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EFFECTS OF URBAN DEVELOPMENT ON THE AQUIFERS IN THE MEMPHIS AREA, TENNESSEE

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 82-4024

Prepared in cooperation with the

CITY OF MEMPHIS LIGHT, GAS AND WATER DIVISION

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Memphis, Tennessee

1982

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
A-413 Federal Building
U.S. Courthouse
Nashville, Tennessee 37203

Copies of this report can be
purchased from:

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CONVERSION FACTORS

To convert inch-pound units to International System of units (SI)

Multiply	By	To obtain
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)
gallons per minute (gal/min)	0.06309	liters per second (L/s)
million gallons per day (Mgal/d)	0.0431	cubic meters per second (m^3/s)

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ABSTRACT

Ground-water withdrawals from aquifers in the Memphis area average about 190 Mgal/d. Potential problems associated with increases in pumpage and urban development are lowered water levels, contamination of the aquifers, and land subsidence.

Long-term water-level declines in the Memphis Sand, the principal artesian aquifer of the area, range from less than 0.1 foot per year near the outcrop area to about 1.8 feet per year near the center of pumping. A 1980 potentiometric map shows that small cones of depression around major pumping centers are superimposed on a regional cone. Except for increased pumping lift, few problems are expected from water-level declines in the Memphis Sand. There is at present very little pumpage from other aquifers in the area--the alluvium, the fluvial deposits, and the Fort Pillow Sand--and no long-term water-level declines are expected unless pumpage is increased significantly.

Low concentrations of leachates from waste-disposal sites in the area have been detected in the water-table aquifers near these sites, but no indication of contamination of the underlying artesian aquifers has yet been found.

Seasonal land-surface elevation changes of less than 0.03 foot have been recorded by an extensometer near the center of the major cone of depression of the Memphis Sand. These changes correlate with seasonal changes in artesian pressure in the Memphis Sand. Over the period of record no significant net change in land-surface elevation has been recorded, indicating that no permanent land subsidence due to declining water level is occurring.

INTRODUCTION

Ground water is the only source of potable water being used for municipal and industrial supplies in the Memphis area. Although a sufficient quantity of water that meets most water-quality criteria is available from depths of less than 2,000 feet, problems associated with resource development and management may occur as withdrawals are increased to meet the demands of a growing metropolitan area. Potential problems are: (1) the effects of the lowering of water levels, (2) possible contamination of the aquifer system as a result of man's activities, and (3) possible land subsidence caused by reductions in artesian pressures.

The term "Memphis area", as used in this report, refers to a 1,300 mi^2 area in the Mississippi embayment comprising parts of three states (fig. 1). It includes all of Shelby and parts of Fayette and Tipton Counties in Tennessee, DeSoto and Marshall Counties in Mississippi, and Crittenden and Mississippi Counties in Arkansas (fig. 2). The locations of wells discussed in the text are also shown in figure 2.

Purpose and Scope

A large amount of information has been and is being collected from the aquifers in the Memphis area. Much of this information has been published in several previous reports. The purpose of this report is to update some of this published information and present additional information pertinent to the potential problems associated with the increasing development of the ground-water resource.

To provide the background information necessary for evaluating changes that are occurring or might occur in the ground-water system, the Geological Survey, in cooperation with the City of Memphis, Memphis Light, Gas and Water Division (MLGW), currently is conducting the following data-collection activities: (1) a network of observation wells is maintained to define water-level trends and provide data necessary for the preparation of potentiometric surface maps, (2) a yearly inventory is conducted to provide information about the distribution and amounts of pumpage, (3) key wells are sampled yearly to monitor changes in water quality in the principal artesian aquifer, (4) wells close to areas of potential contamination from waste-disposal sites are sampled to determine the presence and quantities of hazardous constituents that have entered or might be entering the shallow water-table aquifer, and (5) two recording extensometers are operated to monitor possible land subsidence. Additionally, the Geological Survey makes geophysical logs in new municipal supply wells and other wells in the area to obtain information for use in further defining the subsurface geology.

Previous Investigations

The general hydrology and geology of the Memphis aquifer systems are described in reports by Schneider and Cushing (1948), Criner and Armstrong (1958), Criner and others (1964), and Bell and Nyman (1968). A series of potentiometric maps and a description of historic water-level changes and pumpage from the Memphis Sand and the Fort Pillow Sand are given in Criner and Parks (1976). The configuration of the potentiometric surface of the Memphis Sand for the year 1978 is shown in Graham (1979). Records of water levels

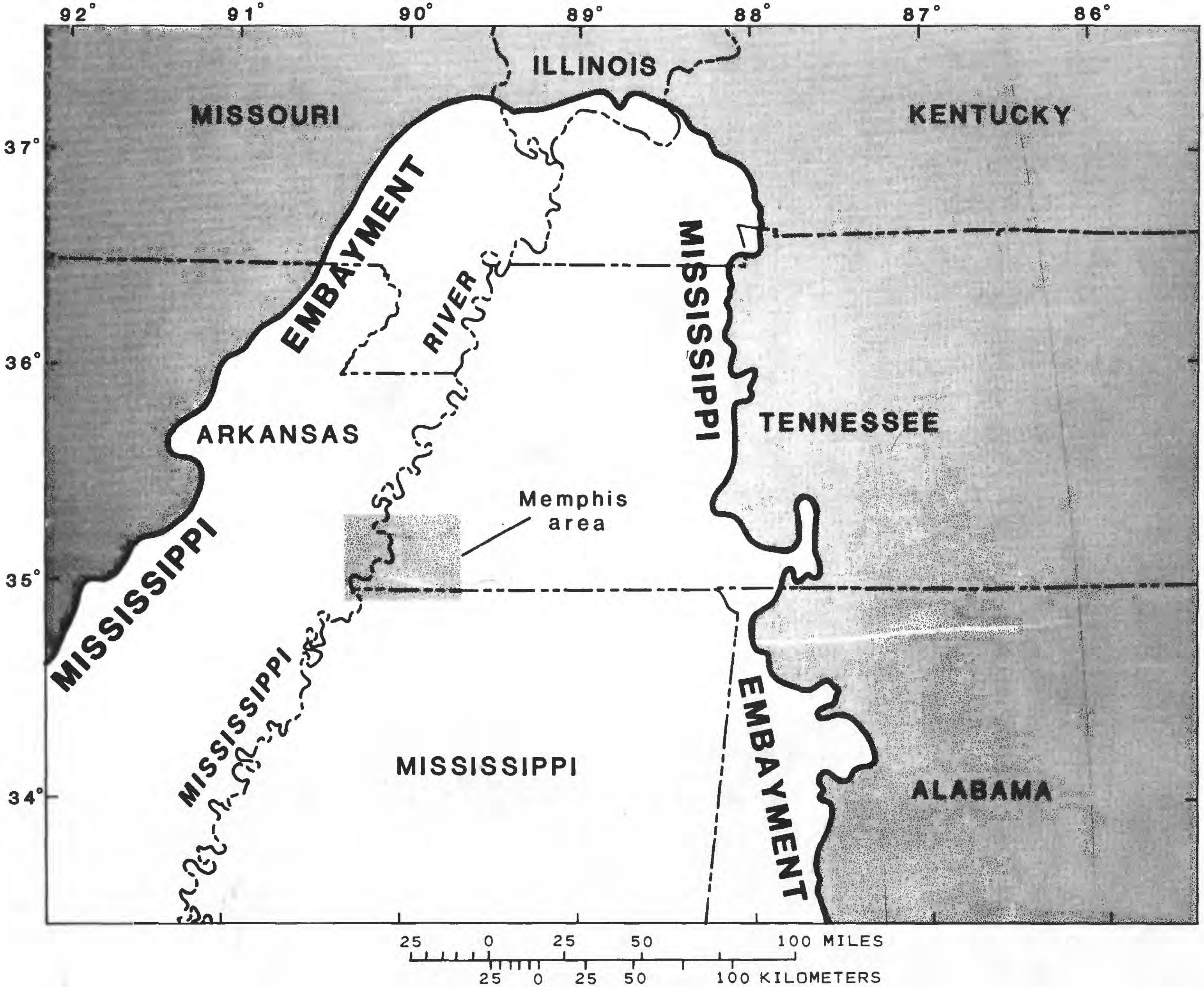


Figure 1.-- The Memphis area in the Mississippi embayment.

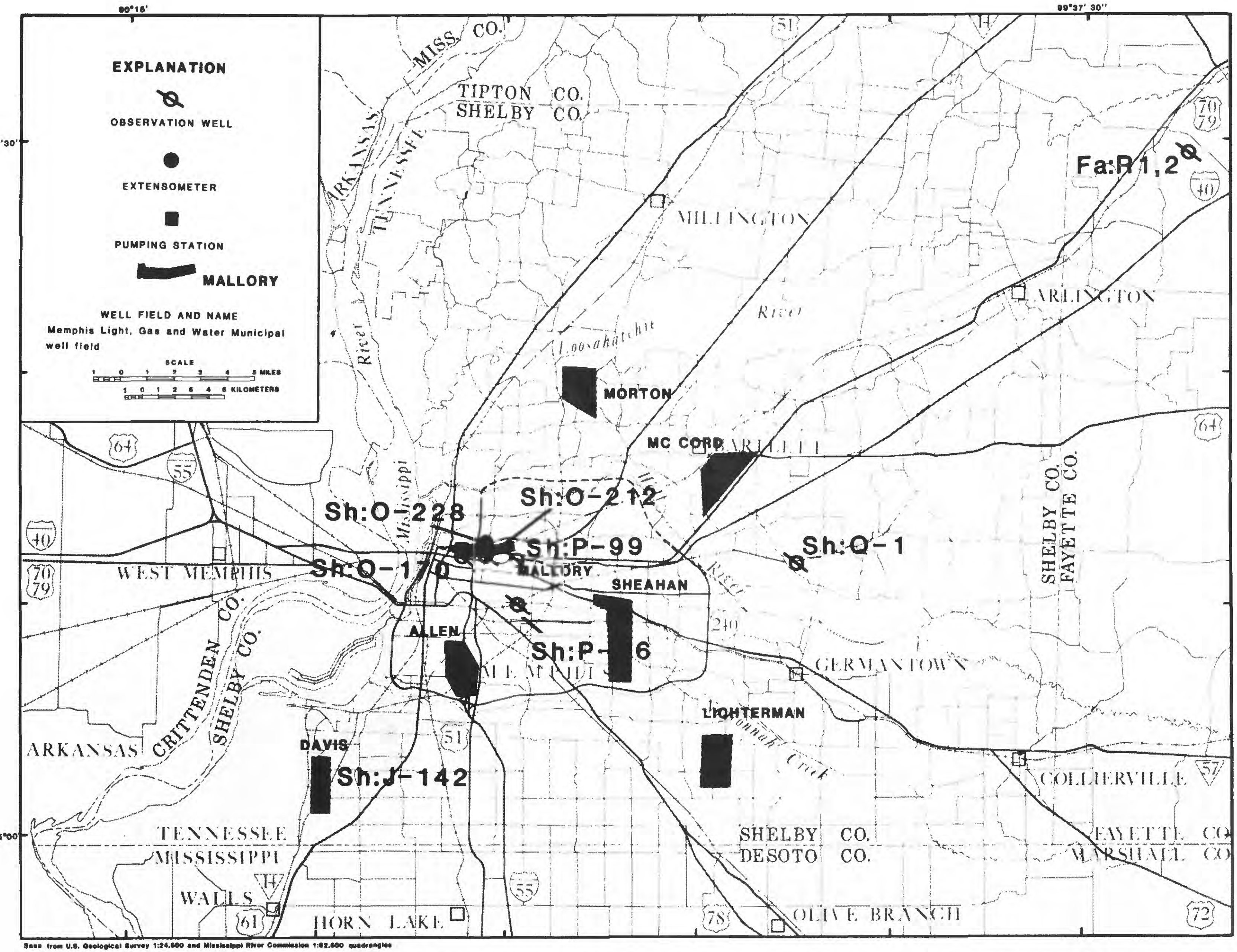


Figure 2.-- The Memphis area with locations of Memphis Light, Gas and Water Municipal well fields and observation wells referred to in the text.

from 1936 through 1973 are published in U.S. Geological Survey Water-Supply Papers 817, 840, 845, 886, 907, 937, 945, 987, 1017, 1024, 1072, 1097, 1127, 1157, 1166, 1192, 1222, 1266, 1322, 1405, 1538, 1803, 1978, and 2171. Information concerning the general quality of water in the aquifers of the Memphis area can be found in Wells (1933), Lanphere (1955), Criner and Armstrong (1958), Criner and others (1964), and Bell and Nyman (1968). Data for the years 1974 to 1979 are published in U.S. Geological Survey Water-Data Reports: Water Resources Data for Tennessee.

A two-dimensional digital computer flow model of the Memphis Sand is described by Brahana (1982). The application of this model as a predictive tool to estimate aquifer response to various hypothetical pumpage projections is described in the U.S. Army Corps of Engineers, Memphis Metropolitan Urban Area Water Resources Study (1981).

A summary of some of the 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). A report by Parks and others (1982) describes the installation and sampling of observation wells at selected waste-disposal sites.

AQUIFER SYSTEMS

Geologic Setting

As much as 3,000 feet of unconsolidated deposits overlie the Paleozoic carbonate bedrock in the Memphis area. These unconsolidated deposits consist chiefly of sand, clay, gravel, silt, and lignite; they range from Late Cretaceous through Holocene in age. Only post-Midway formations (Wilcox Group and younger) will be considered in this report because they include the principal freshwater aquifers. Table 1 provides a summary of the hydrologic significance and stratigraphic relations of these formations.

The principal post-Midway aquifers are: (1) the alluvium, (2) the fluvial (terrace) deposits, (3) the Memphis Sand ("500-foot" sand), and (4) the Fort Pillow Sand ("1400-foot" sand). The alluvium and fluvial deposits make up the shallow water-table (unconfined) aquifers. The deeper Memphis Sand and equivalent deposits are artesian (confined) throughout most of the Memphis area, except in the southeastern part. The Fort Pillow Sand is artesian throughout the Memphis area. The Memphis Sand and the Fort Pillow Sand are separated from one another and, at most places, the shallow water-table aquifers are separated from the Memphis Sand by confining beds of significantly lower permeability.

Recharge

Recharge to the shallow water-table aquifers is provided by precipitation that falls on the land surface of the local area where the topography and surface conditions are favorable for infiltration. During the winter and spring when precipitation is greatest and evaporation and transpiration are least, recharge is greatest because more water is available for infiltration. During the summer and fall when precipitation is least and evaporation and transpiration are greatest, recharge is least.

Table 1.--Geologic and equivalent units underlying

[Modified from Parks

System	Series	Group	Stratigraphic unit	Thickness (ft)
Quaternary	Holocene and Pleistocene		Alluvium	0-175
	Pleistocene		Loess	0-65
Quaternary and Tertiary (?)	Pleistocene and Pliocene		Fluvial deposits (terrace deposits)	0-100
Tertiary	Eocene	?	Jackson Formation and upper part of Claiborne Group ("capping clay")	0-350
		Claiborne	Memphis Sand ("500-foot" sand)	500-880
		Wilcox	Flour Island Formation	160-350
	?		Fort Pillow Sand ("1,400-foot" sand)	210-280
	Paleocene		Old Breastworks Formation	200-250

the Memphis area and their hydrologic significance

and Lounsbury, 1976]

Lithology and environmental significance
Sand, gravel, silt, and clay. Underlies the Mississippi River alluvial plain and the flood plains of other streams in the area. Supplies water to a few domestic and industrial wells. Could be an important source of waer for irrigation and some industrial uses.
Wind-deposited silt; silty clay and minor sand. Forms a blanket over the fluvial deposits in upland area; topographically higher than alluvium. Thickest on the bluffs that border the Mississippi River alluvial plain; generally thinner towards the east. Not a source of ground water.
Sand and gravel; minor ferruginous sandstone. Underlies the upland areas in a broad, irregular belt east of the Mississippi River alluvial plain; may be locally absent. Supplies water to many shallow, small-capacity wells in suburban and county areas.
Gray, bluish-gray, greenish-gray, and tan clay; subordinate beds of fine-sands and fine-grained lignite. Supplies water to some small-capacity wells. Generally considered to be of low permeability and to confine water in Memphis Sand. Absent in southeastern part of Memphis area.
Fine to coarse sand; subordinate lenses of clay and minor amounts of lignite. Thick clay bed locally in lower part; coarse sand lenses locally at base. Very good aquifer supplying over 98 percent of water used in Memphis area.
Gray, greenish-gray, and brown carbonaceous clay. Locally contains fine-sand lenses and some lignite. Serves as lower confining bed for Memphis Sand and upper confining bed for Fort Pillow Sand.
Fine- to medium-grained sand; minor amounts of lignite and some clay lenses. Second most important aquifer but supplies less than 2-percent of water used in Memphis area.
Gray, greenish-gray, and brown carbonaceous clay. Contains some lignite and is sandy near top. Lower confining bed for water in Fort Pillow Sand.

Under natural conditions recharge to the Memphis Sand artesian aquifer generally occurs in areas where it lies at or close to the surface, principally along a broad belt trending northeastward across western Tennessee (fig. 3). Within this belt, recharge occurs by direct infiltration of rainfall through the sand formations. Water entering here moves slowly toward the axis of the Mississippi embayment. Conditions are similar in the Fort Pillow Sand, which crops out immediately east of the Memphis Sand.

Recent studies by the Geological Survey indicate that some of the recharge to the Memphis Sand may be by vertical leakage through the confining bed from the overlying water-table aquifers. Although there is no conclusive evidence that this is occurring at any one site, a strong indication of vertical leakage is that the regional cone of depression in the Memphis area is not as deep as would be expected for the amount of water that is being withdrawn. In order to simulate observed water levels during the calibration of a digital flow model of the Memphis Sand (Brahana, 1982), it was necessary to input a confining bed leakage factor. This factor averaged 20 percent of the recharge to the Memphis Sand over the entire Memphis area. Ongoing efforts by the Geological Survey to use this model along with information being obtained in a study of solute transport should provide additional understanding of the role that vertical leakage plays in determining the water quality of the Memphis Sand (J. V. Brahana, personal commun., 1982).

The stratigraphic relation of the two artesian aquifers in the subsurface in the eastern part of the recharge area is not well known. In this area, the Memphis Sand may overlap the confining bed separating these two aquifers and may directly overlie the Fort Pillow Sand. If so, the two artesian aquifers would share a common source of recharge.

PUMPAGE AND WATER LEVELS

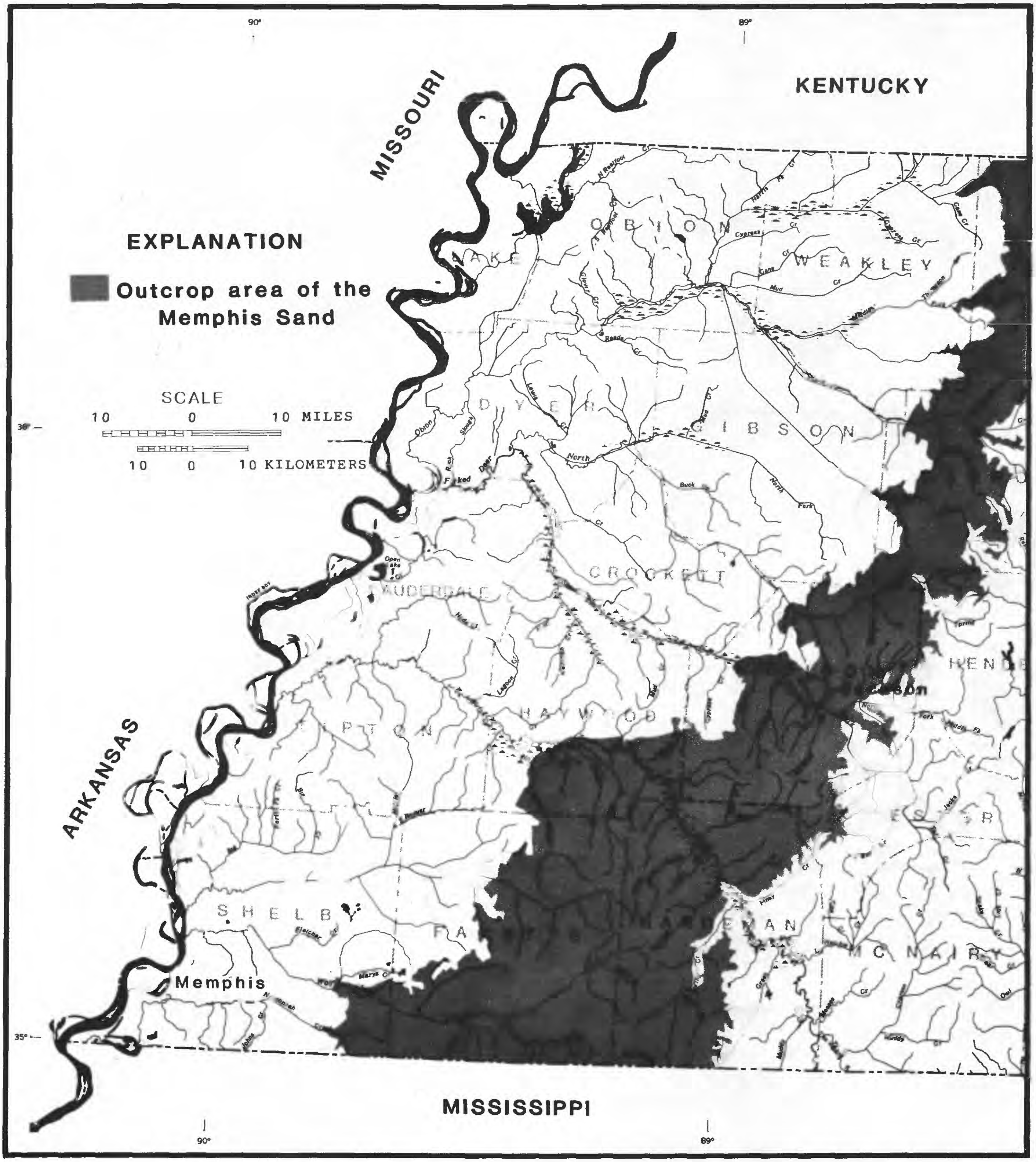
Pumpage

About 98 percent of the inventoried pumpage in the Memphis area, which totaled 193 million gallons per day (Mgal/d) in 1980, is from the Memphis Sand and 2 percent is from the Fort Pillow Sand. Not included in this inventory is water pumped by many small capacity farm and domestic wells in rural areas from fluvial deposits and Memphis Sand and a few industrial wells in the alluvium. Undocumented pumpage probably would add no more than a few million gallons per day to the total. Many of the domestic wells in rural areas are being abandoned as public water-supply systems are extended into these areas.

A historic account of the development of the ground-water resource including a tabulation of pumping rates for the years 1886-1975 is given in Criner and Parks (1976). The pumping rates for the major aquifers of the Memphis area for the years 1976-80 have been added (table 2).

Water Levels

The water-table configuration in the shallow aquifers is a subdued replica of the topography. Water levels are generally at higher altitudes but at greater depths beneath land surface in upland areas than in valleys. Because pumping from the alluvium is negligible, except for a few irrigation wells in



Base from U.S. Geological Survey
State base map, 1977

Figure 3. -- The outcrop area of the Memphis Sand (modified from Rima, 1979).

Arkansas, water-level changes reflect variations in the amount of rainfall and large, sustained changes in stages of nearby streams. Water-level changes in the fluvial deposits are a reflection of the combined effects of urbanization, channelization of streams, clearing of land, and variations in the amount of rainfall. A hydrograph of well Sh:P-99, screened in the fluvial deposits is shown in figure 4. This well is located in a wooded area of Overton Park surrounded by an older, urbanized section of Memphis. The hydrograph shows a definite correlation between the amount of water in storage from year to year in the fluvial deposits and variations in annual rainfall in the Memphis area.

Table 2.--Pumping rates from the Memphis and Fort Pillow Sands by major water users in the Memphis area, 1976-80

[million gallons per day]

	Pumping rates					
	Memphis Sand			Fort Pillow Sand		
Year	MLGW*	Industrial and other	Total	MLGW	Industrial and other	Total
1976	113	72	185	0	4.7	4.7
1977	120	69	189	0	4.5	4.5
1978	117	69	186	0	4.8	4.8
1979	119	69	188	0	5.9	5.9
1980	124	64	188	0	4.7	4.7

* Memphis Light, Gas and Water Division

Water levels in the Memphis Sand have declined in the Memphis area in response to long-term increases in pumping. Water-level declines have not been uniform throughout the area because of the non-uniform distribution of wells. A potentiometric map of the Memphis Sand based upon water-level measurements made in 1980 is shown in plate 1. A potentiometric map depicts an imaginary surface which fluctuates with time because of changes in pumpage and recharge to the aquifer. This map is based on water-level measurements made in wells screened in the Eocene Memphis Sand (formerly "500-foot sand"). Low water levels for the month of September 1980 from Geological Survey maintained recorder equipped wells and supplemental measurements made on Sept. 10, 15, and 16 of private and industrial wells were used as control. Water levels are commonly at their lowest for the year during late August or early September. Small cones of depression around major pumping centers are superimposed on a large regional cone which reflects the composite effect of pumpage. MLGW operates seven major municipal well fields (plate 1). These well fields, in order of their relative age are: (1) Mallory, (2) Sheahan, (3) Allen, (4) McCord, (5) Lichterman, (6) Davis, and (7) Morton. The Morton well field is not yet in production. The cones of depression not centered on municipal well fields are in areas of major industrial pumping.

Progressive water-level declines near pumping centers are caused by limitations on the ability of the aquifer to transmit water rapidly from areas of recharge to areas of concentrated pumping rather than by a lack of available recharge. Water levels are still high in the recharge areas and,

PRECIPITATION (INCHES)												
51.9	42.1	50.0	44.2	58.9	64.2	64.6	58.7	45.5	41.2	63.8	70.9	54.4
DEPARTURE FROM NORMAL												
2.1	-7.6	0.3	-5.4	9.1	14.5	15.5	9.6	-3.6	-7.9	14.7	21.8	5.3

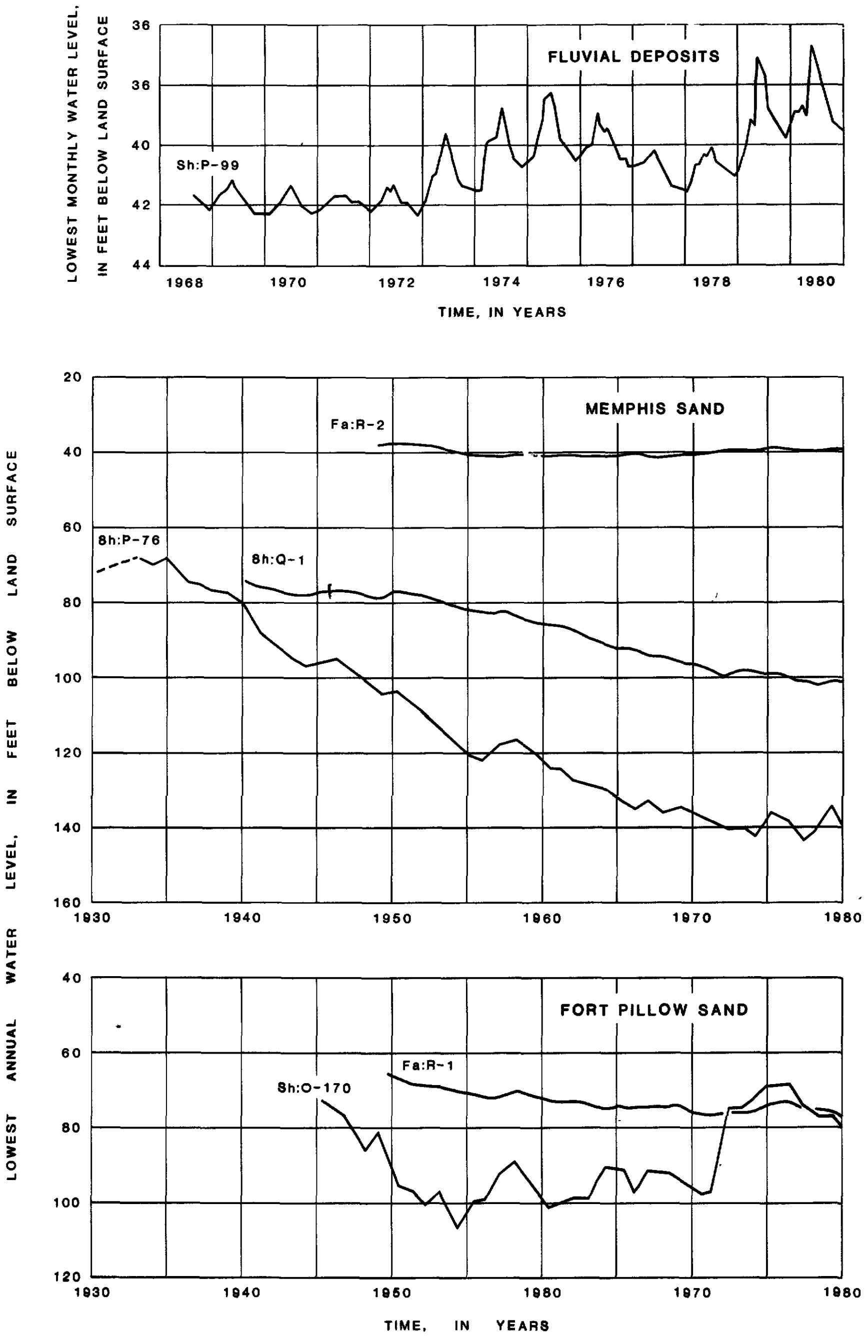


Figure 4.-- Water-level changes in selected observation wells in the Memphis area.

consequently, potential recharge is rejected and runs off as streamflow. In outlying parts of the Memphis area, annual water-level fluctuations are caused by variations in annual rainfall combined with a delayed response to distant pumping. Fluctuations in and near large well fields are caused largely by changes in pumping rates.

Hydrographs of selected observation wells in the Memphis Sand are shown in figure 4. Water levels in Fa:R-2, the most distant from the center of pumping, fluctuate only slightly and declined only 2 feet from 1949 to 1980. On the average, the rate of decline is less than 0.1 foot per year. Well Sh:Q-1, located at an intermediate distance from the center of pumping shows larger water-level fluctuations and a decline averaging about 0.7 foot per year from 1940 to 1980. Well Sh:P-76, located near the center of pumping, shows the largest fluctuations and a decline averaging 1.8 feet per year (ft/yr) since 1930.

Hydrographs for two wells screened in the Fort Pillow Sand are also shown in figure 4. The hydrograph for well Sh:O-170 in Mallory well field clearly shows, by an abrupt rise, a response to the cessation of all municipal pumping from this aquifer in the early 1970's. The hydrograph for well Fa:R-1, about 25 miles from the center of pumping shows a prolonged decline (about 0.4 feet per year) but a much less pronounced response to pumping changes. Current pumping from the aquifer is limited to an industrial area in Memphis and municipal pumping from West Memphis.

Future Water Levels

Unless pumpage from the shallow water-table aquifers or the Fort Pillow Sand increases significantly, large water-level changes in these aquifers are not expected. At the present rate of pumping, water levels in the Memphis Sand are expected to stabilize or show moderate declines. By the year 2000, declines of 25 to 35 feet below 1980 water levels near major pumping centers are predicted if pumping rates increase from about 190 Mgal/d to about 275 Mgal/d as projected by MLGW. At a distance of 10 miles from the main cone of depression, declines of 2 to 10 feet are predicted under these same conditions. These predictions are based on computer simulations by the Geological Survey (U.S. Army Corps of Engineers, Memphis Metropolitan Urban Area Water Resources Study, 1981). The Memphis Sand is expected to continue to provide an adequate supply of water for the Memphis area with few problems other than increased pumping lift being caused by water-level declines.

GROUND-WATER QUALITY

General Characteristics

Over the years, much water-quality information from the aquifers in the Memphis area has been obtained. Table 3 is a statistical summary of Geological Survey water-quality data for the years 1945-80. Although the water from each of the aquifers differs, there is considerable overlap in the ranges determined for many of the water-quality parameters.

The highest median concentrations of all constituents except sodium and chloride are found in water from the alluvium. Sodium is highest in the Fort

Table 3.--Minimum, median, and maximum values observed for selected common constituents and properties of water from the Memphis aquifer systems in the Memphis area.

[mg/L, milligrams per liter; µg/L, micrograms per liter; °C, degrees Celsius; µmho/cm, micromhos per centimeter]

	Silica, dissolved (mg/L as SiO_2)	Iron, dissolved (µg/L as Fe)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Nitrate, dissolved (mg/L as N)	Solids residue at 180°C (mg/L)	Hardness (mg/L as $CaCO_3$)	pH	Color (platinum-cobalt units)	Temperature (°C)	Specific conductance (µmhos/cm)
Alluvium																	
Minimum	28	12,000	104	30	5.9	3.6	464	2.8	5.8	0.2	0.2	418	400	6.5	5	16.1	664
Median	31	20,000	110	36	6.0	3.8	470	14	8.1	.2	1.8	460	410	6.8	5	16.1	748
Maximum	32	28,000	150	46	11	4.2	698	33	10	.4	4.0	674	560	6.8	10	16.7	1,160
Number of analyses.	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Fluvial (terrace) Deposits																	
Minimum	11	0	2.2	1.1	7.0	.3	24	0.0	1.9	0.0	0.1	75	14	5.7	0	16.0	88
Median	23	70	17	6.8	14	.7	92	7.6	9.0	.1	4.1	195	88	6.5	3	16.0	253
Maximum	45	2,400	78	42	56	5.5	459	51	89	0.6	75	388	367	7.3	7	17.2	689
Number of analyses.	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	30
Memphis Sand																	
Minimum	0.7	0	2.2	.70	3.3	.2	18	0.2	0.7	0.0	0.0	35	9	5.5	0	16.0	43
Median	12	410	12	4.8	8.1	.8	74	3.0	3.2	.1	.2	83	50	6.5	3	17.2	130
Maximum	29	16,000	41	18	16	3.7	212	18	22	0.7	4.0	380	164	7.9	18	18.9	350
Number of analyses.	57	77	76	58	50	52	67	82	74	59	55	61	78	65	53	47	56
Fort Pillow Sand																	
Minimum	8.5	180	1.8	0.7	31	1.5	96	4.2	1.0	0.0	0.0	105	8	7.2	9	21.1	145
Median	10	760	2.3	1.1	36	2.1	105	4.8	1.8	.1	0.2	114	10	7.6	25	21.7	174
Maximum	19	1,500	4.0	1.9	40	3.0	112	6.4	2.5	.1	0.4	118	17	7.9	60	22.2	186
Number of analyses.	11	16	16	16	6	6	16	16	16	6	16	16	16	16	11	16	11

Pillow Sand. Chloride is highest in the fluvial deposits. Dissolved solids is lowest in water from the Memphis Sand. Fluoride concentrations are low in water from all of the aquifers. The pH of water from the alluvium, the fluvial deposits, and the Memphis Sand is quite similar. It is markedly higher in water from the Fort Pillow Sand. Temperature of water in all of the aquifers increases with depth.

With the exception of the parameters noted above, the median concentrations of the constituents listed in table 3 generally decrease with increasing depth.

Because it is very hard and contains a high concentration of dissolved iron, water from the alluvium is less desirable for most purposes than water from the other aquifers. Water from the fluvial deposits generally meets most accepted criteria for domestic uses, although the lack of a capping layer makes proper well location and construction particularly important if contamination is to be avoided. Water from the two artesian aquifers, the Memphis Sand, and the Fort Pillow Sand requires minimal treatment for domestic and most industrial uses. High concentrations of dissolved iron are found in water from each of the aquifers. Aeration and filtration are frequently employed methods used to reduce the amount of dissolved iron.

Potential for Contamination

Historically, Memphis and Shelby County, along with commercial establishments and industries, have used dumps and landfills in the flood plains of nearby streams and in gravel pits in the upland areas to dispose of a variety of wastes including garbage, street refuse, construction materials, and chemical and industrial wastes. Although most of these dumps and landfills were closed in the early 1970's when the State began regulation of waste-disposal practices, leachates from these facilities have been and are entering the shallow water-table aquifers (Parks and others, 1982, p. 4).

Before contaminants from the waste-disposal sites of the area could possibly migrate to the Memphis Sand, they would first have to enter the water-table aquifers. Observation wells have been installed and sampled at six abandoned waste-disposal sites in the Memphis area. These sites have been identified as having received unknown quantities and types of industrial wastes. Concentrations of common constituents, selected trace constituents, and selected organic compounds were determined. The water contains constituents which indicate that leachates are entering the water-table aquifer in the immediate vicinity of the dumps (Parks and others, 1982). Several constituents, including chloride, color, iron, manganese, total dissolved solids, barium, cadmium, and endrin, exceed primary or secondary contaminant levels established by the Environmental Protection Agency (EPA) for drinking supplies (U. S. Environmental Protection Agency, 1976 and 1979); and some of the other constituents of EPA's list of priority pollutants such as chlordane, DDT, heptachlor epoxide, and toxaphene are present in trace amounts. All of these data are from wells screened in the upper part of the shallow aquifer, downgradient from the waste-disposal sites, and very close to them. Current investigation is being made at one of these sites to determine if contaminants have moved downward and concentrated at lower horizons in the water-table aquifer.

The Memphis Sand is thought to be separated from the water-table aquifers by a relatively thick and widespread confining bed consisting chiefly of clay (the Jackson Formation and upper part of the Claiborne Group). Locally, however, this confining bed may contain sand lenses or "windows" which could provide preferential paths for the movement of contaminated water from the shallower aquifers to the underlying Memphis Sand (Criner and other, 1964; Bell and Nyman, 1968; and Parks and Lounsbury, 1976). At present there is insufficient geologic information to locate or map these "windows" in the confining bed.

Eight deep wells in the Memphis Sand--one in each of the six MLGW well fields in production and two in outlying industrial areas--are sampled annually at the time of low water levels to monitor any changes in water quality. Since 1977, concentrations of common constituents and trace constituents have been determined. In 1980, concentrations of selected organic compounds were also determined. The results indicated no significant short-term changes in water quality. Moreover, a comparison of the recent values for common constituents with those from earlier analyses from the Memphis area, dating back to the 1930's, indicates no significant long-term changes. No traces of the selected organic compounds determined in 1980 were found. Therefore, based on available data, no indication of contamination of the Memphis Sand is evident.

LAND SUBSIDENCE

A lowering of the land surface, caused by the compaction of underlying material, is called land subsidence. The removal of fluids from the ground, usually water or oil, is one cause of land subsidence. The withdrawal of water from an aquifer causes a loss of the supporting pressure of the stored water and shifts more of the overburden weight to the aquifer skeleton. Where the skeleton consists of unconsolidated sediments, as in the Memphis area, this additional load, if great enough, can cause water to be squeezed out of the fine-grained sediments within and adjacent to the aquifer through a rearrangement of the previously stable configuration of the particle grains. This results in a reduction of porosity and volume which can eventually cause gradual subsidence of the land surface.

Extensometers

Two expanded-scale recording extensometers have been installed in the Memphis area to determine if pumping large quantities of water from the Memphis Sand is causing any detectable subsidence. These devices measure the movement of the land surface relative to fixed points beneath the compacting layer.

Extensometer Sh:O-228 was installed in 1978 in Mallory well field near the center of pumping for the Memphis area where the potential for land subsidence is greatest. It measures any movement that is occurring between land surface and a depth of 1,100 feet (fig. 5). Fluctuations in water levels for Sh:O-212, a nearby Memphis Sand observation well, and monthly pumpage totals for the Mallory well field are also included. Very small vertical land-surface movements are detected with this extensometer. Water levels in the observation well are a measure of artesian pressure. The parallel trends

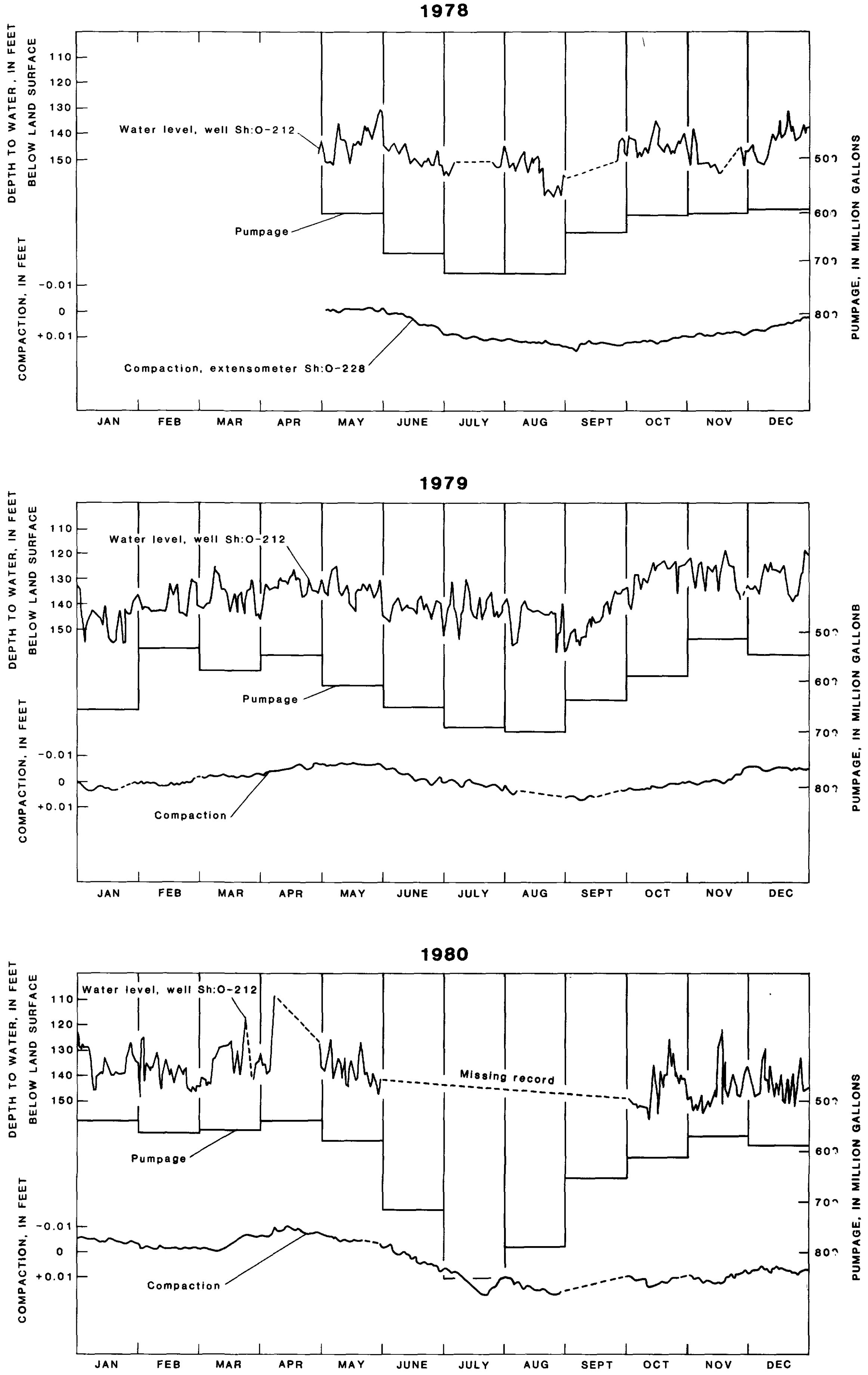


Figure 5. -- Measured compaction, water levels and monthly pumpage in Mallory well field.

of the extensometer record, the water-level hydrograph, and the pumpage bar graph show a relationship between artesian pressure and land-surface movement. Each year, the land surface is at its lowest during the summer months when pumpage is at peak and artesian pressure is lowest. In the spring, when artesian pressure is highest, after a period of less pumping, the land surface is at its highest. The maximum annual elevation change for the 2.5-year period of record has been less than 0.03 foot. This occurred in 1980. Over the period of record there has been no significant net gain or loss in land-surface elevation. Movement is therefore regarded as a result of a loss or gain of the supporting pressure of the water in the aquifer.

Extensometer Sh:J-142 was installed in 1969 in the Davis well field at the time the test holes for the water-supply wells were drilled. It measures movement between land surface and a depth of about 1,500 feet. This extensometer initially was installed to determine if any subsidence could be detected when the well field went into production. The record for Sh:J-142 shows a suggestion of the seasonal vertical land movements similar to those detected with Sh:O-228. However, Sh:J-142 was constructed according to an early design for extensometers and cannot determine very small movement on a long-term basis.

SUMMARY AND CONCLUSIONS

Ground water is the only source of water being used for municipal, industrial and domestic water supplies in the Memphis area. The major aquifers are: (1) the alluvium, (2) the fluvial (terrace) deposits, (3) the Memphis Sand, and (4) the Fort Pillow Sand. The alluvium and fluvial deposits are water-table aquifers, the Memphis and Fort Pillow Sands are artesian aquifers. Currently (1982) withdrawals average about 190 Mgal/d, nearly all of which is from the Memphis Sand. Potential problems associated with increases in pumpage and urban development are the lowering of water levels, contamination of the aquifers, and land subsidence.

Water levels in the Memphis Sand are declining at a rate that varies from less than 0.1 foot per year near the outcrop area to about 1.8 feet per year near the center of pumping. A map of the potentiometric surface of the Memphis Sand shows small cones of depression near major pumping centers superimposed on a large regional cone which reflects the composite effect of pumpage. If present pumping rates were maintained, water levels would stabilize or show moderate declines. A computer model of the Memphis Sand indicates that declines of 25 to 35 feet below 1980 water levels can be expected by the year 2000 near major pumping centers if pumping rates increase at rates projected by Memphis Light, Gas and Water Division.

Water levels in the water-table aquifers exhibit seasonal and annual fluctuations that correlate with variations in rainfall. No long-term declines are expected because there is negligible pumping from these aquifers. Water levels in the immediate Memphis area in the Fort Pillow Sand are currently higher than they were in the early 1970's due to the cessation of municipal pumping from the aquifer. A slight long-term decline of about 0.4 ft/yr is indicated in an observation well about 25 miles from the center of pumping. No long-term declines are expected unless pumping rates increase significantly.

Water taken from observation wells very close to abandoned waste-disposal sites in the Memphis area contains constituents which indicate that leachates are entering the water-table aquifers near these sites. No indications have been found that any of the contaminants from these sites are entering the deeper artesian aquifers.

A recording extensometer installed in the Memphis area indicates a seasonal land-surface elevation change of less than 0.03 foot. The elevation change correlates to seasonal changes in artesian pressure and pumping rates. No significant net gain or loss in land-surface elevation has been recorded over the period of record, indicating that no permanent land subsidence is occurring.

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