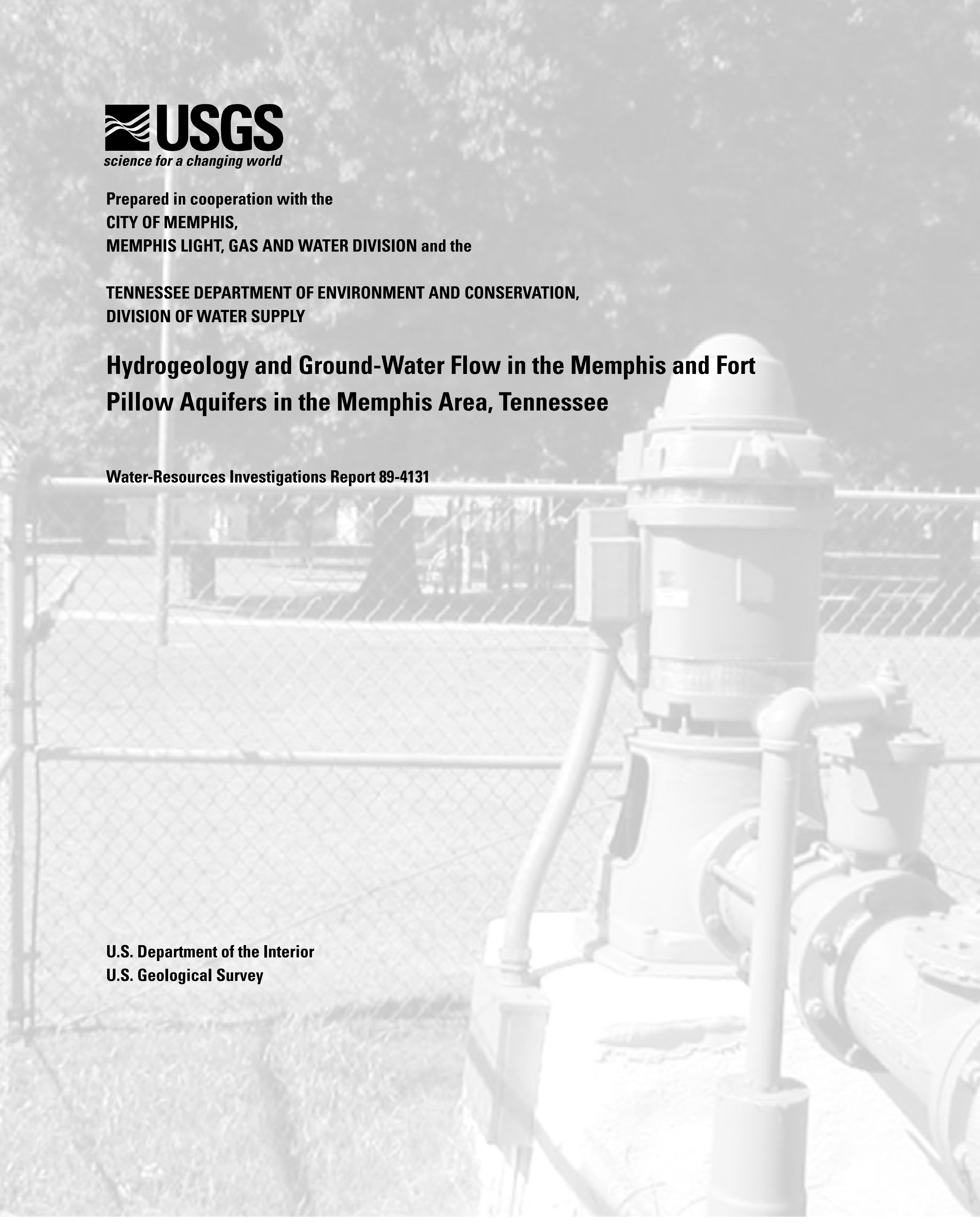

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CITY OF MEMPHIS,
MEMPHIS LIGHT, GAS AND WATER DIVISION and the

TENNESSEE DEPARTMENT OF ENVIRONMENT AND CONSERVATION,
DIVISION OF WATER SUPPLY

Hydrogeology and Ground-Water Flow in the Memphis and Fort Pillow Aquifers in the Memphis Area, Tennessee

Water-Resources Investigations Report 89-4131

U.S. Department of the Interior
U.S. Geological Survey

Cover photograph: Public-supply well in Shelby County, Tennessee. Photograph taken by L.B. Thomas, U.S. Geological Survey.

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Nashville, Tennessee
2001

U.S. DEPARTMENT OF THE INTERIOR
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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS, VERTICAL DATUM, AND WELL-NUMBERING SYSTEM

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per day (ft/d)	3.528×10^{-6}	meter per second (m/s)
square foot per second (ft^2/s)	0.0929	square meter per second (m^2/s)
cubic foot per second (ft^3/s)	2.83×10^{-2}	cubic meter per second (m^3/s)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon per day (gal/d)	4.384×10^{-8}	cubic meter per second (m^3/s)
gallon per minute (gal/min)	6.309×10^{-5}	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	4.384×10^{-2}	cubic meter per second (m^3/s)
gallon per day per foot [(gal/d)/ft]	1.438×10^{-7}	square meter per second (m^2/s)
inch per year (in/yr)	0.0254	meter per year (m/a)

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.

Well-Numbering System: Wells are identified according to the numbering system used by the U.S. Geological Survey throughout Tennessee. The well number consists of three parts: (1) an abbreviation of the name of the county in which the well is located; (2) a letter designating the 7-1/2-minute topographic quadrangle on which the well is plotted; and (3) a number generally indicating the numerical order in which the well was inventoried. The symbol Sh:U-2, for example, indicates that the well is located in Shelby County on the "U" quadrangle and is identified as well 2 in the numerical sequence. Quadrangles are lettered from left to right, beginning in the southwest corner of the county.

Hydrogeology and Ground-Water Flow in the Memphis and Fort Pillow Aquifers in the Memphis Area, Tennessee

By J.V. Brahana *and* R.E. Broshears

ABSTRACT

On the basis of known hydrogeology of the Memphis and Fort Pillow aquifers in the Memphis area, a three-layer, finite-difference numerical model was constructed and calibrated as the primary tool to refine understanding of flow in the aquifers. The model was calibrated and tested for accuracy in simulating measured heads for nine periods of transient flow from 1886-1985. Testing and sensitivity analyses indicated that the model accurately simulated observed heads areally as well as through time.

The study indicates that the flow system is currently dominated by the distribution of pumping in relation to the distribution of areally variable confining units. Current withdrawal of about 200 million gallons per day has altered the prepumping flow paths, and effectively captured most of the water flowing through the aquifers. Ground-water flow is controlled by the altitude and location of sources of recharge and discharge, and by the hydraulic characteristics of the hydrogeologic units.

Leakage between the Fort Pillow aquifer and Memphis aquifer, and between the Memphis aquifer and the water-table aquifers (alluvium and fluvial deposits) is a major component of the hydrologic budget. The study indicates that more than 50 percent of the water withdrawn from the Memphis aquifer in 1980 is derived from vertical leakage across confining units, and the leakage from the shallow aquifer (potential source of contamination) is not uniformly distributed. Simulated leakage was concentrated along the upper reaches of the Wolf and Loosahatchie Rivers, along the upper reaches of Nonconnah Creek, and the surficial aquifer of the Mississippi River alluvial plain. These simulations are supported by the geologic and geophysical evidence suggesting relatively thin or sandy confining units in these general locations. Because water from surficial aquifers is inferior in quality and more susceptible to contamination than water in the deeper aquifers, high rates of leakage to the Memphis aquifer may be cause for concern.

A significant component of flow (12 percent) discharging from the Fort Pillow aquifer was calculated as upward leakage to the Memphis aquifer. This upward leakage was generally limited to areas near major pumping centers in the Memphis aquifer, where heads in the Memphis aquifer have been drawn significantly below heads in the Fort Pillow aquifer. Although the Fort Pillow aquifer is not capable of producing as much water as the Memphis aquifer for similar conditions, it is nonetheless a valuable resource throughout the area.

INTRODUCTION

The Memphis area has a plentiful supply of ground water suitable for most uses, but the resource may be vulnerable to pollution. Withdrawal of nearly 200 million gallons per day (Mgal/d) ranks Memphis second only to San Antonio, Texas, among the nation's cities that depend solely on ground water for municipal-water supply. For the past century, most of the city's ground water has been pumped from the Memphis aquifer, a Tertiary sand unit that is confined in most of the Memphis area. Industrial, public supply, and private withdrawals also have been made from the Fort Pillow aquifer, but these generally have amounted to less than 10 percent of the total pumping in the area.

There has been increasing concern that contaminated ground water in the area's surficial aquifers may leak downward to the Memphis aquifer (Parks and others, 1982; Graham and Parks, 1986; M.W. Bradley, U.S. Geological Survey, written commun., 1987). To assess the potential for such leakage, a cooperative investigation was initiated in 1978 between the City of Memphis, Memphis Light, Gas and Water Division (MLGW) and the U.S. Geological Survey. This investigation is part of a series of studies pursuing a more complete understanding of ground-water flow and chemistry in the area. The main tool of this investigation is a ground-water flow model of the major aquifers in the Memphis area. This flow model integrates all available information on the geology, hydrology, and ground-water chemistry of the region. The model has helped to quantify the potential for leakage between principal aquifers, and it may be a valuable predictive tool to assist water managers in managing ground-water resources.

Approach and Scope

The necessary approaches to this investigation were:

1. to describe the hydrogeologic framework of the Memphis area, with emphasis on the Memphis aquifer and Fort Pillow aquifer;
2. to develop a conceptual model of ground-water flow in the Memphis area;
3. to test the conceptual model through the application of a multilayer, finite-difference ground-water flow model.

As defined for this investigation, the Memphis area comprises a rectangular zone of roughly 1,500 square miles (mi^2), measuring about 45 miles from east to west by 35 miles from north to south. The Memphis area lies near the center of the northern part of the Mississippi embayment and includes all of Shelby County, Tennessee, and parts of Fayette and Tipton Counties, Tennessee, DeSoto and Marshall Counties, Mississippi, and Crittenden and Mississippi Counties, Arkansas (fig. 1).

The study area includes all of metropolitan Memphis, as well as undeveloped, outlying areas where ground water is affected by pumping from metropolitan well fields. Although the study focuses on the Memphis area, the aquifers and confining units are regional in occurrence, and extend far beyond the Memphis area boundaries. Descriptions and maps necessary to define the regional hydrogeology are included within this report only as an aid to understanding ground-water flow in the Memphis area. Readers interested in a full discussion of the regional hydrogeology of the Memphis and Fort Pillow aquifers in the northern Mississippi embayment are referred to Arthur and Taylor (1990).

Previous Investigations

A substantial body of literature exists on the hydrology and hydrogeology of aquifer systems in the Memphis area. The most recent, comprehensive studies include those of Graham and Parks (1986), who studied the potential for leakage in the Memphis area, and Parks and Carmichael (1989a, 1989b, 1989c), who described the geology and ground-water resources of three aquifers in West Tennessee. Extensive bibliographies of previous ground-water studies are included in Brahana (1982a, table 2 and p. 35-40) and in Graham and Parks (1986, p. 41-44). A series of potentiometric maps and a description of historic water-level changes and pumpage from the Memphis aquifer and Fort Pillow aquifer in the Memphis area are included in Criner and Parks (1976). Historic water levels in individual wells are also documented by the U.S. Geological Survey (1936-1973). The potentiometric surface in the Memphis aquifer for 1978 and 1980 in the Memphis area is shown in Graham (1979, 1982), and for 1985 for West Tennessee is shown in Parks and Carmichael (1989d). The potentiometric surface of the Fort Pillow aquifer for 1980 for the northern Mississippi embayment is shown in Brahana and Mesko (1988, fig. 11), and for 1985 for West Tennessee is shown in Parks and Carmichael (1989e, fig. 2).

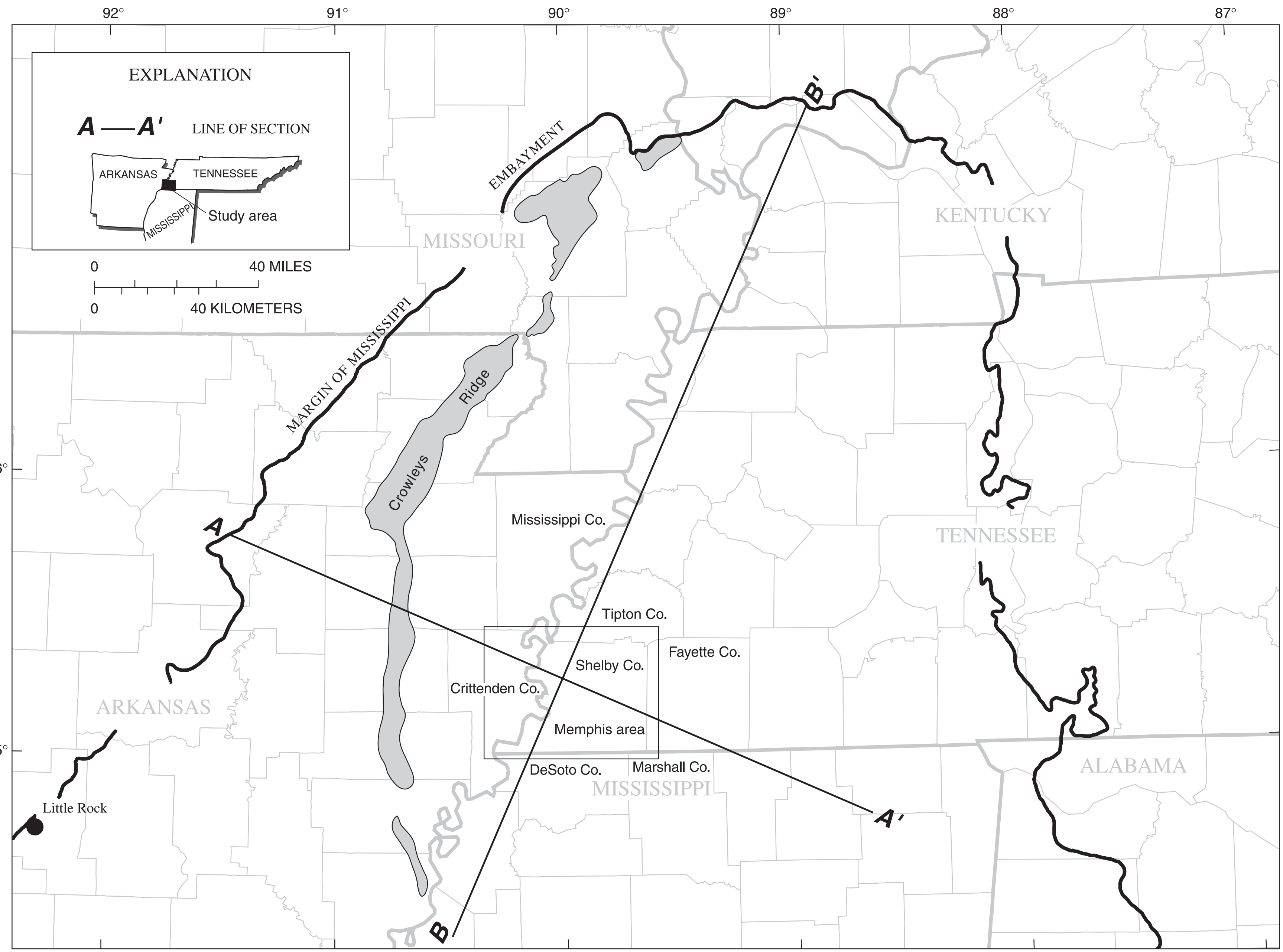


Figure 1. Location of the Memphis area and hydrogeologic sections along lines A-A′ and B-B′ in the Mississippi embayment.

Water quality in aquifers in the Memphis area has been summarized by Brahana and others (1987), and data describing selected water-quality parameters in the water-table aquifers in the Memphis area have been described by McMaster and Parks (1988). Parks (1973, 1974, 1975, 1977b, 1978, 1979a, 1979b) mapped the surface and shallow subsurface geology of the Memphis metropolitan area. A summary of some current and possible future environmental problems related to geology and hydrology in the Memphis area is given in a report by Parks and Lounsbury (1976). Parks and others (1982) described the installation and sampling of observation wells at selected waste-disposal sites.

Analog simulation of water-level declines in the Sparta aquifer (equivalent to the upper part of the Memphis aquifer) in the Mississippi embayment was summarized by Reed (1972). A two-dimensional digital flow model of the Memphis aquifer was described by Brahana (1982a). This model was used as a predictive tool to estimate aquifer response to various hypothetical pumpage projections (Brahana, 1982b). Arthur and Taylor (1990) evaluated the Memphis and Fort Pillow aquifers (as part of the Mississippi embayment aquifer system) in a regional study that encompassed the northern Mississippi embayment. Fitzpatrick and others (1989) described the geohydrologic characteristics and digital model-simulated response to pumping stresses in the Sparta aquifer (equivalent to upper part of Memphis aquifer) in east-central Arkansas.

Reports describing the general geology and ground-water hydrology of the Memphis area include Fisk (1944), Schneider and Blankenship (1950), Caplan (1954), Stearns and Armstrong (1955), Stearns (1957), Cushing and others (1964), Krinitzsky and Wire (1964), Moore (1965), Boswell and others (1965, 1968), Hosman and others (1968), and Cushing and others (1970).

In addition to published reports, there is a substantial body of unpublished hydrogeologic data for the Memphis area. These data include borehole geophysical logs, well-completion data, driller's records, geologic logs, summaries of pumping tests, inventories of pumpage, and individual well records and maps of water levels. Most of these records are located in the files of the U.S. Geological Survey, Water Resources Division; Tennessee Division of Geology; Tennessee Division of Water Resources; and City of Memphis, Memphis Light, Gas and Water Division.

HYDROLOGIC SETTING

Climate and Precipitation

The Memphis metropolitan area is characterized by a temperate climate, with a mean annual air temperature of about 62^{o} F, and abundant precipitation. About 48 inches of precipitation per year is typical, although annual amounts recorded have ranged from 31 to 77 inches.

The distribution of rainfall is nonuniform in space and time. Mean annual precipitation increases approximately 4 inches per year from west to east across the Mississippi embayment (Cushing and others, 1970). The driest part of the year is late summer and fall, and the wettest is late winter.

Topography and Drainage

Land-surface altitudes in the Memphis area range from about 200 feet above sea level on the flat alluvial plain of the Mississippi River to about 400 feet above sea level in the upland hills of eastern Shelby County. A bluff 50 to 150 feet high separates the alluvial plain from the upland. Other than the bluff, local relief seldom exceeds 40 feet.

The Mississippi River dominates surface-water flow in the area. From the upland in the east, it receives drainage from three main tributary streams—Nonconnah Creek, Wolf River, and Loosahatchie River. Along most reaches, these three tributaries flow throughout the year. One notable exception is Nonconnah Creek upstream from the mouth of Johns Creek. Since the 1950's, Nonconnah Creek has been dry in its upstream reaches for short periods during the dry season from July to October (Criner and others, 1964).

Hydrogeologic Framework

The Memphis area is located near the axis of the Mississippi embayment, a regional downwarped trough of Paleozoic rock that has been filled with more than 3,000 feet of unconsolidated sediments (Criner and Parks, 1976). These sediments include uncemented sand, clay, silt, chalk, gravel, and lignite. On a regional scale, the sediments form a sequence of nearly parallel, sheetlike layers of similar lithology. The layers reflect the trough-like shape of the Paleozoic strata (fig. 2).

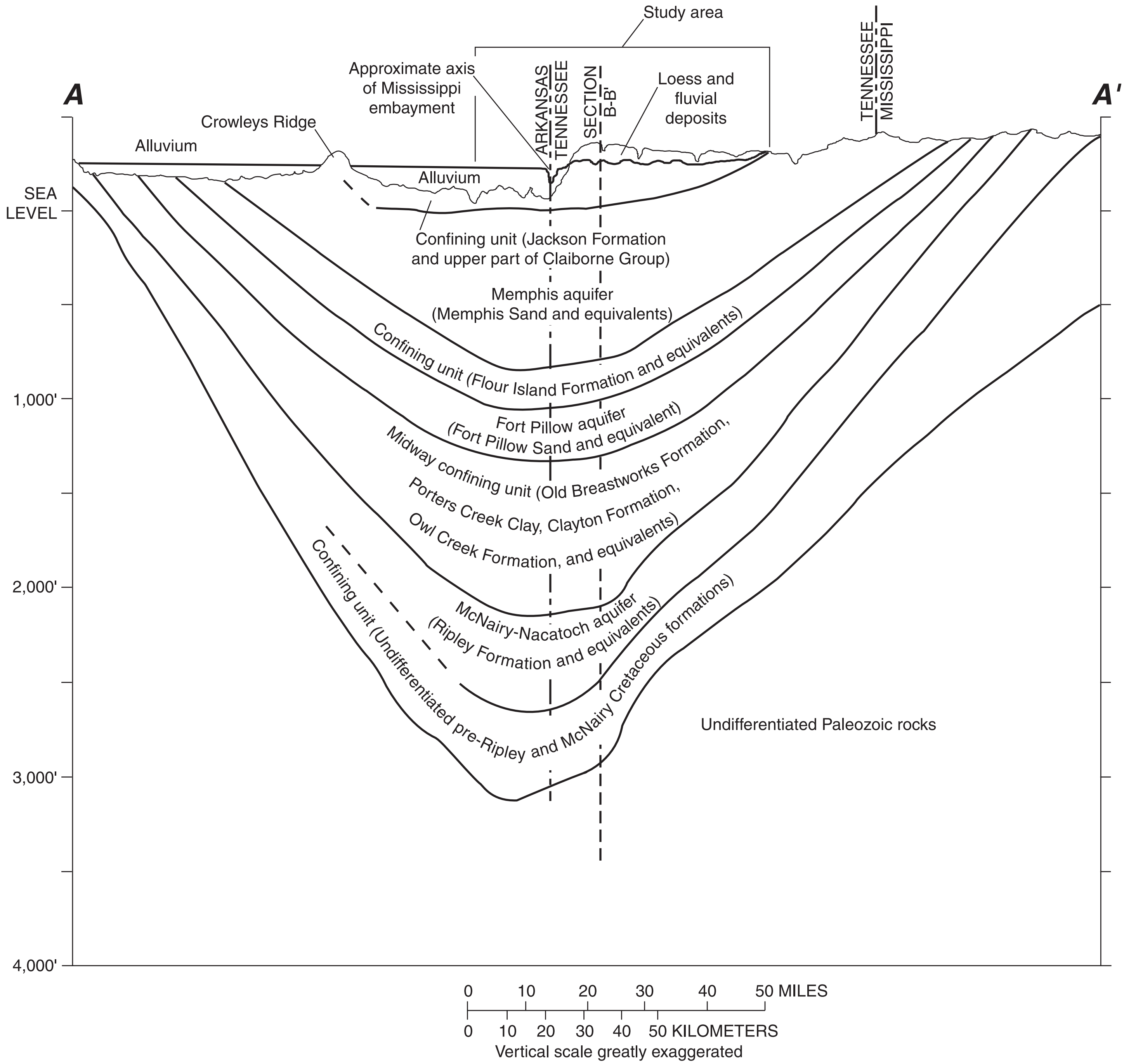


Figure 2. Hydrogeologic section showing principal aquifers and confining units, west to east, through the Mississippi embayment along line A-A'.

On a local scale, however, there are complex lateral and vertical gradations in the lithology of each layer. Of particular interest to this study are variations in thickness and sand percentage of the major clay layers. These confining clay units control the ground-water interchange between the sand layers that form the major aquifers. Zones where the confining clays are thin or sandy are potential sites of high leakage, and the most likely pathways for pollutant migration (Graham and Parks, 1986).

The structural axis of the northern Mississippi embayment is approximately coincident with the Mississippi River, passing south-southwest through the western part of the study area in eastern Crittenden County, Ark. (fig. 1). The sedimentary rock layers which comprise the embayment gently dip 10 to 35 feet per mile from both the west and east toward the axis of the embayment (fig. 2). These layers thicken to the south-southwest (fig. 3).

The thickness, lithology, and hydrologic significance of each stratigraphic unit in the Memphis area are described briefly in table 1. Five of these units represent major water-bearing zones: the alluvium, the surficial fluvial deposits, the Memphis Sand, the Fort Pillow Sand, and the Ripley Formation and McNairy Sand. With the exception of the alluvium and fluvial deposits, water-bearing zones are confined by clay layers over much of the Memphis area. Reported ground-water conditions and hydraulic characteristics of selected units that are the focus of this report have been generalized in table 2.

Water-Table Aquifers

Water-table aquifers in the Memphis area consist of the alluvium and fluvial deposits which are mostly unconfined (Graham and Parks, 1986, p. 5). These aquifers outcrop throughout the study area, and generally occur at shallow depths (table 2).

An interpretive water-table map of the alluvium and fluvial deposits was constructed for "average," steady-state conditions, designated 1980 (fig. 4). The map was based on the most complete set of water-level data available (Graham and Parks, 1986), supplemented by historic water-levels (Wells, 1933), stream stages, and where no other data were available, estimates based on topographic maps, land surface elevations, and extrapolated depths to water (Brahana and Mesko, 1988).

Alluvium

Alluvium occurs at land surface in the stream valleys of the study area. The alluvium is not a major ground-water source in the Memphis area, even though it is a major water-bearing zone and can supply large quantities of water to wells. This lack of use is related to its limited area of occurrence and to the hardness and high iron concentration of the water. West, north, and south of the study area, the alluvium of the Mississippi River alluvial plain is one of the most productive regional aquifers in the Mississippi embayment, supplying over a billion gallons per day to irrigation wells in Arkansas and Mississippi (Boswell and others, 1968; Ackerman, 1989).

The thickness of the alluvium may vary significantly over very short distances (Krinitzsky and Wire, 1964). In the Mississippi River alluvial plain, which lies west of the bluffs (fig. 4), the alluvium is commonly 100 to 175 feet thick (Boswell and others, 1968); along valleys of upland streams tributary to the Mississippi River east of the bluffs (fig. 4), thickness generally is less than 50 feet (Graham and Parks, 1986). Alluvium includes gravel, sand, silt, and clay; the latter is commonly rich in organic matter. Abrupt vertical and horizontal variations in lithology are common.

The alluvium is separated from the Memphis aquifer by a confining unit made up of clays and fine-grained sediments of the Jackson Formation and underlying upper part of the Claiborne Group, which has variable thickness and lithology. Where this confining unit is thin or sandy, leakage of ground water from one aquifer to the other may be substantial. The generalized thickness of this confining unit is shown in figure 5.

Rivers dominate the hydrology of the water-table aquifers. Local streams, as shown by figure 4, are in direct hydraulic connection with these aquifers, functioning as drains during much of the year. Seasonal variations of water level in the alluvium are typically less than 10 feet, although variations of as much as 15 feet have been reported (Plebuch, 1961; Broom and Lyford, 1981; Brahana and Mesko, 1988, fig. 13). During floods when stream stage is temporarily higher than the water table, some recharge to the alluvium occurs. No long-term declines in water level in the alluvium in the Memphis area are known.

Aquifer hydraulic characteristics of the Mississippi River alluvial aquifer in Arkansas and Missouri have been reported by Halberg and Reed (1964), Albin

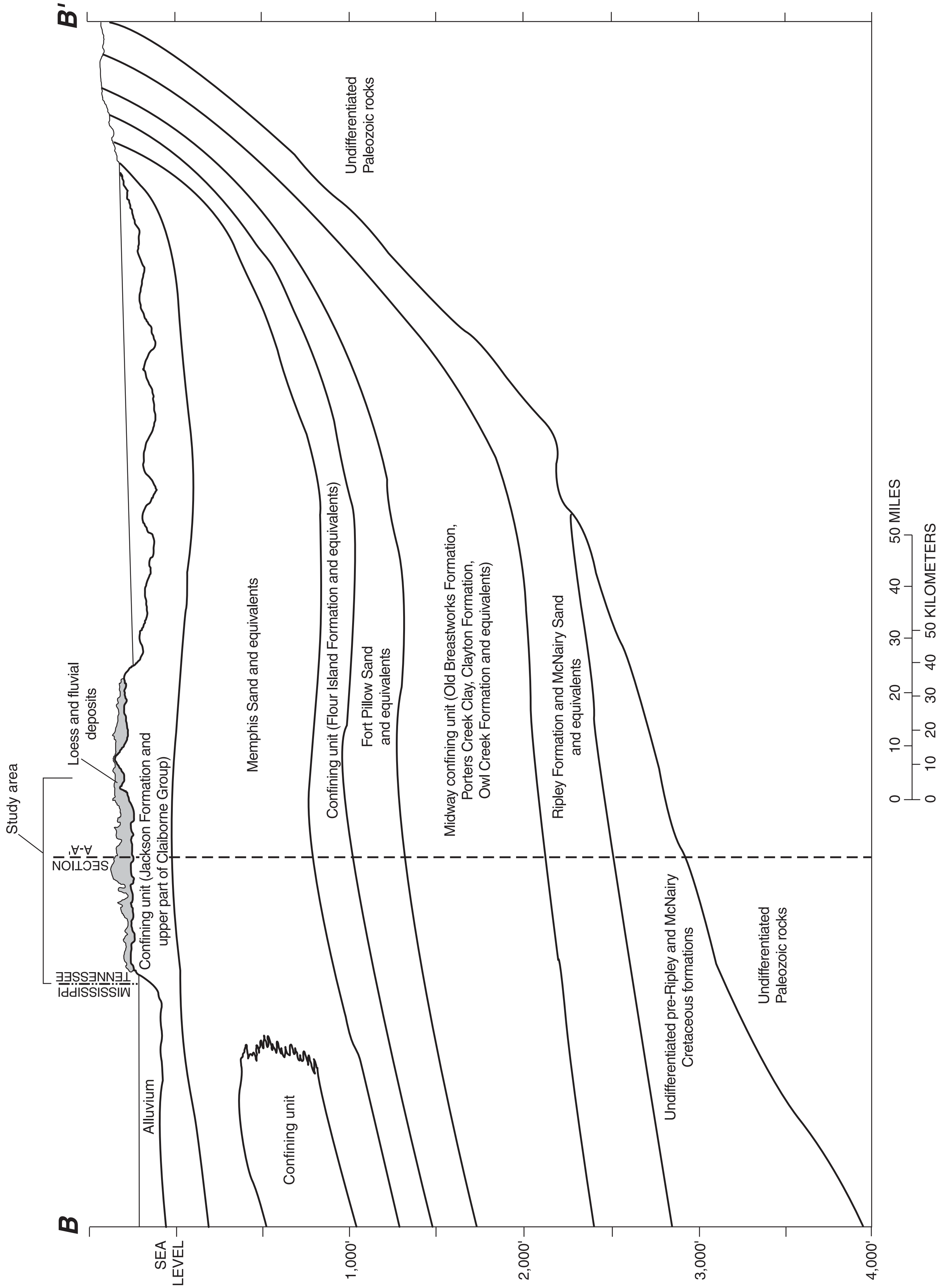


Figure 3. Hydrogeologic section showing principal aquifers and confining units, south to north, through the Mississippi embayment along line B-B′.

Table 1. Post-Paleozoic geologic units underlying the Memphis area and their hydrologic significance

[Modified frcm Criner and Parks, 1976; Moore and Brown, 1969; Plebuch, 1961; Schneider and Blankenship, 1950]

System	Series	Group	Stratigraphic unit	Thick-ness	Hydrologic unit	Lithology and hydrologic significance
Quaternary	Holocene and Pleistocene		Alluvium	0-175	Surficial Aquifer	Sand, gravel, silt, and clay. Underlies the Mississippi Alluvial Plain and alluvial plains of streams in the Gulf Coastal Plain. Thickest beneath the Alluvial Plain, where commonly between 100 and 150 feet thick; generally less than 50 feet thick elsewhere. Provides water to farm, industrial, and irrigation wells in the Mississippi Alluvial Plain.
	Pleistocene		Loess	0-65		Silt, silty clay, and minor sand. Principal unit at the surface in upland areas of the Gulf Coastal Plain. Thickest on the bluffs that border the Mississippi Alluvial Plain; thinner eastward from the bluffs. Tends to retard downward movement of water-providing recharge to the fluvial deposits.
Quaternary and Tertiary(?)	Pleistocene and Pliocene (?)		Fluvial Deposits (terrace deposits)	0-100		Sand, gravel, minor clay and ferruginous sandstone. Generally underlies the loess in upland areas, but are locally absent. Thickness varies greatly because of erosional surfaces at top and base. Provides water to many domestic and farm wells in rural areas.
Tertiary	Eocene	? / Claiborne	Jackson Formation and upper part of Claiborne Group ("capping clay")	0-370	Confining Unit	Clay, silt, sand, and lignite. Because of similarities in lithology, the Jackson Formation and upper part the Claiborne Group cannot be reliably subdivided based on available information. Most of the preserved sequence is equivalent to the Cook Mountain and overlying Cockfleld Formations, but locally the Cockfield may be overlain by the Jackson Formation. Serves as the upper confining unit for the Memphis Sand.
		Claiborne	Memphis Sand ("500-foot" sand)	500-890	Memphis aquifer	Sand, clay, and minor lignite. Thick body of sand with lenses of clay at various stratigraphic horizons and minor lignite. Thickest in the southwestern part of the Memphis area; thinnest in the northeastern part. Principal aquifer providing water for municipal and industrial supplies east of the Mississippi River; primary source of water for the City of Memphis.
	?	Wilcox	Flour Island Formation	140-310	Confining unit	Clay, silt, sand, and lignite. Consists primarily of silty clays and sandy silts with lenses and interbeds of fine sand and lignite. Serves as the lower confing unit for the Memphis Sand and the upper confining unit for the Fort Pillow Sand.
	Paleocene		Fort Pillow Sand ("1400-foot" sand)	92-305	Fort Pillow aquifer	Sand with minor clay and lignite. Sand is fine to medium. Thickest in the southwestern part of the Memphis area; thinnest in the northern and northeastern parts. Once the second principal aquifer supplying the City of Memphis; still used by an industry. Principal aquifer providing water for municipal and industrial supplies west of the Mississippi River.
			Old Breastworks Formation	180-350	Midway confining unit	Clay, silt, sand, and lignite. Consists primarily of silty clays and clayey silts with lenses and interbeds of fine sand and lignite. Serves as the lower confining unit for the Fort Pillow Sand, along with the underlying Porters Creek Clay, Clayton Formation, and Owl Creek Formation.

Table 1. Post-Paleozoic geologic units underlying the Memphis area and their hydrologic significance—Continued

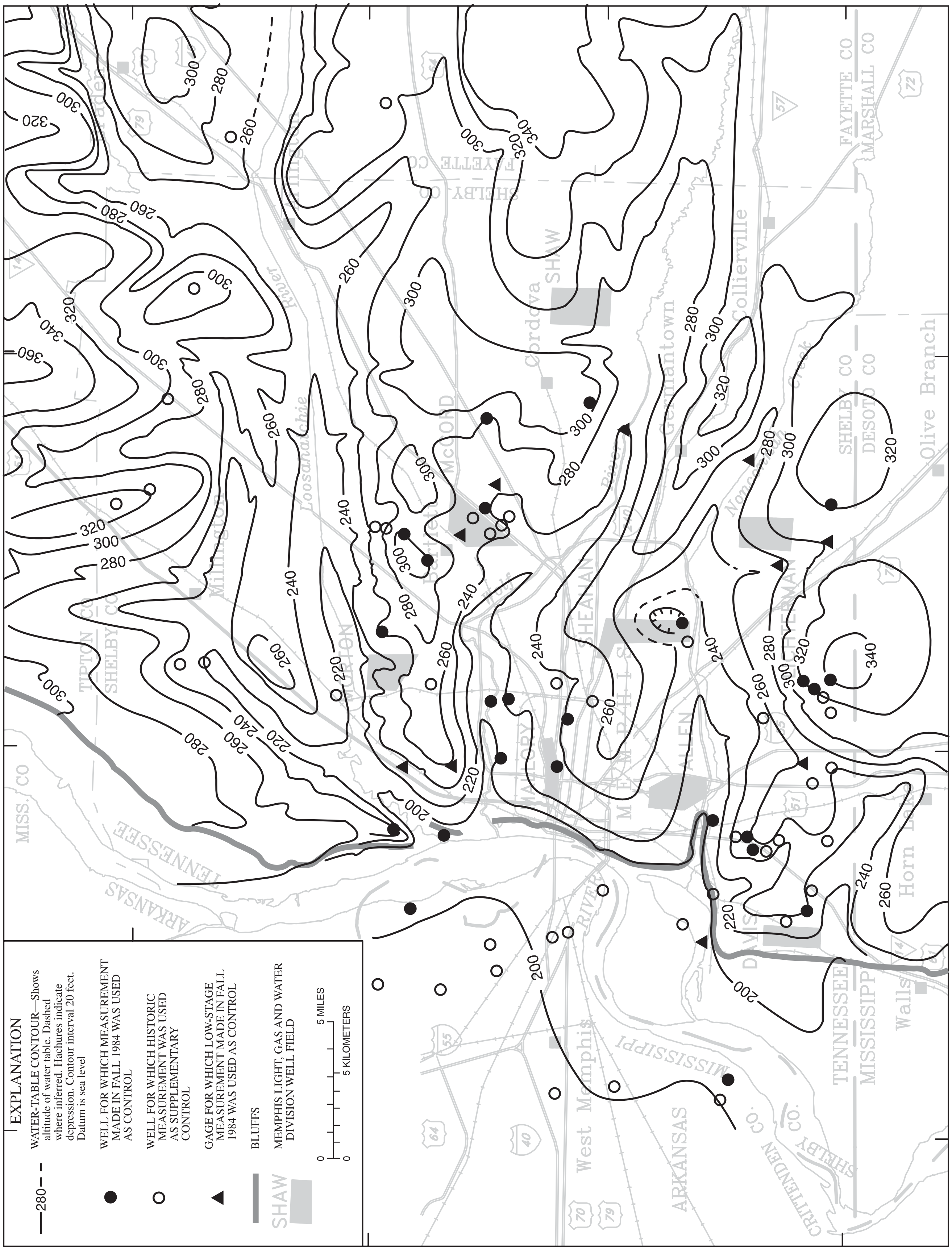
System	Series	Group	Stratigraphic unit	Thick-ness	Hydrologic unit	Lithology and hydrologic significance
Tertiary	Paleocene	Midway	Porters Creek Clay ?	250-320	Midway confining unit	Clay and minor sand. Thick body of clay with local lenses of clayey, glauconitic sand. Principal confining unit separating the Fort Pillow Sand and the Ripley Formation and McNairy Sand.
			Clayton Formation ?	40-120		Clay, sand, and minor limestone. Calcareous clay and glauconitic sand with local lenses of limestone in basal part; fossiliferous. Because of lithologic similarities, upper boundary is difficult to recognize. Confining unit.
Cretaceous	Upper Cretaceous		Owl Creek Formation	40-90		Clay and sand. Calcareous clay and glauconitic sand; fossiliferous. Because of lithologic similarities, the Owl Creek Formation is difficult to distinguish from the overlying Clayton Formation without fossil verification. Confining unit.
			Ripley Formation and McNairy Sand	360-570	McNairy-Nacatoch aquifer	Sand and clay; minor sandstone, limestone, and lignite. Ripley changes facies northeast of Memphis to McNairy Sand. Ripley consists primarily of glauconitic sands and calcareous clays with minor interbeds of calcareous sandstone or sandy limestone; McNairy consists primarily of nonglauconitic sands and non-calcareous clays with local lenses of lignite. Aquifer with low potential for use in Memphis area because of lesser amounts of sand and poorer quality of water than aquifers above. Base of Ripley and McNairy is base of freshwater in the Memphis area.
			Coon Creek Formation	0-60	Confining unit	Clay and sand. Shaley clays with thin interbeds of fine sand; locally glauconitic and fossiliferous; locally contains some thin layers of rock. Probably present only in northeastern Shelby and northwestern Fayette Counties, Tenn. Confining unit.
			Demopolis Formation	270-390		Clay and chalk. Calcareous clays and chalks; glauconitic and fossiliferous. Some layers of chalk form indurated layers. Serves as the principal confining unit separating the Ripley Formation and McNary Sand and Coffee Sand.
			Coffee Sand	0-120	Coffee aquifer	Sand and minor clay. Sand is fine to medium; locally glauconitic or lignitic. Clay occurs as local lenses, particularly at the base. Absent locally in north-central Shelby County, Tenn., where the Demopolis Formation overlies igneous intrusive rock. Contains brackish or saline water; not considered a freshwater aquifer in the Memphis area. Underlain by Paleozoic dolomitic limestones of Ordovician age.

Table 2. Generalized ground-water characteristics and hydraulic properties of select hydrogeologic units in the Memphis area

Hydrogeologic unit	Generalized present-day flow directions	Depth commonly encountered (feet)	Thickness (feet)	Water-bearing character	Hydraulic properties of unit		
					T (ft^2/d)	S (unitless)	K′ (ft/d)
Alluvium	Toward major streams—downstream.	Surface	0-175	Unconfined aquifer Mississippi River alluvium confined in many places.	8,500-50,000 (a)	$1x10^{-4}$ to $4x10^{-2}$ (a)	--
Terrace (fluvial) deposits.	To valleys	Surface	0-100	Unconfined aquifer	No measurements	No measurements	--
Jackson Formation and upper part of Claibome Group (capping clay).	--	0-100	0-370	Confining layer	--	--	No measurements
Memphis Sand	Into pumping center	0-600 500 common	500-890	Confined aquifer in most of Memphis area; unconfined in southeast part of area.	2,700-45,000 (a) 6,700-54,000 (b)	$1x10^{-4}$ to $6x10^{-4}$ (a) $1x10^{-4}$ to $2x10^{-1}$ (b)	--
Flour Island Formation	--	1,000-1,400	140-310	Confining layer	--	--	$.8\text{-}4.4x10^{-11}$
Fort Pillow Sand	Into pumping center, primarily east to west.	1,200-1,500 1,400 common	92-305	Confined aquifer	2,700-21,000 (a) 12,000-19,000 (b)	$2x10^{-4}$ to $2x10^{-3}$ (a) $1.2x10^{-4}$ to $6.1\ x10^{-4}$ (b)	--
Porters Creek Clay, Clayton and Owl Creek Formations.	--	1,400-1,700	150-770	Confining layer	--	--	No measurements
McNairy Sand	Southeast to northwest	2,650	360-430	Confined aquifer	No measurements	No measurements	--

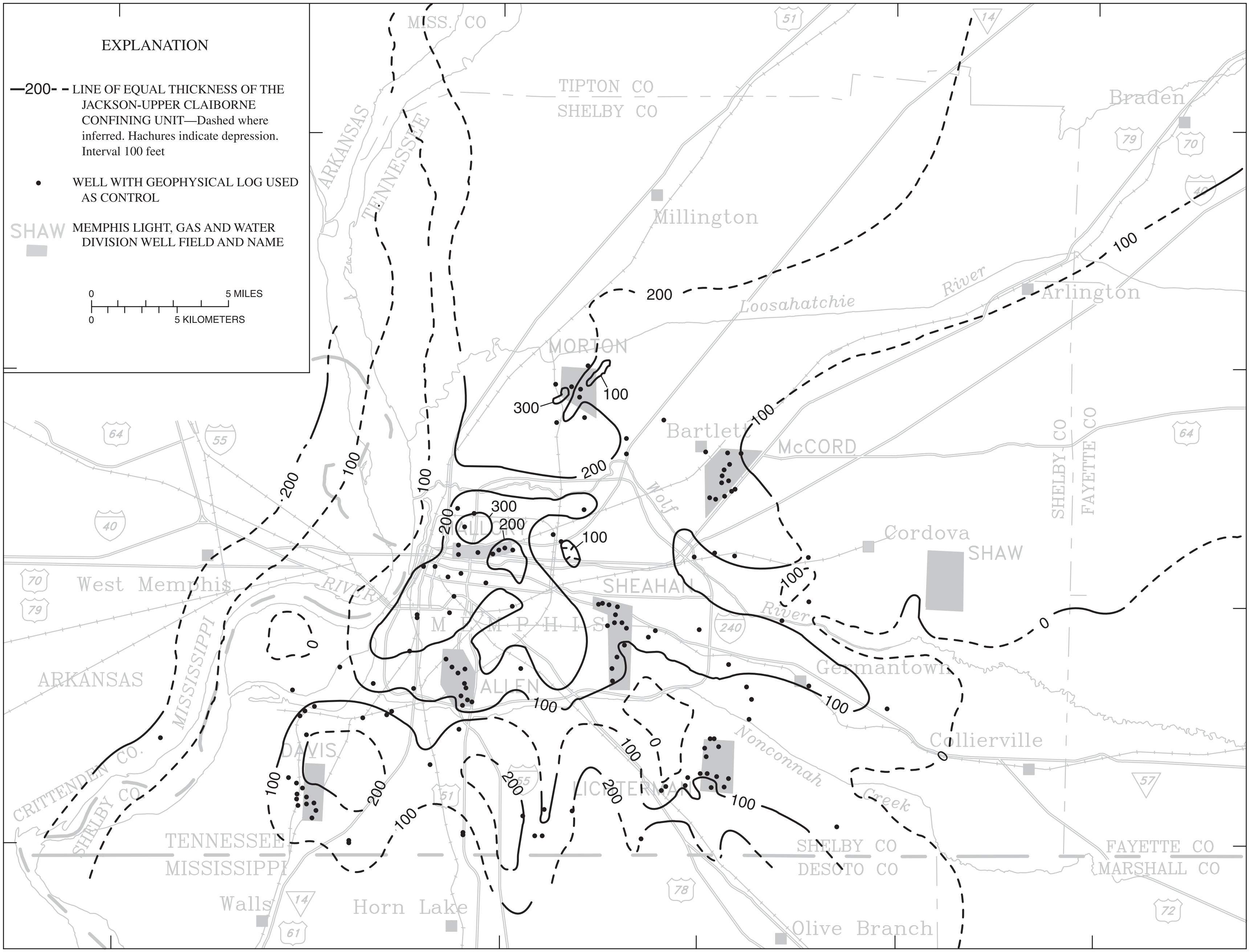
(a) Results from test conducted in the northern Mississippi Embayment, see table 3.

(b) Results for the Memphis area from Criner and others, 1964; Moore, 1965; Hosman and others, 1968; Brahana, 1982a; Arthur and Taylor, 1990; and Parks and Carmichael, 1989a.



Base from U.S. Geological Survey 1:24,000 and Mississippi River Commission 1:62,500 quadrangles

Figure 4. Generalized altitude of the water table in the alluvium and fluvial deposits in the Memphis area, 1980.



Base from U.S. Geological Survey
1:24,000 and Mississippi River
Commission 1:62,500 quadrangles

Figure 5. Generalized thickness of the Jackson-upper Claiborne confining unit in the Memphis area.