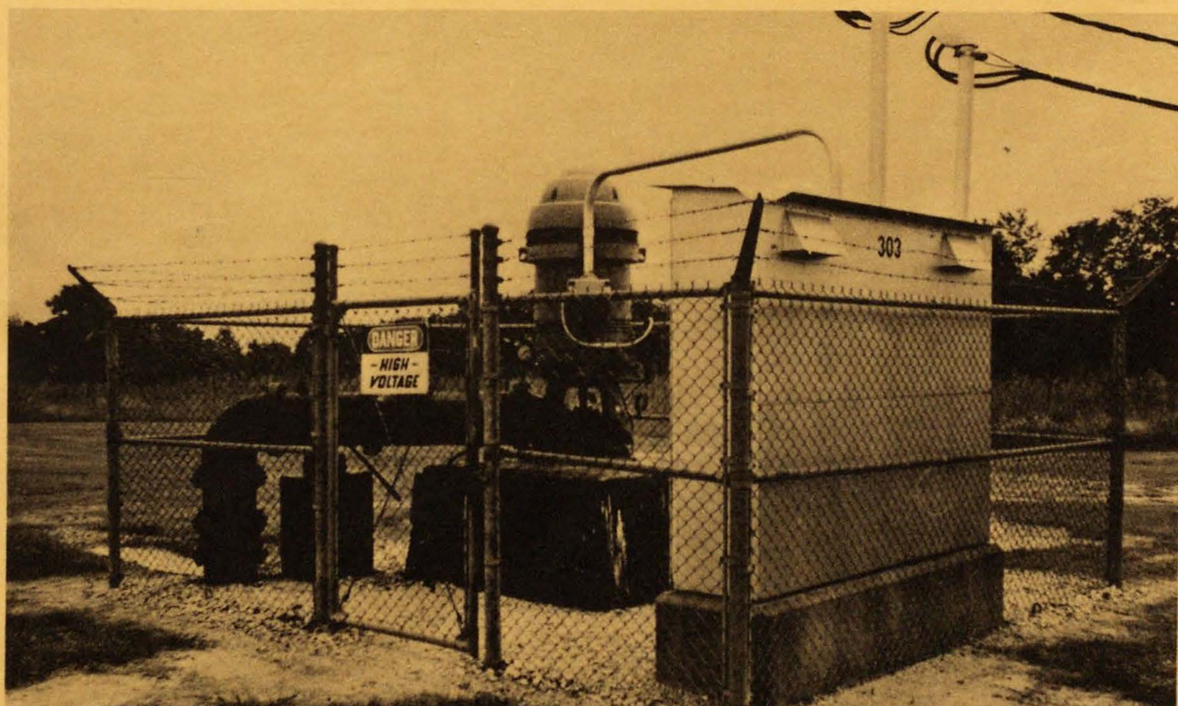
# HISTORIC WATER-LEVEL CHANGES AND PUMPAGE FROM THE PRINCIPAL AQUIFERS OF THE MEMPHIS AREA, TENNESSEE: 1886-1975



U. S. GEOLOGICAL SURVEY
Water-Resources Investigation 76-67




Prepared in cooperation with the

CITY OF MEMPHIS,

MEMPHIS LIGHT, GAS AND WATER DIVISION

# ERRATA

Bibliographic data sheet, item 17 - - change water utili_c_ation to
water utili_z_ation.

Page 6, table 1, column 4, line 15 - - change "1400-f_a_ct" sand to "1400-f_oo_t" sand.

Page 12, figure 3 - - the plots of water levels for wells Sh:U-2 and Sh:U-1 are in error for the years 1968 through 1975 and should be changed slightly to conform with the new values given for these wells on page 41 (table 3) and page 42 (table 4) below.

Page 21, paragraph 2, line 4 - - change Lichterma_nd_ to Lichterman.

Page 40, table 3, item 9 in heading - - change _D_a:R-2 to _F_a:R-2

Page 41, table 3, well Sh:U-2 - - change the values for the years indicated as follows: 1968 - - from 53.8 to 53.1, 1969 - - from 57.2 to 55.6, 1970 - - from 55.3 to 55.2, 1971 - - from 60.2 to 55.8, 1972 - - from 57.8 to 56.7, 1973 - - from 57.4 to 55.4, 1974 - - from 56.1 to 57.0, 1975 - - 54.9 to 55.3.

Page 42, table 4, well Sh:U-1 - - change the values for the years indicated as follows: 1969 - - from 55.6 to 57.2, 1971 - - 55.8 to 60.2, 1972 - - from 56.7 to 57.8, 1973 - - from 55.4 to 57.4, 1974 - - from 57.0 to 56.1, 1975 - - from 55.3 to 54.9.

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By James H. Criner and William S. Parks

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Water Resources Investigations 76-67

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Prepared in cooperation with the

City of Memphis

Memphis Light, Gas and Water Division

May 1976

UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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CONTENTS


| | Page |
|---|---|
| Abstract | 1 |
| Introduction | 1 |
| Well-numbering system | 5 |
| Aquifer systems | 5 |
| Ground-water pumpage | 5 |
| Water levels | 10 |
| Hydrographs | 11 |
| Potentiometric-surface maps | 14 |
| Water-level-change maps | 21 |
| Summary and conclusions | 22 |
| Selected references | 32 |
| Pumpage data | 35 |
| Water-level data | 39 |


ILLUSTRATIONS


| | |
|---|---|
| Figure 1.--Map of Memphis area showing locations of observation wells and Memphis Light, Gas and Water Division well fields | 3-4 |
| Figure 2.--Graphs showing pumping rates from major aquifers by major users | 9 |
| Figure 3.--Graphs showing water-level changes in observation wells screened in the major aquifers | 12 |
| Figure 4.--Map showing potentiometric surface of the Memphis Sand in 1886 | 15-16 |
| Figure 5.--Map showing potentiometric surface of the Memphis Sand in August 1960 | 17-18 |
| Figure 6.--Map showing potentiometric surface of the Memphis Sand in September 1970 | 19-20 |
| Figure 7.--Map showing potentiometric surface of the Memphis Sand in August 1975 | 23-24 |
| Figure 8.--Map showing potentiometric surface of the Fort Pillow Sand in April-August 1970 | 25-26 |
| Figure 9.--Map showing water-level changes in the Memphis Sand from August 1960 to September 1970 | 27-28 |
| Figure 10.--Map showing water-level changes in the Memphis Sand from September 1970 to August 1975 | 29-30 |

## TABLES

| | Page |
|---|---|
| Table 1.--Post-Midway geologic units underlying the Memphis area and their hydrologic significance........... | 6 |
| Table 2.--Pumping rates from the Memphis Sand and Fort Pillow Sand by major water users in Shelby County, Tenn., 1886-1975.................. | 36 |
| Table 3.--Lowest annual water levels recorded from selected observation wells in the Memphis Sand in the Memphis area, Tenn., 1927-1975........ | 40 |
| Table 4.--Lowest annual water levels recorded from selected observation wells in the Fort Pillow Sand in the Memphis area, Tenn., 1945-1975........................................ | 42 |
| Table 5.--Water levels used in preparation of potentiometric-surface maps for the Memphis Sand....... | 43 |
| Table 6.--Water levels used in preparation of potentiometric-surface map for the Fort Pillow Sand............................................... | 45 |

## CONVERSION FACTORS

Factors for converting English units to metric units are shown to four significant figures. In the text, however, the metric equivalents are shown only to the number of significant figures consistent with the values for the English units.

| English | Multiply by | Metric |
|---|---|---|
| ft (feet) | $3.048 \times 10^{-1}$ | m (metres) |
| ft/mi (feet per mile) | $1.894 \times 10^{-1}$ | m/km (metres per kilometre) |
| $ft^2/d$ (feet squared per day) | $9.290 \times 10^{-2}$ | $m^2/d$ (metres squared per day) |
| gal (gallons) | 3.785 | l (litres) |
| gal/min (gallons per minute) | 3.785 | l/min (litres per minute) |
| gal/d (gallons per day) | 3.785 | l/d (litres per day) |
| Mgal/d (million gallons per day) | 3.785 | Ml/d (million litres per day) |
| mi (miles) | 1.609 | km (kilometres) |
| $mi^2$ (square miles) | 2.590 | $km^2$ (square kilometres) |

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16. Abstracts Annual pumpage for both the Memphis Sand ("500-foot" sand) and Fort Pillow Sand ("1400-foot" sand) from the time of initial pumping from these aquifers to 1975 is presented in both tabular and graphic forms. The Memphis Sand supplied 188 million gallons per day in 1975 or 95 percent of the total water used in the area. Pumpage from the Fort Pillow Sand has decreased in recent years and in 1975 was about 4 million gallons per day. Pumping increases from the Memphis Sand have caused an almost continual decline of water levels as shown by graphs, tables, and a series of potentiometric-surface maps. Water-level-change maps show the fluctuations in water levels for two' periods of high water use. Water levels in the Fort Pillow Sand are also shown by tables and graphs and a potentiometric-surface map. These graphs illustrate a rise of water levels since 1963, coincidental with pumping reductions. The data presented suggest that a constant pumping rate will cause little water-level decline and that the water levels can be altered for efficient resource management by areally varying the distribution of pumping. The references listed support the information presented in this report.

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Memphis area, ground-water resources, water-level change, pumpage.

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# HISTORIC WATER-LEVEL CHANGES AND PUMPAGE FROM THE PRINCIPAL AQUIFERS OF THE MEMPHIS AREA, TENNESSEE: 1886-1975

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## ABSTRACT

The Memphis Sand ("500-foot" sand) supplies about 95 percent of the water used in the Memphis area for municipal and industrial purposes. In general, pumpage has increased at an irregular rate since the completion of the first well to this aquifer in 1886. These withdrawals are responsible for an almost continuous decline of water levels in wells throughout the Memphis area. Water-level data indicate that over the years a broad, regional cone of depression has developed in the potentiometric surface of the Memphis Sand and is centered near downtown Memphis. Areally smaller, subsidiary cones are superimposed upon this regional cone in areas heavily pumped by municipal and industrial wells. Pumpage from the Memphis Sand in Shelby County, Tenn., was 188 Mgal/d (million gallons per day) or 712 Ml/d (million litres per day) in 1975, although a maximum of 190 Mgal/d (719 Ml/d) was reached in 1974.

Pumpage from the Fort Pillow Sand ("1,400-foot" sand) began in 1924 and increased at a yearly rate of about 0.6 Mgal/d (2.3 Ml/d) until 1942. From 1943 to 1962, pumpage averaged about 11.5 Mgal/d (43.5 Ml/d), then was reduced as MLGW (Memphis Light, Gas and Water Division) discontinued wells that became unserviceable. MLGW ceased pumping from the aquifer in 1974, and pumpage from the remaining industrial wells in Shelby County in 1975 was 4.4 Mgal/d (16.6 Ml/d). Water levels in the Fort Pillow Sand generally have risen since 1963.

Water levels in the aquifers in the Memphis area fluctuate inversely with changes in pumping. Analysis of observation-well and pumpage data indicates that local water levels can be altered by changing the pumping rates or by varying the areal distribution of pumping.

## INTRODUCTION

The Memphis area, one of the major population and industrial centers of the Mississippi Valley, obtains most of its water supply from a complex artesian aquifer system that underlies a large part of the upper Mississippi embayment. Although water is pumped from both the Memphis Sand and Fort Pillow Sand, known locally as the "500-foot" sand and "1,400-foot" sand respectively, most of the current water supply is withdrawn from the Memphis Sand alone. Pumpage from this aquifer in 1975 was about 188 Mgal/d (712 Ml/d) which is about twice that in 1950, five times that in 1920, and ten times that in 1890. This escalating withdrawal from the Memphis Sand has resulted in a nearly uninterrupted lowering of its potentiometric surface, as indicated by the historic decline of water levels in wells throughout the area.

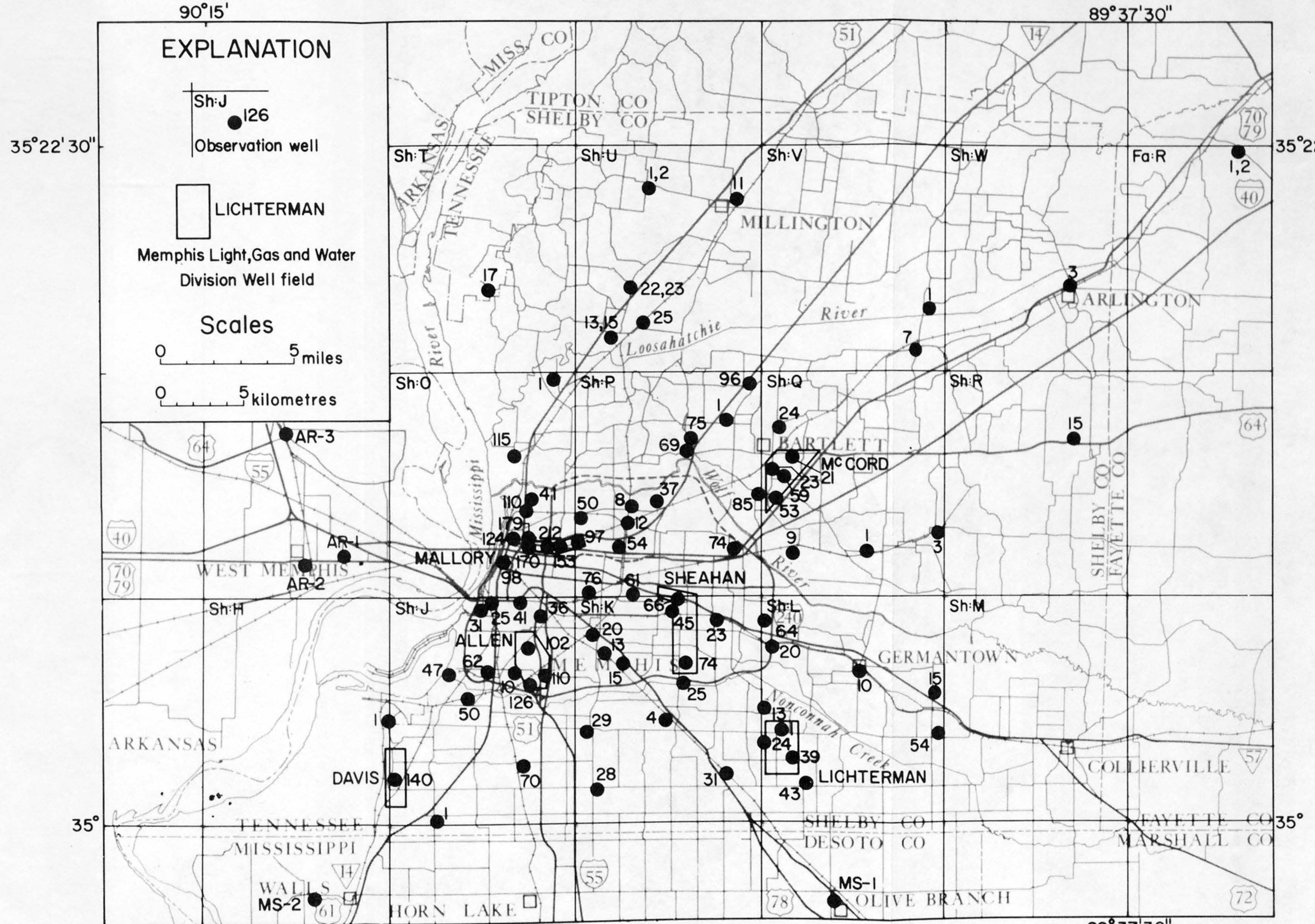
This report reviews the historic changes of water levels in the Memphis area with emphasis on the period after 1960. It also presents information on pumpage from the Memphis Sand since 1886 and from the Fort Pillow Sand since 1924 and discusses the relationship between pumping rate and water-level decline to 1975. The report is intended to provide basic data and interpretive information for use by water managers, planners, and other persons interested in the ground-water resource, and to update prior publications discussing the water-level changes in the Memphis area.

General aspects of the aquifer systems in the Memphis area are described or discussed in reports by Schneider and Cushing (1948), Criner and Armstrong (1958), Criner, Sun, and Nyman (1964), and Bell and Nyman (1968). Other reports which contain pertinent information about pumping rates and water levels for the principal aquifers are included in the selected references. Since 1935, the Geological Survey has published many water-supply papers that give data concerning ground-water levels in the United States. To provide easy reference for readers interested in low water levels on a monthly or 5-day basis, those water-supply papers that include data for the Memphis area are listed in the following table:

Numbers of U.S. Geological Survey Water-Supply Papers containing records of water levels in the Memphis area, Tennessee

| Year | WSP | Year | WSP | Year | WSP | Year | WSP |
|---|---|---|---|---|---|---|---|
| 1936 | 817 | 1942 | 945 | 1948 | 1127 | 1954 | 1322 |
| 1937 | 840 | 1943 | 987 | 1949 | 1157 | 1955 | 1405 |
| 1938 | 845 | 1944 | 1017 | 1950 | 1166 | 1956-58 | 1538 |
| 1939 | 886 | 1945 | 1024 | 1951 | 1192 | 1959-63 | 1803 |
| 1940 | 907 | 1946 | 1072 | 1952 | 1222 | 1964-68 | 1978 |
| 1941 | 937 | 1947 | 1097 | 1953 | 1266 | 1969-73 | 2171 |

As used in this report, the term "Memphis area" refers to a 1,300 $mi^2$ (3,400 $km^2$) area comprising parts of three states. It includes Shelby County and parts of Fayette and Tipton Counties in Tennessee and adjacent counties in Mississippi and Arkansas. The boundaries of the Memphis area have been modified somewhat from the area as defined for previous reports. The present boundaries and the locations of observation wells used for diagrams and maps presented in this report are shown in figure 1.




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

Figure 1.-- Memphis area, Tenn., with locations of observation wells and Memphis Light, Gas and Water Division well fields.

Nyman, D. J., 1965, Predicted hydrologic effects of pumping from the Lichterman well field in the Memphis area, Tennessee: U.S. Geol. Survey Water-Supply Paper 1819-B, 26 p.

Parks, W. S., and Lounsbury, R. W., 1975, Environmental geology of Memphis in Field trips in West Tennessee: Tennessee Div. Geol. Rept. Inv. 36, p. [illegible]

Reed, J. E., 1972, Analog simulation of water-level declines in the Sparta Sand, Mississippi embayment: U.S. Geol. Survey HA-434, 1 pl.

Safford, J. M., 1890, The water supply of Memphis: Tennessee Board of Health Bull., [illegible]

Schneider, Robert, and Cushing, E. M., 1948, Geology and water-bearing properties of the "1,400-foot" sand in the Memphis area: U.S. Geol. Survey Circ. 33, 13 p.

Wells, F. G., 1931, A preliminary report on the artesian water supply of Memphis, Tennessee: U.S. Geol. Survey Water-Supply Paper 638-A, 34 p.

_____1933, Ground-water resources of western Tennessee: U.S. Geol. Survey Water-Supply Paper 656, 319 p.

## Well-Numbering System

Wells are identified according to the numbering system used by the U. S. Geological Survey throughout Tennessee. The well number consists of three parts: (1) an abbreviation of the name of the county in which the well is located; (2) a letter designating the $7\frac{1}{2}$-minute quadrangle, or $7\frac{1}{2}$-minute quadrant of the 15-minute quadrangle, on which the well is plotted; and (3) a number generally indicating the numerical order in which the well was inventoried. The symbol Sh:U-2, for example, indicates that the well is located in Shelby County on the "U" quadrangle and is identified as well 2 in the numerical sequence. The quadrangles are lettered from left to right, beginning in the southwest corner os the county. Quadrangle "U", cited in the example, is the southwest quadrant of the Millington 15-minute quadrangle, now the Millington $7\frac{1}{2}$-minute quadrangle.

For this report, wells in Arkansas and Mississippi are numbered consecutively in order of use in the preparation of illustrations and are assigned prefixes AR and MS, respectively.

## AQUIFER SYSTEMS

About 3,000 ft (900 m) of sand, clay, silt, chalk, gravel, and lignite underlie the Memphis area above the Paleozoic bedrock. These deposits make up geologic units ranging in age from Late Cretaceous to Holocene. In this report, only the post-Midway formations (Wilcox and younger) will be considered. The stratigraphic relations of these units and their hydrologic significance are shown in table 1.

The principal water-bearing formations are the Memphis Sand and the Fort Pillow Sand. More than 95 percent of the ground water used in the Memphis area is supplied by the Memphis Sand. The Fort Pillow Sand is the source of supply for one industry in Tennessee and for a few municipal and industrial wells in Arkansas and Mississippi. The fluvial deposits and alluvium supply water to many domestic and farm wells and to a few industrial wells. Collectively, the shallow aquifers and the Fort Pillow Sand provide less than 5 percent of the water used in this area.

## GROUND-WATER PUMPAGE

The early citizens of Memphis obtained their water supply from streams, cisterns, springs, and shallow wells. As the city grew, these sources became inadequate because of the small quantity or poor quality of the water. The search for a dependable source of good quality water ended in 1886 when the first artesian well was completed to the Memphis Sand. The successful completion of this flowing well encouraged the drilling of additional wells and a greater utilization of the ground-water resource. Within the year, two water companies began drilling to the Memphis Sand, and by 1888 each had completed eight wells and both were supplying water to the city.

Table 1.--Post-Midway geologic units underlying the

| System | Series | Group | Stratigraphic unit | Thickness (feet) |
|---|---|---|---|---|
| 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-fact" sand) | 210-280 |
| | Paleocene | | Old Breastworks Formation | 200-250 |

Memphis area and their hydrologic significance.

| Lithology and hydrologic 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 water for irrigation and some industrial uses. |
| Wind-deposited silt; silty clay and minor sand. Forms a blanket over the fluvial deposits in upland areas; 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-grained sand and 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-grained 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 95 percent of water used in Memphis area. |
| Gray, greenish-gray, and brown carbonaceous clay. Locally contains fine-grained 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 principal aquifer supplying about 3 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. |

Over the years the development of the ground water resource in the Memphis area has progressed at an accelerated rate with the addition of many wells in both the Memphis Sand and Fort Pillow Sand for municipal and industrial supplies. In 1975 the municipal system at Memphis consisted of about 140 wells, most of which are in six well fields - (1) Mallory (formerly Parkway), (2) Sheahan, (3) Allen, (4) McCord, (5) Lichterman, and (6) Davis (fig. 1). In addition to the Memphis supply, other municipal systems and industries have more than 200 wells scattered over the area, some of which are concentrated in well fields or towns or in industrial development sites.

Average-daily pumping rates from the major aquifers and by major users in Shelby County for the period from 1887 to 1975 are shown in figure 2. Specific information concerning annual withdrawals from the major aquifers are given in table 2 in the pumpage-data section of this report. Pumpage data for the Arkansas and Mississippi parts of the Memphis area are not included because the water-use surveys have not extended into these areas.

Since the discovery of the artesian water system in 1886, annual withdrawals from the Memphis Sand have continued to increase at an irregular rate (fig. 2). In the late 1880's and early 1890's, pumpage increased at a yearly rate of about 3.3 Mgal/d (12.5 Ml/d). From 1895 to 1920, however, the rate of increase was only about 0.2 Mgal/d (0.8 Ml/d), and annual withdrawals averaged about 33 Mgal/d (125 Ml/d). Beginning in 1920, pumpage shows a pronounced and sustained yearly rate of increase of about 2.3 Mgal/d (8.7 Ml/d). This rate of increase persisted until 1960 when withdrawal was about 127 Mgal/d (481 Ml/d). Between 1920 and 1960, short-term deviations from the long-term trend include a sharp increase in annual withdrawal from 1941 to 1943 and a sharp decrease from 1944 to 1946. These deviations were the result of increased water use by industry to meet production demands brought on by World War II and of a reduction in water use near the end of the war. Beginning in 1960, pumpage shows another sustained yearly rate of increase which is larger than that for the previous five decades. This increase has averaged about 4.5 Mgal/d (17 Ml/d) and persisted to 1974. In that year, withdrawal from the Memphis Sand in Shelby County was about 190 Mgal/d (719 Ml/d), which is the largest annual pumpage yet recorded. In 1975, pumpage was reduced to 188 Mgal/d (712 Ml/d) probably as a result of above-normal rainfall during the year.

The Fort Pillow Sand was first used at Memphis in 1924 to supplement supplies from the Memphis Sand. From the time of initial use until 1942, pumpage from the Fort Pillow Sand increased at an average yearly rate of about 0.6 Mgal/d (2.3 Ml/d). From 1943 to 1962, annual pumpage remained relatively constant and averaged about 11.5 Mgal/d (43.5 Ml/d). Peak withdrawal within this period was in 1951, when annual pumpage was about 14.3 Mgal/d (54.1 Ml/d). At that time, MLGW[1] had 20 wells pump-

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1/ MLGW, throughout this report, refers to the present Memphis Light, Gas and Water Division since its orgainization in 1939 and to private and municipal predecessors supplying water to the City of Memphis before that time.

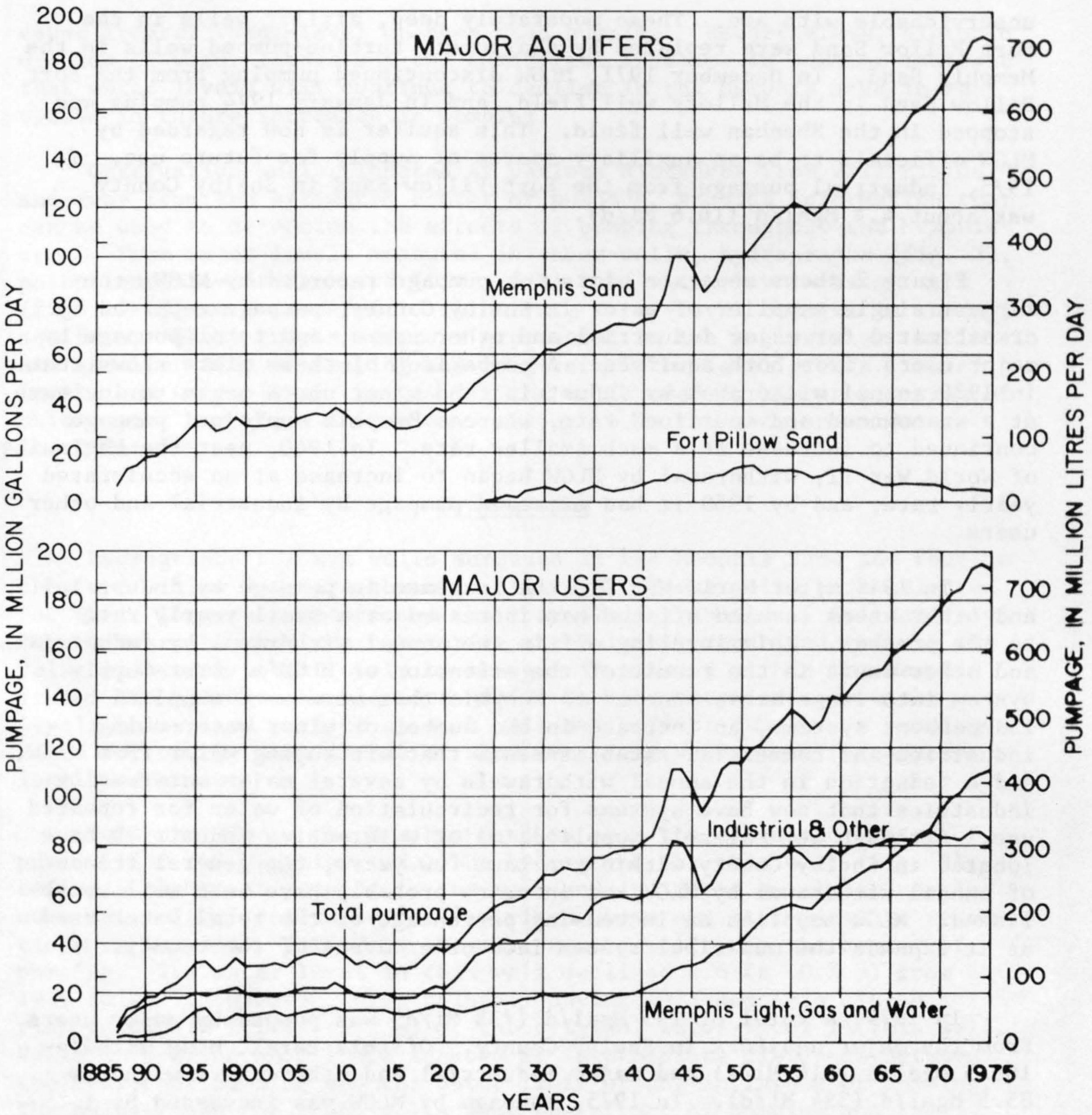


Figure 2.--Pumping rates from major aquifers by major users in Shelby County, Tennessee, 1887-1975.

ing from the Fort Pillow Sand in Mallory and Sheahan well fields, and industry had three wells. In 1962, however, MLGW began a reduction in their withdrawals by discontinuing wells as they became inefficient or unserviceable with age. These moderately deep, airlift wells in the Fort Pillow Sand were replaced by shallower, turbine-pumped wells in the Memphis Sand. In December 1971, MLGW discontinued pumping from the Fort Pillow Sand in the Mallory well field, and in January 1974 pumping was stopped in the Sheahan well field. This aquifer is now regarded by MLGW officials to be an auxiliary source of supply for future use. In 1975, industrial pumpage from the Fort Pillow Sand in Shelby County was about 4.4 Mgal/d (16.6 Ml/d).

Figure 2 shows separate plots for pumpage reported by MLGW, the largest single supplier of water in Shelby County, pumpage reported by or estimated for major industrial and other users, and total pumpage by major users from both aquifers. A comparison of these plots shows that in 1920 annual withdrawal by industrial and other users began to increase at a pronounced and sustained rate, whereas Memphis municipal pumpage continued to increase at a much smaller rate. In 1940, near the beginning of World War II, withdrawal by MLGW began to increase at an accelerated yearly rate, and by 1968 it had exceeded pumpage by industrial and other users.

In 1948 after World War II, the increase in pumpage by industrial and other users leveled off and has increased at a small yearly rate to the present. This leveling off in the annual withdrawal by industrial and other users is the result of the extension of MLGW's water-supply system into large areas annexed to Memphis that were once supplied by independent systems, an increase in the number of minor water-using industries and commercial establishments that are buying water from MLGW, and a reduction in the annual withdrawals by several major water-using industries that now have systems for recirculation of water for repeated use. Although several self-supplied, major water-using industries have located in Shelby County within the last few years, the general trends of annual withdrawal by MLGW and industry probably have been well established. MLGW supplies an increasing percentage of the total water used as it expands the municipal system into other areas of the county.

In 1974, a total of 195 Mgal/d (738 Ml/d) was pumped by major users from the major aquifers in Shelby County. Of this total, MLGW withdrew 109.5 Mgal/d (414 Ml/d) and major industrial and other users withdrew 85.5 Mgal/d (324 Ml/d). In 1975, pumpage by MLGW was increased by 1 Mgal/d (3.8 Ml/d) while withdrawals by industrial and other users was reduced by about 3 Mgal/d (11.4 Ml/d) for a total of 193 Mgal/d (730 Ml/d).

## WATER LEVELS

Water levels have declined throughout the Memphis area as a result of the long-term escalation of pumping. The rates of water-level decline have not been uniform from place to place because of changes in pumping rates and distribution of wells and well fields, and also because of variations in annual rainfall. In some large well fields and adjacent areas, changes in pumping have caused substantial water-level fluctuations, but in outlying parts of the Memphis area, variations in annual rainfall may cause greater water-level changes than pumping. Nevertheless, historic decline of water levels and the concurrent increase in pumping indicate that water levels will continue to decline in the Memphis area in response to future increases in pumping.

Observation wells, located at various distances from well fields and away from the estimated center of pumping, provide information that can be used to determine the effects of pumping throughout the Memphis area. From water levels measured in these wells, hydrographs (fig. 3), potentiometric-surface maps (figs. 5-8), and water-level-change maps (figs. 9-10) were prepared to illustrate water-level changes in the major aquifers. These graphs and maps are useful in the analysis of the local and areal effects of pumping and long-term water-level trends. Water levels and water-level changes for the wells used in the preparation of this report are given in tables 3 through 6 in the section on water-level data.

## Hydrographs

Hydrographs for six wells screened in the Memphis Sand and four in the Fort Pillow Sand are shown in figure 3. These wells were selected for their long-term record and their areal distribution. Collectively, the hydrographs show representative water-level trends and reflect the relationship of water levels to changes in pumping within the Memphis area. The hydrographs also are useful because they indicate water levels below land surface at each well and reflect changes in pumping rates for nearby well fields or show long-term water-level trends for localized areas.

Well Sh:P-76 in the Memphis Sand is near the estimated center of pumping for the Memphis area. The hydrograph for this well (fig. 3) reflects the total pumping in the area and indicates an almost continuous water-level decline. The few rises shown are attributed to reductions in pumpage. Fa:R-2 is the most remote well from the center of pumping. The water level in this well declined 2.6 ft (0.8 m) from 1949 to 1972. However, high rainfall during 1973 and 1975 caused a rise to within 1.1 ft (0.3 m) of the original water-level in this well. Wells Sh:U-2 and Sh:Q-1 are located at intermediate distances between the center of pumping and the outer limit of the influence of pumping. The hydrographs for these wells show the effect of pumping and the declining trend of water levels for their respective areas. Well Sh:K-66 is in Sheahan well field but it is far enough away from production wells that its water-level record is representative of water-level changes in the central part of the Memphis area.

The earliest, continuous, automatically-recorded water-level data collected in the Memphis area began in 1927 on Sh:O-124. This well is near the site of the first well completed to the Memphis Sand in 1886, and for this reason, its hydrograph was projected backward in time to illustrate the probable original water level with respect to the land surface (fig. 3). This projection to an estimated water level of 10 ft (3 m) above land surface or 240 ft (73 m) above sea level is

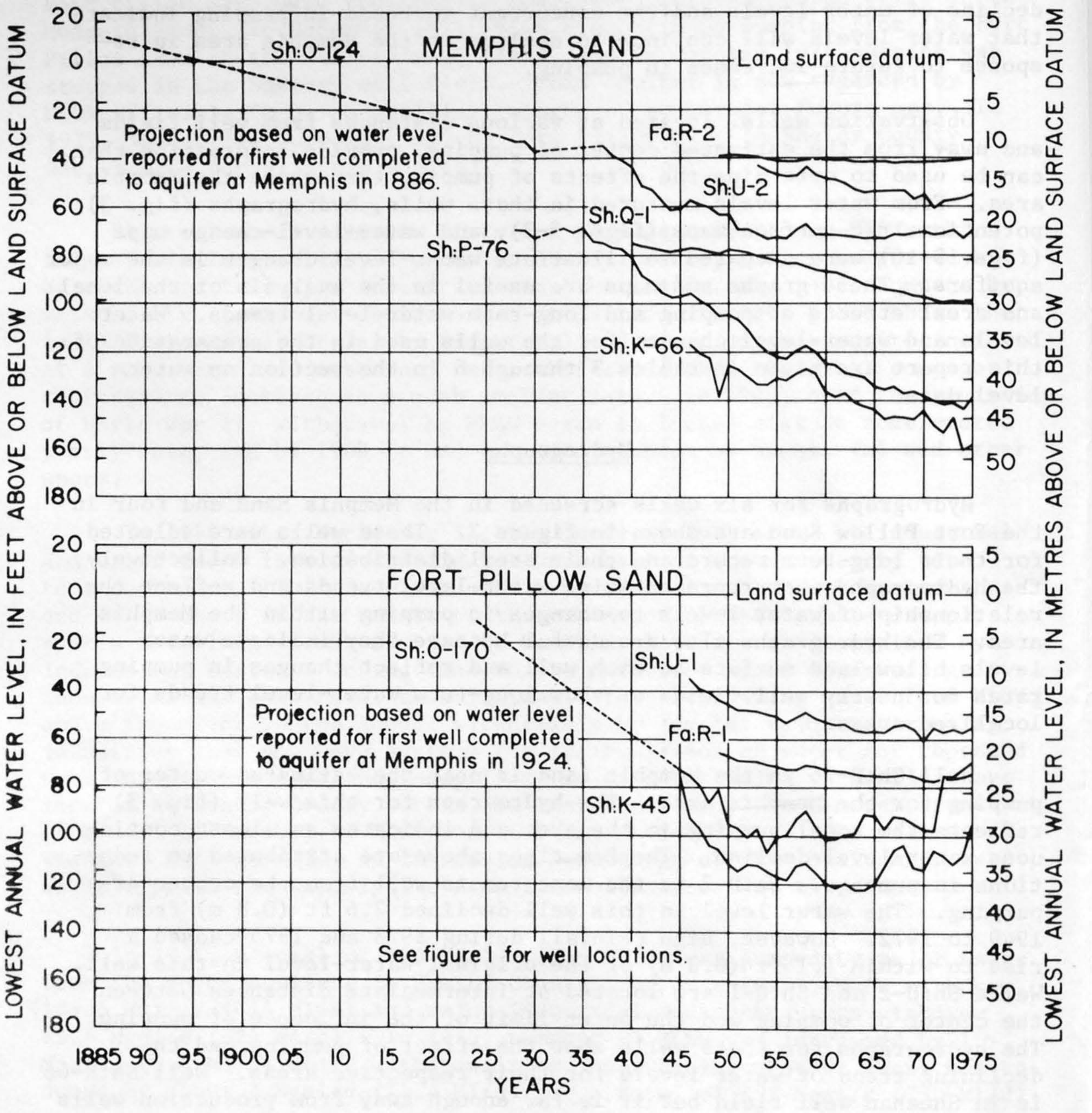


Figure 3. -- Water-level changes in observation wells screened in the major aquifers within the Memphis area, Tenn., 1886-1975.

based on a reported water level in the Bohlen-Huse Ice Company well drilled in 1886 and an estimated land surface altitude at the location of this first well.

It should be noted that well Sh:O-124 is an inspection shaft to an underground tunnel used in an early water-supply system as a collector for water which flowed from several wells screened in the Memphis Sand. Little is known about the tunnel, but it is reported to have been constructed in a clay layer, about 85 ft (26 m) below land surface and below the potentiometric surface of the Memphis Sand. Actual measurement to the bottom of the tunnel at Sh:O-124 in 1975 was 90.4 ft (27.5 m). The tunnel was reported to be brick lined, about 5 ft (1.5 m) in diameter, and about one-quarter mile (0.4 km) in length. Several wells were completed along the tunnel and were constructed so that water would flow into the tunnel through underground outlets. Water was pumped into the city supply system from a large well, 40 ft (12 m) in diameter, at the end of the tunnel at the Auction Avenue Station. The water-level record for well Sh:O-124 appeared responsive to annual pumpage in Memphis until about 1955 (fig. 3). Thereafter, the water level remained nearly constant except during years of high rainfall when it rose, as did the water level in other observation wells in the area.

The hydrograph (fig. 3) and potentiometric-surface maps indicate that the water level in Sh:O-124 is anomalously high and that the tunnel may have become a line of recharge to the Memphis Sand in about 1955. For this reason, the records for this well were not used in the preparation of the potentiometric-surface or water-level-change maps (figs. 5-7 and 9-10). The water level in Sh:O-124 fluctuates seasonally in unison with other wells located about the same distance from pumping centers. Nevertheless, the water level in this well may be affected by leakage from the Mississippi River, other nearby streams, the shallow aquifers, a storm sewer, or any combination of these.

The hydrographs for wells screened in the Fort Pillow Sand (fig. 3) are similar to those for the Memphis Sand, although water levels are more responsive to pumping. The center of pumping for the aquifer has remained near well Sh:O-170 since 1924, although pumping from the well field (Mallory) in which this well is located was stopped in 1971. The hydrograph shows a sharp rise in water level in 1971, reflecting the cessation of pumping. Well Fa:R-1 is the most remote observation well from the center of pumping for the Fort Pillow Sand. The hydrograph for this well shows greater water-level fluctuations than does the one for nearby Fa:R-2 in the Memphis Sand. These greater fluctuations reflect the lower transmissivity of the Fort Pillow Sand which responds to pumping more like an idealized artesian aquifer than the Memphis Sand. The hydrograph for well Sh:U-1, located about 18 mi (30 km) north of the center of pumping, reflects some local variations in pumping, but it is a good indicator of the areal water-level trend. Well Sh:K-45 is in Sheahan well field about 10 mi (16 km) east of the center of pumping. The hydrograph for this well also reflects the areal water-level trend, but the effect of local pumping is more pronounced.

The water level in the first well completed in the Fort Pillow Sand was recorded by MLGW as 11 ft (3.3 m) below land surface or at a potentiometric-surface altitude of 244 ft (74 m) above sea level in November 1924. This production well was about 1,000 ft (300 m) north of Sh:O-170, at about the same land-surface altitude, and therefore, the water level below land surface should have been nearly the same in both wells. Owing to the similarity in altitude, to the closeness of Sh:O-170 to the site of an original water-level measurement, and because this well has the longest water-level record, its hydrograph was projected backward in time to the probable original static level in the Fort Pillow Sand. This projection is shown in figure 3.

## Potentiometric-Surface Maps

Contour maps made from water-level measurements in wells show the configuration of the potentiometric surface of an artesian aquifer at a particular time. The presumed shape of that surface for the Memphis Sand in 1886, prior to the development of wells in the aquifer, is shown in figure 4. The surface was generally flat, dipping northeasterly at a hydraulic gradient of from 1.5 to 2 ft/mi (0.28 to 0.38 m/km). Although the original altitude of the potentiometric surface is uncertain, it is estimated to have been about 240 ft (73 m) above sea level at the site of the first well on Court Avenue at Gayoso Bayou (Bohlen-Huse Ice Company). The control wells shown in figure 4 were selected for their locations away from pumping centers and for their long records which were used to estimate the probable original potentiometric surface.

The shape of the surface in August 1960, after 73 years of pumping from the Memphis Sand, is shown in figure 5. This contour map shows that one of the effects of escalating pumping has been the development of a broad cone of depression in the originally, nearly flat, potentiometric surface. This cone is centered beneath downtown Memphis. Within the major cone of depression were areally smaller, subsidiary cones at Allen, Mallory, and Sheahan well fields and two industrial sites. The two cones shown on figure 5 for Sheahan were centered on the two widely separated clusters of wells in that field. By 1960 only a slight distortion of the potentiometric surface was evident at the eastern edge of the Memphis area, illustrating the decreasing effect of pumping with distance from the pumping centers.

A similar potentiometric-surface map for September 1970 is shown in figure 6. By 1970 the increased pumpage of water from the Memphis Sand has caused the regional cone of depression to deepen and expand throughout the area with subsidiary cones becoming more or less pronounced in accordance with changes in pumping at these localities. The greatest decline of water levels or deepening of the cone was in Allen well field where the annual pumping rate doubled from 1960 to 1970. Also, by 1970 the hydraulic gradient had steepened throughout the area. This gradient was about 10 ft/mi (1.9 m/km) along a line from Olive Branch, Miss., to the Allen well field. The contour map for 1970 (fig. 6) shows that the subsidiary cones at well fields and industrial sites were somewhat deeper than in 1960 and that the two cones at Sheahan well field had been replaced by a single cone for that field.

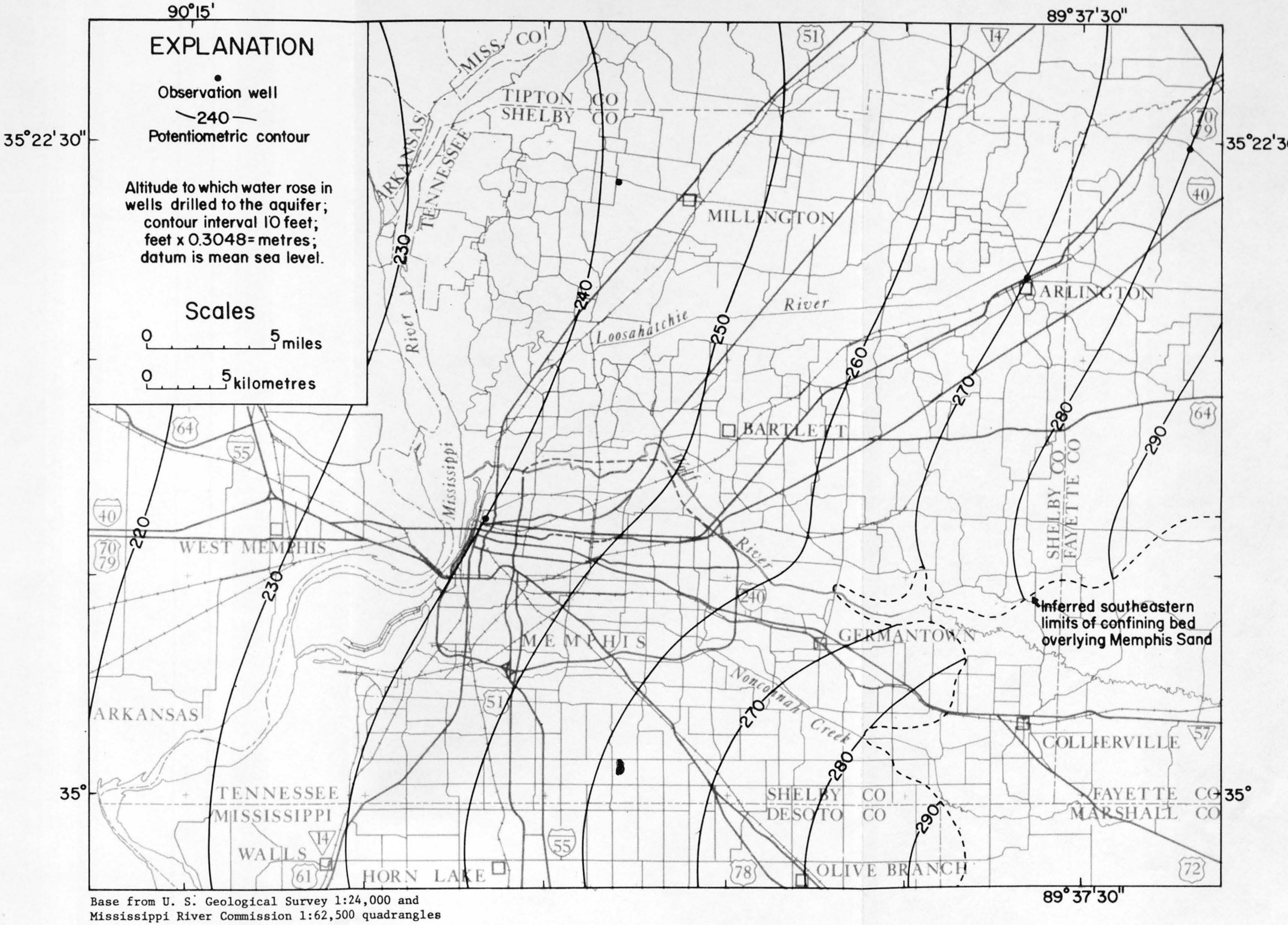


Figure 4.--Potentiometric surface of the Memphis Sand in 1886.

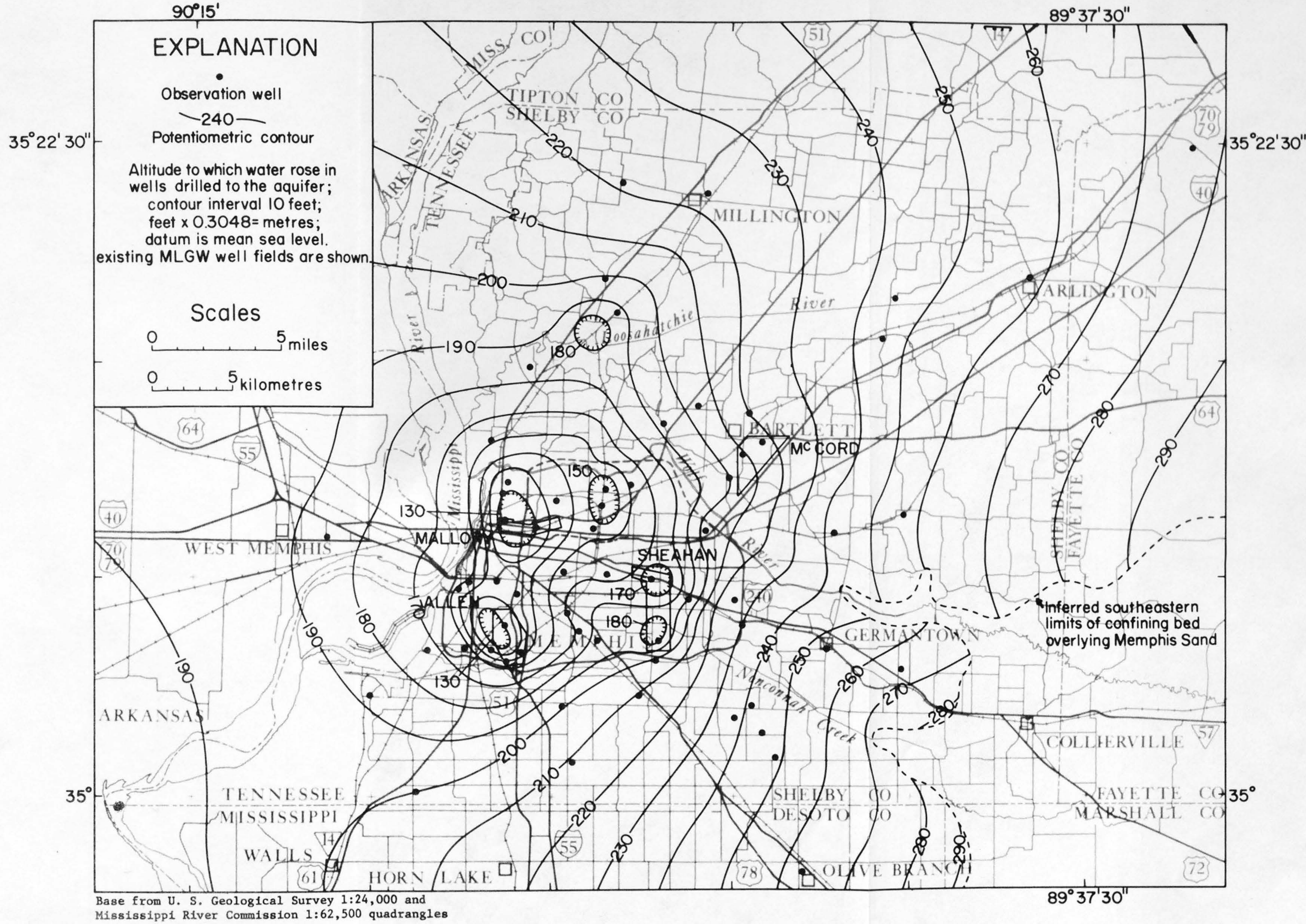


Figure 5.--Potentiometric surface of the Memphis Sand in August 1960.

Nyman, D. J., 1965, Predicted hydrologic effects of pumping from the Lichterman well field in the Memphis area, Tennessee: U.S. Geol. Survey Water-Supply Paper 1819-B, 26 p.

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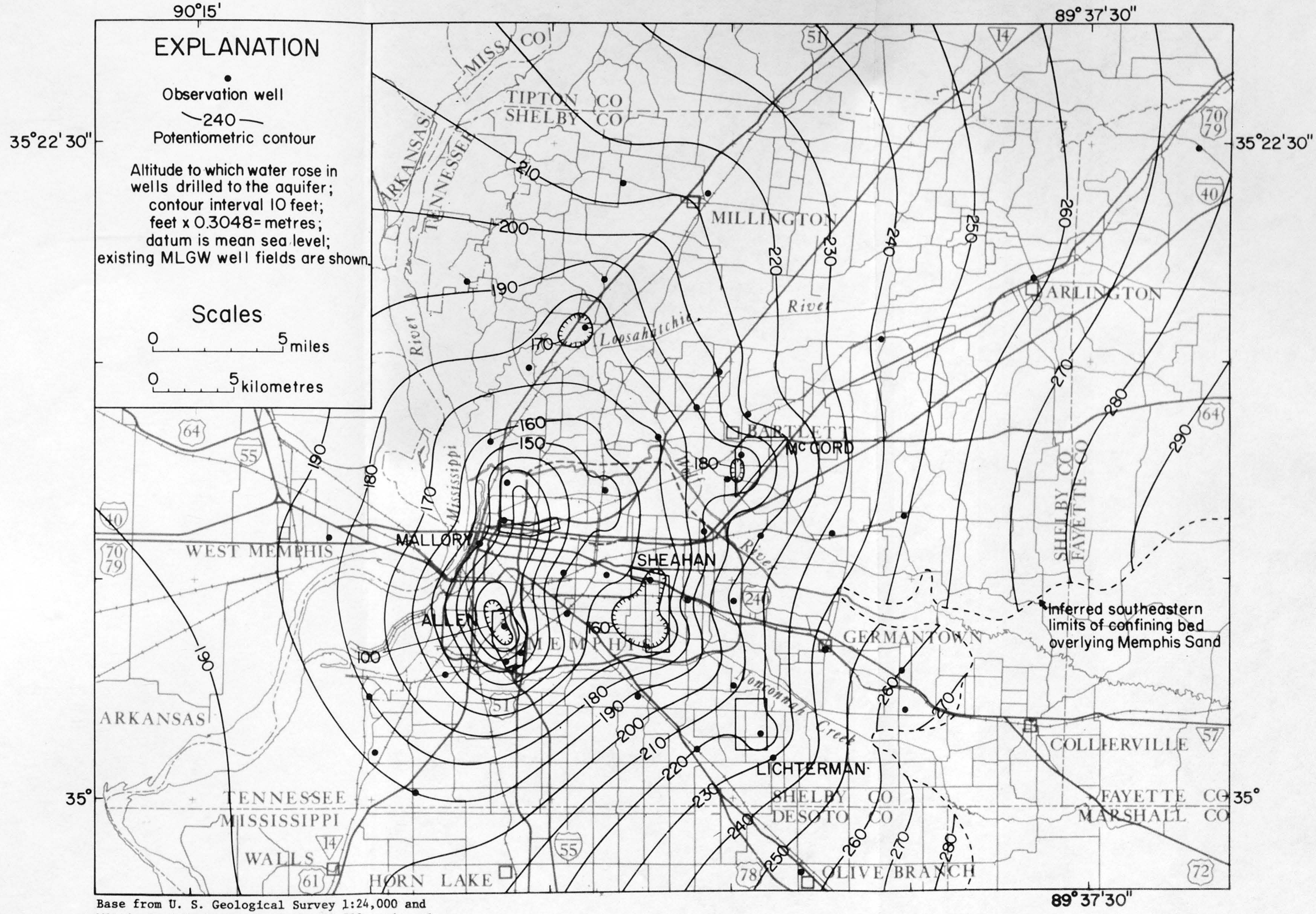


Base from U. S. Geological Survey 1:24,000 and Mississippi River Commission 1:62,500 quadrangles

Figure 6.--Potentiometric surface of the Memphis Sand in September 1970.

The cones at Mallory and Allen well fields had also overlapped, forming a single elongated cone, further indicating the interference of pumping between well fields. The apex of this cone was centered on Allen well field, which in 1970, produced about three times the amount of water produced by Mallory well field.

Other noticeable changes by 1970 included the development of new cones at McCord and Lichterman well fields. The McCord field, which is not shown as a distinct cone on the 1960 map, almost doubled its water production in the decade ending in 1970. Lichtermand began operation in 1965 and averaged more than 16 Mgal/d (60 Ml/d) in 1970.

A potentiometric-surface map for August 1975 is shown in figure 7. This map shows a cone of depression at the Davis well field, which began operation in 1971 and in 1975 pumped about 12 Mgal/d (45 Ml/d). The map also shows a higher potentiometric surface at Allen well field than that of 1970, as a result of a reduction in pumping of about 10 Mgal/d (38 Ml/d). Pumping from Mallory increased about the same amount and the cone deepened in that field to about 90 ft (27 m) above sea level, as determined from the deepest water level recorded in the Memphis area in Sh:0-179. Although the cones at Mallory and Allen well fields remained overlapped in 1975, a large increase in pumpage from Mallory and continued industrial withdrawals in the vicinity, caused the apex of the combined cone to shift from Allen well field to Mallory well field. In 1975, pumpage was about 21 Mgal/d (79 Ml/d) from Allen field and about 28 Mgal/d (105 Ml/d) from Mallory field and nearby industrial wells.

A comparison of the 1960, 1970, and 1975 potentiometric-surface maps (fig. 5-7) shows a progressive steepening of the hydraulic gradient on the western side of the major cone of depression adjacent to the Mississippi River. The exceptionally steep hydraulic gradient west of Mallory well field evident on the 1975 map (fig. 7) indicates recharge to the Memphis Sand. This recharge may be the result of downward leakage from the Mississippi River alluvium, or perhaps, from the river itself.

The original potentiometric surface of the Fort Pillow Sand was probably similar to that of the Memphis Sand, but a few feet higher. Comparatively few observation or production wells are made in the Fort Pillow Sand, and therefore, only a limited number of water-level measurements are available for use in making potentiometric-surface maps. For this reason, the potentiometric surface for 1970, as shown in figure 8, was constructed by using miscellaneous water-level measurements for April, July, and August of that year. Although the resulting map does not show local pumping centers, it outlines the general shape of the major cone of depression. Since 1970, the cessation of pumping from this aquifer at Mallory and Sheahan well fields has caused water levels in Shelby County to recover several feet.

## Water-Level-Change Maps

The net change of potentiometric-surface altitudes can be determined by deriving a water-level-change map from the potentiometric-surface maps and water levels in observation wells for any two years. Such a map, illustrating the water-level changes in the Memphis Sand from 1960 to 1970, is shown in figure 9. The contours generally outline the major municipal and industrial pumping centers and indicate a general water-level decline throughout most of the Memphis area. Those contours encompassing declines of 10 to 30 ft (3 to 9 m) or more form an irregular pattern in and around downtown Memphis. In the northern part of Memphis and outside the irregular band of large decline, are areas of decline from zero to less than 10 ft (3 m) where pumpage has remained nearly constant for more than 10 years.

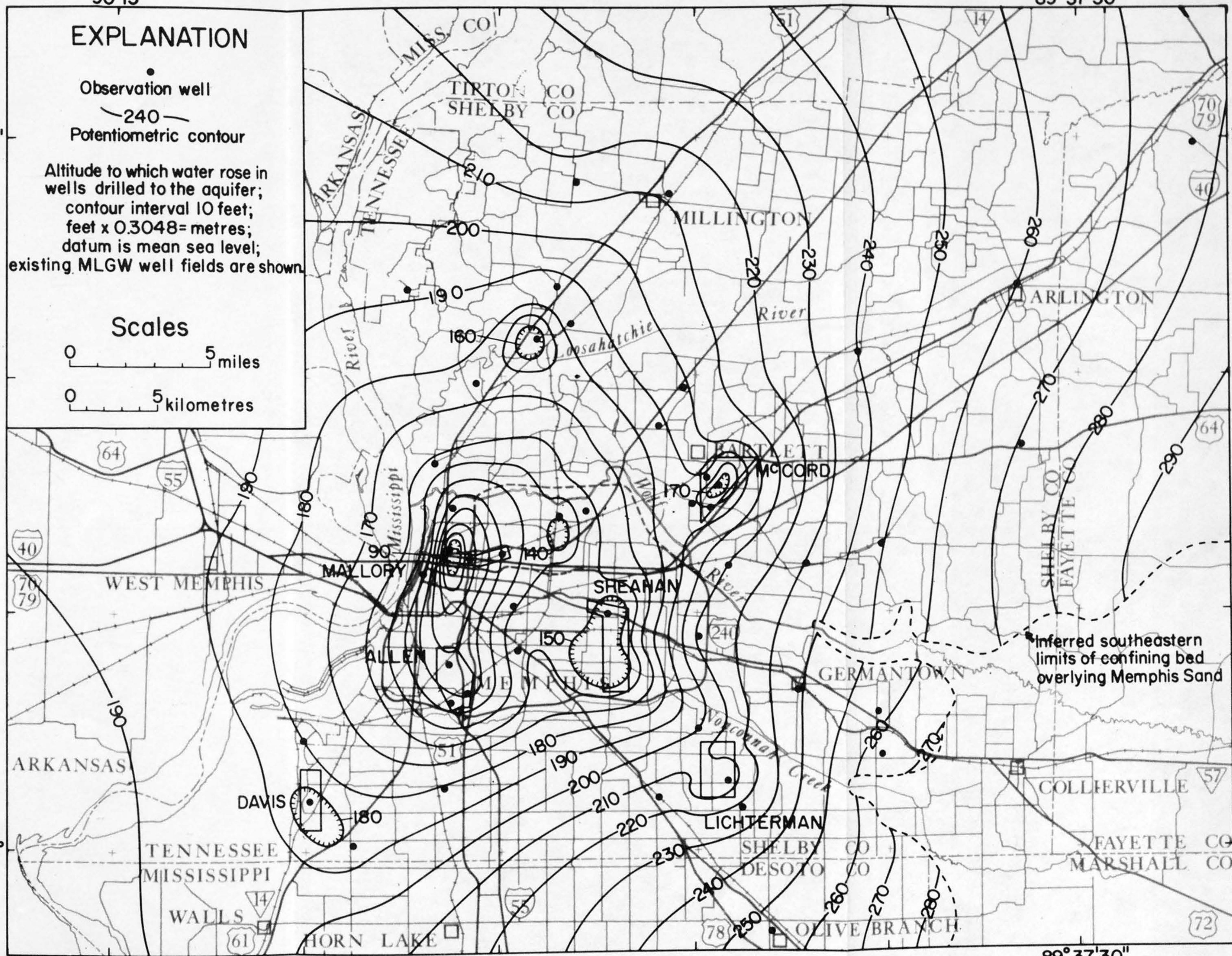
A similar map, illustrating water-level changes in the Memphis Sand from 1970 to 1975, is shown in figure 10. This map shows a general rise in water levels for outlying areas away from the major cone of depression (fig. 7). This rise is attributed to the abnormally high rainfall for 1973 and 1975 and the associated increased recharge to the aquifer. The pronounced local rise in water levels in the area of Allen well field resulted from the reduction in pumping of about 10 Mgal/d (38 Ml/d) from 1970 to 1975. This reduction was offset by water supplied to the system from the new Davis well field, where the water level declined more than 10 ft (3 m).

In the central part of the Memphis area, water levels continued to decline from 1970 to 1975 as a result of increased pumping from several well fields. Pronounced declines are evident in the areas of Mallory and McCord well fields where pumping was greatly increased. Nevertheless, water-level declines generally were less than would have been expected when comparisons are made with water-level declines for the previous decade (1960-70). The cause of the smaller decline rate in this area may be attributed to a more widespread distribution of pumping, a general increase in recharge to the aquifer during the periods of above-normal rainfall in 1973 and 1975, and an increase in leakage induced by a deepening of the major cone of depression.

## SUMMARY AND CONCLUSIONS

The Memphis Sand supplies nearly all of the water used in the Memphis area. Since 1886, when the first well was completed to this aquifer, annual withdrawals generally have increased, but at an irregular rate. The annual pumpage has increased at a faster rate since 1960 than during any previous decade, reaching a maximum of 190 Mgal/d (719 Ml/d) in 1974. Pumpage in Shelby County in 1975 was reduced to about 188 Mgal/d (712 Ml/d).

Long-term escalation of ground-water withdrawals has caused a general decline of water levels throughout the 1,300 mi$^2$ (3,400 km$^2$) Memphis area. The water-level decline in the central part of the regional cone of depression has been about 105 ft (32 m), or about 1.1 ft (0.33 m) per year since 1886. The lowest water level ever recorded in Memphis was about 170 ft (52 m) below land surface in Mallory well field in 1975, which represents an overall decline of more than 150 ft (46 m). About 30 mi (48 km) east of the center of pumping, the rate of decline has been less than 0.1 ft (0.03 m) per year since 1949.



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

Figure 7.-- Potentiometric surface of the Memphis Sand in August 1975.

Nyman, D. J., 1965, Predicted hydrologic effects of pumping from the Lichterman well field in the Memphis area, Tennessee: U.S. Geol. Survey Water-Supply Paper 1819-B, 26 p.

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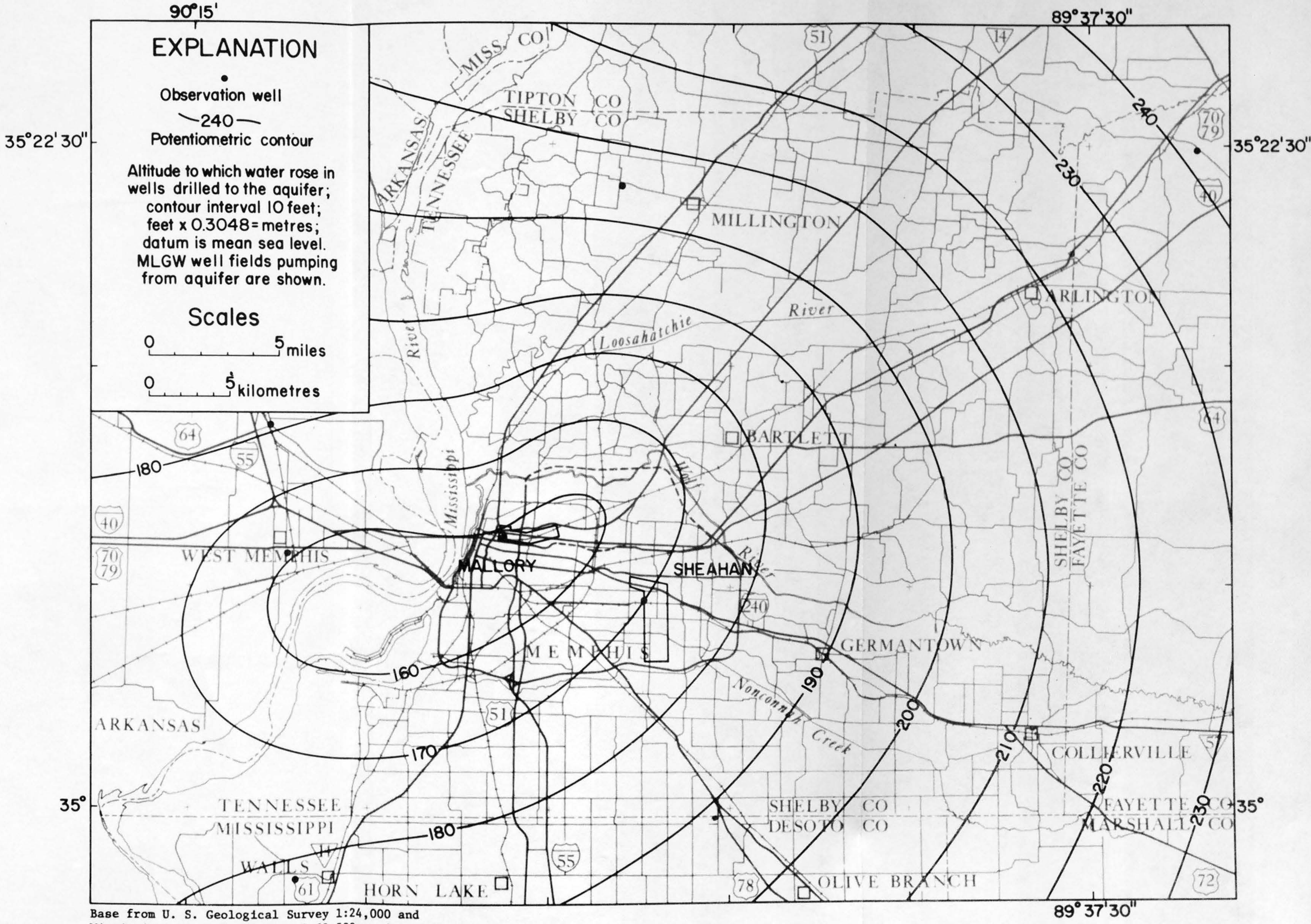


Base from U. S. Geological Survey 1:24,000 and Mississippi River Commission 1:62,500 quadrangles

Figure 8.--Potentiometric surface of the Fort Pillow Sand in April-August 1970.

Nyman, D. J., 1965, Predicted hydrologic effects of pumping from the Lichterman well field in the Memphis area, Tennessee: U.S. Geol. Survey Water-Supply Paper 1819-B, 26 p.

Parks, W. S., and Lounsbury, R. W., 1975, Environmental geology of Memphis in Field trips in west Tennessee: Tennessee Div. Geol. Rept. Inv. 36, p. 35-63.

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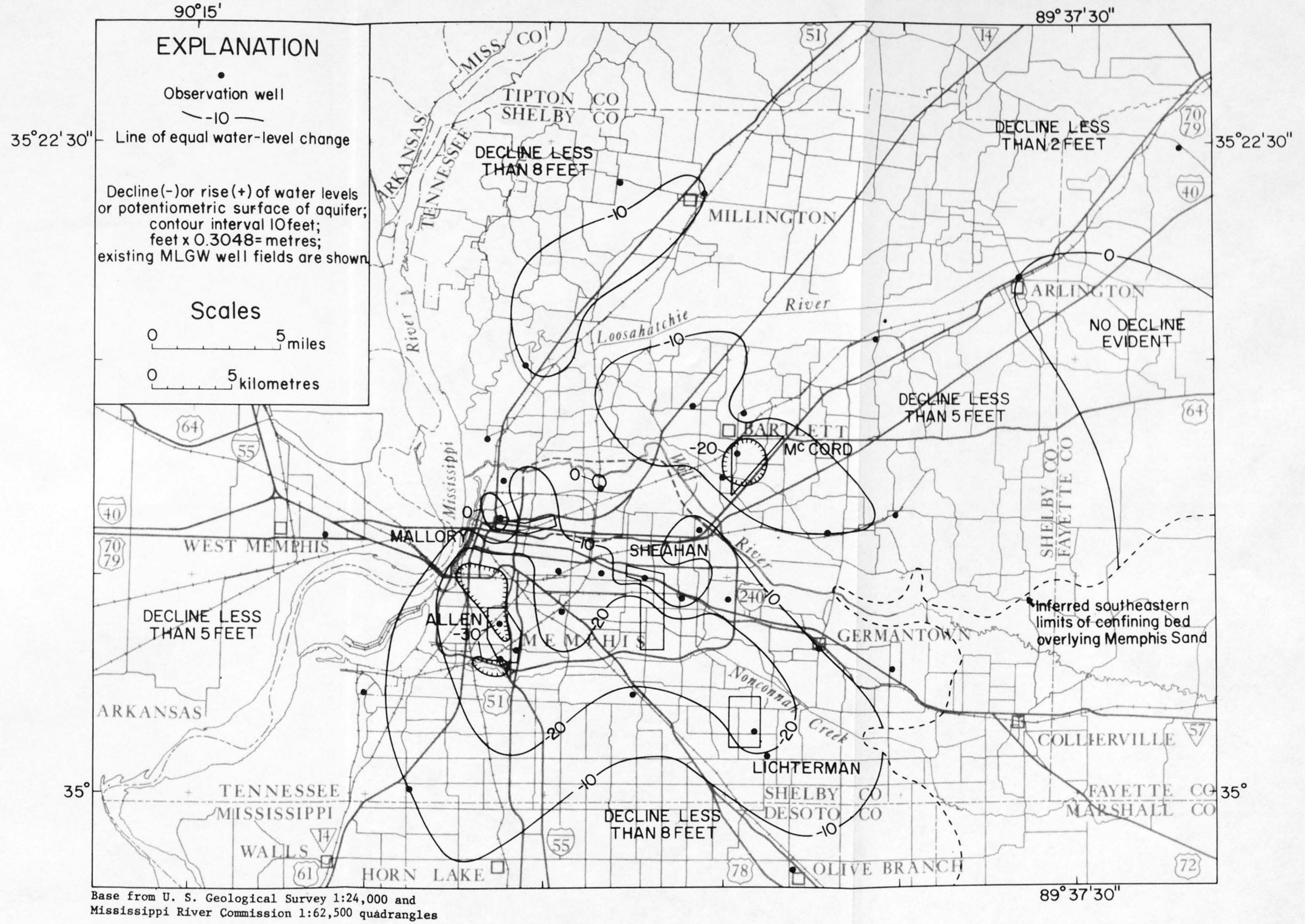


Figure 9.--Water-level changes in the Memphis Sand from August 1960 to September 1970.

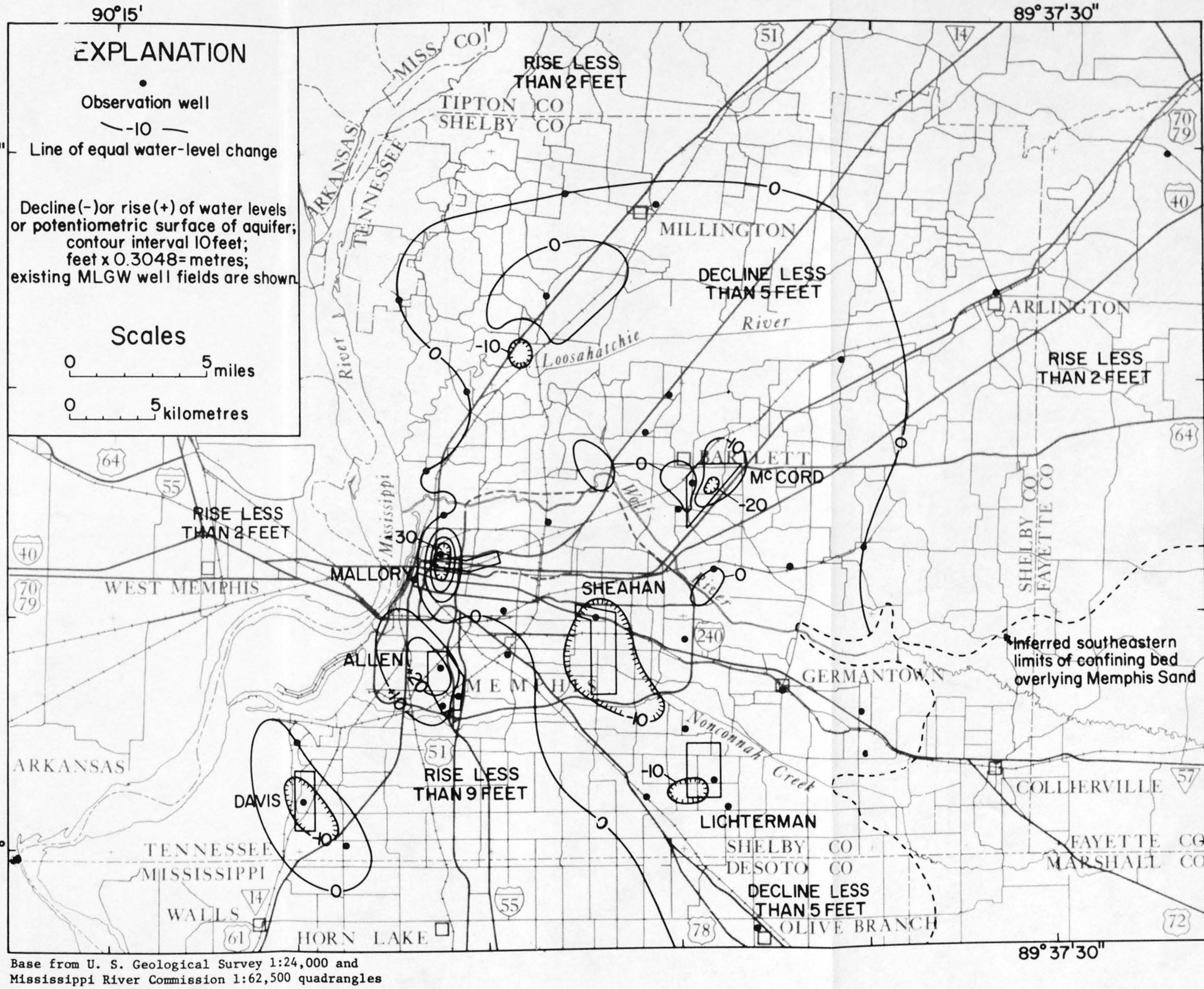


Figure 10.--Water-level changes in the Memphis Sand from September 1970 to August 1975.

Nyman, D. J., 1965, Predicted hydrologic effects of pumping from the Lichterman well field in the Memphis area, Tennessee: U.S. Geol. Survey Water-Supply Paper 1819-B, 26 p.

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Safford, J. M., 1890, The water supply of Memphis: Tennessee Board of Health Bull., v. [illegible]

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Local water-level fluctuations are caused primarily by variations in the pumping rates. In the McCord well field, pumping increased from 1960 to 1970 and, as a result, the hydraulic gradient continued to steepen, as evidenced by a decline of water levels in that part of the area. Water levels fluctuated only slightly from 1970 to 1974 as the result of a nearly constant pumping rate; however, in 1975, pumpage in that field was increased by about 25 percent over the amount for 1974. Consequently, most of the water-level decline from 1970 to 1975 actually occurred during 1975. This indicates that water-level changes in response to pumping changes are immediate or within the year.

Water-level fluctuations have been greatest in the Allen well field. From 1960 to 1970 pumpage was almost doubled and caused a sharp decline of the potentiometric surface in this area. From 1970 to 1975 pumpage was reduced by about 35 percent and resulted in a corresponding rise in water levels.

In areas where pumping is constant, water levels remain stable. In the Mallory well field, pumping was nearly constant from 1960 to 1970. Water levels in this vicinity underwent less change during the 1960's than at any other municipal well field, indicating near equilibrium between pumping rate and the rate of water movement into the vicinity. Then, from 1970 to 1975 when pumpage was increased by about 75 percent, the water level in the field declined more rapidly, as indicated by a 38-ft (11.6-m) drop in well Sh:O-179.

Similarly, water levels in the Fort Pillow Sand declined from 1924 to 1954 as withdrawals increased. Water levels stabilized when pumping was held nearly constant and recently have recovered a large amount following the cessation of pumping from the two largest well fields in the area. The water levels and pumping from this aquifer are expected to remain nearly stable in the immediate future.

The pumpage and water-level data indicate that a constant pumping rate in the area, in time, would result in a stable water level. Thus, the regional and local water levels may be altered by changing the pumping rates or by varying the areal distribution of pumping. This characteristic of the aquifer system is of utmost importance to planners and water managers for developing the aquifers to their full potential and avoiding development that would be detrimental to the resource.

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## PUMPAGE DATA

Records concerning ground-water pumpage for public supply at Memphis have been kept by early private water companies and municipal systems and by MLGW since the discovery of the artesian system in 1886. Since 1940, the Geological Survey has collected pumpage data from all large water-using industries and commercial establishments and municipal water companies in Shelby County. The data for some of the industries have been furnished to the Survey under an agreement that individual company statistics would remain confidential. Many of the reports have been made monthly and have showed daily totals; other reports have been made by telephone and have indicated monthly or yearly estimates. This information has been supplemented by water-use surveys of the nonreporting industries and commercial establishments in 1955 and 1974. The results of these surveys showed that in 1955 about 67 percent of the pumpage by industrial and other users was reported to the Geological Survey, and in 1974 the reported pumpage was about 83 percent of the total. These percentages have been used to adjust pumpage totals for the intervening years. Pumpage reported to the Geological Survey for 1975 was raised to about 85 percent of the total to reflect an increase resulting from the inclusion of an additional major water-using industry.

The water-use surveys did not include pumpage from a few thousand suburban and rural wells nor any wells in the Arkansas and Mississippi parts of the Memphis area. These wells pump from the Memphis Sand, Fort Pillow Sand, fluvial deposits, and alluvium. The annual pumpage from these wells probably does not amount to more than an additional 2 or 3 percent of the total pumpage values given in this report. The pumping rates from the major aquifers by major users in Shelby County from 1886 to 1975 are given in table 2.

Table 2.--Pumping rates from the Memphis and Fort Pillow Sands by major water users in Shelby County, Tennessee, 1886-1975

(in million gallons per day)

| Year | Memphis Sand | | | Fort Pillow Sand | | | Remarks |
|---|---|---|---|---|---|---|---|
| | MLGW 1/ | Industrial and other | Total | MLGW 1/ | Industrial and other | Total | |
| 1886 | 0.1 | ? | ? | | | | First well completed to Memphis Sand. |
| 1887 | 2 | 4 | 6 | | | | |
| 1888 | 2.9 | 10 | 13 | | | | Two water companies completed 16 wells. |
| 1889 | 2.1 | 13 | 15 | | | | Forty-two public supply wells completed. |
| 1890 | 3.0 | 15 | 18 | | | | Auction Avenue station began operation. |
| 1891 | 2.9 | 16 | 19 | | | | |
| 1892 | 4.0 | 18 | 22 | | | | |
| 1893 | 6.5 | 18 | 24 | | | | |
| 1894 | 10.1 | 18 | 28 | | | | |
| 1895 | 12.7 | 20 | 32 | | | | |
| 1896 | 14.0 | 19 | 33 | | | | |
| 1897 | 9.0 | 20 | 29 | | | | |
| 1898 | 9.4 | 21 | 30 | | | | |
| 1899 | 11.7 | 22 | 34 | | | | |
| 1900 | 10.8 | 20 | 31 | | | | |
| 1901 | 11.6 | 19 | 31 | | | | |
| 1902 | 12.0 | 19 | 31 | | | | |
| 1903 | 12.7 | 19 | 32 | | | | Memphis Artesian Water Department organized. |
| 1904 | 11.3 | 20 | 31 | | | | |
| 1905 | 11.8 | 21 | 33 | | | | |
| 1906 | 12.9 | 22 | 35 | | | | South Memphis station began operation. |
| 1907 | 13.8 | 22 | 36 | | | | |
| 1908 | 13.1 | 22 | 35 | | | | Central Avenue station began operation. |
| 1909 | 14.0 | 24 | 38 | | | | |
| 1910 | 13.5 | 22 | 36 | | | | Segregated wells began operation. |
| 1911 | 13.0 | 19 | 32 | | | | |
| 1912 | 13.6 | 19 | 33 | | | | |
| 1913 | 13.0 | 18 | 31 | | | | |
| 1914 | 13.3 | 20 | 33 | | | | |
| 1915 | 11.8 | 18 | 30 | | | | |

Table 2.--Pumping rates from the Memphis and Fort Pillow Sands by major water users in Shelby County, Tennessee, 1886-1975--Continued

(in million gallons per day)

| Year | Memphis Sand | | | Fort Pillow Sand | | | Remarks |
|---|---|---|---|---|---|---|---|
| | MLGW 1/ | Industrial and other | Total | MLGW 1/ | Industrial and other | Total | |
| 1916 | 11.9 | 18 | 30 | | | | |
| 1917 | 12.7 | 18 | 31 | | | | |
| 1918 | 13.7 | 21 | 35 | | | | |
| 1919 | 15.0 | 23 | 38 | | | | |
| 1920 | 14.9 | 22 | 37 | | | | Chester and Fleming engineering study listed 58 self-supplied industries. |
| 1921 | 13.2 | 25 | 38 | | | | |
| 1922 | 12.7 | 30 | 43 | | | | Fuller and McClintock engineering study began. |
| 1923 | 13.4 | 35 | 48 | | | | |
| 1924 | 14.2 | 37 | 51 | 0.1 | - | 0.1 | First well drilled to Fort Pillow Sand and Parkway (Mallory) station began operation. |
| 1925 | 14.5 | 39 | 54 | 0.9 | - | 0.9 | |
| 1926 | 12.9 | 42 | 55 | 2.5 | - | 2.5 | |
| 1927 | 13.8 | 41 | 55 | 2.2 | - | 2.2 | |
| 1928 | 13.1 | 41 | 54 | 4.5 | - | 4.5 | |
| 1929 | 12.2 | 45 | 57 | 5.7 | - | 5.7 | |
| 1930 | 13.4 | 49 | 62 | 6.2 | - | 6.2 | |
| 1931 | 13.3 | 49 | 62 | 5.4 | - | 5.4 | |
| 1932 | 12.4 | 52 | 64 | 6.5 | - | 6.5 | |
| 1933 | 15.3 | 51 | 66 | 3.8 | - | 3.8 | Sheahan station began operation. |
| 1934 | 15.1 | 50 | 65 | 4.9 | - | 4.9 | |
| 1935 | 12.5 | 56 | 68 | 6.3 | - | 6.3 | |
| 1936 | 12.3 | 58 | 70 | 5.4 | - | 5.4 | |
| 1937 | 13.9 | 59 | 72 | 4.5 | - | 4.5 | |
| 1938 | 13.6 | 59 | 72 | 5.6 | - | 5.6 | |
| 1939 | 13.8 | 58 | 72 | 6.0 | - | 6.0 | MLGW organized. |
| 1940 | 15.1 | 59 | 74 | 6.5 | 0.1 | 6.6 | Water-use data collection begun by USGS. |
| 1941 | 15.6 | 59 | 75 | 7.5 | 1.2 | 8.7 | |
| 1942 | 17.5 | 68 | 85 | 7.4 | 1.2 | 8.6 | |
| 1943 | 20.0 | 80 | 100 | 9.4 | 1.7 | 11.1 | |
| 1944 | 21.8 | 79 | 100 | 9.1 | 1.7 | 10.8 | |
| 1945 | 24.4 | 71 | 95 | 6.6 | 2.1 | 8.7 | |

Table 2.--Pumping rates from the Memphis and Fort Pillow Sands by major water users in Shelby County, Tennessee, 1886-1975--Continued

(in million gallons per day)

| Year | Memphis Sand | | | Fort Pillow Sand | | | Remarks |
|---|---|---|---|---|---|---|---|
| | MLGW 1/ | Industrial and other | Total | MLGW 1/ | Industrial and other | Total | |
| 1946 | 24.7 | 60 | 85 | 8.1 | 0.6 | 8.7 | |
| 1947 | 26.6 | 63 | 90 | 9.5 | 0.7 | 10.2 | |
| 1948 | 29.7 | 70 | 100 | 8.6 | 2.0 | 10.6 | |
| 1949 | 31.0 | 69 | 100 | 8.5 | 4.9 | 13.4 | |
| 1950 | 33.5 | 66 | 100 | 8.3 | 5.3 | 13.6 | |
| 1951 | 37.2 | 68 | 105 | 8.6 | 5.7 | 14.3 | |
| 1952 | 41.5 | 68 | 110 | 8.2 | 2.9 | 11.1 | Allen station began operation. |
| 1953 | 44.8 | 71 | 116 | 8.1 | 3.7 | 11.8 | |
| 1954 | 47.4 | 72 | 119 | 7.8 | 3.8 | 11.6 | |
| 1955 | 48.3 | 74 | 122 | 7.7 | 4.8 | 12.5 | Survey of 135 self-supplied water users. |
| 1956 | 48.1 | 72 | 120 | 7.0 | 5.0 | 12.0 | |
| 1957 | 47.6 | 69 | 117 | 6.7 | 3.6 | 10.3 | |
| 1958 | 50.4 | 70 | 120 | 7.5 | 3.3 | 10.8 | McCord station began operation. |
| 1959 | 54.9 | 73 | 128 | 7.6 | 5.1 | 12.7 | |
| 1960 | 55.5 | 72 | 127 | 8.1 | 4.7 | 12.8 | |
| 1961 | 58.1 | 75 | 133 | 7.9 | 4.5 | 12.4 | |
| 1962 | 62.0 | 76 | 138 | 6.9 | 4.4 | 11.3 | |
| 1963 | 66.1 | 75 | 141 | 5.4 | 4.2 | 9.6 | |
| 1964 | 68.3 | 76 | 144 | 3.6 | 4.2 | 7.8 | |
| 1965 | 71.8 | 78 | 150 | 3.2 | 4.5 | 7.7 | Lichterman station began operation. |
| 1966 | 76.3 | 77 | 153 | 2.4 | 5.3 | 7.7 | |
| 1967 | 78.6 | 77 | 156 | 2.6 | 5.1 | 7.7 | |
| 1968 | 81.8 | 79 | 161 | 3.4 | 4.3 | 7.7 | |
| 1969 | 84.0 | 81 | 165 | 2.4 | 5.3 | 7.7 | |
| 1970 | 90.8 | 80 | 171 | 3.0 | 3.5 | 6.5 | |
| 1971 | 97.8 | 80 | 178 | 1.6 | 3.5 | 5.1 | Davis station began operation. |
| 1972 | 101.0 | 79 | 180 | 0.8 | 4.3 | 5.1 | |
| 1973 | 107.2 | 81 | 188 | 1.1 | 4.6 | 5.7 | |
| 1974 | 109.5 | 80 | 190 | 0 | 5.6 | 5.6 | Water-use survey of 99 self-supplied users. MLGW discontinued use of Fort Pillow Sand. |
| 1975 | 110.5 | 78 | 188 | 0 | 4.4 | 4.4 | |

1/ Pumpage by Memphis Light, Gas and Water Division and its predecessors

## WATER-LEVEL DATA

The first systematic collection of water-level records in the Memphis area began in 1927 with the installation of an automatic recorder on Sh:O-124. The following year another recorder was installed on Sh:P-76. These and other early observation wells were screened in the Memphis Sand. It was not until 1945 that observation wells in the Fort Pillow Sand were available for water-level measurements. The lowest annual water levels in selected observation wells in the Memphis and Fort Pillow Sands were computed from recorder charts and are presented in tables 3 and 4, respectively.

In addition to recorder-equipped observation wells, many industrial wells and abandoned or unused municipal wells in the Memphis Sand are measured each year at the estimated time of the lowest annual water level. Generally, the annual low water level occurs in August or September in Memphis when pumping rates are highest. Water-level measurements in these miscellaneous wells and equivalent values determined from recorder charts for August or September each year were converted to sea level reference for the preparation of the potentiometric-surface maps. Values for the Memphis Sand are given in table 5 and those for the Fort Pillow Sand in table 6. The low-water-level values in these tables may differ from those in tables 3 and 4 because of rounding to whole numbers and time lag in a few wells. Because of the time lag with distance from pumping centers, the low water levels in Fa:R-1 and R-2 may not occur until the following December or January.

Table 3.--Lowest annual water levels recorded from selected observation

| Year \ Well number LSD | Sh:O-124 229.7 ft | Sh:P-76 286.7 ft | Sh:O-1 228.7 ft | Sh:P-1 299.8 ft | Sh:Q-1 330.4 ft | Sh:O-179 256.7 ft | Sh:K-66 302.7 ft | Da:R-2 317.2 ft |
|---|---|---|---|---|---|---|---|---|
| 1927 | 31.7 | | | | | | | |
| 1928 | 32.9 | 69.4 | | | | | | |
| 1929 | 32.4 | 69.5 | | | | | | |
| 1930 | 37.0 | 73.4 | | | | | | |
| 1931 | | | | | | | | |
| 1932 | | | | | | | | |
| 1933 | | 68.6 | | | | | | |
| 1934 | | 70.5 | | | | | | |
| 1935 | | 68.7 | | | | | | |
| 1936 | | 74.1 | | | | | | |
| 1937 | 34.9 | 74.7 | | | | | | |
| 1938 | 39.1 | 76.6 | | | | | | |
| 1939 | 41.2 | 77.6 | | | | | | |
| 1940 | 43.8 | 81.4 | 18.1 | 68.2 | 74.6 | | | |
| 1941 | 51.6 | 88.2 | 24.3 | 74.0 | 76.1 | | | |
| 1942 | 52.8 | 90.9 | 25.4 | 75.7 | 76.9 | | | |
| 1943 | 56.9 | 95.3 | 27.5 | 78.2 | 77.9 | | | |
| 1944 | 61.5 | 97.6 | 29.9 | 79.3 | 78.4 | 106.3 | | |
| 1945 | 60.5 | 96.4 | 28.7 | 78.5 | 78.0 | 110.1 | | |
| 1946 | 57.2 | 96.0 | 23.5 | 73.7 | 77.3 | 103.8 | 117.1 | |
| 1947 | 59.2 | 98.9 | 25.9 | 75.8 | 77.7 | 113.4 | 120.5 | |
| 1948 | 60.6 | 101.4 | 28.7 | 78.2 | 78.5 | 115.8 | 122.6 | |
| 1949 | 63.2 | 105.6 | 29.4 | 79.0 | 118.6 | 138.4 | 39.0 | 39.0 |
| 1950 | 63.7 | 105.2 | 27.9 | 77.7 | 77.9 | 116.6 | 125.2 | 38.3 |
| 1951 | 69.4 | 106.5 | 28.9 | 78.6 | 78.2 | 127.5 | 127.1 | 38.4 |
| 1952 | 69.7 | 110.8 | 33.3 | 81.0 | 79.2 | 129.2 | 130.6 | 39.0 |
| 1953 | 71.3 | 116.2 | 39.0 | 85.0 | 80.5 | 129.7 | 133.7 | 39.7 |
| 1954 | 73.4 | 120.0 | 41.4 | 86.5 | 81.8 | 131.9 | 133.8 | 40.5 |
| 1955 | 72.4 | 122.1 | 42.8 | 88.3 | 82.5 | 129.6 | 130.6 | 40.9 |
| 1956 | 72.6 | 123.1 | 43.4 | 89.6 | 83.4 | 130.9 | 132.0 | 41.3 |
| 1957 | 69.8 | 119.7 | 42.4 | 88.8 | 83.4 | 118.4 | 129.1 | 41.4 |
| 1958 | 67.2 | 117.6 | 39.8 | 92.0 | 84.6 | 115.9 | 127.0 | 40.6 |
| 1959 | 71.9 | 120.4 | 44.8 | 96.0 | 86.2 | 138.5 | 128.6 | |
| 1960 | 71.9 | 124.4 | 45.0 | 95.3 | 86.8 | 136.0 | 136.3 | 40.8 |
| 1961 | 71.9 | 124.6 | 47.0 | 97.8 | 87.5 | 131.5 | 138.3 | 40.8 |
| 1962 | 72.2 | 128.8 | 48.4 | 100.0 | 88.6 | 132.0 | 137.1 | 40.9 |
| 1963 | 72.4 | 129.9 | 51.2 | 103.0 | 90.3 | 141.2 | 141.0 | 41.7 |
| 1964 | 73.2 | 130.5 | 53.2 | 105.0 | 92.1 | 142.4 | 142.5 | 41.9 |
| 1965 | 73.3 | 134.2 | 53.6 | 105.8 | 93.0 | 142.9 | 143.9 | 41.8 |
| 1966 | 73.3 | 135.6 | 52.1 | 105.6 | 94.2 | 145.8 | 147.5 | 41.9 |
| 1967 | 71.7 | 134.3 | 51.1 | 105.9 | 95.0 | 136.8 | 146.7 | 42.1 |
| 1968 | 71.8 | 137.0 | 52.1 | 108.4 | 95.8 | 139.4 | 147.0 | 42.0 |
| 1969 | 71.1 | 136.3 | 53.8 | 109.4 | 96.7 | 137.4 | 147.7 | 42.0 |
| 1970 | 70.5 | 138.2 | 54.6 | 110.3 | 97.5 | 131.5 | 144.2 | 41.9 |
| 1971 | 71.3 | 140.3 | 54.9 | 111.6 | 98.4 | 154.3 | 150.3 | 41.7 |
| 1972 | 71.0 | 141.8 | 56.2 | 113.6 | 99.4 | 168.4 | 153.1 | 41.6 |
| 1973 | 69.9 | 141.2 | 55.0 | 114.1 | 99.0 | 164.8 | 147.5 | 40.8 |
| 1974 | 72.9 | 143.6 | 56.0 | 113.5 | 98.9 | 161.3 | 160.3 | 40.3 |
| 1975 | 70.0 | 139.4 | 54.4 | 112.1 | 99.1 | 169.6 | 158.3 | 40.1 |

wells in the Memphis Sand in the Memphis area, Tennessee 1972-1975

| Sh:J-126 234.5 ft | Sh:Q-24 282.4 ft | Sh:U-2 268.8 ft | Sh:P-85 293.1 ft | Sh:J-1 240.5 ft | Sh:L-10 369 ft | Sh:L-39 340.7 ft | Sh:L-15 278.5 ft | Sh:W-3 278.5 ft | Sh:0-41 240 ft |
|---|---|---|---|---|---|---|---|---|---|
| 41.2 | | | | | | | | | |
| 48.3 | | | | | | | | | |
| | | | | | | | | | |
| 46.5 | | | | | | | | | |
| 54.0 | | | | | | | | | |
| 72.0 | 41.3 | 43.3 | 69.3 | | | | | | |
| 79.1 | 61.8 | 45.6 | 72.4 | | | | | | |
| 85.3 | | 46.8 | 71.7 | | | | | | |
| 86.7 | | 47.6 | 73.5 | | | | | | |
| 86.1 | | 47.4 | 73.0 | | | | | | |
| 83.7 | 61.0 | 43.8 | 91.4 | | | | | 18.4 | |
| 82.4 | 63.3 | 46.9 | 94.1 | 40.8 | 115.5 | 100.2 | 73.6 | 18.6 | |
| 82.7 | 62.1 | 48.4 | 93.3 | 40.6 | 116.1 | 100.7 | 73.8 | 19.2 | 104.2 |
| 87.9 | 64.2 | 49.1 | 91.3 | 41.0 | 117.5 | 100.8 | 74.0 | 19.2 | 112.3 |
| 93.7 | 67.0 | 50.1 | | 42.7 | 118.4 | | 74.1 | 19.2 | 113.0 |
| 94.5 | 69.9 | 52.8 | | 45.2 | 118.4 | | 74.9 | | 116.3 |
| 99.6 | 71.8 | 54.2 | | 46.1 | 120.8 | | 76.2 | | 117.2 |
| 101.0 | 72.4 | 54.0 | | 46.4 | 122.1 | 114.6 | 77.0 | | 118.4 |
| 105.1 | 72.8 | 53.8 | | 47.4 | 122.2 | 118.9 | 78.0 | | 122.4 |
| 100.0 | 73.5 | 53.7 | | | 124.4 | 123.3 | 78.8 | | 117.8 |
| 104.2 | 73.9 | 53.8 | | 49.4 | | 126.0 | 79.4 | 19.1 | 118.2 |
| 109.7 | 72.6 | 57.2 | | 49.4 | 127.7 | 127.5 | 81.0 | 19.4 | 119.4 |
| 111.6 | 71.4 | 55.3 | 109.51 | 51.0 | 129.1 | 130.0 | | 19.3 | 124.0 |
| 110.7 | 70.0 | 60.2 | | 55.5 | 129.8 | 131.5 | 81.4 | 19.2 | 120.4 |
| 106.1 | 71.4 | 57.8 | | 58.0 | 129.4 | 134.0 | 81.5 | 19.3 | 118.7 |
| 101.2 | 70.7 | 57.4 | 115.3 | 54.7 | | 135.9 | 81.5 | 18.6 | 118.6 |
| 100.6 | | 56.1 | 116.4 | 55.3 | 136.9 | 137.1 | 81.8 | 18.4 | 119.1 |
| 99.2 | | 54.9 | 114.2 | 56.5 | 138.6 | 137.9 | 82.9 | 18.6 | 113.7 |

Table 4.--Lowest annual water levels in feet below land surface datum (LSD) recorded from selected observation wells in the Fort Pillow Sand in the Memphis area, Tenn., 1945-1975.

| Year | Well number LSD | Sh:K-45 284.2 ft | Sh:O-170 255.4 ft | Sh:U-1 264.2 ft | Fa:R-1 317.5 ft |
|---|---|---|---|---|---|
| 1945 | | 75.3 | 73.2 | | |
| 1946 | | 92.4 | 74.9 | 34.5 | |
| 1947 | | 96.5 | 79.3 | 38.9 | |
| 1948 | | 104.0 | 86.2 | 40.6 | |
| 1949 | | 105.4 | 80.5 | 43.4 | 65.9 |
| 1950 | | 111.8 | 95.0 | 45.5 | 66.6 |
| 1951 | | 114.6 | 96.8 | 47.8 | 68.5 |
| 1952 | | 112.0 | 100.6 | 48.0 | 69.3 |
| 1953 | | 112.3 | 97.1 | 48.2 | 69.6 |
| 1954 | | 114.6 | 107.9 | 49.4 | 70.3 |
| 1955 | | 116.7 | 100.2 | 50.4 | 71.1 |
| 1956 | | 118.0 | 99.8 | 52.6 | 72.3 |
| 1957 | | 112.4 | 93.2 | 50.8 | 72.2 |
| 1958 | | 111.6 | 89.7 | 48.3 | 70.8 |
| 1959 | | 115.4 | 96.2 | 50.7 | 71.3 |
| 1960 | | 119.8 | 101.9 | 52.5 | 72.3 |
| 1961 | | 121.7 | 101.6 | 53.5 | 72.8 |
| 1962 | | 119.4 | 99.7 | 53.5 | 73.3 |
| 1963 | | 122.2 | 98.2 | 56.0 | 74.1 |
| 1964 | | 122.1 | 90.9 | 56.8 | 75.0 |
| 1965 | | 119.6 | 91.8 | 56.6 | 75.2 |
| 1966 | | 113.0 | 97.0 | 56.7 | 75.3 |
| 1967 | | 105.8 | 92.1 | 54.1 | 74.5 |
| 1968 | | 103.7 | 92.4 | 53.8 | 74.1 |
| 1969 | | 112.9 | 95.0 | 55.6 | 75.0 |
| 1970 | | 114.1 | 97.2 | 60.4 | 76.3 |
| 1971 | | 106.0 | 97.7 | 55.8 | 77.0 |
| 1972 | | 108.0 | 75.7 | 56.7 | 76.0 |
| 1973 | | 111.8 | 75.1 | 55.4 | 75.6 |
| 1974 | | 108.3 | 72.4 | 57.0 | 75.4 |
| 1975 | | 96.0 | 69.7 | 55.3 | 74.3 |

Table 5.--Water levels used in the preparation of potentiometric-surface maps (figs. 5-7) for the Memphis Sand

(datum is mean sea level)

| Well Number | Altitude of land surface (feet) | Altitude of water level (feet) | | | Water-level change (feet) | |
|---|---|---|---|---|---|---|
| | | Aug 1960 | Sept 1970 | Aug 1975 | 1960-1970 | 1970-1975 |
| Fa:R-2 | 317 | 276 | 275 | 277 | -1 | +2 |
| Sh:H-1 | 312 | 188 | 180 | 180 | -8 | 0 |
| Sh:J-1 | 240 | 200 | 190 | 184 | -10 | -6 |
| Sh:J-10 | 260 | 139 | | | | |
| Sh:J-25 | 280 | 159 | | | | |
| Sh:J-31 | 292 | 158 | | | | |
| Sh:J-36 | 300 | 144 | | | | |
| Sh:J-41 | 278 | 146 | | | | |
| Sh:J-47 | 235 | 173 | | | | |
| Sh:J-50 | 241 | | 157 | | | |
| Sh:J-62 | 224 | 163 | | | | |
| Sh:J-70 | 298 | | | 181 | | |
| Sh:J-102 | 256 | 130 | 99 | 124 | -31 | +25 |
| Sh:J-110 | 253 | 145 | 123 | 129 | -22 | + 6 |
| Sh:J-126 | 234 | 151 | 122 | 135 | -29 | +13 |
| Sh:J-140 | 293 | | 188 | 171 | | -17 |
| Sh:K-4 | 292 | 211 | 192 | | -19 | |
| Sh:K-13 | 292 | 171 | | | | |
| Sh:K-15 | 292 | 184 | | | | |
| Sh:K-20 | 295 | 170 | 153 | 155 | -17 | + 2 |
| Sh:K-23 | 315 | 190 | 186 | | - 4 | |
| Sh:K-25 | 252 | 201 | | | | |
| Sh:K-28 | 330 | 211 | | | | |
| Sh:K-29 | 271 | 199 | | | | |
| Sh:K-31 | 317 | | 220 | 215 | | - 5 |
| Sh:K-66 | 303 | 166 | 159 | 145 | - 7 | -14 |
| Sh:K-74 | 257 | 178 | | | | |
| Sh:L-1 | 332 | 241 | | | | |
| Sh:L-10 | 369 | 253 | 243 | 239 | -10 | - 4 |
| Sh:L-13 | 295 | | 208 | 200 | | - 8 |
| Sh:L-15 | 341 | 266 | 260 | 258 | - 6 | - 2 |
| Sh:L-20 | 330 | 230 | | | | |
| Sh:L-24 | 344 | 238 | | | | |
| Sh:L-39 | 346 | 245 | 216 | 208 | -29 | - 8 |
| Sh:L-43 | 365 | 249 | 230 | 222 | -19 | - 8 |
| Sh:L-54 | 350 | | 264 | 263 | | - 1 |
| Sh:L-64 | 305 | 225 | 212 | 211 | -13 | - 1 |

Table 5.--Water levels used in the preparation of potentiometric-surface maps (figs. 5-7) for the Memphis Sand--Continued

(datum is mean sea level)

| Well No. | Altitude of land surface (feet) | Altitude of water level (feet) | | | Water-level change (feet) | |
|---|---|---|---|---|---|---|
| | | Aug 1960 | Sept 1970 | Aug 1975 | 1960-1970 | 1970-1975 |
| Sh:O-1 | 229 | 184 | 174 | 174 | -10 | 0 |
| Sh:O-41 | 240 | 133 | 126 | 126 | - 7 | 0 |
| Sh:O-98 | 255 | | 140 | 142 | | + 2 |
| Sh:O-110 | 238 | 131 | | | | |
| Sh:O-115 | 272 | 161 | 157 | 157 | - 4 | 0 |
| Sh:O-153 | 250 | 130 | | | | |
| Sh:O-179 | 257 | 124 | 127 | 88 | +3 | -39 |
| Sh:O-212 | 251 | | | 105 | | |
| Sh:P-1 | 300 | 205 | 190 | 188 | -15 | - 2 |
| Sh:P-8 | 244 | 144 | 144 | 141 | 0 | - 3 |
| Sh:P-12 | 262 | 143 | | | | |
| Sh:P-37 | 249 | 162 | | 157 | | |
| Sh:P-50 | 240 | 145 | | | | |
| Sh:P-54 | 260 | 154 | | | | |
| Sh:P-61 | 280 | 168 | 157 | | -11 | |
| Sh:P-69 | 310 | | 170 | | | |
| Sh:P-74 | 254 | 202 | 190 | | -12 | |
| Sh:P-75 | 325 | 193 | | | | |
| Sh:P-76 | 287 | 163 | 149 | 148 | -14 | - 1 |
| Sh:P-85 | 293 | 200 | 183 | 182 | -17 | - 1 |
| Sh:P-96 | 320 | | 201 | 198 | | - 3 |
| Sh:P-97 | 250 | | | 131 | | |
| Sh:Q-1 | 330 | 243 | 233 | 231 | -10 | - 2 |
| Sh:Q-3 | 332 | 257 | 249 | 249 | - 8 | 0 |
| Sh:Q-9 | 275 | | 210 | 210 | | 0 |
| Sh:Q-21 | 295 | 217 | | | | |
| Sh:Q-23 | 283 | 209 | 184 | 188 | -25 | + 4 |
| Sh:Q-24 | 282 | 220 | 211 | | - 9 | |
| Sh:Q-53 | 282 | | | 181 | | |
| Sh:Q-59 | 307 | | | 168 | | |
| Sh:R-15 | 347 | | | 271 | | |
| Sh:T-17 | 336 | | 192 | 192 | | 0 |
| Sh:U-2 | 269 | 221 | 214 | 214 | - 7 | 0 |
| Sh:U-11 | 267 | 223 | 213 | 212 | -10 | - 1 |
| Sh:U-13 | 241 | | | 157 | | |
| Sh:U-15 | 237 | | 168 | | | |
| Sh:U-22 | 300 | 199 | | | | |

Table 5.--Water levels used in the preparation of potentiometric--surface maps (figs. 5-7) for the Memphis Sand--Continued

(datum is mean sea level)

| Well No. | Altitude of land surface (feet) | Altitude of water level (feet) | | | Water-level change (feet) | |
|---|---|---|---|---|---|---|
| | | Aug 1960 | Sept 1970 | Aug 1975 | 1960-1970 | 1970-1975 |
| Sh:U-23 | 300 | | 186 | 187 | | + 1 |
| Sh:U-25 | 248 | 187 | | 183 | | |
| Sh:V-1 | 250 | 246 | | | | |
| Sh:V-7 | 278 | 246 | 242 | 240 | - 4 | - 2 |
| Sh:W-3 | 279 | 258 | 258 | 260 | 0 | + 2 |
| AR-1 | 215 | 186 | 183 | | - 6 | |
| MS-1 | 388 | 263 | 256 | 254 | - 7 | - 2 |

Table 6.--Water levels used in the preparation of the 1970 potentiometric-surface map (fig. 8) for the Fort Pillow Sand. Datum is mean sea level

| Well No. | Altitude of land surface (feet) | Altitude of water level in 1970 (feet) | Remarks |
|---|---|---|---|
| Fa:R-1 | 318 | 242 | August measurement |
| Sh:K-45 | 284 | 170 | do |
| Sh:O-170 | 255 | 159 | do |
| Sh:U-1 | 264 | 205 | do |
| AR-2 1/ | 210 | 161 | July measurement |
| AR-3 2/ | 222 | 181 | April measurement |
| MS-2 3/ | 205 | 183 | do |

1/ Arkansas number, 6N9E - 18 bbbl.

2/ Arkansas number, 7N8E - 24 bdbl.

3/ Mississippi number, A103.