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GEOLOGY AND WATER-BEARING PROPERTIES OF THE "1,400-FOOT" SAND IN THE MEMPHIS AREA

A PROGRESS REPORT

By

Robert Schneider and E. M. Cushing

Prepared in cooperation with the
MEMPHIS LIGHT, GAS, AND WATER DIVISION

WASHINGTON, D. C.

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ABSTRACT

The entire municipal water supply of Memphis, Tennessee, comes from sandy beds in the Claiborne and Wilcox groups (Eocene). Since 1924 a number of wells have obtained water from a sand in the lower part of the Wilcox group. It is about 1,200 to 1,400 feet below the land surface and is known locally as the "1,400-foot" sand.

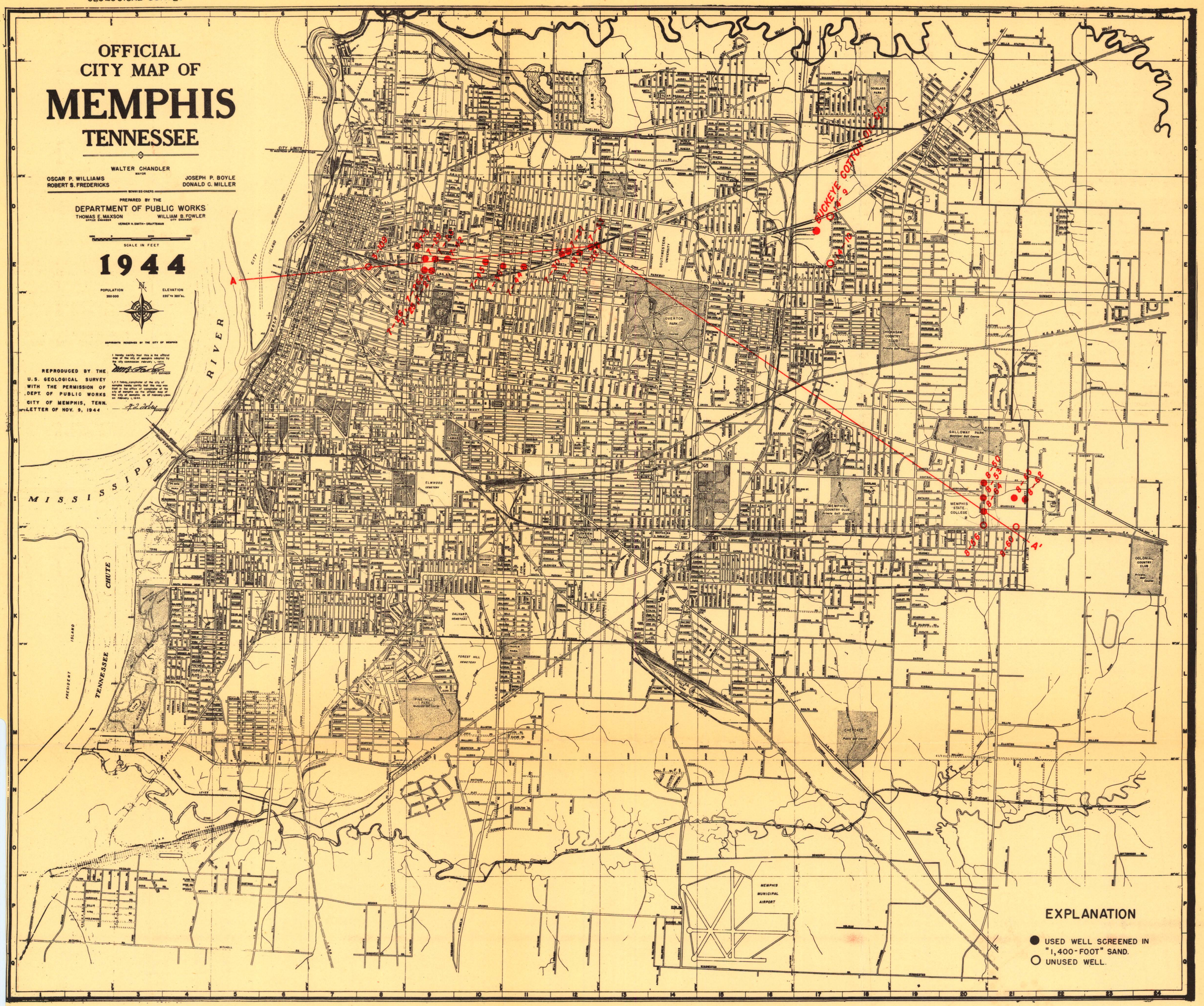
The aquifer is composed of unconsolidated fine- to medium-grained quartz sand interbedded with thin layers of clay. It is apparently about 210 feet thick and the upper surface dips westward about 30 feet a mile. It is believed that the sand can be identified as a hydrologic unit as far as 45 miles west, 78 miles north, 48 miles east, and 80 miles south of Memphis.

Water from the "1,400-foot" sand is very soft but it contains iron. In the Memphis area its temperature ranges from 70° to 72° F.

Pumping tests were made and the values for transmissibility and the coefficient of storage were found to vary somewhat in different parts of the city.

About 49 billion gallons of water was pumped from the "1,400-foot" sand in Shelby County, Tennessee, from 1924 through 1946. In 1946 an average of about 8.7 million gallons of water was pumped daily from the sand in Memphis. It is estimated that about 1 million gallons of water is pumped daily from the "1,400-foot" sand in De Soto County, Mississippi, and Crittenden County, Arkansas.

A study of the available water-level and pumpage data indicates that nearly all the water pumped up to and including 1945 came from storage within the sand. There is, as yet, no indication that recharge has been affected by the pumping.



MAP OF MEMPHIS, TENN., SHOWING LOCATIONS OF DEEP WELLS AND LOCATION OF CROSS SECTION

INTRODUCTION

History of the development of the "1,400-foot" sand

The entire municipal water supply of Memphis, Tennessee, comes from water-bearing sands of Eocene age. Most of the municipal supply is obtained from sandy beds about 400 to 500 feet below the land surface in the Claiborne group that are known locally as the "500-foot" sand. A supplementary source of water is obtained from a sand about 1,200 to 1,400 feet below the land surface in the lower part of the Wilcox group, known locally as the "1,400-foot" sand.

In 1924 a well tapping the "1,400-foot" sand was drilled under the supervision of W. G. Lanham, of the Memphis Light, Gas and Water Division. According to Mr. Lanham, 1/ an exploratory well that reached this aquifer (water-bearing formation) had been drilled in 1902.

By 1928 the City had nine wells in the "1,400-foot" sand. At the present time the city uses 19 wells in this stratum and the Buckeye Cotton Oil Company uses one. (See pl. 1 for location of wells in use.) From 1940 to 1945 a well (No. 148-1D) screened in this sand was pumped at the Chickasaw Ordnance Works near Millington, Tennessee, about 15 miles north of Memphis.

A partial inventory of wells in the vicinity of Memphis has disclosed that the city of West Memphis, Arkansas, about 7 miles west of Memphis, has two wells in this sand and that Marion, Arkansas, about 5 miles north of West Memphis, has one. Several 2- and 3-inch wells probably in the same sand have been reported south of Memphis in De Soto County, Mississippi.

Previous investigations

The earliest report on ground-water conditions in this region was written by L. C. Glenn 2/ in 1906. In 1931 F. G. Wells 3/ wrote a preliminary report on the artesian water supply of Memphis. In 1933 Wells 4/ wrote a fairly comprehensive report on the ground-water resources of western Tennessee.

The Memphis Light, Gas and Water Division conducted a series of pumping tests on the "1,400-foot" aquifer from 1932 to 1934. The results of these tests were analyzed by R. G. Kazmann, together with most of the data obtained during the present investigation.

Records of water levels have been published in Water-Supply Papers 817, 840, 845, 886 907, 937, 945, 987, and 1017 of the Geological Survey under the title "Water levels and artesian pressure in observation wells in the United States." Water-level measurements from April 1927 to March 1931 are presented graphically in Water-Supply Paper 656.

The present investigation

The field work for this report was started in 1945 by R. G. Kazmann, who resigned from the Geological Survey before a report could be prepared. Most of the data in the section on water-bearing properties were obtained by him, except for those on a pumping test at the Buckeye Cotton Oil Company and the most recent data on pumpage. The original analysis of the hydrologic data was also made by Mr. Kazmann.

A typewritten report entitled "A brief review of ground-water conditions in the vicinity of Memphis, Tennessee" was prepared by F. H. Klaer, Jr., and R. G. Kazmann in 1943. A progress report entitled "The water supply of the Memphis area" was written in 1944 by R. G. Kazmann and was issued in mimeographed form.

Acknowledgments

This investigation is being carried on under the general supervision of A. N. Sayre, Geologist in Charge of the Ground Water Division of the Geological Survey. It was started under the general supervision of O. E. Meinzer (deceased), Geologist in Charge of the Division. The investigation is under the immediate supervision of V. T. Stringfield, senior geologist in the Geological Survey. It is being carried on in cooperation with the Memphis Light, Gas and Water Division. The writers express their thanks for the cooperation and assistance of Major T. H. Allen, C. M. McCord, W. G. Lanham, and A. J. Rumley, of the Memphis Light, Gas and Water Division.

1/ Personal communication from W. G. Lanham to R. G. Kazmann, formerly with the U. S. Geological Survey.

2/ Glenn, L. C., Underground waters of Tennessee and Kentucky west of Tennessee River and of an adjacent area in Illinois: U. S. Geol. Survey Water-Supply Paper 164, 1906.

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

4/ Wells, F. G., Ground-water resources of western Tennessee: U. S. Geol. Survey Water-Supply Paper 656, 1933.

The officials of the Du Pont Company, who operated the Chickasaw Ordnance Works near Millington, were most cooperative in furnishing pumpage records of their deep well for the period 1940-45. W. F. Bowld, A. E. Logan, and C. B. Metz, of the Buckeye Cotton Oil Company, Chemical Pulp Division, were very cooperative in furnishing records of pumpage from their deep well and also in permitting the writers to make a pumping test.

GEOLOGY

Regional geology

Several times during Upper Cretaceous and Tertiary time the area from about Cairo, Illinois, to the Gulf of Mexico and from Little Rock, Arkansas, to about the Tennessee River (near the latitude of Memphis) was an arm of the sea. Several thousand feet of sand, gravel, lignite, clay, chalk, and limestone was deposited in this embayment or geosyncline, which has been termed the Mississippi Embayment. The Tertiary deposits dip from 15 to 30 feet a mile toward the axis of the Embayment, which coincides approximately with the present course of the Mississippi River.

Memphis is near the center of the northern or Upper Embayment region. The strata underlying the city, one of which is known as the "1,400-foot" sand, dip generally westward because the axis of the Embayment in this latitude is west of the Mississippi River.

Little is known about the "1,400-foot" sand beyond the Memphis area. A study of available electrical logs and drillers' logs of water wells and wildcat oil tests seems to indicate a thickening of the sand toward the axis of the Embayment. It is believed that the sand can be mapped as a hydrologic unit in the subsurface for about 30 miles and possibly as much as 45 miles west of Memphis. A cross section prepared by G. F. Brown 5/ of the Geological Survey indicates that the sand can be mapped about 80 miles to the south. It is recognizable about 15 miles east of Memphis and possibly as far as 48 miles east. The sand can be identified on an electrical log and on logs of water wells about 55 miles and possibly as far as 78 miles to the north.

Generalized table of Cenozoic formations underlying Memphis, Tennessee

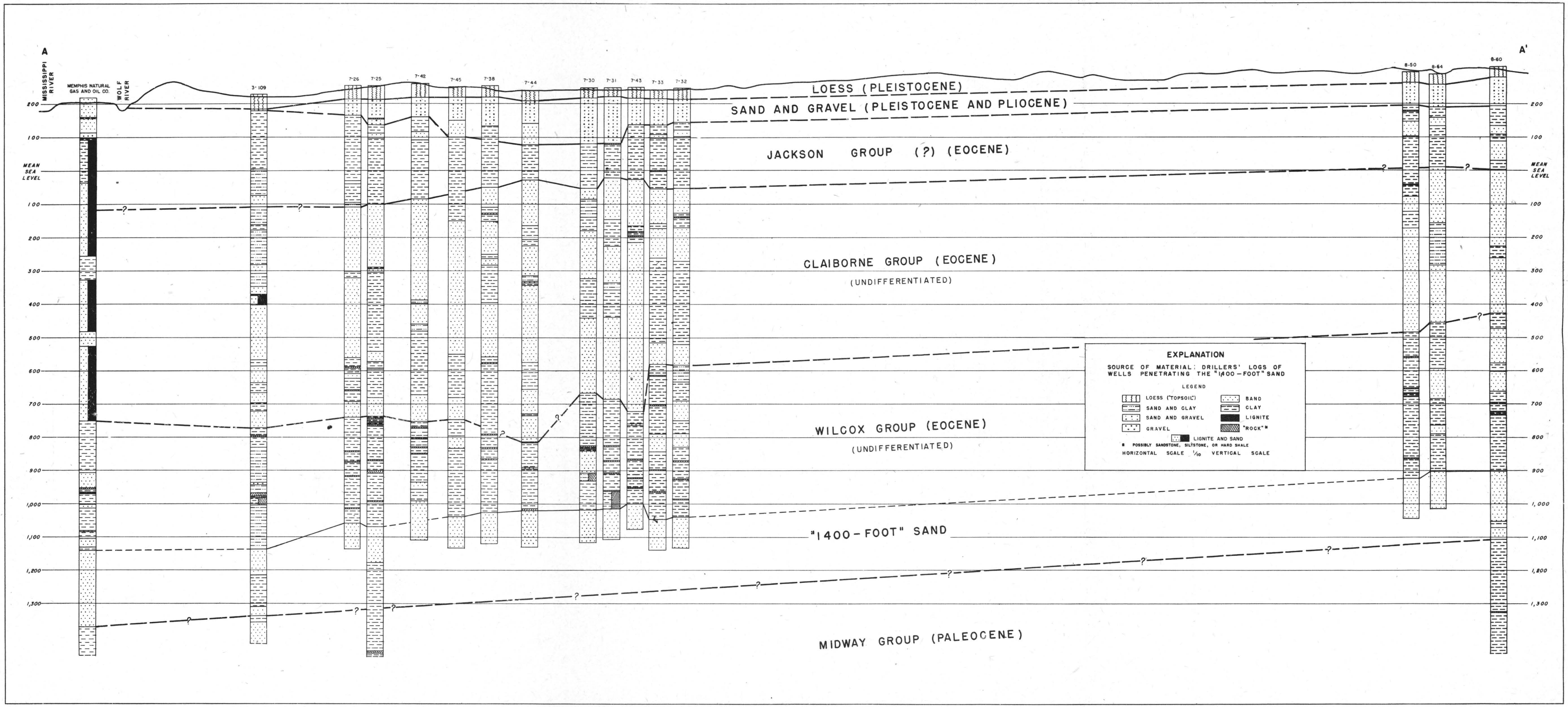
System	Series	Group	Thickness (feet)	Physical character
Quaternary	Recent			Alluvial sands, clays, and gravels
	Pleistocene		0-80	Loess
	Pleistocene and Pliocene		0-100	Terrace deposits of sand and gravel
Tertiary	Eocene	Jackson group (?) (Undifferentiated; possibly equivalent to part of Yazoo clay of Mississippi)	150-200	Gray and bluish-gray clays, minor amounts of lignite and fine sand
		Claiborne group 1/ (Undifferentiated)	600-700	Sand, clay, and lignite
		Wilcox group 1/ (undifferentiated)	500-600	Sand, clay, and lignite
	Paleocene	Midway group Porters Creek Formation	500-600	Dark-gray to black clay and shaly clay

1/ It is extremely difficult to differentiate the Claiborne group from the Wilcox group in the subsurface.

Geology of the "1,400-foot" sand

Stratigraphy.- The accompanying generalized table of Cenozoic formations underlying Memphis was compiled mainly with the aid of

5/ Brown, G. F., Geology and artesian water of the alluvial plain in northwestern Mississippi, 425 pp., 38 figs., 13 pls., 1947. Mississippi Geol. Survey Bull 65



GEOLOGIC CROSS SECTION (A-A') THROUGH MEMPHIS, TENNESSEE the geologic maps of the States of Arkansas 6/, Mississippi 7/, and Tennessee. 8/ Correlations are based on stratigraphic positions and lithologic characteristics as described for the most part in drillers' logs. The "1,400-foot" sand is presumed to be in the lower part of the Wilcox group of sands, clays, and lignite.

Roberts and Collins 9/ differentiated the Wilcox group of Tennessee, subdividing it into the Grenada, Holly Springs, and Ackerman formations. The middle Eocene (Claiborne group) was presumed to be absent. This interpretation, which was followed by Wells 10/ was based on a subdivision of the Eocene of north-central Mississippi by Lowe. 11/ According to the most recent geologic map of Mississippi, 12/ part of the strata which were mapped earlier as Wilcox may actually be, in part at least, of Claiborne age.

In this report no attempt has been made to subdivide the Wilcox group in the subsurface because the history of marine advances and regressions in the upper embayment was so complicated that marine and continental beds grade laterally and vertically into one another. In earlier work correlations on the surface have generally been based on fragmentary remains of plants, but these are generally destroyed by rotary drilling.

At least locally the "1,400-foot" sand consists predominantly of unconsolidated fine- to medium-grained quartz sand. Drillers' logs generally describe the upper third of the unit as "sand", "artesian sand", "good sand", or "water-bearing sand." Electrical logs of wells in the vicinity of Memphis essentially agree with these descriptions, although they also indicate that there are some beds of argillaceous sand and sandy clay, up to 5 or 10 feet thick, interbedded with the sand. Overlying the sand are thick beds of gray, bluish-gray, and green clays and shaly clays interbedded with thin layers of lignite, sand, and sandy clay. The Porters Creek formation (Paleocene) and possibly some younger beds of clay and shale lie immediately beneath the "1,400-foot" sand.

On the geologic map of Tennessee the Midway-Wilcox contact is about 60 miles east of Memphis. If the "1,400-foot" sand is assumed to be a continuous hydrologic unit eastward from Memphis, the distance to this contact would be the approximate distance to the area where the basal part of the sand crops out on the surface. In Mississippi 13/ there is some doubt as to whether the sand is continuous to the east and the same condition may possibly prevail in Tennessee. However, if the sand is continuous eastward, there is also a possibility that it is completely overlapped by the Claiborne group.

Regardless of whether the sand is overlapped eastward by the Claiborne group, the possibility of recharge still remains because the Claiborne group includes sandy beds which would permit the percolation of water downward toward the "1,400-foot" sand.

Structure and thickness.- It should be kept in mind that practically all the information on the "1,400-foot" sand in the Memphis area has been recorded by water-well drillers. Unless a test hole is being drilled, the accumulation of data of scientific value is of secondary importance to drillers because they are primarily interested in completing the well. Even though some of the logs may be very poor, the drillers are to be commended for keeping the existing records.

The apparent westward dip of the upper surface of the "1,400-foot" sand along the line of section A-A' (pl. 2) is about 30 feet to the mile. This figure is fairly reliable because the driller usually makes accurate observations about the time he expects the drill to penetrate the sand in which he is going to set the screen.

The structural contour map of the upper surface of the "1,400-foot" sand in Shelby County (fig. 1) was drawn with 16 control points. Three of the points are wells which were logged electrically. The rest are selected drillers' logs which were considered to be relatively accurate. It should be noted that eight of the control points are concentrated in Memphis. Consequently, the map is a very generalized picture of the configuration of this surface.

In the North Parkway Pumping Station area (wells with prefix number 7 in pl. 1), where the mean land-surface elevation is about 250

6/ Arkansas Geol. Survey, 1929.
7/ Mississippi Geol. Soc., 1945.
8/ Tennessee Div. Geology, 1933.
9/ Roberts, J. K., and Collins, R. L., The Tertiary of west Tennessee: Am. Jour. Sci., 5th ser., vol. 12, pp. 235-243, 1926.
10/ Wells, F. G., Ground-water resources of western Tennessee: U. S. Geol. Survey Water-Supply Paper 656, pp. 89-95, 1933.
11/ Lowe, E. N., Preliminary report on iron ores of Mississippi: Mississippi Geol. Survey Bull. 10, pp. 23-25, 1913.
12/ Op. cit.

13/ Personal communication from G. F. Brown, U. S. Geological Survey, University, Mississippi.

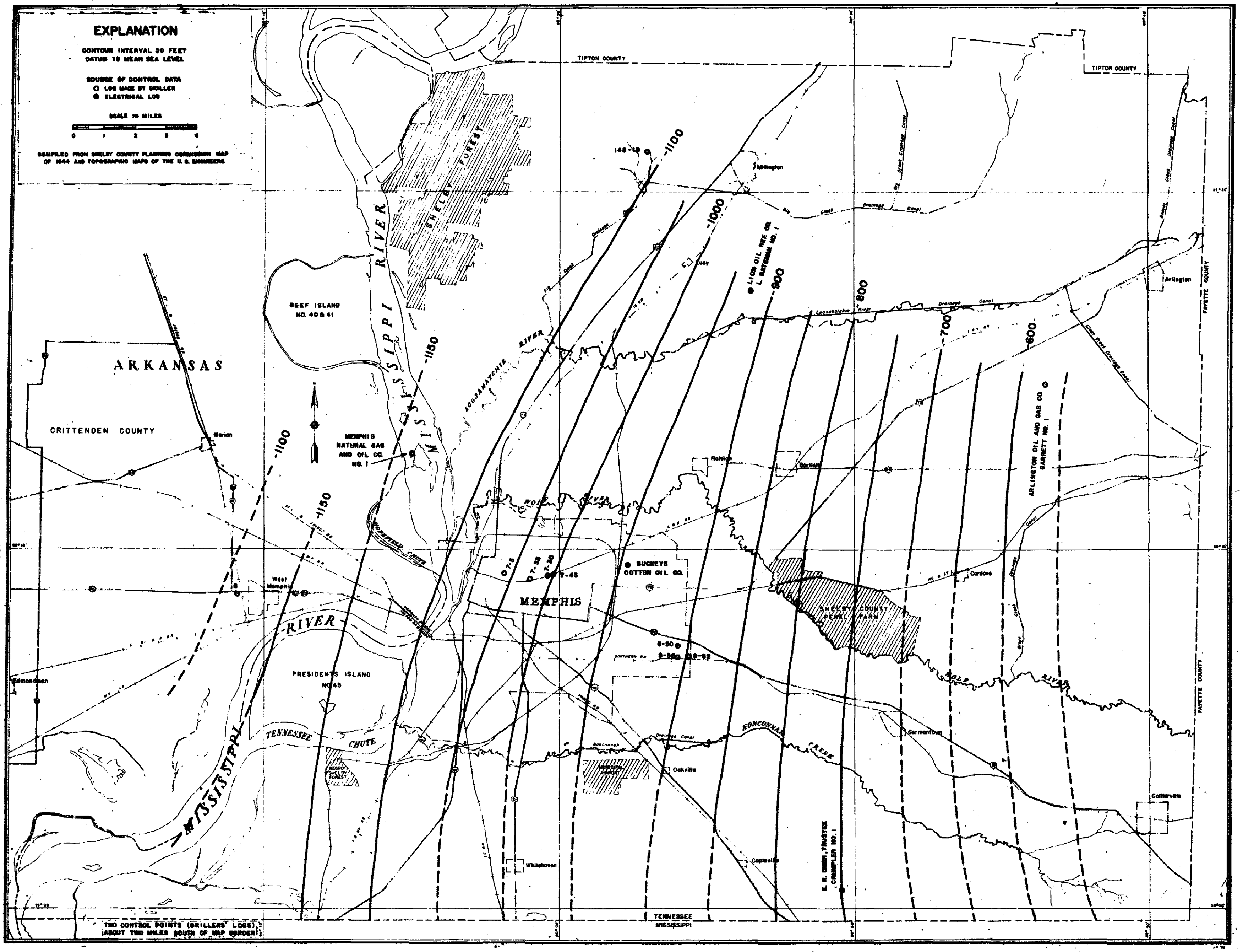


Figure 1.--Map of Shelby County, Tenn., showing generalized structural contours on upper surface of "1,400-foot" sand.

feet above mean sea level, the average depth to the top of the "1,400-foot" sand is about 1,292 feet.

In the Sheahan Pumping Station area (wells with prefix number 8), where the mean land-surface elevation is about 300 feet above mean sea level, the average depth to the top of the aquifer is about 1,207 feet.

Three City test wells (Nos. 3-109, 7-25, and 8-60) have completely penetrated the aquifer. In well 3-109 the driller's log indicates that the sand is 77 feet thick. In well 7-25 it is 106 feet thick and in well 8-60 it is 203 feet thick. In a test well of the Memphis Natural Gas and Oil Company on Hen and Chicken Island, in the Mississippi River, the sand is 265 feet thick. An electrical log of an unused well on the property of the Buckeye Cotton Oil Company, owned by the War Assets Administration, indicates that the sand is 210 feet thick.

According to W. G. Lanham[14] of the Memphis Light, Gas, and Water Division, the logs of wells 3-109 and 7-25 are not entirely reliable. It is possible that the drillers of these wells, in recording their logs from the action of the drill, described argillaceous sand or sandy clay as merely "clay". The apparent average thickness of the sand in the Memphis area is about 210 feet.

Mechanical composition.- The samples used in this study were collected from rotary drilling operations by drillers of the Memphis Light, Gas, and Water Division. They represent at most the upper third of the "1,400-foot" sand. Some of the samples were collected from the sluice trough or at the mouth of the well near the top of the surface casing pipe. Others were collected with a sand bucket which was bailed down into the water-bearing

[14] Personal communication.

Mechanical analyses of samples from the "1,400-foot" sand at Memphis

Well number	Depth interval (feet)	Total weight of sample (grams)	Size fractions							Mean size of grains[1] (mm.)	Coefficient of uniformity [2]
			2 + mm.	Very coarse 1-2mm.	Coarse 0.5-1 mm.	Medium 0.25-0.5mm.	Fine 0.125-0.25mm.	Very fine 0.062-0.125mm.	Residue on pan		
7-42	1344-1354	134.37	0.06	0.07	0.25	1.53	89.21	8.23	0.65	0.19	1.3
7-42	1354-1362	219.16	.09	.23	.37	1.35	90.49	6.65	.82	.19	1.3
7-42	1362-1368	142.96	.00	.27	1.00	5.88	87.56	4.74	.55	.20	1.4
7-43	1324-1334	147.65	.00	.00	1.69	69.60	28.37	.27	.12	.33	1.6
7-43	1334-1344	111.16	.04	.10	3.61	67.37	27.93	.58	.37	.34	1.5
7-43	1344-1369	315.19	.00	.03	4.57	71.52	23.64	.13	.11	.35	1.6
7-45	1311-1382	165.40	.00	.22	3.37	74.02	21.21	.45	.73	.35	1.6
8-50	1245-1260	147.31	.07	.16	2.65	40.83	55.01	.95	.33	.28	1.5
8-50	1260-1275	131.46	.05	.17	2.27	41.28	54.99	.87	.37	.28	1.5
8-50	1290-1320	157.34	.00	.10	2.00	44.29	52.44	.99	.18	.28	1.4
8-56[3]	[4]1280	125.10	.06	.07	.82	41.96	55.32	1.22	.55	.27	1.5
8-56	1285	152.65	.00	.11	1.62	48.91	48.65	.58	.13	.29	1.4
8-56	1310	157.44	.00	.10	3.03	61.83	34.35	.45	.24	.32	1.6
8-53	1235	96.30	.00	.58	5.37	32.21	60.42	1.11	.31	.29	1.5
8-53	1235-1260	168.42	.04	.36	5.36	32.89	59.76	1.40	.19	.28	1.5
8-53	1260-1290	124.84	.00	.42	5.74	36.57	55.91	1.12	.24	.29	1.4
8-60	1250-1270	139.04	.00	.04	.20	41.20	56.73	1.54	.29	.27	1.5
8-60	1270-1290	147.17	.00	.05	.18	42.15	55.59	1.75	.28	.27	1.6
8-60	1290-1305	159.64	.00	.08	.17	42.40	55.66	1.50	.19	.27	1.4
8-65	1250-1267	167.86	.17	.20	6.40	60.10	31.87	.88	.38	.34	1.6
8-65	1278-1288	134.21	.00	.05	2.73	63.64	30.88	2.03	.67	.32	1.6
8-65	1288-1306	147.83	.00	.01	.31	35.11	59.06	4.55	.96	.25	1.6

1/ A weighted average of the figures in the size-interval columns.
2/ Computed from cumulative-frequency curve.
3/ Well C-51 in U. S. Geological Survey Water-Supply Paper 656.
4/ Solitary figures in the column headed, "Depth interval" represent the depth to the drill bit at the time the sample was collected.

sand. The latter method provides samples that are more truly representative than those collected by the first method, although in both cases some or all the finer mineral grains are lost. Samples collected by the first method are generally more or less mixed with material from other horizons, owing to the constant circulation of the drilling mud in the hole. The possibility of mixture with materials from shallower horizons exists in the sand-bucket method of collection also, but to a far less degree.

There is no record as to which method of sampling was used in collecting the samples studied. Therefore, the results, can be used only to make general comparisons between samples as far as texture and the degree of sorting are concerned. It should be emphasized that size-analysis data for a single sample are of little value unless they are used for comparison with data for samples which have been collected in a similar manner.

The sand samples studied range in texture from fine to medium, the average falling in the medium grade (Wentworth 15/ scale). The coefficient of uniformity is a numerical index of the degree to which the sand has been sorted. It represents the ratio of the diameter of a grain that is coarser than 60 percent of the sample to the diameter of a grain that is coarser than 10 percent of the sample. Thus, a sand that is perfectly sorted would have a coefficient of uniformity of 1.0; that is, all the grains would be of the same size.

The average coefficient of uniformity for 22 samples from the "1,400-foot" sand is 1.5, the maximum recorded is 1.6, and the minimum is 1.3. These coefficients are all somewhat lower than the true value because it must be assumed that some of the finer mineral grains have been lost. Even though it is likely that some of the coarser grains have been lost also, most of the loss is probably in the smaller grain sizes, owing to the fact that they remain in suspension in the drilling mud longer than the coarser grains.

It is of interest to note that, even though the coefficients of uniformity for the samples from the Sheahan well field and the North Parkway well field show little difference in the degree of sorting, the mechanical analysis data indicate some difference. At least 67.37 percent of the weight of each sample from the North Parkway well field is confined in one size interval. According to the analysis, 90.49 percent of the sample from 1,354-62 feet in well 7-42 is in the size interval 0.125-0.25 mm.

15/ Wentworth, C. K., A scale of grade and class terms for clastic sediments: Jour. Geology, vol. 30, No. 5, pp. 377-392, July-Aug. 1922.

In general, the bulk of the weight of each sample from the Sheahan well field is distributed between two size intervals, 0.125-0.25 mm. and 0.25-0.5 mm. The most even distribution occurs in a sample from well 8-56 (1,285 feet) in which 48.65 percent of the sample is in the interval 0.125-0.25 mm. and 48.91 percent is in the interval 0.25-0.5 mm. The most uneven distribution in this well field occurs in a sample from 1,278-88 feet in well 8-65, in which 30.88 percent of the weight is in the size interval 0.125-0.25 mm. and 63.64 percent is in the size interval 0.25-0.5 mm.

These data should not be interpreted to mean that the coefficient of uniformity is of no value. A more accurate value for this coefficient can be obtained by adding intermediate size intervals in the mechanical analysis. Considering the method of sampling and the scope of this report, it was not deemed necessary to make the mechanical analyses more detailed.

As far as the samples used in this study are concerned, the mechanical analyses indicate that the "1,400-foot" sand in the Sheahan well field is somewhat less well sorted than in the North Parkway well field. It is believed that the slight difference in the degree of sorting is responsible to some extent for the differences in the water-bearing properties of the sand in the two fields because the size and arrangement of the grains effects the permeability.

<u>Preliminary microscopic study</u>.- A binocular microscope was used to study the sand samples. The following observations should be appraised critically in view of the fact that the samples were collected from rotary drilling operations. No attempt was made to identify all the mineral grains present in minor amounts, owing to the possibility that the sand may have been contaminated with grains from other horizons.

The sand is composed essentially of fine to medium, subangular to sharply angular grains of quartz. A few of the grains are well-rounded and frosted. About half the quartz grains are clear and half are milky. The milky appearance is due in part to numerous tiny fractures in the quartz. A few of the quartz grains are smoky or amber-colored. Almost every grain of smoky quartz is crystalline. Minerals present in minor amounts include kyanite, staurolite, tourmaline, feldspars, pyrite, magnetite, muscovite, rutile, and a dark glassy mineral.

Every sample examined contains minor amounts of kaolinite. The kaolinite is generally in slightly elongated "books" which are subrounded to subangular in shape. This mineral is extremely soft in comparison to the detrital minerals listed above. If the kaolinite had been derived directly from the weathering of feldspars in the sand it would have been more or less amorphous, except for possible preservation of the general outlines of cleavage fragments. In addition, there should have been some partially kaolinized feldspar grains in the sand. The worn edges of the kaolinite grains suggest that they have been transported for some distance, but the relatively weak physical character of the mineral limits the possible distance to the source area. The stratigraphic position of the sand (near the contact between the Wilcox and Midway groups) suggests a possible source for the kaolinite because kaolinitic clays, bauxite, bauxitic clays, and kaolinized bauxite are quite commonly associated with this contact in Arkansas, Tennessee, Mississippi, and Alabama. It is possible that the kaolinite was eroded and transported in post-Midway time from deposits of kaolinite on the surface of the formations of the Midway group.

QUALITY OF THE WATER

Water from the "1,400-foot" sand is generally of good quality and ranges from 70° to 72° F. in temperature. The average hardness determined from 10 analyses is 9.5 parts per million (as $CaCO_3$). The maximum value recorded is 17 and the minimum is 5. This is generally considered to be a very soft water. The following table presents three typical analyses of waters from the "1,400-foot" sand.

Analyses of waters from the "1,400-foot" sand in Memphis
[Analyzed by G. A. Billingsley, U. S. Geological Survey]

	Well 7-38	Well 8-62	Buckeye Cotton Oil Co.
(Parts per million except pH)			
Silica (SiO_2)	10	10	12
Iron (Fe)	.84	1.4	.55
Aluminum (Al)	.7	.7	1.8
Calcium (Ca)	1.8	4.0	2.0
Magnesium (Mg)	.9	1.7	.9
Sodium (Na)	41	31	38
Potassium (K)	1.3	1.7	1.6
Carbonate (CO_3)	0	0	0
Bicarbonate (HCO_3)	112	96	105
Sulfate (SO_4)	4.4	4.7	4.4
Chloride (Cl)	2.0	1.8	2.0
Fluoride (F)	.2	.1	.1
Nitrate (NO_3)	.2	.2	.2
Dissolved Solids	119	105	115
Total hardness	8	17	9
pH	7.8	7.7	7.6

An objectionable quality of the water is that it contains an average of 0.86 part per million of iron. The maximum value recorded is 1.7 parts per million and the minimum is 0.45 part per million. The presence of the iron necessitates its removal by aeration and filtration. Practically all the iron in the public supply of the City of Memphis is eliminated in this manner.

WATER-BEARING PROPERTIES

Pumpage and water-level history

As far as is known the only major water withdrawals from the "1,400-foot" sand occur in Shelby County, Tennessee. A partial well inventory conducted in July 1945 in Crittenden County, Arkansas, indicated a total withdrawal of about three-quarters of a million gallons of water a day. The quantity of water withdrawn from the 2- and 3-inch wells penetrating the sand in De Soto County, Mississippi, is small. Outside Shelby County the total amount of water pumped from the "1,400-foot" sand is probably about a million gallons a day, and these withdrawals are distributed over a large area.

In Shelby County, owing to a combination of fortuitous circumstances, it has been possible to obtain an almost complete record of the water pumped from the aquifer. To obtain this record it was necessary to make a thorough check of all the records of the Memphis Light, Gas and Water Division and its predecessors. Fortunately, W. G. Lanham, the Superintendent of Wells, has insisted on the compilation and maintenance of adequate pumpage records. As Mr. Lanham has been associated with the municipal water supply of Memphis for nearly 40 years, the records are in good condition. The records of deep-well pumpage are continuous from the time the first well was put into operation on November 11, 1924. From 1924 through 1946 about 49 billion gallons of water was pumped from the "1,400-foot" sand in Shelby County. The average daily pumpage is given in the following table:

Average daily pumpage, in million gallons a day, from the "1,400-foot" sand in Shelby County

Year	Pumpage	Year	Pumpage	Year	Pumpage
1924	0.1	1932	6.5	1940	6.6
1925	0.9	1933	3.8	1941	8.7
1926	2.5	1934	4.9	1942	8.6
1927	2.2	1935	6.3	1943	11.1
1928	4.5	1936	5.4	1944	10.8
1929	5.7	1937	4.5	1945	8.7
1930	6.2	1938	5.6	1946	8.7
1931	5.4	1939	6.0	----	----

In the records of the Memphis Light, Gas and Water Division, it was found that the elevation of the water level in well 7-5 on November 9, 1924, was about 11 feet below the land surface or about 244 feet above mean sea level. This elevation is believed to be the original static level in the Memphis area.

Systematic records of water levels in the "1,400-foot" sand are not available from 1924 to 1945, principally because all the wells were being pumped and no unused wells were available in which to make measurements. Periodic water-level measurements were started in a well screened in this sand in January 1945.

Figure 2 presents three hydrographs of wells screened in the "1,400-foot" sand and a graph showing the average daily pumpage in 1945 and 1946. It is apparent that water-

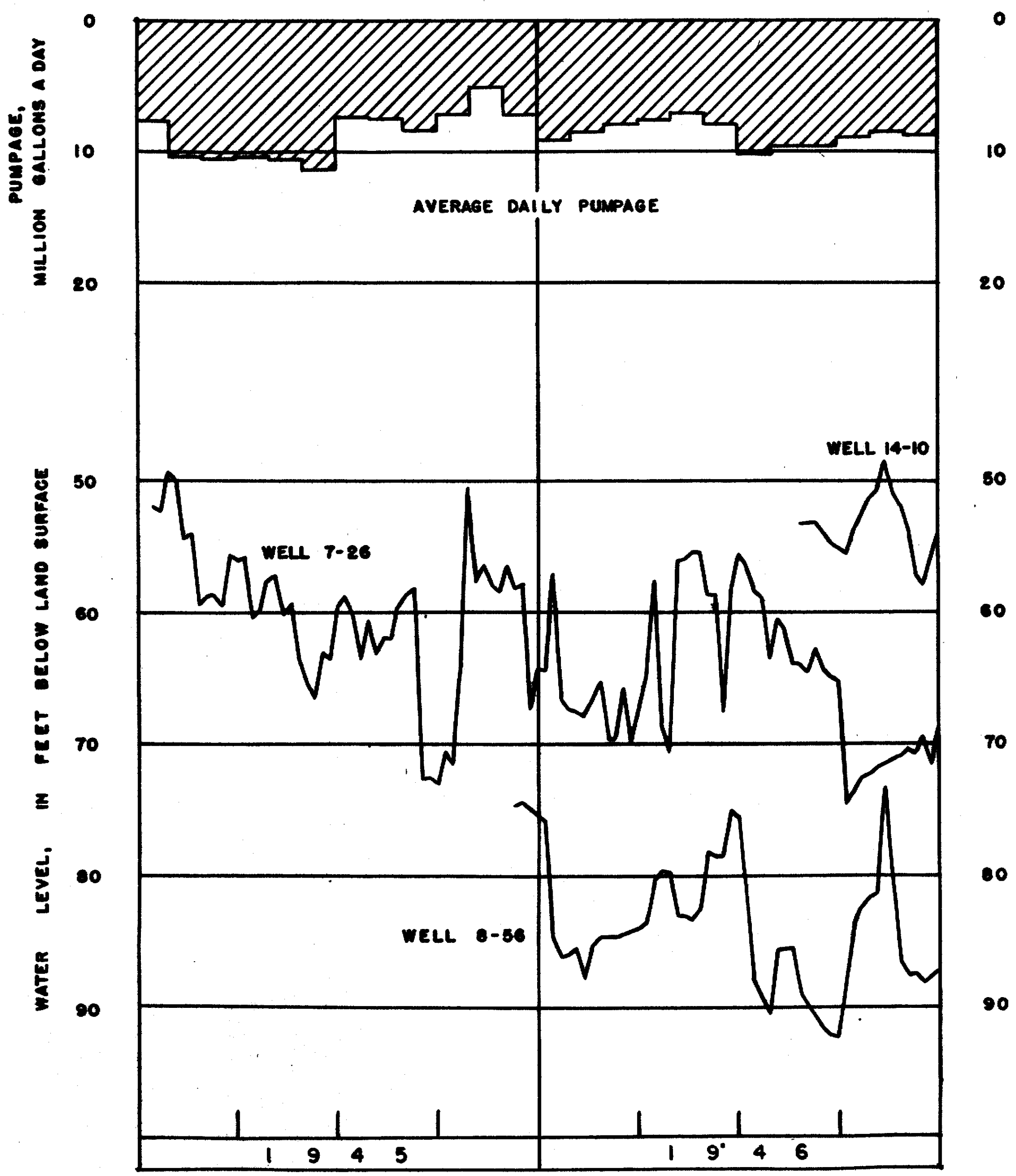


Figure 2.— Graphs showing relation between water-level fluctuations and pumpage from the "1,400-foot" sand.

level fluctuations in a particular observation well tend to reflect the pumpage in the well field in which the observation well is located more than they do the total pumpage in the area. The relation between the fluctuations of the water level in an observation well and the total pumpage is obscured by the fact that water is being pumped from several widely scattered points.

In De Soto County, Mississippi, a few measurements of water levels were made in wells that probably tap the "1,400-foot" sand. These measurements have been published in water-supply papers of the Geological Survey entitled "Water levels and artesian pressure in observation wells in the United States," beginning with the 1942 volume. Although measurements were not made early enough and were not numerous enough to justify any conclusions, it is apparent that water levels in the aquifer have declined, for the wells in Mississippi that formerly flowed freely under several feet of head now must be pumped.

A number of water-level measurements have been made in individual wells of the Parkway and Sheahan fields since the wells were first operated. These measurements are not strictly comparable, owing to changes in pumping conditions. Systematic measurements have been tabulated for the period from July 1933 to February 1934, during which time all the wells screened in the "1,400-foot" sand were shut off for an experiment. However, all the measurements made by members of the water works staff over the 20-year period have not yet been tabulated.

Depths to water, in feet below the land surface in 1931 and 1945 under similar conditions of pumping, are given below:

Well number	January 18, 1931		January 18, 1945	
	Depth to water in feet	Pumping rate in gallons a minute	Depth to water in feet	Pumping rate in gallons a minute
7-5	(1/)	-	-	620
7-26	-	700	51.6	-
7-27	-	700	(1/)	-
7-28	36.7	-	52.1	-
7-29	31.5	-	47.7	-
7-30	26.8	-	44.9	-
7-31	27.2	-	45.5	-
7-32	-	700	-	760
7-33	-	700	40.0	-
7-38	-	-	-	850

1/ No measurement made.

Note: Wells in Sheahan field not yet drilled in 1931. Sheahan wells shut off for 2 days when measurements were made in 1945.

The average change in water level between 1931 and 1945 is apparently about 17 feet in the Parkway well field. This is not a large change over a 14-year period. Part of the change can be attributed to the effect of pumping in the Sheahan well field during the past 10 years. Computations made on the basis of data obtained from pumping tests indicate that a drawdown between 6 and 8 feet would be produced in the Parkway field by pumping an average of 2 million gallons a day at the Sheahan well field for about 10 years.

On the basis of pumping-test data, and assuming that an average of 5 million gallons of water was pumped daily in the Parkway field between 1931 and 1945, the static water level would be expected to decline about 4 feet. Adding this to the figures of 6 to 8 feet, given in the previous paragraph, it is believed that 10 to 12 feet of the apparent loss of head of 17 feet between 1931 and 1945 can be accounted for by the pumping in the two municipal well fields. The interference caused by the Chickasaw Ordnance Works, where a daily average of about 1.5 million gallons of water was pumped from January 1941 to January 1945, was between 2 and 3 feet at the Parkway field by January 1945. Added to the 10 to 12 feet given above, this gives a total of 12 to 15 feet.

Basing conclusions on the results of the pumping tests and assuming that the character of the sand is unchanged from the Memphis area to the area where the sand is at or near the surface, it would seem that the decline of the water level in the Parkway field between 1931 and 1945 is largely accounted for by the known water withdrawals in the area.

The difference between the drawdown computed from the effect of pumping since 1931, 12 to 15 feet, and the actual measured drawdowns, about 17 feet, is 2 to 5 feet. It is believed that this discrepancy is largely due to variations in pumpage within the field and to pumpage in Crittenden County, Arkansas, and De Soto County, Mississippi, and to variations in the transmissibility and the coefficient of storage. The effect of recharge is not yet discernible. This would indicate that the recharge area is quite distant, probably more than 50 or 60 miles from the Memphis area.

The available water-level data, combined with pumpage and pumping-test information, seem to show that until now the aquifer has behaved as would be expected of the theoretically infinite aquifer postulated in the derivation of the formulas used to compute the effects of withdrawals. Apparently the quantity of water withdrawn has been small compared to the total quantity in storage and the effect of the boundaries of the aquifer is not yet manifest.

Pumping tests

The quantity of water that can be obtained from a well or a group of wells depends in part upon the hydraulic characteristics of the water-bearing formations tapped by the wells. Pumping tests may be used to determine these characteristics. The quantity of water that is transmitted by a formation depends upon its permeability, thickness, extent, and continuity, and on the hydraulic gradient that is induced in the formation.

The permeability of a formation is defined as the rate at which the formation will transmit water through a unit cross section under unit difference of head per unit distance. Permeability may be expressed as the number of gallons of water a day that will percolate through a cross section of the formation 1 mile wide and 1 foot thick, for each foot per mile of hydraulic gradient.

Transmissibility is the product of the permeability and the thickness of the saturated portion of the aquifer, and in this report is measured in gallons a day per foot.

The coefficient of storage is the valume of water released from storage in each vertical prism of the aquifer of unit cross section by unit decline of head. The water is derived from storage, owing largely to the expansion of the water and the compaction of the aquifer. There is no actual unwatering of the formation.

After the deep wells of the Sheahan well field were completed between 1932 and 1934 by the Water Department (now included in the Memphis Light, Gas and Water Division), pumping tests were conducted on each well and the interference among the different wells screened in the same stratum was measured. The tests were planned and conducted by W. G. Lanham and most of the measurements were made by A . J. Rumley. After discussing the testing procedure with Messrs. Lanham and Rumley, it was concluded that all the data needed for computing the values for the transmissibility and for the storage coefficient were obtained to the required degree of accuracy.

In addition to the tests made in the Sheahan well field after the completion of the wells, another test was conducted by Mr. Lanham, starting in the summer of 1933 and continuing into February 1934. The test consisted of stopping all municipal pumping from the "1,400-foot" sand. At the same time, measurements were made each day of the depth to water in all the wells in the Sheahan and Parkway fields. On February 9, 1934, after the wells had been idle for 196 days, well 7-26 was started. On February 21, well 7-28 was started and pumped intermittently until March 9, when it was shut off. On March 31 other deep wells were started and on April 1 wells 7-26, 7-27, 7-28, and 7-29 were all pumping. All the other wells in the Parkway field and well 8-56 in the Sheahan field were measured during the entire period. From data collected during the course of this test, values for the transmissibility and for the storage coefficient within the Parkway and Sheahan fields and between the fields were computed.

On January and February 1945 another series of pumping tests was conducted in the Parkway and Sheahan well fields and an attempt was made to measure the interference between the fields. These tests yielded values for the transmissibility and for the storage coefficient essentially the same as those computed from the tests made in 1932-34.

A pumping test was made on the property of the Buckeye Cotton Oil Company during March 1947. The company's deep well was used as the discharge well and was pumped for 3 days at a rate of 1,400 gallons a minute. Two wells on the company's property, which were owned by the War Assets Administration, were used as observation wells. The decline of the water level produced by pumping the Buckeye Company well was recorded in well 8-56 in the Sheahan well field, about 3.5 miles away.

The values obtained from the pumping tests have a moderate range. For example, in the Parkway field, values ranging from 110,000 to 144,000 gallons a day per foot were obtained for the transmissibility, and the values for the storage coefficient ranged from 2.3×10^{-4} to 6.1×10^{-4}. In the Sheahan field values for the transmissibility ranged from 87,000 to 117,000 gallons a day per foot and values for the coefficient of storage ranged from 1.21×10^{-4} to 2.15×10^{-4}. At the Buckeye plant the values for the transmissibility ranged from 97,000 to 103,000 gallons a day per foot and the values for the coefficient of storage ranged from 2.13×10^{-4} to 2.52×10^{-4}.

The differences in transmissibility, which are about ±15 percent from the average, are not greater than usual in unconsolidated aquifers.

The following table presents the averages of the results obtained from the pumping tests:

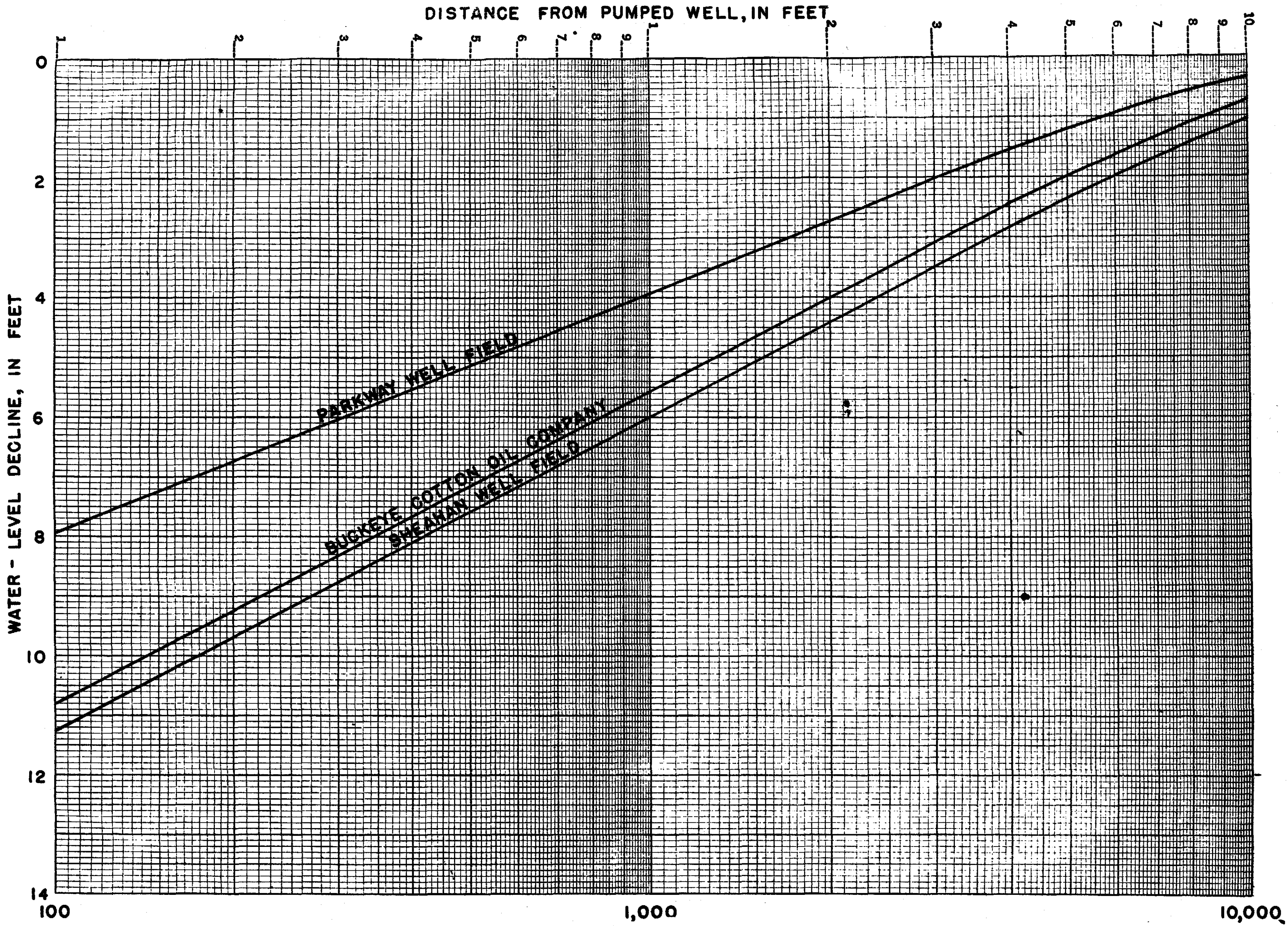


Figure 3.—Approximate water-level declines at the end of 1 day at various distances from a well being pumped at 1,000 gallons a minute.

Location	Number of sets of data	Average transmissibility (gallons a day per foot)	Number of sets of data	Average coefficient of storage (x 10^{-4})
Sheahan well field	14	100,000	12	1.6
Parkway well field	5	130,000	4	4.5
Buckeye Cotton Oil Company	2	100,000	2	2.3
Between Sheahan and Parkway well fields	6	138,000	2	3.8
Between Buckeye Cotton Oil Company and Sheahan well field	1	113,000	1	2.1

The differences in the transmissibility and coefficient of storage in the Sheahan and Parkway well fields and at the Buckeye plant are important in considering any future increase in the use of deep-well water. A well drilled in the Parkway field should have a specific capacity 25 to 30 percent greater than an identically constructed well in the Sheahan field or in the vicinity of the Buckeye property. The specific capacity of a well is defined as the yield per unit of drawdown and is commonly expressed as the yield in gallons a minute per foot of drawdown of the water level after a definite period of pumping. For equal well spacing and the same pumpage, the interference among the Parkway wells will be less than the interference among wells at the Sheahan field or at the Buckeye plant.

Figure 3 shows the approximate water-level decline to be expected at the end of 1 day at various distances from a well that is being pumped at 1,000 gallons a minute. Separate curves have been drawn for the Sheahan and Parkway well fields and for the vicinity of the Buckeye plant, using the following values for the transmissibility and coefficient of storage at the three locations:

Location	Transmissibility	Coefficient of storage
Parkway well field	130,000	4.5×10^{-4}
Sheahan well field	100,000	1.6×10^{-4}
Buckeye Cotton Oil Company	100,000	2.3×10^{-4}

As far as static water levels are concerned, over a long period of years the differences in water-level declines at each of the locations will be small if equal amounts of water are pumped constantly at each location. However, the Parkway field and the Buckeye plant have a practical advantage over the Sheahan field in that their elevations are about 50 feet lower and consequently the pumping lifts are less.

SUMMARY

A study of the available subsurface data indicates that the "1,400-foot" sand is probably in the lower part of the Wilcox group (Eocene). It is composed essentially of fine- to medium-grained, subangular to sharply angular quartz sand interbedded with a few thin layers of clay. The sand is apparently about 210 [redacted] feet thick and the upper surface dips westward about 30 feet to the mile. It is believed that the sand can be identified as a hydrologic unit as far as 45 miles west, 78 miles north, 48 miles east, and 80 miles south of Memphis. In the Memphis area the aquifer has been found to be remarkably uniform both geologically and hydrologically. A study of the available water-level and pumpage data indicates that nearly all the water pumped up to and including 1945 came from storage within the aquifer. There is, as yet, no indication that the rate of recharge of the aquifer has been affected by the pumping.

Water from the "1,400-foot" sand is very soft but it contains iron.

More investigative work will be necessary before these tentative conclusions can be substantiated fully.

Indianapolis, Ind.

List of corrections for Circular 33, "Geology and water-bearing properties of the '1,400-foot' sand in the Memphis area."

Cover page and page 1. "1,400 foot" should be "1,400-foot".

Plate 1. The solid and open circles under the explanation should be red instead of black.

Page 2, column 1, paragraph 3, line 6. No. 148-LD should be 148-1D.

Page 2, column 2, paragraph 3, line 6. "Measurement" should be "measurements".

Page 3, column 1, paragraph 2, line 2. "Teritary "should be "Tertiary".

Page 3, table. Line between Quaternary and Tertiary in "System" column should be dashed, and should be moved up, opposite "Pleistocene and Pliocene."

Page 3, footnote 5. "Mississippi" should be followed directly by a colon and the phrase "Mississippi Geol. Survey Bull. 65".

Page 6, column 2, line 9. 230 feet should be 210 feet.

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