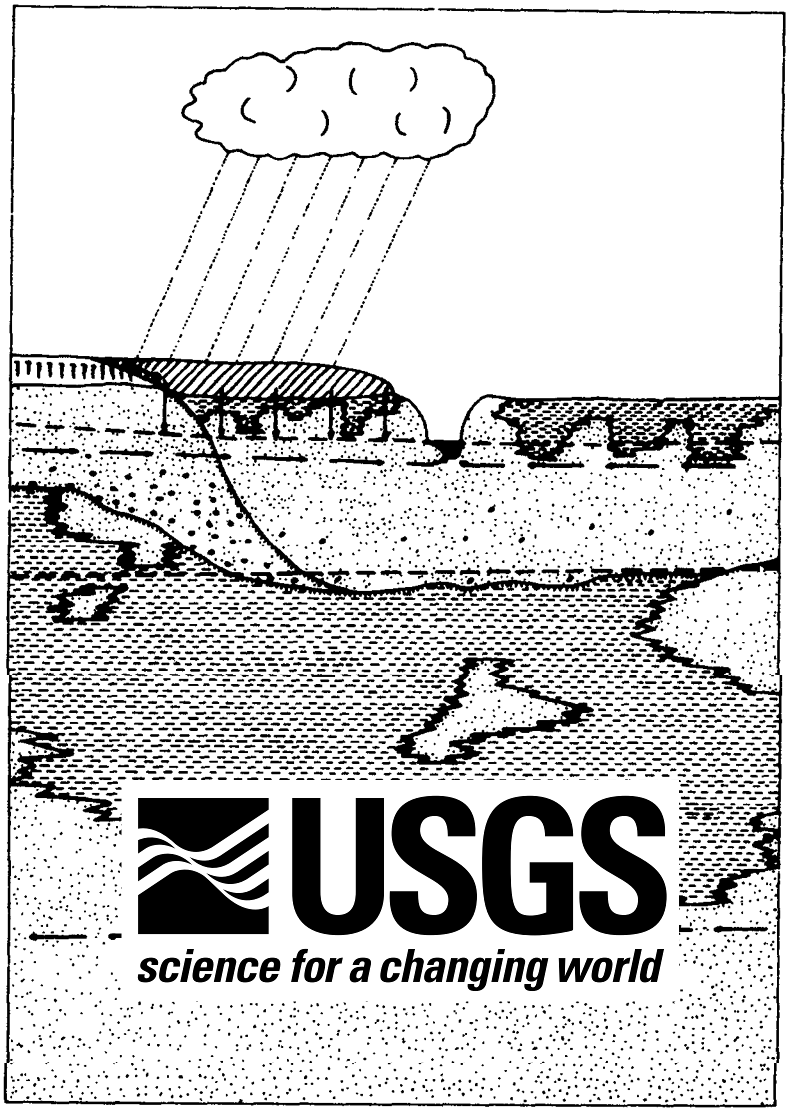
Water-Resources Investigations Report 90-4092

HYDROGEOLOGY AND PRELIMINARY ASSESSMENT OF THE POTENTIAL FOR CONTAMINATION OF THE MEMPHIS AQUIFER IN THE MEMPHIS AREA, TENNESSEE



Prepared by the
U.S. GEOLOGICAL SURVEY

in cooperation with the
CITY OF MEMPHIS,
MEMPHIS LIGHT, GAS AND WATER DIVISION

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By William S. Parks

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Memphis, Tennessee
1990

DEPARTMENT OF THE INTERIOR

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U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS AND DEFINITIONS

Factors for converting inch-pound units to metric units are shown to four significant digits:

Multiply inch-pound units	By	To obtain metric units
inch (in.)	2.540	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

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 (USGS) 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 USGS 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 well number Sh:K-141, for example, indicates that the well is located in Shelby County on the "K" quadrangle and is identified as well 141 in the numerical sequence. Quadrangles are lettered from left to right, beginning in the southwest corner of the county. In this report, wells in Crittenden County, Ark., and DeSoto County, Miss., are numbered using the prefixes "Ar:" and "Ms:" for the preparation of illustrations. The suffixes (for example, "A-7") for the wells in DeSoto County are the same as the well designations assigned by the USGS in Mississippi.

HYDROGEOLOGY AND PRELIMINARY ASSESSMENT OF THE POTENTIAL FOR CONTAMINATION OF THE MEMPHIS AQUIFER IN THE MEMPHIS AREA, TENNESSEE

By William S. Parks

ABSTRACT

Detailed maps of the thickness of the Jackson-upper Claiborne confining unit and the altitude of the water table in the alluvium and fluvial deposits provide much new information concerning areas where downward leakage is or may be occurring from the water-table aquifers to the Memphis aquifer in the Memphis area. A detailed map of the altitude of the potentiometric surface of the Memphis aquifer and the locations of 44 sites where contaminants have been detected in the water-table aquifers indicate that many of these sites are located in areas where the direction of ground-water flow in the Memphis aquifer is toward municipal well fields. Consequently, if contaminants enter the Memphis aquifer, a hydraulic potential exists for their transport to those well fields.

Recently (1986-88), volatile organic compounds were detected in water from five municipal wells screened in the Memphis aquifer—three in the Allen well field of the Memphis Light, Gas and Water Division at Memphis and two in the west well field at Collierville. Concentrations of seven volatile organic compounds totaled about 11 micrograms per liter in a sample from one well in the Allen well field at Memphis, and the concentration of one compound was 25 micrograms per liter in a sample from one well at Collierville. These are the first reported occurrences of synthetic organic compounds in the Memphis aquifer and prove that the principal aquifer in the Memphis area is vulnerable to contamination.

INTRODUCTION

The City of Memphis presently (1989) depends solely on the Memphis aquifer for its water supply. Withdrawals from this aquifer in the Memphis area for municipal, industrial, and commercial uses were about 200 Mgal/d in 1988. Historically, the Memphis aquifer was thought of as an ideal artesian aquifer overlain by a thick, impermeable clay layer that serves as an upper confining unit and protects it from contamination from near-surface sources. Studies made over the past few decades, however, indicate that the confining unit locally is thin or absent or contains sand "windows" that could provide "pathways" for contaminants to reach the Memphis aquifer (Criner and others, 1964; Bell and Nyman, 1968; Parks and Lounsbury, 1976; Graham and Parks, 1986).

Other studies indicate that downward leakage from the water-table aquifers to the Memphis aquifer is widespread in the Memphis area (Graham and Parks, 1986; J.V. Brahana and

R.E. Broshears, USGS, written commun., 1987). Areas particularly susceptible to leakage are places where the confining unit is thin or absent and in the vicinity of the Memphis Light, Gas and Water Division (MLGW) well fields where leakage is accelerated as a result of pumping stress in the Memphis aquifer (Graham and Parks, 1986).

Recently, volatile organic compounds were detected in water from five municipal wells pumping from the Memphis aquifer--three in the MLGW Allen well field at Memphis (J.H. Webb, MLGW, oral commun., 1986-88) and two in the west well field at Collierville (J.L. Ashner, Tennessee Department of Health and Environment (TDHE), oral commun., 1986). These are the first reported occurrences of synthetic organic compounds in the Memphis aquifer and prove that the principal aquifer in the Memphis area is vulnerable to contamination.

The concerns about the effectiveness of the confining unit to protect the Memphis aquifer prompted the City of Memphis, MLGW, and the U.S. Geological Survey (USGS) in 1987 to initiate a cooperative investigation of the potential for contamination of the aquifer. This report summarizes the findings of the investigation.

Purpose and Scope

The objectives of this investigation were to: (1) prepare detailed maps of the thickness of the Jackson-upper Claiborne confining unit, the water table in the alluvium and fluvial deposits, and the potentiometric surface of the Memphis aquifer; (2) identify potential sources of contamination of the Memphis aquifer; (3) update knowledge of indications of downward leakage from the water-table aquifers to the Memphis aquifer; and (4) make a preliminary assessment of the potential for contamination of the Memphis aquifer.

The investigation was limited to the Memphis area, as defined in recent reports (about 1,500 square miles), which includes all of Shelby County and parts of Fayette and Tipton Counties, Tenn., DeSoto and Marshall Counties, Miss., and Crittenden and Mississippi Counties, Ark. (fig. 1). Emphasis was placed on Shelby County, Tenn., where most of the municipal well fields are located (fig. 1).

Tasks included in the investigation were to: (1) interpret and correlate geophysical logs selected from a USGS file of more than 500 logs, (2) measure water levels in about 140 wells in the water-table and Memphis aquifers, (3) search for historic water levels in the USGS and State files to supplement data for the water-table aquifers, (4) collect information from various regulatory agencies relative to the location and type of potential sources of contamination of the Memphis aquifer, and (5) prepare interpretive maps and the final report.

Previous Investigations

Many previous reports include information concerning the local and regional aspects of the aquifer systems in the Memphis area, and many others contain water-level and water-quality data. Consequently, this discussion of previous investigations is limited to primary sources of information concerning the hydrology, geology, water levels, and water quality of the principal aquifers and associated environmental concerns. This report and primary previous reports contain lists of references that provide additional information sources. Extensive lists of selected references (although not all inclusive) are given in reports by Graham and Parks (1986) and Brahana and others (1987).

The hydrology and general geology of the principal aquifers are described in reports by Safford (1890), Glenn (1906), Wells (1931, 1933), Kazmann (1944), Schneider and Cushing

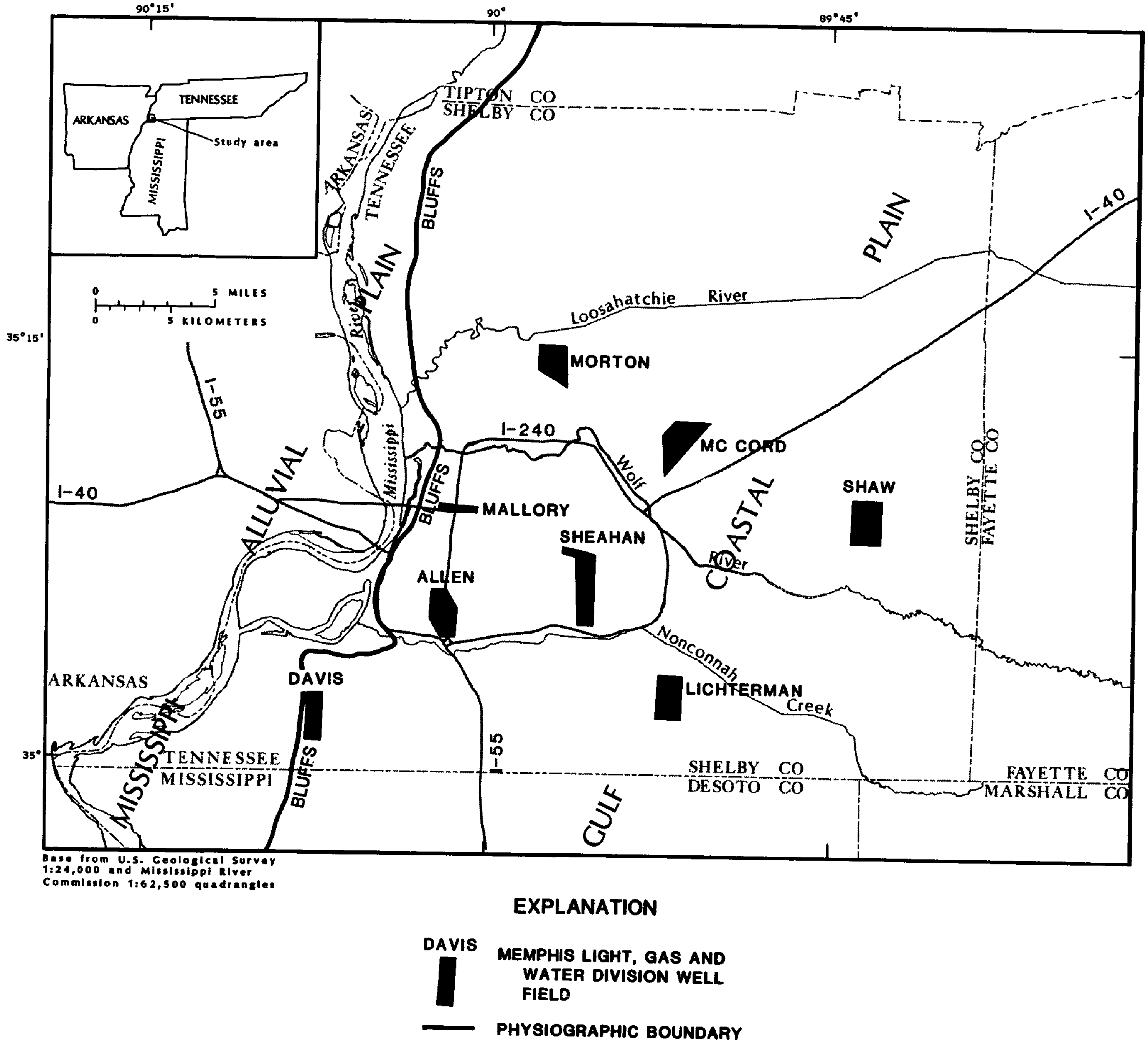

Figure 1.--Major physiographic subdivisions in the Memphis area and locations of Memphis Light, Gas and Water Division well fields. (Modified from Brahana and others, 1987).

(1948), Criner and Armstrong (1958), Plebuch (1961), Criner and others (1964), Nyman (1965), Bell and Nyman (1968), and Dalsin and Bettandorff (1976). Parks (1973, 1975, 1977, 1978, 1979a, 1979b, 1987a) mapped and described the surface and shallow subsurface geology of the Memphis urban area.

A series of potentiometric-surface maps and graphs showing historic water-level changes and pumpage (1886-1975) from the Memphis and Fort Pillow aquifers are included in a report by Criner and Parks (1976). The potentiometric surface of the Memphis aquifer in August 1978 was given by Graham (1979). Graham (1982) updated pumpage and water-level information for the Memphis and Fort Pillow aquifers through 1980 and included a map of the potentiometric surface of the Memphis aquifer for September 1980. The altitude of the water table in the alluvium and fluvial deposits and the potentiometric surfaces of the Memphis and Fort Pillow aquifers in the Memphis urban area for the fall 1984 are included in a report by Graham and Parks (1986).

A two-dimensional digital computer flow model of the Memphis aquifer was described by Brahana (1982). The application of this model as a predictive tool to estimate aquifer response to various hypothetical pumpage projections was described by Brahana and included in the U.S. Army Corps of Engineers, Memphis Metropolitan Urban Water Resources Study (1981). Brahana and Broshears (USGS, written commun., 1987) described the hydrologic framework of the Memphis area and documented the development of an integrated conceptual model of the ground-water flow and testing of this conceptual model through application of a multilayer finite-difference flow model.

Information concerning quality of water in the principal aquifers in the Memphis area is in reports by Wells (1933), Schneider and Cushing (1948), Lanphere (1955), Criner and Armstrong (1958), Plebuch (1961), Criner and others (1964), Bell and Nyman (1968), and Dalsin and Bettandorff (1976). Graham (1982) summarized the quality of water in the principal aquifers and discussed the potential for contamination of the aquifers. A report by Parks and others (1982) describes the installation and sampling of observation wells at six abandoned or inactive dumps in the Memphis area and provides data on the quality of water in the water-table aquifers at these sites. Graham (1985) described the installation and sampling of additional wells at the North Hollywood Dump and gave a summary of the quality of water in the water-table aquifers in the area of the dump.

Brahana and others (1987) provided background information concerning the quality of natural, uncontaminated water from the principal aquifers in the Memphis area, including tables summarizing the minimum, median, and maximum concentrations of selected major and trace inorganic constituents. This report also summarizes water-quality data for the MLGW well fields. McMaster and Parks (1988) provided background information concerning concentrations of selected trace inorganic constituents and synthetic organic compounds in the water-table aquifers. This report summarizes the results of previous investigations that give information concerning quality of water in the water-table aquifers.

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). Rima (1979) discussed the susceptibility of the Memphis ground-water supply to contamination from a pesticide waste-disposal site in northeastern Hardeman County, Tenn. Graham and Parks (1986) described the potential for leakage among the principal aquifers in the Memphis area and provided information to support the fact that downward leakage from the water-table aquifers to the Memphis aquifer is widespread.

They also summarize information from previous investigations documenting downward leakage. Parks (1987b) summarized indications of downward leakage from the water-table aquifers to the principal artesian aquifer (Memphis aquifer) at Memphis.

Acknowledgments

Acknowledgments are due many individuals who contributed information or provided assistance during this investigation, particularly in regard to the identification of potential sources of contamination and the measurement of water levels. Early in the investigation, Ms. Jennifer L. Ashner, formerly with the TDHE, Division of Solid Waste Management (DSWM), provided information about sites under investigation in Shelby County, Tenn. Later, Mr. John Fox, Jr., with the TDHE, Division of Ground Water Protection (DGWP), provided lists of 1,679 underground storage tanks in Shelby County, Tenn. Before water-level measurements were made, Mr. James C. Ozment, then with the DGWP, provided information concerning investigations of underground storage tanks in Shelby County where wells installed in the water-table aquifers were available for measurement. Ms. Gwynne A. Woodward of the DSWM provided information on wells in the water-table aquifers at landfills and other sites under investigation and assisted in measuring water levels at many sites. Messrs. Fred P. Von Hofe and William J. Cole, MLGW, arranged to turn off many wells in the Memphis aquifer in the MLGW well fields during a high water-demand period and provided personnel to make airline measurements in the wells. Mr. Ozment, with the TDHE Underground Storage Tank Program, also reviewed the files of underground-storage-tank investigations and identified sites where the water-table aquifers are contaminated. Mr. J. Paul Patterson and Ms. Woodward of the DSWM provided information about contamination of the water-table aquifers at several sites under investigation. Ms. Betty J. Maness and Mr. W. Jordan English of the TDHE, Division of Superfund, reviewed a list and identified sites where contaminants have been detected in the water-table aquifers and provided water-quality analyses for these sites and the two contaminated wells screened in the Memphis aquifer at Collierville. Mr. R.R. Franklin of the U.S. Environmental Protection Agency (U.S. EPA) provided information concerning the Gallaway pits. Mr. James H. Webb, MLGW, provided information concerning contaminants that have been detected in water from wells screened in the Memphis aquifer in the Allen well field.

PHYSIOGRAPHIC SETTING

The Memphis area is situated in two major physiographic subdivisions (fig. 1). The eastern three-quarters of the area is in the Gulf Coastal Plain section and the western one-quarter is in the Mississippi Alluvial Plain section of the Coastal Plain physiographic province (Fenneman, 1938). The principal river in the area is the Mississippi River; the major tributaries are the Wolf River, the Loosahatchie River, and Nonconnah Creek.

The Gulf Coastal Plain is characterized by gently rolling to steep topography formed as a result of erosion of geologic formations of Quaternary and Tertiary age. During the later stages of Pleistocene glaciation, this topography was covered by a relatively thick blanket of loess that makes up the present land surface. The gently rolling to steep topography is broken in many places by the flat-lying alluvial plains of streams crossing the area. Perhaps the most distinctive feature of the Gulf Coastal Plain is the loess covered bluffs that rise abruptly above the Mississippi Alluvial Plain at its eastern boundary. Land-surface altitudes in the Gulf Coastal Plain are as low as 190 feet above sea level at the mouth of Nonconnah Creek in southwestern

Shelby County, Tenn., and are as high as 470 feet above sea level in southwestern Fayette County, Tenn. Maximum local relief between the Gulf Coastal Plain and the Mississippi Alluvial Plain is about 200 feet along the bluffs in northwestern Shelby County.

The Mississippi Alluvial Plain is flat lying and is characterized by features of fluvial deposition such as point bars, abandoned channels, and natural levees. Land-surface altitudes are as low as 180 feet above sea level on the banks of the Mississippi River in extreme northwestern DeSoto County, Miss., and as high as 230 feet above sea level adjacent to the bluffs in southwestern Tipton County, Tenn. Maximum local relief commonly is not more than 10 or 20 feet, except where the Mississippi Alluvial Plain is built up above flood levels by man-placed fill.

HYDROGEOLOGY

The Memphis area is located in the north-central part of the Mississippi embayment, a broad structural trough or syncline that plunges southward along an axis that approximates the Mississippi River (Cushing and others, 1964). This syncline is filled with a few thousand feet of unconsolidated to semiconsolidated sediments that make up formations of Cretaceous and Tertiary age. These formations dip gently westward into the embayment and southward down the axis. Overlying the Cretaceous and Tertiary formations in many areas are the fluvial deposits (terrace deposits), loess, and alluvium of Tertiary(?) and Quaternary age. Descriptions of the post-Wilcox Group geologic units and their hydrologic significance in the Memphis area are given in table 1.

Table 1.--*Post-Wilcox Group geologic units underlying the Memphis area and their hydrologic significance*

[Modified from Graham and Parks, 1986]

System	Series	Group	Stratigraphic unit	Thickness, in feet	Lithology and hydrologic significantce
Quaternary	Holocene and Pleistocene		Alluvium	0-175	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 domestic, 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 underlie 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, includes Cockfield and Cook Mountain Formations ("cappling clay")	0-375	Clay, silt, sand, and lignite. Because of similarities in lithology, the Jackson Formation and upper part of the Claiborne Group cannot be reliably subdivided areally based on present work. Most of the preserved sequence consists of the Cockfield and Cook Mountain Formations, but the Jackson Formation occurs beneath the higher hills and ridges in the northern part of the Memphis area. Serves as the upper confining unit for the Memphis aquifer.
		Claiborne	Memphis Sand ("500-foot" sand)	500-890	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. Prinicpal aquifer providing water for municipal and industrial supplies east of the Mississippi River; sole source of water for the City of Memphis. Underlain by the Flour Island Formation of the Wilcox Group, which serves as the lower confining unit for the Memphis aquifer.

Hydrogeologic units considered in this report (discussed in descending order of age) are: (1) the alluvium and fluvial deposits that comprise the shallow water-table aquifers, (2) the Jackson Formation and the Cockfield and Cook Mountain Formations in the upper part of the Claiborne Group that comprise the Jackson-upper Claiborne confining unit, and (3) the Memphis Sand that comprises the Memphis aquifer. Hydrogeologic sections showing the principal aquifers and confining units in the Memphis area are given in figure 2.

The alluvium occurs beneath the Mississippi Alluvial Plain and alluvial plains of streams draining the Gulf Coastal Plain (fig. 1) and consists primarily of sand, gravel, silt, and clay. The unit generally consists of fine sand, silt, and clay in the upper part, and sand and gravel in the lower part. The alluvium ranges from 0 to 175 feet in thickness. It commonly is about 100 to 150 feet thick beneath the Mississippi Alluvial Plain and less than 50 feet thick beneath the alluvial plains of major streams draining the Gulf Coastal Plain. The alluvium supplies water to many domestic, farm, industrial, and irrigation wells in the Mississippi Alluvial Plain.

The fluvial deposits occur beneath the uplands and valley slopes of the Gulf Coastal Plain (fig. 1) and consist primarily of sand, gravel, and minor clay lenses. Locally, the sand and gravel is cemented with iron oxide to form thin layers of ferruginous sandstone or conglomerate in the lower or basal parts. The fluvial deposits range from 0 to 100 feet in thickness. Thickness varies because of erosional surfaces at both the top and base of the unit. The fluvial deposits provide water to many domestic and farm wells in rural areas of the Gulf Coastal Plain.

Because of the lithologic similarities of the Jackson, Cockfield, and Cook Mountain Formations and upper part of the Memphis Sand, a detailed study of the stratigraphy and geologic structure would be needed to correlate the units on the many geophysical logs available for wells and test holes drilled in the Memphis area. Such a study is beyond the scope of the present investigation. For the Gulf Coast Regional Aquifer-System Analysis (GC RASA) investigation (Grubb, 1984), however, the Jackson, Cockfield, and Cook Mountain Formations were correlated and mapped regionally in the subsurface of western Tennessee and the occurrence of these units was extended into the Memphis area (Parks and Carmichael, 1990a,b). From the GC-RASA work and additional observations made during the present investigation, some generalizations can be made concerning the occurrence of these units.

The Jackson Formation, which was once thought to comprise most of the thickness of the confining unit separating the water-table aquifers from the Memphis aquifer, occurs only beneath the higher hills and ridges in the northern part of the Memphis area. Based on geophysical-log correlations, this unit consists generally of fine sand or sandy clay and ranges from 0 to about 50 feet in thickness. The Jackson Formation (Tennessee, Kentucky, and Missouri) and the Jackson Group (Mississippi, Arkansas, Louisiana, and Texas) overlies the Cockfield Formation (Yegua Formation in Texas) and is part of a thick regional confining unit for the Cockfield aquifer (Hosman, 1988). In the Memphis area, the Jackson Formation is included in the upper part of the Jackson-upper Claiborne confining unit.

The Cockfield Formation occurs in the subsurface in most of the Memphis area, extending eastward at places nearly to the approximate eastern limits of the Jackson-upper Claiborne confining unit (plate 1). The Cockfield Formation consists of interfingering fine sand, silt, clay, and local lenses of lignite. The unit ranges from 0 to about 250 feet in thickness. In most of the Memphis area, the formation is an erosional remnant, and the original thickness is preserved

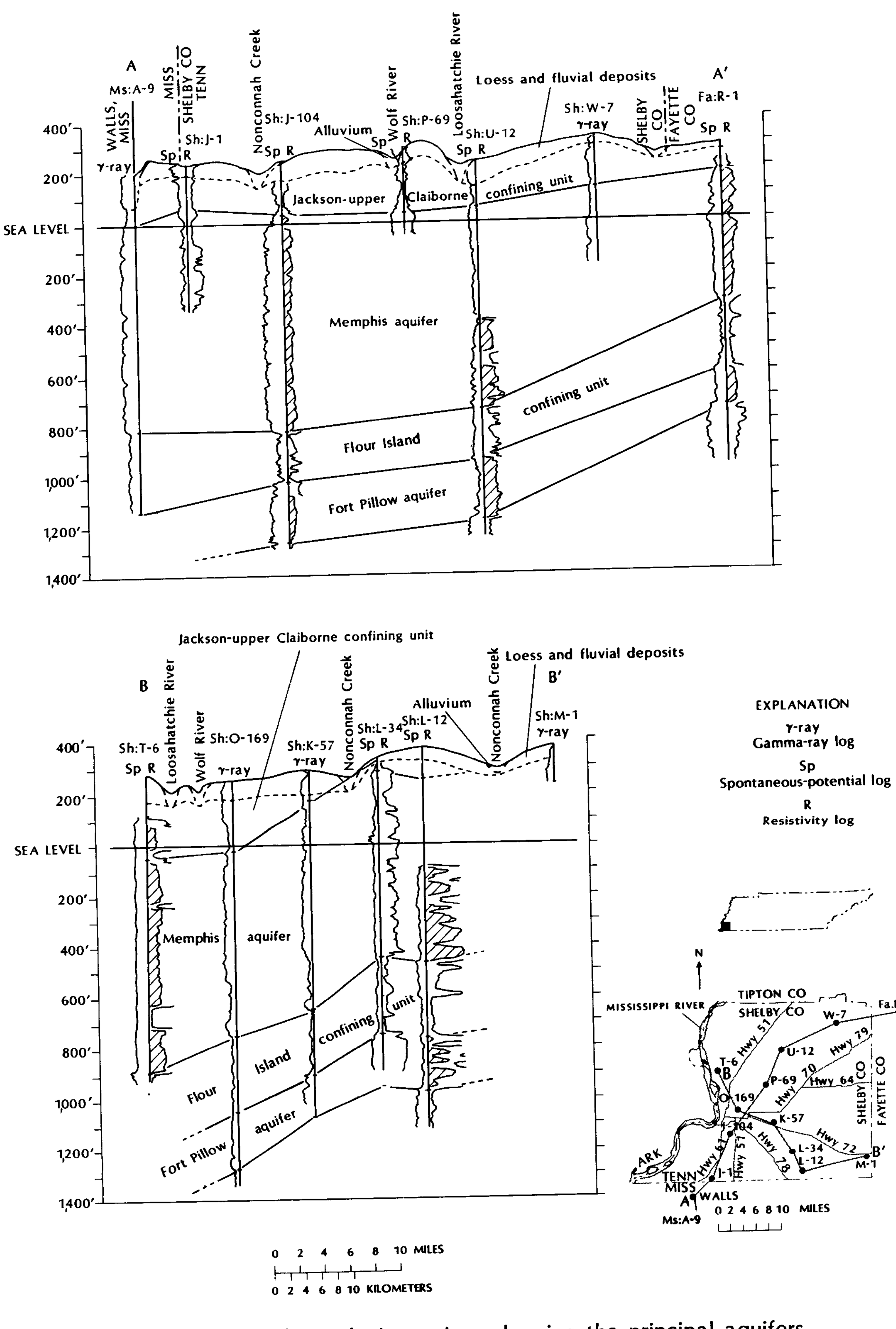

Figure 2.--Hydrogeologic sections showing the principal aquifers and confining units in the Memphis area (Modified from Graham and Parks, 1986.)

only beneath the higher hills and ridges in the northern part. The discontinuous and interconnected sands of the Cockfield Formation constitute a regional aquifer in some parts of the area of occurrence in Tennessee, Kentucky, Missouri, Arkansas, Louisiana, Texas (Yegua Formation), and Mississippi (Hosman, 1988). In the Memphis area, the Cockfield Formation consists predominantly of fine sediments and lacks the thicker, coarser sands present in other areas. Consequently, the formation is included in the Jackson-upper Claiborne confining unit. A few domestic wells in the Memphis area are screened in sands in the Cockfield Formation.

The Cook Mountain Formation occurs in the subsurface of most of the Memphis area, extending eastward to the approximate eastern limits of the Jackson-upper Claiborne confining unit (plate 1). The Cook Mountain Formation consists primarily of clay, but it locally contains varying amounts of fine sand. The formation ranges from about 30 to 150 feet in thickness, but it is commonly about 60 to 70 feet thick. The Cook Mountain Formation is a regional confining unit overlying the Memphis Sand in Tennessee, Missouri, and northeastern Arkansas and the Sparta Sand in Kentucky, southern Arkansas, Louisiana, and Mississippi (Hosman, 1988). In the Memphis area, the formation is the most persistent clay layer in the Jackson-upper Claiborne confining unit.

The Memphis Sand occurs in the subsurface of all of the Memphis area. Eastward from the approximate eastern limits of the Jackson-upper Claiborne confining unit (plate 1), the eroded upper part of the Memphis Sand directly underlies the alluvium and fluvial deposits. The Memphis Sand consists primarily of a thick body of sand that includes subordinate lenses of clay and silt at various horizons and ranges from about 500 to 900 feet in thickness. The Memphis Sand (and its equivalents) is a regional aquifer in Tennessee, Missouri, Kentucky (Tallahatta Formation and Sparta Sand), and northeastern Arkansas. The Memphis Sand is equivalent to (in ascending order) the Tallahatta Formation, Winona Sand, Zilpha Clay, and Sparta Sand of northern Mississippi and the Carrizo Sand, Cane River Formation, and Sparta Sand of southern Arkansas (Hosman, 1988). In the Memphis area, the Memphis aquifer provides water for most municipal, industrial, and commercial supplies.

Thickness of the Confining Unit Overlying the Memphis Aquifer

The thickness of the Jackson-upper Claiborne confining unit and aggregate thicknesses of clay beds in the confining unit thicker than 10 feet are shown in plate 1. This map was prepared by interpretation and correlation of 236 geophysical logs made primarily in test holes for water wells or through the casings of observation wells and abandoned water wells. These logs were selected from a file of more than 500 electric and gamma-ray logs made by the USGS in the Memphis area from the early 1950's to 1989. Most of the logs in the file were examined during this investigation. Because many of the geophysical logs were made in test holes drilled at MLGW and industrial well fields, the logs used for making the map were selected on the basis of well spacing and, when a choice could be made, on the basis of the quality of the log. Through the years, wells were drilled on some MLGW well field lots to both the Memphis and Fort Pillow aquifers or to replace wells in the Memphis aquifer to about the same or greater depths. Thus, the file may contain as many as three logs for wells on the same well lots. In addition, lots in MLGW well fields are commonly about 1,000 feet apart, necessitating a further selection of logs based on well spacing for the scale of the map. Interpretive information from the geophysical logs used to prepare the map showing the thickness of the Jackson-upper Claiborne confining unit and aggregate thicknesses of clay beds in the confining unit thicker than 10 feet (plate 1) are given in table 2.

Table 2.--*Thickness of the Jackson-upper Claiborne confining unit and aggregate thicknesses of clay beds in the confining unit thicker than 10 feet in the Memphis area*

[Latitude and longitude are in degrees, minutes, and seconds; altitude is in feet above sea level; base of water-table aquifer, base of Cook Mountain Formation, and tops and bottoms of clay beds are depths in feet below land surface; thicknesses are in feet; dashes (--) indicate no data given for any clay beds below base of the Cook Mountain Formation]

Well No.	Latitude	Longitude	Altitude	Base of water-table aquifer	Base of Cook Mountain Formation	Thickness of confining unit	Clay bed top	Clay bed bottom	Clay bed thickness	Clay bed top	Clay bed bottom	Clay bed thickness	Aggregate thicknesses of clay beds
Ar:C-1	350958	0901738	209	148	288	140	172	204	32	220	288	68	100
Ar:E-2	350519	0901810	207	102	313	211	102	142	40	256	313	57	97
Ar:H-2	350344	0901300	211	90	266	176	90	120	30	162	266	104	134
Ar:H-4	350724	0901347	214	154	272	118	190	272	82	--	--	--	82
Ar:N-1	350849	0900928	211	84	182	98	84	99	15	110	182	72	87
Ar:O-1	351349	0900628	217	105	302	197	105	120	15	126	167	41	
							223	302	79	--	--	--	135
Ar:O-2	350745	0900553	227	99	227	128	99	131	32	150	227	77	109
Ms:A-7	345919	0900826	220	57	150	93	74	150	76	--	--	--	76
Ms:A-9	345731	0900911	211	127	204	77	134	204	70	--	--	--	70
Ms:A-12	345712	0900915	210	117	198	81	117	198	81	--	--	--	81
Ms:A-29	345748	0900629	302	78	318	240	130	140	10	178	204	26	
							242	318	76	--	--	--	112
Ms:A-103	345737	0901028	211	124	226	102	124	226	102	--	--	--	102
Ms:B-5	345835	0900054	325	60	177	117	90	177	87	--	--	--	87
Ms:B-6	345740	0895945	335	49	161	112	104	161	57	--	--	--	57
Ms:B-7	345917	0900100	305	28	123	95	40	54	14	77	113	36	50
Ms:B-63	345657	0900311	289	86	172	86	86	172	86	--	--	--	86
Ms:C-4	345817	0895712	373	50	147	97	119	147	28	--	--	--	28
Ms:C-15	345812	0895851	345	40	198	158	98	198	100	--	--	--	100
Ms:C-17	345805	0895400	402	56	66	10	56	66	10	--	--	--	10
Ms:D-3	345747	0894943	391	53	124	71	53	124	71	--	--	--	71
Ms:D-26	345903	0894741	402	61	82	21	61	82	21	--	--	--	21
Ms:D-46	345709	0895014	412	51	174	123	51	84	33	98	174	76	109
Ms:D-57	345820	0895142	390	36	101	65	36	101	65	--	--	--	65
Fa:R-1	352226	0893301	318	40	122	82	40	122	82	--	--	--	82
Sh:E-3	345842	0895221	335	24	65	41	24	65	41	--	--	--	41
Sh:E-4	345943	0894802	403	76	153	77	76	87	11	101	153	52	63
Sh:H-1	350331	0900729	312	110	270	160	134	270	136	--	--	--	136
Sh:H-2	350405	0900738	215	94	201	107	94	201	107	--	--	--	107
Sh:H-8	350157	0900742	305	84	246	162	138	164	26	181	246	65	91
Sh:H-11	350115	0900740	274	50	191	141	50	65	15	86	102	16	
							139	191	52	--	--	--	83
Sh:H-13	350452	0900759	238	114	198	84	123	175	52	185	198	13	65
Sh:J-1	350004	0900546	240	50	162	112	50	66	16	76	162	86	102
Sh:J-10	350501	0900239	270	104	214	110	104	214	110	--	--	--	110
Sh:J-27	350716	0900330	268	60	265	205	60	107	47	202	265	63	110
Sh:J-32	350657	0900426	280	122	262	140	122	139	17	197	262	65	82

Table 2.--*Thickness of the Jackson-upper Claiborne confining unit and aggregate thicknesses of clay beds in the confining unit thicker than 10 feet in the Memphis area*--Continued

Well No.	Lati-tude	Longi-tude	Alti-tude	Base of water-table aquifer	Base of Cook Mountain Formation	Thickness of confining unit	Clay bed top	Clay bed bot-tom	Clay bed thick-ness	Clay bed top	Clay bed bot-tom	Clay bed thick-ness	Aggregate thicknesses of clay beds
Sh:J-38	350711	0900107	315	97	238	141	109	238	129	--	--	--	129
Sh:J-41	350723	0900213	275	49	248	199	82	116	34	185	248	63	97
Sh:J-47	350508	0900459	230	94	226	132	94	108	14	154	226	72	86
Sh:J-49	350611	0900344	280	75	277	202	112	141	29	149	189	40	109
							220	243	23	260	277	17	
Sh:J-50	350411	0900416	241	54	187	133	104	187	83	--	--	--	83
Sh:J-59	350402	0900513	241	104	189	85	104	189	85	--	--	--	85
Sh:J-62	350459	0900330	223	45	183	138	45	76	31	89	183	94	125
Sh:J-65	350232	0900249	303	94	205	111	94	132	38	145	205	60	98
Sh:J-71	350206	0900212	295	97	165	68	97	108	11	115	165	50	61
Sh:J-74	350022	0900117	303	65	140	75	72	140	68	--	--	--	68
Sh:J-83	350319	0900144	280	45	167	122	45	95	50	112	144	32	82
Sh:J-84	350536	0900627	243	168	197	29	168	186	18	--	--	--	18
Sh:J-104	350537	0900145	248	82	202	120	117	202	85	--	--	--	85
Sh:J-111	350503	0900132	280	114	240	126	114	128	14	140	240	100	114
Sh:J-113	350449	0900136	272	85	174	89	85	174	89	--	--	--	89
Sh:J-115	350553	0900223	295	101	262	161	101	119	18	131	262	131	149
Sh:J-119	350521	0900204	260	98	180	82	112	180	68	--	--	--	68
Sh:J-127	350438	0900136	245	40	168	128	40	57	17	65	79	14	111
							88	168	80	--	--	--	
Sh:J-129	350353	0900640	290	103	249	146	103	160	57	180	249	69	126
Sh:J-133	350653	0900119	300	88	310	222	88	164	76	230	310	80	156
Sh:J-138	350148	0900702	300	84	242	158	162	242	80	--	--	--	80
Sh:J-144	350053	0900708	280	96	204	108	136	204	68	--	--	--	68
Sh:J-166	350611	0900205	278	100	210	110	130	210	80	--	--	--	80
Sh:K-13	350541	0895902	295	80	224	144	117	224	107	--	--	--	107
Sh:K-16	350523	0895801	293	55	206	151	55	110	55	132	206	74	129
Sh:K-23	350647	0895420	320	112	220	108	112	136	24	161	198	37	77
							204	220	16	--	--	--	
Sh:K-28	350111	0895905	320	36	150	114	88	117	29	123	150	27	56
Sh:K-29	350258	0895929	271	58	94	36	58	94	36	--	--	--	36
Sh:K-31	350143	0895357	317	27	52	25	27	52	25	--	--	--	25
Sh:K-33	350545	0895925	275	65	210	145	65	102	37	110	210	100	137
Sh:K-72	350509	0895553	252	44	150	106	44	150	106	--	--	--	106
Sh:K-79	350024	0895827	350	36	172	136	36	66	30	85	172	87	117
Sh:K-81	350103	0895719	380	44	184	140	44	86	42	99	184	85	127
Sh:K-98	350633	0895438	313	83	176	93	128	176	48	--	--	--	48
Sh:K-99	350627	0895533	285	92	118	26	105	118	13	--	--	--	13
Sh:K-104	350151	0895340	300	32	37	5	32	37	5	--	--	--	5
Sh:K-108	350153	0895259	295	24	74	50	24	74	50	--	--	--	50
Sh:K-109	350532	0895553	258	66	194	128	66	84	18	119	194	75	93
Sh:K-114	350205	0895341	302	21	47	26	21	47	26	--	--	--	26
Sh:K-115	350560	0895547	273	92	170	78	92	102	10	132	170	38	48

Table 2.--*Thickness of the Jackson-upper Claiborne confining unit and aggregate thicknesses of clay beds in the confining unit thicker than 10 feet in the Memphis area*--Continued

Well No.	Latitude	Longitude	Altitude	Base of water-table aquifer	Base of Cook Mountain Formation	Thickness of confining unit	Clay bed top	Clay bed bottom	Clay bed thickness	Clay bed top	Clay bed bottom	Clay bed thickness	Aggregate thicknesses of clay beds
Sh:K-120	350008	0895450	362	29	133	104	46	63	17	83	133	50	67
Sh:K-122	350434	0895739	240	33	155	122	33	155	122	--	--	--	122
Sh:K-125	350114	0895822	311	26	138	112	54	72	18	104	138	34	52
Sh:K-127	350024	0895838	320	36	178	142	60	81	21	107	178	71	92
Sh:K-139	350810	0895528	295	96	120	24	102	120	18	--	--	--	18
Sh:K-141	350724	0895553	311	106	176	70	121	176	55	--	--	--	55
Sh:K-142	350642	0895550	278	99	105	6	99	105	6	--	--	--	6
Sh:K-143	350233	0895938	281	59	112	53	80	112	32	--	--	--	32
Sh:K-148	350228	0895232	300	35	51	16	35	51	16	--	--	--	16
Sh:L-9	350504	0894828	370	45	127	82	45	73	28	100	127	27	55
Sh:L-15	350412	0894530	341	26	74	48	26	74	48	--	--	--	48
Sh:L-17	350721	0895130	310	20	108	88	20	45	25	60	76	16	
							91	108	17	--	--	--	58
Sh:L-18	350516	0894940	320	17	93	76	17	93	76	--	--	--	76
Sh:L-21	350540	0895211	330	51	151	100	99	151	52	--	--	--	52
Sh:L-23	350519	0895212	330	76	155	79	94	155	61	--	--	--	61
Sh:L-25	350435	0895034	288	24	128	104	38	128	90	--	--	--	90
Sh:L-26	350248	0895123	352	43	91	48	43	91	48	--	--	--	48
Sh:L-27	350457	0895044	317	45	154	109	70	154	84	--	--	--	84
Sh:L-29	350440	0894947	325	27	135	108	27	135	108	--	--	--	108
Sh:L-32	350146	0895200	332	23	86	63	23	86	63	--	--	--	63
Sh:L-38	350232	0895158	315	16	72	56	16	72	56	--	--	--	56
Sh:L-46	350658	0894920	260	42	113	71	42	113	71	--	--	--	71
Sh:L-52	350024	0894722	390	52	120	68	52	120	68	--	--	--	68
Sh:L-57	350534	0895121	320	44	157	113	48	157	109	--	--	--	109
Sh:L-61	350354	0895038	272	26	75	49	26	75	49	--	--	--	49
Sh:L-64	350639	0895225	305	53	165	112	88	165	77	--	--	--	77
Sh:L-67	350447	0894826	380	36	136	100	75	85	10	96	136	40	50
Sh:L-69	350259	0895213	329	33	78	45	33	78	45	--	--	--	45
Sh:L-70	350207	0895224	307	21	71	50	20	71	50	--	--	--	50
Sh:L-81	350450	0894807	380	52	156	104	52	82	30	94	156	62	92
Sh:L-88	350730	0894900	257	42	42	0	--	--	--	--	--	--	0
Sh:L-95	350349	0894501	369	58	114	56	58	114	56	--	--	--	56
Sh:L-96	350323	0895156	331	38	90	52	38	90	52	--	--	--	52
Sh:L-97	350207	0895110	353	26	82	56	26	82	56	--	--	--	56
Sh:L-99	350441	0894809	368	32	142	110	32	42	10	44	85	41	
							99	142	43	--	--	--	94
Sh:L-102	350155	0895137	342	90	105	15	90	105	15	--	--	--	15
Sh:M-11	350223	0894459	338	60	71	11	60	71	11	--	--	--	11
Sh:M-17	350017	0894417	338	41	41	0	--	--	--	--	--	--	0
Sh:M-24	350653	0894215	340	33	87	54	33	87	54	--	--	--	54
Sh:M-26	350404	0894356	332	49	66	17	49	66	17	--	--	--	17

Table 2.--*Thickness of the Jackson-upper Claiborne confining unit and aggregate thicknesses of clay beds in the confining unit thicker than 10 feet in the Memphis area*--Continued

Well No.	Lati-tude	Longi-tude	Alti-tude	Base of water-table aquifer	Base of Cook Mountain Formation	Thickness of confining unit	Clay bed top	Clay bed bot-tom	Clay bed thick-ness	Clay bed top	Clay bed bot-tom	Clay bed thick-ness	Aggregate thicknesses of clay beds
Sh:M-27	350334	0894355	355	54	75	21	62	75	13	--	--	--	13
Sh:M-37	350642	0894300	335	42	72	30	42	72	30	--	--	--	30
Sh:M-39	350344	0894449	363	62	98	36	62	98	36	--	--	--	36
Sh:M-40	350460	0894444	342	34	97	63	34	97	63	--	--	--	63
Sh:M-41	350407	0894457	355	64	126	62	64	126	62	--	--	--	62
Sh:M-43	350413	0894133	320	64	64	0	--	--	--	--	--	--	0
Sh:O-1	351437	0900046	229	57	290	233	150	290	140	--	--	--	140
Sh:O-18	351034	0900243	235	76	240	164	76	98	22	118	240	122	144
Sh:O-54	351119	0900223	238	77	306	229	77	185	108	203	306	103	211
Sh:O-67	350828	0900214	266	91	264	173	91	126	35	150	264	114	149
Sh:O-82	350833	0900147	288	87	258	171	87	102	15	164	196	32	
							220	258	38	--	--	--	85
Sh:O-93	350839	0900239	238	46	242	196	46	114	68	129	242	113	181
Sh:O-115	351219	0900232	272	60	328	268	123	328	205	--	--	--	205
Sh:O-120	351050	0900035	230	72	158	86	89	113	24	124	158	34	58
Sh:O-184	350956	0900139	251	78	333	255	78	184	106	193	333	140	246
Sh:O-191	350818	0900335	278	99	292	193	100	148	48	158	292	134	182
Sh:O-194	350817	0900043	295	64	278	214	184	278	94	--	--	--	94
Sh:O-199	350846	0900311	265	65	289	224	102	164	62	179	289	110	172
Sh:O-202	351032	0900143	242	71	256	185	71	256	185	--	--	--	185
Sh:O-204	350922	0900154	257	78	301	223	78	140	62	176	301	125	187
Sh:O-206	350805	0900204	272	82	264	182	82	110	28	166	264	98	126
Sh:O-207	350913	0900109	255	81	236	155	130	236	106	--	--	--	106
Sh:O-213	350916	0900030	250	78	246	168	160	246	86	--	--	--	86
Sh:O-243	350808	0900022	280	70	254	184	70	90	20	166	254	88	108
Sh:P-1	351320	0895401	300	41	239	198	103	120	17	149	239	90	107
Sh:P-11	351028	0893050	244	62	182	120	62	88	26	101	182	81	107
Sh:P-14	350943	0895757	252	62	194	132	62	94	32	107	194	87	119
Sh:P-34	350807	0895825	283	104	188	84	125	188	63	--	--	--	63
Sh:P-36	350950	0895833	243	80	217	137	120	217	97	--	--	--	97
Sh:P-39	351045	0895655	251	62	270	208	62	75	13	83	95	12	
							193	270	77	--	--	--	102
Sh:P-54	350904	0895805	255	80	234	154	166	234	68	--	--	--	68
Sh:P-62	350735	0895733	280	94	170	76	94	106	12	127	170	43	55
Sh:P-69	351220	0895525	300	64	200	136	80	104	24	111	123	12	
							132	200	68	--	--	--	104
Sh:P-71	351323	0895754	290	65	289	224	99	134	35	144	289	145	180
Sh:P-73	350901	0895246	250	52	102	50	52	102	50	--	--	--	50
Sh:P-75	351246	0895525	330	41	276	235	139	276	137	--	--	--	137
Sh:P-76	350735	0895932	287	84	176	92	84	124	40	132	176	44	84
Sh:P-79	350736	0895635	311	109	131	22	109	131	22	--	--	--	22
Sh:P-85	351101	0895240	293	76	220	144	76	117	41	168	220	52	93
Sh:P-86	351131	0895312	275	30	226	196	123	226	103	--	--	--	103

Table 2.--*Thickness of the Jackson-upper Claiborne confining unit and aggregate thicknesses of clay beds in the confining unit thicker than 10 feet in the Memphis area*--Continued

Well No.	Lati-tude	Longi-tude	Alti-tude	Base of water-table aquifer	Base of Cook Mountain Formation	Thickness of confining unit	Clay bed top	Clay bed bot-tom	Clay bed thick-ness	Clay bed top	Clay bed bot-tom	Clay bed thick-ness	Aggregate thicknesses of clay beds
Sh:P-93	350831	0895656	279	88	191	103	88	105	17	181	191	10	27
Sh:P-94	350913	0895739	248	78	171	93	98	171	73	--	--	--	73
Sh:P-96	351435	0895300	312	67	266	199	106	122	16	174	266	92	108
Sh:P-103	350927	0895950	258	86	246	160	152	246	94	--	--	--	94
Sh:P-113	351439	0895722	301	72	287	215	116	138	22	166	287	121	143
Sh:P-114	351449	0895641	232	48	209	161	101	209	108	--	--	--	108
Sh:P-115	351327	0895658	292	43	268	225	43	80	37	142	268	126	163
Sh:P-116	351411	0895748	290	51	270	219	140	160	20	204	270	66	86
Sh:P-117	351409	0895709	245	38	205	167	112	205	93	--	--	--	93
Sh:P-118	351458	0895747	265	58	294	236	168	294	126	--	--	--	126
Sh:P-143	351058	0895739	229	50	258	208	68	88	20	192	258	66	86
Sh:Q-1	350900	0894822	330	66	103	37	66	103	37	--	--	--	37
Sh:Q-7	350940	0894504	313	40	101	61	40	101	61	--	--	--	61
Sh:Q-8	350901	0895113	270	32	144	112	80	144	64	--	--	--	64
Sh:Q-16	350909	0895153	260	48	121	73	48	121	73	--	--	--	73
Sh:Q-21	351215	0895127	295	90	210	120	107	210	103	--	--	--	103
Sh:Q-22	351144	0895044	305	81	136	55	81	136	55	--	--	--	55
Sh:Q-23	351138	0895207	283	66	186	120	86	186	100	--	--	--	100
Sh:Q-24	351315	0895150	281	27	205	178	123	205	82	--	--	--	82
Sh:Q-27	351216	0895103	288	65	166	101	65	166	101	--	--	--	101
Sh:Q-30	351113	0895145	295	78	185	107	78	91	13	140	185	45	58
Sh:Q-34	351055	0895206	273	93	171	78	154	171	17	--	--	--	17
Sh:Q-39	351128	0895130	309	81	152	71	81	95	14	120	152	32	46
Sh:Q-42	351127	0895105	309	78	145	67	120	145	25	--	--	--	25
Sh:Q-68	351155	0895142	281	49	130	81	82	130	48	--	--	--	48
Sh:Q-74	351223	0895221	295	82	154	72	97	108	11	112	154	42	53
Sh:Q-82	351326	0895046	322	60	163	103	85	102	17	142	163	21	38
Sh:Q-88	350733	0894825	262	41	118	77	50	118	68	--	--	--	68
Sh:Q-89	350737	0894856	259	31	49	18	31	49	18	--	--	--	18
Sh:Q-90	350749	0895058	247	54	58	4	54	58	4	--	--	--	4
Sh:Q-124	350822	0895003	273	33	60	27	33	60	27	--	--	--	27
Sh:Q-125	350817	0895035	250	37	66	29	37	66	29	--	--	--	29
Sh:Q-130	350835	0894994	320	56	81	25	56	81	25	--	--	--	25
Sh:R-5	351350	0894425	395	35	252	217	54	78	24	126	152	26	
							171	252	81	--	--	--	131
Sh:R-8	351141	0894411	372	34	174	140	68	80	12	86	106	20	
							142	174	32	--	--	--	64
Sh:R-9	351248	0894053	375	40	121	81	57	121	64	--	--	--	64
Sh:R-10	350841	0893940	375	56	56	0	--	--	--	--	--	--	0
Sh:R-15	351239	0893943	342	26	112	86	54	112	58	--	--	--	58
Sh:R-21	350913	0894338	305	46	59	13	46	59	13	--	--	--	13
Sh:R-22	350843	0894240	370	42	98	56	42	98	56	--	--	--	56

Table 2.--*Thickness of the Jackson-upper Claiborne confining unit and aggregate thicknesses of clay beds in the confining unit thicker than 10 feet in the Memphis area*--Continued

Well No.	Latitude	Longitude	Altitude	Base of water-table aquifer	Base of Cook Mountain Formation	Thickness of confining unit	Clay bed top	Clay bed bottom	Clay bed thickness	Clay bed top	Clay bed bottom	Clay bed thickness	Aggregate thicknesses of clay beds
Sh:R-23	350848	0894355	340	48	114	66	48	114	66	--	--	--	66
Sh:R-24	350811	0894244	330	45	110	65	45	110	65	--	--	--	65
Sh:R-25	350737	0894342	276	31	78	47	31	78	47	--	--	--	47
Sh:R-26	351402	0893935	285	31	92	61	31	92	61	--	--	--	61
Sh:R-28	350848	0894316	360	34	87	53	34	84	53	--	--	--	53
Sh:R-29	350835	0894341	315	48	107	59	48	107	59	--	--	--	59
Sh:R-30	350811	0894309	325	40	120	80	80	120	40	--	--	--	40
Sh:T-6	351505	0900322	290	165	326	161	296	326	30	--	--	--	30
Sh:T-7	352040	0900154	400	99	420	321	99	120	21	136	206	70	
							209	219	10	286	296	10	
							328	420	92	--	--	--	203
Sh:T-13	352213	0900056	400	90	454	364	123	166	43	228	262	34	
							367	454	87	--	--	--	164
Sh:T-16	352044	0900249	355	102	398	296	112	150	38	321	337	16	
							344	398	54	--	--	--	108
Sh:T-17	351747	0900329	330	92	448	356	110	159	49	182	243	61	
							305	323	18	385	448	63	191
Sh:T-18	352127	0900107	391	75	450	375	120	148	28	366	450	84	112
Sh:U-1	352113	0895706	264	68	216	148	154	216	62	--	--	--	62
Sh:U-5	352057	0895727	268	79	232	153	172	232	60	--	--	--	60
Sh:U-12	351705	0895320	238	92	180	88	92	180	88	--	--	--	88
Sh:U-19	351603	0895840	242	73	207	134	105	118	13	130	207	77	90
Sh:U-22	351737	0895749	300	60	226	166	98	109	11	124	166	42	
							171	226	55	--	--	--	108
Sh:U-29	351556	0895859	242	71	194	123	109	194	85	--	--	--	85
Sh:U-48	352114	0895727	267	74	152	78	80	152	72	--	--	--	72
Sh:U-49	352023	0895627	251	50	155	105	82	155	73	--	--	--	73
Sh:U-52	352038	0895708	257	54	198	144	102	114	12	124	158	34	
							174	198	24	--	--	--	70
Sh:U-54	352034	0895345	265	74	212	138	74	94	20	152	166	14	
							192	212	20	--	--	--	54
Sh:U-55	352036	0895334	265	96	216	120	137	150	13	166	182	16	
							204	216	12	--	--	--	41
Sh:U-56	351907	0895709	292	60	230	170	178	230	52	--	--	--	52
Sh:U-58	352024	0895257	265	66	174	108	66	174	108	--	--	--	108
Sh:U-59	352009	0895253	265	97	164	67	97	164	67	--	--	--	67
Sh:U-60	352027	0895232	292	88	204	116	148	204	56	--	--	--	56
Sh:V-4	352044	0895219	283	78	205	127	78	110	32	160	205	45	77
Sh:V-7	351544	0894616	278	27	177	150	27	72	45	124	177	53	98
Sh:V-9	352012	0895038	273	60	222	162	150	222	72	--	--	--	72
Sh:V-10	352010	0895036	271	63	185	122	116	144	28	150	185	35	63
Sh:V-16	351904	0894900	283	61	164	103	94	134	40	--	--	--	40
Sh:V-17	351850	0894935	282	63	180	117	120	180	60	--	--	--	60
Sh:V-24	352227	0895043	375	69	362	293	255	362	107	--	--	--	107

Table 2.--*Thickness of the Jackson-upper Claiborne confining unit and aggregate thicknesses of clay beds in the confining unit thicker than 10 feet in the Memphis area*--Concluded

Well No.	Lati- tude	Longi- tude	Alti- tude	Base of water- table aquifer	Base of Cook Mountain Formation	Thickness of confining unit	Clay bed top	Clay bed bot- tom	Clay bed thick- ness	Clay bed top	Clay bed bot- tom	Clay bed thick- ness	Aggregate thicknesses of clay beds
Sh:W-3	351750	0893943	279	49	66	17	49	66	17	--	--	--	17
Sh:W-7	352026	0894408	322	31	202	171	31	44	13	49	60	11	
							102	202	100	--	--	--	124
Sh:W-13	351938	0894130	320	42	147	105	84	147	63	--	--	--	63
Sh:W-16	351923	0894228	364	44	216	172	44	113	69	124	216	92	161
Tp:E-3	352641	0894721	441	102	411	309	160	194	34	338	411	73	107
Tp:F-3	352517	0894124	405	55	296	241	210	296	86	--	--	--	86

Geophysical logs were chosen as the primary source of information about the confining unit. The logs can be interpreted and correlated based on recorded measurements of the electrical characteristics (electric logs) of the sediments and contained water, and the natural radioactivity (gamma-ray logs) of the sediments. Descriptive driller's and geologist's logs, when available, were used to supplement the geophysical logs. These logs were particularly useful in determining the base of the water-table aquifers in wells where geophysical logs were not made in the upper parts of the bore holes that included the contact with the underlying Jackson-upper Claiborne confining unit. During the drilling of some wells, the near surface formations were cased off to prevent caving before drilling was continued to total depth.

Driller's and geologist's logs of test holes for water wells drilled by hydraulic rotary methods, when used alone, generally were not considered to be satisfactory for determining the thickness of the confining unit or estimating the thickness of clay beds within the confining unit. The sand and gravel of the water-table aquifers commonly cave into the bore hole and obscure recognition of the top of the Jackson-upper Claiborne confining unit. Because of caving, some driller's and geologist's logs indicate the occurrence of gravel to unreasonable depths. In addition, sand in the upper part of the confining unit commonly is included with the sand and gravel of the alluvium and fluvial deposits. This gives an exaggerated impression of the thickness of these units. The local occurrence of clay and interbedded clay and fine sand in the upper part of the Memphis Sand obscures determination of the base of the confining unit. In addition, very fine or silty fine sand in the upper part of the Memphis Sand commonly is logged as "clay" or "sandy clay."

Sediments encountered in a bore hole and described in driller's logs often are identified by drill penetration rate, drill action, and sample material recovered from the drilling mud returns. This precludes any further interpretation or correlation of the logs based on visual inspection, as is possible using geophysical logs. In the Memphis area, driller's logs of test holes drilled for water wells are made primarily to record thickness and grain size of the sands that have potential for installing water wells. The logs also record the thickness of sediments that may cause caving or penetration problems while drilling a water well, such as thick intervals of sand and gravel or clay. Consequently, intervals of fine sand, silt, and clay are logged in general terms, such as "sand and clay mixed," "clay with streaks of sand," or "clay." Very fine sand and silt commonly pass through in the drilling mud unnoticed and are difficult to collect and examine unless a special effort is made.

Geophysical logs also have some limitations. The more than 500 geophysical logs in the USGS files were made during a period of about 35 years. Modifications in the instrumentation were made several times, and the geophysical logs were made by many individuals with varying degrees of experience. As a result of problems with the logging equipment and bore-hole conditions, the logs vary greatly in quality. One problem that affects the quality of electric logs are local "stray" electrical currents near high-voltage lines or utility power substations. Factors affecting gamma-ray logs, not easily recognizable, are possible shielding of the logger tool by cement grout and casing in large diameter wells. This may result in clay being recorded with a log trace that might be interpreted as sand. Also, the possible presence of radioactive mineral grains (for example, monazite) may result in some sands being recorded with a log trace that might be interpreted as clay.

The map in this report (plate 1) showing the thickness of the Jackson-upper Claiborne confining unit and aggregate thicknesses of clay beds in the confining unit thicker than 10 feet differs significantly from the small scale maps in a previous report by Graham and Parks (1986, fig. 3 and 4). The thickness of the confining unit on plate 1 is shown as much as 150 feet thinner in some areas, and consequently, not as much clay is included in the confining unit in these areas. This difference is the result of new data from many additional geophysical logs made since the previous investigation, a refinement in the definition of the lower boundary of the Jackson-upper Claiborne confining unit, and a re-correlation of the geophysical logs in the USGS files.

For the previous investigation by Graham and Parks (1986), the Jackson-upper Claiborne confining unit was considered to be that interval of sediments between the base of the water-table aquifers and the top of the first prominent sand in the Memphis aquifer. This definition of the lower boundary of the confining unit included thick local intervals of clay or interbedded clay and fine sand in the upper part of the Memphis Sand. These thick intervals of clay or interbedded clay and fine sand are highly variable and may interfinger with sand in the main body of the Memphis aquifer within short lateral distances.

For the present investigation, the Jackson-upper Claiborne confining unit was redefined to be that interval of sediments between the base of the water-table aquifers and the base of the Cook Mountain Formation (top of the Memphis Sand). The base of the Cook Mountain Formation commonly is very difficult to recognize, particularly where it overlies a thick interval of clay or interbedded clay and fine sand in the upper part of the Memphis Sand. However, a determined effort was made to identify this contact. Possible positions of this contact on the geophysical logs were compared as related to an altitude where this contact locally would be expected assuming a relatively low, "normal" (as opposed to extreme) dip of the base of the formation toward the axis of the Mississippi embayment (approximately the Mississippi River). In addition, consideration was given to the expected local thickness of the underlying Memphis Sand (where geophysical logs are available to provide information to this depth), a range in thickness to be expected for the Cook Mountain Formation, and tentative identification of the overlying Cockfield Formation.

The GC-RASA work indicated that many faults exist in the Memphis area that displace the bases of the Cockfield Formation, Memphis Sand, and the Fort Pillow Sand (Parks and Carmichael, 1989; 1990a,b). During the present investigation, while comparing the expected altitude of the base of the Cook Mountain Formation between individual wells and among groups of wells, displacements in this contact between some areas indicated that many other faults may exist. Vertically, these displacements seemed to be less than 50 to 100 feet, which is comparable to the displacements of the faults identified during the GC-RASA investigation.

Water Table in the Alluvium and Fluvial Deposits

The altitude of the water table in the alluvium and fluvial deposits in the Memphis area is shown in plate 2. This map was prepared using: (1) water levels measured in 60 wells in the fall 1988; (2) water levels from historic records (1944-87) of 39 wells in the USGS files; (3) a composite reduction of 15-minute topographic quadrangles to overlay for topographic control; and (4) altitudes of water levels in the larger perennial streams based on USGS 7 1/2-minute topographic quadrangles published during 1965-71 (only 20-foot-contour-interval data was used). Most water-level data are from wells screened in the alluvium or fluvial deposits. However, several wells were screened in sand in the Cockfield Formation just below the fluvial deposits where the Cockfield and fluvial deposits are in direct hydraulic connection. Water-level data from wells used to prepare the water-table map are given in tables 3 and 4.

Table 3.--*Water levels measured in wells screened in the water-table aquifers in the Memphis area, fall 1988*

[Latitude and longitude are in degrees, minutes, and seconds; USGS local aquifer designations are 111ALVM for the alluvium, 112TRRC for the fluvial deposits (terrace deposits), and 124CCKF for the Cockfield Formation]

Well No.	Latitude	Longitude	Altitude of land-surface datum, in feet above sea level	Well depth, in feet	Aquifer	Water level below land-surface datum: Depth, in feet	Water level below land-surface datum: Date of measurement	Water-level altitude, in feet above sea level
Ar:H-3	350344	0901300	211	63	111ALVM	25.67	11-08-88	185
Fa:R-10	352130	0893614	395	39	112TRRC	31.30	10-19-88	364
Sh:J-152	350302	0900412	216	29	111ALVM	16.08	10-17-88	200
Sh:J-163	350255	0900411	280	69	112TRRC	33.76	10-17-88	246
Sh:J-164	350107	0900636	270	68	112TRRC	32.01	10-17-88	238
Sh:J-171	350508	0900150	232	71	112TRRC	24.77	10-25-88	207
Sh:J-172	350124	0900722	292	110	112TRRC	53.05	10-26-88	239
Sh:J-173	350554	0900222	295	112	112TRRC	59.30	10-20-88	236
Sh:J-174	350510	0900200	247	44	112TRRC	40.80	10-20-88	206
Sh:J-175	350359	0900148	226	26	111ALVM	13.48	10-18-88	213
Sh:J-176	350343	0900123	238	36	111ALVM	23.10	10-21-88	215
Sh:J-177	350512	0900454	241	53	112TRRC	29.15	10-18-88	212
Sh:J-178	350505	0900523	223	40	111ALVM	39.16	10-18-88	184
Sh:J-179	350728	0900317	274	43	112TRRC	15.57	10-21-88	258
Sh:K-75	350514	0895537	257	91	124CCKF	51.05	10-25-88	206
Sh:K-123	350107	0895747	342	38	124CCKF	23.97	10-17-88	318
Sh:K-129	350024	0895715	380	94	124CCKF	63.77	10-17-88	316
Sh:K-137	350704	0895555	293	86	112TRRC	81.60	10-25-88	211
Sh:K-144	350308	0895811	266	53	112TRRC	48.10	10-18-88	218
Sh:K-145	350416	0895647	260	38	112TRRC	31.35	10-18-88	229
Sh:K-146	350020	0895807	365	56	112TRRC	47.71	10-17-88	317
Sh:K-147	350427	0895241	273	30	112TRRC	20.42	10-20-88	253
Sh:L-66	350021	0895051	349	20	112TRRC	13.26	10-17-88	336
Sh:O-230	351058	0900050	217	31	111ALVM	14.55	10-17-88	202
Sh:O-244	350916	0900149	252	93	112TRRC	18.72	10-26-88	233
Sh:O-245	350915	0900052	242	80	112TRRC	8.30	10-26-88	234
Sh:O-246	350817	0900229	258	56	112TRRC	13.50	10-18-88	244
Sh:O-247	351225	0900159	271	39	112TRRC	38.00	10-19-88	233
Sh:O-248	351240	0900305	235	57	112TRRC	37.41	10-19-88	198
Sh:P-99	350858	0895914	271	59	112TRRC	38.30	10-26-88	233

Table 3.--*Water levels measured in wells screened in the water-table aquifers in the Memphis area, fall 1988*--Concluded

Well No.	Latitude	Longitude	Altitude of land-surface datum, in feet above sea level	Well depth, in feet	Aquifer	Water level below land-surface datum: Depth, in feet	Water level below land-surface datum: Date of measurement	Water-level altitude, in feet above sea level
Sh:P-107	351437	0895551	295	62	112TRRC	30.78	10-20-88	264
Sh:P-123	351115	0895833	220	29	111ALVM	13.78	10-19-88	206
Sh:P-144	351040	0895828	245	74	112TRRC	25.62	10-19-88	219
Sh:P-148	351318	0895256	321	58	112TRRC	21.25	10-20-88	300
Sh:P-197	351430	0895732	301	80	112TRRC	57.54	10-25-88	243
Sh:P-198	350945	0895647	263	40	112TRRC	29.20	10-20-88	234
Sh:P-199	351317	0895434	320	40	112TRRC	31.11	10-20-88	289
Sh:P-200	350915	0895808	260	45	112TRRC	29.85	10-19-88	230
Sh:Q-57	350812	0894700	330	50	112TRRC	23.65	10-19-88	306
Sh:Q-86	351120	0895057	299	70	112TRRC	59.74	10-20-88	239
Sh:Q-94	351111	0895125	310	90	112TRRC	70.72	10-26-88	239
Sh:Q-95	350749	0895058	247	36	111ALVM	15.23	10-24-88	232
Sh:Q-98	350739	0895017	254	52	111ALVM	35.83	10-24-88	218
Sh:Q-101	350741	0894909	258	38	111ALVM	35.64	10-24-88	222
Sh:Q-107	350844	0895032	264	44	111ALVM	26.28	10-25-88	238
Sh:Q-114	350753	0894933	260	45	111ALVM	44.65	10-25-88	215
Sh:Q-116	350853	0895140	246	28	111ALVM	17.06	10-26-88	229
Sh:Q-131	351406	0895157	328	59	112TRRC	23.65	10-20-88	304
Sh:T-21	351928	0900136	362	85	112TRRC	50.71	10-20-88	311
Sh:T-22	352132	0900112	401	120	112TRRC	87.88	10-20-88	313
Sh:U-39	352018	0895652	245	53	111ALVM	27.28	10-20-88	218
Sh:U-61	351856	0895507	300	68	112TRRC	27.40	10-19-88	273
Sh:U-62	352045	0895713	261	22	112TRRC	14.25	10-19-88	247
Sh:U-63	351907	0895631	257	38	112TRRC	9.45	10-19-88	248
Sh:U-64	351905	0895707	280	51	112TRRC	32.40	10-19-88	248
Sh:W-20	351702	0894033	281	30	112TRRC	7.45	10-19-88	274
Sh:W-21	351657	0893858	379	38	112TRRC	37.20	10-19-88	342
Sh:W-22	351715	0893857	318	20	112TRRC	10.95	10-19-88	307
Tp:D-3	352524	0895646	430	102	112TRRC	72.12	10-21-88	358
Tp:F-10	352539	0894018	335	20	112TRRC	15.72	10-21-88	319

Table 4.--*Water levels from records of wells screened in the water-table aquifers in the Memphis area, 1944-87*

[Latitude and longitude are in degrees, minutes and seconds; USGS local aquifer designations are 111ALVM for the alluvium, 112TRRC for the fluvial deposits (terrace deposits), and 124CCKF for the Cockfield Formation; less than (<) indicates that in wells that were dry the altitude of the water level is below the altitude of the bottom of the well]

Well No.	Latitude	Longitude	Altitude of land-surface datum, in feet above sea level	Well depth, in feet	Aquifer	Water level below land-surface datum: Depth, in feet	Water level below land-surface datum: Date of measurement	Water-level altitude, in feet above sea level
Ar:O-4	350744	0900556	227	130	111ALVM	44	1976	183
Ar:O-5	351349	0900628	217	61	111ALVM	19	1984	198
Ms:A-8	345741	0900717	290	100	124CCKF	52	1971	238
Ms:A-14	345930	0901331	209	115	111ALVM	17	1971	192
Ms:A-55	345710	0900940	209	32	111ALVM	14	1980	195
Ms:A-56	345753	0901152	213	112	111ALVM	23	1981	190
Ms:A-104	345827	0900844	213	116	111ALVM	18	1970	195
Ms:B-54	345940	0900131	275	63	112TRRC	16	1973	259
Ms:B-59	345810	0900527	305	105	124CCKF	46	1972	259
Sh:H-12	350152	0901046	213	56	111ALVM	13	1964	200
Sh:J-7	350053	0900133	309	61	112TRRC	43	1958	266
Sh:J-149	350512	0900710	245	111	111ALVM	50	1969	195
Sh:J-150	350029	0900345	300	61	112TRRC	48	1969	252
Sh:J-155	350203	0900349	285	52	112TRRC	28	1966	257
Sh:J-162	350310	0900341	280	90	112TRRC	30	1984	250
Sh:J-182	350022	0900112	295	70	112TRRC	35	1969	260
Sh:K-95	350617	0895526	310	94	112TRRC	dry	1965	<216
Sh:K-106	350023	0895840	325	43	112CCKF	10	1967	315
Sh:K-134	350023	0895738	375	66	112TRRC	39	1984	336
Sh:L-94	350228	0895122	352	67	112TRRC	dry	1986	<285
Sh:O-192	351248	0900330	221	80	111ALVM	30	1984	191
Sh:O-215	351040	0900255	248	100	111ALVM	55	1971	193
Sh:O-236	351417	0900327	283	107	112TRRC	23	1984	260
Sh:P-33	350807	0895824	295	97	112TRRC	47	1944	248
Sh:P-105	351310	0895753	300	62	112TRRC	35	1968	265
Sh:Q-54	351221	0895221	295	92	112TRRC	43	1964	252
Sh:Q-79	351124	0895200	291	70	112TRRC	50	1968	241
Sh:Q-85	351130	0894734	320	60	112TRRC	36	1984	284
Sh:Q-93	351454	0895146	290	62	112TRRC	17	1966	273
Sh:Q-128	350817	0895035	250	39	111ALVM	34	1987	216

Table 4.--*Water levels from records of wells screened in the water-table aquifers in the Memphis area, 1944-87*--Concluded

Well No.	Latitude	Longitude	Altitude of land-surface datum, in feet above sea level	Well depth, in feet	Aquifer	Water level below land-surface datum		Water-level altitude, in feet above sea level
						Depth, in feet	Date of measurement	
Sh:R-17	351340	0894334	380	50	112TRRC	40	1967	340
Sh:R-27	350854	0894320	330	39	112TRRC	dry	1987	<291
Sh:U-33	352050	0895453	275	80	112TRRC	45	1970	230
Sh:U-34	351758	0895603	300	85	112TRRC	35	1970	265
Sh:U-40	352006	0895707	245	60	111ALVM	28	1981	217
Sh:U-43	351956	0895932	301	83	112TRRC	43	1964	258
Sh:V-13	351737	0894930	305	70	112TRRC	30	1970	275
Sh:V-14	352124	0894648	320	88	112TRRC	20	1970	300
Sh:V-18	351945	0894534	318	72	112TRRC	30	1970	288

For the fall 1988, when much of the data were collected, the map (plate 2) probably is accurate to one-half a contour interval (10 feet) where control is abundant and the land surface is not too irregular. In other areas where control is sparse and the land surface is irregular, the map may be accurate to one contour interval (20 feet), depending on the degree of local irregularity and relief. In areas of sparse control, as yet unidentified areas may exist where the water table is depressed because of downward leakage from the water-table aquifers to the Memphis aquifer. In any such areas, of course, the above estimates of map accuracy do not apply. Water levels in the water-table aquifers generally are high in the winter and spring and low in the summer and fall. Therefore, the water-table map (plate 2) is considered to represent low water-level conditions during 1988. Water levels in water-table aquifers fluctuate seasonally at varying rates from place to place.

Long-term records are available for only a few observation wells in the water-table aquifers. Well Sh:P-99 (plate 2), located in a wooded area of Overton Park about 1 mile east of the Mallory well field, is screened in the fluvial deposits. Water levels in this well do not seem to be affected by downward leakage from the water-table aquifers to the Memphis aquifer as indicated by a correlation of changes in water levels with variations in annual precipitation (Graham, 1982). Water-levels in Sh:P-99 fluctuate from about 1 to 8 feet each year. Well Sh:K-75 (plate 2), located in the southern part of the Sheahan well field, is screened in sand in the upper part of the Cockfield Formation just below the base of the fluvial deposits. The water level in this well is affected by leakage from the water-table aquifers to the Memphis aquifer and has declined about 22 feet in 34 years (1951-85) (Graham and Parks, 1986). The early part of the record for this well (1948-50), before pumping was begun from the Memphis aquifer in this area, shows seasonal fluctuations of about 5 feet each year. Later record (1977-85) shows that seasonal fluctuations are less than "normal" at about 1 to 3 feet each year.

During 1986 and 1987, nine wells were installed in the fluvial deposits in the MLGW well fields (McMaster and Parks, 1988). Monthly water-level measurements in seven of these wells (two were dry) indicate seasonal fluctuations ranging from less than 0.5 foot in well Sh:Q-94 at the McCord well field to about 5 feet in well Sh:J-172 in the Davis well field (plate 2). Well Sh:Q-94 is in or on the margin of a depression in the water table associated with downward leakage in the McCord well field area. Fluctuations in the water table greater than 10 feet within a year probably occur in the alluvium adjacent to the Mississippi River and major tributaries in the Memphis area where water levels are affected by variations in the stages of these rivers.

The mapped area of the water table is not extended into the southeastern and eastern parts of the Memphis area where the Jackson-upper Claiborne confining unit is absent because of a general lack of control. In this area, the water table is in the alluvium beneath the alluvial plains and in the fluvial deposits or the Memphis aquifer beneath the hills, ridges, and valley slopes.

West of the approximate eastern limits of the Jackson-upper Claiborne confining unit occurs a belt of disconnected areas designated "NSST" on the water-table map (plate 2). The phrase "no significant saturated thickness" (NSST), as used in this report, implies that the fluvial deposits are dry or are saturated for only a few inches or feet in the basal part. Mapping of the "NSST" areas is based on (1) a lack of historic records of shallow wells in these areas in the files of the USGS and the TDHE, (2) unsuccessful searches for shallow wells in which to measure water levels or to collect samples for water-quality analyses for this and previous investigations (Graham and Parks, 1986;

McMaster and Parks, 1988), and (3) a few wells installed in the fluvial deposits that were essentially dry (McMaster and Parks, 1988). Upon consideration of the large extent of some of these areas, it is evident that significant refinements can be made to the boundaries.

Because the water-table aquifers generally are unconfined, the configuration of the water table is complex (plate 2). The water table is lower than the land surface (except at springs and seeps), but it generally conforms to the topography. Beneath the hills and ridges, the water table is at higher altitudes and greater depths; whereas beneath the valleys and alluvial plains, it is at lower altitudes and lesser depths. In areas of moderate to high relief, local perched water tables above clay or silt beds in the loess or fluvial deposits add to the complexity of determining the configuration of the principal water-table surface. These perched water tables are higher than the principal water-table surface, commonly occur as only a few feet of saturated material, and probably occur in "pockets" that are not very extensive.

Along and for a few miles east of the bluffs, water in the fluvial deposits locally is confined beneath the loess, and water levels in tightly cased wells rise above the top of the fluvial deposits. During the winter and spring when the Mississippi River is at high or flood stages, water in the alluvium locally is confined beneath fine sediments in the upper part, and water levels in tightly cased wells rise above the top of the lower sand and gravel to near or above land surface.

Recharge to the water-table aquifers is primarily from downward infiltration of precipitation that falls on the land surface and is greatest in the winter and spring months when precipitation is greatest. In the summer and fall months, water levels decline in the water-table aquifers because water discharges to perennial streams and maintains base flows. Under natural conditions, the water table is not lower in altitude than low stages or base flows in adjacent streams. However, where leakage is taking place from the water-table aquifers to the Memphis aquifer, depressions in the water table can be as much as 14 feet below the stage of base flow of adjacent streams, such as in an area adjacent to the Wolf River just north of the Shelby County landfill (M.W. Bradley, USGS, written commun., 1989).

Horizontal flow directions in the water-table aquifers at any particular place can be approximated by drawing flow lines perpendicular to the contours on the water-table map (plate 2). Horizontal flow in the water-table aquifers is from the higher water-table altitudes toward the lower altitudes along these lines.

Potentiometric Surface of the Memphis Aquifer

The altitude of the potentiometric surface of the Memphis aquifer is shown in plate 3. This map was prepared using water-level measurements made in 81 observation and production wells screened in the upper or middle parts of the Memphis aquifer. Methods of measurement included steel-tape measurements in observation wells and nonpumping municipal and industrial wells and airline measurements in MLGW wells that were turned off over night to allow for recovery from pumping levels. Data used to prepare the map of potentiometric surface of the Memphis aquifer are given in table 5.

For the late summer and fall 1988, when the data were collected, the map (plate 3) of the potentiometric surface of the Memphis aquifer probably is accurate to one-half a contour interval (5 feet). However, water levels in the Memphis aquifer fluctuate seasonally. In most of the Memphis area, these seasonal fluctuations are more the result of increases or decreases in pumping from the aquifer rather than to the direct effects of recharge. In general, pumping from the Memphis aquifer is less in the winter

Table 5.--*Water levels measured in wells screened in the Memphis aquifer in the Memphis area, late summer and fall 1988*

[Latitude and longitude are in degrees, minutes, and seconds; USGS local aquifer designation is 124MMPS for the Memphis Sand]

Well No.	Latitude	Longitude	Altitude of land-surface datum, in feet above sea level	Well depth, in feet	Water level below land-surface datum: Depth, in feet	Water level below land-surface datum: Date of measurement	Water-level altitude, in feet above sea level
Ar:C-1	350958	0901738	209	622	25.24	09-16-88	184
Ar:H-2	350344	0901300	211	500	31.70	09-16-88	179
Ar:O-1	351349	0900628	217	497	41.63	09-16-88	175
Ms:B-9	345709	0900205	301	392	99.98	11-16-88	201
Ms:D-58	345820	0895142	390	220	150.35	11-16-88	240
Fa:R-2	352226	0893301	317	365	41.75	10-04-88	275
Sh:H-1	350331	0900729	312	348	143.73	09-13-88	168
Sh:H-8	350157	0900742	305	622	137.10	09-13-88	168
Sh:J-1	350004	0900546	240	334	63.66	09-16-88	176
Sh:J-4	350524	0900458	285	302	132.40	09-13-88	153
Sh:J-28	350639	0900436	288	308	137.13	09-13-88	151
Sh:J-37	350707	0900122	305	510	179.82	09-13-88	125
Sh:J-52	350408	0900415	241	498	92.66	09-13-88	148
Sh:J-70	350201	0900212	298	581	127.72	11-08-88	170
Sh:J-74	350022	0900117	303	398	118.26	11-08-88	185
Sh:J-97	350602	0900210	271	378	147.90	09-13-88	123
Sh:J-110	350507	0900110	253	390	117.90	09-13-88	135
Sh:J-120	350511	0900200	247	452	123.30	09-13-88	124
Sh:J-126	350433	0900151	234	265	98.40	09-13-88	136
Sh:J-139	350100	0900703	291	466	123.20	09-13-88	168
Sh:J-140	350124	0900722	293	553	127.72	10-05-88	165
Sh:J-165	350538	0900631	245	400	85.61	11-08-88	159
Sh:K-14	350539	0895855	292	440	145.22	09-12-88	147
Sh:K-20	350618	0895922	295	220	139.53	09-12-88	155
Sh:K-31	350143	0895357	317	176	113.84	09-12-88	203
Sh:K-66	350724	0895552	303	499	165.70	09-15-88	137
Sh:K-72	350509	0895553	252	292	81.22	09-12-88	171
Sh:K-79	350024	0895827	350	370	155.91	09-12-88	194
Sh:K-122	350434	0895739	240	210	80.94	09-12-88	159
Sh:K-133	350113	0895543	338	210	135.53	09-12-88	202
Sh:K-138	350625	0895549	280	598	128.60	09-15-88	151
Sh:K-140	350653	0895517	297	624	141.50	09-13-88	156
Sh:L-8	350506	0894832	375	305	162.05	09-15-88	213
Sh:L-13	350354	0895218	302	275	109.97	09-12-88	192
Sh:L-15	350412	0894530	341	220	92.24	09-12-88	249
Sh:L-24	350243	0895213	345	427	168.30	09-13-88	177
Sh:L-26	350248	0895123	352	432	166.70	09-13-88	185
Sh:L-39	350206	0895109	346	349	151.95	09-15-88	194
Sh:L-43	350115	0895049	365	185	154.54	09-12-88	210
Sh:L-54	350252	0894503	352	135	92.68	09-12-88	259

Table 5.--*Water levels measured in wells screened in the Memphis aquifer in the Memphis area, late summer and fall 1988*--Concluded

Well No.	Latitude	Longitude	Altitude of land-surface datum, in feet above sea level	Well depth, in feet	Water level below land-surface datum: Depth, in feet	Water level below land-surface datum: Date of measurement	Water-level altitude, in feet above sea level
Sh:L-64	350639	0895225	305	261	108.60	09-12-88	196
Sh:O-1	351437	0900046	229	434	66.75	10-04-88	162
Sh:O-29	350853	0900307	265	442	132.05	09-14-88	133
Sh:O-46	351029	0900149	240	471	107.08	09-13-88	133
Sh:O-115	351219	0900232	272	563	125.56	09-13-88	146
Sh:O-204	350922	0900154	257	471	138.20	09-14-88	119
Sh:O-238	350913	0900104	251	517	134.70	09-14-88	116
Sh:P-1	351320	0895401	300	342	129.12	09-14-88	171
Sh:P-8	351029	0895750	244	428	106.88	09-13-88	137
Sh:P-22	350931	0895758	245	315	106.25	09-14-88	139
Sh:P-37	351025	0895654	252	335	100.98	09-13-88	151
Sh:P-61	350735	0895734	288	361	132.91	09-14-88	155
Sh:P-76	350735	0895932	287	488	144.05	09-14-88	143
Sh:P-85	351101	0895240	293	319	121.82	10-04-88	171
Sh:P-96	351435	0895300	312	456	125.62	09-19-88	186
Sh:P-131	351420	0895706	247	404	106.20	09-14-88	141
Sh:P-134	351440	0895723	301	411	155.60	09-14-88	145
Sh:P-143	351058	0895739	229	442	90.39	09-13-88	139
Sh:P-146	350926	0895949	255	512	130.50	09-14-88	125
Sh:Q-1	350900	0894822	330	384	108.24	09-16-88	222
Sh:Q-60	351224	0895215	285	491	126.73	09-14-88	158
Sh:Q-63	351124	0895143	309	506	140.45	09-14-88	169
Sh:Q-69	351203	0895129	281	477	104.45	09-14-88	177
Sh:Q-71	351045	0895151	302	406	131.40	09-14-88	171
Sh:Q-76	351359	0894829	310	430	86.50	09-14-88	224
Sh:Q-81	351325	0895049	317	509	125.16	09-14-88	192
Sh:Q-84	351347	0894952	325	200	121.80	09-14-88	203
Sh:Q-125	350817	0895035	250	100	41.73	09-19-88	208
Sh:R-5	351350	0894425	395	330	160.89	09-15-88	234
Sh:R-15	351239	0893943	342	150	78.20	09-15-88	264
Sh:R-29	350835	0894341	315	585	72.20	09-13-88	243
Sh:U-2	352113	0895709	269	440	63.41	10-04-88	206
Sh:U-7	352032	0895344	265	411	55.85	09-15-88	209
Sh:U-15	351602	0895829	240	431	96.19	09-19-88	144
Sh:U-22	351737	0895749	300	387	127.97	09-15-88	172
Sh:U-25	351641	0895713	248	430	79.16	09-15-88	169
Sh:V-7	351544	0894616	278	300	43.67	09-15-88	234
Sh:V-9	352012	0895038	273	445	58.45	09-15-88	215
Sh:W-3	351750	0893943	279	221	21.83	09-15-88	257
Sh:W-16	351923	0894228	364	499	116.20	09-15-88	248
Tp:E-12	352445	0894944	337	470	106.83	11-17-88	230

and spring, and water levels rise. Beginning in early summer, the demand for water increases and pumping increases. Pumping continues to increase through the summer, and water levels continue to decline. Low water levels are reached in the late summer or fall. Therefore, the map of the potentiometric surface of the Memphis aquifer (plate 3) is considered to represent low water-level conditions during 1988.

Because of variations in amounts of water pumped in different areas and changes in pumping patterns in and among MLGW well fields, the effect of pumping on water levels varies spatially. The amount of local seasonal fluctuation can only be determined from the records of observation wells at particular places. An indication of the magnitude of water-level fluctuations in the Memphis aquifer is provided by the long-term record of a few principal observation wells in areas away from MLGW well fields. In well Fa:R-2 (plate 3), located in northwestern Fayette County, Tenn., water levels fluctuate about 1 to 1.5 feet each year. In well Sh:Q-1 (plate 3), located in southeastern Shelby County, Tenn., water levels fluctuate about 2 to 3 feet each year. In well Sh:P-76 (plate 3), located in midtown Memphis, water levels fluctuate about 7 to 17 feet each year. In contrast, water levels in Sh:O-179, an observation well located on a MLGW well lot with production well Sh:O-204 (plate 3), fluctuate as much as 45 feet each year. Near the Mississippi River, water levels in wells screened in the Memphis aquifer may rise as a result of loading effects from sustained high stages of the Mississippi River, particularly during winter and spring flood events (Parks and others, 1985).

Outside of the Memphis area where the Memphis aquifer is confined, the potentiometric surface slopes gently westward toward the axis of the Mississippi embayment, and the water moves slowly in that direction (Parks and Carmichael, 1990c). In the Memphis area, a major depression has developed in the potentiometric surface as a result of the long-term (1886-present) pumping at municipal and industrial well fields. Superimposed on this major depression are localized cones of depression centered at municipal and industrial well fields (plate 3). The velocity of water moving into the major depression is relatively slow but increases considerably in the proximity of pumping centers (Bell and Nyman, 1968).

In addition to seasonal fluctuations, water levels in the Memphis aquifer are also affected by long-term changes. A few principal observation wells in areas away from MLGW well fields also give an indication of the magnitude of these changes. Well Fa:R-2 (plate 3) is the farthest of these wells from the center of the major depression in the potentiometric surface at Memphis. The water level in Fa:R-2 has declined about 3 feet in 39 years (1949-88), an average rate of less than 0.1 foot per year. Well Sh:Q-1 (plate 3) is at an intermediate distance between Fa:R-2 and the center of the major depression. The water level in Sh:Q-1 has declined about 34 feet in 48 years (1940-88), an average rate of about 0.7 foot per year. Well Sh:P-76 (plate 3) is near the center of the major depression. The water level in Sh:P-76 has declined about 78 feet in 60 years (1928-88), an average rate of about 1.3 feet per year.

Recharge to the Memphis aquifer from precipitation generally occurs along the broad outcrop or subcrop belt where it is at or near the surface across western Tennessee (Graham, 1982). This outcrop or subcrop belt extends into the Memphis area east and southeast of the approximate eastern limits of the Jackson-upper Claiborne confining unit (plate 3). In this area, the Memphis aquifer generally is unconfined but is covered by the alluvium and fluvial deposits. Therefore, recharge is by downward infiltration of water from precipitation through the alluvium and fluvial deposits into the Memphis aquifer.

Where that aquifer is confined and head differences are favorable, a component of recharge locally enters the Memphis aquifer by downward leakage from the water-table aquifers or the Jackson-upper Claiborne confining unit. Conditions for downward leakage are particularly favorable where the confining unit is thin or absent or where leakage is induced by intense pumping from the Memphis aquifer, as in the vicinity of MLGW well fields (Graham and Parks, 1986). Conditions for downward leakage also may be favorable where the Cook Mountain Formation has been displaced vertically by faults, leaving sands in the Cockfield Formation and the Memphis aquifer in direct hydraulic connection (Parks and others, 1985).

Horizontal flow direction in the Memphis aquifer at any particular place can be approximated by drawing flow lines perpendicular to the potentiometric contours on plate 3. In general, horizontal flow is toward the center of the major depression, which is deepest in the area of the Mallory and Allen well fields. Locally, ground water also flows towards smaller cones of depression at other MLGW and industrial well fields.

POTENTIAL SOURCES OF CONTAMINATION OF THE MEMPHIS AQUIFER

Forty-four sites where contaminants have been detected in the water-table aquifers, five municipal wells where contaminants have been detected in the Memphis aquifer, and areas where the Jackson-upper Claiborne confining unit is thin or absent are shown in plate 4. Included in the 44 sites on plate 4 are the locations of several abandoned or inactive waste-disposal dumps or landfills where contaminants were detected in the water-table aquifers during previous investigations of the USGS (Parks and others, 1982; Graham, 1985; M.W. Bradley, USGS, written commun., 1989). Included also are two private wells (Sh:J-155 and Sh:Q-93) and an industrial well (Sh:O-215) where contaminants have been detected in the water-table aquifers during another previous investigation of the USGS (McMaster and Parks, 1988).

Information concerning the 44 sites where contaminants have been detected in the water-table aquifers are given in table 6. Most of the information concerning 33 of these sites was obtained from records supplied by the offices of the appropriate Federal and State regulatory agencies, as follows:

U.S. Environmental Protection Agency
Waste Management Division
Site Investigation and Support Branch
345 Courtland Street N.E.
Atlanta, GA 30365

Tennessee Department of Health
and Environment
Division of Groundwater Protection
T.E.R.R.A. Building - 5th floor
150 Ninth Avenue N.
Nashville, TN 37219-5404

Tennessee Department of Health
and Environment
Division of Solid Waste Management
Room 1101, State Office Building
170 Mid America Mall N.
Memphis, TN 38103

Tennessee Department of Health
and Environment
Division of Superfund
Southwest Tennessee Regional Office
295 Summar Avenue
Jackson, TN 38301-3984

Tennessee Department of Health
and Environment
Division of Underground Storage Tanks
200 Doctors Building
706 Church Street
Nashville, TN 37247-4101

Table 6.--*Sites where synthetic organic compounds or relatively high concentrations of inorganic trace constituents have been detected in the water-table aquifers in the Memphis area*

[Sources: U.S. Environmental Protection Agency (EPA); Tennessee Department of Health and Environment, Division of Superfund (DSF), Division of Solid Waste Management (DSWM), and Underground Storage Tank Program (UGST); map numbers refer to plate 4 of this report]

Map number	Latitude	Longitude	Type of site	Contaminants detected	Source of information
1	352006	0895707	Millington Dump/Landfill	PCB's; cadmium	Parks and others (1982)
2	352018	0895654	Old Ordnance Dump	chlordane, endrin, mirex, toxaphene	Do.
3	352027	0895244	underground storage tank	benzene, toluene, xylenes	UGST
4	352130	0893614	industrial waste burial	2-methylphenol, phenol; chromium	EPA
5	351758	0899334	industrial spill	pesticides	DSWM
6	351548	0893956	underground storage tank	product (gasoline)	UGST
7	351755	0895750	underground storage tank	benzene, trans-1,2-dichloroethene, tetrachloroethene, toluene, trichloroethene, vinyl chloride, xylenes	Do.
8	351647	0895753	industrial spill	acetone, benzene, BHC, 2-butanone, carbon disulfide, chloroform, 4,4-DDE, 4,4-DDT, 1,1-dichloroethylene, 1,2-dichloroethylene, trans-1,2-dichloroethylene, endosulfan, heptachlor, tetrachloroethylene, toluene, trichloroethylene, vinal chloride	DSF
9	351454	0895146	private well Sh:Q-93	aldrin, DDT, endosulfan, perthane	McMaster and Parks (1988)
10	351230	0900245	industrial spill	chromium	DSF
11	351225	0900159	underground storage tank	gasoline "floating" on ground water	UGST
12	351300	0895910	underground storage tank	benzene, toluene, xylenes	Do.
13	351317	0895435	underground storage tank	benzene, toluene, ethylbenzene/xylenes	Do.
14	351215	0895131	underground storage tank	benzene, toluene, xylenes	Do.
15	351151	0895831	underground storage tank	benzene, toluene, xylenes	Do.
16	351133	0895342	underground storage tank	benzene, toluene, xylenes	Do.
17	351050	0900040	Bellevue Dump	chlordane, dieldrin, endrin, heptachlor epoxide, PCB's, phenol; arsenic, barium	Parks and others (1982)
18	351110	0895832	North Hollywood Dump area	chlordane, chlordene, cyanide, DDT, diazinon, dieldrin, diethyl phthlate, dimethyl phthlate, di-n-octyl phthlate, endrin, heptachlor, heptachlor epoxide, mirex, PCB's, phenol, 2,4,5-T; arsenic, barium, cadmium	Do. Graham (1985)
19	351005	0895150	underground storage tanks	benzene, toulene, xylenes	UGST
20	351040	0900255	industrial well Sh:O-215	barium	McMaster and Parks (1988)
21	350945	0895647	underground storge tank	acrolein, benzene, 1,2-dichloroethane, ethylbenzene, toluene	UGST
22	350915	0895808	industrial spill	1,1,1-trichloroethane	DSWM
23	350858	0895755	underground storage tank	benzene, ethylbenzene, toluene, xylenes	UGST
24	350858	0895626	underground storage tank	benzene, ethylbenzene, toluene, xylenes	Do.
25	350852	0900236	underground storage tank	benzene, toluene, xylenes	Do.

Table 6.--*Sites where synthetic organic compounds or relatively high concentrations of inorganic trace constituents have been detected in the water-table aquifers in the Memphis area*--Concluded

Map number	Latitude	Longitude	Type of site	Contaminants detected	Source of information
26	350817	0900229	underground storage tank	benzene, toluene, xylenes	UGST
27	350729	0900318	underground storage tank	benzene, ethylbenzene, toluene, xylenes	Do.
28	350755	0895050	Shelby County Landfill	benzene, chlorobenzene, 1,4-dichlorobenzene, 1,1-dichloroethane, cis-1,2-dichloroethene, trans-1,2-dichloroethylene, ethylbenzene, methylene chloride, tetrachloroethylene, trichloroethane, vinyl chloride, xylenes; arsenic, barium, chromium, lead	USGS DSWM
29	350621	0895327	underground storage tank	ethylbenzene, xylenes; other unidentified volatile organic compounds	UGST
30	350625	0895302	underground storage tank	benzene, ethlybenzene, toluene, xylenes	Do.
31	350552	0900017	military and industrial waste disposal	purgeable organic compounds	DSWM
32	350500	0900703	industrial waste disposal	benzene, ethlybenzene, tetrachloroethylene, 1,1,1 trichloroethane, trichloroethylene, toluene, vinyl chloride, xylenes	Do.
33	350507	0900456	industrial spill	petroleum products	UGST
34	350504	0900202	industrial spill	benzene, chlorobenzene, chloroform, 1,1-dichloroethane, 1,2-dichloroethane, ethylbenzene, methylene chloride, toluene, xylenes	DSWM
35	350416	0895647	underground storage tank	benzene, toulene, xylenes	UGST
36	350442	0895307	underground storage tank	petroleum hydrocarbons	Do.
37	350405	0900255	Brooks Road Dump	chlordane, cyanide, DDT, diazinon, dieldrin, endrin, heptaclor, heptachlor epoxide, phenol	Parks and others (1982)
38	350359	0900148	underground storage tank	petroleum hydrocarbons, including diesel fuel	UGST
39	350343	0900123	underground storage tank	gasoline "floating" on ground water	Do.
40	350308	0895811	underground storage tank	benzene, ethylbenzene, toluene, xylenes	Do.
41	350203	0900349	private well Sh:J-155	aldrin, DDT, endosulfan, perthane, 1,1,1-trichloroethane	McMaster and Parks (1988)
42	350115	0900028	underground storage tank	benzene, toluene, xylenes (as total BTX)	UGST
43	350100	0895745	Jackson Pit Dump	chlordane, chlorobenzene, chloroethane, chloroform, diazinon, 1,4-dichlorobenzene, 1,1-dichloroethane, cis- 1,2,-dichloroethene, heptachlor, methyl parathion, methylene chloride, PCB's, phenol, tetrachloroethane, trichloroethene, toluene; arsenic, lead	Parks and others (1982) DSF
44	350230	0894125	industrial spill	chlorinated hydrocarbons	DSF

Because of the voluminous records in the files of these agencies that concern both the regulatory and investigative aspects of the sites, personnel with investigative responsibility were asked to assist by identifying those sites where contaminants have been detected in the ground water and to provide an analysis (or analyses) showing the contaminants detected. Many of the sites are still under investigation, so the information provided was from the data available at the time (1987-89).

In the selection of sites, consideration generally was not given to the degree and extent of contamination or the regulatory aspects of the definition of the word "contamination." If synthetic organic compounds have been detected in the water-table aquifers (or perched water tables), then the ground water was considered to be contaminated. Maximum contaminant levels (MCL) in drinking water have been established for some synthetic organic compounds by the U.S. EPA, but only recommended maximum contaminant levels exist for others (U.S. Environmental Protection Agency, 1986). Consequently, the presence of synthetic organic compounds in the water-table aquifers was considered an indication of contamination inasmuch as man-made organic compounds do not occur naturally in ground water. Because trace inorganic constituents occur naturally in the ground water of the Memphis area in small concentrations (Brahana and others, 1987; McMaster and Parks, 1988), these constituents are included in table 6 only if they exceeded the MCL's established by the U.S. EPA. For the trace inorganic constituents included in table 6, the MCL's are arsenic [50 micrograms per liter (μg/L)], barium (1,000 μg/L), cadmium (10 μg/L), chromium (50 μg/L), and lead (50 μg/L).

Some of the 41 sites (excluding wells Sh:J-155, Sh:O-215, and Sh:Q-93) have only one monitoring well, but others have many. Most of these monitoring wells generally are shallow (commonly less than 50 feet deep) and are screened in the upper part of the water-table aquifer, although some may be screened in perched water-table zones. Some wells have been sampled only once, but others have been sampled several times. The analyses, which were made by various commercial or government laboratories, generally are limited to reporting the synthetic organic compounds or trace inorganic constituents that are specifically important to assessing contamination based on the type of site under investigation. For example--benzene, toluene, and xylene generally are analyzed for assessing ground-water contamination at leaky underground storage tanks (table 6). These volatile organic compounds are common components of gasoline. Reported concentrations of contaminants range from trace amounts of pesticides just above the detection limits (in micrograms per liter) at some abandoned dumps to several feet of "product" floating on the ground-water surface at some industrial or underground-storage-tank sites.

Thousands of potential point and nonpoint sources of contamination of the water-table aquifers exist in the Memphis area. These sources include abandoned dumps, active and inactive landfills, underground storage tanks, industries and commercial establishments that process or use hazardous chemicals, demolition disposal sites, sewers, septic tanks, and local spills. Locations of abandoned dumps and active landfills in Shelby County, Tenn., that were known in 1975 are given in a report by Parks and Lounsbury (1976). Early in the present investigation, a list of 1,679 underground storage tanks in Shelby County was obtained from the TDHE, Division of Ground Water Protection. Personnel with that agency estimated that this list included about 70 percent of the underground storage tanks in the county, which were still being inventoried (John Fox, Jr., TDHE, oral commun., 1987). In addition, many other sites where contamination of the soils or surface waters has been detected are included in the lists of the U.S. EPA and TDHE. However, no contamination of the ground water presently is known at these sites, or investigations of the sites have not progressed to the stage where ground-water contamination has been determined.

All of the above sources have potential for contaminating the water-table aquifers. Work in determining the degree and extent of contamination of the water-table aquifers is still in the beginning stage, although much progress has been made in recent years. The Memphis aquifer is a step removed from these potential sources of contamination inasmuch as under "natural" conditions contaminants must enter the water-table aquifers before they enter the Memphis aquifer.

INDICATIONS OF DOWNWARD LEAKAGE TO THE MEMPHIS AQUIFER

Indications that downward leakage from the water-table aquifers to the Memphis aquifer is widespread were provided by Graham and Parks (1986). This previous investigation used a multi-aspect approach that included studies of: (1) areal variations in the thickness of the Jackson-upper Claiborne confining unit that indicated areas where the confining unit is thin or absent, (2) the configuration of the water table that indicated an anomaly in this surface where the water table is depressed because of downward leakage, (3) differences in hydraulic head between the water-table and Memphis aquifers that indicated a general downward gradient, (4) areal and local variations in carbon-14 and tritium concentrations in water from the upper part of the Memphis aquifer that indicated relatively recent water has entered the Memphis aquifer, and (5) deviations from the normal geothermal gradient that indicated the coolest temperatures in areas of intense pumping are at greater depths (as a result of leakage) than in areas away from this pumping. The present investigation, which includes detailed studies of the thickness of the confining unit and the configuration of the water table, has resulted in much refinement of the previous work and identification of several additional areas where leakage is or may be occurring.

Graham and Parks (1986) indicated four general areas in the Memphis urban area (as defined in that report) where the Jackson-upper Claiborne confining unit is thin or absent and a high potential for downward leakage exists. These areas are: (1) in the eastern part along and north of the Wolf River, (2) in the southeastern part along Nonconnah Creek, (3) in the south-central part along Nonconnah and Johns Creeks in the vicinity of the southern part of Sheahan well field, and (4) in the western part in a belt along the Mississippi River. The areas in the eastern and southeastern parts along the Wolf River and Nonconnah Creek are extensions of the outcrop or subcrop belt of the Memphis aquifer into the Memphis urban area. The boundaries of these areas are refined on the maps prepared for the present investigation as the eastern limits of the Jackson-upper Claiborne confining unit (plates 1-4).

The area in a belt along the Mississippi River where the confining bed is shown to be thin or absent by Graham and Parks (1986, figs. 3 and 21) was significantly modified during the present investigation. The extension of the belt north of Memphis where the confining bed was thought to be thin or absent was removed from the present map showing the thickness of the Jackson-upper Claiborne confining unit (plate 1). This modification of the northern extension of the belt is based on a re-correlation of geophysical logs partly as a result of a new geophysical log made in well Sh:O-115 (plate 1). No new information from geophysical logs is available for the southern part of the belt. However, a study by Richardson (1989) indicates that water-quality changes in several wells in the Davis well field are the result of leakage of water from the Mississippi River alluvium to the Memphis aquifer.

Richardson concluded that the confining unit is thin or absent beneath the alluvium west of the Davis well field or that a "window" exists in the confining unit.

The area in the south-central part of the Memphis urban area along Nonconnah and Johns Creeks in the vicinity of the southern part of the Sheahan well field has the most information to indicate that downward leakage from the water-table aquifers to the Memphis aquifer is occurring. Indications given by Parks and Graham (1986) include: (1) a loss of water along the stretch of Nonconnah Creek south and southeast of the southern part of Sheahan well field, (2) an adjacent area to the southeast where the confining unit is thin or absent, (3) a depression in the water-table surface, (4) long-term water-level declines in shallow observation well Sh:K-75, (5) carbon-14 and tritium concentrations indicating the presence of relatively recent water in the Memphis aquifer, (6) a distorted geothermal gradient with the coolest temperature at a depth of 230 feet below land surface, and (7) head differences between the water-table and Memphis aquifers favoring downward movement of water. The area where the confining unit is thin or absent is shown on plate 1 as the large area southeast of the southern part of Sheahan well field and west of Lichterman well field. This area is enlarged from the area shown by Graham and Parks (1986, fig. 3), based partly on a new geophysical log of the test hole for well Sh:K-148 in the western part of Lichterman well field (plate 1). The depression in the water-table aquifer, shown on plate 2 as the area extending from the southern part to the northern part of Sheahan well field, also is enlarged from the area shown by Graham and Parks (1986, fig. 7), based partly on the water level in new observation well Sh:K-137.

New information from test holes for wells drilled in the northern part of Sheahan well field since the Graham and Parks report (1986) indicates an area west of that part of the well field with a high potential for leakage. The Jackson-upper Claiborne confining unit in this area is shown by Graham and Parks (1986, fig. 3) to be about 150 feet thick. The stratigraphy of the Sheahan well field is complex and faults may exist. The tops of at least two sand beds in the geologic sequence can be interpreted on geophysical logs as being the top of the Memphis Sand and two clay beds can be interpreted as being the Cook Mountain Formation. The top of the shallower clay bed underlies the fluvial deposits and varies in thickness, but it commonly is thin. The deeper clay bed is thick and seems to be persistent throughout the area. Consequently, during the Graham and Parks investigation, the lower clay was interpreted to be the Cook Mountain Formation and the underlying (deeper) sand to be at the top of the Memphis Sand. During 1986 and 1987, test holes for several new MLGW production wells were drilled in the northern part of Sheahan well field. The geophysical and driller's logs for the test hole for well Sh:K-142 (plate 1) indicate that the confining unit, if present, consisted of only about 6 feet of sandy clay (or clayey sand) overlying a thick interval of sand in the Memphis Sand. In addition, the geophysical log of well Sh:K-141 (plate 1), drilled at the Tennessee Earthquake Information Center for installation of a seismic instrument, indicated that the Cook Mountain Formation may be the shallower clay and that the top of the Memphis Sand may be at the top of the shallower sand. Based on this new information, a re-correlation of the geophysical logs available for the northern part of the Sheahan well field and surrounding areas indicates that the confining unit is thin or absent in an area west of the northern part of the well field (plate 1). This area of high potential for leakage is consistent with a depression in the water table as indicated by a deeper than expected water level in observation well Sh:K-137 (plate 2) installed at the Sheahan pumping station in 1986. In addition, in an area between the Sheahan and Allen well fields (defined by the 160-foot contour on plate 3), the potentiometric surface of the

Memphis aquifer is higher than would be expected when considering the intense pumping at these well fields. This "high" in the potentiometric surface may be the result of leakage from the water-table aquifers in the area where the confining unit is thin or absent (plate 1).

A new area of leakage from the water-table aquifers to the Memphis aquifer identified since the Graham and Parks (1986) report is just north and northeast of the Shelby County landfill (plate 4). During an investigation of the area to satisfy requirements of the TDHE, Division of Solid Waste Management, for expansion of the landfill, water levels in auger holes and observation wells drilled in the vicinity of the landfill indicated that the water table is depressed to levels below low-flow stages of the nearby Wolf River (J.L. Ashner, TDHE, oral commun., 1986). Subsequently, the USGS investigated the geohydrology of the area with emphasis on determining the effects of vertical leakage and leachate migration on the ground-water quality. The results of the investigation indicate that (1) the depression in the water table is centered just north or northeast of the landfill and is as much as 14 feet below the low-flow stages of the Wolf River, (2) a downstream loss of water from the Wolf River occurs along the stretch that flows past the landfill, (3) leachate from the landfill has entered the Wolf River alluvium and is moving northward toward the depression in the water table, and (4) uncontaminated water from the alluvium has entered the Memphis aquifer (M.W. Bradley, USGS, written commun., 1989). The map of the thickness of the Jackson-upper Claiborne confining unit indicates an area in the vicinity and east of the landfill where the confining unit is thin or absent. This is based partly on the geophysical log of well Sh:Q-90 drilled for the landfill investigation (plate 1). A depression in the water table is defined by the 220-foot contour on the map of the altitude of the water table in the alluvium and fluvial deposits. The center of this depression is near well Sh:Q-128 installed for the landfill investigation (plate 2).

New areas identified during the present investigation where the Jackson-upper Claiborne confining unit is thin or absent or where depressions are in the water table include: (1) in the southeastern part of Lichterman well field based on the geophysical log for well Sh:L-102 (plate 1), (2) in the vicinity of McCord well field based on an area east of the well field along Fletcher Creek where the confining bed is interpreted to be thin or absent (plate 1) and the lower than expected water levels in wells Sh:Q-86 and Sh:Q-94 (plate 2), (3) south of Nonconnah Creek and between Interstate 55 and U.S. Highway 78 based on the geophysical log of well Sh:K-143 (plate 1) and the lower than expected water levels in wells Sh:K-144 and Sh:K-145 (plate 2), and (4) west of Olive Branch based on the geophysical log of well Ms:C-17 (plate 1). These newly identified areas have a high potential for downward leakage from the water-table aquifers to the Memphis aquifer.

POTENTIAL FOR CONTAMINATION OF THE MEMPHIS AQUIFER

A sequence of events that would result in contamination of the Memphis aquifer under "natural" conditions is: (1) contaminants enter the water-table aquifers; (2) contaminants are transported downward through the Jackson-upper Claiborne confining unit or enter the Memphis aquifer directly in areas where the confining unit is absent; and (3) contaminants persist despite the effects of various physical, chemical, and biological processes, including dilution and adsorption. Other events that would result in contamination of the Memphis aquifer include: (1) contaminated water in the water-table aquifers leaks downward through faulty well seals (cement grout or backfill material) outside the casings of wells screened in the Memphis aquifer and (2) contaminants from spills, vandalism, or illegal waste disposal enter the casings of wells screened in the Memphis aquifer.

Based on "natural" conditions, the potential for contamination of the Memphis aquifer generally is least in the northern and west-central parts of the Memphis area where the confining bed is thickest and contains much clay, and is greatest in the southern and eastern parts where the confining bed is thin or absent (plate 1). The Jackson-upper Claiborne confining unit is as much as 375 feet thick in the northwestern part of the Memphis area in well Sh:T-18 (plate 1). In this area, the confining unit consists of fine sand, silt, clay, and lignite in the Jackson, Cockfield, and Cook Mountain Formations. The confining unit is absent in the southeastern part of the Memphis area in wells Sh:M-17, Sh:M-43, and Sh:R-10 (plate 1). Aggregate thickness of clay beds within the confining unit thicker than 10 feet is greatest in the west-central part of the Memphis area. In the Mallory well field, an aggregate thickness of clay beds thicker than 10 feet makes up 246 feet of the total thickness of 255 feet for the confining unit in well Sh:O-184 (plate 1).

Sites where the water-table and Memphis aquifers are reported to contain contaminants and areas where the Jackson-upper Claiborne confining bed is thin or absent are shown on plate 4. Thus far, 44 sites have been identified where contaminants have been detected in the water-table aquifers (table 6). Many of these sites, which are potential sources of contamination of the Memphis aquifer, are located in areas where the direction of ground-water flow in the Memphis aquifer is toward cones of depression at MLGW well fields (plate 3). Based on present (1989) information, the Allen well field has the most sites in close proximity. Some sites also are located in areas where the confining unit is thin or absent or in areas where the direction of flow in the water-table aquifers is toward these areas (plate 2). It is likely that additional sites where the water-table aquifers are contaminated will be found as monitoring and investigations continue.

Thus far, only two sites have been found where volatile organic compounds have been detected in the Memphis aquifer—wells Sh:J-119 (398 feet deep), Sh:J-120 (452 feet) and Sh:J-121 (436 feet) in the Allen well field at Memphis and wells Sh:M-31 (324 feet) and Sh:M-35 (287 feet) in the west well field at Collierville (plate 4). Volatile organic compounds detected in wells Sh:J-119 and Sh:J-120 are: 1,1-dichlorethane, 1,1-dichloroethylene, cis-1,2-dichloroethylene, 1,2-dichloropropane, 1,2-dichloroethene, trichloroethylene, and vinyl chloride. Concentrations of these compounds ranged from 0.02 to 5.52 μg/L in these two wells—the highest concentration was for 1,2-dichloroethane detected in a sample collected from well Sh:J-120. The concentrations of the seven compounds in a sample from this well totaled about 11 μg/L (J.H. Webb, MLGW, written commun., 1988). Well Sh:J-120 is about 650 feet and well Sh:J-119 is about 2,000 feet from the nearest known potential source of contamination in the water-table aquifers (site 34, plate 4; table 6). The wells in the Allen well field are in an area where the confining unit is as thin as 82 feet and contains as little as 68 feet of aggregate thickness of clay beds thicker than 10 feet, based on the geophysical log of well Sh:J-119 (plate 1). Driller's logs for wells Sh:J-120 and Sh:J-121 provide no indication that a sand "window" exists in this area, although it is possible.

The volatile organic compound detected in water from wells Sh:M-31 and Sh:M-35 at Collierville is trichloroethylene. Since August 1988, these two municipal wells have been sampled periodically to determine concentrations of trichloroethylene. Concentrations detected have ranged from 1.6 to 25.0 μg/L with the highest concentration in a sample collected from well Sh:M-35 (B.J. Maness, TDHE, written commun., 1989). These wells are about 2,000 feet from the nearest known potential source of contamination (site 44, plate 4; table 6). The wells at Collierville are east of the eastern limits of the Jackson-upper Claiborne confining unit (plate 4). However, the driller's logs for wells Sh:M-31 and Sh:M-35 indicate at least 60 feet of clay in the Memphis aquifer separating the water-table aquifers from sand in the Memphis aquifer.

The facts that these volatile organic compounds (1) have been transported through the Jackson-upper Claiborne confining unit or through (or around) relatively thick intervals of clay in the Memphis aquifer, (2) have persisted despite the effects of various physical, chemical, and biological processes, and (3) have been detected in wells ranging from 287 to 452 feet in depth at distances as far as 2,000 feet from the nearest known potential sources of contamination in the water-table aquifers, emphasize the vulnerability of the Memphis aquifer to contamination.

Recently (1987-88), MLGW began a yearly routine sampling of all of their production wells in the Memphis aquifer and analytical "scans" of the water to determine the presence of organic compounds. If unidentified organic compounds are detected, a follow-up analysis is conducted to identify specific compounds. The results of the first sampling of all production wells indicated that only the water from the three wells in the Allen well field contained contaminants (J.H. Webb, MLGW, oral commun., 1989).

SUMMARY AND CONCLUSIONS

The City of Memphis presently (1989) depends solely on the Memphis aquifer for its water supply. Withdrawals from the Memphis aquifer in the Memphis area for municipal, industrial, and commercial uses totaled about 200 Mgal/d in 1988. Historically, the Memphis aquifer was thought of as an ideal aquifer overlain by a thick, impermeable clay layer that serves as a confining unit and protects the aquifer from contamination from near-surface sources. Studies in recent decades (1964-86), however, indicate that the confining unit locally may be thin or absent and may contain sand "windows" that could provide "pathways" for contaminants to reach the Memphis aquifer. Studies also indicate that downward leakage from the water-table aquifers (alluvium and fluvial deposits) to the Memphis aquifer is widespread in the Memphis area.

Indications of areas where downward leakage from the water-table aquifers to the Memphis aquifer is or may be occurring that were recognized during the previous and present investigations are as follows:

- areas where the confining unit is thin or absent and downward leakage can occur directly from the water-table aquifers to the Memphis aquifer;
- differences in hydraulic head between the water-table aquifers and the Memphis aquifer indicate a general downward gradient in most of the Memphis area;
- local depressions in the water-table surface indicate that leakage from the water-table aquifers to the Memphis aquifer is occurring;
- long-term declines and reduced seasonal fluctuations in observation wells in the water-table aquifers indicate that leakage is occurring;
- downstream losses of water along a stretch of a major stream based on a series of discharge measurements made during low-flow conditions indicate that leakage is occurring;
- areal and local variations in carbon-14 and tritium concentrations in water from the Memphis aquifer show the presence of relatively recent water, indicating leakage;

- local deviations in geothermal gradient in areas of intense pumping indicate that shallow subsurface temperatures in the water-table aquifers, confining unit, and Memphis aquifer are warmer than expected as a result of leakage;

- water-quality anomalies and changes in water quality in the Memphis aquifer indicate downward leakage from the water-table aquifers to the Memphis aquifer; and

- volatile organic compounds detected in water from the Memphis aquifer indicate that contaminants in water from the water-table aquifers has reached the Memphis aquifer.

Detailed maps of the thickness of the confining unit and the altitude of the water table in the alluvium and fluvial deposits prepared during the present investigation have provided much refinement of previously identified areas of downward leakage. Several new areas where downward leakage is or may be occurring also have been identified. Maps showing the altitude of the potentiometric surface of the Memphis aquifer and the locations of 44 sites where contaminants have been detected in the water-table aquifers indicate that many potential sources of contamination are located in areas where the direction of ground-water flow in the Memphis aquifer is toward cones of depression at MLGW well fields. Based on present information, the MLGW Allen well field has the most sites in close proximity. The water-table map also indicates that some of the sites where contaminants have been detected are in areas where the confining unit is thin or absent or in areas where the direction of flow in the water-table aquifer is toward these areas.

Recently, (1986-88) volatile organic compounds were detected in water from five municipal wells in the Memphis area—three in the MLGW Allen well field at Memphis and two in the west well field at Collierville. Concentrations totaled about 11.0 μg/L for seven compounds in a sample from one of the wells at the Allen well field and 25.0 μg/L for one compound in a sample from one of the wells at Collierville.

The facts that volatile organic compounds (1) have been transported downward through the confining unit or through (or around) relatively thick intervals of clay in the Memphis aquifer; (2) have persisted despite the effects of various physical, chemical, and biological processes; and (3) have been detected in wells ranging from 287 to 452 feet in depth at distances as far as 2,000 feet away from the nearest known potential source of contamination in the water-table aquifers, emphasize the vulnerability of the Memphis aquifer to contamination.

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