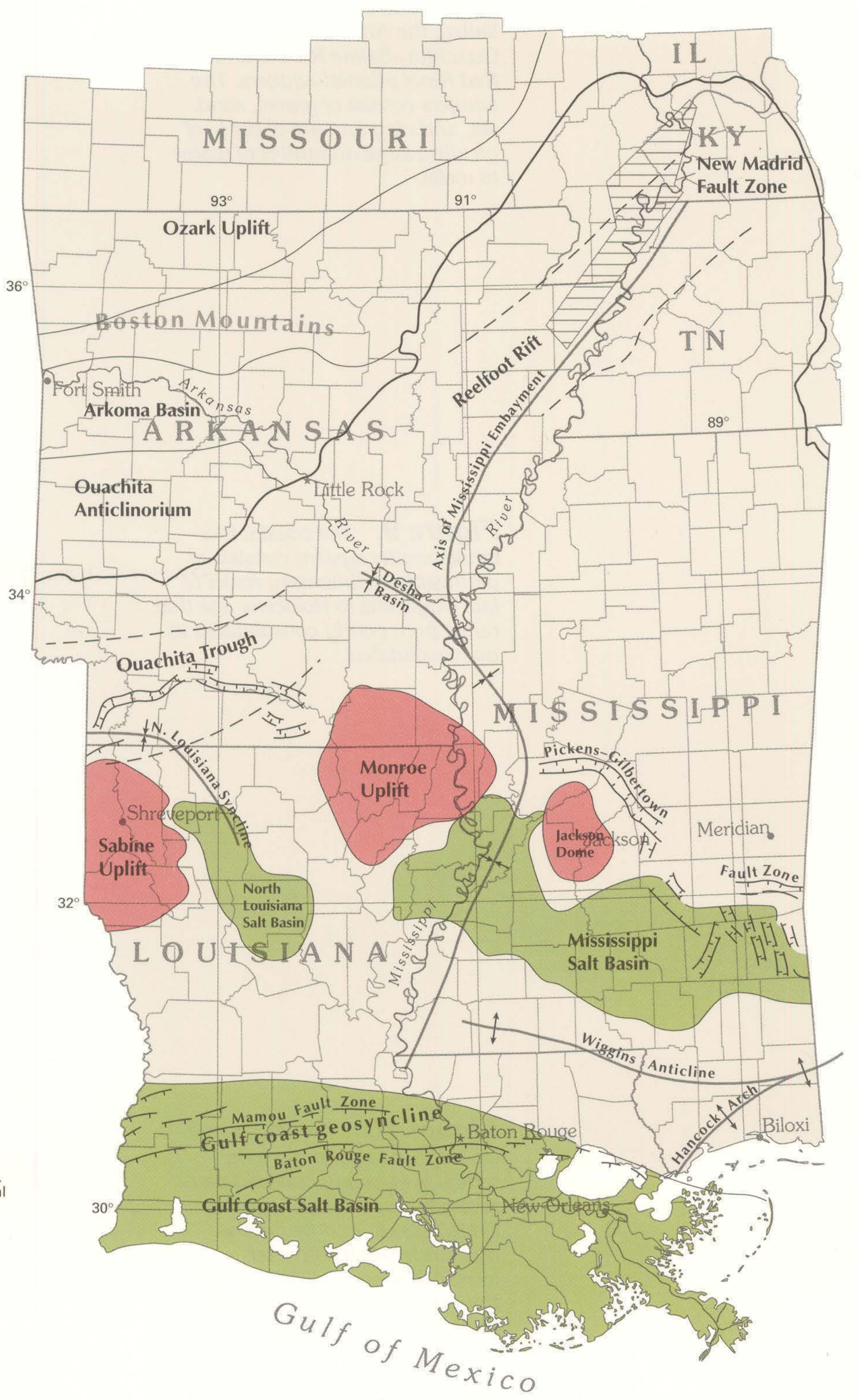
- Qs — Quaternary sedimentary deposits
- Tpm — Pliocene and Miocene sedimentary rocks
- Toe — Oligocene and upper Eocene sedimentary rocks
- Te — Middle to lower Eocene sedimentary rocks
- Tx — Paleocene sedimentary rocks
- K — Cretaceous sedimentary rocks
- IP — Pennsylvanian sedimentary rocks
- M — Mississippian sedimentary rocks
- DS — Devonian and Silurian sedimentary rocks
- O — Ordovician sedimentary rocks
- O€ — Ordovician and Cambrian sedimentary rocks
- Fault

SCALE 1:5,000,000
0 25 50 MILES
0 25 50 KILOMETERS

Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Modified from King and Beikman, 1974, and Haley and others, 1976

Figure 15. Major tectonic features influence the attitude of rocks that form the aquifers and aquifer systems of Arkansas, Louisiana, and Mississippi.



EXPLANATION

- Positive tectonic feature
- Salt basin
- Syncline
- Anticline
- Fault—Hachures on apparent downthrown side
- Inner Margin of Coastal Plain

SCALE 1:5,000,000
0 25 50 MILES
0 25 50 KILOMETERS

Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Modified from Hosman and Weiss, 1991

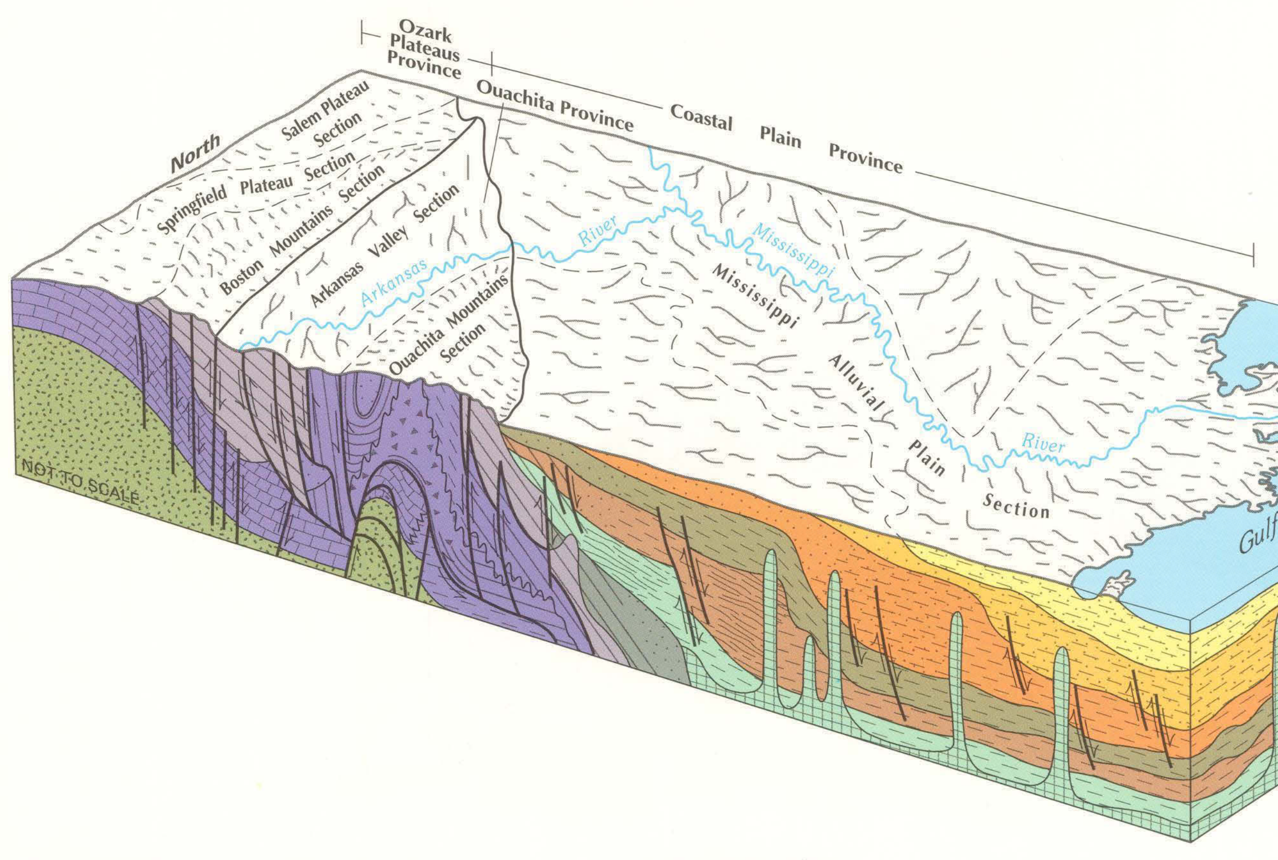


Figure 14. Coastal Plain rocks dip gently toward the Gulf of Mexico geosyncline or toward the center of the Mississippi Embayment. Growth or listric faults, which formed during and after these rocks were deposited, displace some strata. Diapiric flowage of salt strata, which is caused by the salt being overloaded by thick accumulations of younger sedimentary strata, has resulted in the formation of intrusive salt domes. Flat-lying carbonate rocks dominate much of the Ozark Plateaus Province in northern Arkansas, whereas intensely folded and faulted shale, sandstone, and chert-novaculite underlie the Ouachita Province.

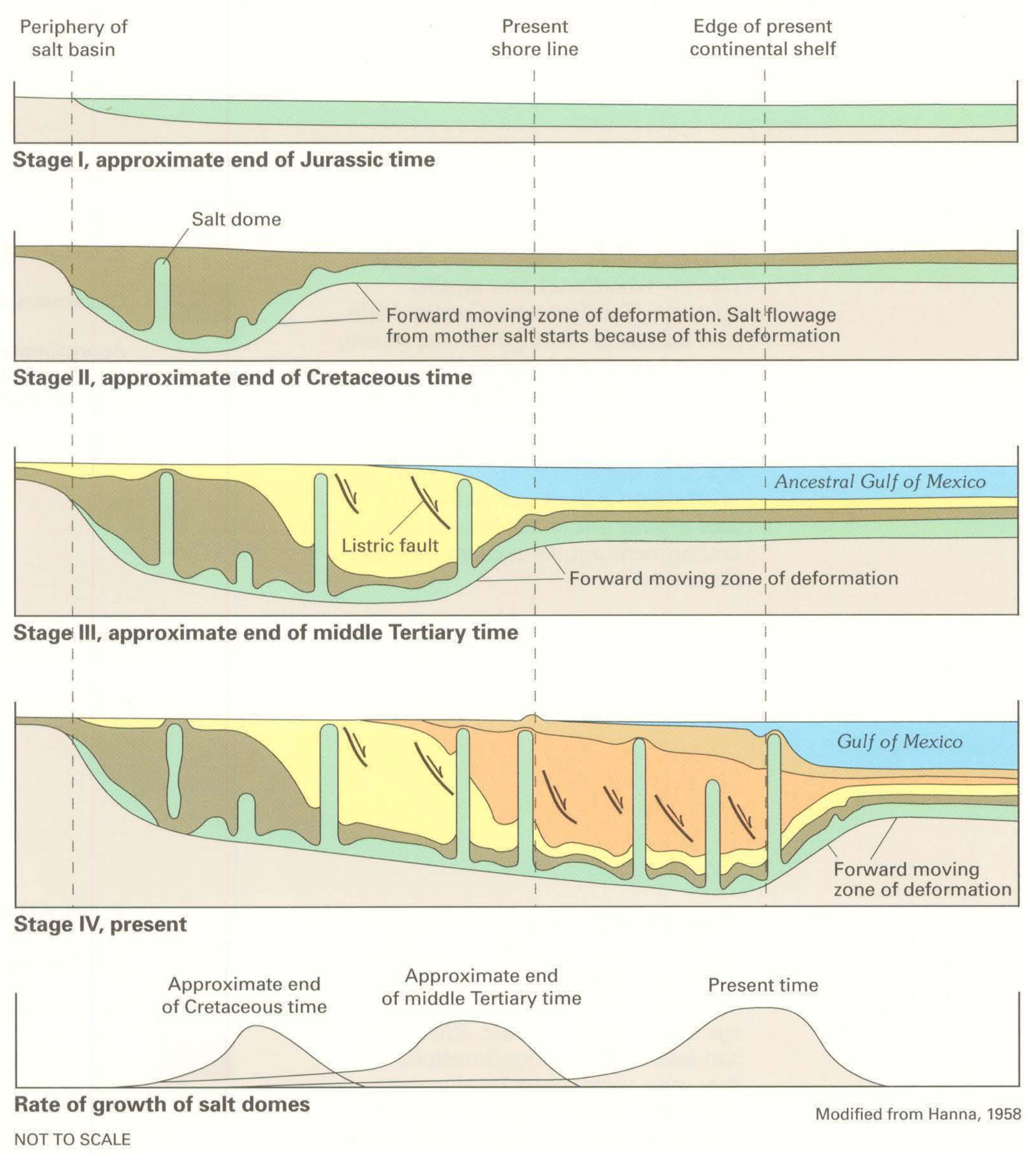
EXPLANATION

Geologic units

- Quaternary sedimentary deposits
- Late Tertiary sedimentary rocks
- Early Tertiary sedimentary rocks
- Late Cretaceous sedimentary rocks
- Early Cretaceous sedimentary rocks
- Jurassic sedimentary rocks
- Triassic and Permian sedimentary rocks
- Pennsylvanian sedimentary rocks
- Mississippian, Devonian, Silurian, Ordovician, and Cambrian sedimentary rocks
- Precambrian igneous and metamorphic rocks

Lithologic units

- Crystalline rocks
- Limestone and dolomite
- Sandstone, siltstone, and shale
- Novaculitic and cherty sandstone and shale
- Marl, limestone, sandstone, limey clay and shale
- Clay and/or shale
- Sand
- Evaporite (salt)
- Fault—Arrows show relative movement
- Boundary of physiographic province
- Boundary of physiographic section



Modified from Hanna, 1958

Figure 16. At least three cycles of salt movement and infilling characterize the Gulf Coast geosynclines. This idealized figure shows one Cretaceous and two Tertiary cycles. Salt domes grow at a more rapid rate as the thickness of loading sediments increases.

EXPLANATION

- Holocene and Pleistocene sediments
- Upper Tertiary sediments
- Lower Tertiary sediments
- Cretaceous sediments
- Jurrasic salt

FRESH GROUND-WATER WITHDRAWALS

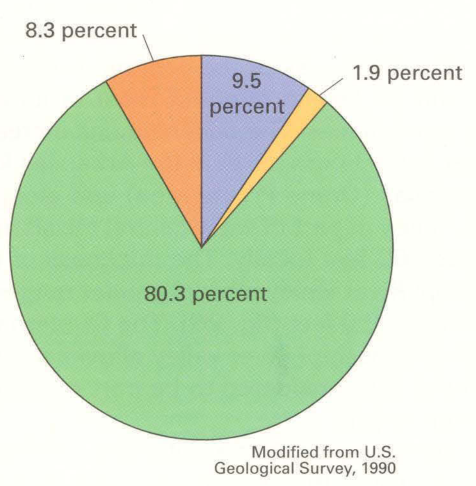
Ground water serves as an important source of water for many of the 9 million people that live in Arkansas, Louisiana, and Mississippi and supplies 38 percent of all water needed for public supply, agriculture, industry, mining, thermoelectric power, domestic, and commercial uses. About 6,800 million gallons per day of ground water were withdrawn in the three States of Segment 5 during 1985; about 80 percent of the ground water withdrawn is utilized by irrigated agriculture, mostly for growing rice, commercial vegetables, corn, and soybeans (**fig. 17**). The greatest increase in withdrawal rates occurred between 1970 and 1980, mostly within the Mississippi Alluvial Plain Section. In recent years, irrigation pumping has caused Arkansas to withdraw larger amounts of ground water than the other States of Segment 5 (**fig. 18**). Public supply represents the second largest user of ground water but accounts for less than 10 percent of the total water withdrawn. Ground water provides about 64 percent of the total freshwater withdrawn in Arkansas, about 68 percent of the freshwater used in Mississippi, and about 14 percent of the total freshwater withdrawn in Louisiana.

Total ground-water withdrawals, by county, during 1985 are shown in **fig. 19**. The largest withdrawals are in two major areas—the Mississippi Alluvial Plain in eastern Arkansas and northeastern Mississippi and a five-county area in southwestern Louisiana. Much of the ground water withdrawn is used for agricultural purposes, mostly irrigation of rice with smaller amounts for aquaculture (primarily catfish farming), both of which provide an important economic base for the three-State area.

Total ground-water withdrawals during 1985 from each of the major aquifers and aquifer systems are shown in **fig. 20**. The Mississippi River Valley alluvial aquifer and minor alluvial aquifers (the surficial aquifer system), which are the most heavily used, provide about 5.1 billion gallons per day of ground water or about 75 percent of all water used in Segment 5. Of this amount, about 5,050 million gallons per day was withdrawn from the Mississippi River Valley alluvial aquifer. The second most heavily used source of ground water is the coastal lowlands aquifer system, which provided nearly 1,150 million gallons per day, or 17 percent of all ground water used. The Mississippi embayment aquifer system provided about 6 percent of the total ground water withdrawn in the three-State area, whereas Cretaceous and Paleozoic aquifers provided only about 1 percent each of the total ground-water withdrawals.

Withdrawals of large quantities of water from Coastal Plain aquifer systems during the last 90 years have lowered water levels, decreased the saturated thickness of several aquifers, caused encroachment of salt water, and even altered patterns of regional ground-water flow. Before development of the Coastal Plain aquifers, recharge entered the regional flow system in the upland, interstream areas between major rivers (**fig. 21**). Ground water was discharged in the valleys of the major rivers or along the coast. Recent regional investigations have shown that large, long-term withdrawals have caused an increase in the rate of recharge in some upland areas and that most of the major rivers no longer represent sites of regional ground-water discharge (**fig. 22**). Rather, because of extensive irrigation or the lowering of ground-water levels owing to pumpage near the rivers, most of the major river valleys have become recharge areas that provide water to the underlying Coastal Plain aquifers.

Figure 17. *Agricultural withdrawals account for more than 80 percent of all ground-water use in Segment 5. Public supply is the second largest use.*



EXPLANATION

Use of fresh ground-water withdrawals during 1985, in percent—Total withdrawals 6,820 million gallons per day

- 9.5 Public supply
- 1.9 Domestic and commercial
- 80.3 Agricultural
- 8.3 Industrial, mining, and thermoelectric power

Figure 18. *The largest rates of ground-water withdrawals in Segment 5 are in Arkansas. Expansion of irrigated agriculture from 1975 through 1985 greatly increased withdrawals in that State.*

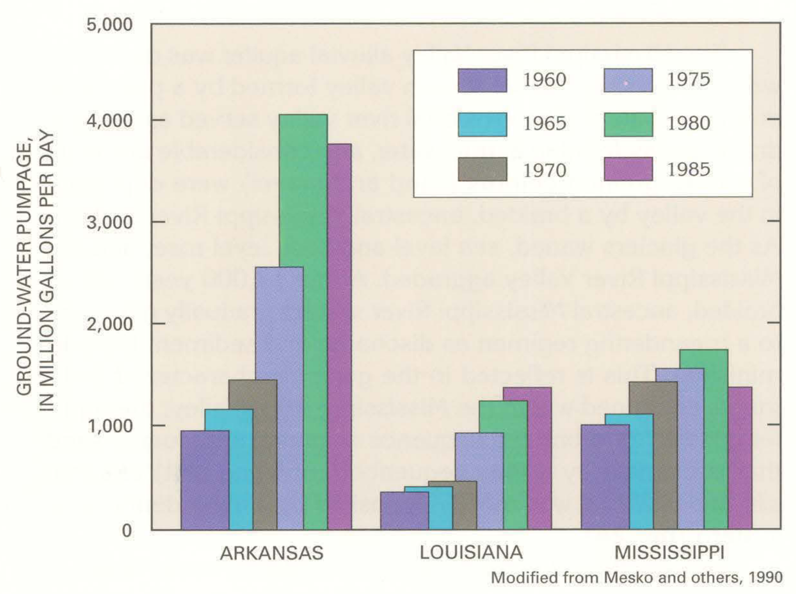


Figure 19. *Fresh ground-water withdrawals were highest during 1985 in eastern Arkansas, southwestern Louisiana, and northwestern Mississippi because of extensive agricultural water use.*

EXPLANATION

Fresh ground-water withdrawals during 1985, in million gallons per day

- 0 to 5
- 5 to 10
- 10 to 50
- 50 to 500

SCALE 1:5,000,000
0 25 50 MILES
0 25 50 KILOMETERS

Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

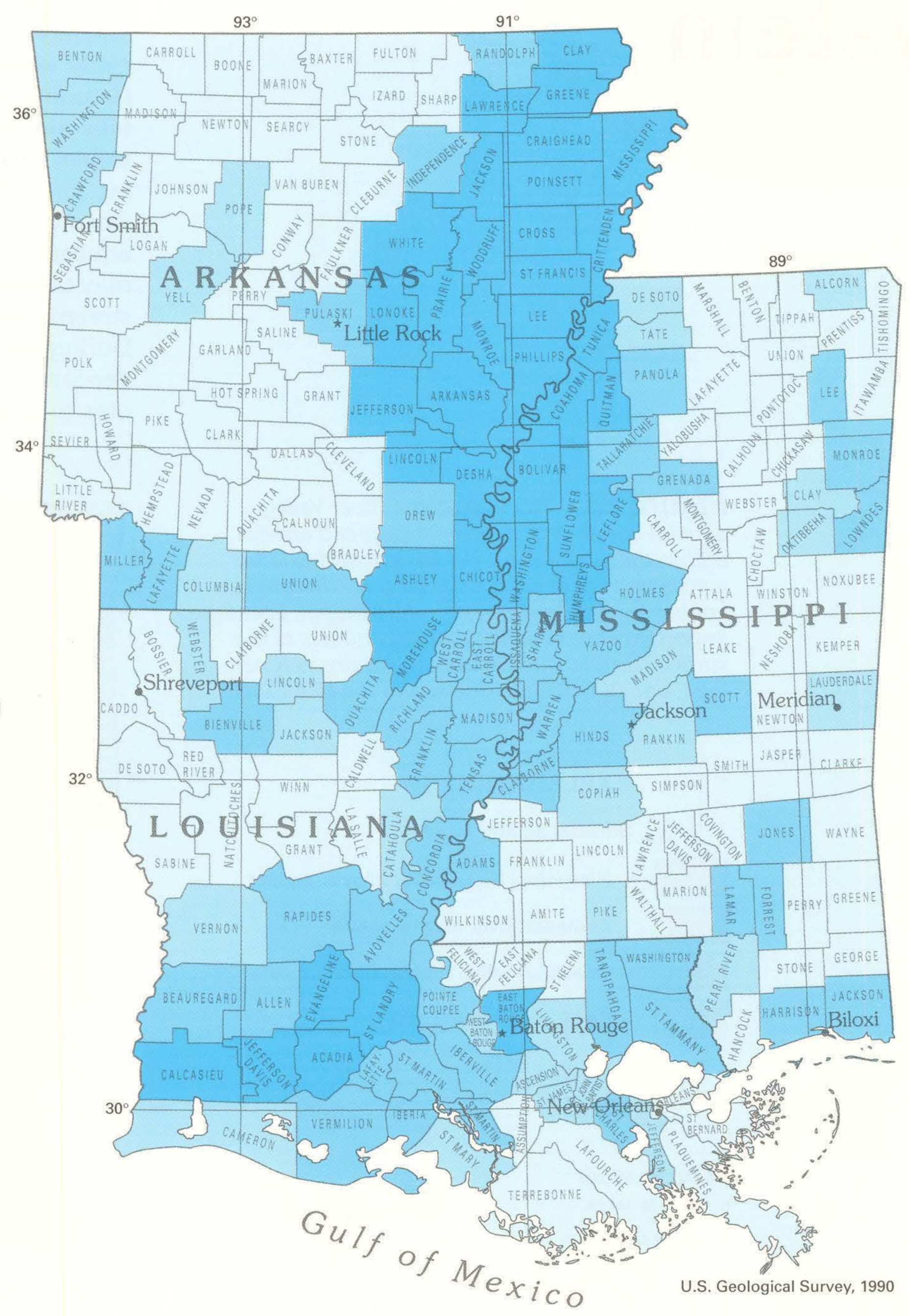


Figure 20. *Withdrawals from the surficial aquifer system during 1985 accounted for approximately 75 percent of the ground water used in Segment 5.*

EXPLANATION

Fresh ground-water withdrawals during 1985, in million gallons per day

- Surficial aquifer system—5,097
- Coastal lowlands aquifer system—1,141
- Mississippi embayment aquifer system—433
- Cretaceous aquifers and aquifer systems—81
- Paleozoic aquifers—68

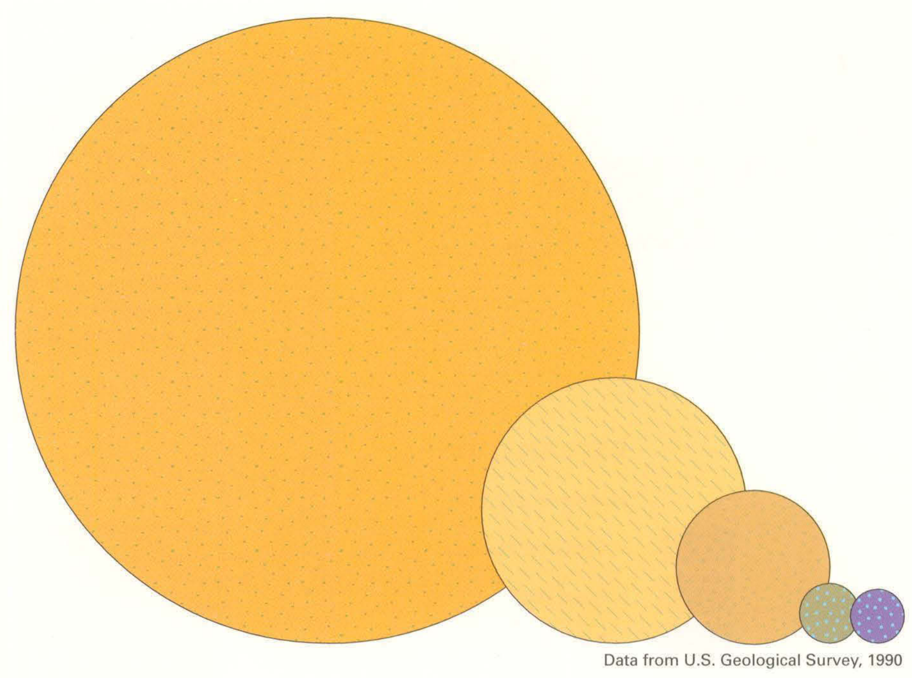


Figure 21. *Before development of the Coastal Plain aquifers, the predominant regional ground-water flow pattern was from topographically elevated interstream recharge areas on the eastern and western sides of the Mississippi River Valley to discharge areas within the valley. In southern Louisiana and southern Mississippi, ground water moved southward from interstream areas of recharge to coastal areas of discharge.*

EXPLANATION

Recharge, in inches per year

- 0 to 0.17
- 0.17 to 0.66
- Greater than 0.66

Discharge, in inches per year

- 0 to 0.17
- 0.17 to 0.66

SCALE 1:5,000,000
0 25 50 MILES
0 25 50 KILOMETERS

Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

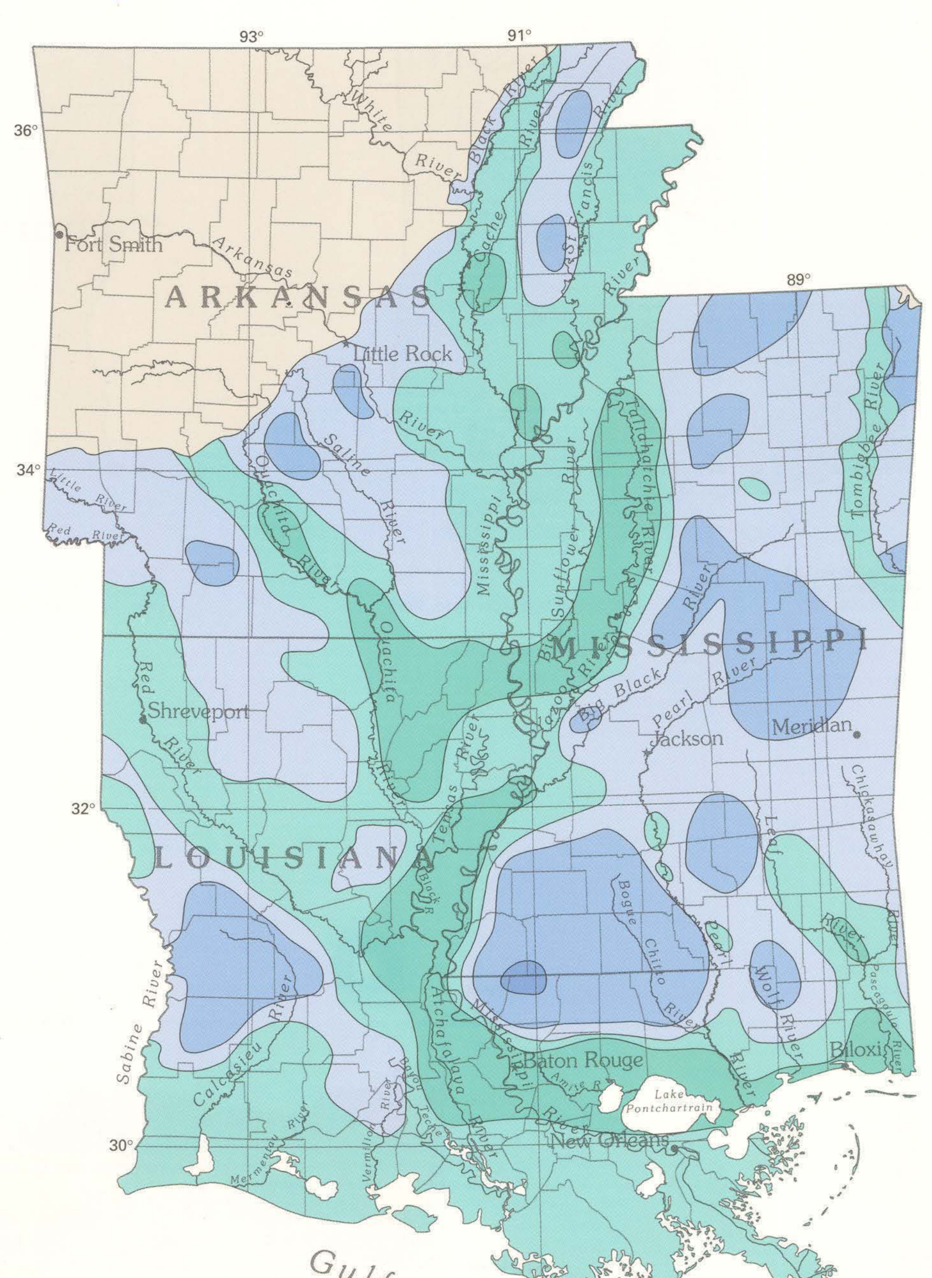


Figure 22. *Large well withdrawals used to meet agricultural water demands in Coastal Plain areas of Segment 5 have greatly impacted the regional ground-water flow system. Extensive ground-water development of Coastal Plain aquifers has been accompanied by a fivefold increase in regional recharge and by local declines in water levels. The amount of water that was regionally discharged from the system before development has decreased by more than one-half.*

EXPLANATION

Recharge, in inches per year

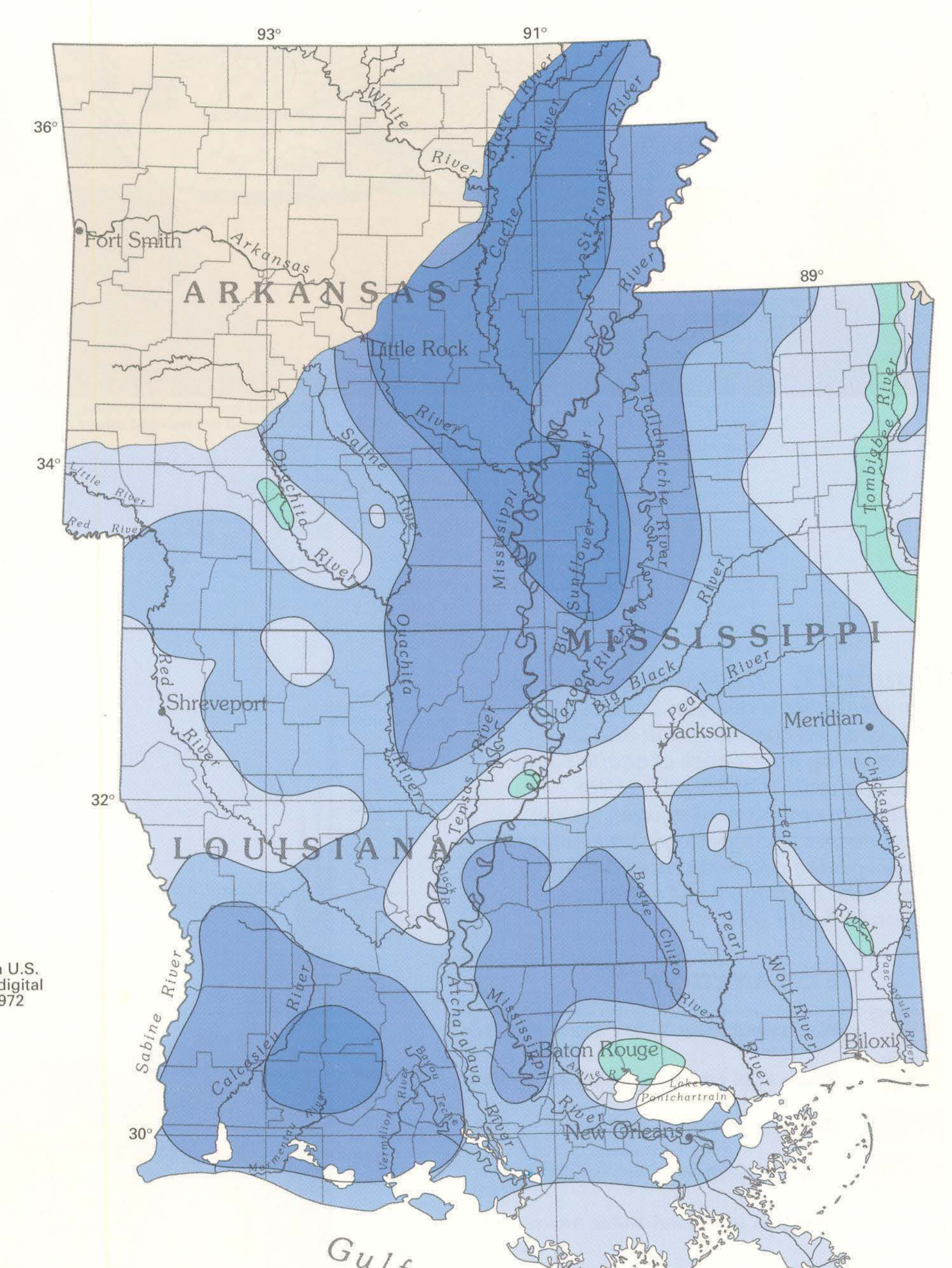
- 0 to 0.17
- 0.17 to 0.66
- 0.66 to 3.0
- Greater than 3.0

Discharge, in inches per year

- 0 to 0.17

SCALE 1:5,000,000
0 25 50 MILES
0 25 50 KILOMETERS

Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972



Surficial aquifer system

INTRODUCTION

The surficial aquifer system of Segment 5 contains one major and three minor alluvial aquifers, of which the Mississippi River Valley alluvial aquifer is the largest and most important. Some regional studies have included the Mississippi River Valley alluvial aquifer as part of the Mississippi embayment aquifer system. Less extensive but locally important are the stream-valley alluvial aquifers of the Arkansas River, the Ouachita–Saline Rivers, and the Red River (**fig. 23**). Alluvial aquifers of the surficial aquifer system are characterized by their ability to yield large volumes of water and by their hydraulic interconnection with the rivers and streams that cross them. The alluvial aquifers generally are characterized by a basal gravel that fines upward to sand.

The alluvial aquifers of Segment 5, with the exception of the aquifer along the Arkansas River, are located within the Coastal Plain Physiographic Province; the Arkansas River alluvial aquifer is in the Ouachita Physiographic Province. The alluvial aquifers consist of gravel and sand deposits of Quaternary age and generally contain ground water under unconfined conditions. Beds and lenses of poorly permeable silt and clay, however, locally create confined conditions. The alluvial aquifers are capable of yielding large amounts of water, especially where the saturated thickness of the aquifer is large. Natural recharge to the alluvial aquifers is by precipitation that falls directly on the alluvial deposits, runoff from adjacent slopes, upward flow from aquifers underlying the alluvial aquifer, and infiltration from streams during periods of high flow when water levels in the streams are higher than those in the aquifers. Additional recharge from induced stream infiltration may take place where withdrawals from wells located near the streams lower the adjacent water table below the stream level. During dry periods, water may discharge from the alluvial deposits or adjoining aquifers into the streams, which contributes to base flow.

Figure 23. The Mississippi River Valley alluvial aquifer is the most widespread aquifer within the surficial aquifer system and extends across parts of eastern Arkansas, northeastern Louisiana, and northwestern Mississippi. Locally important stream-valley alluvial aquifers of the surficial aquifer system are the Arkansas River, the Ouachita–Saline Rivers, and the Red River.

EXPLANATION

Surficial aquifer system

- Mississippi River Valley alluvial aquifer
- Arkansas River alluvial aquifer
- Ouachita–Saline Rivers alluvial aquifer
- Red River alluvial aquifer

SCALE 1:7,500,000
0 25 50 MILES
0 25 50 KILOMETERS

Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

MISSISSIPPI RIVER VALLEY ALLUVIAL AQUIFER

The Mississippi River Valley alluvial aquifer underlies the Mississippi River Valley, which is an extensive, low, flat plain that is a major physiographic feature of the segment. The aquifer extends southward from the head of the Mississippi Embayment, which is described in chapters D and K of this Atlas, and merges with the coastal lowlands aquifer system band of sediments in low-lying areas parallel to the Gulf Coast. The Mississippi River Valley alluvial aquifer underlies nearly 33,000 square miles in Segment 5 and ranges from about 75 miles wide between Vicksburg, Mississippi and Monroe, Louisiana to about 120 miles wide near the latitude of Little Rock, Arkansas. Sand, gravel, silt and minor clay deposits of Quaternary age that make up the aquifer in eastern Arkansas, northwestern Mississippi, and northeastern Louisiana also extend to the Gulf Coast in southeastern Louisiana (**fig. 13**). For purposes of this Atlas, however, the extent of the Mississippi River Valley alluvial aquifer is limited to the area shown in **figure 23**. Quaternary alluvial and deltaic deposits of the lower Mississippi River Valley generally are lithologically similar to and in good hydraulic connection with the underlying deposits of the coastal lowlands aquifer system and, therefore, are included in that system.

Hydrogeology

The Mississippi River Valley alluvial aquifer was deposited within a broad erosional stream valley formed by a preglacial drainage system. The erosional river valley served as a major drainageway for glacial meltwater, and considerable amounts of coarse-grained detritus (sand and gravel) were deposited in the valley by a braided, ancestral Mississippi River system. As the glaciers waned, sea level and base level rose, and the Mississippi River Valley aggraded. About 12,000 years ago, a braided, ancestral Mississippi River system gradually gave way to a meandering regimen as discharge and sediment load diminished. This is reflected in the geologic character of sediments contained within the Mississippi River Valley; the aquifer consists of a braided sequence of gravel and coarse sand that is overlain by a finer sequence (confining unit) of sand, silt, and clay that was mostly deposited by a meandering river system (**fig. 24**).

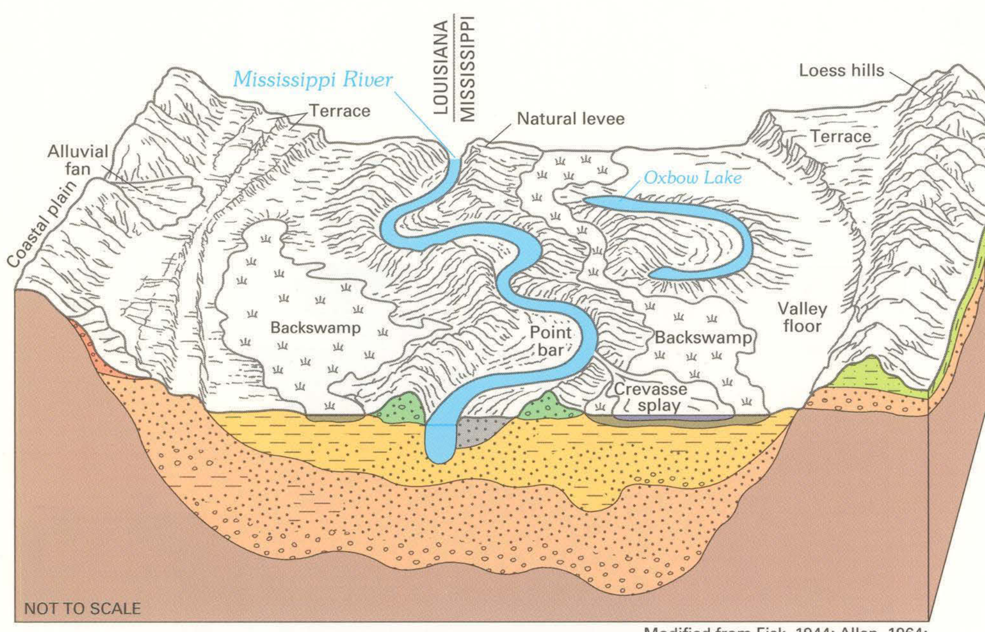
Downcutting, lateral migration, sudden channel shifting, shift in stream regimen, and aggradation by the Mississippi River have resulted in a wide variety of depositional and geomorphic landforms from Pleistocene to early Holocene time (**fig. 24**). During sea-level rise, the Mississippi River aggraded, and the valley infilled with alluvial deposits. Sea-level decline lowered the base level of the Mississippi River and caused the river to entrench into the adjoining valley fill. The Mississippi River Valley contains four stream terraces that formed in response to cyclic base-level change. Successive periods of entrenchment helped form the different erosional terraces. Braided streams that carried silt-laden glacial meltwater also served as the source of thick, wind-transported loess deposits.

The modern-day meandering Mississippi River system contains a wide assemblage of flood-plain depositional features that include point bars, natural levees, crevasse splays, backswamps, oxbow lakes, and alluvial fans. Meandering streams, which are formed by the helical, secondary flow of surface water as it moves downstream, shift their position by eroding outer banks of meander bends; transporting eroded, sandy sediment; and depositing it on the inside of downstream meander bends. When viewed in a vertical section, point-bar sediments are coarse at their base but fine upward. Natural levees build upward and outward, form as floodwaters rise above the bank level, and deposit sediment in bands that parallel the stream channel. Crevasse splays form where levees are breached and surface waters flow out onto the flood plain, which deposits sediment as a deltaic lobe. Backswamp areas generally form in low-lying, closed depressions, are underlain by silt and organic clay, and are covered by water for lengthy periods. Oxbow lakes form by meander cutoff, in which the upstream and downstream parts of a meander bend intersect, which shortens the length of the river. This crescent-shaped bend forms a closed lake that eventually fills with clay sediment. Alluvial fans form where smaller streams enter the valley and deposit sediment onto the flood plain. As surface waters diminish in depth and velocity, coarse detritus is deposited as a fan.

The deposits of the Mississippi River alluvial valley can be separated into two hydrogeologic units—an upper confining unit of silt, clay, and fine sand that impedes the downward movement of water into a lower coarse sand and gravel aquifer. The confining unit was deposited in flood plain, backswamp, meander belt, and some braided stream environments. The thickness of the confining unit averages between 20 and 30 feet throughout most of its extent but is missing in some places. The confining unit increases to more than 60 feet in thickness north of the Arkansas River in east-central Arkansas (Grand Prairie area) and along the Mississippi River Valley in part of west-central Mississippi (**fig. 25**) and exceeds 100 feet locally. The thickness of the underlying Mississippi River Valley alluvial aquifer ranges from about 25 to more than 150 feet (**fig. 26**). The Quaternary sand and gravel of the Mississippi River Valley alluvial aquifer continue southward but are considered to be part of the coastal lowlands aquifer system.

The layered sequence of aquifer and confining units that lies east and west of the alluvial plain and that is part of the Mississippi embayment aquifer system also extends beneath the Mississippi River Valley alluvial aquifer (**fig. 27**). In places, the Mississippi River Valley alluvial aquifer directly overlies and is hydraulically interconnected with aquifers of the Mississippi embayment aquifer system; in such places, water moves freely between the aquifers (**fig. 27**). The movement may be into or out of the Mississippi River Valley alluvial aquifer; this depends on whether the hydraulic head in the aquifer is higher or lower than that in the underlying aquifers. The ground water also moves from areas of high head toward areas of lower head. In other areas, the aquifer overlies poorly permeable strata that function as confining beds. In general, the permeability of the Mississippi River Valley alluvial aquifer is greater than that of the underlying aquifers.

Figure 24. Complex topographic and depositional features are associated with the Mississippi River Valley alluvial aquifer. All the features are due to erosion or deposition by the river except for alluvial fans, which were deposited by tributary streams, and loess, which was deposited by wind.



Modified from Fisk, 1944; Allen, 1964; and Boswell and others, 1968

EXPLANATION

Holocene deposits

- Crevasse splay
- Point bar
- Backswamp
- Natural levee
- Alluvium (meandering river)
- Alluvial fan

Pleistocene deposits

- Loess
- Alluvium (braided river)

Sediment type

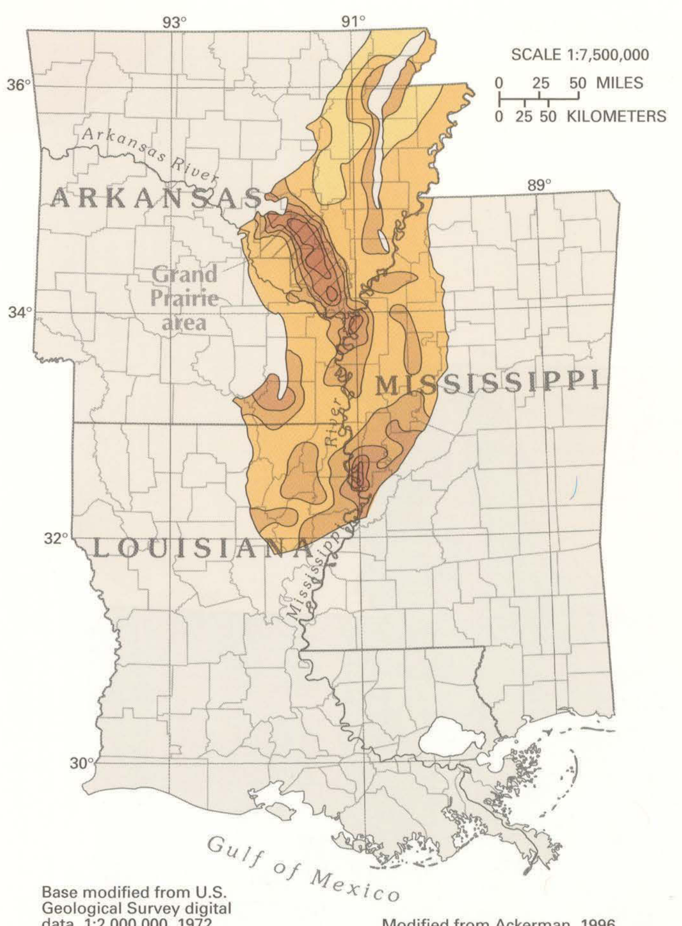
- Silt (wind blown)
- Silt and clay
- Sand
- Gravel
- Organic clay

Figure 25. A confining unit of clay, silt, and fine sand overlies the Mississippi River Valley alluvial aquifer and ranges from less than 20 to more than 60 feet in thickness. The confining unit is thickest in east-central Arkansas and west-central Mississippi.

EXPLANATION

Thickness of confining unit, in feet

20
30
40
50
60



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Modified from Ackerman, 1996

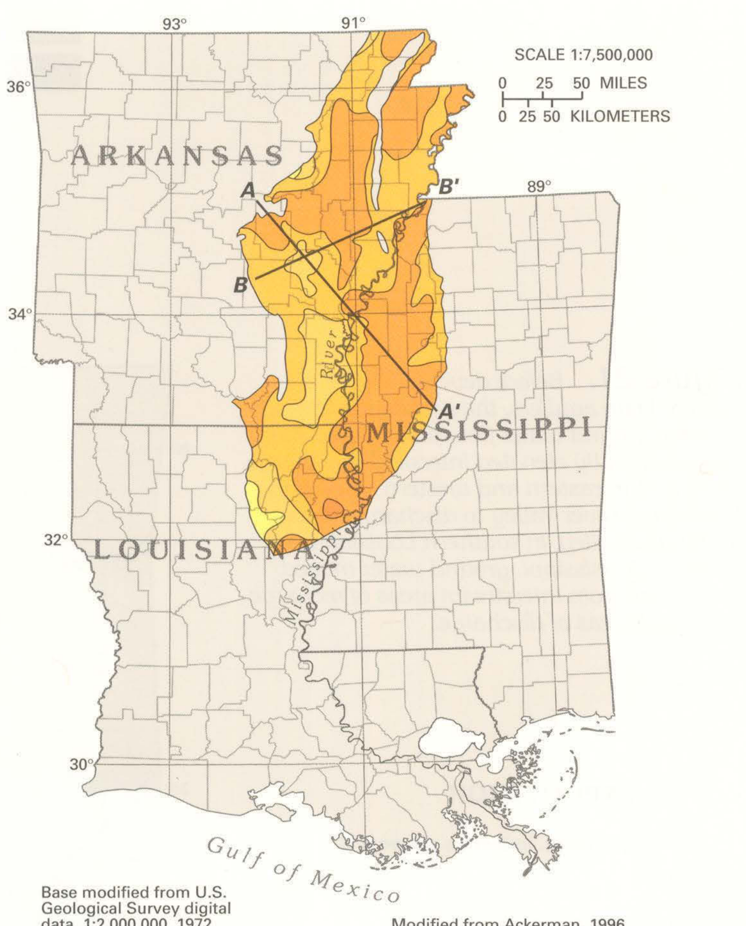
Figure 26. The thickness of the Mississippi River Valley alluvial aquifer ranges from about 25 to more than 150 feet. The aquifer is more than 75 feet thick in most locations.

EXPLANATION

Thickness of aquifer, in feet

- 25 to 50
- 50 to 75
- 75 to 100
- 100 to 150
- Greater than 150

A——A′ Line of hydrogeologic section



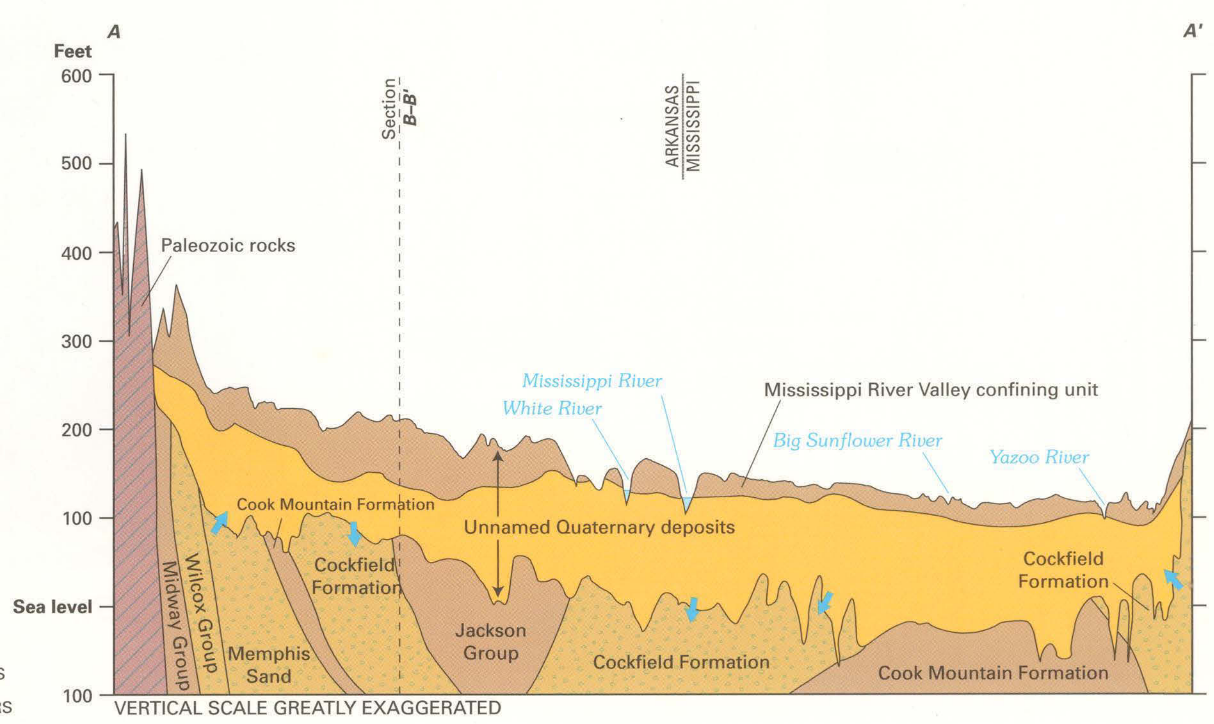
Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

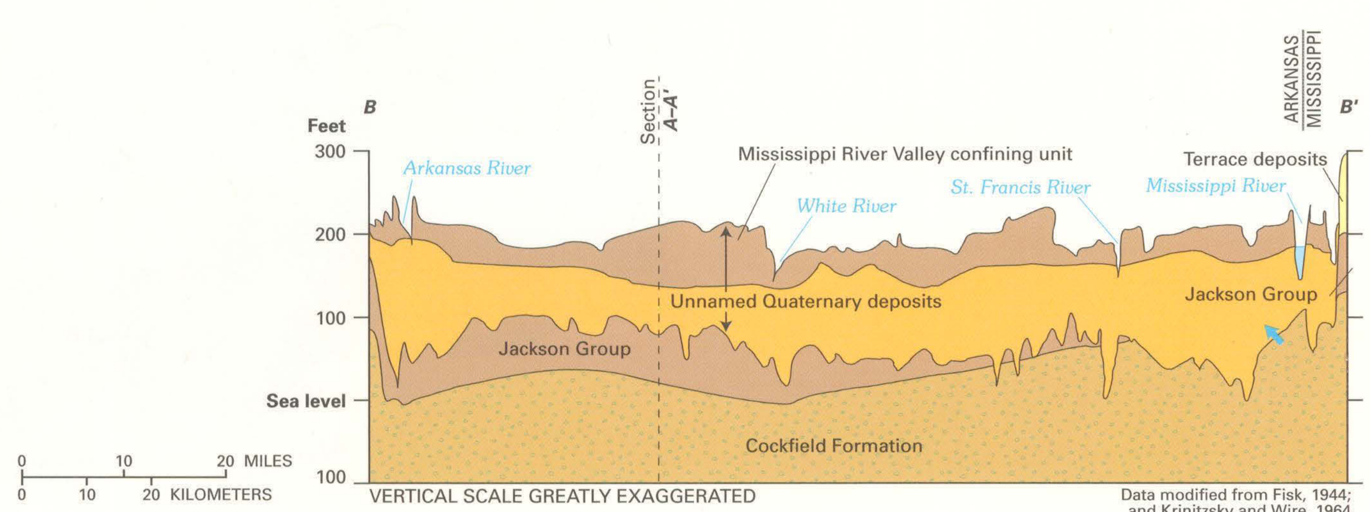
Modified from Ackerman, 1996

Figure 27. The Mississippi River Valley alluvial aquifer is overlain in most places by a fine-grained confining unit and is underlain by a sequence of aquifers and confining units that are part of the Mississippi embayment aquifer system. These deeper hydrogeologic units are within several geologic formations and groups. The lines of the hydrogeologic sections are shown in figure 26.

EXPLANATION

- Mississippi River Valley alluvial aquifer
- Mississippi embayment aquifer system
- Ouachita Mountain aquifer
- Confining unit
- Direction of ground-water movement





Data modified from Fisk, 1944; and Krinitzsky and Wire, 1964

Relation Between Geology and Permeability

Understanding the physical framework and facies of the Mississippi River Valley alluvial aquifer is useful in predicting permeability and hydraulic conductivity. Hydraulic conductivity is a measure of how rapidly water will pass through an aquifer and is a good indication of the probable yield of wells completed in the aquifer—the higher the hydraulic conductivity, the greater the expected well yield. Permeability is another way of measuring the ability of an aquifer to transmit water under a hydraulic gradient. Permeability is equal to the hydraulic conductivity of an aquifer multiplied by the gravitational constant and divided by the density and dynamic viscosity of the water. Transmissivity is a third way of measuring the capacity of an aquifer to transmit water of the prevailing viscosity. The transmissivity of an aquifer is equal to the horizontal hydraulic conductivity of the aquifer multiplied by the saturated thickness of the aquifer. The hydraulic conductivity, transmissivity, and permeability of an aquifer are directly influenced by the particle size, particle shape, degree of packing, sorting, amount of material that fills pore space, and cementation of the mineral and rock material that composes the aquifer. These factors are, in large part, a reflection of the depositional history of the rock. The distribution of the hydraulic conductivity of an alluvial aquifer, therefore, might be estimated from a map of the geologic facies of the aquifer because of the direct correlation between rock type and aquifer permeability. Hydraulic and lithofacies data also can be compared to help understand lateral variations within the alluvial sequence. Lithofacies maps of the Mississippi River Valley alluvial aquifer provide some insight to the distribution of hydraulic conductivity. To a degree, lithofacies maps can be used as a predictive tool in the search for overlooked or undeveloped sites that might prove suitable for ground-water resource development.

The distribution of the percentage of sand and gravel within the Mississippi River Valley alluvial aquifer is shown in **Figure 28**. The distribution of coarse-grained sediment indicates that higher concentrations of coarse detritus underlie the eastern one-half of the aquifer in a north–south band. In this area, sand and gravel compose more than 80 percent of the aquifer. Less coarse detritus is located on both sides of this band and may possibly be associated with an ancient flood plain.

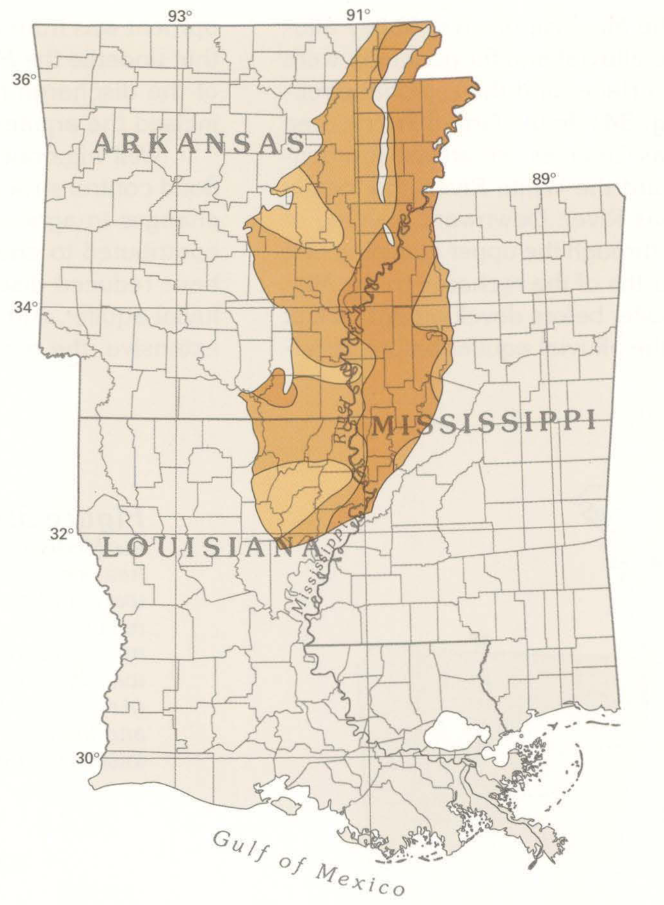
The map of the distribution of hydraulic conductivity of the Mississippi alluvial aquifer shown in **figure 29** was constructed by using aquifer and specific-capacity test data, supplemented with trial-and-error estimates of hydraulic conductivity that were obtained by computer simulation of the ground-water flow system. The areas of highest hydraulic conductivity (greater than 245 feet per day) correspond well with the eastern part of the alluvial plain; this is an area in which sand and gravel have been concentrated (greater than 80 percent; **fig. 28**). In the western part of the alluvial plain (eastern Arkansas and northeastern Louisiana), the hydraulic conductivity of the alluvial aquifer generally ranges from 200 to 245 feet per day. **Figure 28** shows a parallel reduction in the concentration of coarse-grained sediment in this area. Southward, the hydraulic conductivity of the aquifer diminishes; this reduction may reflect a progressive change in depositional facies southward from alluvial sand to a more clayey deltaic facies where the alluvial aquifer merges southward with the uppermost sediments of the coastal lowlands aquifer system.

Figure 28. *The greatest concentrations of sand and gravel within the Mississippi River Valley alluvial aquifer are located in an elongate band on the eastern side of the valley. Less coarse detritus on both sides of this band possibly reflects the location of the ancestral flood plain that was covered with mostly fine-grained backswamp deposits.*

EXPLANATION

Sand and gravel, in percent

- 40 to 60
- 60 to 80
- 80 to 100



SCALE 1:7,500,000
0 25 50 MILES
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Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

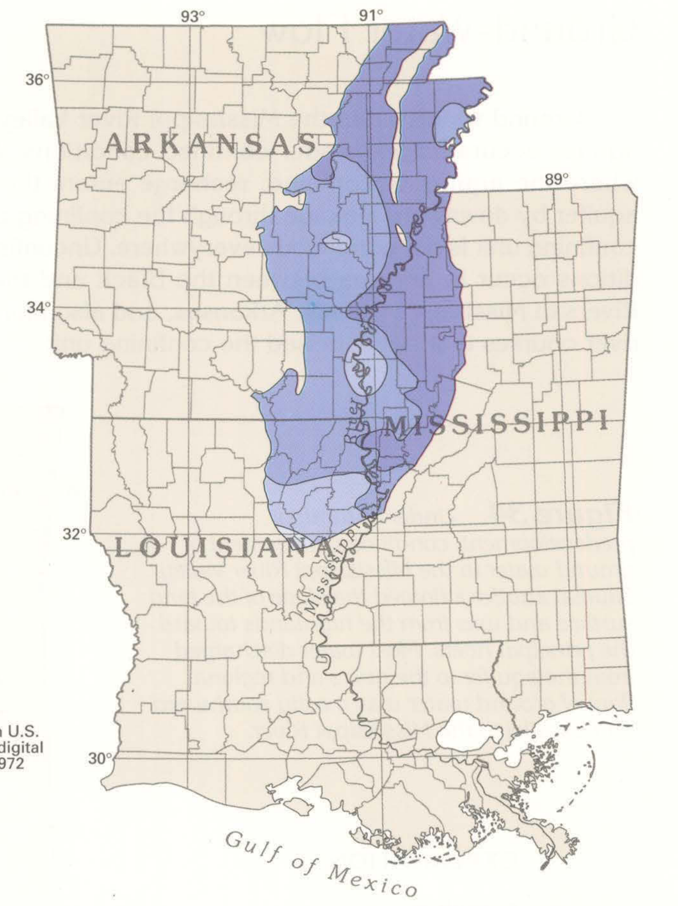
Modified from Hosman and Weiss, 1991

Figure 29. *The hydraulic conductivity of the Mississippi River Valley alluvial aquifer is greatest in the eastern one-half of the valley and corresponds well with the location of the high percentages of sand and gravel shown in figure 28.*

EXPLANATION

Estimated hydraulic conductivity, in feet per day

- 100
- 200
- 245



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Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

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River-Aquifer Interaction

The hydrology of an alluvial aquifer is greatly influenced by the rivers that cross and incise it. When a stream channel incises an unconfined aquifer, the stream may recharge the aquifer, or the aquifer may discharge water to the river. River stage altitude tends to be high owing to greater stream flow; water from the river seeps laterally into the river banks and vertically through the streambed and thus raises water levels in the aquifer. When this occurs, the alluvial aquifer receives water from the river (**fig. 30*A***), and the river is called a losing stream because it loses water to the aquifer. Water-table contours "point" downstream where they cross a losing stream. When streamflow and altitude of river stage are low, ground water stored in the aquifer and river banks is discharged to the river (**fig. 30*B***). Under such conditions, water moves from the aquifer to the river, and the river is called a gaining stream. Where water-table contours cross a gaining stream, they "point" in an upstream direction.

The Mississippi River Valley alluvial aquifer is incised by the Mississippi River, as well as several smaller rivers and streams that traverse the alluvial plain. The hydraulic connection of the rivers depends on the nature of the riverbed material or the depth to which the rivers penetrate the confining unit and aquifer. A deep incision by the major river drains tends to enhance the hydraulic connection of the rivers with the alluvial aquifer. Because the larger streams incise deeply, they are likely to breach the upper confining unit and, thus, are in direct hydraulic connection with the aquifer. These rivers, therefore, are more likely to be affected by withdrawals by large wells completed in the alluvial aquifer. In contrast, streams that do not or only partially breach the confining unit are not likely to be hydraulically well-connected with the aquifer and may even be above the regional water table. Hydrographs that compare river stage and water-table altitude in wells located near some of the rivers that are tributaries of the Mississippi River show different degrees of river-aquifer interconnection (**fig. 31**). Stream hydrographs for the White River at St. Charles, Arkansas (**fig. 31*A***) and the Cache River near Patterson, Arkansas (**fig. 31*B***) closely correspond with water levels in nearby wells and show that high and low water levels in the aquifer parallel high and low flow periods in the rivers. The alluvial aquifer and the rivers are in direct hydraulic connection at these places, and water moves freely between the aquifer and the river. Conversely, hydrographs of stream stage and water levels in nearby wells for the Cache River at Egypt, Arkansas (**fig. 31*C***) and L'Anguille River near Colt, Arkansas (**fig. 31*D***) show poor correspondence. In these places, the rivers either have not breached or only partially breach the confining unit or alluvial aquifer and not as much water is exchanged between the river and the aquifer. In the Cache River area, long-term potentiometric decline has lowered water levels such that it lies beneath the streambed the entire year. Because the river stage levels are above aquifer water levels throughout the year, some water probably leaks downward from the rivers through the confining bed to recharge the aquifer.

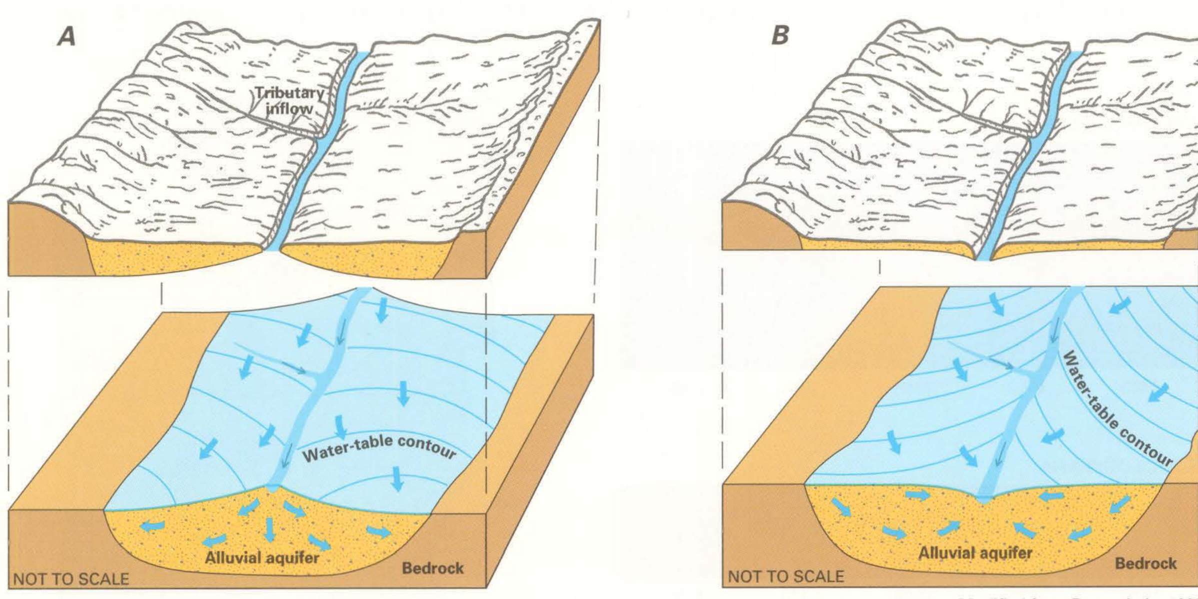
Large ground-water withdrawals have resulted in a long-term decline of water levels in some areas and also have reduced the amount of water that discharges to the rivers. By the early 1980's pumpage for irrigation and aquaculture, primarily to catfish farms, caused water levels in the alluvial aquifer to fall below the streambed of the Big Sunflower River in Mississippi (**fig. 32**). The Big Sunflower River and the lower part of the Yazoo River have historically acted as long-term drains from the alluvial aquifer; the potentiometric surface of the aquifer has sloped toward the Big Sunflower River even though the hydraulic connection was poor. During the early 1980's, pumpage for irrigation and catfish ponds caused water levels to decline from 1 to 2 feet per year and below the level of the lower stage of the Big Sunflower River. Because of the large amounts of water withdrawn, water levels in the aquifer did not recover during the winter and spring months even though the amount of precipitation is greater than the amount that falls during the growing season. Accordingly, water leaks downward from the Big Sunflower River to the aquifer year round. Water likewise moves from the Yazoo River to the aquifer throughout the year, but withdrawals from wells near the Yazoo River are not great enough to lower aquifer water levels below streambed levels. In contrast, flow between the Mississippi River and the aquifer is different at different times of the year. Precipitation is considerably less during the summer and fall, and the river stage is below that of the alluvial aquifer. In these conditions, water discharges from the aquifer to the river (**fig. 32*A***). When precipitation increases during the winter and spring, the positions of river and aquifer water levels may be reversed (**fig. 32*B***), and the Mississippi River becomes a source of recharge for the aquifer. Away from the rivers, aquifer levels are lowered locally owing to pumping of irrigation wells during the growing season but recover during the winter and spring. Water levels remain low near catfish ponds, however, because wells that supply the ponds are pumped year-round.

The configuration of the water table near rivers that incise the Mississippi River Valley alluvial aquifer also is influenced by seasonal change in river stage altitude. During the winter and spring, river-stage altitude tends to be high owing to greater stream flow; water from the river seeps into the river banks and raises water levels in the aquifer. During the summer and fall, streamflow and river-stage altitude are low, and ground water stored in the aquifer and river banks is discharged to the river. The seasonal changes in water levels in the alluvial aquifer can be large. For example, the decline in water levels in the Mississippi River Valley alluvial aquifer from spring to fall 1965 was greater than 10 feet in some places (**fig. 33**).

Figure 30. *During months of high rainfall and high stream stage, water moves from losing streams as recharge into the alluvial aquifer (A). In dry periods, the stage of the same stream may drop until it becomes a gaining stream into which the aquifer discharges (B). The shape of the water-table contours is very different for losing and gaining streams.*

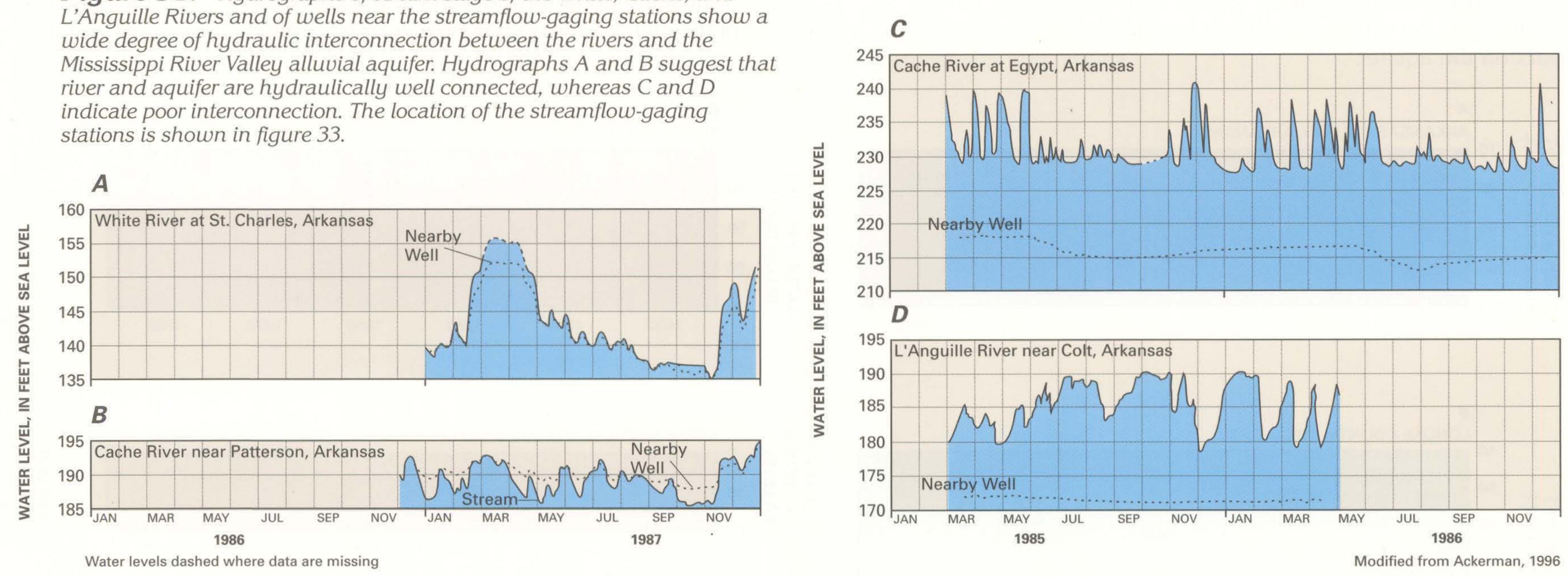
EXPLANATION

Direction of ground-water movement



Modified from Rosenshein, 1988

Figure 31. *Hydrographs of stream stage of the White, Cache, and L'Anguille Rivers and of wells near the streamflow-gaging stations show a wide degree of hydraulic interconnection between the rivers and the Mississippi River Valley alluvial aquifer. Hydrographs A and B suggest that river and aquifer are hydraulically well connected, whereas C and D indicate poor interconnection. The location of the streamflow-gaging stations is shown in figure 33.*



Water levels dashed where data are missing

Modified from Ackerman, 1996

EXPLANATION

Direction of ground-water movement

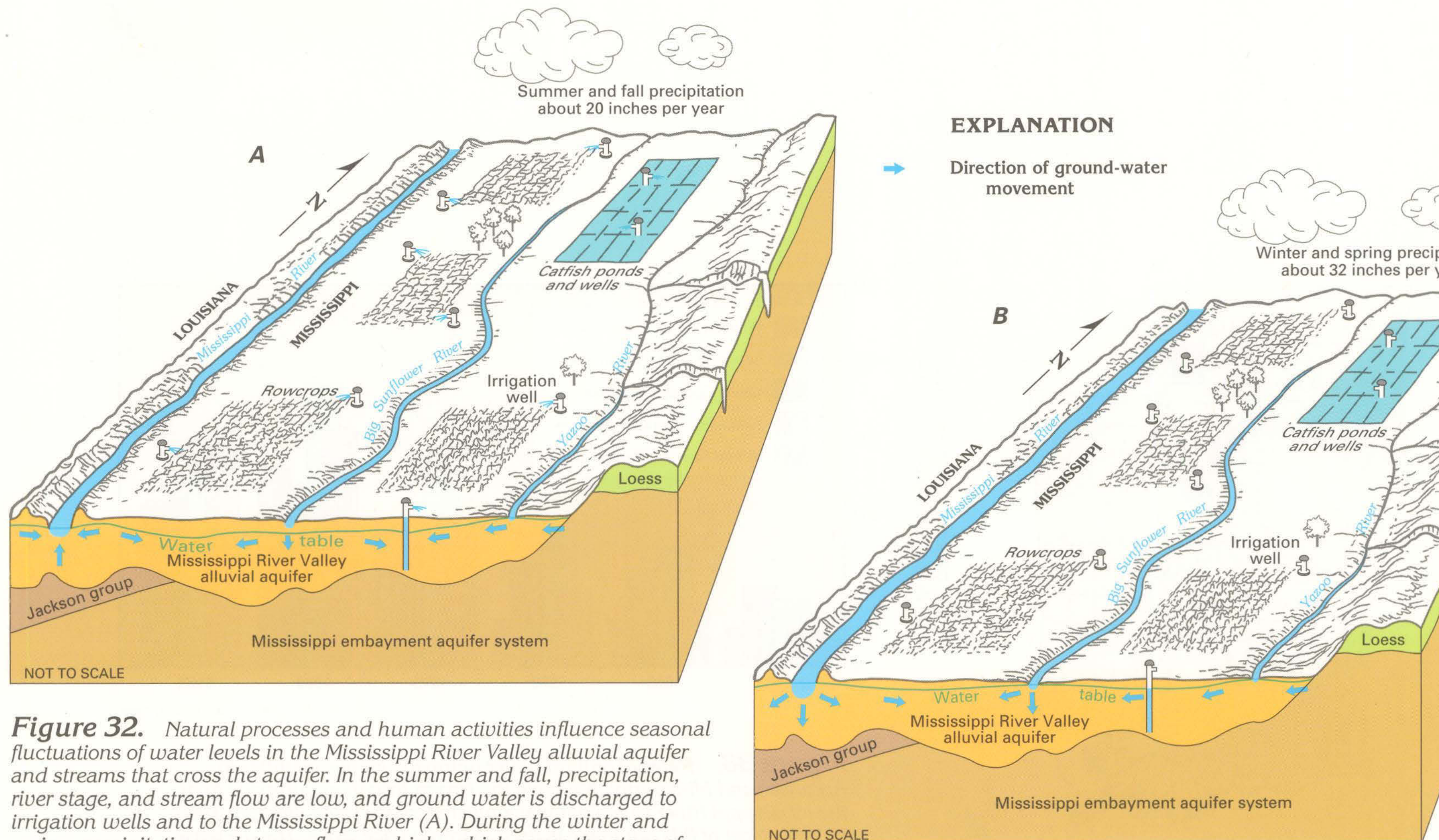


Figure 32. *Natural processes and human activities influence seasonal fluctuations of water levels in the Mississippi River Valley alluvial aquifer and streams that cross the aquifer. In the summer and fall, precipitation, river stage, and stream flow are low, and ground water is discharged to irrigation wells and to the Mississippi River (A). During the winter and spring, precipitation and stream flow are high, which cause the stage of some rivers to rise higher than water levels in the adjoining aquifer; water from the river may recharge the aquifer (B). Along some streams, such as the Big Sunflower River in Mississippi, aquifer water levels may be below stream levels year round.*

Modified from Sumner and Wasson, 1984

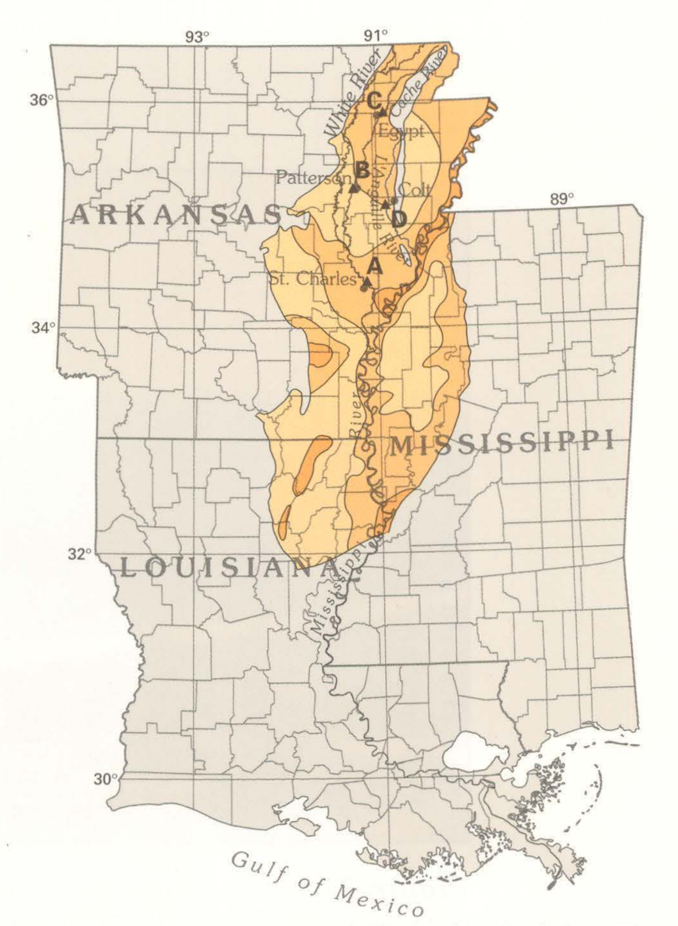
Figure 33. *Water levels in the Mississippi River Valley alluvial aquifer declined more than 10 feet in places from spring to fall 1965. The greatest change in water levels generally was along some reaches of the Mississippi River. In these places, the aquifer is deeply incised by the river, the seasonal change in river stage is greatest, and a high degree of hydraulic inter-connection exists between the river and aquifer.*

EXPLANATION

Water-level decline from spring to fall (1965), in feet

- 2
- 10

▲A Streamflow gaging station and identification letter



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Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Modified from Boswell and others, 1968

Ground-Water Flow

Ground water within the Mississippi River Valley alluvial aquifer occurs largely under confined conditions. In areas where the aquifer is confined, recharge enters the alluvial aquifer by downward leakage through the confining unit. The confining unit is not continuous everywhere. Unconfined conditions occur in an area between the Black and the Cache Rivers in Mississippi County, Arkansas, and also along major river courses that have incised the confining unit.

Before development of the Mississippi River Valley alluvial aquifer, water levels in the alluvial aquifer generally were less than 20 feet below land surface, and the regional direction of flow was southward (**fig. 34**). In the Grand Prairie area of Prairie, Monroe, and Arkansas Counties, Arkansas, flow generally was southeastward toward the White River and locally southward toward the Arkansas River. Downward leakage of rainfall (0.5–1.0 inch per year) through the upper confining unit accounted for nearly three-fourths of the recharge to the Mississippi River Valley alluvial aquifer before development. About one-fourth of the recharge to the alluvial aquifer before development was from upward leakage from Coastal Plain aquifers that underlie the Mississippi River Valley alluvial aquifer. Most of the discharge from the alluvial aquifer was to rivers that incised the aquifer.

Well withdrawals, the construction of drainage canals and flood control structures, river navigational improvements, and changes in agricultural land use over the last 70 years have contributed to changes in the ground-water flow system and have reduced discharge from the Mississippi River Valley alluvial aquifer. Although development of this aquifer has been extensive, the regional movement of ground water generally remains unchanged (**fig. 35**). Many areas within the Mississippi River Valley have only a local change in the ground-water flow direction. The most dramatic area of change in water level-decline and ground-water flow direction is within the Grand Prairie and the Cache River areas of Arkansas. Large amounts of ground water are withdrawn in these areas to irrigate rice crops. The large withdrawals have caused water-level declines within the alluvial aquifer, which resulted in a cone of depression between the White and the Arkansas Rivers. A second depression in the potentiometric surface is located between the Cache River and the southern one-half of Crowleys Ridge (**fig. 35**).

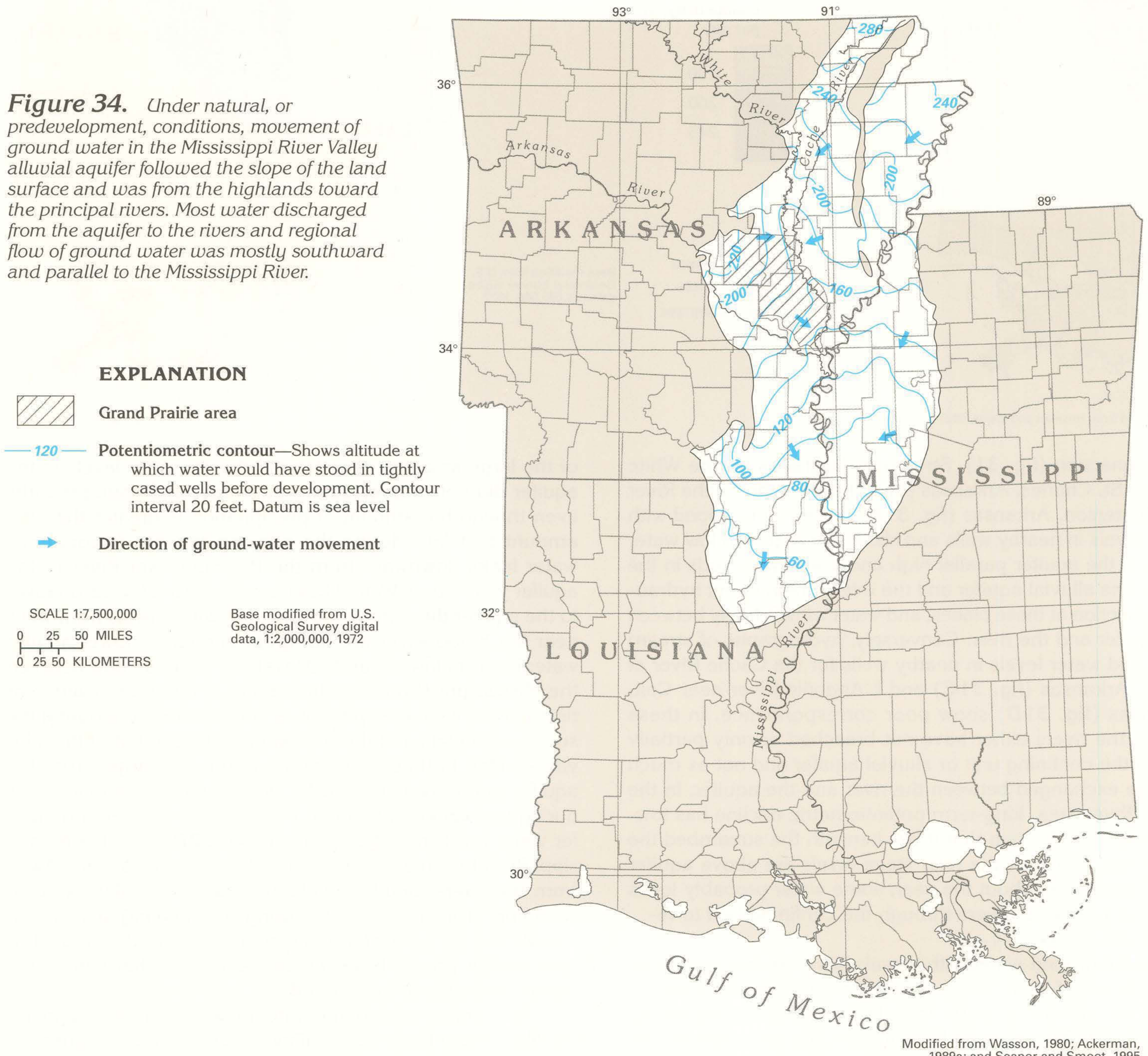


Figure 34. Under natural, or predevelopment, conditions, movement of ground water in the Mississippi River Valley alluvial aquifer followed the slope of the land surface and was from the highlands toward the principal rivers. Most water discharged from the aquifer to the rivers and regional flow of ground water was mostly southward and parallel to the Mississippi River.

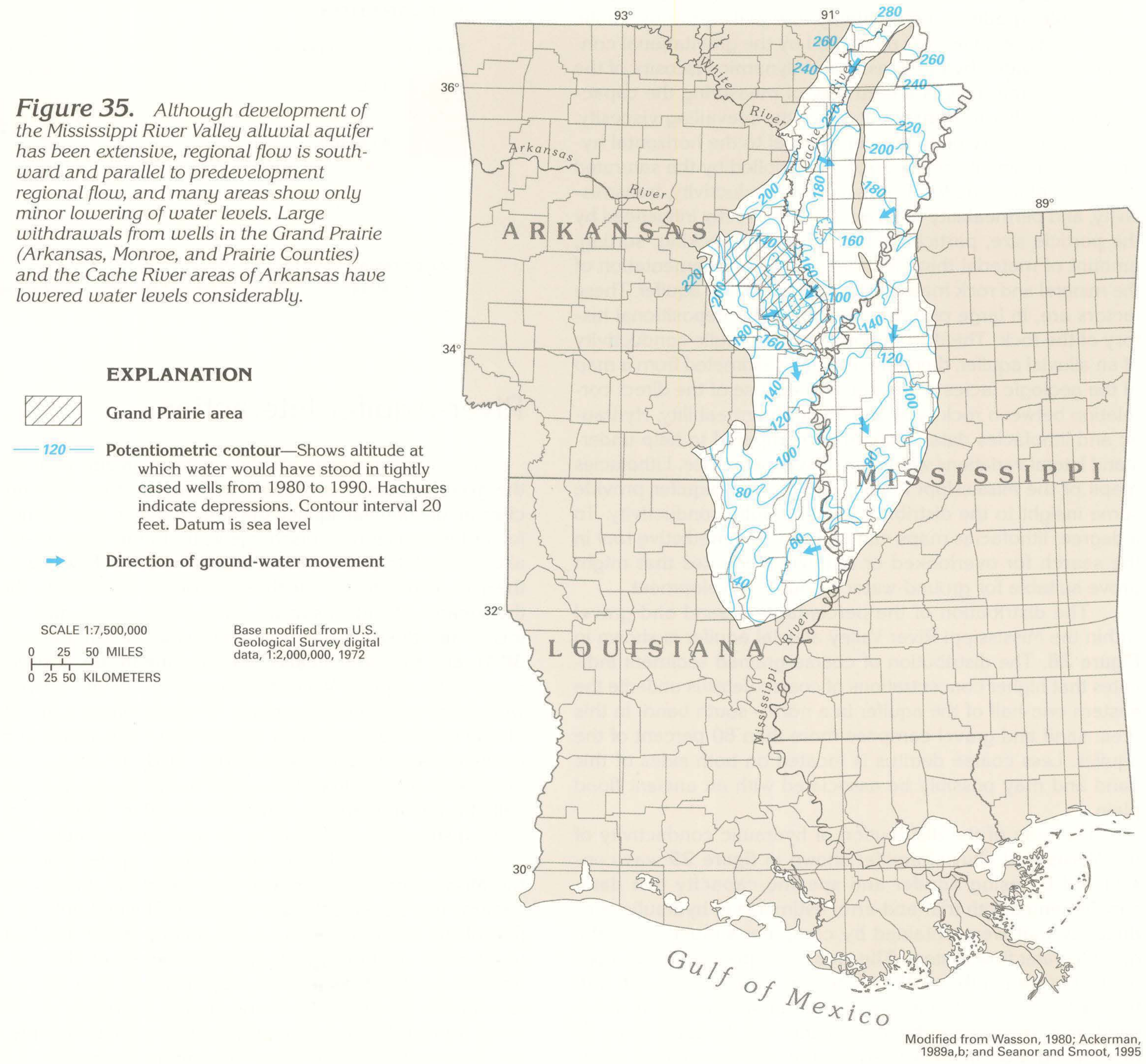


Figure 35. Although development of the Mississippi River Valley alluvial aquifer has been extensive, regional flow is southward and parallel to predevelopment regional flow, and many areas show only minor lowering of water levels. Large withdrawals from wells in the Grand Prairie (Arkansas, Monroe, and Prairie Counties) and the Cache River areas of Arkansas have lowered water levels considerably.

Well Yield, Pumpage, and Long-Term Water-Level Decline

Before the middle 1970's, most ground-water discharge was to the major rivers that incised the Mississippi River Valley alluvial aquifer. During the middle 1970's, withdrawals by wells reduced the amount of water that naturally discharged to the Mississippi River and its tributaries by nearly two-thirds. Well withdrawals presently (1997) represent the principal mechanism of ground-water discharge.

Properly constructed wells capable of yielding 500 gallons per minute can be completed almost anywhere within the Mississippi River Valley alluvial aquifer. Some irrigation wells yield from 1,000 to as much as 5,000 gallons per minute. However, long-term decline in water levels in some areas has resulted in diminished saturated aquifer thickness and reduced aquifer transmissivity. These factors limit the amount of water that can be withdrawn without producing an adverse impact on the aquifer.

Hydrographs for some observation wells completed in the alluvial aquifer show a long-term decline of the potentiometric surface. Most of the long-term decline shown in **figures 36*A* through *C*** is attributed to rice-crop irrigation in eastern Arkansas. Water levels in some wells in Arkansas declined more than 55 feet between 1930 and 1985 as a result of irrigation withdrawals. Long-term declines also are evident locally in Mississippi, as shown in **figure 36*E***, but are not as great as those in Arkansas. In some areas, the Mississippi River Valley alluvial aquifer water levels are not greatly affected by well withdrawals as indicated by **figures 36*D* and *F***. These hydrographs show only seasonal fluctuations or response to variations in precipitation.

Concurrent with a long-term decline in the potentiometric surface of the alluvial aquifer has been a steady change in recharge to and discharge from the aquifer. Before development, recharge entered the aquifer in topographically high areas and most of the water was discharged to rivers. By the middle 1970's, the potentiometric surface had been greatly lowered, and downward leakage from rivers accounted for more than 20 percent of the recharge to the alluvial aquifer. Recharge by upward leakage from the deeper aquifers was increased by the decline in the potentiometric surface of the alluvial aquifer.

Of the water withdrawn by wells completed in the Mississippi River Valley alluvial aquifer, about 20 to 50 percent is obtained from ground water held in storage. A change in the volume of water that discharges from the aquifer or that recharges it results in a change in the volume of water in storage within the aquifer. In an unconfined aquifer, a change in storage is produced by draining or filling pore space within the aquifer. In a confined aquifer, a change in storage is produced by expansion or compression of the aquifer and the water it contains.

Increased rates of withdrawal from wells completed in the Mississippi River Valley alluvial aquifer has paralleled the increase in rice acreage. The cultivation of rice requires large quantities of water to maintain the 4- to 6-inch depth of water on rice fields (**fig. 37**) for the May to August growing season. The rice acreage expanded greatly between 1972 and 1982, but decreased in 1983 in response to a change in the national farm policy. Ground-water withdrawals in rice-growing counties of Arkansas and Mississippi (**fig. 38**) showed a steady increase from 1960 until 1980, then declined in 1985 in direct proportion to a decline in the amount of acreage irrigated for rice.

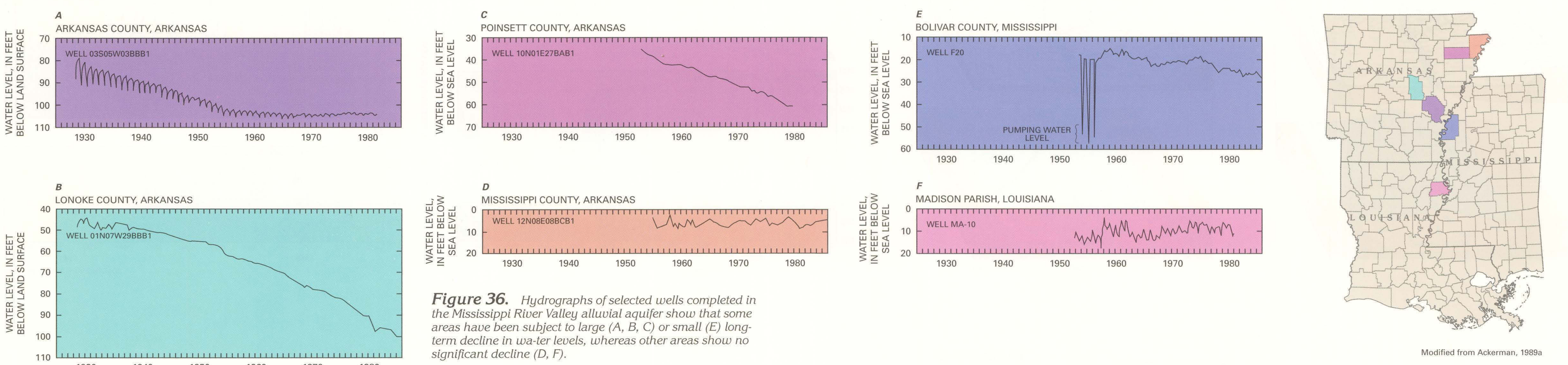


Figure 36. Hydrographs of selected wells completed in the Mississippi River Valley alluvial aquifer show that some areas have been subject to large (A, B, C) or small (E) long-term decline in wa-ter levels, whereas other areas show no significant decline (D, F).

Figure 37. Ground water from the Mississippi River Valley alluvial aquifer is heavily used as a source of water to cultivate rice.

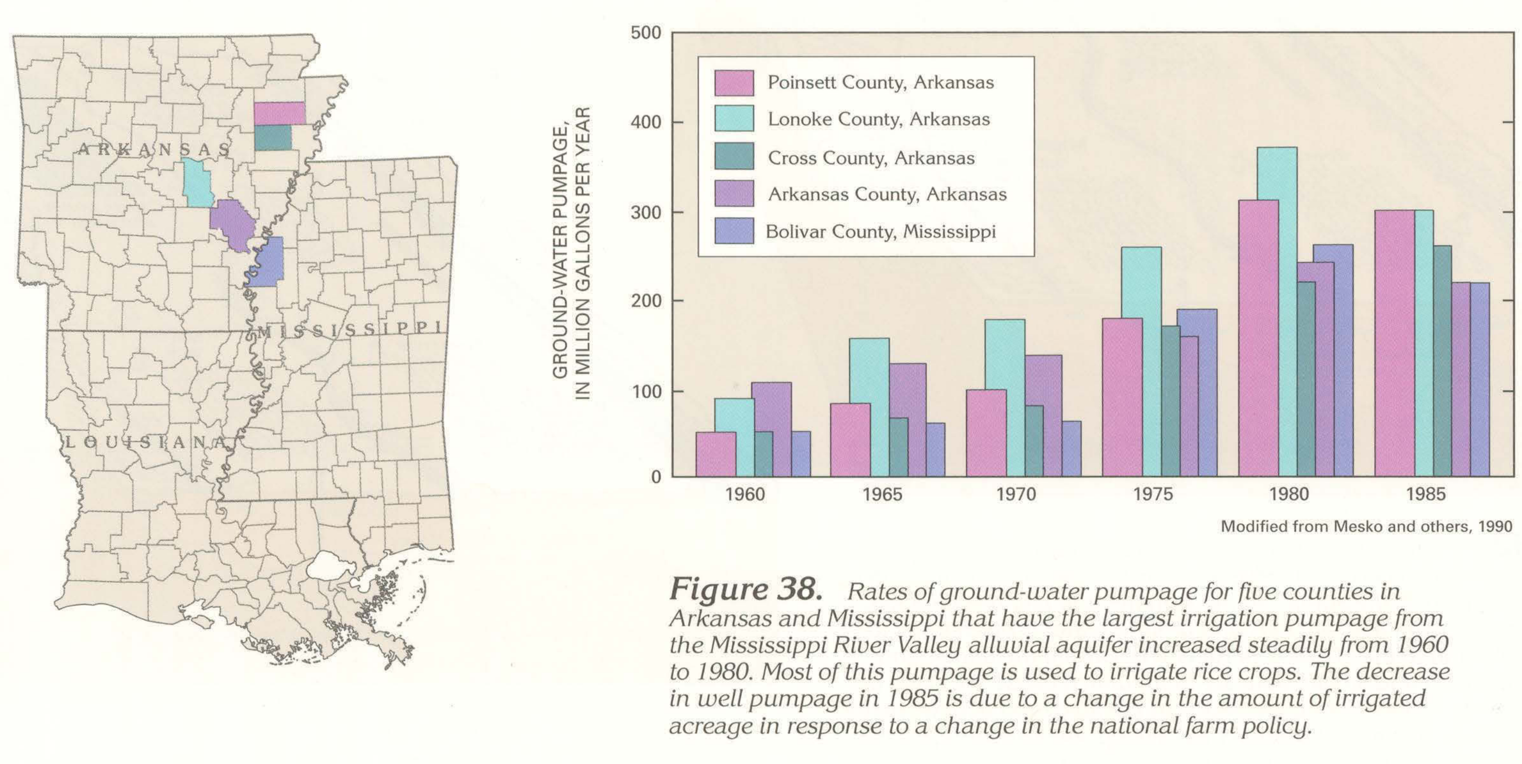
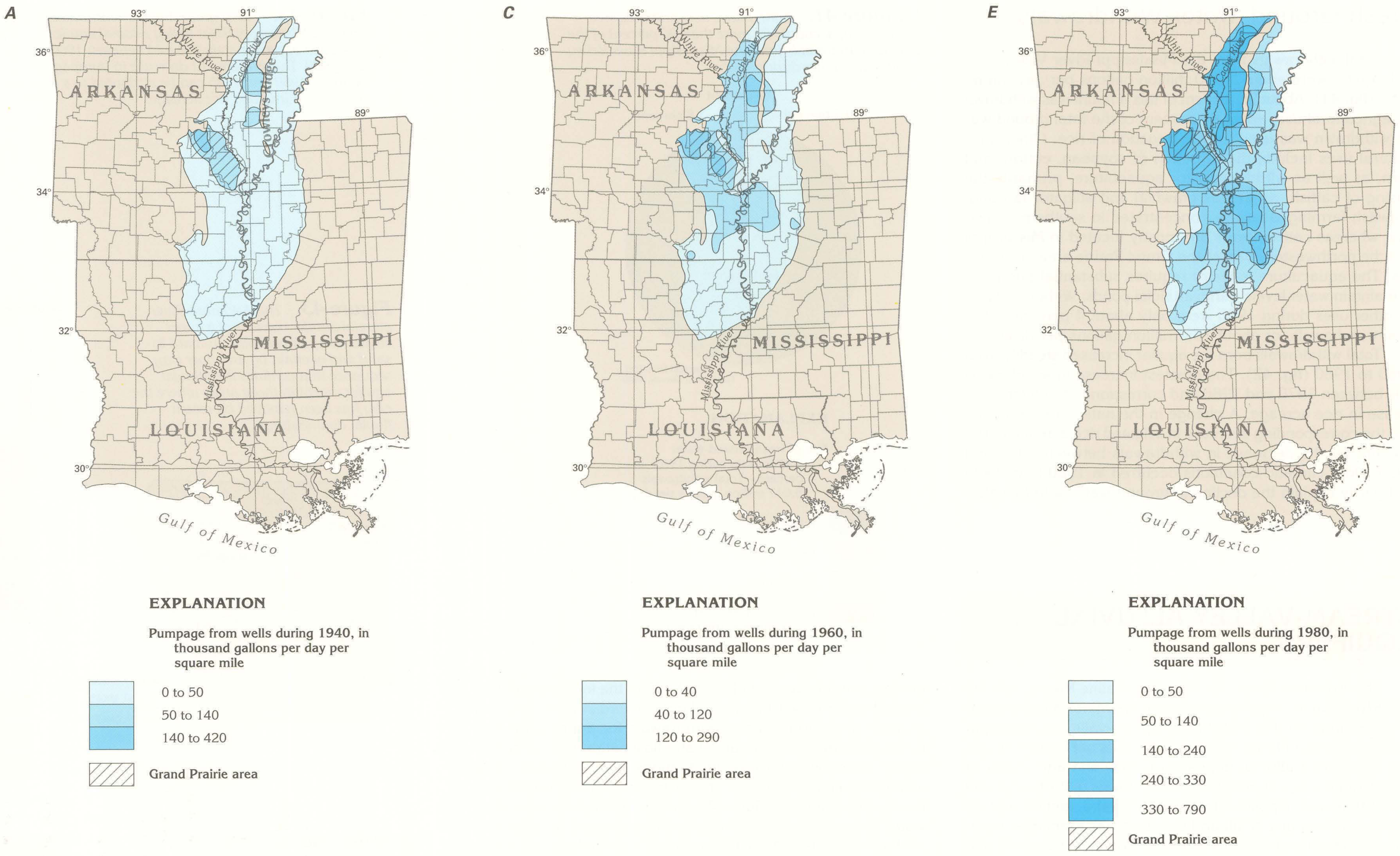


Figure 38. Rates of ground-water pumpage for five counties in Arkansas and Mississippi that have the largest irrigation pumpage from the Mississippi River Valley alluvial aquifer increased steadily from 1960 to 1980. Most of this pumpage is used to irrigate rice crops. The decrease in well pumpage in 1985 is due to a change in the amount of irrigated acreage in response to a change in the national farm policy.

Well Yield, Pumpage, and Long-Term Water-Level Decline—Continued

Pumpage from wells completed in the Mississippi River Valley alluvial aquifer in 1940, 1960, and 1980 (**figs. 39*A, C, E***) illustrates a direct cause-and-effect relation with water-level declines in 1942, 1962, and 1982 (**figs. 39*B, D, F***). In the Grand Prairie, Arkansas, area, adjacent to the White River, water-level decline within the Mississippi River Valley alluvial aquifer was reported as early as 1929. Areas with large water-level declines generally coincide with areas that have been stressed by heavy, long-term pumpage. In 1942, declines that ranged from 40 to 60 feet were reported in the Grand Prairie area (**fig. 39*B***), where withdrawal rates during 1940 were high (**fig. 39*A***). West of Crowleys Ridge, in the Cache River area, irrigation withdrawals were initiated in the 1940's with little decline in the potentiometric surface in 1942. However, as pumpage increased during 1960 (**fig. 39*C***), water-level declines ranged from 40 to 60 feet (**fig. 39*D***). The early 1980's marked a zenith in rice cultivation in Arkansas, northeastern Louisiana, and Mississippi. Large withdrawals from wells during 1980 (**fig. 39*E***) contributed to water level-declines that ranged from 60 to 90 feet in the Grand Prairie and the Cache River areas of Arkansas and from 10 to 20 feet in northwestern Mississippi by 1982 (**fig. 39*F***).



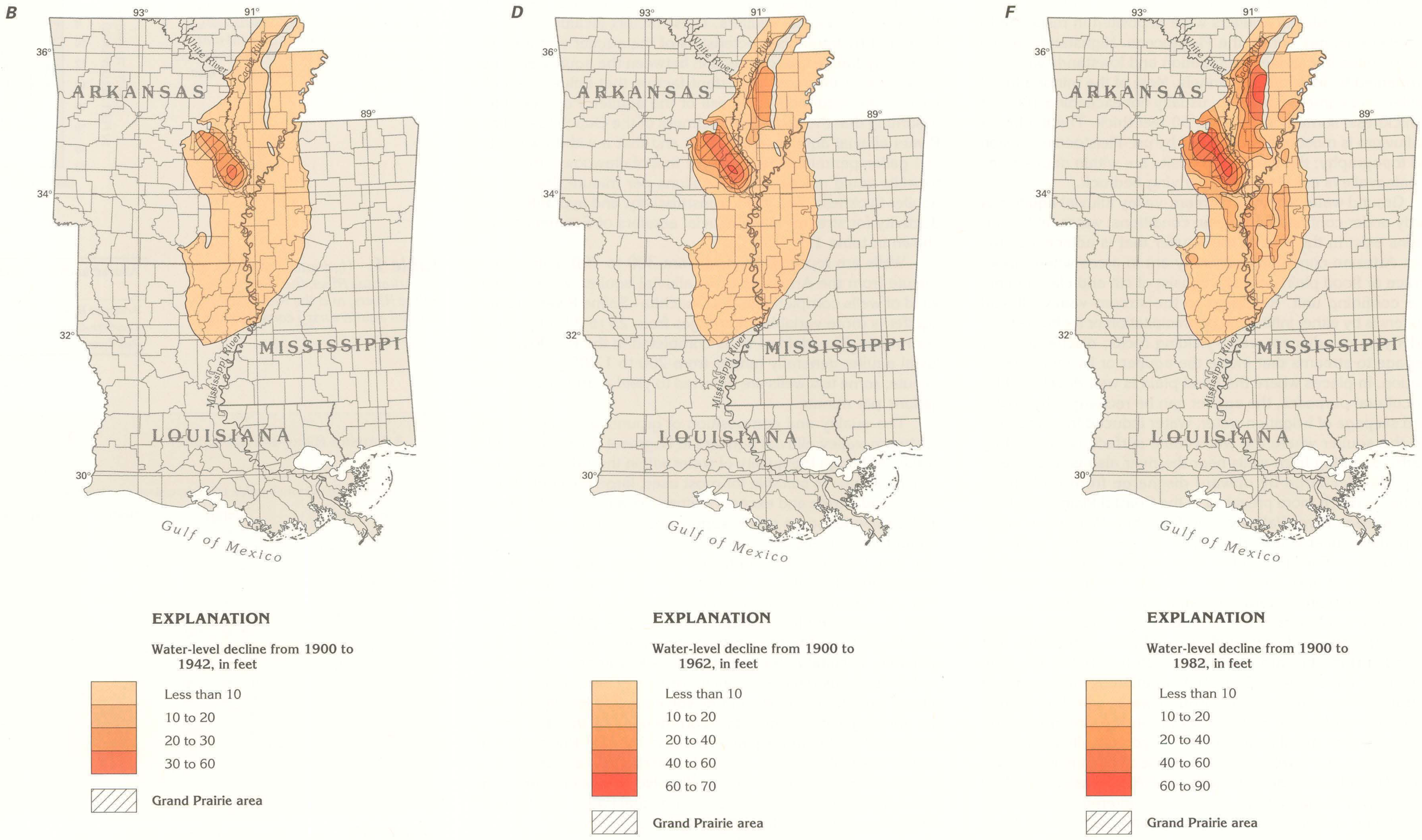


Figure 39. *Expansion of areas of water-level decline in the Mississippi River Valley alluvial aquifer (1942–82) shown in B, D, and F follows trends in pumpage of ground water from wells (1940–80) as shown in A, C, and E. Pumpage of ground water from wells during 1940 (A) was small, and water-level declines in 1942 were restricted to the Grand Prairie area (B). Agricultural needs increased greatly by 1960, and greater pumpage of ground water from wells (C) resulted in a larger drawdown trough in the Grand Prairie and the Cache River areas by 1962 (D). Very large withdrawals in 1980 (E) resulted in large water-level declines recorded over about one-half of the aquifer's extent by 1982 (F).*

Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

SCALE 1:7,500,000
0 25 50 MILES
0 25 50 KILOMETERS

Modified from Ackerman, 1996

Ground-Water Quality

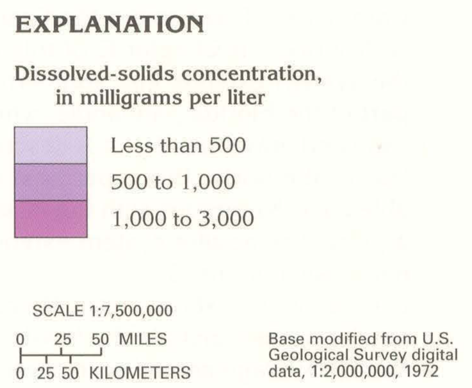
The quality of ground water can be characterized in terms of the hydrochemical facies of the water and its dissolved-solids concentration. Hydrochemical facies are determined by the dominant anions and cations contained within the ground water. For example, a calcium bicarbonate water is one which calcium ions are more than 50 percent of the total cations in the water, and bicarbonate ions are more than 50 percent of the anions. The dissolved-solids concentration is the total concentration of minerals that are in solution. In this report, the dissolved-solids concentration in ground water is used to classify the water as fresh, saline, or brine. The concentrations used to categorize the water are as follows:

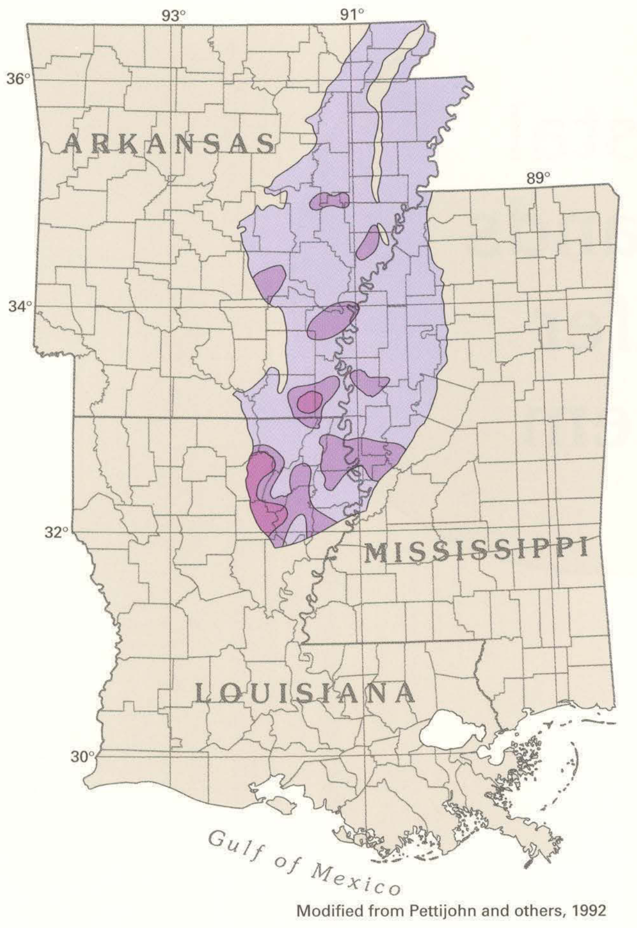
Term	Dissolved-solids concentration, in milligrams per liter
Freshwater	Less than 1,000
Slightly saline water	1,000 to 3,000
Moderately saline water	3,000 to 10,000
Very saline water	10,000 to 35,000
Brine	Greater than 35,000

The chemical constituents in ground water are determined, in part, by the mineralogy of the materials that compose the aquifer and by the length of time the water is in contact with these materials. Meteoric water contains few dissolved solids and enters the flow system as precipitation. As the meteoric water moves down the hydraulic gradient, either the water partially dissolves aquifer minerals or an exchange of ions takes place between the water and the minerals. Accordingly, water in the deeper parts of the aquifer tends to be more mineralized than that in the shallower parts. The water quality of the Mississippi River Valley alluvial aquifer also may be influenced by the upward movement of more mineralized water from underlying aquifers.

The quality of water within the Mississippi River Valley alluvial aquifer generally is suitable for most uses. For the most part, the water can be characterized as a calcium bicarbonate type with dissolved-solids concentrations that are usually less than 500 milligrams per liter (**fig. 40**). In some areas, however, dissolved-solids concentrations range from 1,000 to 3,000 milligrams per liter. Water-quality characteristics that often limit usefulness of water from the Mississippi River alluvial aquifer for public supply are excessive hardness and large concentrations of iron and manganese. The north-to-south increase in dissolved solids within the Mississippi River Valley alluvial aquifer is attributed to mineral-water interaction along ground-water flow paths.

Figure 40. *The dissolved-solids concentrations of water within the Mississippi River Valley alluvial aquifer is less than 500 milligrams per liter in most areas but is larger in the central and southern parts of the aquifer.*





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Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

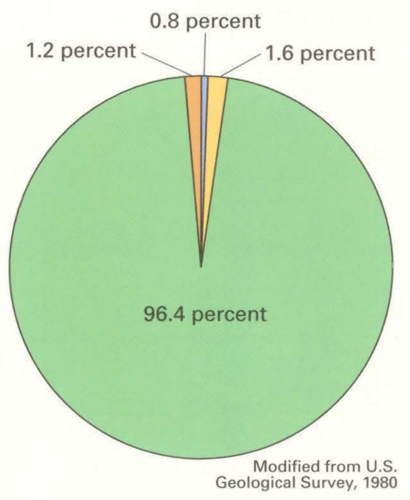
Modified from Pettijohn and others, 1992

Fresh Ground-Water Withdrawals

Total withdrawals from the Mississippi River Valley alluvial aquifer were about 5,050 million gallons per day during 1985 (**fig. 41**). About 96 percent of this amount was withdrawn for agricultural use; about 80 percent of the total ground water withdrawn was used for the irrigation of rice. Other agricultural uses include the irrigation of soybean, cotton, and corn, as well as withdrawals for aquaculture, primarily the raising of catfish, as well as crawfish and alligator farming. Crawfish farming is largely concentrated in southern Louisiana, whereas catfish farms are mostly located in Mississippi and the northwestern part of the Grand Prairie area in Arkansas. The aquaculture industry requires substantial pumpage to maintain water levels within artificial ponds. Withdrawals for all other uses during 1985 were only about 4 percent of the total withdrawals, or about 182 million gallons per day.

Total withdrawals from the aquifer increased steadily from 1960 to 1980 (**fig. 42**). The greatest increase in withdrawals was between 1970 and 1980 and corresponded to a large increase in rice acreage. A change in the national farm policy and the corresponding decrease in irrigated rice acreage partly account for the decrease in withdrawals between 1980 and 1985. Drier climatic conditions occurred in 1980 than 1985 and partly explain the decline in ground-water withdrawals.

Figure 41. *Agricultural use, primarily rice irrigation, accounts for more than 96 percent of the total withdrawals from the Mississippi River Valley alluvial aquifer during 1985.*

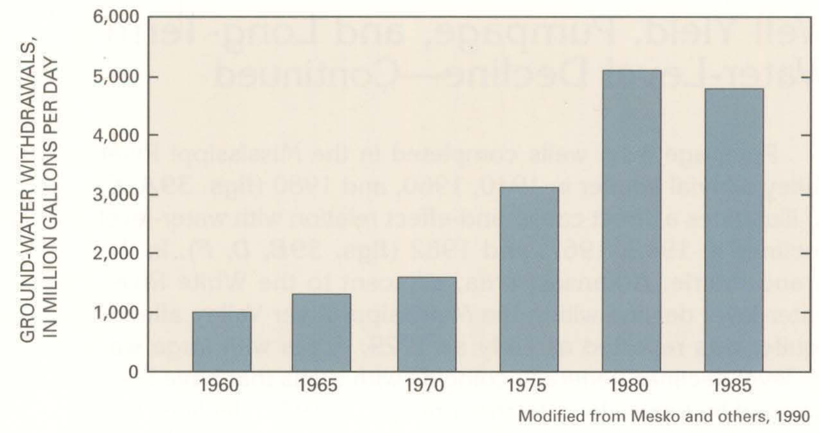


EXPLANATION

Use of fresh ground-water withdrawals during 1985, in percent—Total withdrawals 5,047 million gallons per day

- 0.8 — Public supply
- 1.6 — Domestic and commercial
- 96.4 — Agricultural
- 1.2 — Industrial, mining, and thermoelectric power

Figure 42. *Total ground-water withdrawals from the Mississippi River Valley alluvial aquifer increased approximately five-fold between 1960 and 1980. The subsequent decrease in pumpage between 1980 and 1985 can be attributed to a decrease in irrigated rice acreage.*



STREAM-VALLEY ALLUVIAL AQUIFERS

The Arkansas River, the Ouachita–Saline Rivers, and the Red River alluvial aquifers represent the minor alluvial aquifers of Segment 5 (**fig. 23**). All are stream-valley alluvial aquifers that consist of terraced alluvial deposits of Pleistocene age and flood plain alluvial deposits of Holocene age. Many of these aquifers are characterized by a lower unit of sand and gravel that was deposited by lateral fluvial accretion and an upper confining unit of silt and clay that was formed by vertically accreted flood deposits (**fig. 43**). Holocene sand, silt, and clay deposits that underlie the modern flood plain generally are restricted to a smaller area within the alluvial valley. For the most part, alluvial and terrace deposits that compose these stream-valley alluvial aquifers were deposited in response to sea-level changes during the Pleistocene. Highstands of sea level resulted in channel aggradation and lowstands were accompanied by incision of channels. Most of the minor alluvial aquifers in Segment 5 are thin, usually not exceeding 100 feet in thickness; some are less than 50 feet thick. The thickness of alluvium is most often controlled by pre-Pleistocene erosion and topography; the thickest deposits are within depressions or paleovalleys cut into the underlying bedrock.

Ground water within the stream-valley alluvial aquifers is partly under confined or artesian conditions; water-table conditions exist in the part of the aquifer that is adjacent to the river. Artesian conditions generally are in areas where upper terrace or flood plain deposits consist of silt and clay and act as a confining unit. Recharge to the stream-valley alluvial aquifers is by either infiltration of precipitation or recharge from underlying or adjacent water-yielding rocks; discharge is by seepage to streams that incise the aquifer or by evapotranspiration. In places where the flood plain is well-developed for agricultural purposes, the aquifer can be recharged by downward seepage of irrigation water. Water induced from the river into the aquifer where the water-table surface is lowered by nearby pumping from wells near the river also is a source of recharge. Recharge by upward discharge from underlying aquifers is much more prevalent in the Coastal Plain areas than the Arkansas River Valley or the Ouachita Mountains areas where the aquifer is underlain by poorly permeable bedrock. Ground-water flow in all three stream-valley alluvial aquifers is, for the most part, largely downstream with a local component of movement toward the major stream channels.

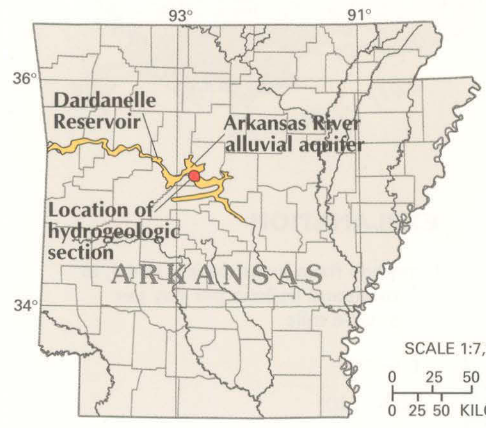
Water levels within the Arkansas, the Ouachita–Saline, and the Red River alluvial aquifers usually are within a few feet of land surface but are as much as 25 feet below the land surface in some places. Seasonal variation in the amount of rainfall and varying rates of ground-water withdrawal may cause as much as a 10-foot change in the potentiometric surface. Where the alluvial aquifer is hydraulically connected to the river, water levels vary in response to change in the river stage. Hydrologic conditions within the Arkansas and the Red River alluvial aquifers have been locally altered by the reservoirs, locks and dams, and levees built on these rivers. Such control structures have locally raised upstream river stages and nearby ground-water levels, which affect the local direction of ground-water flow. Changes in land use and in the amount of ground- and surface-water withdrawals for agricultural purposes also affect local ground-water flow patterns. The "dampening" effect on water-level fluctuations in the Arkansas River alluvial aquifer as a result of construction of the Dardanelle Reservoir is shown on **figure 44**. Before reservoir construction, water levels near the river fluctuated seasonally as much as 10 feet each year. After the reservoir was completed, water levels have varied less than 5 feet per year.

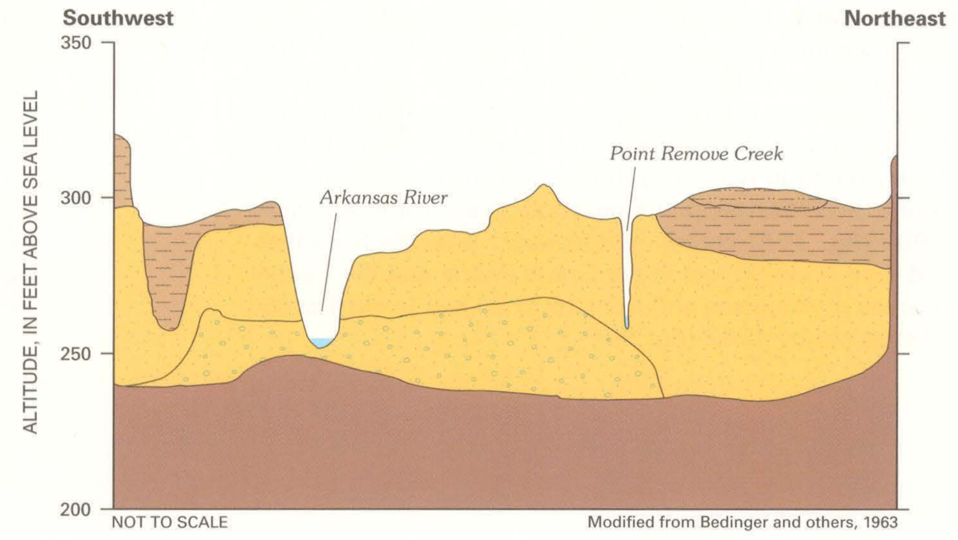
Several factors control the yield of water to wells completed in the Arkansas River, the Ouachita–Saline Rivers, and the Red River alluvial aquifers. These factors include the lithologic and hydraulic characteristics of the aquifer and the degree of hydraulic interconnection between the aquifer and the river. One of the most important factors that influences well yield is the saturated thickness of the aquifer. For example, assuming that the saturated thickness of the Ouachita–Saline Rivers alluvial aquifer was 25 feet and that a withdrawal rate of 1 gallon per minute resulted in 1 foot of drawdown, the yield to wells could not exceed 25 gallons per minute. Ranges of aquifer thickness, well yield, transmissivity, and hydraulic conductivity for stream-valley alluvial aquifers of Segment 5 are shown in **table 1**.

Wells are reported to yield from 300 to 700 gallons per minute from the Arkansas River alluvial aquifer, whereas the yield of wells completed in the Ouachita–Saline River alluvial aquifer is more variable and ranges from 25 to 2,500 gallons per minute. The yield of wells completed in the Red River alluvial aquifer generally ranges from 200 to 1,700 gallons per minute; some test wells are reported to yield as much as 2,800 gallons per minute.

The quality and composition of ground water contained in stream-valley alluvial aquifers in Segment 5 varies considerably. Although the quality of water within the Arkansas River alluvial aquifer is suitable for most uses, large concentrations of iron and nitrate and excess hardness locally make the water undesirable for some public supply and industrial uses. Water within this aquifer is a calcium magnesium bicarbonate type (**fig. 45**). Ground-water contained within the Ouachita–Saline Rivers alluvial aquifer can vary greatly in chemical composition and hardness. Water from this aquifer ranges from a sodium bicarbonate to a sodium chloride type. Although water withdrawn from the Ouachita–Saline Rivers alluvial aquifer generally is suitable for irrigation, stock watering, domestic, and some industrial uses, concentrations of iron, manganese, nitrate, sulfate, chloride, and dissolved solids locally exceed the drinking water standards recommended by the U.S. Environmental Protection Agency. Water in the Red River alluvial aquifer is suitable chiefly for stock watering and irrigation purposes; concentrations of iron and dissolved solids in water from this aquifer may exceed U.S. Environmental Protection Agency recommended secondary drinking water standards.

Figure 43. *The Arkansas River alluvial aquifer consists of a lower sequence of gravel fining upward to sand and overlain by an upper clay sequence that confines the alluvial aquifer except in those areas where the clay has been removed by recent fluvial downcutting.*





EXPLANATION

Aquifer	Confining unit
Arkansas River alluvial aquifer	Silt
Sand	Clay
Sand and gravel	Bedrock

Figure 44. *Fluctuations in water levels in a well completed in the Arkansas River alluvial aquifer near the Dardanelle Reservoir show the effect of construction of the reservoir on aquifer water levels. Before its construction, seasonal fluctuations in ground-water levels ranged from 6 to 10 feet, whereas postconstruction fluctuations are less than 5 feet.*

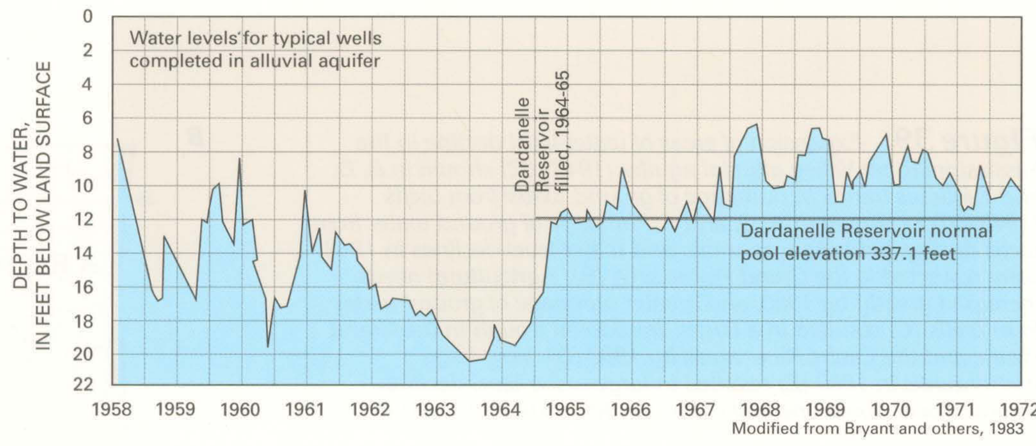


Table 1. *Hydraulic properties of the Arkansas River, the Ouachita–Saline Rivers, and the Red River alluvial aquifers vary considerably.*

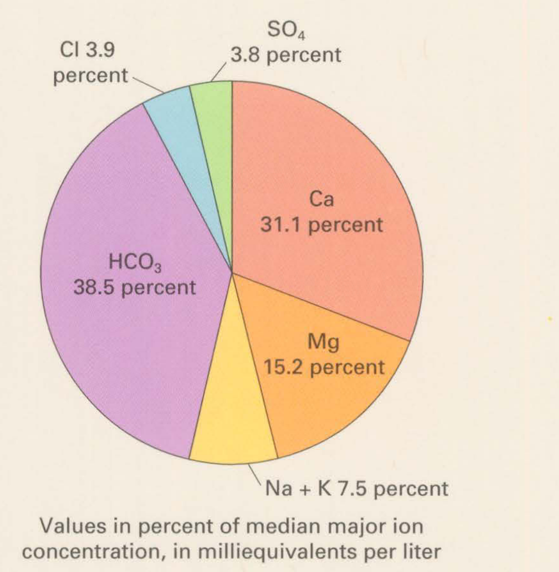
Alluvial aquifer	Aquifer thickness, in feet	Well yield, in gallons per minute	Transmissivity, in feet squared per day	Hydraulic conductivity, in feet per day
Arkansas River	40 to 80	300 to 700	5,360 to 21,440	174 to 402
Ouachita–Saline Rivers	1 to 40	25 to 2,500	25 to 3,500	[1]25 to [1]100
Red River	1 to 150	200 to 2,800	3,900 to 15,400	138 to 257

[1]Estimated from Bedinger and others, 1963; Plebuch and Hines, 1969; and Ludwig, 1972

Arkansas River alluvial aquifer

Concentrations in milligrams per liter, unless otherwise specified

Constituent	Range	Median	Number of samples
pH (units)	6.3 to 9.5	8.1	428
Hardness ($CaCO_3$)	20 to 1,260	228	370
Calcium (Ca)	0.5 to 159	54	54
Magnesium (Mg)	3 to 70	16	53
Sodium (Na)	3.7 to 63	14	36
Potassium (K)	0.8 to 8.2	1.6	37
Bicarbonate (HCO_3)	7.9 to 1,050	204	298
Sulfate (SO_4)	0.4 to 253	16	306
Chloride (Cl)	1 to 270	12	463
Fluoride (F)	0.1 to 0.2	0.1	7
Silica (SiO_2)	16 to 35	21	9
Dissolved solids	88 to 685	297	19
Nitrate (NO_3)	0 to 298	5.8	265
Iron (Fe)	0 to 6.2	0.1	224



Data from Bryant and others, 1983

Figure 45. *Water from the Arkansas River alluvial aquifer is hard and is a calcium magnesium bicarbonate type. Dissolved-solids concentrations locally exceed 500 milligrams per liter.*

Coastal lowlands aquifer system

INTRODUCTION

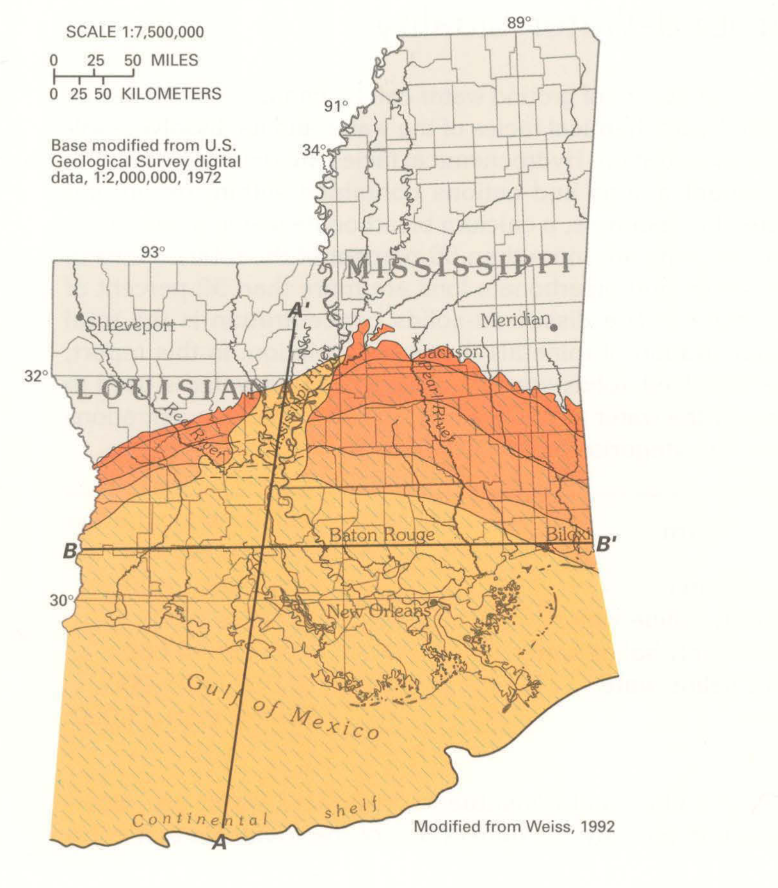
The coastal lowlands aquifer system consists of a gulfward-thickening, heterogeneous, unconsolidated to poorly consolidated wedge of discontinous beds of sand, silt, and clay that range in age from Oligocene to Holocene (**fig. 46**). The aquifer system underlies parts of the East and West Gulf Coastal Plain and the Mississippi Alluvial Plain Sections of the Coastal Plain Physiographic Province. The coastal lowlands aquifer system in Segment 5 extends eastward from Texas across southern and central Louisiana into southern Mississippi. The aquifer system extends westward and southwestward across Texas to the Rio Grande; this part of the system is described in Chapter E of this Atlas. A very small part of the system extends into southern Alabama and the western part of the Florida panhandle, where the system is called the sand and gravel aquifer; it is described in Chapter G of this Atlas. To the north, the uppermost unit of the system (Permeable zone A) merges with the Mississippi River Valley alluvial aquifer. The aquifer system extends to the edge of the continental shelf in the Gulf of Mexico, but it contains saline water in most of its offshore areas. Major rivers that flow across this aquifer system include the Mississippi, the Pearl, and the Red Rivers. Average annual precipitation ranges from 56 inches in western Louisiana to as much as 68 inches in southeastern Mississippi. The coastal lowlands aquifer system yields large quantities of water for agricultural, public supply, domestic and commercial, and industrial uses.

Figure 46. *The coastal lowlands aquifer system crops out in a large area in southern Louisiana and Mississippi. Five regional zones of permeability (Permeable zones A–E) compose the aquifer system.*

EXPLANATION

Coastal lowlands aquifer system

- Permeable zone A (Holocene to upper Pleistocene deposits)
- Permeable zone B (lower Pleistocene to upper Pliocene deposits)
- Permeable zone C (lower Pliocene to upper Miocene deposits)
- Permeable zone D (middle Miocene deposits)
- Permeable zone E (lower Miocene to upper Oligocene deposits)
- Contact of hydrogeologic unit—Dashed where buried
- Downdip limit of aquifer system
- A——A' Line of hydrogeologic section



COASTAL LOWLANDS AQUIFER SYSTEM—Continued

Permeable zones of the coastal lowlands aquifer system typically consist of interbedded sand and clay, rather than the massive, areally extensive sand beds common in other Coastal Plain aquifers and aquifer systems described in this Atlas segment. Numerous water-yielding and confining zones within the coastal lowlands aquifer system have been identified and mapped locally. Many local aquifer names have been applied to parts of the aquifer system primarily in Louisiana (**fig. 47**). The "Chicot aquifer" and the "Evangeline aquifer" are names commonly applied to the upper part of the coastal lowlands aquifer system in southwestern Louisiana. However, these aquifers do not extend into southeastern Louisiana as mappable hydrogeologic units. In the southeastern part of the State, therefore, an entirely different nomenclature is used for local aquifers; many of the aquifers in southeastern Louisiana have been named according to the depth at which they are usually encountered in the industrial districts of Baton Rouge and New Orleans, where ground-water pumpage is substantial (for example, the "1,200-foot" sand). Because of the regional southward dip of the aquifers and because they are cut and displaced by faults, the "1,200-foot" sand at New Orleans is not the same permeable unit as the "1,200-foot" sand at Baton Rouge. In this case, as in other cases, the same name has been applied locally to water-yielding strata that are neither stratigraphically equivalent nor hydraulically interconnected.

The diverse nature of the texture and thickness of the strata in the coastal lowlands aquifer system makes extension of local hydrogeologic units into a regional sequence extremely difficult. Lenticular sand and clay beds of the aquifer system have lateral and vertical boundaries that are gradational, poorly constrained, and difficult to trace over more area than a few counties or parishes. Some water-yielding zones and local aquifers have been distinguished solely on the basis of local differences in hydraulic head or hydraulic conductivity. In many cases, such distinguishing characteristics are important only locally. The aquifer system composes mostly deltaic and associated marginal marine deposits in which changes in lithologic facies are rapid, numerous, and complex. Intrastate and interstate correlation, even with the aid of geophysical well logs and paleontologic information, usually is extremely tenuous. Correlation is further complicated by the presence of numerous growth faults that vertically displace the hydrogeologic units and by the lack of widespread marker horizons or continuous clay beds. The lack of widespread clay beds means that few continuous confining units can be used to divide the section into the customary sequence of alternating aquifers and confining units. Despite all these difficulties, intensive studies have indicated that the aquifer system can be divided into five permeable zones of regional extent (**fig. 47**).

THICKNESS AND EXTENT

From a landward featheredge, sediments that compose the coastal lowlands aquifer system extend and thicken coastward or toward the axis of the Mississippi Embayment. The oldest sediments of the aquifer system are exposed farthest inland, with belts of progressively younger sediments exposed coastward in an offlap relation. A notable exception are the youngest sediments that compose the aquifer system's uppermost water-yielding unit, Permeable zone A. This zone locally overlaps older strata where it extends northward and merges with the Mississippi River Valley alluvial aquifer.

The thickness of the coastal lowlands aquifer system is greatest in southern Louisiana and adjoining offshore areas where the aquifer system is more than 14,000 feet thick (**fig. 48**). The thickness of the aquifer system and its downdip, gulfward extent are determined, in part, by progressive facies change as permeable deltaic sands grade seaward to less permeable prodelta silt and clay. These prodelta sediments are fine-grained terrigenous clastics deposited from suspension seaward of the delta front. The coastal lowlands aquifer system consists largely of sediments deposited in a deltaic to marginal marine environment. The aquifer system, therefore, contains a highly interbedded mix of sand and clay. Thick sand beds of wide areal extent are uncommon.

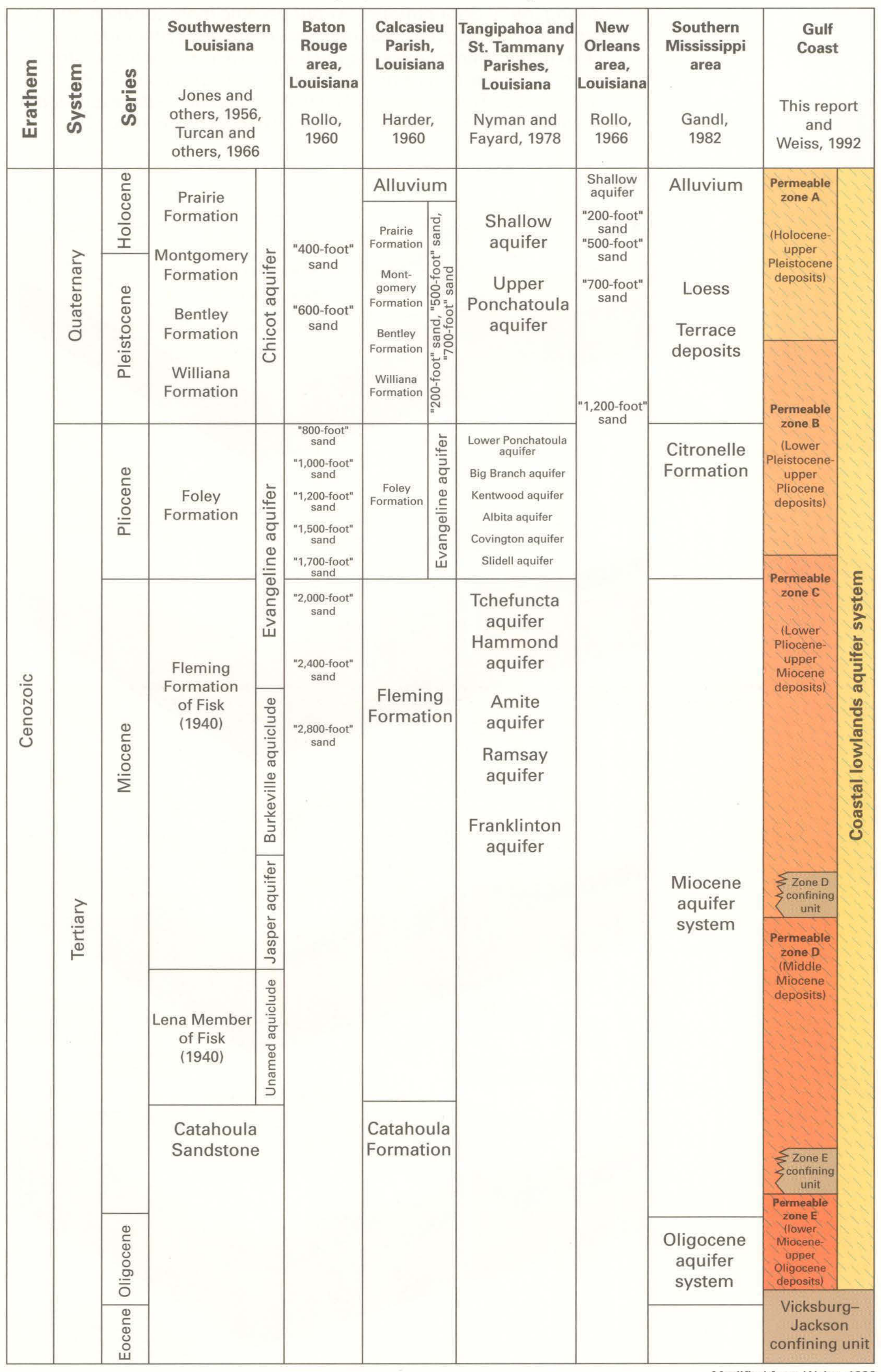
A second factor that determines the gulfward extent and thickness of the coastal lowlands aquifer system is the depth to the top of the geopressured zone (**figs. 49, 50**). In deep subsurface areas of southern Louisiana, southern Mississippi, and the Gulf of Mexico, the coastal lowlands aquifer system is truncated downdip by the geopressured zone, which is a zone of abnormally high fluid pressures that lies at depths that usually range from more than 5,000 to 13,000 feet in southern Louisiana. Under normal rates of sedimentation, water called formation water is trapped between sediment grains but is expelled when the sediments compact as they are slowly buried by younger sediments. The geopressured zone, however, contains formation water that was trapped in the sediments under conditions of very rapid burial and sediment compaction; the buried sediments remain undercompacted and the formation water is under great pressure. Extensive growth faulting in southern Louisiana also contributed to formation of the geopressured zone. The faults isolated and hydraulically cut off beds into sealed compartments. These faults eliminated the opportunity for pressured pore water to dissipate as sediments were more deeply buried. Movement of water within the geopressured zone is extremely slow and a small volume of geopressured water moves upward toward the meteoric flow system, but the amount is minuscule relative to the quantity of water that circulates within the coastal lowlands aquifer system. The geopressured water moves only into deeply buried parts of the aquifer system that contain highly mineralized water.

HYDROGEOLOGIC UNITS

Recent studies have separated the coastal lowlands aquifer system into five zones of permeability as part of a regional assessment of ground-water conditions in coastal Texas, southern Louisiana, and southern Mississippi. The equivalency of the five permeable zones with local aquifers is shown in **figure 48**. Owing to the difficulty of making stratigraphic and hydrogeologic correlations within the coastal lowlands aquifer system and to the general absence of widespread confining units, a set of hydrologic criteria is used to delineate and map the regional permeable zones. A comparison of conditions in the permeable zones indicates that large contrasts in hydraulic head increase with depth and that differences in hydraulic conductivity between different zones are large. Where such differences are not readily observable, separation of the permeable zones tends to be arbitrary. Although the five zones are called permeable zones because they are difficult to define precisely, they can be considered to be regional aquifers because of their wide extent and great thickness. All the zones consist of unconsolidated to poorly consolidated beds of sand and clay.

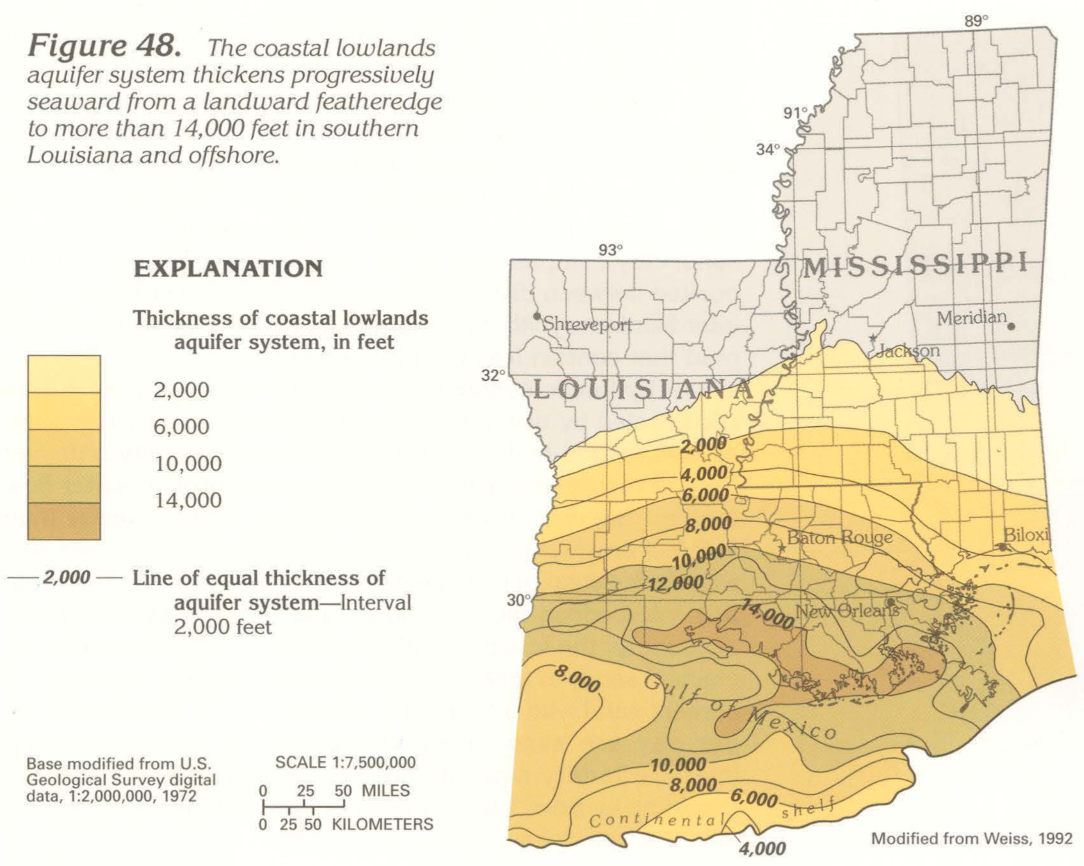
In the deep subsurface of southern Louisiana and offshore areas near southwestern Louisiana, the deltaic sediments of the coastal lowlands aquifer system grade to a marine sequence that contains two extensive clay beds. These clay beds were used to separate and map regionally the two lowermost permeable zones of the coastal lowlands aquifer system. A widespread, effective confining unit underlies the coastal lowlands aquifer system throughout its extent in Louisiana and Mississippi (**figs. 49, 50**). This confining unit, known as the Vicksburg–Jackson confining unit, separates the coastal lowlands aquifer system from the underlying Mississippi embayment aquifer system.

Figure 47. *Rocks of Oligocene to Holocene age compose the coastal lowlands aquifer system in Louisiana and Mississippi. Several different naming schemes have been applied to numerous local aquifers in different parts of the aquifer system. This chart is not a comprehensive list of rock-stratigraphic names and aquifers.*



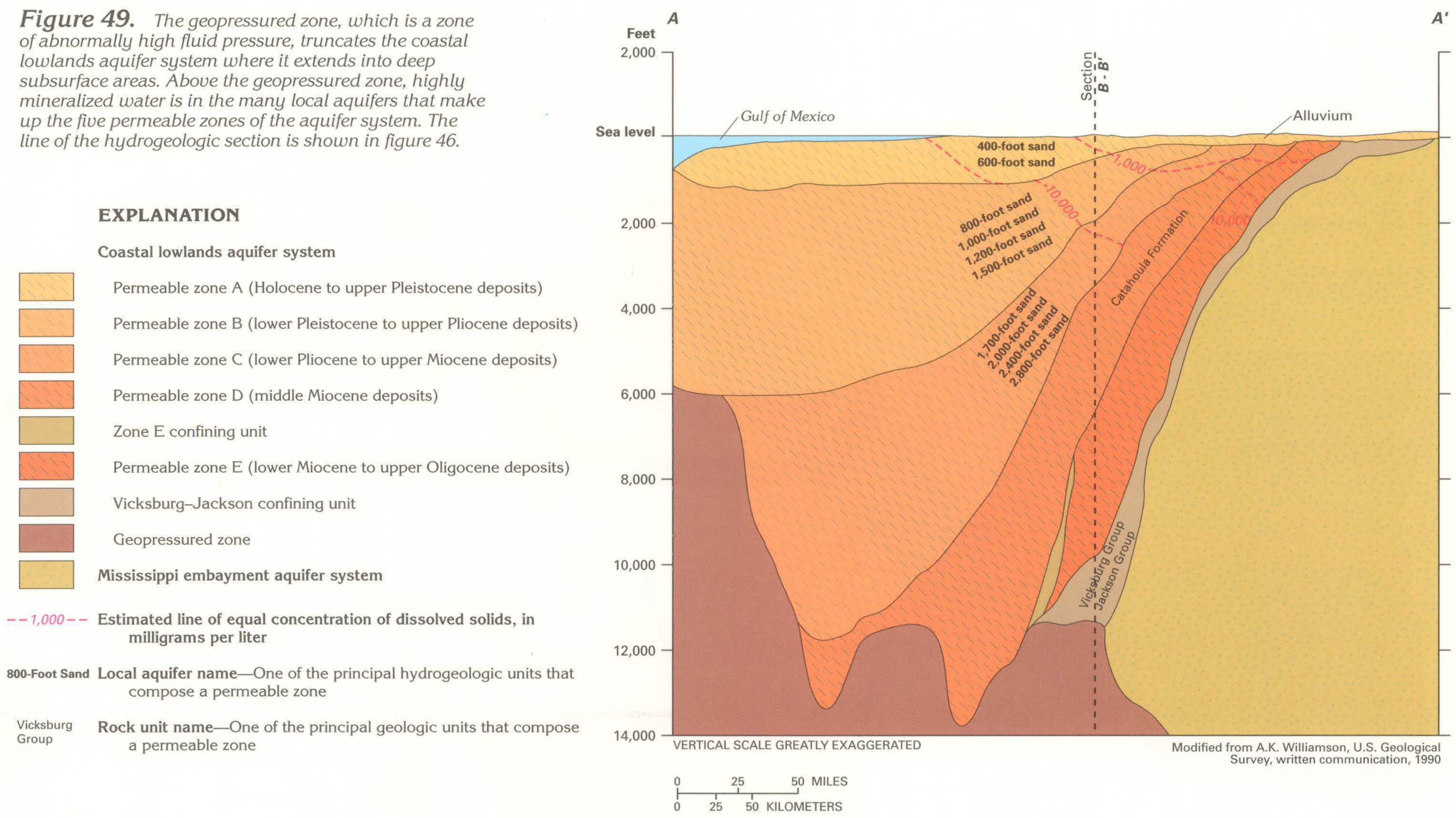
Modified from Weiss, 1992

Figure 48. *The coastal lowlands aquifer system thickens progressively seaward from a landward featheredge to more than 14,000 feet in southern Louisiana and offshore.*



Modified from Weiss, 1992

Figure 49. *The geopressured zone, which is a zone of abnormally high fluid pressure, truncates the coastal lowlands aquifer system where it extends into deep subsurface areas. Above the geopressured zone, highly mineralized water is in the many local aquifers that make up the five permeable zones of the aquifer system. The line of the hydrogeologic section is shown in figure 46.*



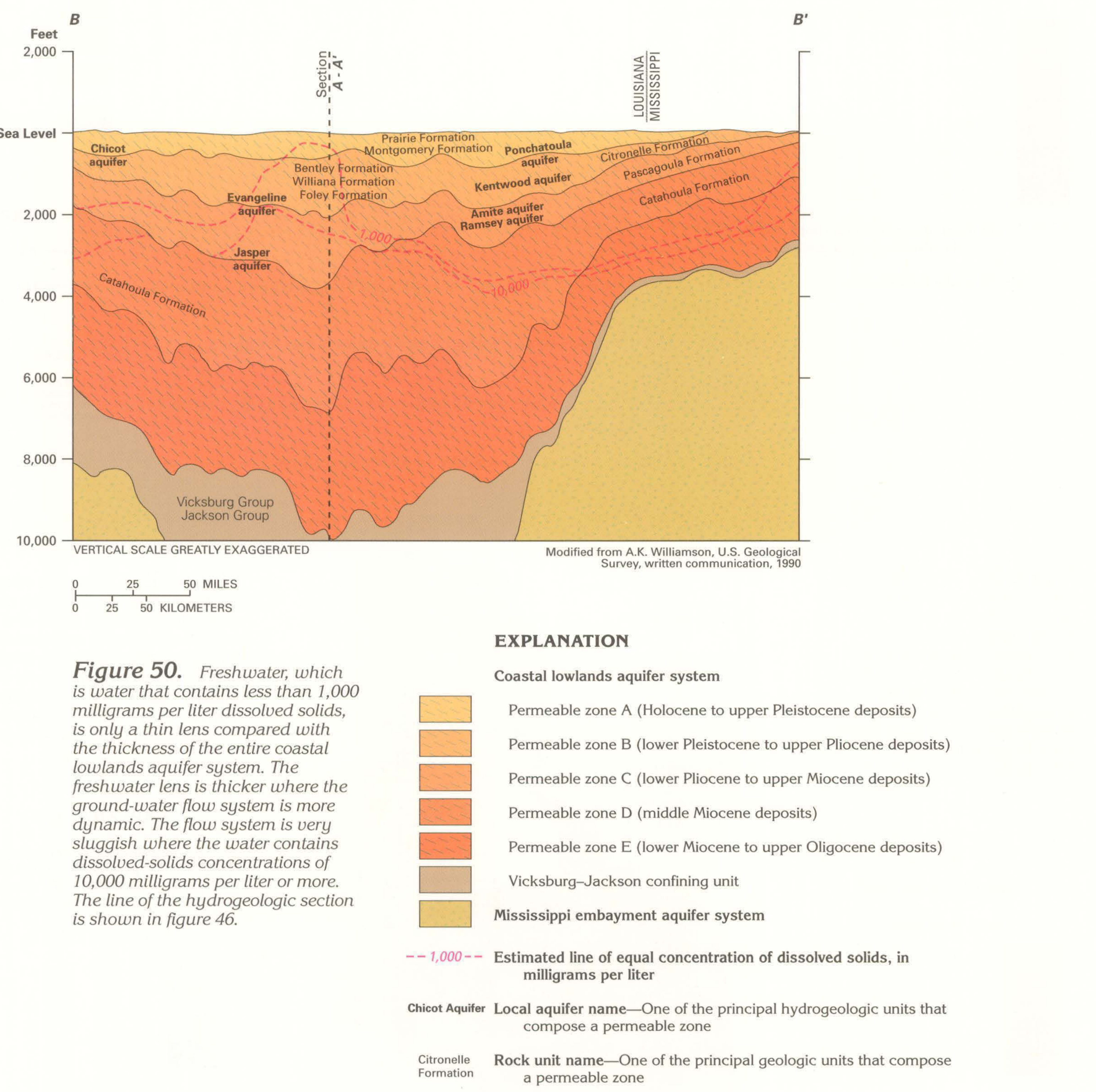


Figure 50. *Freshwater, which is water that contains less than 1,000 milligrams per liter dissolved solids, is only a thin lens compared with the thickness of the entire coastal lowlands aquifer system. The freshwater lens is thicker where the ground-water flow system is more dynamic. The flow system is very sluggish where the water contains dissolved-solids concentrations of 10,000 milligrams per liter or more. The line of the hydrogeologic section is shown in figure 46.*

HYDROGEOLOGIC UNITS—
Continued

Permeable zone A consists of deposits of Holocene to late Pleistocene age. Because it is widespread and contains freshwater in most places, it is the most intensively pumped aquifer of the system, and, for this reason, it is the only zone for which the hydrogeology is described in this report in detail. Permeable zone A is thickest in southern Louisiana where its thickness is greater than 1,000 feet near the coast (**fig. 51**). In northeastern Louisiana, it merges with the Mississippi River Valley alluvial aquifer. Alluvial deposits of the Mississippi River Valley that overlie Permeable zones B through E of the coastal lowlands aquifer system are not considered to be part of the Mississippi River Valley alluvial aquifer because those deposits are hydraulically well connected to the wide, coast-parallel band of Holocene and upper Pleistocene deposits in southern Louisiana and southwestern Mississippi that makes up the main body of Permeable zone A.

Permeable zone B, which comprises deposits of early Pleistocene to late Pliocene age, underlies zone A. The two zones are not separated by an intervening confining unit; separation of the two aquifers is based solely on differences in vertical hydraulic gradient and hydraulic conductivity. The part of Permeable zone B that contains freshwater generally is less than 1,000 feet thick. Freshwater parts of the aquifer in the southern Mississippi and central Louisiana subsurface generally are at depths of more than 500 feet below sea level. In eastern Louisiana, the aquifer may contain freshwater at depths from 600 to 700 feet below sea level. Permeable zone B is the second most intensively pumped aquifer of the coastal lowlands aquifer system; most withdrawals from the zone are concentrated in the Baton Rouge industrial area.

Permeable zone C consists of deposits of early Pliocene to late Miocene age, Permeable zone D comprises deposits of middle Miocene age, and Permeable zone E consists of deposits of early Miocene to late Oligocene age. Permeable zones C, D, and E crop out as narrow bands that extend across central Louisiana and southern Mississippi and thicken in the subsurface as they extend coastward (**fig. 50**). Each aquifer is truncated at its southernmost extent by the geopressured zone. In the coastal areas of Louisiana and adjacent offshore areas, a deeply buried confining zone separates Permeable zones D and E. Offshore from southwestern Louisiana, a second confining unit separates Permeable zones C and D. These confining zones pinch out, or grade by facies change to more permeable strata, as they extend updip into the shallower subsurface. For the most part, however, the confining units separate only the parts of Permeable zones C, D, and E that contain saline water or brine. The freshwater lens contained within Permeable zones C, D, and E generally is less than 2,000 feet thick and lies at depths that are shallower than 2,000 feet below sea level.

RELATION BETWEEN GEOLOGY AND PERMEABILITY

Understanding the physical framework of the clastic lithofacies of the aquifers of the coastal lowlands aquifer system is useful in predicting the hydraulic characteristics of the aquifers. Hydraulic and lithofacies data can be compared to help understand lateral heterogeneity within the aquifer system. Lithofacies maps provide valuable insight into the distribution of permeability in clastic Coastal Plain aquifers, especially where hydraulic data are limited, and can be used as a predictive tool in the search for previously overlooked or unexplored sites suitable for development of ground-water resources.

In an aquifer that comprises clastic sediments, the hydraulic conductivity of the aquifer is directly influenced by particle size and shape, the degree of particle packing and sorting, the amount of clay or fine-grained material that fills intergranular pore spaces, and cementation of the sediments. To a large degree, these factors are influenced by the depositional history of the rock. In southern Louisiana, the compaction of sediments that follows their burial results in a systematic loss in the porosity of sand beds that averages 1.28 percent per 1,000 feet of burial depth. The reduction in porosity of clay beds as a result of burial is much greater and averages 20 percent per 1,000 feet of burial depth. The hydraulic conductivity of the unconsolidated to poorly consolidated sediments that compose Coastal Plain aquifers does not appear to be greatly altered by diagenesis and geochemical processes. The distribution of hydraulic conductivity in Coastal Plain aquifer, therefore, can be estimated from maps of lithofacies, because the correlation between sediment type and aquifer permeability is direct.

Sediments that compose the coastal lowlands aquifer system were, for the most part, transported by rivers and streams that flowed coastward and were deposited in deltaic environments. For the most part, sufficient quantities of fluvially transported sand, silt, and clay were deposited in subaerial and subaqueous environments near the coast at a rate that exceeded removal of the sediments by wave action and longshore currents. As a result, constructional deltas prograded or built outward into the Gulf of Mexico, primarily from the mouth of the Mississippi River.

Constructional deltas are characterized by either distributaries with a lobate (fan) shape (**fig. 52*A***) or an elongate (bird-foot) shape (**fig. 52*D***). Lobate and elongate distributaries have sand deposits in the distributary channels and as arcuate accumulations at the delta front, where the sand settles out of suspension when the river water confined in the distributary loses velocity as it enters deeper water (**fig. 53**). Fine-grained deposits of silt and clay accumulate as interdistributary bay, swamp and marsh deposits within the delta plain as prodelta clays are deposited seaward of the delta-front sands.

Delta-plain and delta-front facies show a complex distribution associated with lobe (**fig. 52*B***) and elongate (**fig. 52*E***) distributary patterns. The branching of lobate distributaries resembles the splayed fingers of a human hand, and these distributaries tend to build a fan-shaped delta outward into the Gulf of Mexico. In the lobate delta front, the coarsest sands are in the distributary mouth bars; grain size diminishes seaward through the delta-front slope, with only silt and clay deposited within the prodelta area. Delta-front deposits are a mixture of clay, silt, and fine to coarse sand and accumulate mostly under the influence of currents and wave action. On the lobate delta plain, coarse-grained deposits are in distributary channels and adjacent levees, whereas interdistributary deposits are fine grained. Lower delta-plain distributary channel sands tend to be restricted in lateral extent, thus forming straight, narrow channels. Upper delta-plain point-bar sands form disconnected, linear, lenticular sand bodies that show evidence of lateral migration by meandering. Sandy crevasse-splay deposits are located in the lower part of the delta plain where lowlying levees are easily breached; sand accumulates as a small fan or delta as floodwaters flow over the levee into the interdistributary areas. Silt and clay are the principal sediment types of interdistributary bay, marsh, and swamp environments; these sites areally compose the largest part of the lower delta plain. The delta-front facies is small in an elongate delta compared with a lobate delta. The delta-plain facies parallel elongate distributary channels and are more complex than the facies of a lobate delta but show a banded pattern of sediment that is progressively finer with increasing distance from the distributary channel.

Sand accumulations along lobate (**fig. 52*C***) and elongate (**fig. 52*F***) distributaries reflect the general shape of the distributary. In both types of distributaries, the axis of maximum sand thickness is located at the distributary channel. Sand thickness decreases in all directions away from the channel. An important factor that controls the type of constructional delta that forms is the thickness of the underlying clay beds. Elongate deltas tend to overlie thick prodelta clay deposits that subside and compact in response to sediment loading, thus helping preserve the distributary channels. Lobate deltas tend to overlie thinner prodelta clays that do not afford great differential subsidence; distributary channels are more numerous and thinner. Lobate and elongate (bird-foot) distributary channel facies are reported in buried sedimentary strata of the coastal lowlands aquifer system.

Figure 51. *Permeable zone A, which is the uppermost aquifer of the coastal lowlands aquifer system, consists of deposits of Holocene to late Pleistocene age and is locally more than 1,200 feet thick offshore. Water that contains less than 1,000 milligrams per liter dissolved solids is located near or just north of the coastline and where the aquifer generally is less than 1,000 feet thick.*

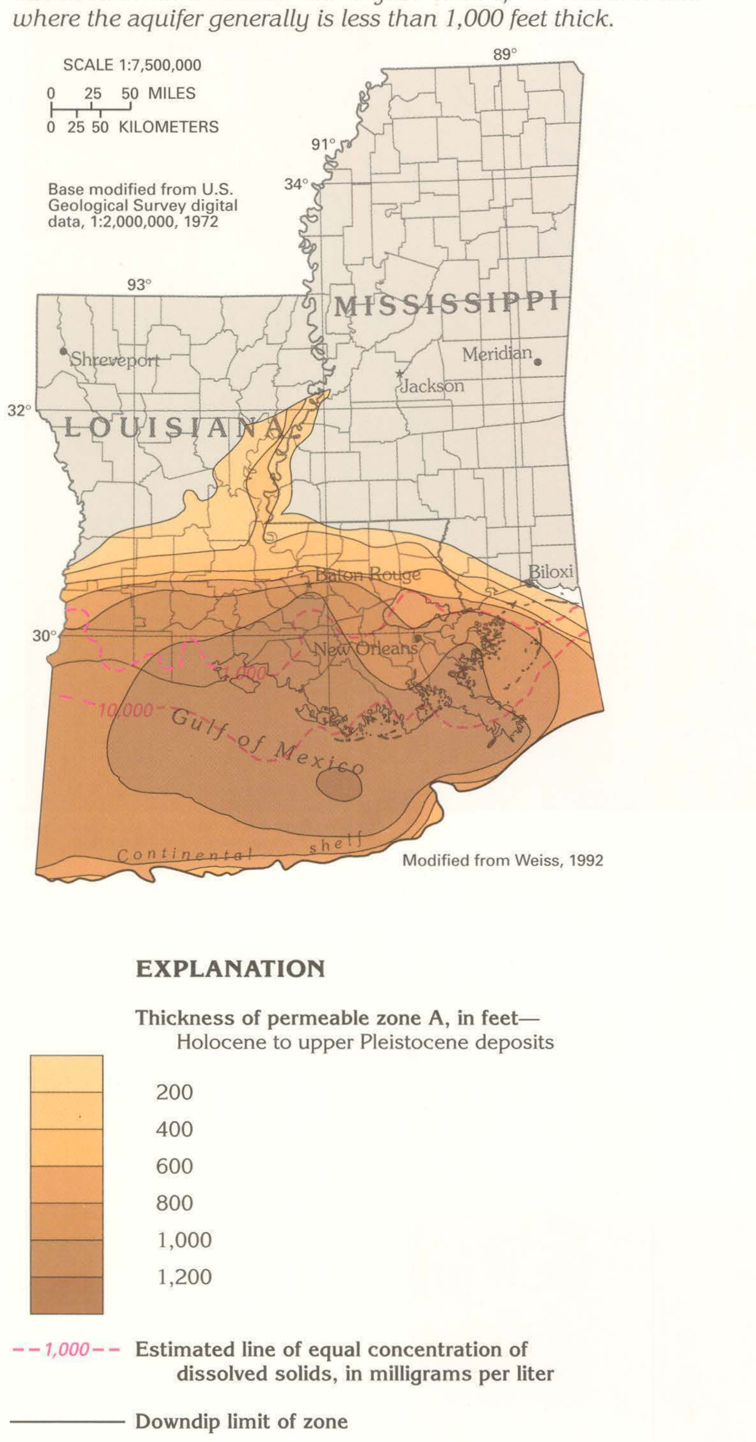


Figure 52. *Constructional deltas are characterized by lobate (A) and elongate (D) shapes. The different delta sedimentary facies are arranged in a fan shape in the lobate delta (B) but are fingerlike in the elongate delta (E). Sand thickness distribution patterns (C, F) are different for the two delta types, but sands are thickest in the distributary channels of both types.*

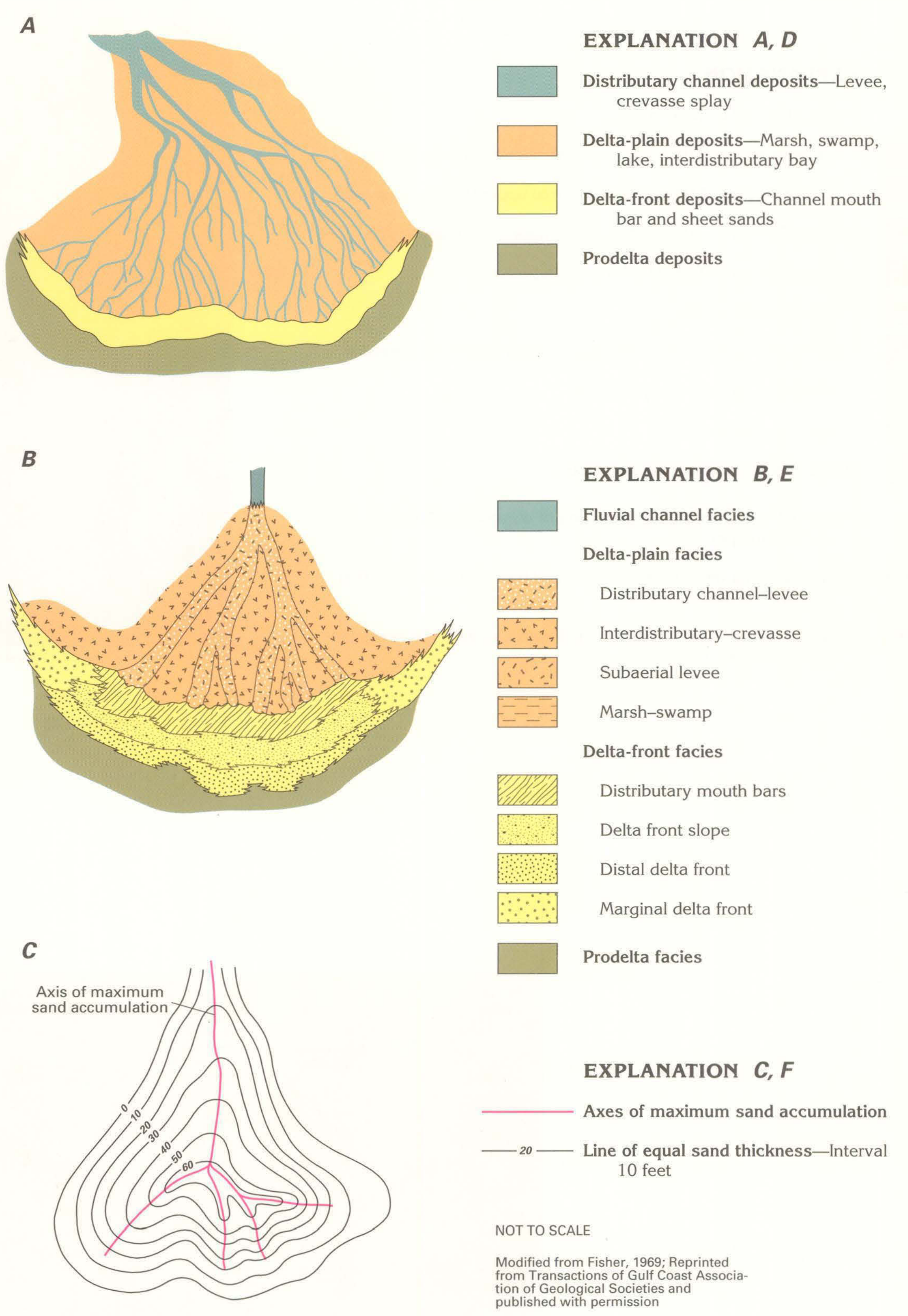
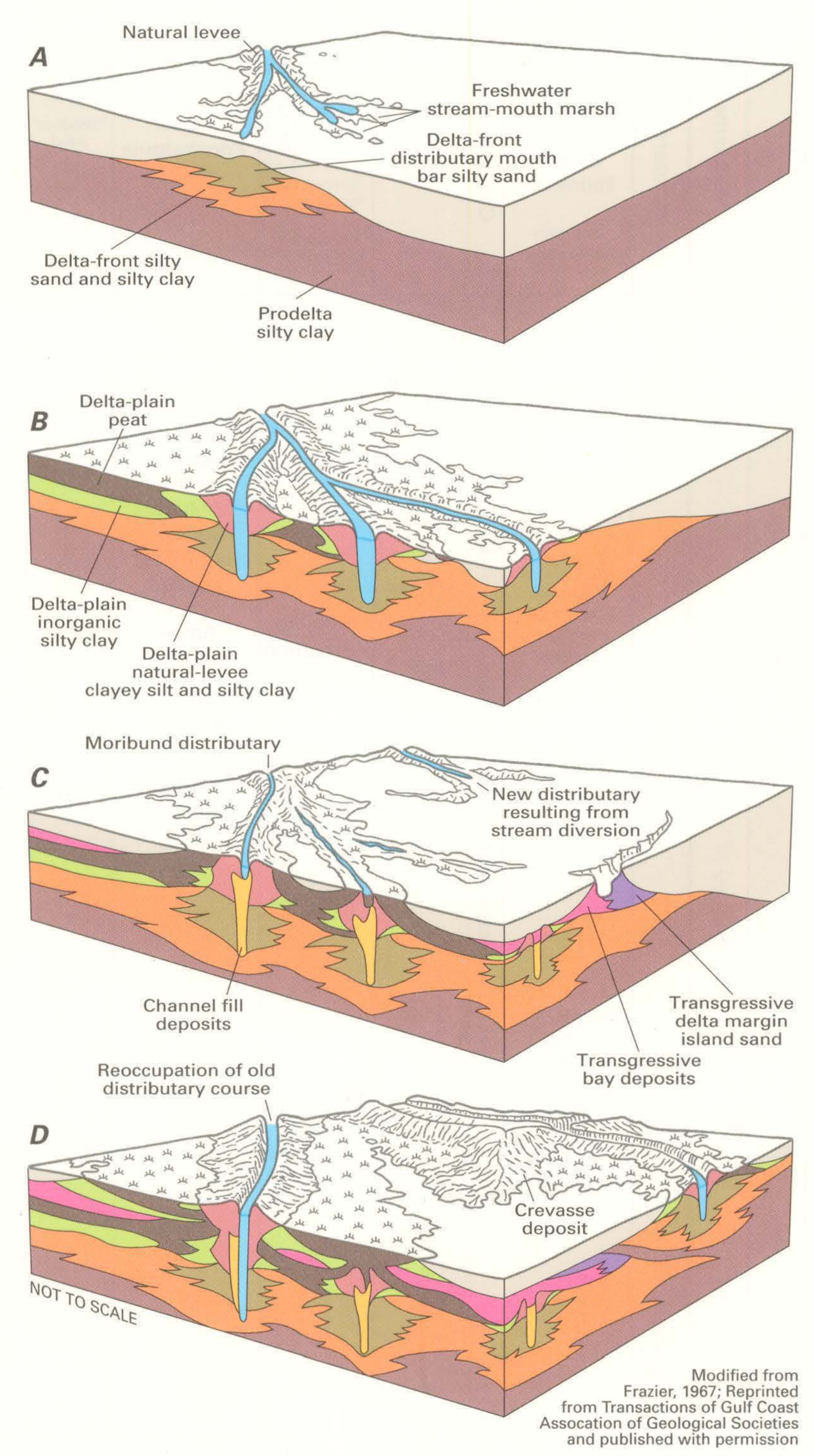


Figure 53. *Distributary and interdistributary channel deposits, for the most part, characterize a constructive delta complex. Distributary channel and delta-front sands are sparse during initial delta buildup (A) but become more common and are separated by clay and peat deposits as the delta progrades (B). Flow in the distributaries may wane or cease altogether as stream courses change or as a result of marine transgression (C). A complex stacking of fine- and coarse-grained deposits results with continued deposition and subsidence over geologic time (D).*



The overall distribution of sand within Permeable zone A (**fig. 54**) is similar to that of a lobate, rather than an elongate, delta system. Although some parts of the zone are characterized by sand concentrations as high as 100 percent that extend as narrow sand bodies, the zone comprises a series of small delta lobes that are combined as a single hydrogeologic unit. Locally, some areas contain concentrated sand bodies that may be part of small elongate deltas. These elongate sand bodies are located offshore and possibly reflect areas where distributary channels have prograded over thicker prodelta clays. Interdistributary deposits contain only 20 to 60 percent sand; they comprise mostly silt, clay, and lignite and were deposited between distributary channel sands. Distributary and interdistributary lithofacies grade gulfward to prodelta silt and mud that contain less than 20 percent sand.

A hydraulic conductivity map of Permeable zone A was constructed by using aquifer and specific-capacity test data, as well as trial-and-error estimates of permeability obtained from computer simulation of the regional ground-water flow system. Areas of moderately high (from 100 to greater than 120 feet per day) hydraulic conductivity (**fig. 55**) compare well with the location of high sand percentages within the zone (**fig. 54**). Interbedded silt, mud, lignite and very fine sand probably account for the less permeable nature of possible distributary channel sands in more coastward areas. Areas of less than 10 percent sand with a hydraulic conductivity of less than 5 feet per day are associated with probable prodelta areas. Interdistributary deposits are poorly permeable (hydraulic conductivity from 5 to 100 feet per day) but are more permeable than prodelta deposits.

Figure 54. *The distribution of sand strata in Permeable zone A is controlled by deltaic sedimentation. The overall distribution of sand is that of a lobate type of constructive delta; in contrast, current (1997) sedimentation patterns of the Mississippi River delta are those of an elongate, or "bird-foot," delta system.*

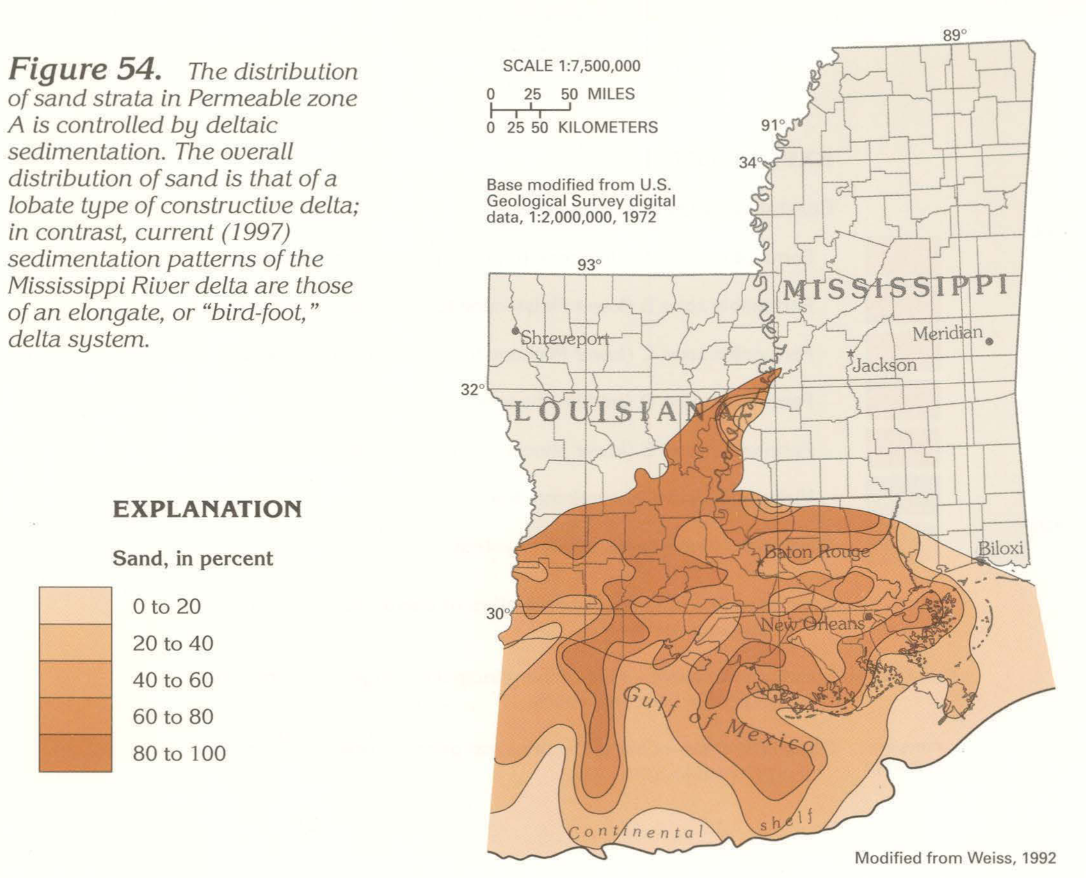
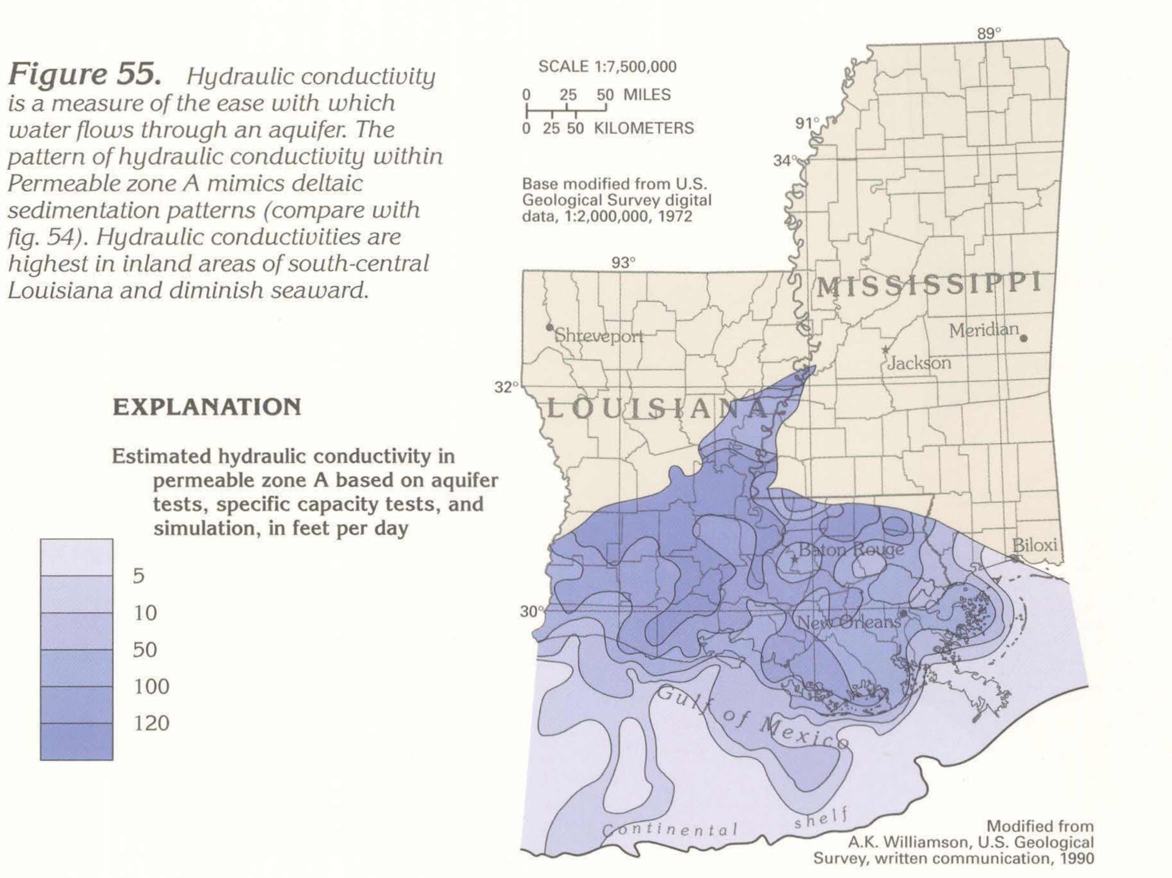


Figure 55. *Hydraulic conductivity is a measure of the ease with which water flows through an aquifer. The pattern of hydraulic conductivity within Permeable zone A mimics deltaic sedimentation patterns (compare with fig. 54). Hydraulic conductivities are highest in inland areas of south-central Louisiana and diminish seaward.*



GROUND-WATER FLOW

Under natural conditions, precipitation entered the coastal lowlands aquifer system in mostly landward, interstream areas. Owing to the gravity-driven nature of the ground-water flow system, topography greatly influences the areas most likely to be sites of recharge and discharge, as well as the rate and direction of ground-water flow. Under natural conditions, recharge to the coastal lowlands aquifer system was greatest in the topographically high areas east and west of the Mississippi River and along the landward margin of the aquifer (**fig. 56**). Regional ground-water flow was directed southward to the coast with ground water discharged by diffuse upward leakage to major rivers, low-lying coastal marsh areas, and to the ocean as seabed seepage in shallow nearshore areas.

Although Permeable zone A is not overlain by a regional confining unit, ground water is contained within the deeper parts of the zone under confined conditions. This is due to abundant, but discontinuous, fine-grained beds of local extent that act as confining units, but cannot be traced over an area larger than several counties. Because these local confining units combine to retard the vertical movement of ground water, water in the aquifer at depths of a few hundreds of feet is under confined conditions in most locations.

More than 90 years of increasingly large withdrawals of water from the coastal lowlands aquifer system in southwestern and southeastern Louisiana, primarily for agricultural and municipal uses, has greatly altered the ground-water flow system. Large ground-water withdrawals from Permeable zone A have resulted in water-level declines and large cones of depression (**fig. 57**). The greatest water-level declines in this zone are in southwestern Louisiana and in the New Orleans area. Water-level decline has resulted in a considerable change in horizontal and vertical components of ground-water flow. Near pumping centers, the current (1987) direction of ground-water flow was in places opposite to natural or predevelopment direction. Large withdrawals also have induced greater infiltration of precipitation at aquifer outcrop areas and greater streambed leakage. The areal extent of discharge areas (**compare figs. 56 and 57**) has correspondingly decreased. Large withdrawals have caused similar large declines in water levels in Permeable zone B in the Baton Rouge area.

GROUND-WATER QUALITY

Dissolved-solids concentrations of water in the coastal lowlands aquifer system are directly related to ground-water flow in the system. In updip areas where the aquifers are recharged, ground water has small concentrations of dissolved solids, but the water becomes increasingly saline as it moves toward the coast. Several factors contribute to the coastward increase in dissolved-solids concentration. Dissolved solids increase, in part, as a result of dissolution of aquifer minerals. Water that approaches the coastline becomes even more mineralized as a result of mixing with sea water. Ground-water movement near the coast is sluggish and may not be sufficient to flush saltwater from the aquifer.

Permeable zone A contains fresh or slightly saline water nearly to the coast in most areas (**fig. 58**). A band of water that contains dissolved-solids concentrations from 500 to 1,000 milligrams per liter parallels the Atchafalaya River. In coastal areas of Louisiana, the zone contains water with dissolved-solids concentrations of more than 1,000 milligrams per liter.

Water in aquifer recharge areas of Permeable zone A is primarily a calcium bicarbonate type (**fig. 59**). As the water moves downgradient, it becomes a sodium bicarbonate type because calcium ions are exchanged for sodium ions in aquifer minerals, primarily clay minerals. A sodium chloride hydrochemical facies near the coast is in an area that corresponds to the gulfward increase in dissolved solids and mixing with saline water (**fig. 59**).

FRESH GROUND-WATER WITHDRAWALS AND DECLINE OF WATER LEVELS

The coastal lowlands aquifer system is the second most important source of ground water in Segment 5. During 1985, about 1,140 million gallons per day of fresh ground water was withdrawn from the aquifer system for all uses (**fig. 60**). Withdrawals for agricultural use accounted for more than 51 percent of the total withdrawals from the aquifer system, or about 585 million gallons per day. About 25 percent, or about 283 million gallons per day, of the total withdrawals were used for public supply purposes. Domestic and commercial users withdrew about 178 million gallons per day, nearly 16 percent of the total withdrawals. Industrial, mining and thermoelectric power withdrawals were about 95 million gallons per day, or about 8 percent of the total withdrawals.

Most ground-water withdrawals from the coastal lowlands aquifer system are concentrated in New Orleans, Baton Rouge, and southwestern Louisiana (**fig. 61**). Of the five aquifers in the coastal lowlands aquifer system, Permeable zone A has the largest withdrawals. However, ground-water withdrawals from the Baton Rouge pumping center have been mostly from Permeable zones B and C with smaller amounts from Permeable zone D. Withdrawals in New Orleans and Baton Rouge are primarily for industrial purposes. Agricultural withdrawals from Permeable zone A in southwestern Louisiana are mostly for irrigation of rice.

Several hundred wells were constructed in Permeable zone A before 1903 to provide water for rice irrigation in southwestern Louisiana. Ground-water withdrawals in this area increased from about 280 to about 800 million gallons per day between 1947 and 1980. In **figure 62**, hydrographs of two wells in southwestern Louisiana completed in the zone show a steady decline in water levels from 1943 to 1983. Hydraulic heads declined during this period by almost 150 feet near the center of intense pumping and about 75 feet at a more distant location (**fig. 62**). A decrease in total withdrawals caused a rise in water levels between 1983 and 1990.

Withdrawals primarily for industrial uses and smaller withdrawals for public supply are concentrated in Baton Rouge and New Orleans. In New Orleans, ground-water withdrawals of about 5 million gallons per day from Permeable zone A in 1900 increased to approximately 55 million gallons per day in 1970. Water levels declined steadily from 1950 to 1970, as shown in **figure 63**. Industrial activities changed, however, and smaller quantities of ground water were withdrawn from 1970 through 1985. This decrease in pumpage was followed by a steady period of recovery, and water levels rose to within 10 feet of the 1950 levels. In the Baton Rouge area, estimated withdrawals of 2 million gallons per day in 1900 increased steadily until 1970 when shallow water-yielding strata (Permeable zone A) were abandoned in favor of deeper zones as withdrawal rates increased. Between 1970 and 1990, withdrawal rates ranged from 120 to 150 million gallons per day. Wells completed in Permeable zones C and D in the Baton Rouge area withdraw smaller volumes of water; in **figure 64**, hydrographs of two wells screened in Permeable zone C show a steady decline in water levels until 1974. Both wells are located near a heavily pumped industrial district in which 1990 withdrawals were estimated to be 20 million gallons per day. The difference in water levels of the two wells is attributed to their proximity to the center of a large cone of depression that surrounds the industrial district; well EB–90 is located at a greater distance from the center of the depression than well EB–367. The recovery of water levels in Permeable zone C that began in the early 1980's may reflect changes in the amount of water withdrawn for industrial needs.

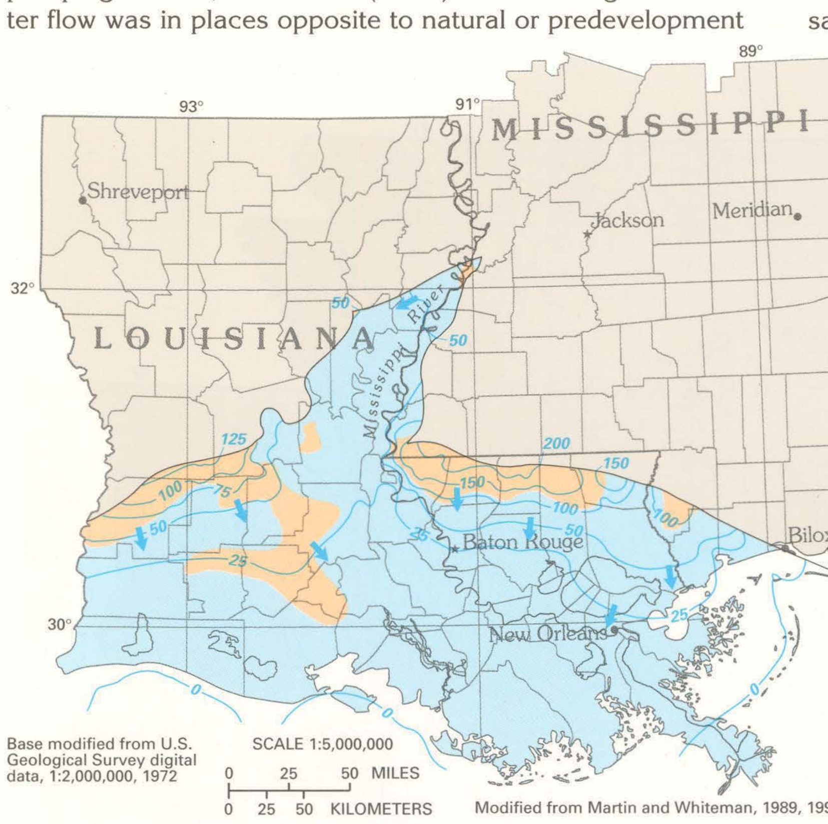


Figure 56. *Under predevelopment conditions, precipitation recharged Permeable zone A in topographically high interstream areas along the zone's landward margin. Ground water flowed mostly toward the coast or toward the Mississippi River and discharged to low-lying coastal wetlands, streams and rivers, or the Gulf of Mexico.*

EXPLANATION

Vertical flow

- Mostly upward
- Mostly downward

Potentiometric contour—Shows altitude at which water would have stood in tightly cased wells before development. Contour interval, in feet, is variable. Datum is sea level

Direction of ground-water flow

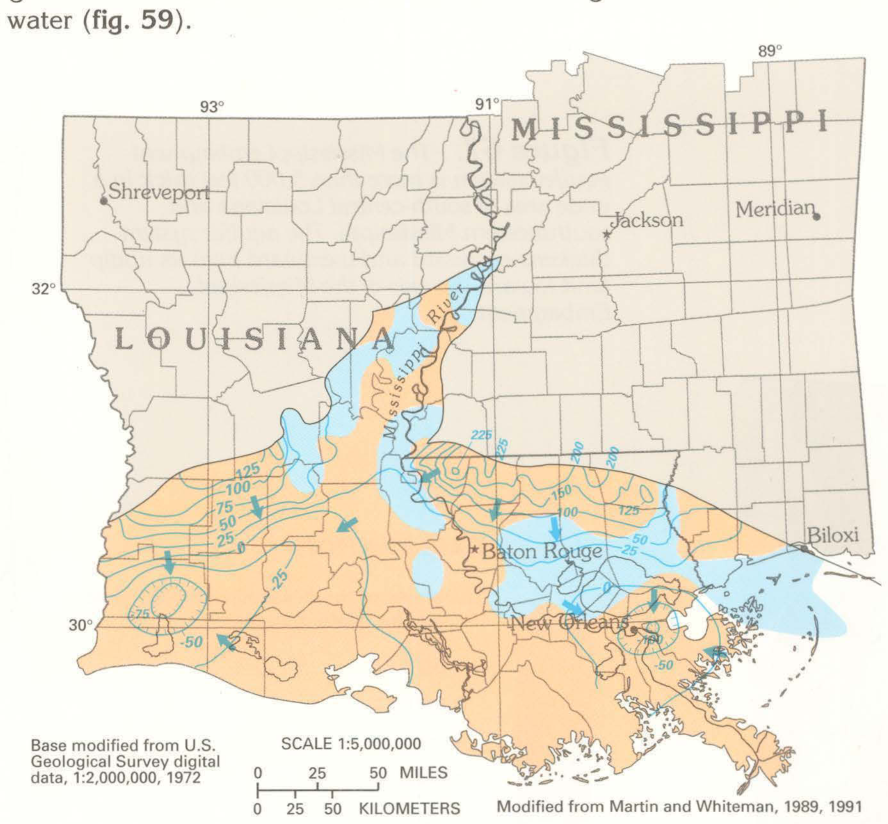


Figure 57. *Large withdrawals at major pumping centers have resulted in decline of the potentiometric surface and have formed two large cones of depression in southwestern and southeastern Louisiana. Ground water moves radially toward these two principal pumping centers. Regional withdrawals have greatly altered the vertical movement of ground water so that it moves downward throughout most of the aquifer system.*

EXPLANATION

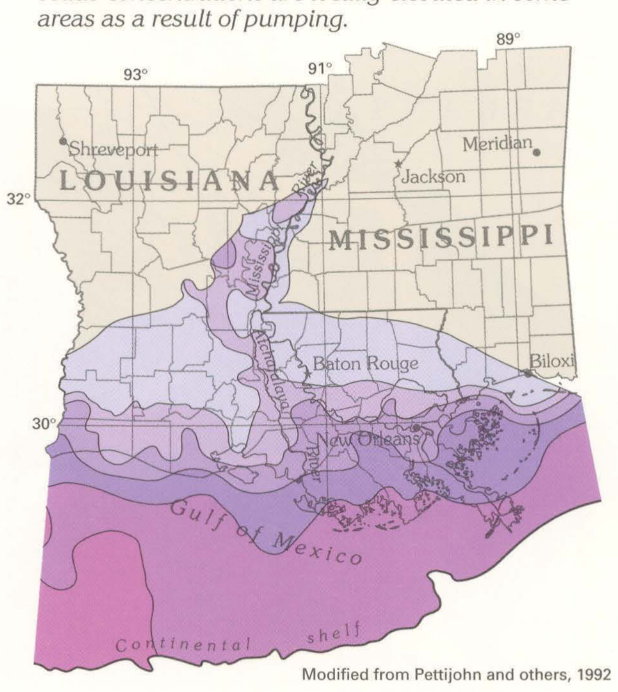
Vertical flow

- Mostly upward
- Mostly downward

Potentiometric contour—Shows altitude at which water would have stood in tightly cased wells in 1987. Hachures indicate depressions. Contour interval, in feet, is variable. Datum is sea level

Direction of ground-water flow

Figure 58. *Concentrations of dissolved solids in water from Permeable zone A increase at the coast principally because of mixing of freshwater with sea water and the dissolution of minerals within the aquifer. Where flow within the aquifer is dynamic, dissolved-solids concentrations are low because of flushing; where the gradient of the potentiometric surface is low, concentrations are higher. Dissolved-solids concentrations are locally elevated in some areas as a result of pumping.*



EXPLANATION

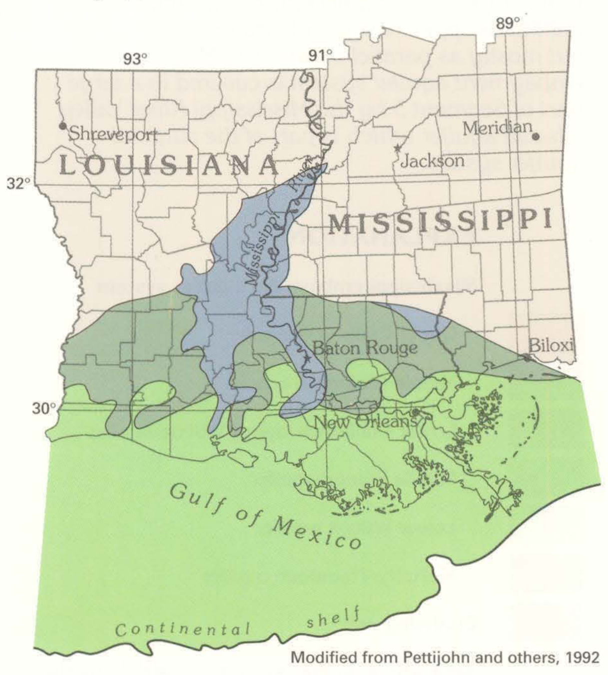
Dissolved-solids concentration, in milligrams per liter

- Less than 500
- 500 to 1,000
- 1,000 to 3,000
- 3,000 to 10,000
- 10,000 to 35,000
- 35,000 to 70,000

SCALE 1:7,500,000

Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Figure 59. *The chemical character of the water in Permeable zone A changes as the water moves from aquifer recharge areas coastward. The sodium chloride type water near the coast is the result of the mixing of fresh and saline waters.*



EXPLANATION

Hydrochemical facies

- Calcium bicarbonate
- Sodium bicarbonate
- Sodium chloride

SCALE 1:7,500,000

Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Figure 61. *Withdrawals of ground water from permeable zone A are greatest in southwestern Louisiana, where withdrawal rates that range from 200,000 to 400,000 gallons per day per square mile are reported. Smaller quantities of water are withdrawn in the Baton Rouge and the New Orleans areas.*

EXPLANATION

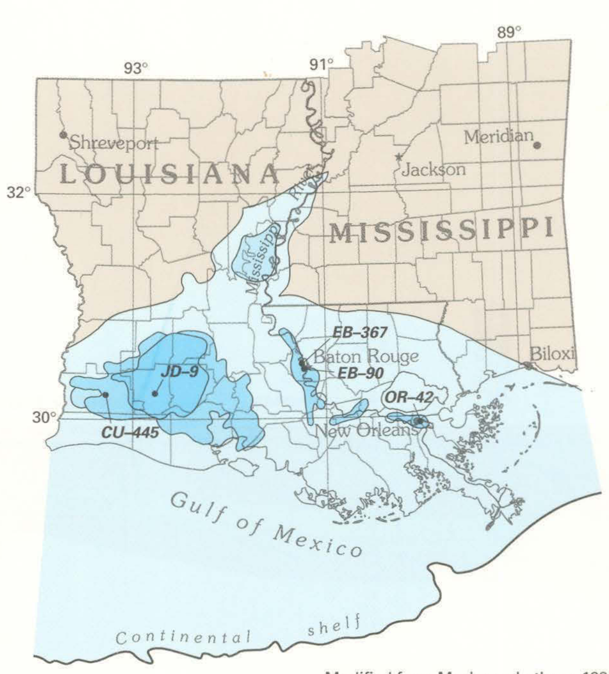
Fresh ground-water withdrawals during 1980, in gallons per day per square mile

- Less than 20,000
- 20,000 to 40,000
- 40,000 to 200,000
- 200,000 to 400,000

EB–90 Well and number

SCALE 1:5,000,000

Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972



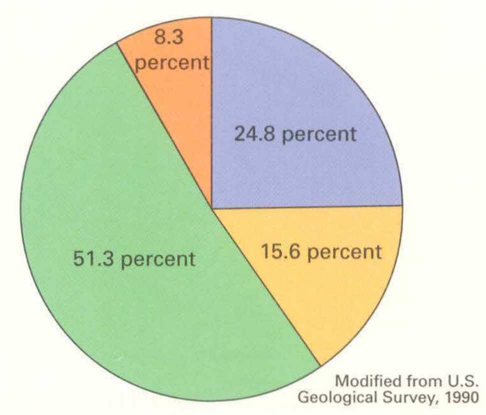


Figure 60. *About one-half of the fresh ground water withdrawn from the coastal lowlands aquifer system during 1985 was used for agricultural purposes.*

EXPLANATION

Use of fresh ground-water withdrawals during 1985, in percent—Total withdrawals 1,141 million gallons per day

- 24.8 Public supply
- 15.6 Domestic and commercial
- 51.3 Agricultural
- 8.3 Industrial, mining, and thermoelectric power

WELL YIELD

The coastal lowlands aquifer system is capable of yielding large quantities of water to properly constructed wells. Large-capacity industrial and municipal wells have been reported to flow as much as 4,000 gallons per day when they are first drilled. Many large-capacity wells screened opposite water-bearing sands of Permeable zones A through D typically yield more than 1,000 gallons per minute. The uppermost part of Permeable zone A is apparently less productive than its lower part. Many wells completed in the upper part yield less than 1,000 gallons per minute; shallow sands commonly yield less than 500 gallons per minute. Conversely, wells completed in the lower part of Permeable zone A characteristically yield more than 1,000 gallons per minute; the greatest reported yield of large industrial wells is 3,000 gallons per minute. Wells screened opposite water-bearing sands of Permeable zone B in southwestern Louisiana yield from 100 to more than 2,000 gallons per minute, whereas industrial wells completed in the same zone located in Baton Rouge have a reported average yield of 830 gallons per minute. Permeable zone C is highly productive in terms of well yield. In southwestern Louisiana, some wells completed in this zone are reported to yield between 2,100 and 4,000 gallons per minute, whereas the yield to large-capacity wells in Permeable zone C in the remainder of Louisiana range from 1,000 to 3,000 gallons per minute. Wells screened in Permeable zone D yield between 300 and 1,000 gallons per minute and average 750 gallons per minute in the Baton Rouge area. In southwestern Louisiana, municipal wells completed in Permeable zone D reportedly yield between 300 and 800 gallons per minute; a few wells produce as much as 1,000 gallons per minute. No information is available regarding the yield of wells completed in Permeable zone E.

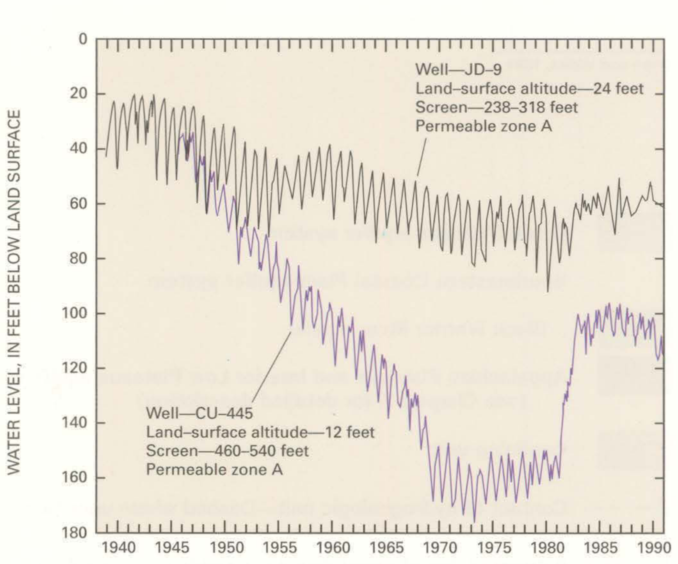


Figure 62. *Water levels in wells screened in Permeable zone A in the rice growing area of southwestern Louisiana exhibited a period of steady water-level decline from 1943 to 1983. In one well, hydraulic head decreased more than 140 feet. The recovery of water levels in both wells began in the early 1980's and was the result of decreased withdrawals for rice irrigation.*

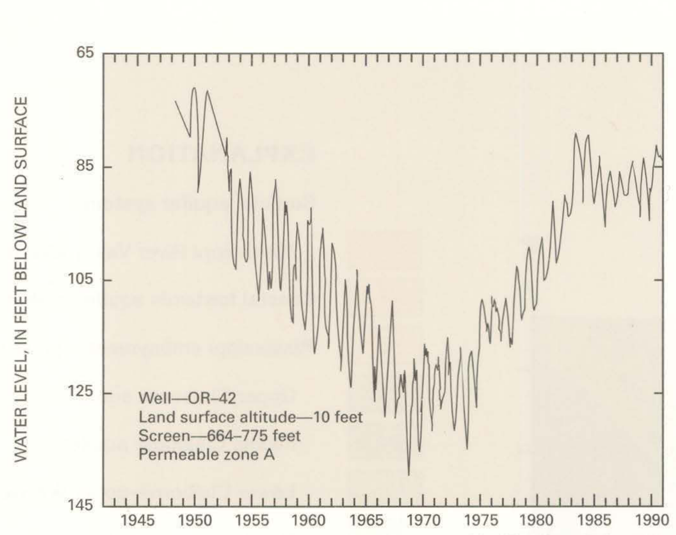


Figure 63. *Water levels in a well screened in Permeable zone A in New Orleans showed a steady decline from 1949 to 1968 of about 70 feet. The recovery of water levels that began in 1975 may reflect changes in the amount of water withdrawn for industrial needs.*

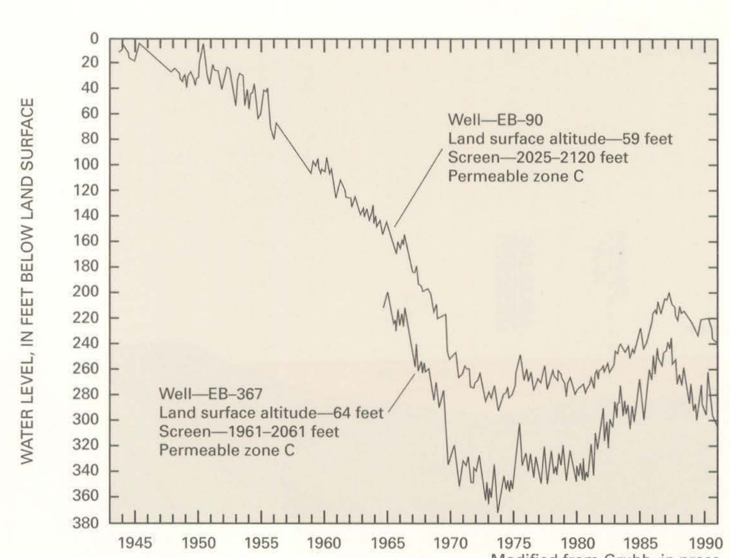


Figure 64. *Water levels in two wells screened in Permeable zone C in Baton Rouge show a steady water-level decline from 1943 through 1974. These declines reflect growth in population and industry. The modest recovery of water levels during the 1980's probably reflects a slight decrease in the amount of water withdrawn. Drawdown in well EB–90 is not as great as EB–367 because the former is located at a greater distance from the center of the cone of depression.*

Mississippi embayment aquifer system

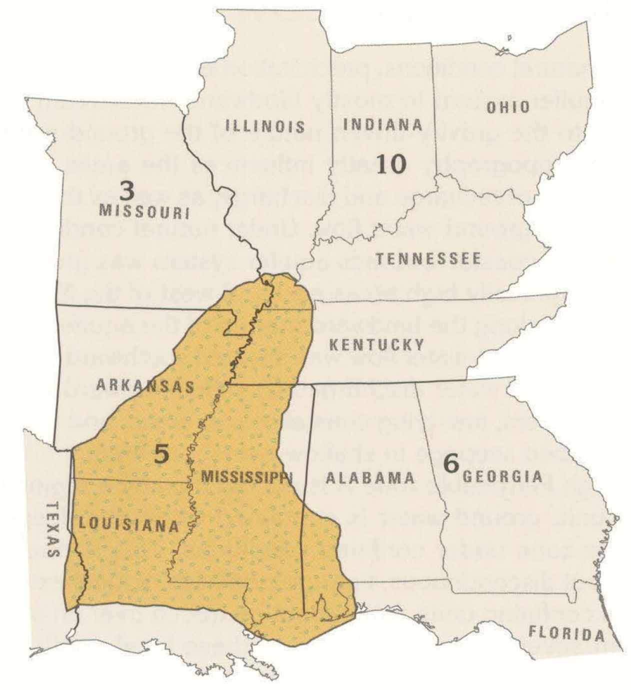
INTRODUCTION

The Mississippi embayment aquifer system is the most extensive aquifer system in Segment 5, and parts of the system are discussed in Chapters C,D,G, and K (**fig. 65**) of this Atlas. The system underlies most of the East and West Gulf Coastal Plains and the Mississippi Alluvial Plain Sections of the Coastal Plain Province. The Mississippi embayment aquifer system merges eastward in Mississippi and in Alabama with the Pearl River aquifer that is part of the Southeastern Coastal Plain aquifer system (see Chapter G of this Atlas) and merges westward with the Coastal uplands aquifer system in Texas and Oklahoma (see Chapter E of this Atlas). A small area of equivalent rocks in southwestern Arkansas and northwestern Louisiana has been mapped as part of the Texas coastal uplands aquifer system in some reports but is considered to be part of the Mississippi embayment aquifer system in this Atlas.

The Mississippi embayment aquifer system extends eastward from Arkansas to northwestern Mississippi and comprises six aquifers that crop out as an arcuate band of poorly consolidated to unconsolidated, bedded sand, silt and clay (**fig. 66**). Geologic units of the aquifer system range from Late Cretaceous to middle Eocene in age. In southern Mississippi and central Louisiana, an extensive, thick, clay confining unit, the Vicksburg–Jackson confining unit, separates the Mississippi embayment aquifer system from the overlying Oligocene and younger water-yielding strata of the coastal lowlands aquifer system. In the embayed part of the Gulf Coastal Plain of eastern Arkansas, northeastern Louisiana, and northwestern Mississippi, the southward-dipping strata of the Mississippi embayment aquifer system are hydraulically connected to the Mississippi River Valley alluvial aquifer.

The geologic formations and groups that compose the Mississippi embayment aquifer system thicken greatly in southern Mississippi and Louisiana (**fig. 67**) where large volumes of sediment were deposited by streams that emptied into the ancestral Gulf of Mexico. The Mississippi embayment aquifer system ranges in thickness from a featheredge to more than 6,000 feet (**fig. 67**). The aquifer system thickens eastward and westward from its updip limits toward the axis of the Mississippi Embayment. The aquifer system is thickest in south-central Louisiana and southwestern Mississippi. Three of the system's six aquifers, the upper and the middle Claiborne and the lower Claiborne–upper Wilcox aquifers, become increasingly clayey and pinch out to the south (**fig. 68**). Some of the clayey confining units pinch out northward as they become increasingly sandy and more permeable.

A different perspective of the geologic and hydrogeologic units that make up the aquifer system is shown in a section that crosses the central part of the Mississippi Embayment (**fig. 69**). Some of the aquifers (for example, the lower Claiborne–upper Wilcox aquifer) thicken eastward across the embayment locally, the middle Claiborne, the lower Claiborne–upper Wilcox, and the middle and the lower Wilcox aquifers are in direct hydraulic contact near the western side of the embayment.



Modified from Hosman and Weiss, 1991

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Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Figure 65. The Mississippi embayment aquifer system extends over parts of 10 States and 5 segments of this Atlas and is the most widespread aquifer system in Segment 5.

EXPLANATION

Mississippi embayment aquifer system

5 Atlas segment number

Figure 66. Coastal Plain sedimentary rocks that compose the aquifers and confining units of the Mississippi embayment aquifer system crop out mostly as parallel bands. The Mississippi embayment aquifer system is covered in a large part of Segment 5 by the Mississippi River Valley alluvial aquifer which is part of the surficial aquifer system.

EXPLANATION

Mississippi embayment aquifer system

- Upper Claiborne aquifer
- Middle Claiborne aquifer
- Lower Claiborne–Upper Wilcox aquifer
- Middle Wilcox aquifer
- Lower Wilcox aquifer
- McNairy–Nacatoch aquifer

Confining unit

Area where aquifer system is overlain by the Mississippi River Valley alluvial aquifer

Area where aquifer system is overlain by the coastal lowlands aquifer system

Contact of hydrogeologic unit—Dashed where uncertain

Downdip limit of aquifer system

A——A' Line of hydrogeologic section

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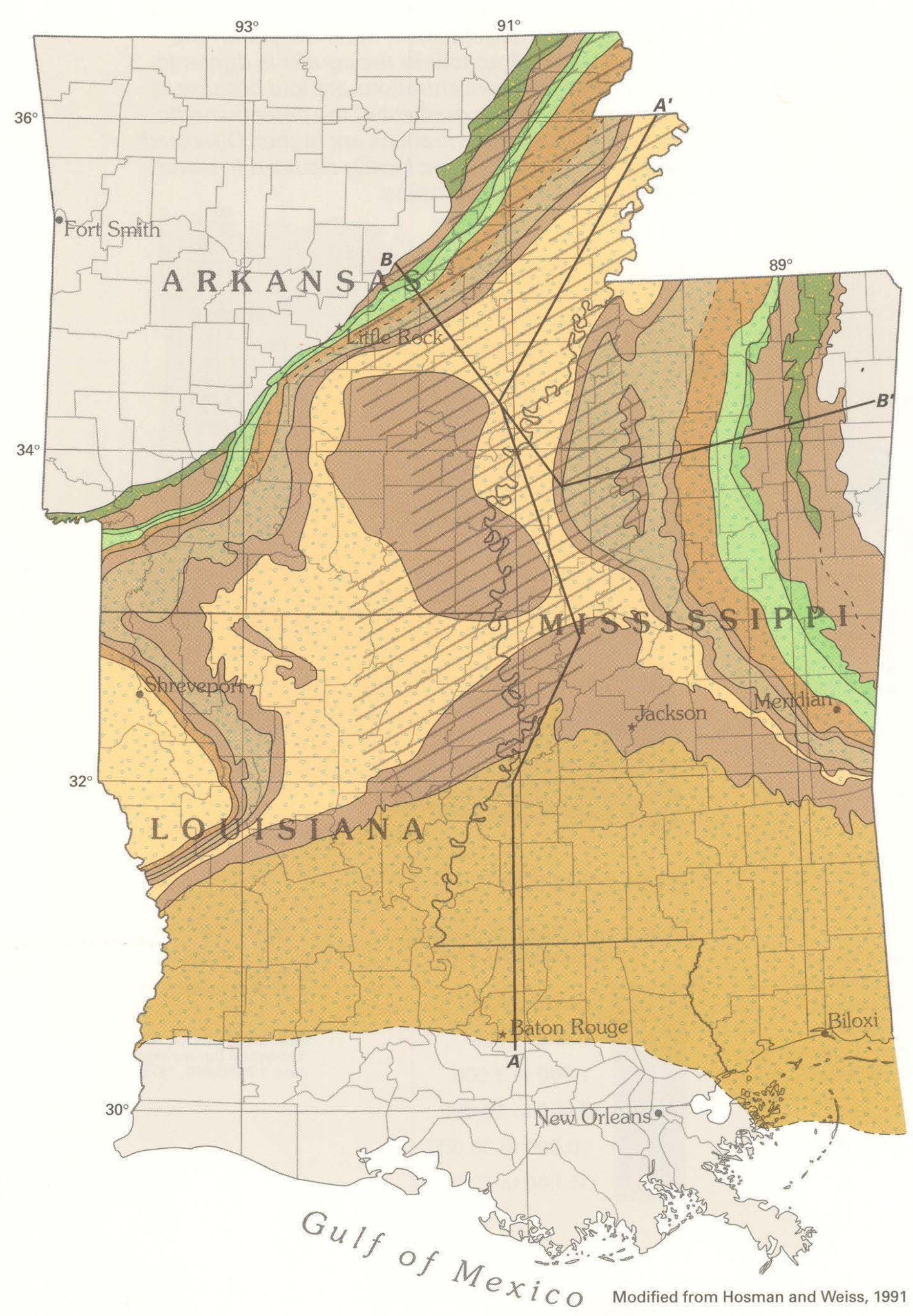
0 25 50 KILOMETERS

Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972



Modified from Hosman and Weiss, 1991

Figure 67. The Mississippi embayment aquifer system is more than 5,000 feet thick in a wide area of south-central Louisiana and southwestern Mississippi. The aquifer system thickens eastward and westward from its updip limits toward the axis of the Mississippi Embayment.

EXPLANATION

Thickness of the Mississippi embayment aquifer system, in feet

- 1,000
- 2,000
- 3,000
- 4,000
- 5,000
- 6,000

Aquifer absent

Downdip limit of aquifer system

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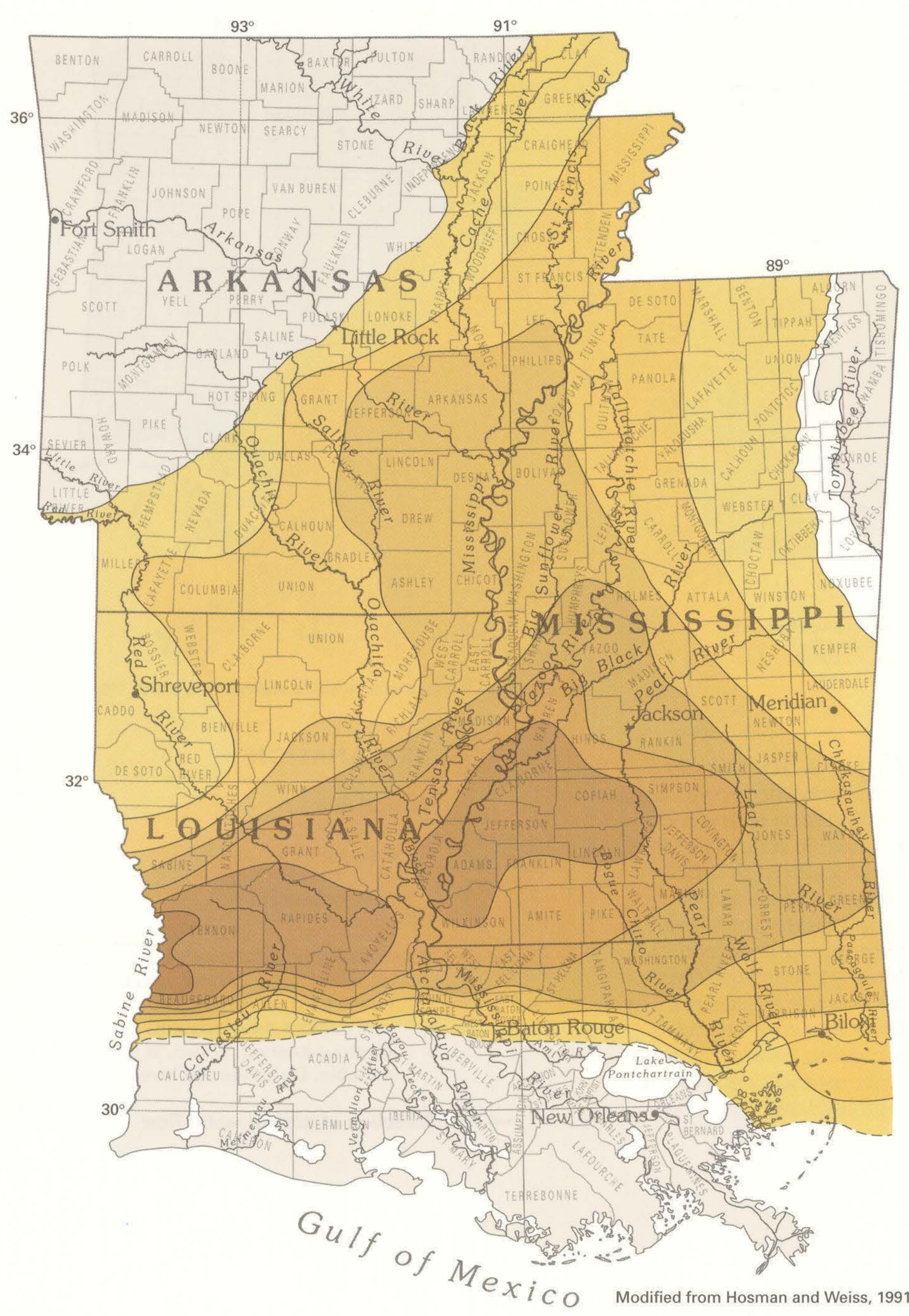
Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972



Modified from Hosman and Weiss, 1991

Figure 68. A hydrogeologic section of the Mississippi embayment aquifer system shows that the Coastal Plain sedimentary rocks that compose the system dip southward beneath the rocks that compose the coastal lowlands aquifer system. The line of the section is shown in figure 66.

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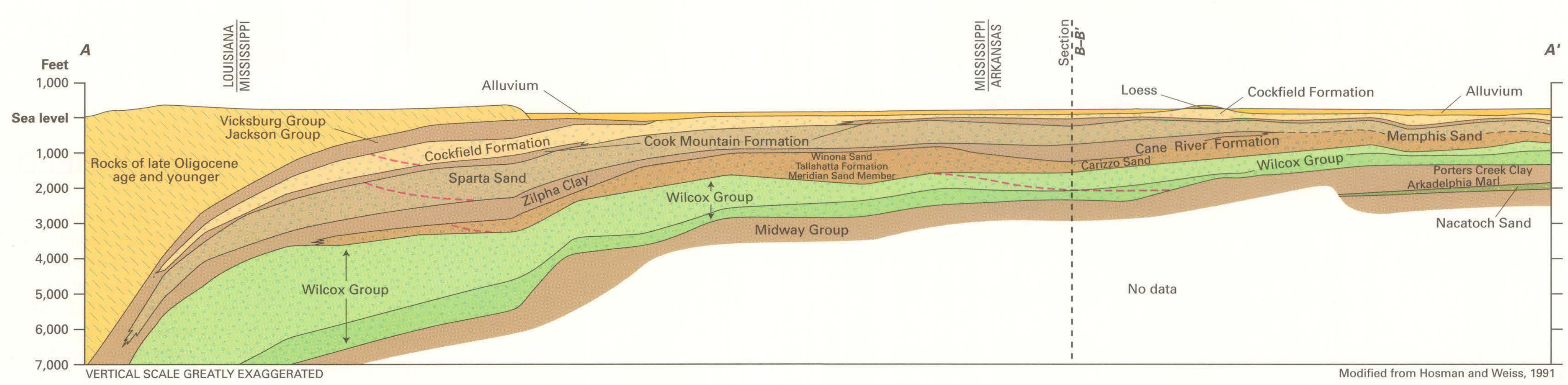

Modified from Hosman and Weiss, 1991

Figure 69. An idealized hydrogeologic section drawn westward from south-central Arkansas to north-central Mississippi shows that most aquifers and confining units of the Mississippi embayment aquifer system are continuous across the downwarped embayment. Some of the aquifers thicken, and others thin from west to east across the embayment. The line of the section is shown in figure 66.

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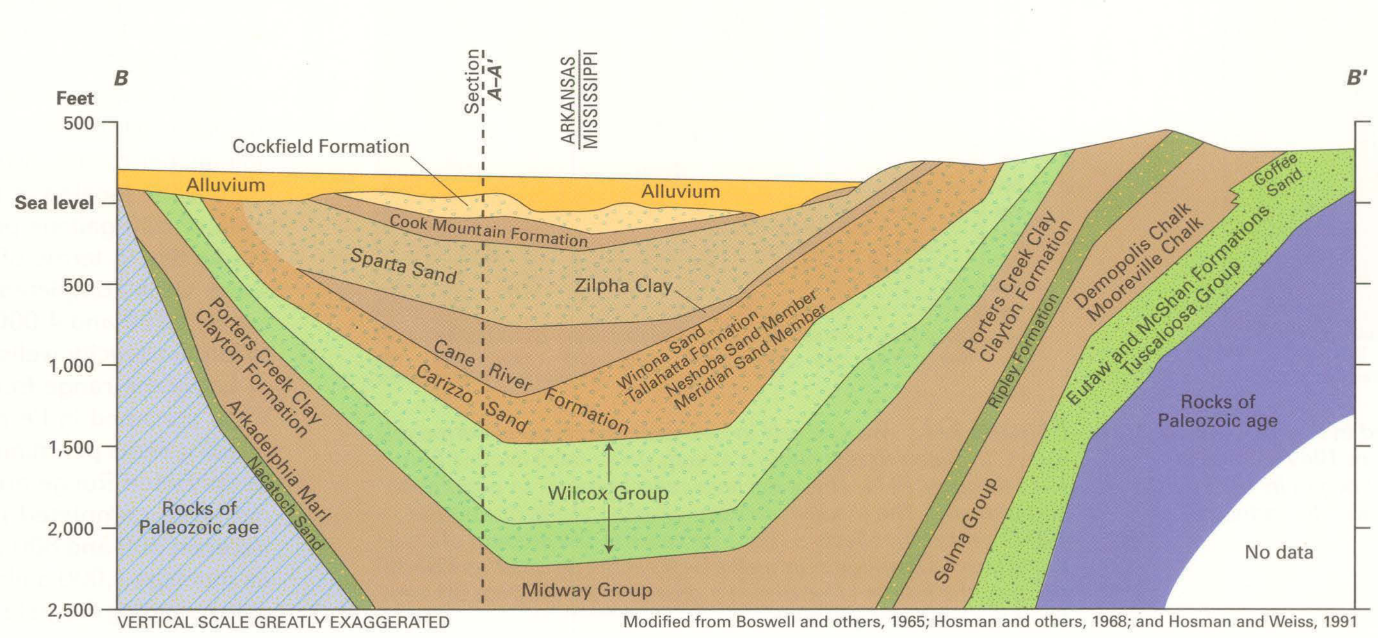


Modified from Boswell and others, 1965; Hosman and others, 1968; and Hosman and Weiss, 1991

EXPLANATION

Surficial aquifer system

- Mississippi River Valley alluvial aquifer

Coastal lowlands aquifer system

Mississippi embayment aquifer system

- Upper Claiborne aquifer
- Middle Claiborne aquifer
- Lower Claiborne–upper Wilcox aquifer
- Middle Wilcox aquifer
- Lower Wilcox aquifer

Ozark Plateaus aquifer system

Southeastern Coastal Plain aquifer system

- Black Warrior River aquifer

Appalachian Plateaus and Interior Low Plateaus aquifers (see Chapter K for detailed description)

Confining unit

Contact of hydrogeologic unit—Dashed where uncertain

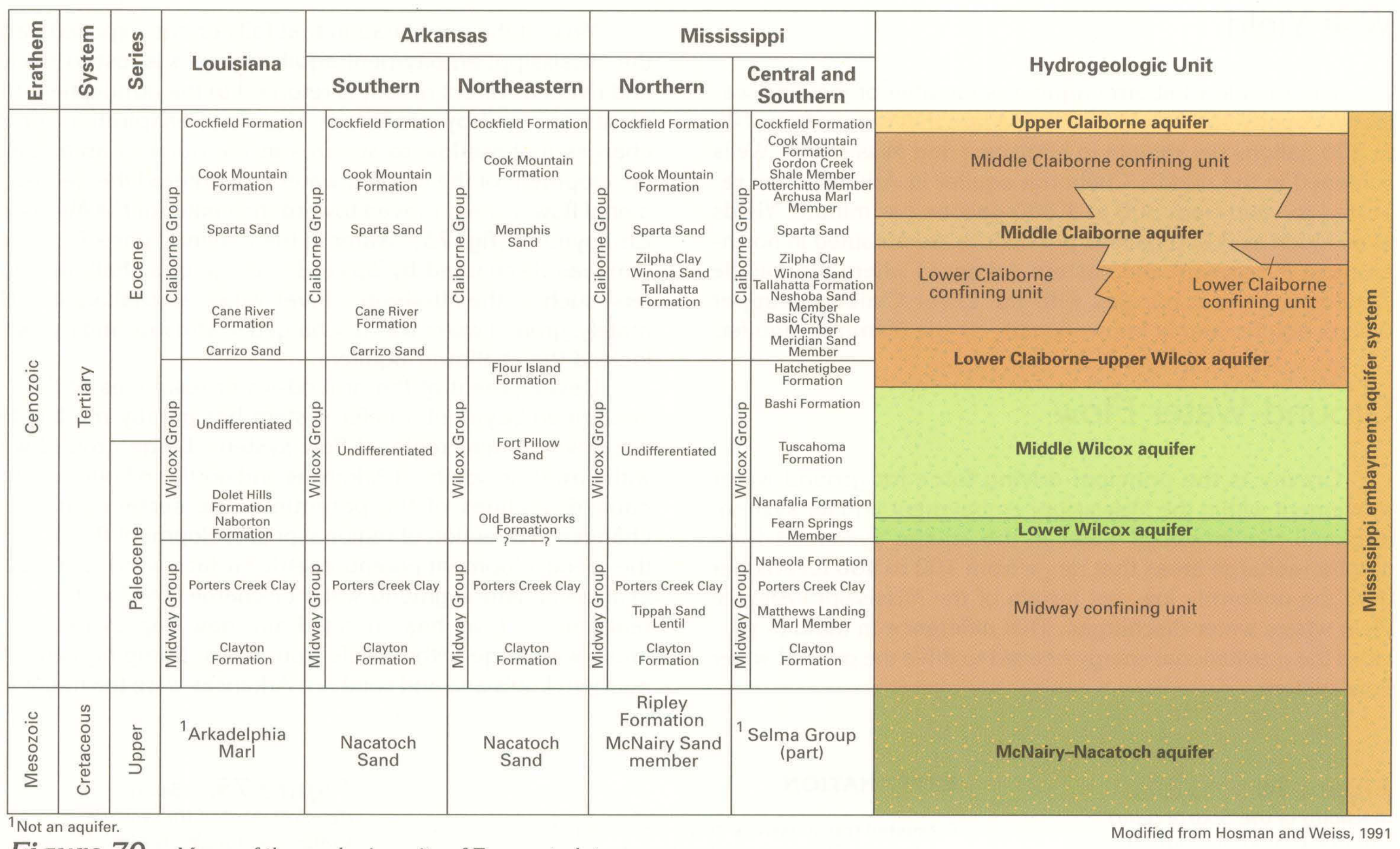
Estimated line of equal dissolved-solids concentration equal to 10,000 milligrams per liter dissolved solids

HYDROGEOLOGIC UNITS

The Mississippi embayment aquifer system is divided into nine hydrogeologic units—six regional aquifers and three regional confining units. Thick, regionally-extensive clay and shale confining units separate some parts of the aquifer system into distinct, regionally mappable aquifers that are largely homogeneous sand. Other parts of the aquifer system lack regional confining units, and the regional aquifers in these parts are defined on the basis of different geohydrologic characteristics. The contacts of many aquifers and confining units within the Mississippi embayment aquifer system conform well to the contacts of geologic units (**fig. 70**). For example, the Midway confining unit coincides exactly with the different geologic formations that compose the Midway Group, and the upper Claiborne aquifer is identical to the Cockfield Formation. For some hydrogeologic units, however, particularly those that include rocks of the Claiborne Group, there is little or no equivalency with geologic units. The conformance of aquifers and confining units with geologic units also departs markedly as the Mississippi embayment aquifer system merges eastward with the Southeastern Coastal Plain aquifer system, which is described in Chapter G of this Atlas.

The extensive Jackson–Vicksburg confining unit is formed by massive clay beds and separates the Mississippi embayment system from the overlying coastal lowlands aquifer system. The Midway confining unit within the Mississippi embayment aquifer system also consists of massive clay beds and separates the aquifers in sediments of Tertiary age from underlying aquifers of rocks of Cretaceous age. Although the uppermost aquifers of the Mississippi embayment aquifer system, the upper and the middle Claiborne aquifers, are bounded above and below by confining units in most places, the lower Claiborne–upper Wilcox aquifer and the middle and the lower Wilcox aquifers are not separated by confining units. Sandy strata of the Wilcox Group are more heterogeneous than other rocks of Tertiary age and consist of a highly variable sequence of massive to thinly bedded sand and thin clay beds that are part of the three aquifers. The middle Wilcox aquifer differs considerably from overlying and underlying aquifers because its thin beds of sand and clay result in lower hydraulic conductivity than that of the massive, more permeable strata that lie above and below it.

Of the six aquifers contained within the Mississippi embayment aquifer system, the middle Claiborne aquifer is the most heavily used. Consequently, the description of the Mississippi embayment aquifer system in this chapter principally focuses on the hydrogeologic, hydraulic, and hydrochemical characteristics of the middle Claiborne aquifer. The McNairy–Nacatoch aquifer of this system also is described because the ground-water flow system is quite different from that of the other aquifers in this aquifer system.



[1]Not an aquifer.

Modified from Hosman and Weiss, 1991

Figure 70. Many of the geologic units of Eocene to late Cretaceous age in Segment 5 conform well with the six aquifer and three confining units of the Mississippi embayment aquifer system. This chart does not imply the thickness or exact equivalency of the different geologic units, but does show the principal units that compose the regional aquifers and confining units.

Figure 71. The middle Claiborne aquifer is thickest in east-central Louisiana, southwestern Mississippi, and southeastern Arkansas where its thickness is greater than 800 feet. The aquifer generally is less than 800 feet thick where it contains water with less than 1,000 milligrams per liter of dissolved solids.

EXPLANATION

Thickness of the middle Claiborne aquifer, in feet

200
400
600
800
1,000

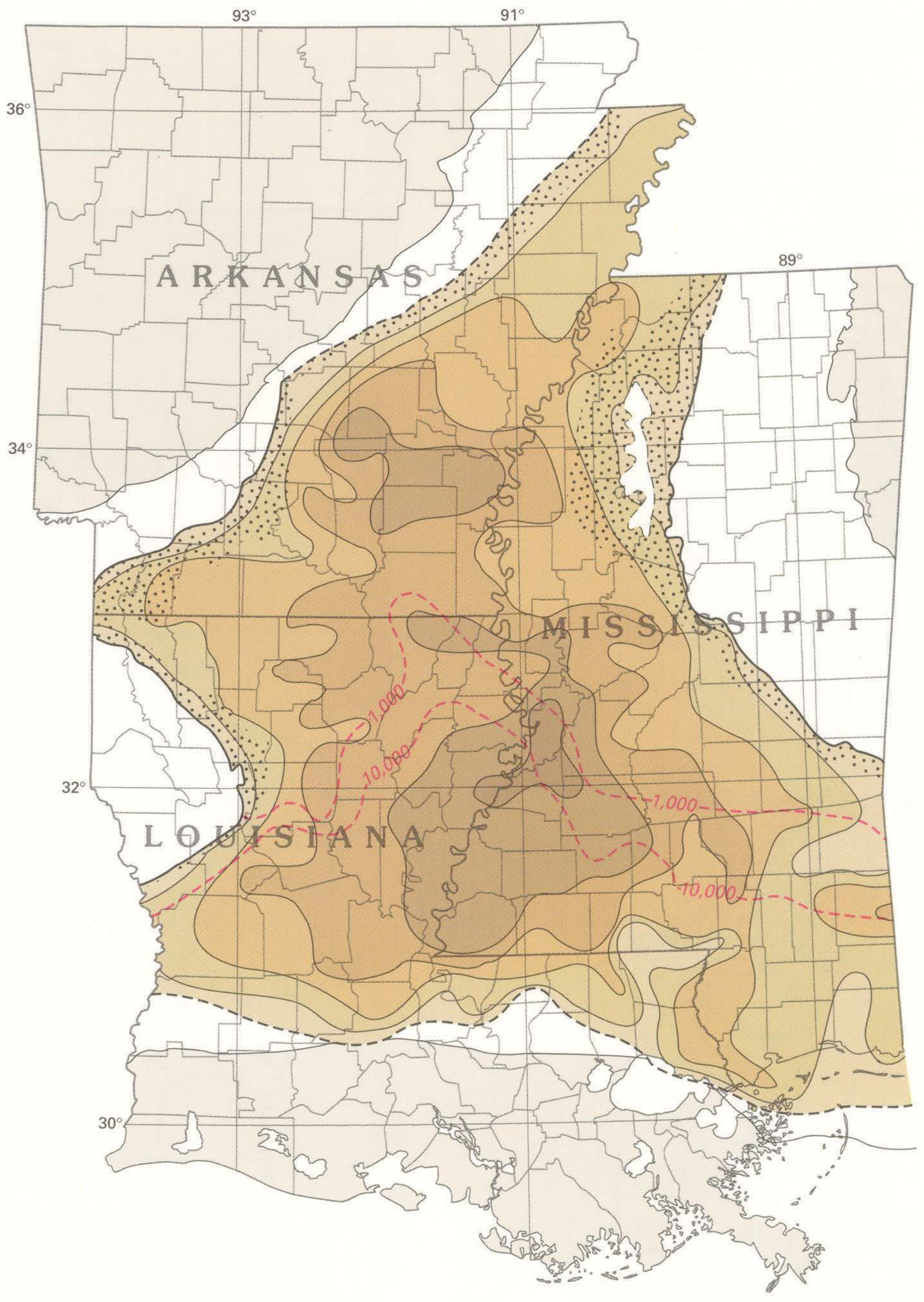
Area of outcrop or shallow subcrop of the middle Claiborne aquifer

- - 1,000 - - Estimated line of equal concentration of dissolved-solids, in milligrams per liter

——— - - - Limit of middle Claiborne aquifer—Dashed where uncertain

SCALE 1:5,000,000
0 25 50 MILES
0 25 50 KILOMETERS

Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972



Modified from Hosman and Weiss, 1991

Figure 72. The distribution of sand within the Sparta Sand that makes up most of the middle Claiborne aquifer suggests that the sand was deposited in constantly shifting distributary channels separated by interdistributary marshes, lakes, and swampy areas that received fine-grained sediment. This is a sedimentary environment that typifies a constructive delta.

EXPLANATION

Sand in the Sparta Sand (middle Claiborne aquifer), in percent

0 to 10
10 to 30
30 to 50
50 to 70
Greater than 70
No data

Area of outcrop or shallow subcrop of the middle Claiborne aquifer

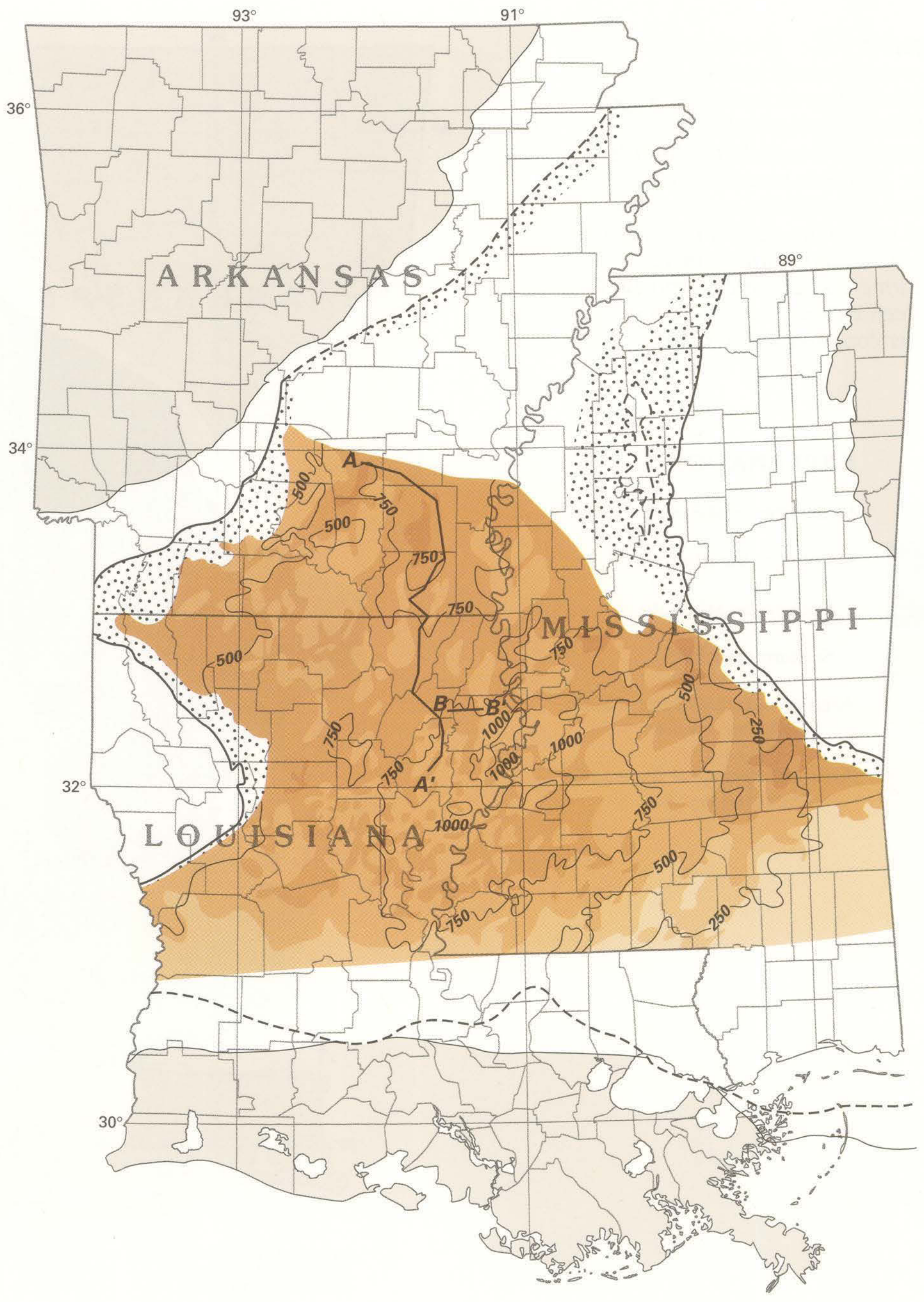
- - - - Limit of middle Claiborne aquifer—Dashed where uncertain

—750— Line of equal thickness of Sparta Sand (middle Claiborne aquifer)—Interval 250 feet

A——A' Line of hydrogeologic section

SCALE 1:5,000,000
0 25 50 MILES
0 25 50 KILOMETERS

Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972



Modified from Payne, 1968

MIDDLE CLAIBORNE AQUIFER

The middle Claiborne aquifer comprises mostly the Sparta Sand but also includes the Memphis Sand in the northern part of the Mississippi Embayment. In this area, the Memphis Sand is equivalent to the Sparta Sand, the Cane River Formation, and the Carrizo Sand/Meridian Sand Member of the Tallahatta Formation (**fig. 70**). The aquifer is thickest in a large area of east-central Louisiana and southwestern Mississippi, and in a smaller area of southeastern Arkansas (**fig. 71**). Although its thickness is greater than 1,000 feet in Louisiana and Mississippi, the aquifer largely contains water with more than 1,000 milligrams per liter dissolved solids. Such highly mineralized water is considered to be unsuitable for most purposes. In most areas where water in the middle Claiborne aquifer contains smaller concentrations of dissolved solids, the thickness of the aquifer generally ranges from 200 to 800 feet.

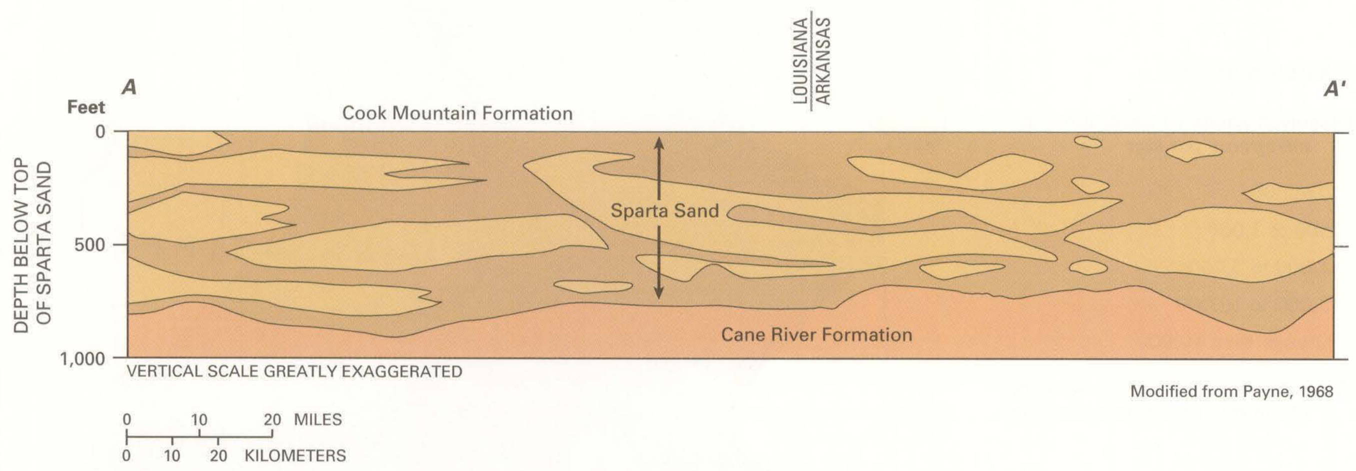
Confining units separate the middle Claiborne aquifer from overlying and underlying aquifers in most places. These confining units comprise prodelta and marine shelf deposits of clay, mud, marl, and shale. The lower Claiborne confining unit (the Cane River Formation) which underlies the middle Claiborne aquifer, and the middle Claiborne confining unit (the Cook Mountain Formation), which overlies the aquifer, were deposited as a result of widespread marine invasions that interrupted progradation of clastic sediments into the Gulf Coast Basin. Clay and shale of the lower Claiborne confining unit coarsens northward and grades to sandy channel sediments (the Winona Sand and the Tallahatta Formation) deposited in a coastal margin delta system. The predominantly marine clay facies of the lower Claiborne confining unit thus changes to an updip sand facies that forms part of the middle Claiborne aquifer. In Arkansas and northernmost Mississippi, where the lower Claiborne confining unit is missing, the middle Claiborne aquifer and the lower Claiborne–upper Wilcox aquifers function as a single aquifer, which is known locally as the Memphis aquifer.

Relation Between Geology And Permeability

Basinwide changes in geologic facies have been shown in preceding sections of this chapter to be a principal factor that controls the hydraulic character of the surficial and the coastal lowlands aquifer systems. A similar relation exists for the Mississippi embayment aquifer system. Aquifers of the Mississippi embayment aquifer system consist of an interbedded sequence of poorly consolidated fluvial, deltaic, and marine deposits in which diagenesis or postdepositional geochemical processes have not greatly altered the original pattern of permeability. The hydraulic conductivity of the unconsolidated to poorly consolidated sediments that compose the aquifers of the Mississippi embayment aquifer system does not appear to have been greatly reduced by cementation or compaction. Consequently, the distribution of hydraulic conductivity and transmissivity of the Mississippi embayment aquifer system can be inferred from maps of sediment lithofacies, if a direct correlation between sediment type and aquifer permeability is assumed.

The Sparta Sand that composes most of the middle Claiborne aquifer in Louisiana and Mississippi (**fig. 72**) was deposited within a constructional delta system. A constructional delta system is characterized by a large-scale complex of elongate and lobate deltas formed by rivers with large discharge and sediment loads; the delta progrades into ocean water. Constructive delta systems contain mostly fluvial and deltaic facies in which coarser sediment is concentrated in landward fluvial tributaries or meandering channels and as deltaic distributaries and delta front-sand bodies. Distributary channels that contain permeable sand are separated by less permeable interdistributary clay (**fig. 54**). In constructional delta systems, fluvially transported sand, silt, and clay are deposited near the coast at a rate that exceeds the rate at which they are removed by wave energy and longshore currents. The meandering fluvial channel facies is characterized by wide, uniform, multilateral sand bodies with little clay content. The distributary channel facies differs in terms of its sand content and pattern of sedimentation. Channel sand bodies within the delta plain show a distributary pattern of sedimentation and do not show extensive lateral migration. Distributary channels are effectively isolated by the weight of sandy channel sediment, which causes compactional subsidence. Eventually, channel progradation results in its overextension, and the distributary channel shifts position by abandonment and diversion of floodwaters to an area with a steeper gradient. Younger distributary channels may overlap older channels as the delta builds up thick sequences of complexly interbedded deposits.

Distributary deposits are in the middle Claiborne aquifer as elongate bodies separated by areas almost devoid of sand that represent interdistributary deposits (**fig. 72**). The distribution of sand in the middle Claiborne aquifer, expressed as a percentage of the total thickness of the aquifer, suggests that the sand was deposited within a distributary channel facies of a constructive delta system. Distributary channels of the middle Claiborne aquifer area characterized by high concentrations of sand (50 percent or greater) that extend as narrow, slightly meandering, elongate sand bodies (**fig. 73**). Interdistributary deposits contain from 30 to 50 percent sand and consist primarily of silt, clay, and lignite. Distributary and interdistributary channel lithofacies grade gulfward to prodelta silt and mud, which contains small concentrations of sand (less than 30 percent). The sandy channel sediments represent the most permeable parts of the middle Claiborne aquifer in Louisiana and Mississippi. The predominant direction of the distributary channels is southward or southwestward. Comparison of sand percentage and the distribution of transmissivity in the middle Claiborne aquifer (Sparta Sand) suggests that the more transmissive parts of the aquifer correspond to its sandier parts, which are interpreted as distributary channel facies (**compare figs. 72 and 74**). In these areas, transmissivity is more than 13,000 feet squared per day generally and locally exceeds 27,000 feet squared per day. Less transmissive sediments appear to be associated with the interdistributary channel facies that contain smaller percentages of sand. In the poorly transmissive areas, transmissivity is reported to be less than 13,000 feet per day.

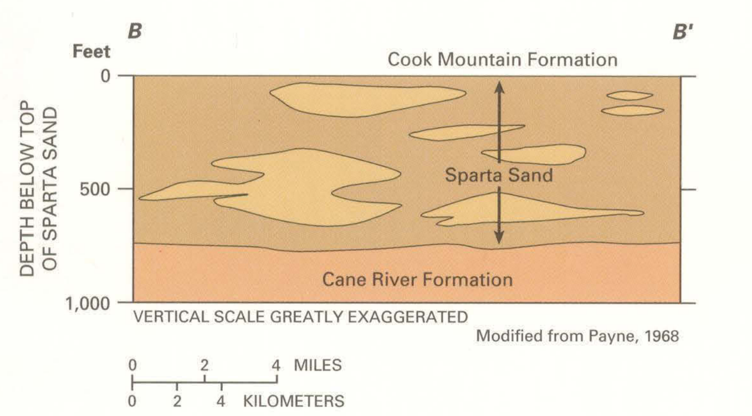


Modified from Payne, 1968

EXPLANATION

Sand

Silt and clay



Modified from Payne, 1968

Figure 73. Lenticular beds of sand that extend southward for several tens of miles characterize the Sparta Sand, which composes most of the middle Claiborne aquifer. Section A–A' is parallel to the general course of the ancient distributary channels that contain the permeable sands of the aquifer. Section B–B' is perpendicular to the channel direction and shows that the water-yielding sands were deposited in narrow channels. The lines of the hydrogeologic sections are shown in figure 72.

Well Yield

The middle Claiborne aquifer is capable of yielding water to properly constructed wells at a rate that ranges from 100 to 300 gallons per minute in Louisiana and Mississippi. Wells screened in the middle Claiborne aquifer in Arkansas are reported to yield from 300 to 1,000 gallons per minute. Yields of as much as 2,000 gallons per minute are obtained in northernmost Mississippi and eastern Arkansas where the middle Claiborne aquifer merges with the lower Claiborne–upper Wilcox aquifer and is known locally as the Memphis aquifer.

Ground-Water Flow

Gravity is the principal driving force for ground-water movement within the Mississippi embayment aquifer system. Regional movement of water in the aquifer system is from aquifer recharge areas that range from 100 to 400 feet higher than the uniformly low, flat terrain of the Mississippi Alluvial Plain where water discharges. This difference in altitude provides the gravitational energy needed to drive the ground-water flow system.

Most of the precipitation that falls on the exposed part of the Mississippi embayment aquifer system is lost to streams and rivers as direct runoff, is returned to the atmosphere from plants and soil by processes of evapotranspiration, or discharges as baseflow to streams in the outcrop area. Before development of the aquifer, water that entered the deeper, regional flow system moved toward the center of the Mississippi Embayment (**fig. 75**). Water in the confined parts of the system was discharged by upward leakage into shallower aquifers, such as the Mississippi River Valley alluvial aquifer. Ultimately, ground water was discharged to streams and rivers that incised the shallower aquifers.

Development of the ground-water resources of the Mississippi embayment aquifer system has greatly modified the pre-development regional flow system. Large ground-water withdrawals in southern Arkansas and northern Louisiana have caused declines of the potentiometric surface and some changes in direction of regional predevelopment flow. Lows in the predevelopment potentiometric surface were located only in areas of natural ground-water discharge. The location of potentiometric lows has changed and now depressions are in areas with large withdrawals from wells. Pumping centers in northern Louisiana and southern Arkansas were the major sites of regional ground-water discharge from the middle Claiborne aquifer in 1980 (**fig. 76**). Within the middle Claiborne aquifer, large withdrawals have resulted in a long-term decline in water levels, which locally exceeds 100 feet, and have created cones of depression in several places. Declines in the potentiometric surface have helped to induce greater areal recharge and recharge from incised streams in outcrop areas. Ground water removed from storage also has contributed to the long-term decline in water levels within the aquifer. Large withdrawal rates from the middle Claiborne aquifer have induced downward leakage of water into the middle Claiborne aquifer from the upper Claiborne and the Mississippi River Valley alluvial aquifers.

Ground-Water Quality

The middle Claiborne aquifer in Segment 5 contains water with less than 500 milligrams per liter dissolved solids over about one-half of its extent (**fig. 77**). However, the dissolved-solids concentration increases to more than 1,000 milligrams per liter where the aquifer underlies the junction of the Mississippi and the Ouachita Rivers, an area of natural ground-water discharge. The aquifer contains moderately saline water (3,000–10,000 milligrams per liter dissolved solids) in middip areas, but contains brine in the deep surface.

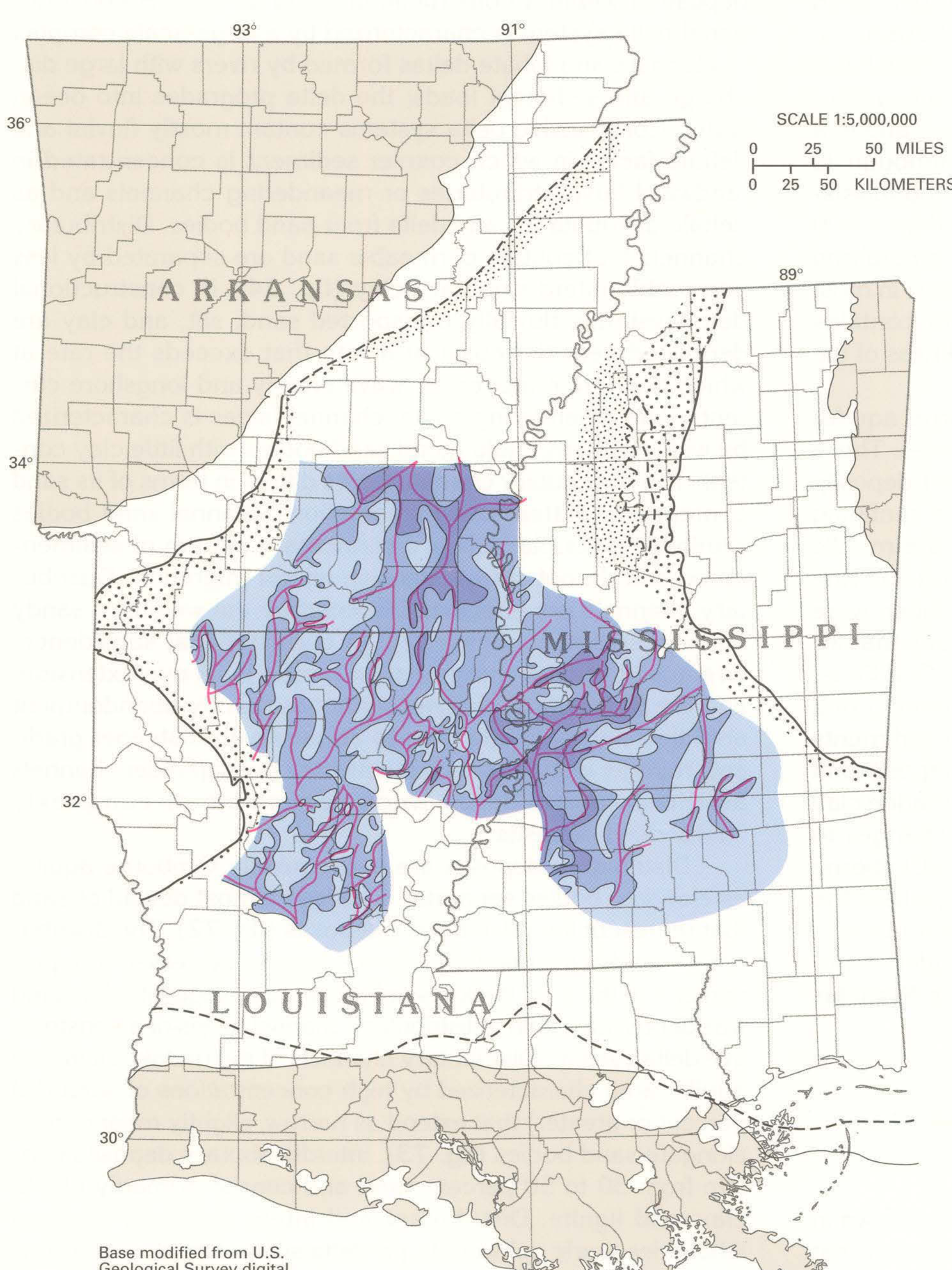
The hydrochemical character of water in the Mississippi embayment aquifer system changes progressively downgradient in a pattern that is consistent with the pattern of other aquifer systems in clastic Coastal Plain sediments. Chemical constituents in the ground water of clastic Coastal Plain aquifer systems are controlled, in part, by solution of the minerals in the sediments that make up the aquifers; in part, by the exchange of ions between the water and the minerals in the sediments as the water moves down the hydraulic gradient; and in part, by mixing of freshwater and saltwater in deep parts of the aquifers. The major hydrochemical facies (the dominant cations and anions) in water from the Mississippi embayment aquifer system are calcium bicarbonate, sodium bicarbonate, and sodium chloride. Other hydrochemical facies are local in extent. Calcium bicarbonate and sodium bicarbonate waters dominate the exposed and shallow subsurface areas of the Middle Claiborne aquifer (**fig. 78**). Sodium bicarbonate water is the major type in middip subsurface areas, whereas sodium chloride water is in the deeply buried parts of the aquifer.

Figure 74. The transmissivity of the Sparta Sand (middle Claiborne aquifer) ranges from less than 13,000 to more than 27,000 feet squared per day. Areas of higher transmissivity correlate to ancient distributary channels mapped on the basis of the percentage of sand. Areas of low transmissivity compare well with the probable location of interdistributary deposits.

EXPLANATION

Estimated transmissivity of the Sparta Sand (middle Claiborne aquifer) based on aquifer and specific capacity tests, in feet squared per day

- 13,000
- 27,000
- No data
- **Area of outcrop of the middle Claiborne aquifer**
- **Area of subcrop of the middle Claiborne aquifer**
- **Line showing axis of higher transmissivity**
- **Limit of aquifer**—Dashed where uncertain



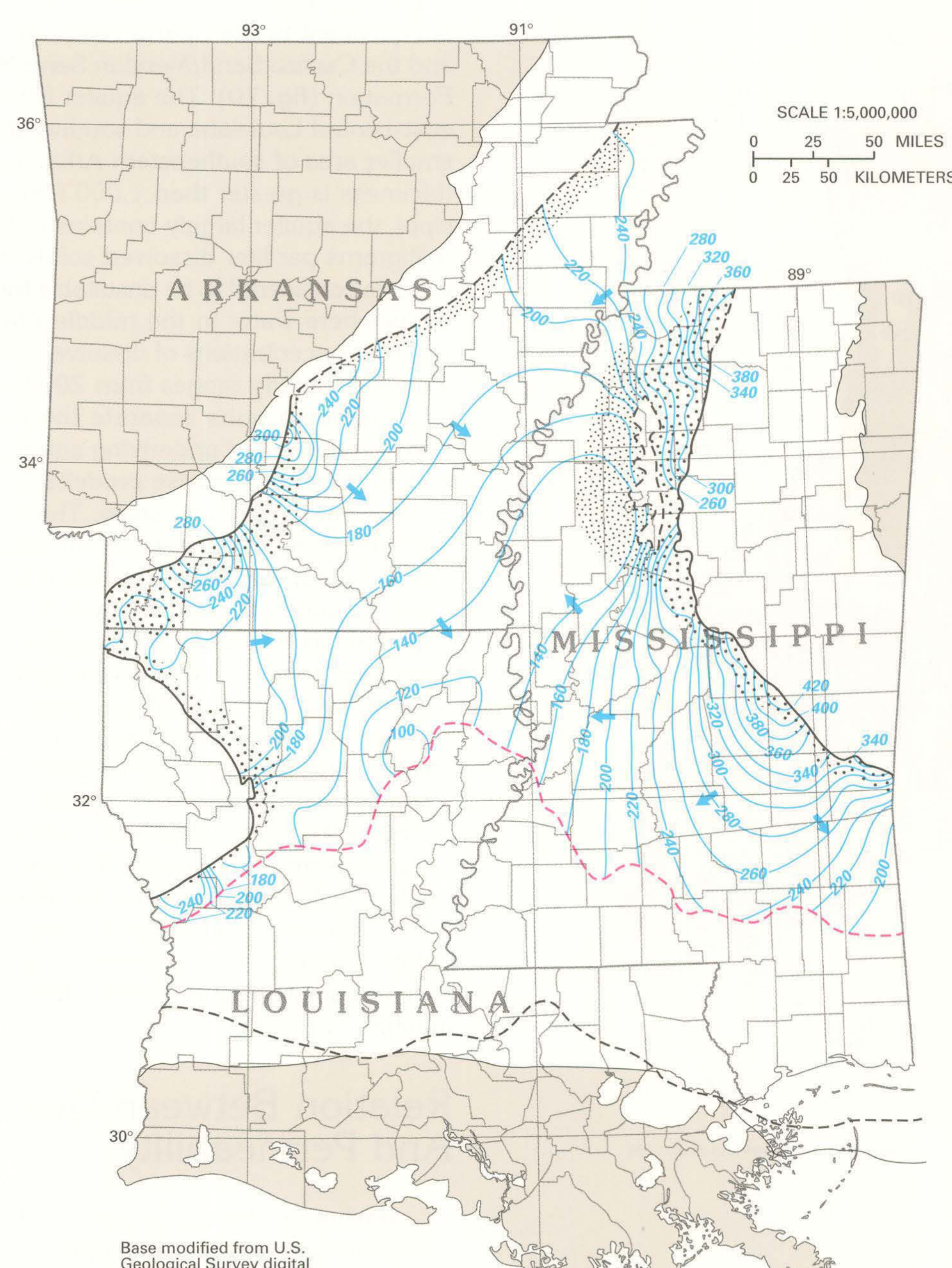
Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Modified from Payne, 1968

Figure 75. Before development of the middle Claiborne aquifer, water entered the aquifer at outcrop areas and moved toward the center of the Mississippi Embayment. Regional discharge was mostly by diffuse upward leakage to shallower aquifers and eventually to major streams such as the Mississippi River.

EXPLANATION

- **Area of outcrop of the middle Claiborne aquifer**
- **Area of subcrop of the middle Claiborne aquifer**
- 100 — **Potentiometric contour**—Shows altitude at which water would have stood in tightly cased wells before development. Contour interval 20 feet. Datum is sea level
- **Limit of aquifer**—Dashed where uncertain
- **Approximate updip limit of water containing 10,000 milligrams per liter dissolved solids**
- **Direction of ground-water movement**



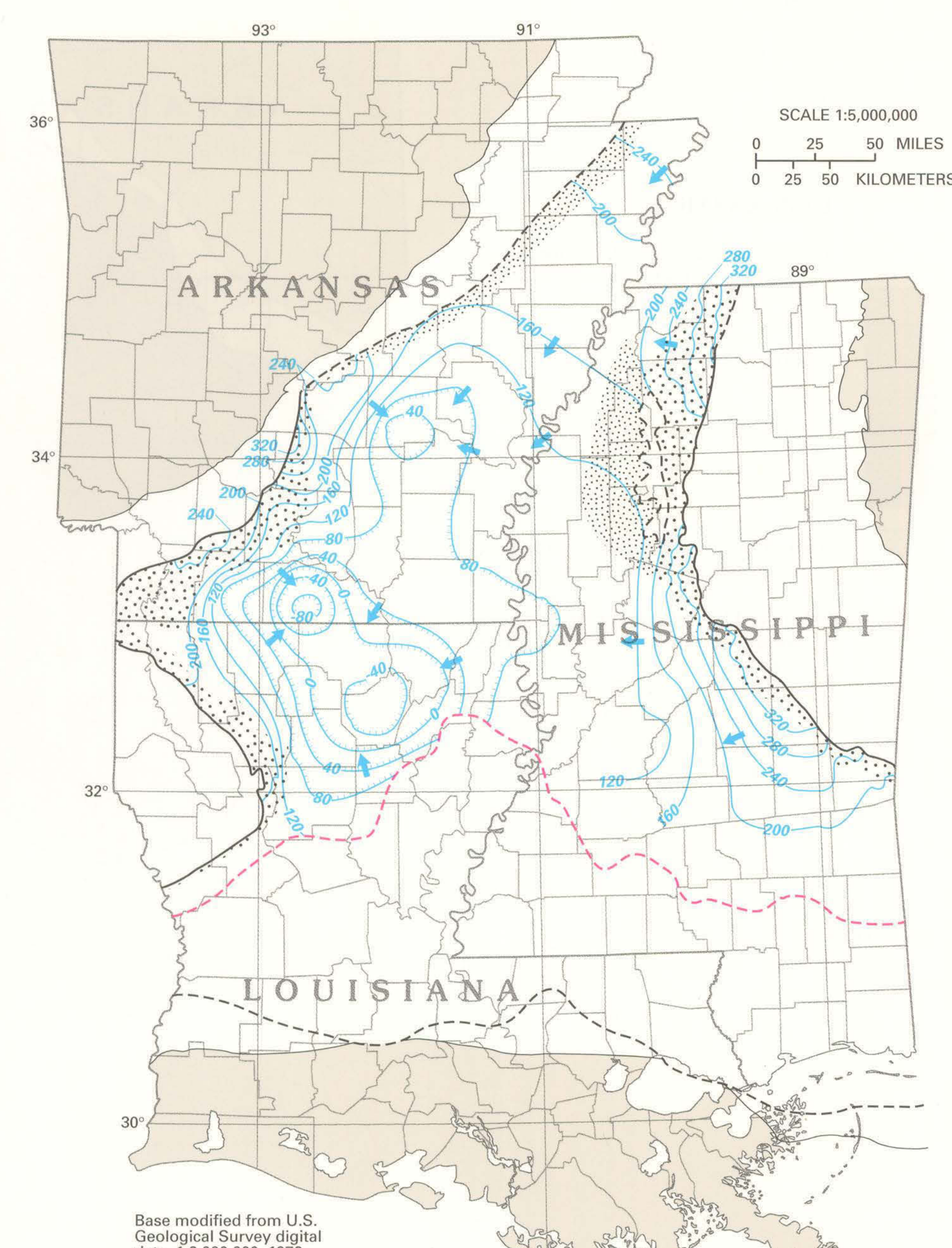
Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Modified from Arthur and Taylor, 1990

Figure 76. Large withdrawals from the middle Claiborne aquifer in northern Louisiana and in southeastern Arkansas have caused a regional decline in water levels and formation of major cones of depression. Regional ground-water movement and discharge have shifted toward these pumping centers.

EXPLANATION

- **Area of outcrop of the middle Claiborne aquifer**
- **Area of subcrop of the middle Claiborne aquifer**
- 200 — **Potentiometric contour**—Shows altitude at which water would have stood in tightly cased wells in 1980. Hachures indicate depressions. Contour interval 40 feet. Datum is sea level
- **Limit of aquifer**—Dashed where uncertain
- **Approximate updip limit of water containing 10,000 milligrams per liter dissolved solids**
- **Direction of ground-water movement**



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

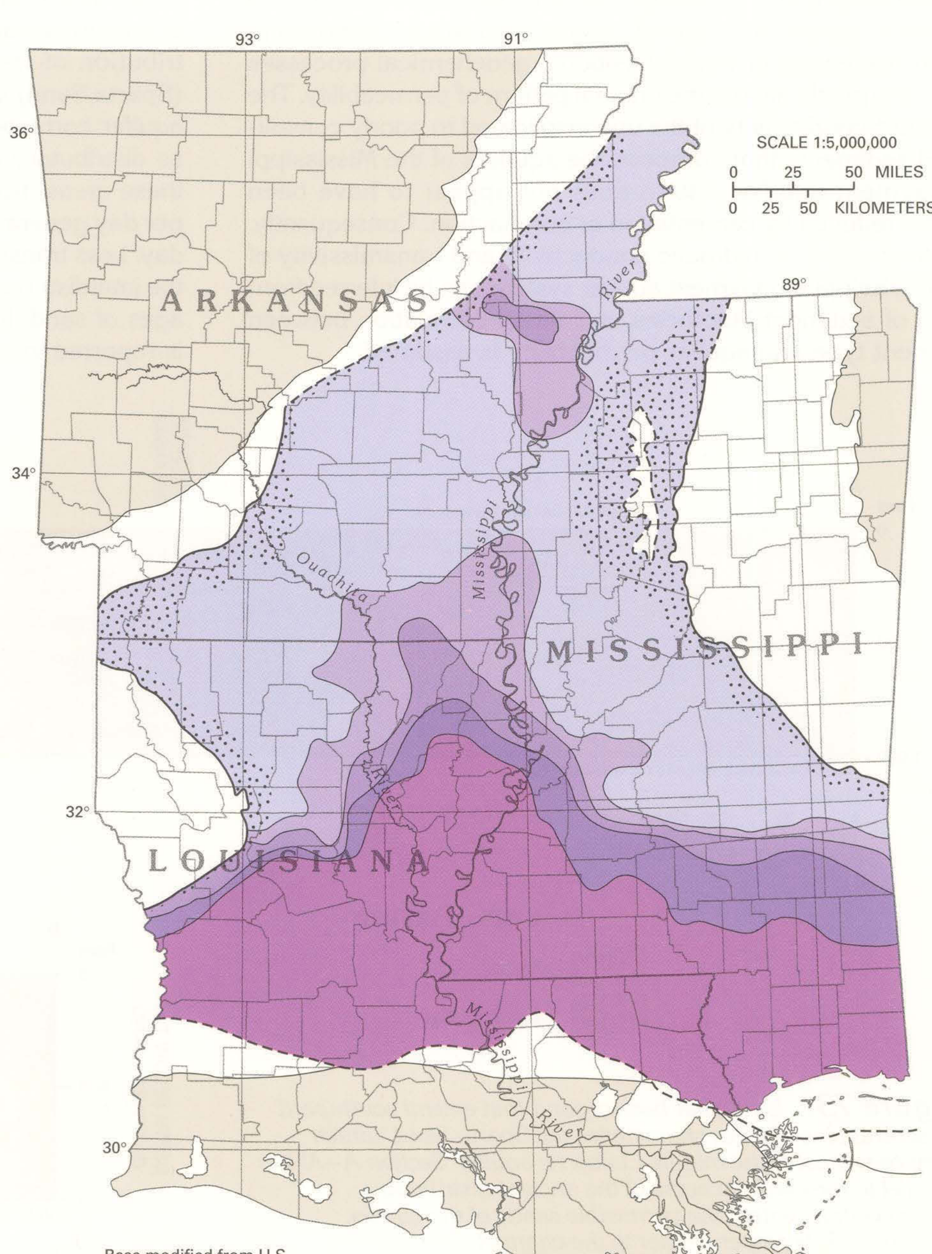
Modified from Arthur and Taylor, 1990

Figure 77. Concentrations of dissolved solids in water from the middle Claiborne aquifer increase southward, primarily as a result of mixing of fresh and salt water. Concentrations of less than 500 milligrams per liter are mostly present where the aquifer crops out or is in the shallow subsurface, and ground-water movement is rapid.

EXPLANATION

Dissolved-solids concentration, in milligrams per liter

- 0 to 500
- 500 to 1,000
- 1,000 to 3,000
- 3,000 to 10,000
- Greater than 10,000
- **Area of outcrop or shallow subcrop of the middle Claiborne aquifer**



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

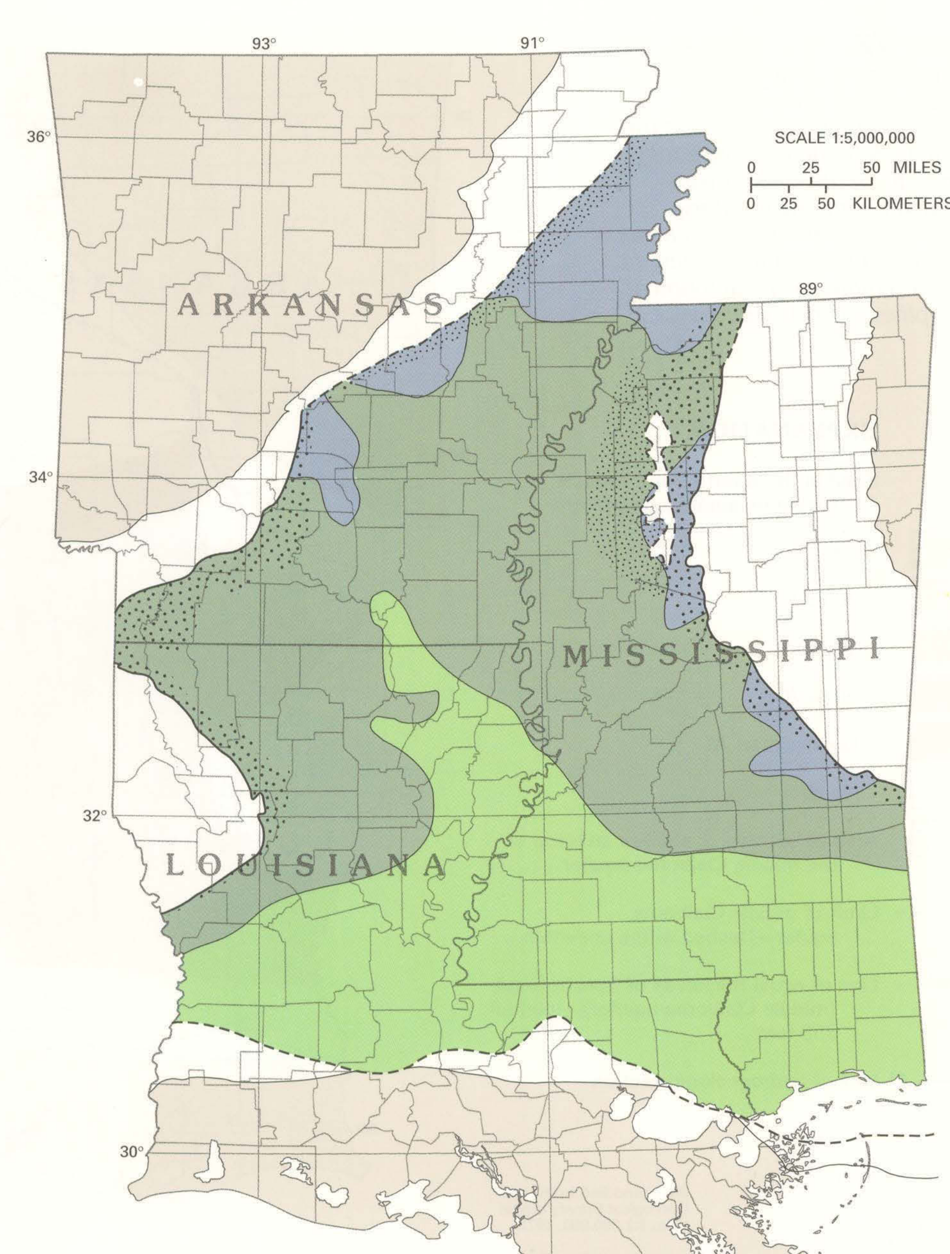
Modified from Pettijohn, 1988; and Pettijohn and others, 1993

Figure 78. The chemical character of water within the middle Claiborne aquifer changes southward from a calcium bicarbonate to a sodium chloride water. Calcium bicarbonate and sodium bicarbonate waters are in areas where the aquifer crops out or is in the shallow subsurface. Sodium chloride water is mostly in the deep subsurface where the aquifer contains saline water.

EXPLANATION

Hydrochemical Facies

- Calcium bicarbonate
- Sodium bicarbonate
- Sodium chloride
- **Area of outcrop of the middle Claiborne aquifer**
- **Area of subcrop of the middle Claiborne aquifer**



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Modified from Pettijohn, 1988; and Pettijohn and others, 1993

MCNAIRY-NACATOCH AQUIFER

The McNairy-Nacatoch aquifer (**fig. 79**) comprises sand of Late Cretaceous age. The aquifer crops out or subcrops in parts of northern Mississippi and eastern and southwestern Arkansas and is the lowermost aquifer of the Mississippi embayment aquifer system. The McNairy–Nacatoch aquifer (**fig. 79**) extends northward into southeastern Missouri, which is described in Chapter D of this Atlas, and northeastward into western Tennessee, southern Illinois, and southwestern Kentucky, which is described in Chapter K of this Atlas. Although Missouri, Illinois, and Kentucky are not within Segment 5, the pattern of regional ground-water flow within the McNairy–Nacatoch aquifer cannot be described without also describing intersegment ground-water movement. The hydrogeology of the entire McNairy–Nacatoch aquifer is, therefore, described in this chapter.

The McNairy–Nacatoch aquifer consists of the Nacatoch Sand in Arkansas and the McNairy Sand in Mississippi. The McNairy Sand is considered to be a member of the Ripley Formation in Mississippi but is of formational rank where it extends into Tennessee and the northern part of the Mississippi Embayment. The McNairy–Nacatoch aquifer crops out as a narrow band that extends northward from Mississippi into southern Illinois and as a second narrow band in southwestern Arkansas. The aquifer subcrops beneath the Mississippi River Valley alluvial aquifer in northeastern Arkansas, southeastern Missouri, and southernmost Illinois. A confining unit separates the McNairy–Nacatoch aquifer from part of the underlying Southeastern Coastal Plain aquifer system in Mississippi, but the McNairy-Nacatoch aquifer directly overlies the Ozark Plateaus aquifer system along part of the western margin of the Coastal Plain of Arkansas and Missouri. The McNairy–Nacatoch aquifer consists of glauconitic, clayey sand deposited in a deltaic to prodeltaic environment in Arkansas and Mississippi. The aquifer is interbedded with and grades into chalk and clay as it extends southward. Deltaic deposits of sand, minor gravel, and clay compose the aquifer where it extends northward into Tennessee, southeastern Missouri, and beyond.

Ground-Water Flow

Water enters the McNairy–Nacatoch aquifer as precipitation that falls directly on the aquifer where it crops out in eastern Mississippi and the northern part of the Mississippi Embayment. Water in the aquifer moves westward from topographically high interstream areas on the northern and eastern sides of the Mississippi Embayment to a large area of regional discharge on the western side of the embayment (**fig. 80**). The discharge zone, which is identified by a low area of the potentiometric surface, encompasses some of the places where the McNairy–Nacatoch aquifer directly underlies the Mississippi River Valley alluvial aquifer in northeastern Arkansas and southeastern Missouri. The discharge zone also includes a large area where the McNairy–Nacatoch aquifer is confined by clay and shale of the Midway confining unit. Discharge of ground-water from the McNairy–Nacatoch aquifer does not coincide with any surface drainage features, but does correspond closely to an area subject to large ground-water withdrawals. The discharge area also is nearly coincident with the western margin of the Reelfoot Rift. Hydrochemical data and simulation of ground-water flow suggest that fractures and a tensional fault, both of which were caused by deep-seated, periodic crustal rifting in northeastern Arkansas, enhance vertical upward leakage of water from the Ozark Plateaus aquifer system and the McNairy–Nacatoch aquifer to shallower aquifers of the Mississippi embayment aquifer system.

Ground-Water Quality

The concentration of dissolved solids in water from the McNairy–Nacatoch aquifer increases in a southwesterly direction (**fig. 81**). Dissolved-solids concentrations are generally lowest in areas where the aquifer crops out and where it is buried only to shallow depths. In northeastern Arkansas, dissolved-solids concentrations generally are greater than 500 milligrams per liter. Concentrations of more than 1,000 milligrams per liter are present in a small area in southeastern Missouri apparently as the result of upward leakage of water from the Ozark Plateaus aquifer system. The McNairy–Nacatoch aquifer generally contains more than 3,000 milligrams per liter dissolved-solids concentration in its deepest parts. The aquifer is dominated by sodium bicarbonate water where it contains water with less than 2,000 milligrams per liter dissolved solids and by sodium chloride water where it contains water with more than 2,000 milligrams per liter dissolved solids.

Figure 79. *The McNairy–Nacatoch aquifer crops out or subcrops as a narrow band along the margin of the Mississippi Embayment and thickens to more than 400 feet in the north-central part of the embayment.*

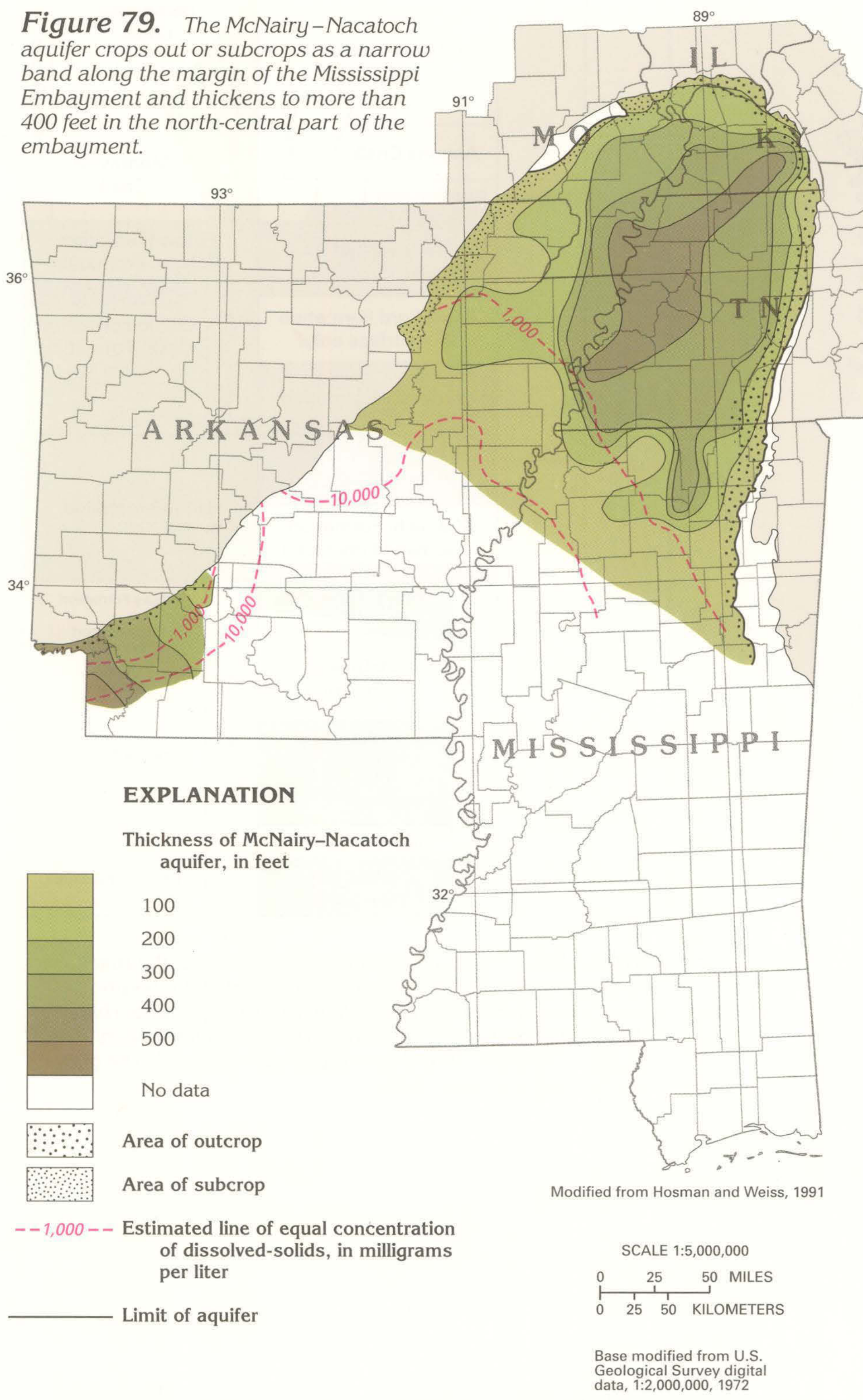


Figure 80. *Regional ground-water flow in the McNairy–Nacatoch aquifer is westward from elevated interstream aquifer outcrop areas in the northern and eastern parts of the Mississippi Embayment. Discharge from the aquifer takes place over a wide area located along the western margin of the embayment. Water that leaks upward from the underlying Ozark Plateaus aquifer system recharges the McNairy–Nacatoch aquifer in this same area. Water discharged from the Ozark Plateaus aquifer system and the McNairy–Nacatoch aquifer is believed to move upward along tensional fractures formed by movement of the Reelfoot Rift. However, withdrawals from wells account for most of the water that discharges from the McNairy–Nacatoch aquifer.*

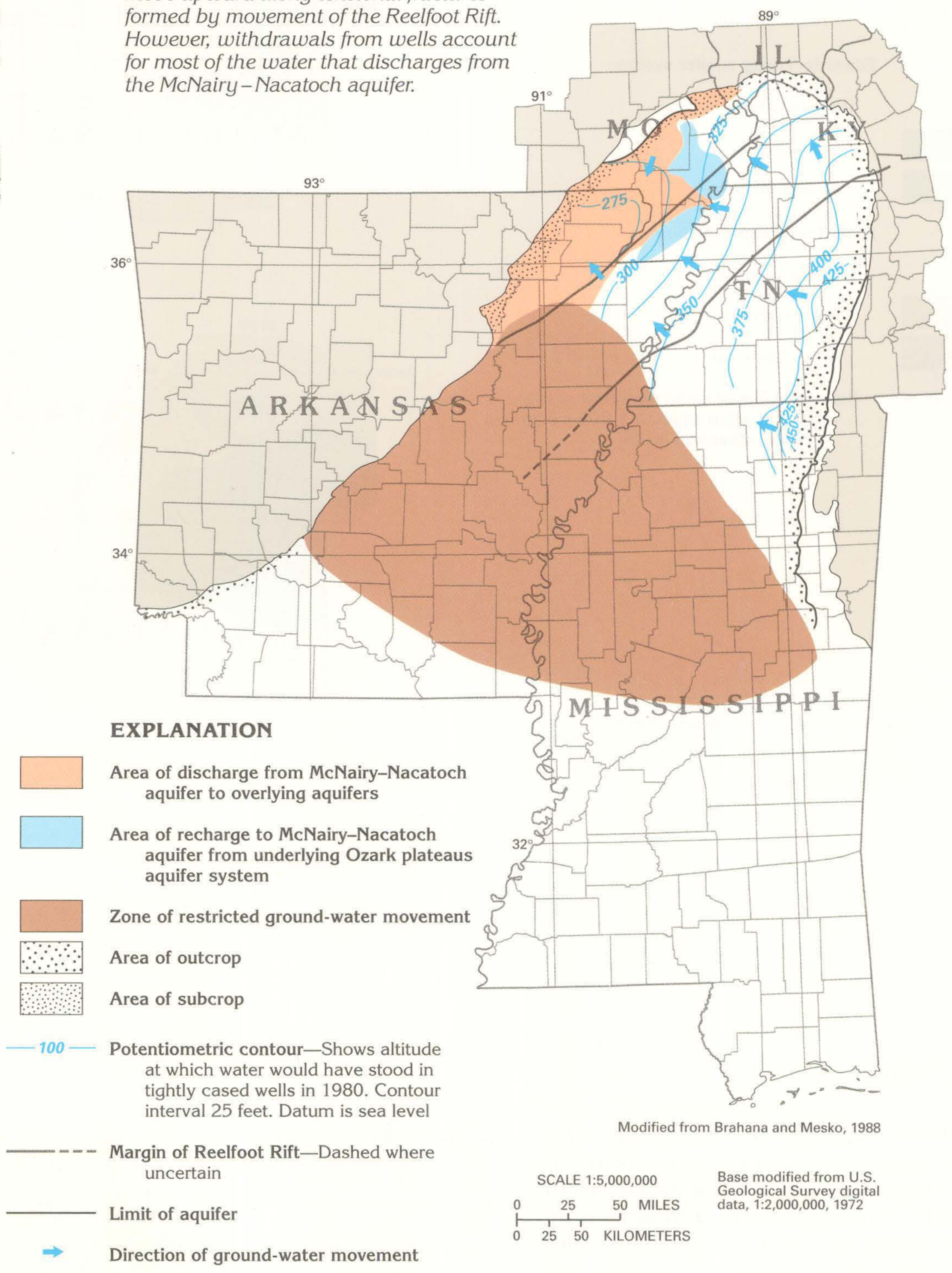
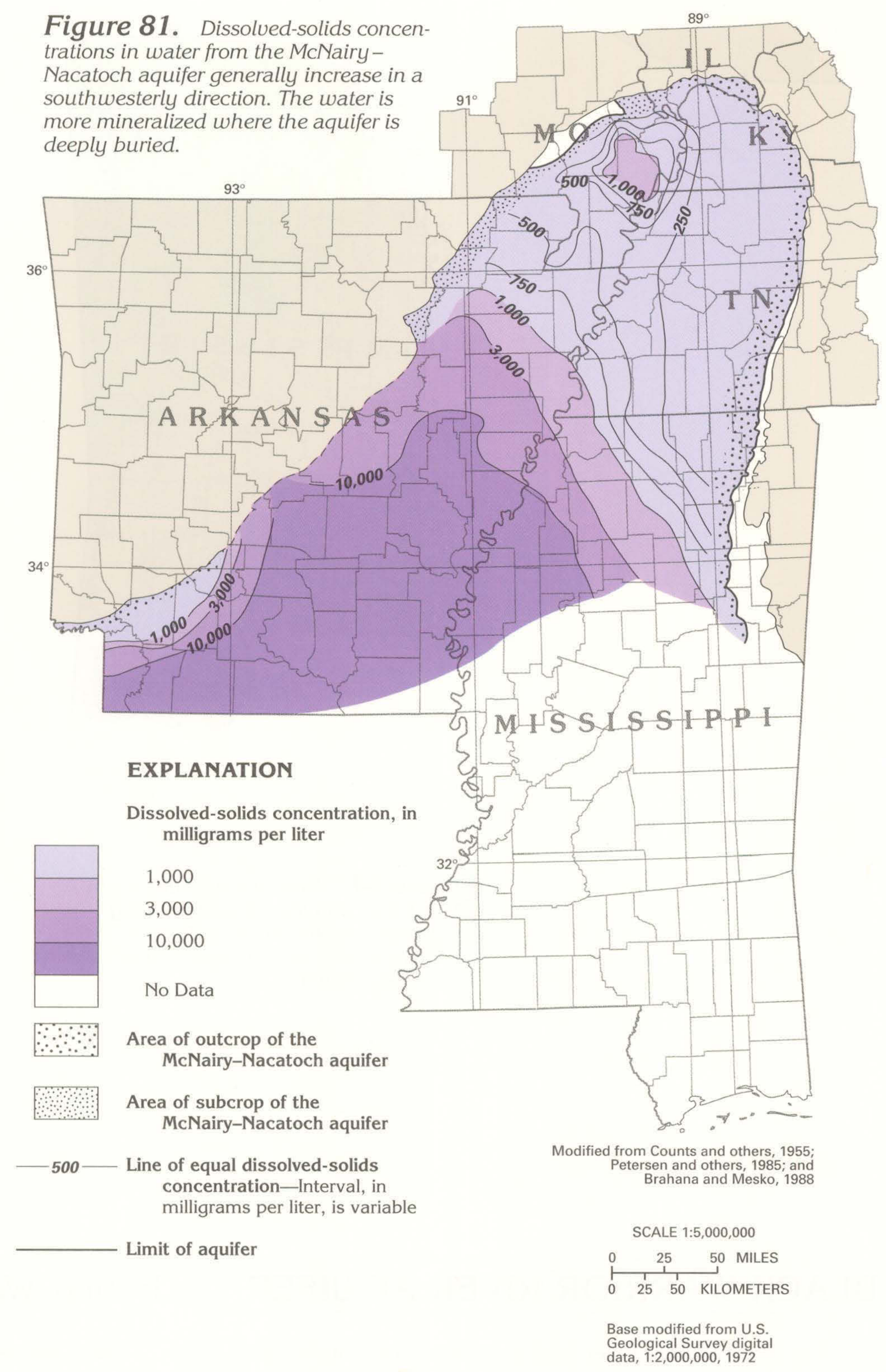


Figure 81. *Dissolved-solids concentrations in water from the McNairy–Nacatoch aquifer generally increase in a southwesterly direction. The water is more mineralized where the aquifer is deeply buried.*



FRESH GROUND-WATER WITHDRAWALS

Fresh ground-water withdrawals from the Mississippi embayment aquifer system are estimated to be 433 million gallons per day (**fig. 82**). Public supply use accounts for about 52 percent of the total water withdrawn from the aquifer system, or about 224 million gallons per day. Withdrawals for domestic and commercial use were about 23 percent of the total withdrawals, or about 99 million gallons per day. Agricultural withdrawals from the Mississippi embayment aquifer system averaged about 71 million gallons per day, or about 16 percent of the total ground-water withdrawn. Industrial, mining, and thermoelectric power users withdrew about 39 million gallons per day, or about 9 percent of the total withdrawals.

More water is withdrawn from the middle Claiborne aquifer than from any other aquifer of the Mississippi embayment aquifer system. In 1980, for example, about 308 million gallons per day was withdrawn from the aquifer principally from major pumping centers (**fig. 83**) in the cities of Stuttgart, Pine Bluff, El Dorado, and Magnolia, Arkansas; Ruston, Jonesboro, Monroe, and Bastrop, Louisiana, and Yazoo City and Jackson, Mississippi. Large withdrawals are also made by pumping centers in the Memphis, Tennessee area (Chapter K).

Figure 82. *Withdrawals for public supply accounted for slightly more than 50 percent of all the freshwater withdrawn from the Mississippi embayment aquifer system during 1985.*

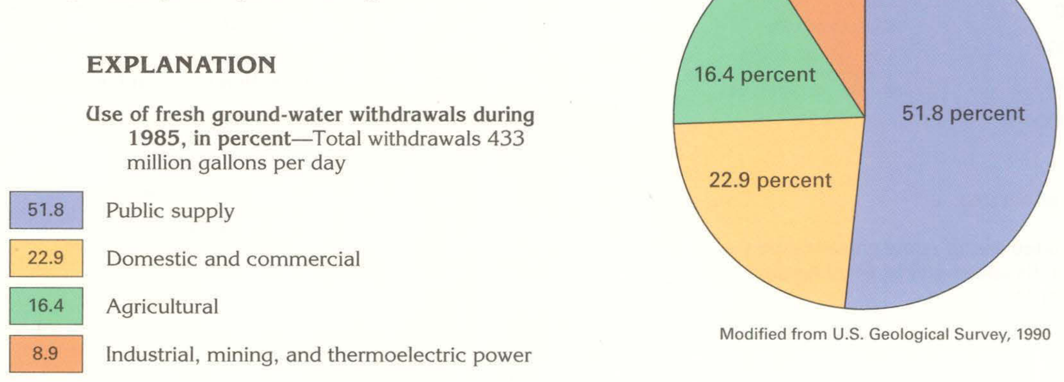
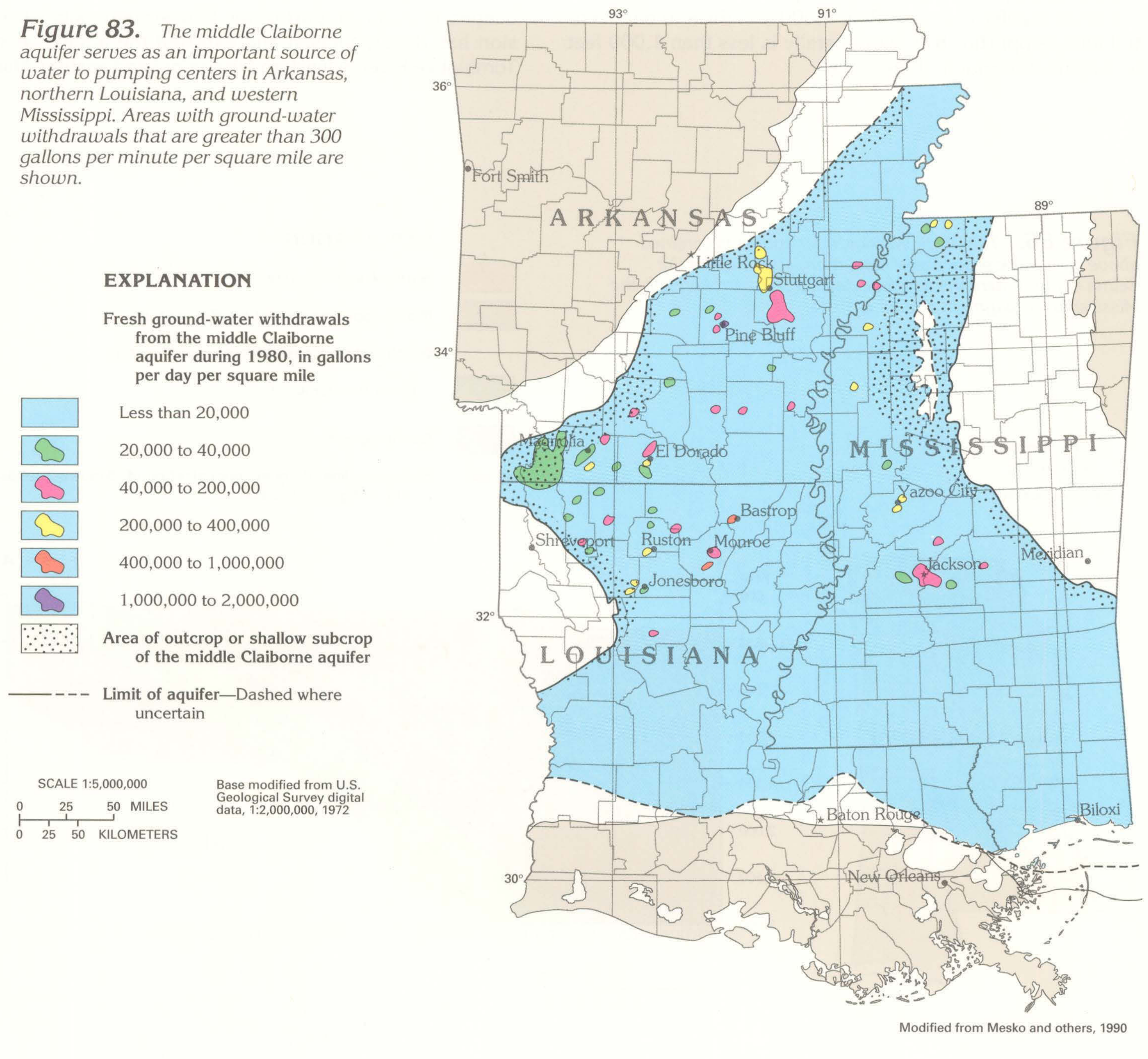


Figure 83. *The middle Claiborne aquifer serves as an important source of water to pumping centers in Arkansas, northern Louisiana, and western Mississippi. Areas with ground-water withdrawals that are greater than 300 gallons per minute per square mile are shown.*



Cretaceous aquifers

INTRODUCTION

In Segment 5, Coastal Plain sediments of Cretaceous age compose parts of two aquifer systems and one minor aquifer. Small parts of the Southeastern Coastal Plain and the Edwards–Trinity aquifer systems are within the segment as is the Tokio–Woodbine aquifer, which is a minor aquifer in southwestern Arkansas (**fig. 84**).

The Southeastern Coastal Plain aquifer system is a multi-aquifer system that consists of three major aquifers that comprise unconsolidated and poorly consolidated clastic sedimentary strata of Tertiary and Cretaceous age. Most of this aquifer system underlies Alabama, Georgia, and South Carolina and is described in Chapter G of this Atlas. However, the aquifer system extends westward into Mississippi where the Chickasawhay and the Pearl River aquifers merge with and are considered to be part of the Coastal Lowlands and the Mississippi embayment aquifer systems, respectively. The Black Warrior River aquifer, which is the lowermost aquifer of the Southeastern Coastal Plain aquifer system, underlies about 32,000 square miles in Mississippi. The geologic formations that compose this aquifer are shown in **figure 85**.

The Edwards–Trinity aquifer system comprises rocks of Cretaceous age that crop out as a wide, looping band that extends across the middle of Texas, into the southeastern corner of Oklahoma and southwestern Arkansas. The aquifer system is separated into the Edwards, Edwards–Trinity, and the Trinity aquifers, all of which are described in detail in Chapter E of this Atlas. The Trinity aquifer is the only part of the Edwards–Trinity aquifer system that extends into southwestern Arkansas. The water-yielding formations that compose the Trinity aquifer in Arkansas are part of the Trinity Group (**fig. 85**).

The Tokio–Woodbine aquifer crops out and extends into the subsurface in a limited area in southwestern Arkansas but extends westward into Oklahoma and Texas where it is considered to be a minor aquifer and is known as the Woodbine aquifer (Chapter E of this Atlas). The Tokio–Woodbine aquifer in Arkansas is a minor aquifer that serves only as a local source of water for domestic use.

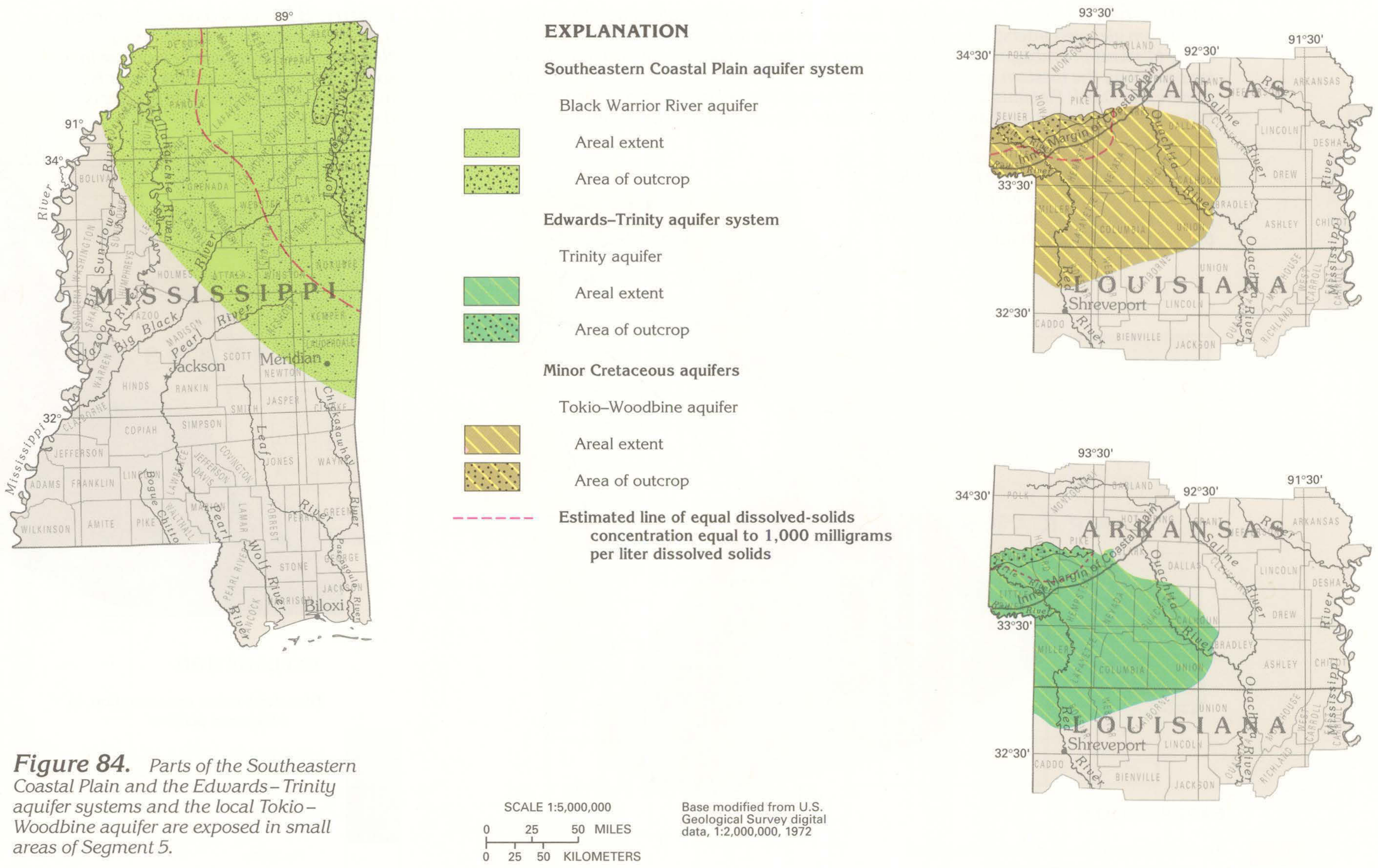


Figure 84. Parts of the Southeastern Coastal Plain and the Edwards–Trinity aquifer systems and the local Tokio–Woodbine aquifer are exposed in small areas of Segment 5.

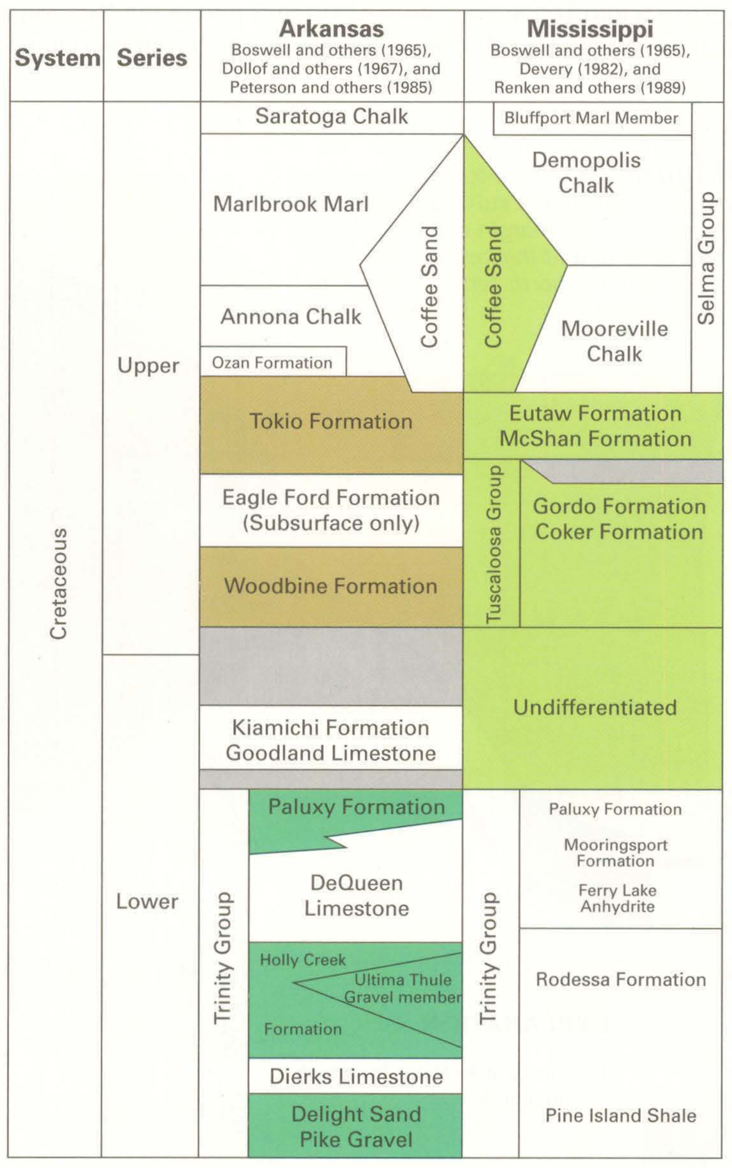


Figure 85. Rocks of Cretaceous age compose the Black Warrior River aquifer (lime green) that is part of the Southeastern Coastal Plain aquifer system; the Trinity aquifer (blue green) that is part of the Edwards – Trinity aquifer system; and the local Tokio–Woodbine aquifer (army green). The gray areas represent missing rocks.

BLACK WARRIOR RIVER AQUIFER

The Black Warrior River aquifer consists of an interbedded mix of fluvial sand and gravel, deltaic sand, silt and clay, and marginal marine sand, silt, and clay. In Mississippi, the Black Warrior River aquifer includes unnamed water-yielding rocks of Early Cretaceous age and the Tuscaloosa Group, the McShan and the Eutaw Formations, and the Coffee Sand of Late Cretaceous age. The Black Warrior River aquifer is confined by a thick sequence of clay and marl of the Selma Group, which effectively separates it from overlying rocks of the Mississippi embayment aquifer system (**fig. 86**). The Black Warrior River aquifer is greater than 4,000 feet thick in east-central Mississippi (**fig. 87**) but generally is less than 1,000 feet in thickness in much of the State.

Ground-Water Flow

Water enters the Black Warrior River aquifer as precipitation that falls on the aquifer outcrop areas in northeastern Mississippi, as well as Alabama. Most of this water moves to streams as direct runoff, is returned to the atmosphere by evapotranspiration, or follows short flow paths in the aquifer and discharges to local streams as baseflow. A small part of the precipitation enters deeper parts of the ground-water flow system, moves downgradient into the confined part of the aquifer, and reemerges as discharge in the valleys of major streams (**fig. 88**). Ground water that discharges from the deeper, or regional, part of the flow system exits where erosion has deeply incised and exposed the aquifer along the Tombigbee River in western Mississippi and eastern Alabama.

Figure 86. The Black Warrior River aquifer is confined above by a thick sequence of clay, marl, and chalk of the Selma Group where the aquifer extends westward beneath the Mississippi embayment aquifer system.

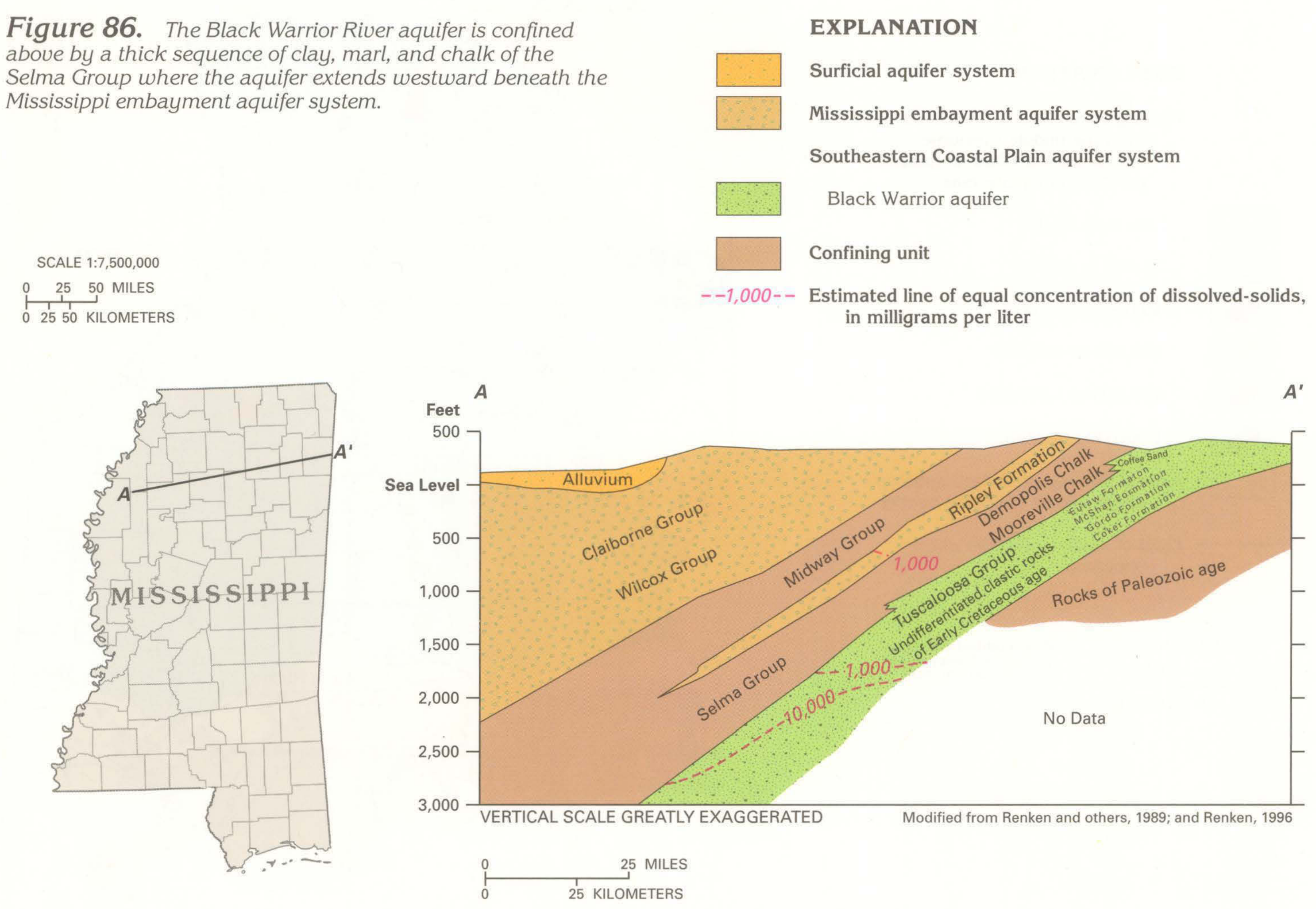


Figure 87. The Black Warrior River aquifer is more than 4,000 feet thick in east-central Mississippi but generally is less than 1,000 feet thick where it contains freshwater.

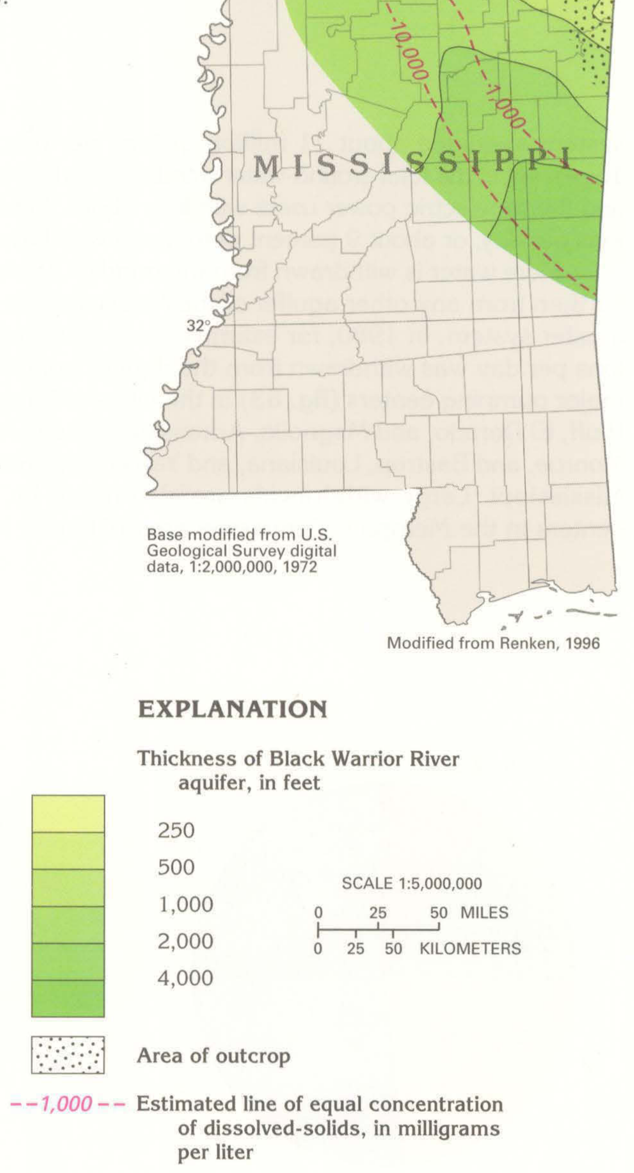
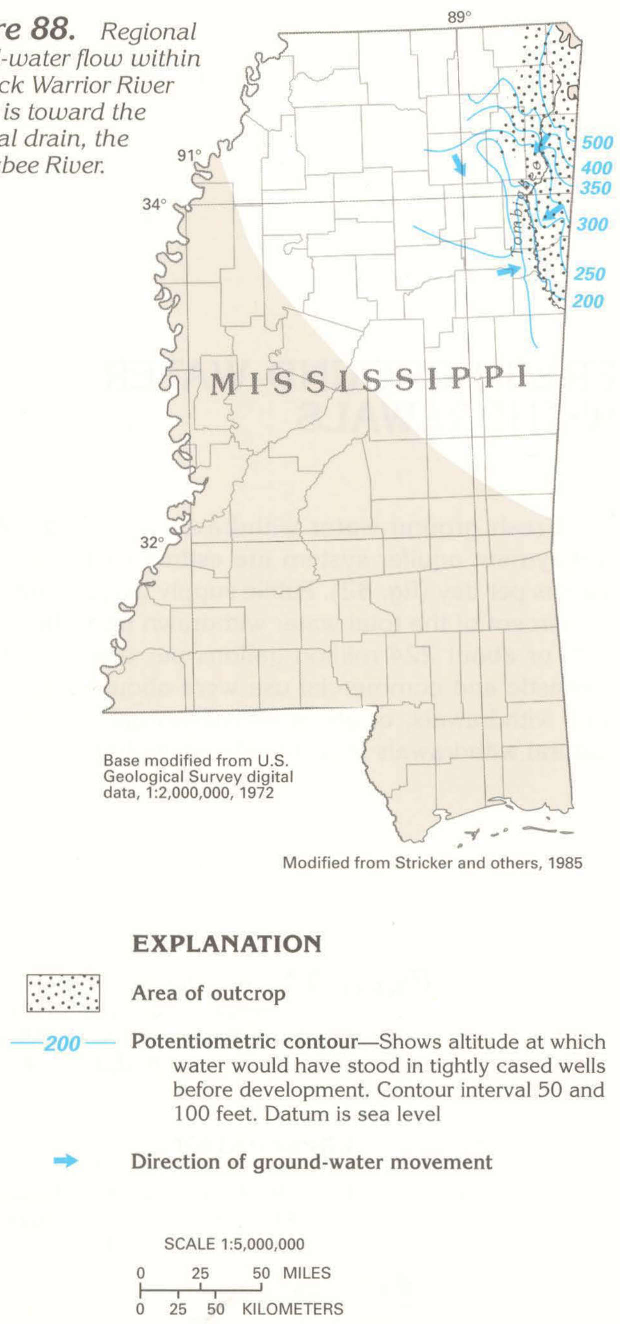


Figure 88. Regional ground-water flow within the Black Warrior River aquifer is toward the principal drain, the Tombigbee River.



Transmissivity

The highest estimated transmissivity (8,500–50,000 feet squared per day) within the Black Warrior River aquifer is in two areas in northeastern Mississippi (**fig. 89**). The largest area is where the aquifer is thickest and the part of the aquifer consists of highly permeable, fluvial strata. The aquifer is less transmissive (950–8,500 feet squared per day) as it extends northward, owing, in part, to a decrease in the amount of fluvial sand and gravel within the aquifer's lower section and, in part, to a thinning (less than 1,000 feet thick) of the aquifer. In the smaller area in the extreme northeastern-most corner of Mississippi, the aquifer consists primarily of unconsolidated, highly permeable gravel. Transmissivity decreases westward and southward because the aquifer contains saline water in its lower parts, and, thus, its effective thickness is less (**fig. 89**).

Ground-Water Quality

The principal chemical constituents that vary areally within the Black Warrior River aquifer are dissolved solids, dissolved iron, and dissolved chloride, all of which increase in concentration from outcrop to downgradient areas. Dissolved-solids concentrations generally are less than 400 milligrams per liter in water from the upper part of the aquifer where it crops out or is buried only to shallow depths (**fig. 90**). Dissolved-solids concentrations of more than 1,000 milligrams per liter may result from the mixing of fresh and saline (mostly mineralized water not flushed from the aquifer system) waters. The concentration of dissolved iron in the ground water of the Black Warrior River aquifer locally can range from 0.5 to 20 milligrams per liter.

Changes in dissolved-solids concentrations correlate reasonably well with changes in the hydrochemical facies of the water in the aquifer (**compare figs. 90 and 91**). "Hydrochemical facies" refers to a classification scheme used to describe the water in terms of the major anions and cations that the aquifer contains. Three major hydrochemical facies are in water from the upper part of the Black Warrior River aquifer. A calcium bicarbonate facies is mostly in updip, landwardmost interstream areas where the aquifer is recharged, whereas a sodium bicarbonate facies dominates the parts of the aquifer that are shallow downgradient areas of the flow system. The concentration of dissolved solids within the calcium bicarbonate waters is small, usually not more than 100 milligrams per liter. Sodium bicarbonate ground waters generally contain dissolved-solids concentrations that are not greater than 400 milligrams per liter. Dissolved-solids concentrations of greater than 1,000 milligrams per liter are characteristic of the sodium chloride hydrochemical facies.

Figure 89. The transmissivity of the Black Warrior River aquifer is highest in two areas of northeastern Mississippi where the aquifer is thick or consists mostly of highly permeable sand and gravel.

SCALE 1:5,000,000
0 25 50 MILES
0 25 50 KILOMETERS

EXPLANATION

Estimated transmissivity of the Black Warrior River aquifer, in feet squared per day, based on aquifer and specific capacity tests and computer simulation of ground-water flow

- 900 to 4,500
- 4,500 to 8,500
- 8,500 to 50,000
- No data
- **Area of outcrop**

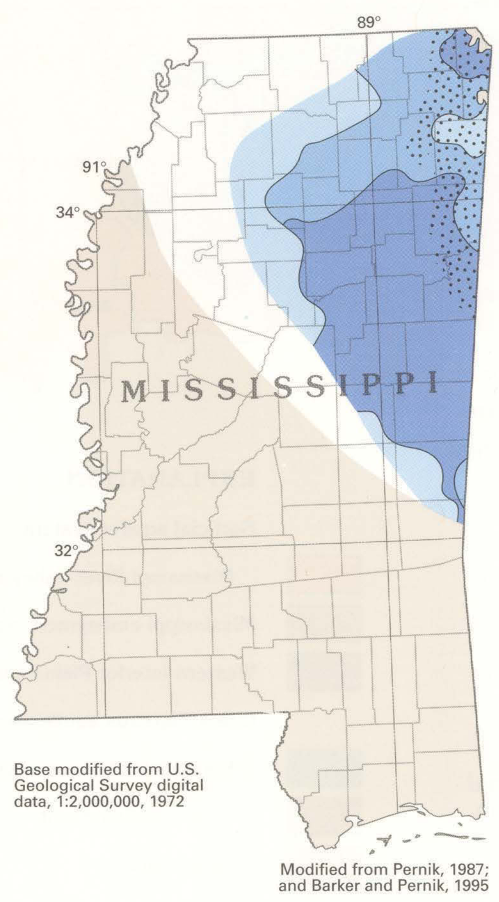


Figure 90. Dissolved-solids concentrations in water from the water-bearing unit of the Black Warrior River aquifer (the Eutaw and the McShan Formations) increase as the water moves downgradient from aquifer outcrop areas. Dissolved-solids concentrations generally are less than 200 milligrams per liter where the unit crops out.

SCALE 1:5,000,000
0 25 50 MILES
0 25 50 KILOMETERS

EXPLANATION

Dissolved-solids concentration, in milligrams per liter

- Less than 200
- 200 to 400
- 400 to 600
- 600 to 1,000
- Greater than 1,000
- No data
- **Area of outcrop**
- **Limit of upper part of Black Warrior River aquifer**

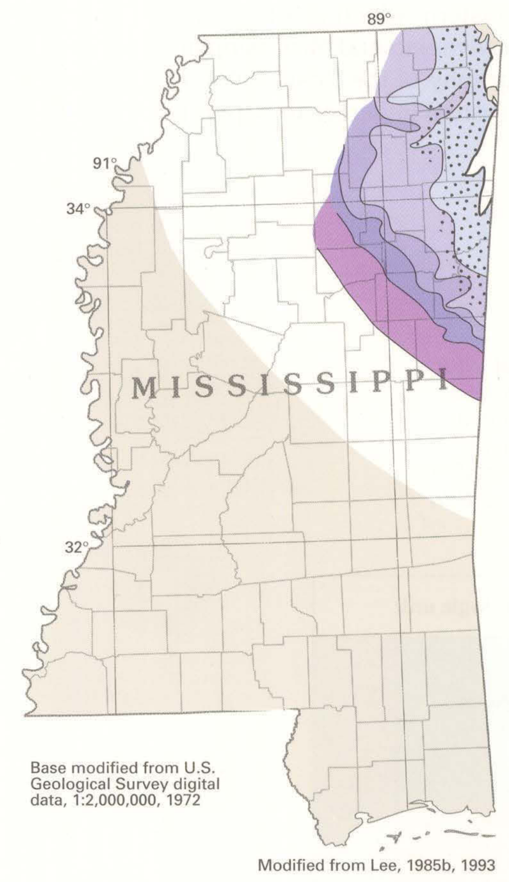


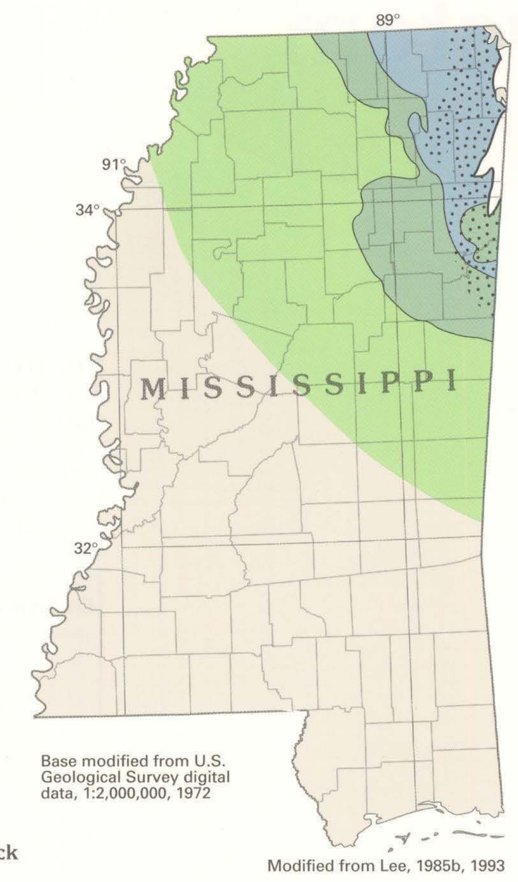
Figure 91. The chemical character of water in the upper water-bearing unit of the Black Warrior River aquifer (the Eutaw and the McShan Formations) changes downgradient from a calcium bicarbonate type near outcrop areas to a sodium chloride type where the aquifer is deeply buried.

SCALE 1:5,000,000
0 25 50 MILES
0 25 50 KILOMETERS

EXPLANATION

Hydrochemical facies

- Calcium bicarbonate
- Sodium bicarbonate
- Sodium chloride
- **Area of outcrop**
- **Limit of upper part of Black Warrior River aquifer**



TOKIO–WOODBINE AQUIFER

The Tokio–Woodbine aquifer serves as a local source of water for domestic use in southwestern Arkansas. The aquifer overlies and in places is hydraulically interconnected with water-yielding sands of the Trinity aquifer. The upper part of the Tokio–Woodbine aquifer consists of the Tokio Formation, which is a sequence of cross-bedded sand, gravel, and lignitic clay that grades downdip to sand and shale. The lower part of the aquifer comprises the Woodbine Formation, which is a red and gray clay that includes a massive, cross-bedded sand and gravel lithofacies where the formation extends into the shallow subsurface.

Freshwater in the Tokio–Woodbine aquifer is very limited in Arkansas and is restricted to a narrow band that extends southward from the outcrop area of the aquifer and lies between the Little and Little Missouri Rivers (**fig. 84**). Factors that appear to control freshwater within the aquifer include the degree of incision by rivers in outcrop areas and a rapid downdip decrease in permeability as the aquifer extends into the subsurface.

FRESH GROUND-WATER WITHDRAWALS

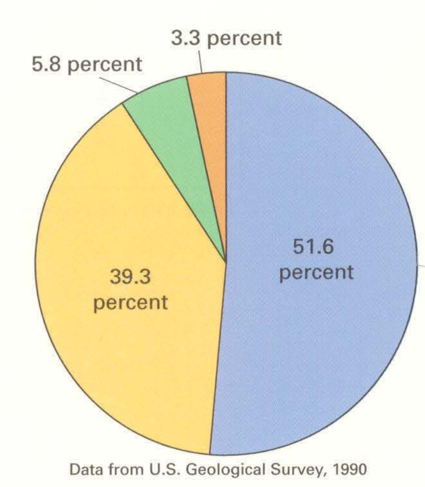
Total fresh ground-water withdrawals from the Black Warrior River, Trinity, and Tokio–Woodbine aquifers of Segment 5 were estimated to be 81 million gallons per day in 1985 (**fig. 92**). Public supply withdrawals represent about 42 million gallons per day, or nearly 52 percent of the total withdrawals. Domestic and commercial users withdrew nearly 32 million gallons per day, or about 39 percent of the total amount of water withdrawn. Pumpage by agricultural users was estimated to be about 4.7 million gallons per day, or about 6 percent of the total; industrial, mining, and thermoelectric users withdrew about 2.7 million gallons per day, or about 3 percent of the total.

Figure 92. More than 50 percent of the total water withdrawn from Cretaceous aquifers and aquifer systems in 1985 was used for public supply purposes.

EXPLANATION

Use of fresh ground-water withdrawals during 1985, in percent—Total withdrawals 81 million gallons per day

51.6	Public supply
39.3	Domestic and commercial
5.8	Agricultural
3.3	Industrial, mining, and thermoelectric power



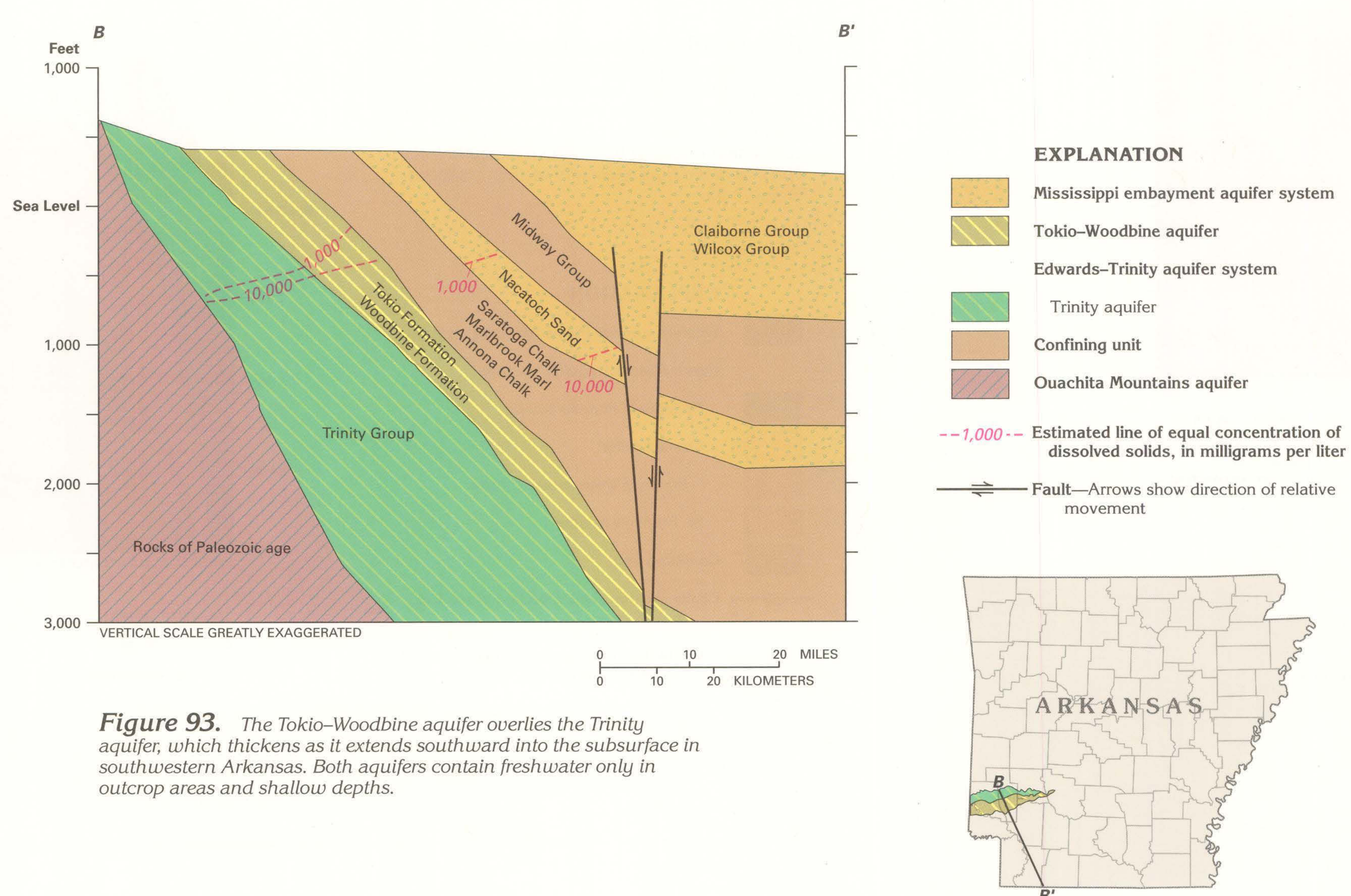


Figure 93. The Tokio–Woodbine aquifer overlies the Trinity aquifer, which thickens as it extends southward into the subsurface in southwestern Arkansas. Both aquifers contain freshwater only in outcrop areas and shallow depths.

TRINITY AQUIFER

The Trinity aquifer consists of Coastal Plain rocks of Early Cretaceous age that yield mostly freshwater where they crop out in southwestern Arkansas. The Trinity aquifer is part of the larger Edwards–Trinity aquifer system, which extends westward into Oklahoma and southwestward across Texas (Chapter E of this Atlas) where it functions as an important source of potable water. The Trinity aquifer was deposited as part of a wedge of sediments that thickens southward from an erosional featheredge in southwestern Arkansas (**fig. 93**). The Trinity aquifer is overlain by the Tokio–Woodbine aquifer and underlain by the Ouachita Mountains aquifer. The Tokio–Woodbine aquifer is more than 1,000 feet thick (**fig. 93**) in the deep subsurface.

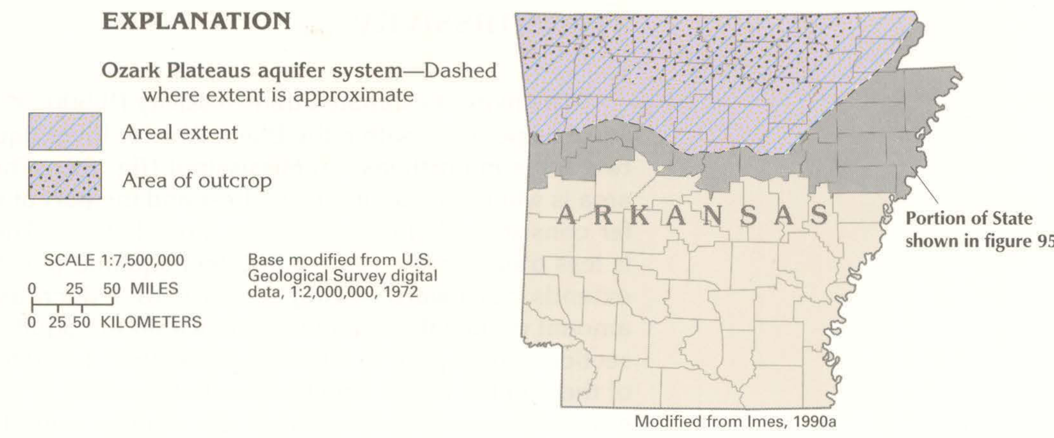
Several water-yielding geologic formations compose the Trinity aquifer in southwestern Arkansas; from oldest to youngest, they are the Pike Gravel, the Delight Sand, the Holly Creek Formation (including the Ultima Thule Gravel Member), and the Paluxy Formation (**fig. 85**). Intervening limestone, anhydrite, clay and shale of the Dierks and the DeQueen Limestones are poorly permeable and serve to separate water-yielding zones in the aquifer. The uppermost permeable rocks of the Trinity aquifer, which are equivalent to the Paluxy Sand, extend westward into Oklahoma where they are locally called the Antlers aquifer. The occurrence of freshwater within the Trinity aquifer is quite limited in Arkansas and is restricted to a 10- to 25-mile wide band that extends southward from aquifer outcrop areas between the Little and the Little Missouri Rivers (**fig. 84**).

INTRODUCTION

Ozark Plateaus aquifer system

The Ozark Plateaus aquifer system, which includes the Springfield Plateau, Ozark, and St. Francois aquifers, crops out in a 40- to more than 50-mile wide band that extends across most of northern Arkansas (**figs. 94, 95**). The aquifer system consists of a thick sequence of lithified, flat-lying to southward-dipping limestone and dolomite that contains some beds of sandstone, shale, and chert. Rocks that comprise the system range in age from Cambrian to Mississippian (**fig. 96**). The aquifer system extends northward into Missouri and westward into southeastern Kansas. It is discussed in detail in Chapter D of this Atlas, which describes aquifers in these States. A small part of the aquifer system extends into eastern Oklahoma and is discussed in Chapter E. The Ozark Plateaus aquifer system extends eastward beneath Coastal Plain and alluvial sediments where it is overlain regionally by the Mississippi embayment aquifer system and locally by the Mississippi River Valley alluvial aquifer (**fig. 97**). The Ozark Plateaus aquifer system is confined on its southern margin in Arkansas by the Western Interior Plains confining system (**fig. 98**). Northern Arkansas is physiographically characterized by three erosional plateaus from southwest to northeast—these are the Boston Mountains and the Springfield and the Salem Plateaus. The Western Interior Plains confining system, which is a thick sequence of poorly permeable Pennsylvanian and Mississippian rocks, underlies the rugged topography of the Boston Mountains. The Ozark Plateaus aquifer system underlies the Springfield and the Salem Plateaus.

Figure 94. *The Ozark Plateaus aquifer system crops out in a 40- to 50-mile wide band in northern Arkansas. The aquifer system extends southward beneath the Western Interior Plains confining system and eastward beneath the Mississippi embayment aquifer system and the Mississippi River Valley alluvial aquifer.*



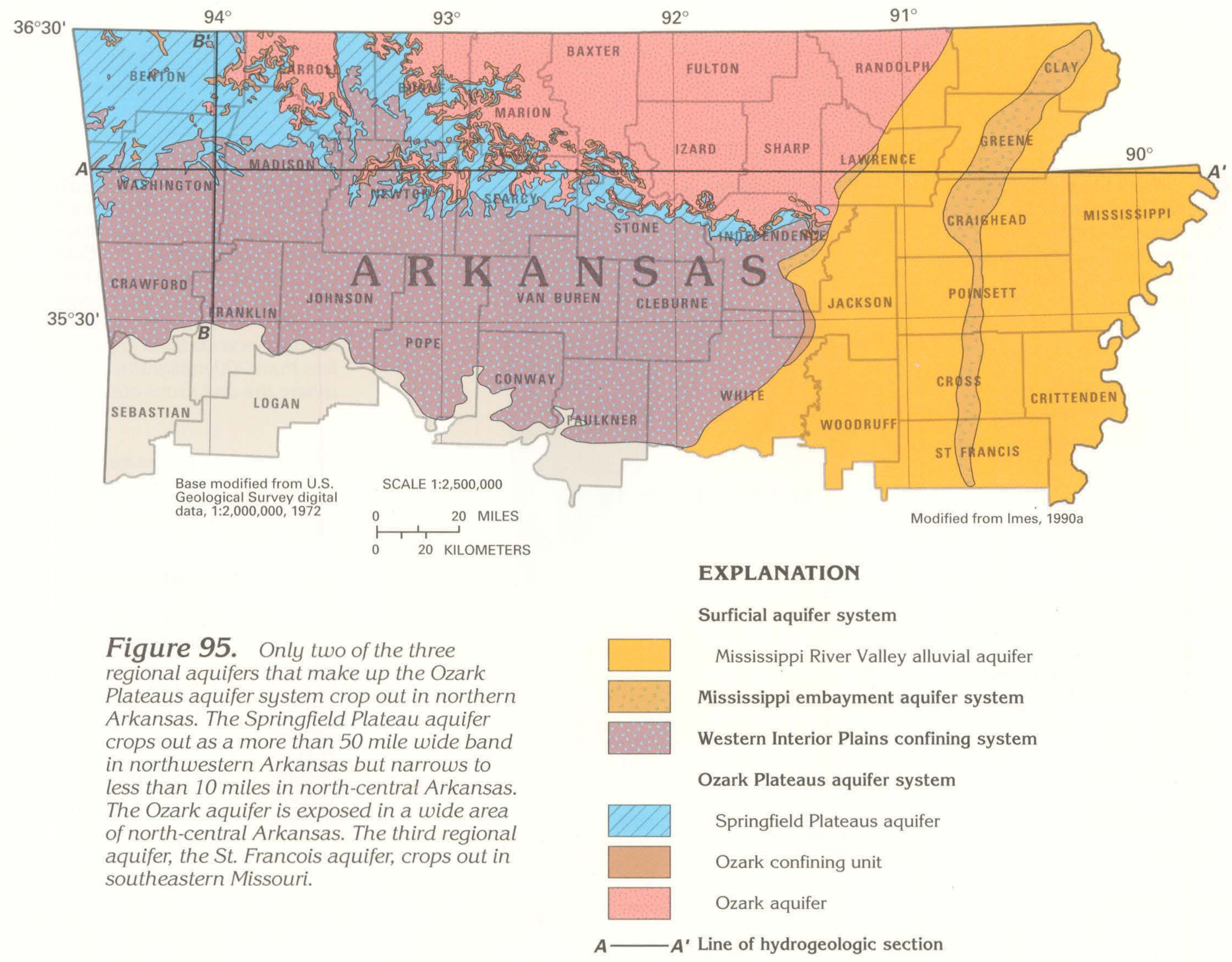


Figure 95. *Only two of the three regional aquifers that make up the Ozark Plateaus aquifer system crop out in northern Arkansas. The Springfield Plateau aquifer crops out as a more than 50 mile wide band in northwestern Arkansas but narrows to less than 10 miles in north-central Arkansas. The Ozark aquifer is exposed in a wide area of north-central Arkansas. The third regional aquifer, the St. Francois aquifer, crops out in southeastern Missouri.*

Figure 96. *The large number of geologic formations that underlie northern Arkansas can be grouped into three regional aquifers separated by two regional confining units. The Springfield Plateau and the Ozark aquifers are of greatest importance in the area. In northern Arkansas, the Roubidoux Formation and sandstones of the Van Buren Formation form the principal water-yielding zone within the Ozark aquifer.*

Erathem	System	Geologic unit	Hydrogeologic unit	
Paleozoic	Mississippian	Boone Formation St. Joe Limestone Member	Springfield Plateau aquifer	Ozark Plateaus aquifer system
	Devonian	Chattanooga Shale (Sylamore Sandstone Member) Clifty Limestone Penters Chert	Ozark confining unit	
	Silurian	Lafferty Limestone St. Clair Limestone Brassfield Limestone	Ozark aquifer	
	Ordovician	Cason Shale Fernvale Limestone Kimmswick Limestone Plattin Limestone Joachim Dolomite St. Peter Sandstone Everton Formation Smithville Formation Powell Dolomite Cotter Dolomite Jefferson City Dolomite Roubidoux Formation[1] Gasconade Dolomite Van Buren Formation[1] (Gunter Sandstone Member)		
	Cambrian	Eminence Dolomite Potosi Dolomite		
		Doe Run Dolomite Derby Dolomite Davis Formation	St. Francois confining unit	
		Bonneterre Dolomite Lamotte Sandstone	St. Francois aquifer	

[1] Principal water-bearing zone within the Ozark aquifer of northern Arkansas

Modified from Imes, 1990a

HYDROGEOLOGIC UNITS

Three regional aquifers, separated by two regional confining units, compose the Ozark Plateaus aquifer system. From shallowest to deepest, the regional aquifers are the Springfield Plateau, the Ozark, and the St. Francois aquifers. The Ozark confining unit separates the Springfield Plateaus and the Ozark aquifers, and the St. Francois confining unit is between the Ozark and the St. Francois aquifers (**fig. 96**). In Segment 5, the Springfield Plateau aquifer and the upper and the middle parts of the Ozark aquifer yield most of the ground water withdrawn (**figs. 97, 98**). It usually is not economically feasible to drill wells into the lower parts of the aquifer system that lies at great depths. Only a few wells penetrate the lower parts of the Ozark aquifer, and none are known to produce water from the St. Francois aquifer.

The Springfield Plateau aquifer consists of interbedded Mississippian limestone and chert that generally yield only small volumes of water to wells. Because the aquifer is thin, relative to the great thickness of the Ozark aquifer, and has been highly dissected by erosion, it is used primarily as a source of water for domestic and stock-watering wells. The Springfield Plateau aquifer is underlain by the Ozark confining unit, which consists of the Chattanooga Shale in Segment 5. Where this confining unit is present and has not been breached by erosion, it effectively separates the Springfield Plateau and the Ozark aquifers.

The thick, extensive, and productive Ozark aquifer is the principal source of ground water in northern Arkansas. Although this aquifer consists of numerous geologic formations, which consist chiefly of limestone and dolomite (**fig. 96**), the most important water-yielding strata in the aquifer are sandstones of the Roubidoux Formation and the Van Buren Formation. Wells that obtain water from these formations commonly yield from 100 to 300 gallons per minute; yields of 500 gallons per minute have been reported for some wells. Shale and dolomite of the St. Francois confining unit underlie the Ozark aquifer and separate it everywhere from the deeper St. Francois aquifer. No wells are known to yield water from the St. Francois aquifer in Segment 5.

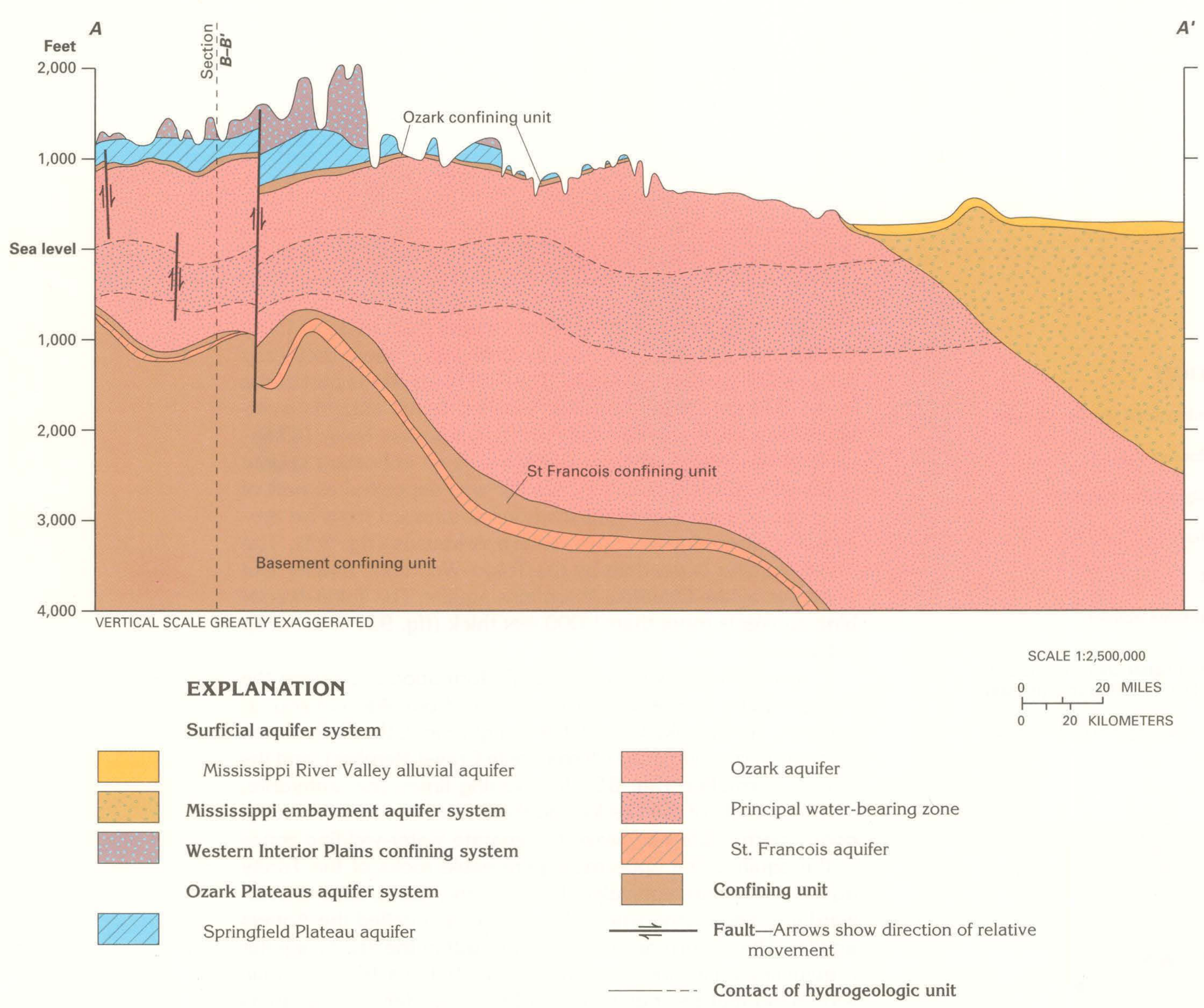
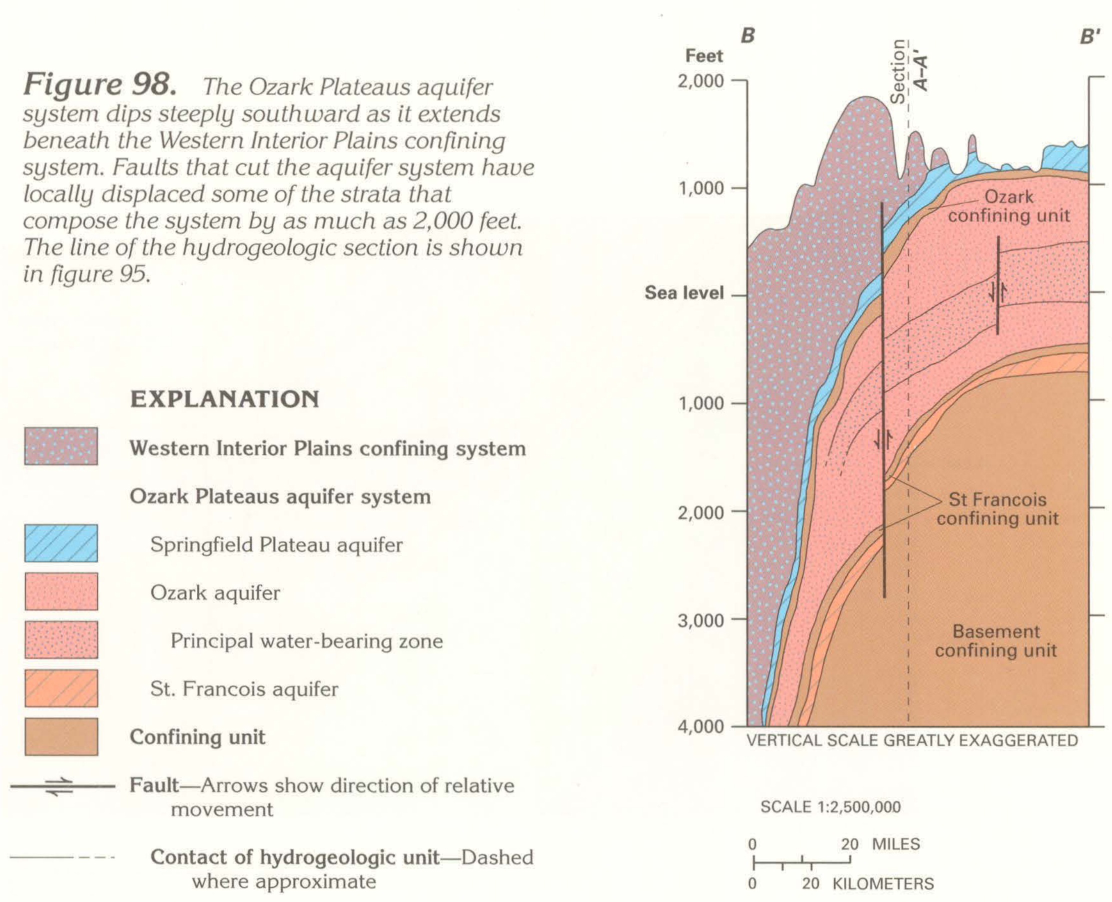


Figure 97. *The Ozark Plateaus aquifer system extends eastward beneath the Mississippi embayment aquifer system. The Ozark aquifer is by far the most extensive aquifer of the system. The line of the hydrogeologic section is shown in figure 95.*

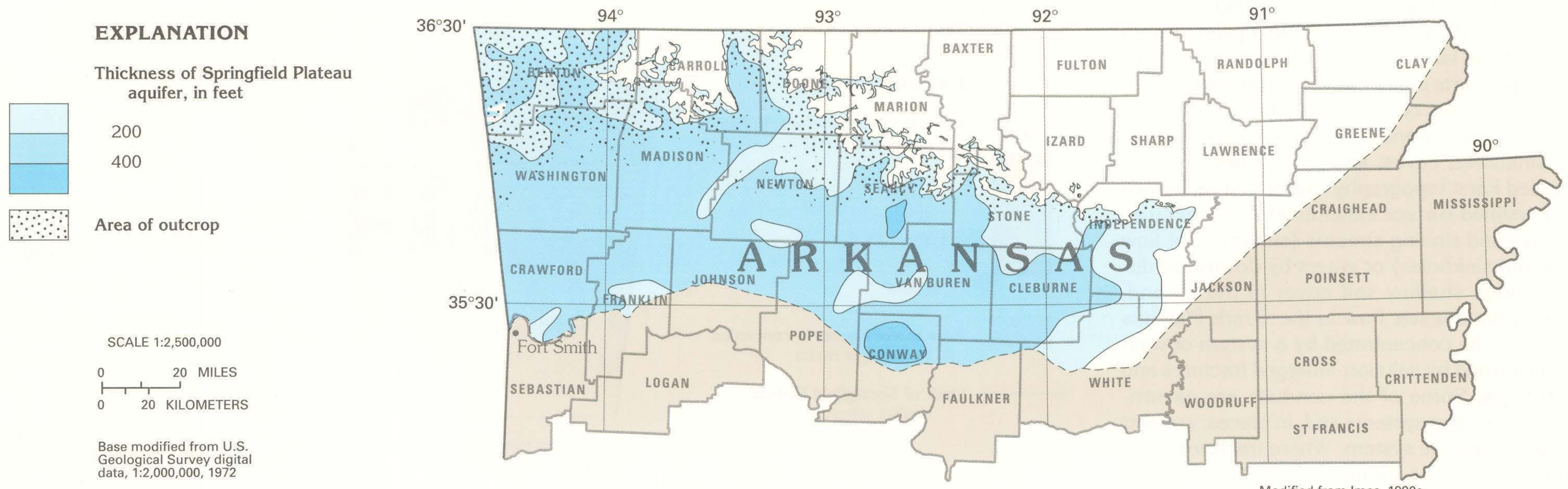
Figure 98. *The Ozark Plateaus aquifer system dips steeply southward as it extends beneath the Western Interior Plains confining system. Faults that cut the aquifer system have locally displaced some of the strata that compose the system by as much as 2,000 feet. The line of the hydrogeologic section is shown in figure 95.*



SPRINGFIELD PLATEAU AQUIFER

The Springfield Plateau aquifer is the uppermost aquifer of the Ozark Plateau aquifer system. The aquifer crops out along the southern and western perimeter of the Springfield Plateau as a narrow belt 5- to 10-mile wide belt in north-central Arkansas but is exposed in a more than 50-mile wide band in northwestern Arkansas (**fig. 99**). Outside Segment 5, the Springfield Plateau aquifer extends northward into western Missouri and westward into Oklahoma. Before deposition of the Coastal Plain sediments, erosion removed rocks in northeastern Arkansas equivalent to those that compose the Springfield aquifer. In northern Arkansas, beds of the Springfield Plateau aquifer dip southward beneath the Western Interior Plains confining system and extend to depths of more than 4,000 feet below sea level (**fig. 98**). The Springfield Plateau aquifer generally ranges from 200 to 400 feet thick throughout northern Arkansas. In Arkansas, the aquifer is composed entirely of the Boone Formation of Mississippian age and is characterized by gray crinoidal limestone and interbedded chert. Its basal member, the St. Joe Limestone, lacks the chert nodules common to the upper part of the formation and is less than 60 feet thick.

Sparse hydrologic data are available for the Springfield Plateau aquifer in northern Arkansas, in part, because the aquifer is exposed in a limited area and, in part, because the aquifer dips steeply beneath the thick shale, siltstone, and sandstone sequence of the Western Interior Plains confining system. Where the aquifer dips beneath this confining system, it is buried at great depths, which makes water-well drilling costs prohibitive. The yield of wells completed in the Springfield Plateau aquifer are reported to range from less than 1 to more than 75 gallons per minute; average yield is reported to be 5 gallons per minute.



Modified from Imes, 1990a

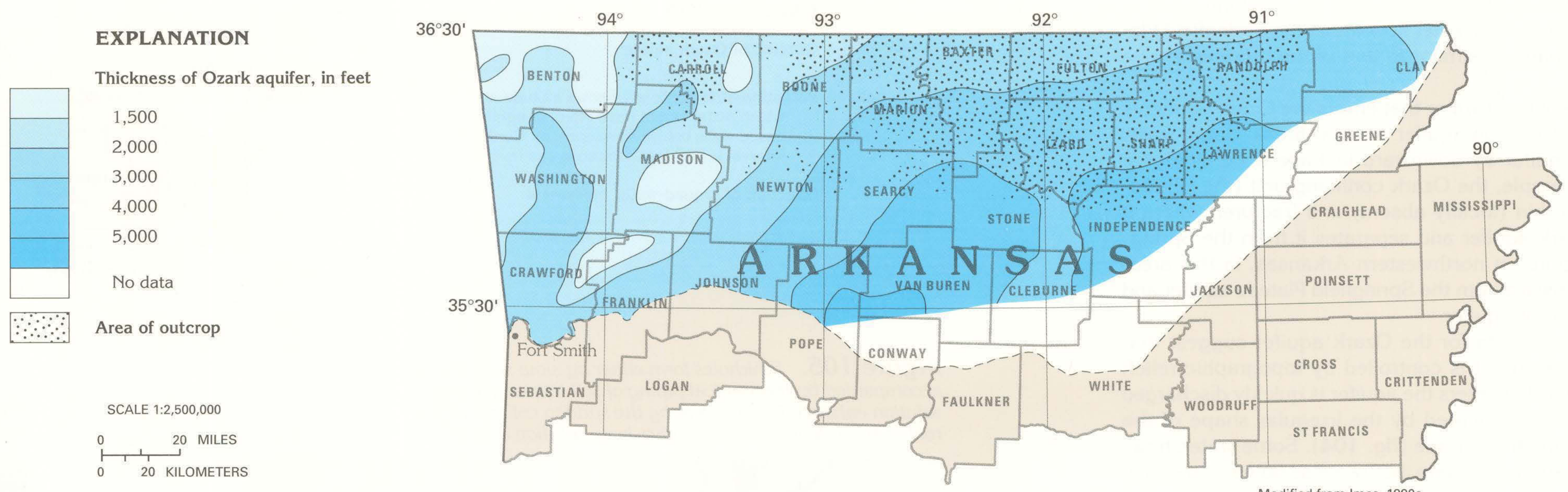
Figure 99. The Springfield Plateau aquifer crops out in a more than 50-mile wide band in northwestern Arkansas but narrows eastward in outcrop to a 5- to 10-mile wide band. The Springfield Plateau aquifer is between 200 and 400 feet thick in much of northern Arkansas.

OZARK AQUIFER

The Ozark aquifer (**fig. 100**), which is the thickest and most extensive aquifer within the Ozark Plateaus aquifer system of northern Arkansas, comprises limestone and dolomite and includes sandstone and minor chert and shale beds that range from Late Cambrian to Middle Devonian in age. The Ozark aquifer crops out in the deeply dissected, rugged terrain of the Salem Plateau. The aquifer serves as a source of water chiefly for agricultural and domestic purposes but supplies some water for municipal and industrial uses. Outcropping rocks of the Ozark aquifer are nearly flat lying in northern Arkansas, but the dip of the rocks progressively steepens as they extend southward beneath the Ozark confining unit, the Springfield Plateau aquifer, and the north-facing escarpment of the Boston Mountains, which marks the northern extent of the Western Interior Plains confining unit (**fig. 98**). In northeastern Arkansas, the Ozark aquifer extends eastward beneath the embayed part of the Coastal Plain where the aquifer is overlain by the Mississippi embayment aquifer system and the Mississippi River Valley alluvial aquifer. The Ozark aquifer is more than 5,000 feet thick in the central part of northern Arkansas (**fig. 100**). The aquifer generally is more than 3,000 feet thick in most outcropping localities. In western Arkansas, the aquifer is less than 1,500 feet thick in local areas in the subsurface.

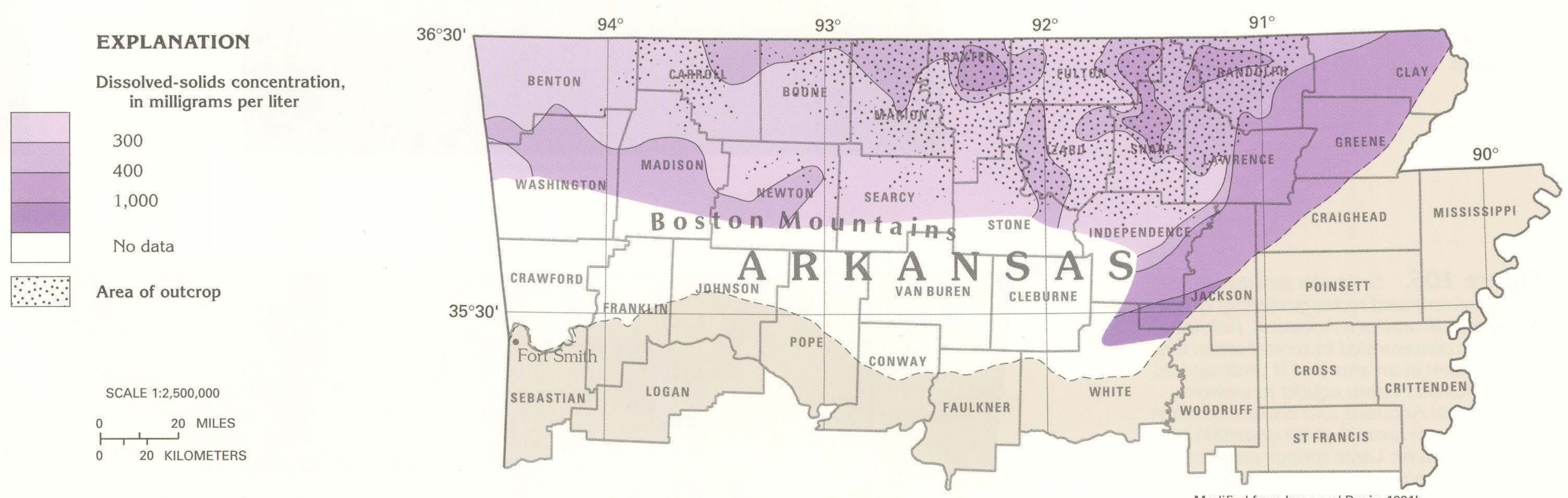
Although the Ozark aquifer is very thick, most of the water withdrawn from the aquifer is obtained from only a few water-yielding zones. Water-yielding sandstones, such as the Roubidoux Formation and the Gunter Sandstone Member of the Van Buren Formation are notable because of their large yields. The Gasconade Dolomite, which is a bed of cherty dolomite that is about 100 feet thick and yields little water, separates the productive sandstone beds. The Roubidoux Formation is comprised of dolomite, quartz sandstone, and chert and thickens eastward across northern Arkansas from 180 to 260 feet. The yield of wells completed in the formation is reported to average 60 gallons per minute, but some wells yield 600 gallons per minute. The Gunter Sandstone Member is the principal water-yielding zone within the Ozark aquifer; wells that penetrate the unit commonly yield from 150 to 300 gallons per minute, and some wells yield as much as 730 gallons per minute. The Gunter Sandstone Member consists of quartz sandstone; weak to strong cementation of sandstone generally reflects dolomitic or siliceous intergranular cement, respectively. The Potosi Dolomite of Cambrian age is the principal source of water for municipalities in the Salem Plateau area of Missouri, as described in Chapter D of this Atlas. In northern Arkansas, however, the water-yielding characteristics of this formation are poorly understood because it is buried at great depths and, accordingly, is economically unsuited for development as a water resource. Minor water-yielding zones of the Ozark aquifer are contained within the Jefferson City, the Cotter, and the Powell Dolomites; the upper part of the Everton Formation; the St. Peter Sandstone; and the St. Clair, the Lafferty, and the Clifty Limestones (**fig. 96**). These strata generally yield less than 50 gallons per minute but are capable of yielding as much as 80 gallons per minute. However, the yield of wells completed in these rocks shows that they are not as permeable as the sandstone beds in the lower part of the aquifer.

Dissolved-solids concentrations of water in the Ozark aquifer are, for the most part, less than 400 milligrams per liter throughout northern Arkansas (**fig. 101**). The largest concentrations of dissolved solids are in eastern Arkansas where the aquifer dips beneath the Coastal Plain. The hydrochemical facies reflect, in part, the limestone and dolomite lithology of the aquifer and, in part, saline water in the deeper parts of the aquifer. Most of the water in the Ozark aquifer in northern Arkansas can be classified as either a calcium bicarbonate or a sodium chloride facies (**fig. 102**). The calcium bicarbonate facies results from the partial dissolution of carbonate rocks that compose the aquifer, whereas the sodium chloride facies is indicative of mixing of freshwater with saltwater contained within the deep, stagnant part of the ground-water flow system. Sodium bicarbonate is representative of a transition zone that separates the fresh and saline parts of the flow system. The small area of magnesium bicarbonate facies is probably due to partial dissolution of dolomite, which is a calcium-magnesium bicarbonate mineral.



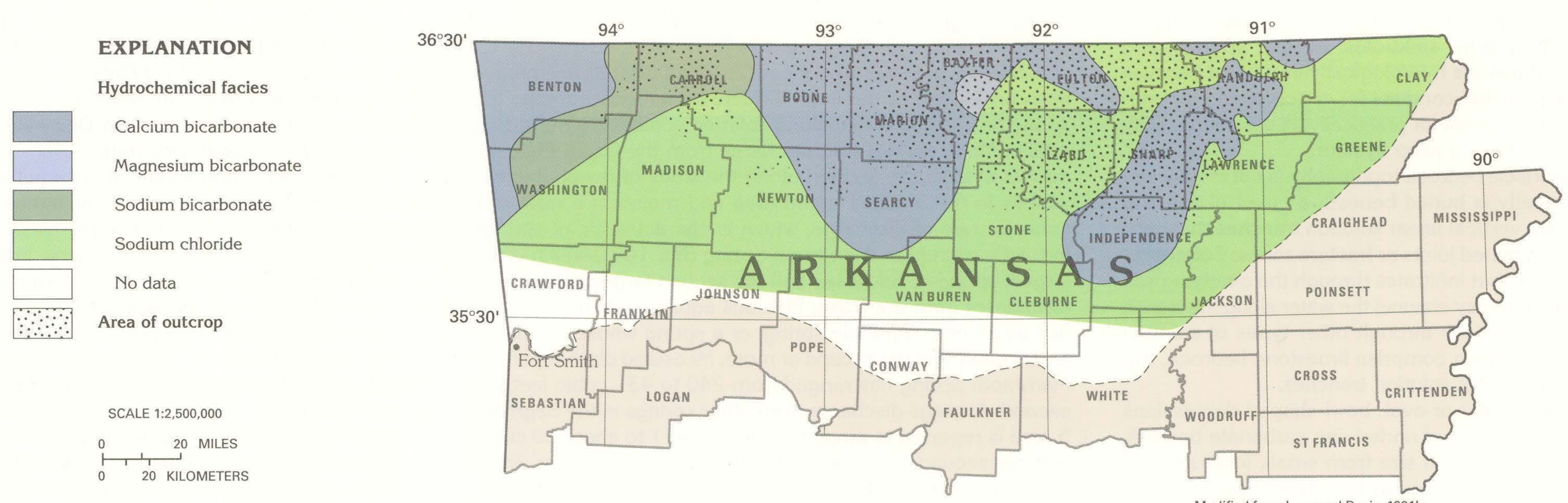
Modified from Imes, 1990a

Figure 100. The Ozark aquifer thickens to more than 5,000 feet in north-central Arkansas. In most places, the aquifer is between 2,000 and 4,000 feet thick.



Modified from Imes and Davis, 1991b

Figure 101. Dissolved-solids concentrations of water within the Ozark aquifer generally are less than 400 milligrams per liter in most of northern Arkansas. Concentrations of dissolved solids generally increase from regional ground-water divides to areas of regional discharge. Ground water that contains the smallest dissolved-solids concentrations is in an area that underlies the crest of the Boston Mountains and extends eastward.



Modified from Imes and Davis, 1991b

Figure 102. Calcium bicarbonate and sodium chloride are the two principal hydrochemical facies of the Ozark aquifer. The calcium bicarbonate water results from partial dissolution of aquifer minerals, and the sodium chloride water is due to the mixture of fresh and saline waters.

ST. FRANCOIS AQUIFER

The St. Francois aquifer, which is the basal aquifer of the Ozark Plateaus aquifer system, is deeply buried in northern Arkansas, usually to depths that range from 1,500 to more than 4,000 feet below land surface (**figs. 97, 98**). The thickness of the St. Francois aquifer generally is less than 250 feet , and its irregular thickness reflects a rugged Precambrian paleotopographic surface. The aquifer is not used as a source of water in northern Arkansas because the depth to the top of the aquifer makes the costs of drilling and completing wells in the aquifer prohibitively expensive. Other ground-water supplies, which are sufficient in terms of quantity and suitable water quality, are more easily obtained from shallower aquifers.

GROUND-WATER FLOW

The source of the water that recharges the Ozark Plateaus aquifer system is precipitation that falls on the aquifer system where it is exposed at the land surface. The carbonate rocks that compose the upper parts of the aquifer system are readily dissolved, and the end results of partial dissolution are a network of subsurface openings and an irregular rock surface characterized by sinkholes, caves, and other types of openings, which are called karst topography. Water that recharges an aquifer with a karstified surface either enters as direct runoff through sinkholes and sinking streams (streams that flow into shallow holes and sinkholes) or enters by downward diffuse infiltration through shallow soil cover in the upland, interstream areas. Ground-water flow in the Ozark Plateaus aquifer system tends to be concentrated by a system of well-connected conduits formed by solution-enlarged fractures and bedding-plane partings. Some of the conduits are cavern-sized, form parts of large cave systems and, in places, are part of a subsurface trunk drainage system. Where fractures, bedding-plane partings, and other solution conduits are widely spaced, the flow system tends to be poorly interconnected; in such places, subsurface conduits can cross one another without interference, and water levels can vary widely among closely spaced wells. Conversely, where solution conduits are closely spaced and well-connected, the potentiometric surface will probably reflect the shape of the local topography. Such is the case with the Springfield Plateau aquifer in northwestern Arkansas (**fig. 103**).

Sparse data are available for the Springfield Plateau aquifer in northwestern Arkansas owing to the limited area in which the aquifer crops out and thick deposits of low-permeability material that overlie the aquifer where it extends beneath the Boston Mountains and the Western Interior confining system. However, regional ground-water flow within the Springfield Plateau aquifer probably is similar to that of the more extensive Ozark aquifer.

The source of most water that enters the Ozark aquifer is precipitation that falls on aquifer outcrop areas. Some water recharges the aquifer by downward leakage from overlying aquifers. For example, the Ozark confining unit (the Chattanooga Shale) is thin (locally absent) and fractured where it overlies the Ozark aquifer and separates it from the Springfield Plateau aquifer in northwestern Arkansas. In this area, water leaks downward from the Springfield Plateau aquifer and recharges the Ozark aquifer.

Potentiometric data for the Ozark aquifer suggest that ground-water movement is controlled by topographic relief; much of the water that enters the aquifer is quickly discharged to local streams as indicated by the irregular shape of the aquifers potentiometric surface (**fig. 104**). Some water, however, moves toward major rivers that serve as points of regional discharge. In extreme northwestern Arkansas, there is a component of westward and northwestward ground-water movement into Oklahoma. Limited data make it difficult to assess the direction of ground-water flow where the Ozark aquifer dips beneath the Western Interior Plains confining system. However, a ground-water divide is thought to underlie the Boston Mountains, and available geologic and hydrologic data suggest that the freshwater part of the flow system probably does not extend very far southward beyond the northern edge of the Western Interior Plains confining system. In the eastern part of the Ozark aquifer, ground-water flow is southeastward. Ground water discharges to the overlying Coastal Plain deposits of the Mississippi embayment aquifer system and the Mississippi River Valley alluvial aquifer.

Figure 103. Topographic relief is the principal factor that influences the direction of ground-water movement within the Springfield Plateau aquifer. Water levels within the aquifer reflect the land-surface altitude.

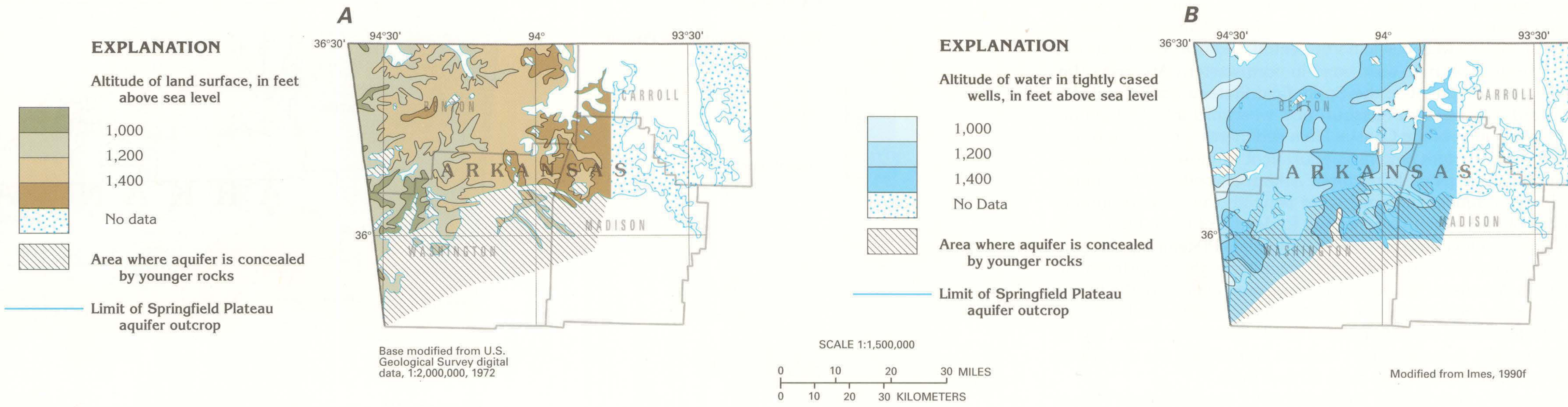


Figure 104. Most of the water in the Ozark aquifer of northern Arkansas moves along short flow paths and discharges to streams. Regional ground-water movement in eastern Arkansas is southeast-ward. Regional ground-water flow in western Arkansas is north-westward and westward into Oklahoma.

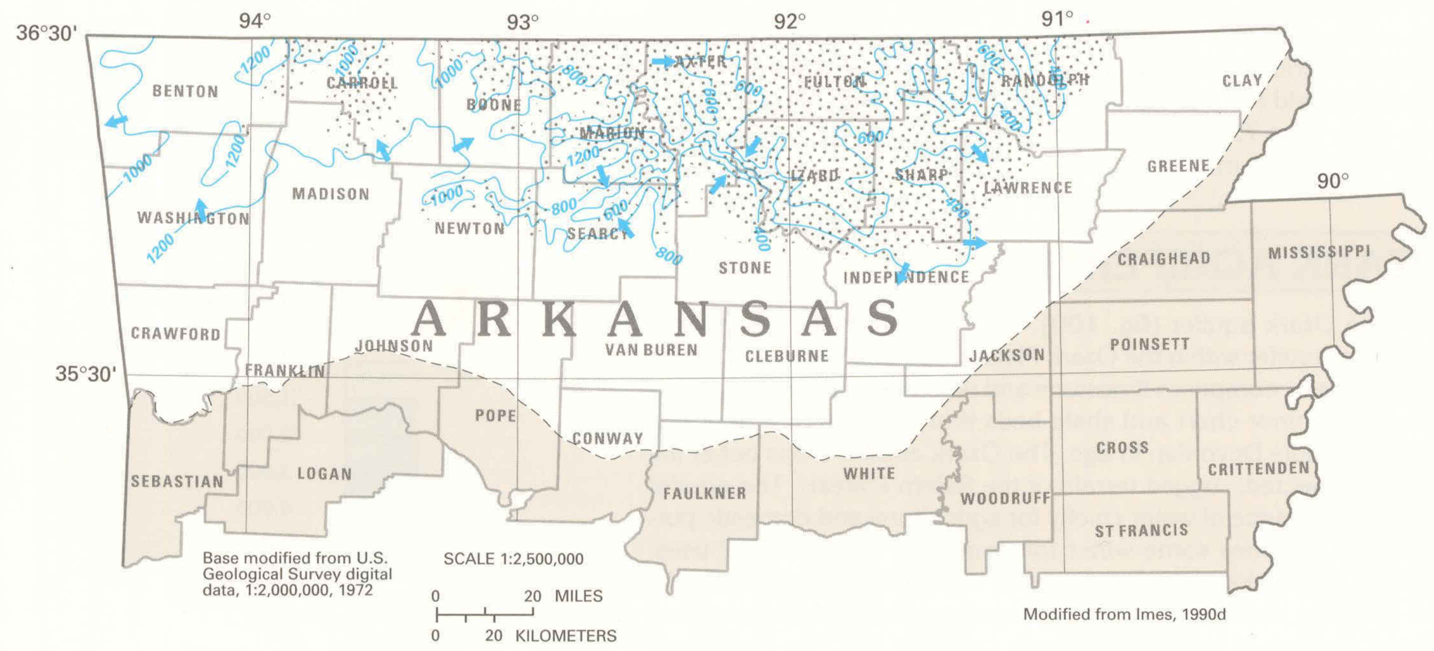
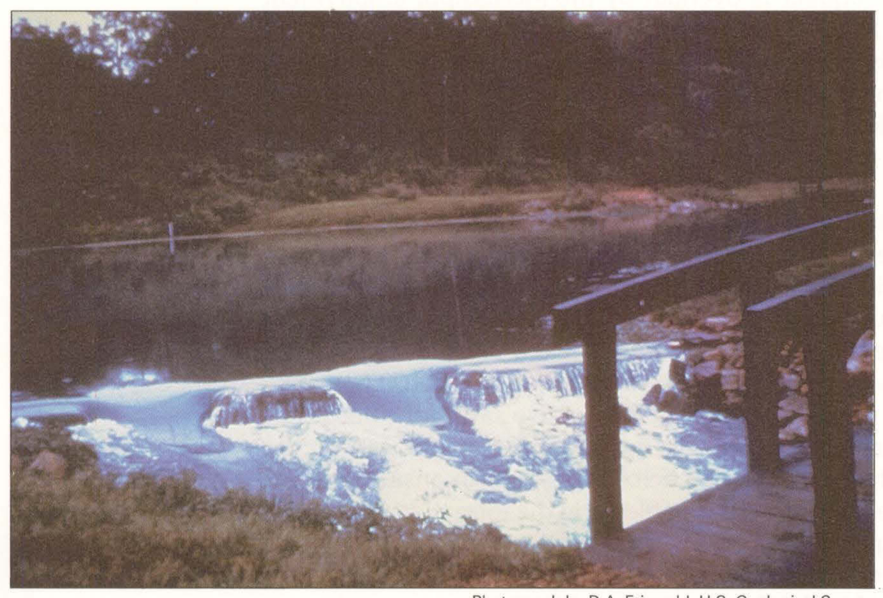


Figure 105. Sinkholes form either by slow subsidence accompanied by mechanical piping of soil into underlying solution-enhanced fractures or by the sudden collapse of the roof of an underlying cave or other large solution opening.

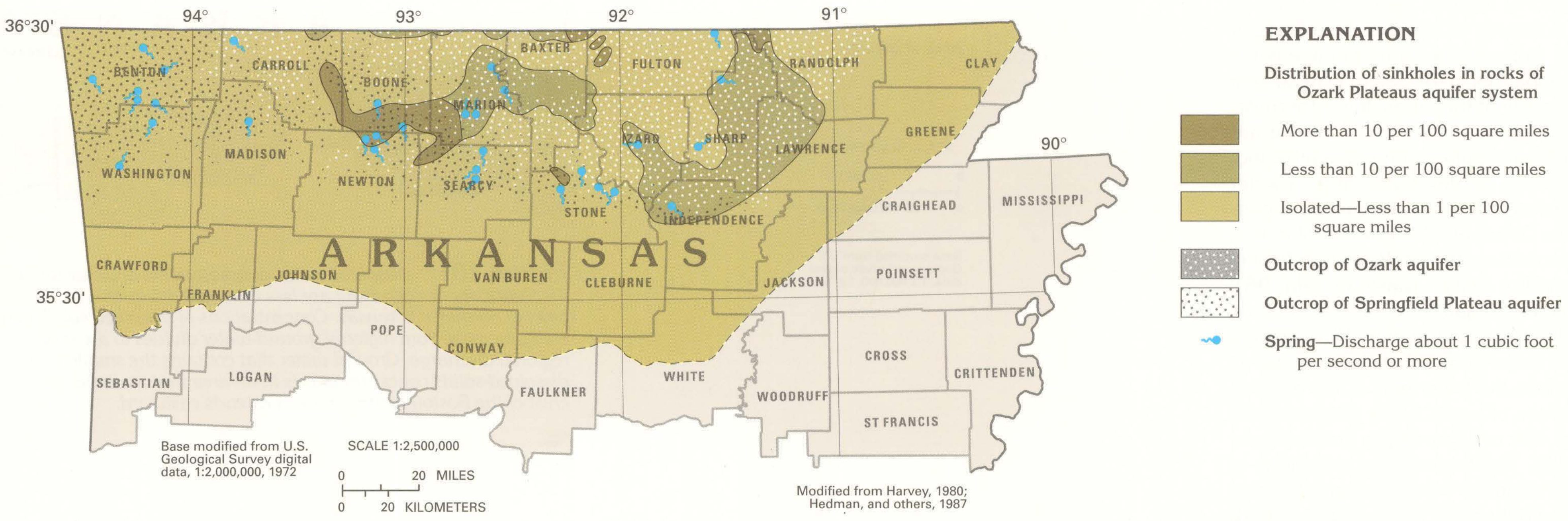
Photograph by J.V. Brahana, U.S. Geological Survey, 1994

Figure 107. Mammoth Spring is the largest spring in northern Arkansas. Discharge is reported to be as much as 431 cubic feet per second.



Photograph by D.A. Friewald, U.S. Geological Survey

Figure 106. Sinkholes function as sites where concentrated recharge directly enters the aquifer. In northern Arkansas, sinkholes tend to be concentrated in several areas; they are abundant in an area that is underlain by the Springfield Plateau aquifer in western north-central Arkansas and also are common in two separate areas that are underlain by the Ozark aquifer. Large springs are sites of concentrated ground-water discharge.



SOLUTION FEATURES

Dissolution of limestone and dolomite rocks of the Ozark Plateaus aquifer system has resulted in the development of karst terrain in much of northern Arkansas. In the Ozark Plateaus aquifer system, karstic features that have developed on rocks of hydrologic significance include buried cutter and pinnacle bedrock topography, sinkholes, conduit springs, and caves. Solution features are hydrologically important because they serve as the principal conduits for concentrated ground-water flow and, thus, account for practically all the permeability within the Ozark Plateaus aquifer system.

Cutter and pinnacle bedrock topography is not readily visible because it usually is buried beneath a cover of soil and regolith. Cutters are vertical linear solution trenches that generally develop along buried joints or fracture zones. Cutters act as collectors of water that infiltrates through the overlying soil cover and regolith, and they channel the water along the trench before it enters the bedrock through other types of solution openings. Pinnacles, which comprise limestone bedrock, are located between the cutter solution trenches.

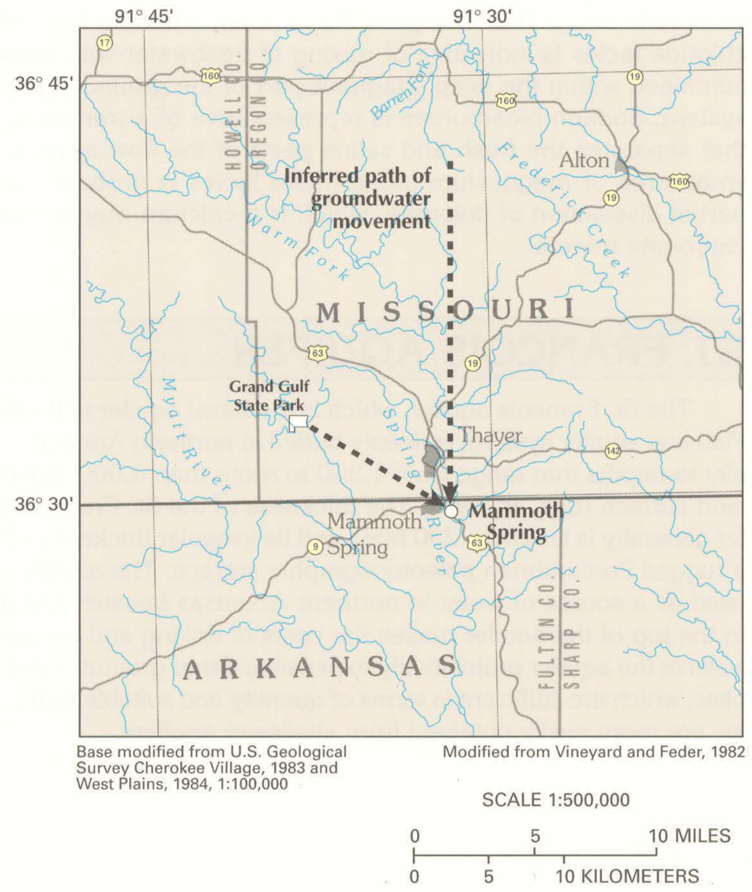
Sinkholes are circular or oval, bowl-shaped depressions that form by the dissolution of underlying carbonate bedrock (**fig. 105**). Sinkholes range in size from small, local depressions to broad, shallow depressions that extend over an area of a square mile or more. Sinkholes can form by slow subsidence or by sudden collapse. Sinkholes that form by slow subsidence are the result of the dissolution of the upper part of the limestone bedrock and may be accompanied by piping (mechanical transportation) of thick overlying soil into underlying fractures and conduits. Collapse sinkholes form by the sudden collapse of the roof of an underlying cave or other large solution opening. In northern Arkansas, sinkholes are most abundant in the north-central part of the Springfield Plateau, where they develop in the rocks that form the Springfield Plateau aquifer (**fig. 106**). Sinkholes are less common in the north-central and northeastern areas of northern Arkansas that are underlain by carbonate rock of the Ozark aquifer. Sinkholes are hydrologically important because they are sites where concentrated recharge directly enters the aquifer.

Springs are sites where concentrated discharge emerges from an aquifer at the land surface. In carbonate rocks, the spring flow is channeled along solution conduits to the spring orifice. Many springs that discharge from the Ozark Plateaus aquifer system are located along the sides of deeply incised valleys in the Salem Plateau area and maintain a relatively constant rate of discharge, which is characteristic of springs in the Ozark region. Mammoth Spring (**fig. 107**), which is the largest spring in Arkansas and the second largest spring that discharges from the Ozark Plateaus aquifer system, is classified as a first-magnitude spring, or a spring whose discharge is 100 cubic feet per second or more. Measured discharge from Mammoth Spring has ranged from 240 to 431 cubic feet per second. Average discharge from other springs in the Segment 5 area is reported to range from less than 1 to about 80 cubic feet per second, which suggests that the other springs probably drain smaller catchment areas. Dye-trace studies of Mammoth Spring have shown that water from this spring discharges from a subterranean system of conduits and channels that extends from 9 to 15 miles to the northwest and north into Missouri (**fig. 108**).

Caves represent the third major type of solution feature in the Ozark Plateaus aquifer system. An accurate survey of caves is not available for Arkansas; however, more than 1,000 caves with passageways that are 100 feet long are estimated to be in northern Arkansas. Some zones of cavernous porosity have been reported to be more than 1,000 feet below land surface. Caves in northern Arkansas are located mostly within the Springfield and Salem Plateaus, with only a few along the escarpment of the Boston Mountains. The greatest concentration of caves is in the Boone Formation and its lower member, the St. Joe Limestone Member, which are geologic units that compose the Springfield Plateau aquifer. Caves within the Ozark aquifer reportedly are developed in the Kimmswick and Plattin Limestones, the Joachim Dolomite, the Everton Formation, and the Powell Dolomite.

Caves in the Springfield Plateau aquifer formed randomly in response to changes in lithology, fracture density, and the presence or absence of local, low-permeability rock layers that created perched water-table conditions. In the Springfield Plateau aquifer, caves appear to have formed above and below the saturated part of the aquifer. Small caves that formed above the water table were probably caused by discontinuous, poorly permeable shale, siltstone, or chert within the aquifer. These poorly permeable confining units perch water above the main water table, which allows partial dissolution of the limestone or may reflect an earlier, higher base level. The larger, connected caves are within the lower part of the Springfield Plateau aquifer (the St. Joe Limestone Member) where it immediately overlies the Ozark confining unit (the Chattanooga Shale). These caves formed at or below the main water table of the aquifer. Small caves are within some sandstone beds of the Ozark aquifer. These "pseudocaves" probably formed as water leaked downward into solution-enlarged fractures in underlying carbonate strata. Continued dissolution of the underlying carbonate rocks and removal of carbonate cement in the sandstone beds allowed sand to enter solution cavities in the carbonate rocks by piping and (or) cave collapse.

Figure 108. Water-tracing studies that used fluorescent dye showed that most of the water that discharges from Mammoth Spring was derived from two different source areas in Missouri.



GEOLOGIC FACTORS THAT CONTROL PERMEABILITY

The movement of ground water in the carbonate rocks of the Ozark Plateaus aquifer system is very different from that in the clastic deposits of the surficial aquifer system and the aquifer systems in Coastal Pain clastic sediments. Groundwater moves through clastic materials by diffuse flow through intergranular pore spaces in the poorly consolidated to unconsolidated sediments. The carbonate rocks of northern Arkansas have been subjected to the geologic processes of lithification, compaction, burial, tectonic uplift, and diagenesis during which some to most of the intergranular pore spaces in the rocks have been filled or destroyed. These rocks are very dense and commonly consist of thick-bedded, massive, crystalline limestone and dolomite. Porosity and permeability within such carbonate rocks is, for the most part, secondary. Dissolution of carbonate rocks enlarges vertical fractures caused by joining and faulting and horizontal surfaces formed along bedding planes and unconformities. In some geologic formations, however, movement of water in the carbonate rocks is not limited to these types of secondary openings. For example, ground water within the Potosi Dolomite reportedly moves within interconnected vugs. Vugs are cavities within a carbonate rock that are large enough to be seen without the aid of magnification and do not necessarily conform to the internal fabric of the rock.

As described above, the dense crystalline limestone and dolomite strata of northern Arkansas transmit water chiefly through fractures and along bedding planes that have been enlarged by dissolution. As precipitation falls through the atmosphere, it absorbs small amounts of carbon dioxide to form a weak carbonic acid. Much more carbon dioxide is absorbed from plant roots and decaying organic matter in the soil as the precipitation infiltrates through the soil cover and percolates downward to underlying limestone and dolomite bedrock. Water that enters fractures dissolves parts of the adjoining bedrock, which slowly enlarges the fractures. As the fractures widen to form conduits, more water is funneled to the conduits that grow even larger. Soil and regolith thicken over these fracture zones; contain more decaying organics, and thus higher concentrations of carbon dioxide; and serve as an even greater source of carbonic acid. The high permeability zones within dense crystalline rocks of the Ozark Plateaus aquifer system are characteristically separated by low-permeability, unfractured blocks of limestone and dolomite through which water moves more slowly (**fig. 109**).

The development of a vertical fracture system that has created directional differences in permeability within the Ozark Plateaus aquifer system is thought to be related, at least in part, to the continental collision that helped form the Ouachita Mountains and, in part, to tectonic stresses associated with the formation of the Reelfoot Rift. The Reelfoot Rift is a northeast-trending graben structure that is buried beneath the Coastal Plain sediments in northeastern Arkansas and has been intermittently active from late Precambrian to Holocene time. Northeast- and northwest-trending faults, grabens, and half-graben structures also vertically displace deeply buried rocks of the Roubidoux Formation, which is part of the Ozark Plateaus aquifer system (**fig. 110**).

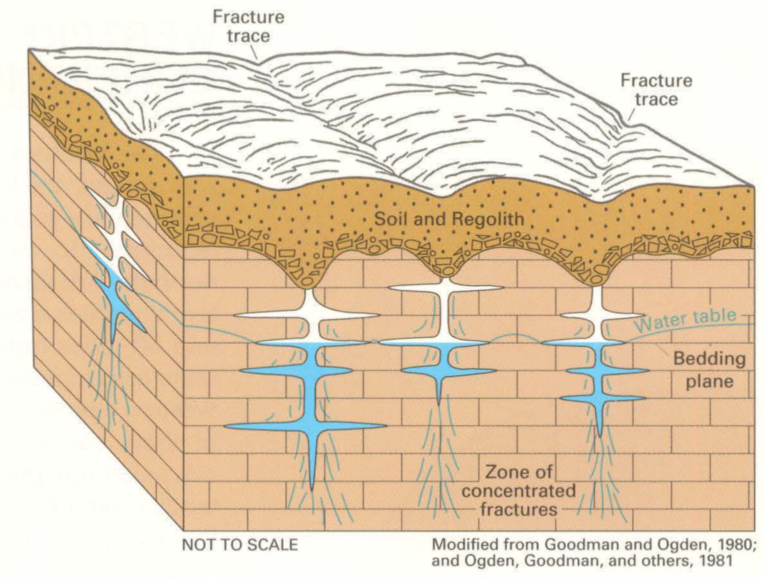


Figure 109. *The massively bedded limestone shown here is interlaced with zones of high permeability that are developed along solution-enlarged fractures and bedding planes. These zones channel ground-water flow and the concentrated flow causes an increase in carbonate dissolution.*

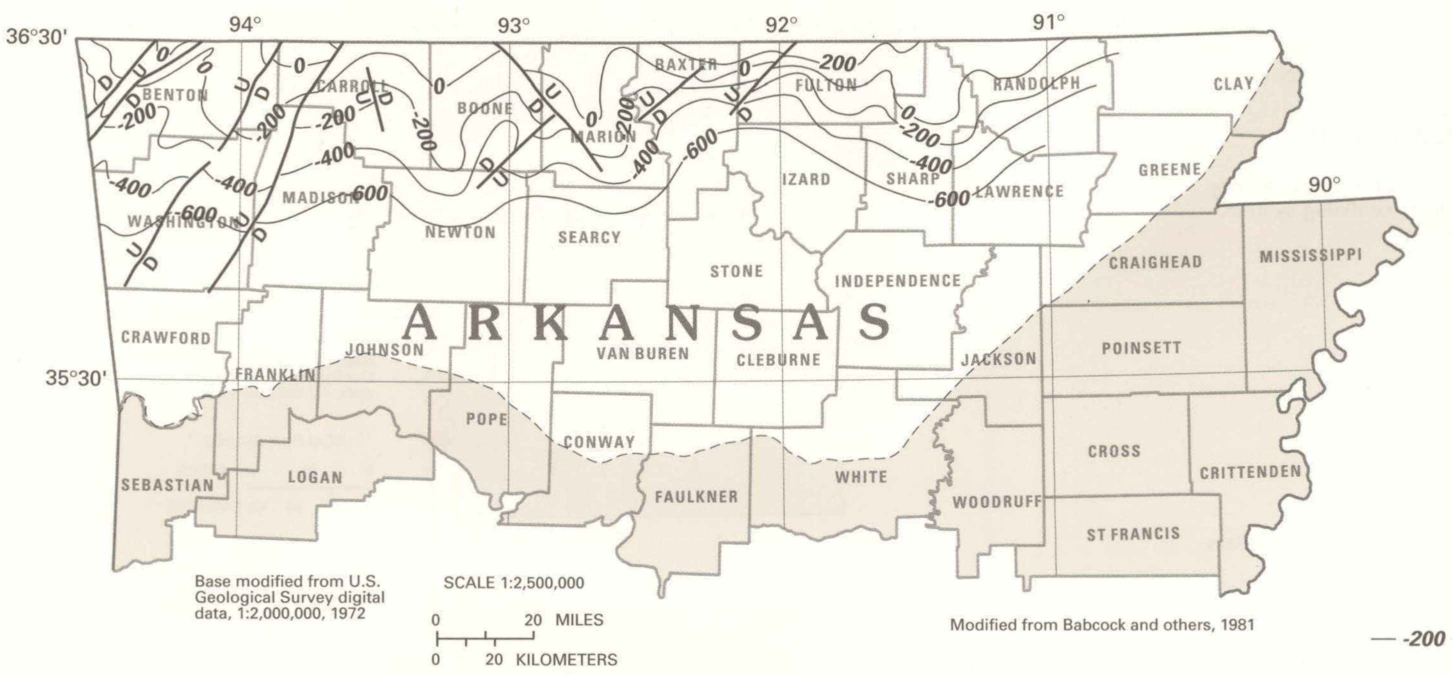


Figure 110. *Deeply buried carbonate rocks of the Roubidoux Formation in northern Arkansas are vertically displaced by faults that strike northeast and northwest. The faults that strike to the northeast parallel the orientation of the Reelfoot Rift and are thought to be related, in part, to the formation of the rift and, in part, to the continental collision that formed the Ouachita Mountains.*

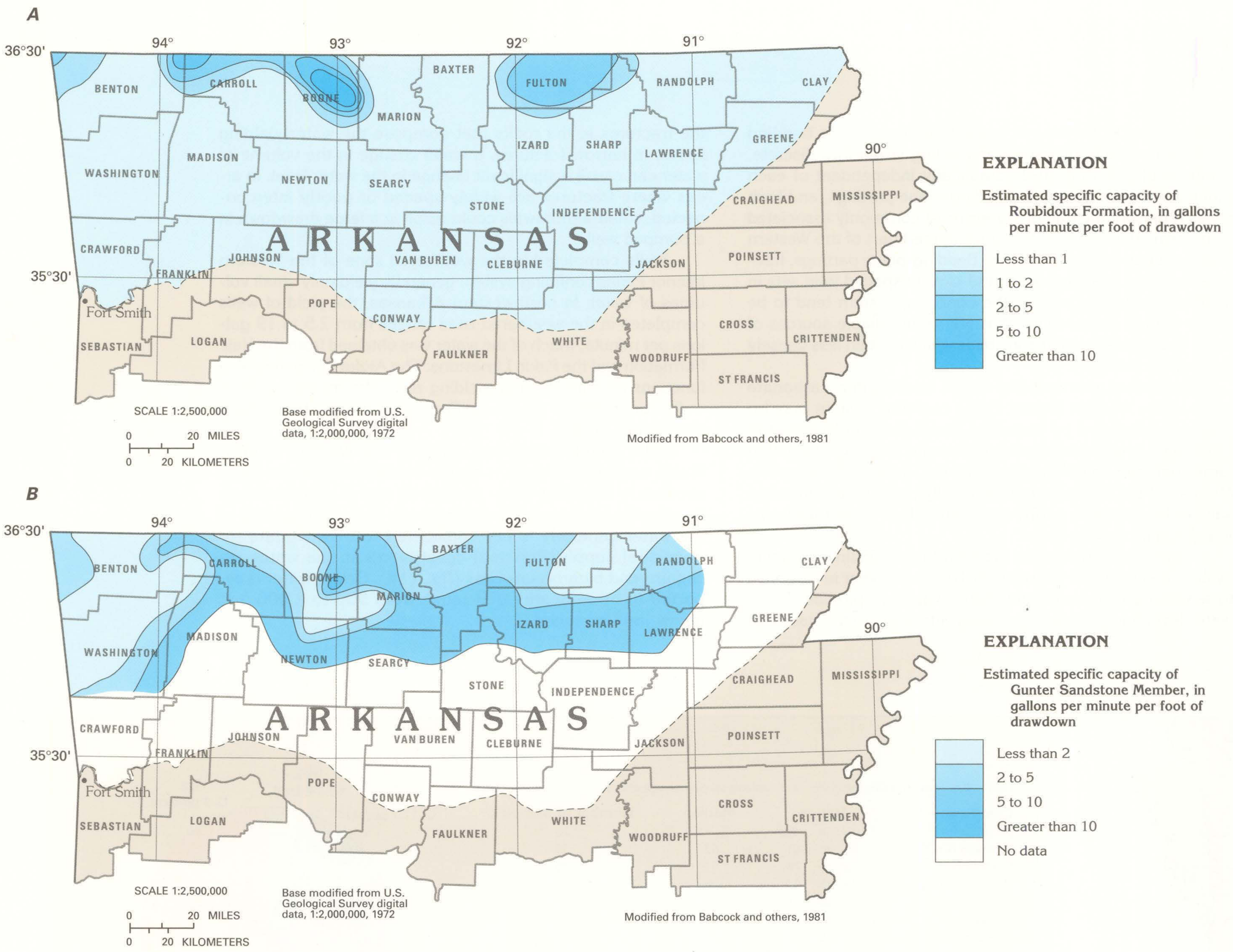


Figure 111. *Areas of high specific capacity generally correspond to areas of higher transmissivity within an aquifer. Areas within the Roubidoux Formation (A) and the Gunter Sandstone Member (B) with higher specific capacities appear to be associated with zones of increased permeability related to secondary dissolution along zones of fracturing and faulting.*

Figure 112. *Vertical fractures, such as the one shown, yield much more water to wells than does the surrounding low-permeability carbonate bedrock.*

The specific capacity of a well is the rate the well yields water per unit of distance the water level in the well drops as the well is being pumped. Specific capacity is usually expressed as gallons per minute (the rate) per foot of drawdown (the water level drop). In general, high values of specific capacity indicate that wells are completed in an aquifer that has a high transmissivity, and low specific capacities suggest the aquifer has a low transmissivity. Regional fault and (or) fracture zones appear to be directly related to variations in the specific capacity of wells with two water-yielding zones of the Ozark aquifer. These zones are the Roubidoux Formation and the Gunter Sandstone Member of the Van Buren Formation. Areas of high specific capacity in both geologic units seem to correlate with areas that are in proximity to inferred faults and horst and graben structures (**compare fig. 110 and fig. 111**). The areas of high specific capacity within the Roubidoux Formation appear to be related to the development of increased secondary permeability due to dissolution along fault and fracture zones.

A well completed in a carbonate-rock aquifer is likely to yield large volumes of water if the well is drilled into a fracture zone (**fig. 112**). Vertical fracture zones commonly are expressed as linear topographic features at the land surface. These linear features, which are called lineaments, may consist of straight stream segments, aligned sinkholes, or different soil colors, all of which can be seen on aerial photographs (**fig. 113**). Some of the linear features extend continuously or discontinuously for many miles. Individual fracture traces are aligned parallel to the lineaments but are smaller in lateral extent. Numerous studies have shown a strong correlation between aquifer transmissivity and photographic lineaments in the Ozark Plateaus aquifer system of northern Arkansas. Hydrologic studies in northern Arkansas also indicate that areas of fractured rock commonly have a greater thickness of regolith than those of nonfractured rocks; the same investigations show that well yields are greater in areas with a thicker regolith. The thick regolith serves to store ground water and subsequently releases the stored water slowly so that it percolates downward into bedrock aquifers. The largest limestone and dolomite conduits may parallel the orientation of regional fracture systems rather than local fracture bedrock systems.

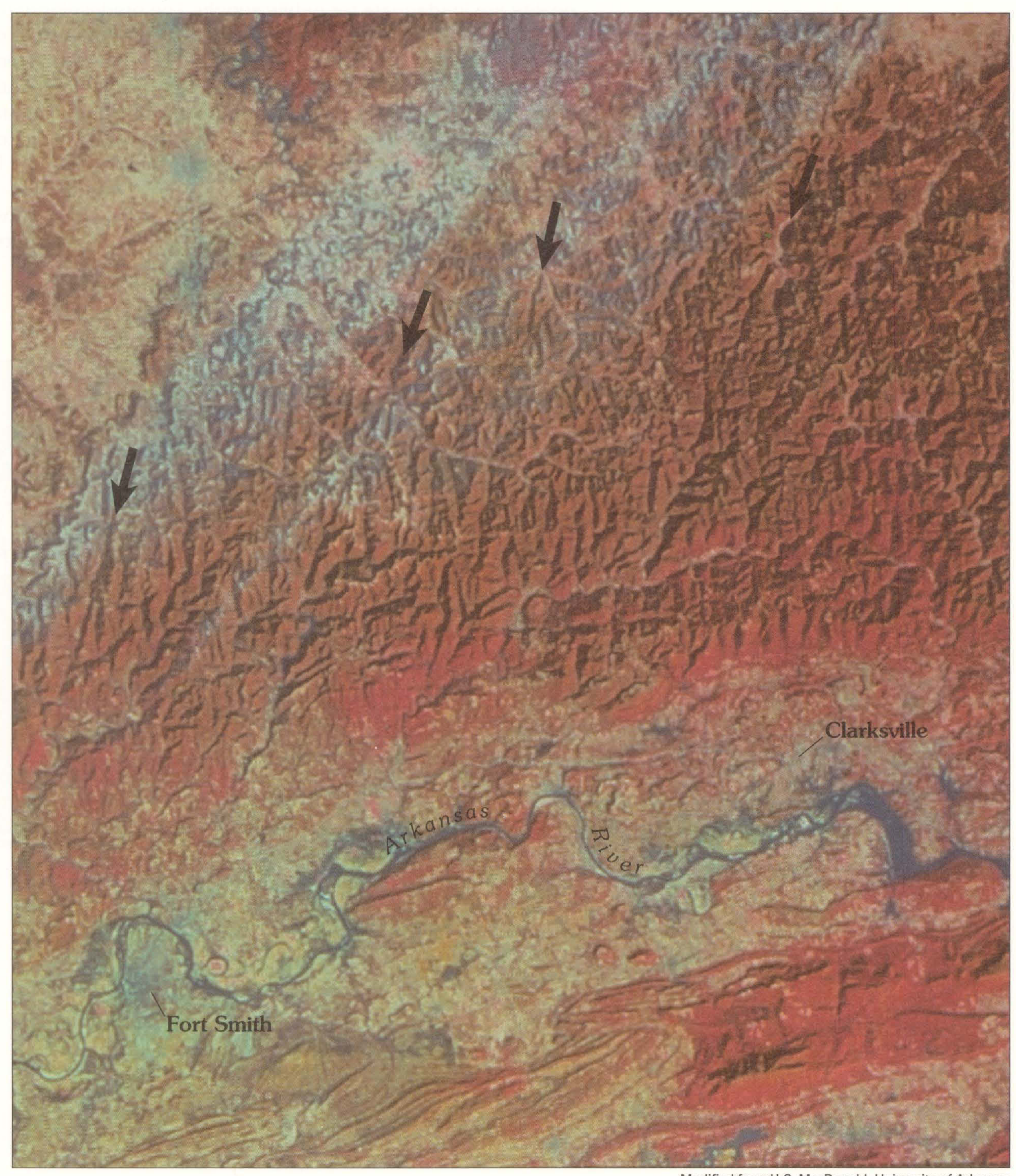


Figure 113. *Prominent northeast-southwest lineaments, such as those shown on this National Aeronautics and Space Administration (NASA) LANDSAT color infrared composite image of northern Arkansas, are likely places to locate fractured bedrock. Wells drilled on these lineaments are likely to yield large amounts of ground water. The Arkansas River is blue and traverses the lower part of the image. Arrows identify the orientation of major lineaments.*

WESTERN INTERIOR PLAINS CONFINING SYSTEM

The Western Interior Plains confining system is part of a widespread, thick, geologically complex, poorly permeable, sedimentary sequence that extends eastward from the Rocky Mountains to western Missouri and northern Arkansas. In northern Arkansas, the Western Interior Plains confining system underlies a wide area that extends southward between 60 and 80 miles from its northern margin at the Boston Mountains escarpment to the Ouachita Mountains (**fig. 114**). The Western Interior Plains confining system consists of a sequence of shale, sandstone, and limestone of Mississippian to Pennsylvanian age that thickens to more than 8,000 feet as it extends southwestward (**fig. 115**). On a regional scale, the rocks that compose the confining system are poorly permeable and function as a confining unit. Locally, however, individual geologic units or parts of units within the confining system yield as much as 19 gallons per minute to wells. The confining system is, therefore, considered to be a minor aquifer.

The Western Interior Plains confining system is topographically characterized by the rugged relief of the Boston Mountains and the low relief of the Arkansas River Valley. The Boston Mountains range in altitude from 1,000 to 2,000 feet above sea level, and the Arkansas River Valley ranges in altitude from 300 to 600 feet above sea level but locally contains east to west-trending ridges whose summits range from 1,000 to over 2,000 feet above sea level. Rocks of the confining system that underlie the Arkansas Valley Section are dominated by siltstone and shale that are overlain by a weathered zone that ranges from 10 to 30 feet thick. Sandstone beds of the system that are in the Arkansas Valley Section are well-cemented by silica and iron, resistant to erosion and form higher ridges. The Boston Mountains area, which is the highest erosional plateau in northern Arkansas, is underlain by sandstone, shale, and minor limestone beds of the confining system. The geologic formations that compose the confining system are shown in **figure 116**.

Figure 114. *The Western Interior Plains confining system underlies a broad band in northwestern Arkansas that includes the rugged topography of the Boston Mountains and the low relief of the Arkansas Valley Section.*

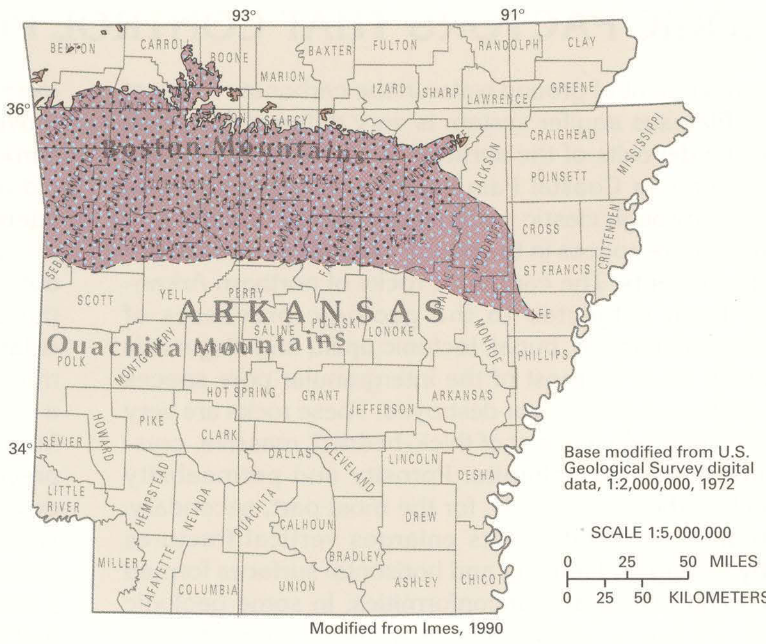


Figure 115. *The thickness of the Western Interior Plains confining system is more than 8,000 feet in Sebastian and Logan Counties, Arkansas. In most places, however, the system is less than 4,000 feet thick. The confining system extends beneath Coastal Plain sediments.*

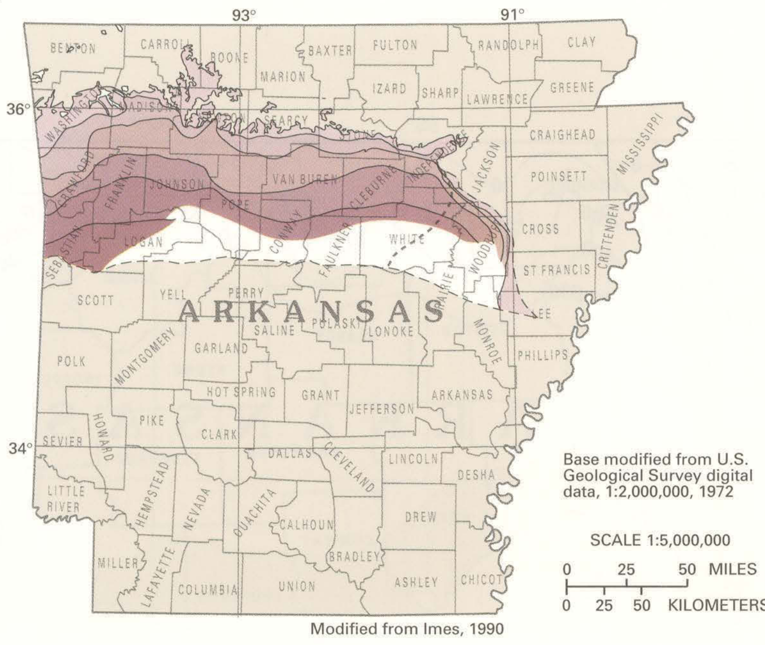


Figure 116. *The Western Interior Plains confining system is comprised of consolidated sedimentary rocks of Mississippian and Pennsylvanian age.*

Erathem	System	Geologic unit
Paleozoic	Pennsylvanian	McAlester Formation Hartshorne Formation Atoka Formation Bloyd Shale (Brentwood Limestone Member) Hale Formation
	Mississippian	Pitkin Limestone Fayetteville Shale Batesville Sandstone Moorefield Formation

Modified from Imes, 1990

The ground-water flow system within the Western Interior Plains confining system can be separated into two zones: an upper zone within soil and highly weathered bedrock and a lower zone within moderately weathered to unweathered bedrock. The base of the weathered rock zone generally is no more than 300 feet below land surface. Weathering processes that act on the upper zone have increased its porosity and permeability, and the movement of water within it is primarily through interparticle pore spaces.

A map of the potentiometric surface of the upper zone of the Western Interior Plains confining system before development (**fig. 117**) shows the altitude of the water table within the weathered zone. Wells withdraw water from the confining system mostly for domestic use because well yield and water quality are inadequate for public supply. The predevelopment potentiometric map, therefore, probably is representative of current (1997) conditions. Water enters the confining system as precipitation that falls on topographically high interstream areas and then moves through the weathered zone toward stream valleys where much of the water is discharged. Regional ground-water movement toward the Arkansas River is southward.

Ground water within the unweathered zone is, for the most part, dependent on fracture density and fracture interconnection of the bedrock. Vertical or horizontal fractures or bedding planes can locally divide water-yielding strata into discrete, separate blocks that are hydraulically independent of each other. Joint sets, fractures, bedding-plane partings, and fault zones represent the fracture types most commonly associated with permeable zones of the unweathered part of the Western Interior Plains confining system. Bedding-plane partings, fracture cleavage in shaly rocks, and closely spaced joint sets in shale and siltstone beds of the confining system tend to be zones of high permeability that are more reliable sources of water than massive sandstone beds which contain less densely spaced fractures.

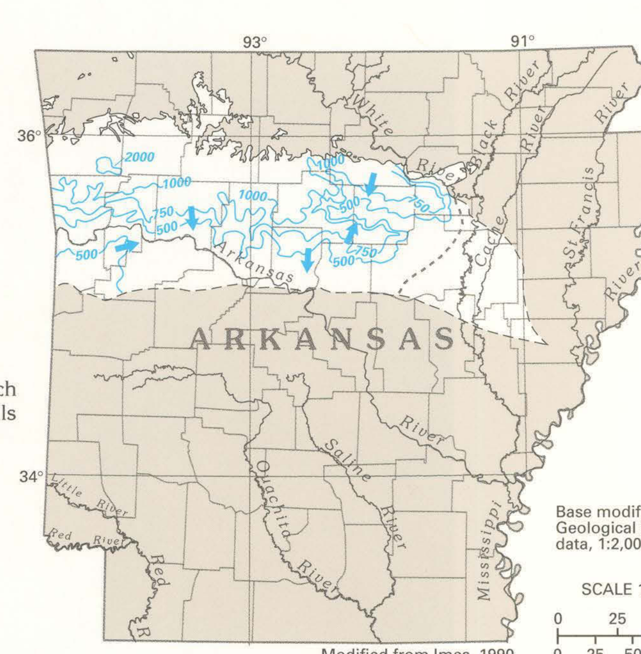
Secondary permeability within interbedded carbonate rocks of the Western Interior Plains confining system may locally be enhanced by meteoric dissolution. In the Boston Mountains area, outcropping carbonate rocks of the Pitkin Limestone, the Hale Formation, and the Brentwood Limestone Member of the Bloyd Formation locally contain cave systems sandwiched between poorly permeable shale beds, thus forming mazelike passageways.

Water levels within the Western Interior Plains confining system can fluctuate as much as 10 feet per year in response to seasonal variations in rainfall and evapotranspiration. These water-level fluctuations are directly attributed to the nature of the fractures in the rocks that compose the water-yielding zones. In narrow fractures, a small change in the volume of water can cause a significant change in the water level. In areas where fractures are widely spaced or poorly interconnected, small withdrawals could result in a large drawdown in a pumped well.

Wells completed in the weathered zone of the Western Interior Plains confining system generally yield only small volumes of water. In northwestern Arkansas, the yield of wells completed in the weathered zone ranges from 2.5 to 19 gallons per minute; much of the water was obtained from the Hale Formation and the Pitkin Limestone. The Atoka Formation also functions as a local water-yielding zone; the median yield of wells completed in the Atoka Formation is reported to be 9 gallons per minute.

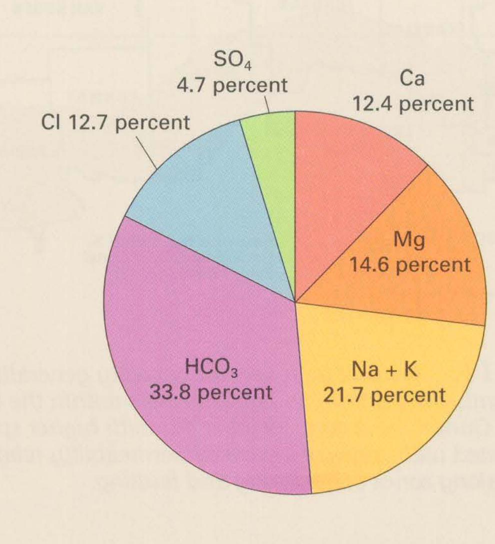
The quality of ground water in the Western Interior Plains confining system is highly variable but meets most secondary drinking-water standards and is considered to be suitable for domestic and livestock uses. The quality of the water generally is not considered to be adequate for municipal supply. Principal constituents in the water are sodium and bicarbonate ions (**fig. 118**). Saline water is reported to be at depths that range from 500 to 2,000 feet below land surface.

Figure 117. *Water enters the Western Interior Plains confining system as precipitation in elevated interstream areas, most of it moves toward and is discharged to local streams. Regional ground-water flow toward the Arkansas River is southward.*



Concentrations in milligrams per liter, unless otherwise specified

Constituent	Range	Median	Number of samples
pH (units)	5.7 to 8.3	7.2	36
Hardness ($CaCO_3$)	4 to 412	69	33
Calcium (Ca)	1.2 to 78	12	30
Magnesium (Mg)	0.2 to 53	8.6	30
Sodium (Na)	3.1 to 211	23	31
Potassium (K)	0.5 to 24	2.1	31
Bicarbonate (HCO_3)	8 to 508	100	31
Sulfate (SO_4)	0.2 to 535	11	32
Chloride (Cl)	2.5 to 288	22	35
Fluoride (F)	0.1 to 0.7	0.2	28
Silica (SiO_2)	0.3 to 23	9.8	22
Dissolved solids	24 to 870	176	23
Nitrate (NO_3)	0 to 34	1.4	32
Iron (Fe)	0 to 0.15	0	15



Data from Bryant and others, 1983

Figure 118. *Water from the Western Interior Plains confining system is a sodium bicarbonate type. Locally, the water contains large concentrations of sulfer.*

OUACHITA MOUNTAINS AQUIFER

The Ouachita Mountains aquifer has a north-to-south width of 80 miles along the Arkansas–Oklahoma State line but progressively narrows eastward (**fig. 119**). The maximum length of the aquifer is about 130 miles. The Ouachita Mountains aquifer consists mostly of shale, sandstone, and chert beds of Cambrian to Pennsylvanian age (**fig. 120**), all of which were deposited in deep-marine water conditions; the coarsest deposits were part of turbidity-current or debris-flow deposits. The Ouachita Mountains are topographically characterized by alternating mountains and intermontane valleys to the north and a southernmost piedmont area. The mountains rise to summit altitudes of as much as 2,600 feet above sea level near the Oklahoma border but are only about 500 feet above sea level where they abut the Coastal Plain. Bedrock units that underlie the Ouachita Mountains have been thrust faulted, are highly folded, and contain overturned formations. The piedmont area is underlain by shale and sandstone and borders the Coastal Plain in southwestern Arkansas. The surface of the area generally is flat to gently rolling but contains a series of low ridges and swells that strike east to west.

The importance of the Ouachita Mountains aquifer is due more to its wide areal extent than to its water-yielding characteristics. Only limited quantities of water for domestic and nonirrigation farm uses can be obtained from wells completed in the aquifer. Base-flow discharge during periods of low or no precipitation is not large enough to sustain streamflow. Streams that drain areas of less than 100 square miles usually go dry every year, while streams that drain more than 100 but less than 200 square miles go dry every 10 years on average. Most wells completed in the aquifer yield less than 50 gallons per minute; "large-yield" wells generally are viewed as those capable of yielding more than 10 gallons per minute. Water levels in the aquifer can fluctuate by as much as 10 feet per year as rainfall and evapotranspiration rates change seasonally.

High-permeability fracture zones in the Ouachita Mountains commonly form along bedding-plane partings but are best developed where folding has caused differential movement along contacts between shale and sandstone beds. Wells in the Ouachita Mountain aquifers should be drilled along the flanks of anticlines or near a plunging anticlinal nose (**fig. 121**). Bedrock areas that include fractured chert-novaculite or limestone also are considered to be preferred drilling sites. Fault zones, which often contain milky quartz veins, also function as local conduits for ground-water flow within the Ouachita Mountains aquifer. However, the fault zones may conduct little water if they are filled with fault gouge or cemented breccia. In Hot Springs, Arkansas, faults are the principal conduit for deep-seated, thermal ground-water discharge. Most joints and fractures in the Ouachita Mountains aquifer, however, are within 300 feet of land surface. Joints and other fractures tend to close or decrease in width with depth owing to lithostatic pressure, which is the vertical pressure caused by the weight of overlying rock and soil.

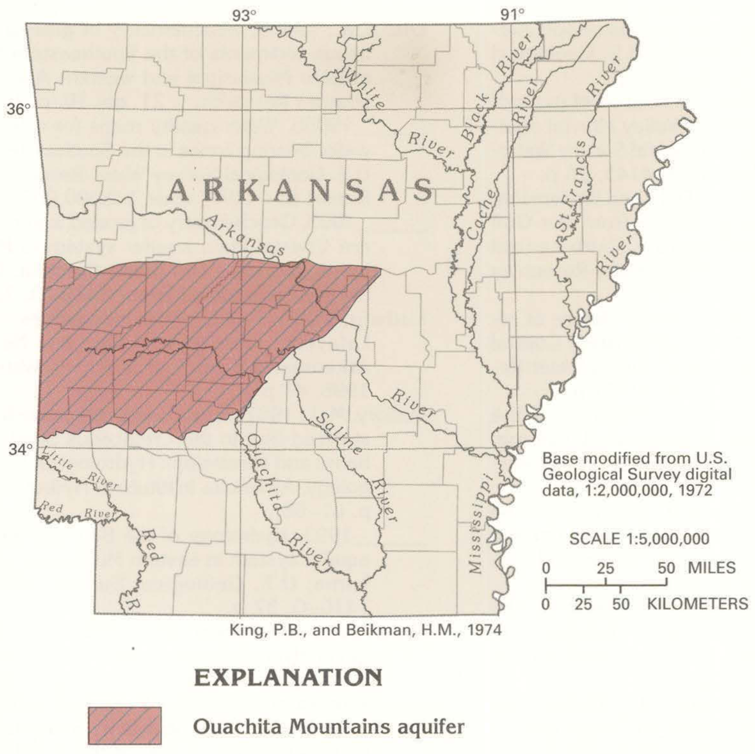
The thermal springs of the Hot Springs area represent an interesting and unique aspect of ground-water flow in the Ouachita Mountains aquifer. Before their development for commercial resort purposes in the late to middle 1800's, the Hot Springs area may have contained as many as 72 spring openings. Many of the springs were concentrated along a faulted and jointed bedrock area that is a few hundred feet wide and 0.25 mile long and that is located on the southwestern slope of Hot Springs Mountain. Many spring openings were walled in and covered to prevent contamination, and an extensive piping system was developed to supply hot water to various bathhouses (**fig. 122**).

Springs classified according to temperature are described as nonthermal and thermal types. Nonthermal, or cold, springs have about the same temperature as the mean annual air temperature in the area where they are located. Thermal springs are separated into hot- and warm-water types. Hot springs have temperatures that are higher than 98 degrees Fahrenheit. The temperatures of warm springs are less than 98 degrees Fahrenheit but higher than the mean annual air temperature. Many "cold-water" springs in the Hot Springs and the west-central Ouachita areas should more correctly be classified as warm-water springs. The temperatures of the hottest springs may have declined slightly with time. In 1804, the maximum temperature for the hottest spring was reported to be 154 degrees Fahrenheit, whereas the hottest spring temperature reported in 1972, for example, was 143.2 degrees Fahrenheit.

The mechanics of spring flow associated with thermal springs of central Arkansas parallels that of other fault- or fracture-related springflow systems. Topographic relief provides the hydraulic energy needed to drive the movement of water in fault- and fracture-spring settings, and the spring openings function as a focal point of concentrated ground-water discharge (**fig. 123**). Water enters the aquifer as precipitation in a topographically high area and is discharged in a topographically low area. A fault or fracture zone serves as a high-permeability avenue that allows ground water to exit the flow system. The principal difference between thermal and nonthermal springs is that thermal springs discharge water that has been circulated to a great depth. In the Hot Springs area, thermal springs discharge water that is estimated to have circulated to depths that range from 4,500 to 7,500 feet below land surface. However, thermal and nonthermal springs of the Hot Springs area discharge some water that apparently has circulated only to shallow depths. The heat that warms the water from warm- and hot-water springs is derived from the geothermal gradient, which is the progressive warming of the Earth's crust with depth. The normal increase in temperature with depth is about 1 degree Fahrenheit per 100 feet. In general, waters that circulate to great depths are warmer than those that circulate to shallower depths.

The Bigfork Chert, which is an important water-yielding zone in the Ouachita Mountains aquifer, is moderately to highly fractured and contains some intergranular permeability. Meteoric waters recharge the chert within a 3- to 10-square mile upland area northwest of the city of Hot Springs, in which the central part of a large anticline is exposed (**fig. 123**). The regional movement of ground water is to the southwest, and bedrock fracturing is of sufficient density and interconnection to allow some water to move downward to depths that range from 4,500 to possibly 7,500 feet below land surface. Ground water at such depths is warmed by heat conduction from adjoining low-permeability rocks. Fractured and faulted bedrock compose high-permeability zones that function as conduits for heated water and allow it to move rapidly to the surface with only a slight decrease in water temperature.

Figure 119. *The Ouachita Mountains aquifer underlies a wide area in west-central Arkansas. The extent of the aquifer coincides with that of the Ouachita Mountains.*



Erathem	System	Geologic unit
Paleozoic	Pennsylvanian	Boggy Formation
		Savanna Formation
		McAlester Formation
		Hartshorne Sandstone
		Atoka Formation
		Johns Valley Shale
		Jackfork Sandstone
	Mississippian	Stanley Shale
		Arkansas Novaculite
	Devonian	
	Silurian	Missouri Mountain Shale
		Blaylock Sandstone
	Ordovician	Polk Creek Shale Bigfork Chert Womble Shale Blakely Sandstone Mazarn Shale Crystal Mountain Sandstone
		Collier Shale
	Cambrian	

Figure 120. *Rocks of Cambrian to Pennsylvanian age comprise the Ouachita Mountains aquifer.*

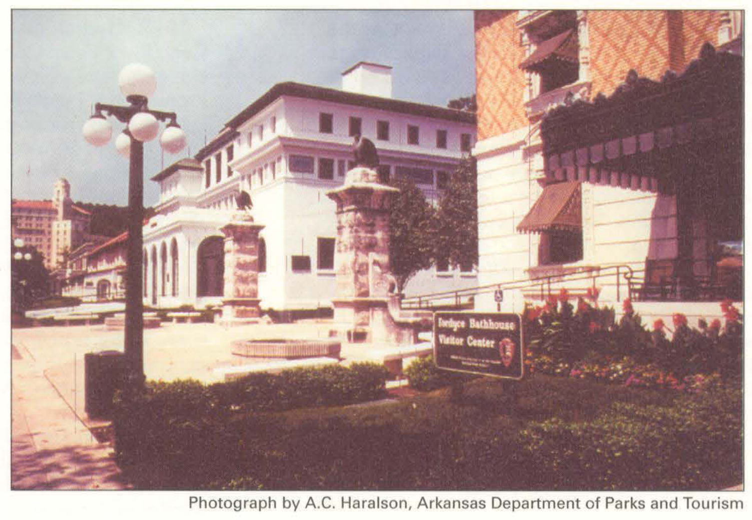
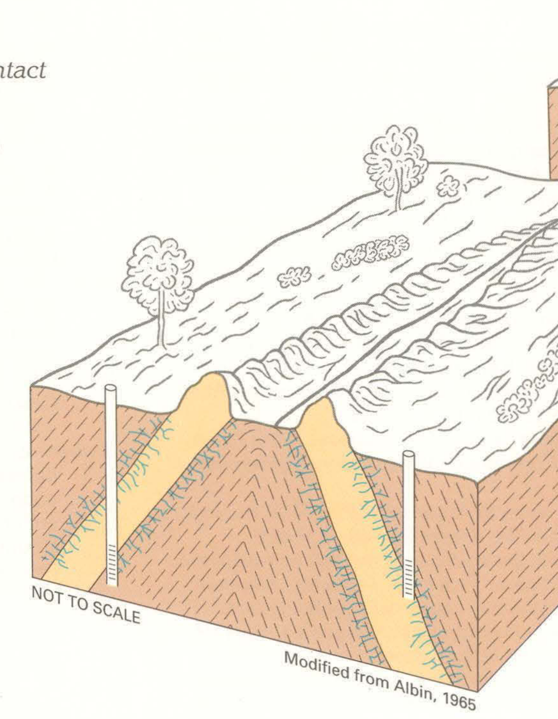


Figure 122. *A collecting system diverts flow of more than 40 springs to a central reservoir. The heated water is redistributed to the individual bathhouses, some of which are shown here at Bathhouse Row in Hot Springs, Arkansas.*

Figure 121. *Fracture zones at the contact between sandstone and shale beds and in fractured novaculite-chert beds are good locations for wells to obtain water from the Ouachita Mountains aquifer.*

EXPLANATION

- **Sandstone**—Fracture zone at top
- **Shale**—Fracture zone at top and bottom



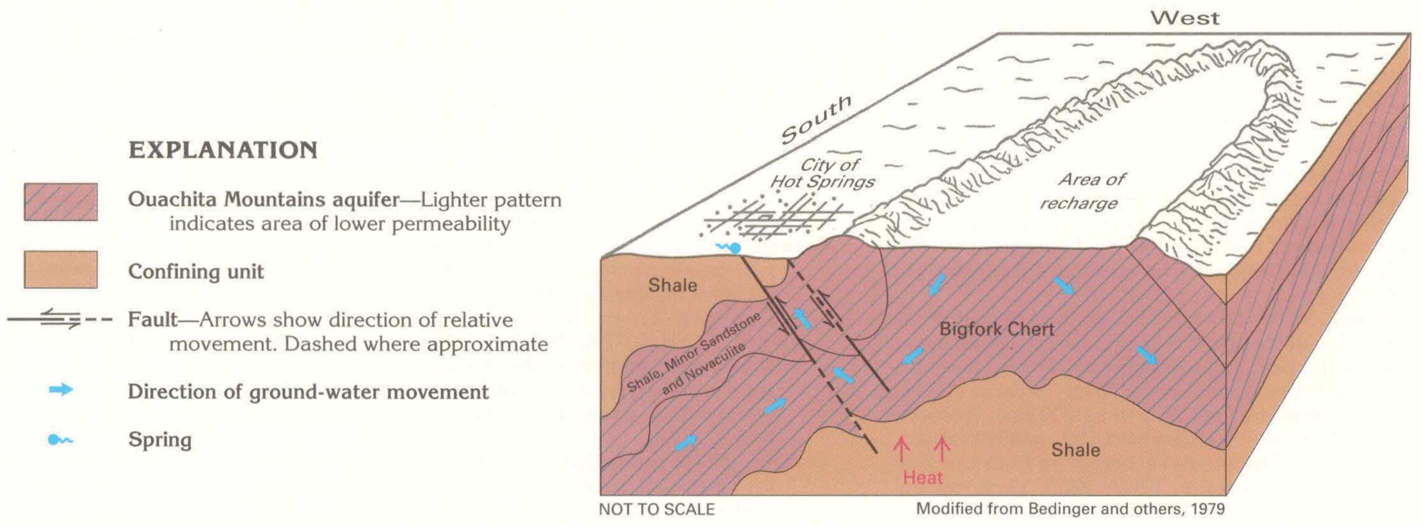


Figure 123. *This generalized diagram conceptually depicts ground-water flow within the Bigfork Chert, which is a water-yielding zone of the Ouachita Mountains aquifer, and the probable path of the water discharged from thermal (warm-water) springs in the Hot Springs, Arkansas, area. Water enters the Bigfork Chert as precipitation that falls on upland outcrop areas and seeps downward through bedrock fractures into deeper parts of the flow system. Water is heated by circulating through rocks that have high temperatures as a result of the effects of the geothermal gradient. The heated water escapes the flow system with little loss in heat energy by moving rapidly upward along a fault or fracture zone that intersects the land surface.*

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