UNITED STATES DEPARTMENT OF THE INTERIOR

A PRELIMINARY REPORT ON THE ARTESIAN WATER SUPPLY OF MEMPHIS, TENNESSEE

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 638–A

Prepared in cooperation with the Tennessee Division of Geology

UNITED STATES DEPARTMENT OF THE INTERIOR
Ray Lyman Wilbur, Secretary
GEOLOGICAL SURVEY
George Otis Smith, Director

Water-Supply Paper 638–A

A PRELIMINARY REPORT ON THE ARTESIAN WATER SUPPLY OF MEMPHIS, TENNESSEE

BY

F. G. WELLS

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By F. G. WELLS

ABSTRACT

Memphis is located in the part of the Gulf Coastal Plain known as the Mississippi embayment. It is underlain by unconsolidated sand and clay formations of Tertiary and Cretaceous age. The Wilcox group, of Tertiary age, and the Ripley formation, of Cretaceous age, are excellent aquifers, and all the water consumed in Memphis is derived from them. The maximum pumpage from the Wilcox group was reached about 1920; in that year an estimated average of 37,575,000 gallons a day was pumped. In 1928 the average daily pumpage from the Wilcox group was about 33,984,000 gallons, and in addition to this the Memphis Artesian Water Department pumped an average of 4,616,000 gallons a day from the Ripley formation.

The static level at Memphis varies with the pumpage and the stage of the Mississippi River. The original static level was about 235 feet above mean sea level. In 1928 the average static level at the Auction Avenue plant was 202 feet above mean sea level, which was about 33 feet lower than the original level. The yield is therefore about a million gallons a day for each foot of drawdown. The drawdown is not excessive, and additional pumpage can be developed without undue lowering of head.

The water from both the Wilcox group and the Ripley formation is fairly soft and has a moderately low content of dissolved mineral matter. The iron content is sufficiently high to be objectionable, but the iron is easily removed by aeration followed by either settling or filtration for removal of sediment.

INTRODUCTION

On June 1, 1928, field work was started for a report on the ground-water resources of western Tennessee, one of a series to be prepared by the United States Geological Survey and the Tennessee Geological Survey that will treat in a comprehensive way of the water supplies of Tennessee available from wells and springs for muncipal, industrial, and other uses. During the summer and fall of 1928 the field work was completed in 10 counties in the southwestern part of the State, including Shelby County, in which Memphis is situated. It was realized from the beginning that the ground-water conditions at Memphis constituted a very important part of the investigation, and two months was given to the accumulation of data in this city.

Through the cooperation of the Memphis Artesian Water Department it was possible to install automatic water-stage recorders over two representative observation wells, one on Auction Avenue and one

on Central Avenue, and thus to obtain for these wells continuous records of the depth to the water level, which show with much precision the relation between the withdrawal of the artesian water and the subterranean inflow of new supplies to recharge the artesian reservoir. It becomes continuously more apparent that any adequate quantitative study of the ground-water supply in an area must be based on data accumulated over a considerable period of time, and that the longer the record the more accurate are the resulting conclusions. Any deduction as to quantity of water made from measurements taken during a brief period are likely to be premature and may lead to erroneous conclusions. For this reason it is planned to continue observations at Memphis for a period of years. The present preliminary report gives the data that have been thus far obtained and such generalizations as can safely be made at this stage of the investigation. A comprehensive report on the ground-water resources of all of western Tennessee is now being prepared for publication.

HISTORY OF ARTESIAN-WATER DEVELOPMENT IN MEMPHIS

The early history of the development of the municipal water supply in Memphis is given by Lundie [1] as follows:

> Prior to 1870 Memphis relied wholly for its water supply on cisterns and shallow wells.
>
> In 1867-68 an investigation as to a general system of water supply was made by Charles Hermany, C. E., a report on which was presented to the board of commissioners of the city July 15, 1868. In this report Mr. Hermany recommended that a supply be taken from Wolf River near its mouth. This led to the formation of the Memphis Water Co., which in 1870 secured a charter from the State legislature to supply water to the city. The company erected a pumping plant on the south bank of the Wolf River about 2 miles from the center of the city, and laid 17 miles of pipe through which the city was supplied with water pumped from the river. The enterprise was a financial failure, and the plant was sold under foreclosure proceedings in the United States circuit court in December, 1879, to the reorganized Memphis Water Co. for $200,000, the company's statement of cost being $472,278.
>
> The yellow-fever scourge in 1878-79 aroused the citizens of Memphis to a thorough sense of the crying demand for improved sanitary conditions, which resulted in the adoption of a sewerage system, the first sections of which were built in 1879-80, under the direction of George E. Waring, jr., C. E. These sewers called for an extension of the water pipes to supply the flushing tanks which are an integral part of the system.
>
> The Memphis Water Co. in May, 1882, concluded a contract with the taxing district of Shelby County (now the city of Memphis) for public water supply—the contract to remain in force for a period of 20 years from May 1, 1882. Rapid extension of the piping system followed this contract.
>
> In 1885 a citizens' movement was instituted with a view toward securing a better water supply, the principal objection to the supply urged at that time

[1] Lundie, John, Report on the waterworks system of Memphis, Tenn., pp. 4–6, 1898.

being its turbidity. A committee was appointed by the legislative council of the taxing district to investigate and report on the question. Gen. Colton Greene made a preliminary report to this committee in February, 1866, and in December, 1866, the committee presented its report to the council.

The committee considered three principal sources of supply which seemed available, viz, the Mississippi River, South Horn Lake, and Wolf River at a point near the Louisville & Nashville railroad crossing about 8 miles east of the city. All projects involved methods of filtration.

Prospective supply from wells had been brought to the attention of the committee, but evidence at that time seemed to cast doubt on the practicability of such a system of water supply for city purposes, after the failure of several experimental wells was reported, which had been sunk at the instance of the Memphis Water Co. * * *

While the report of this committee was in preparation, the late Mr. R. C. Graves, then superintendent of the Bohlen-Huse Ice Co., had a well sunk on the company's property on Court Street near the bayou, primarily for the object of obtaining water for condensing purposes, to a depth of 354 feet. After having passed through a stratum of clay 150 feet thick, water-bearing sand—the source of the present supply—was reached, and a flowing well was the result, the water from which rose several feet above the surface of the ground.

A company was organized for the purpose of supplying the city with water from this source, which, after some further experimentation, entered into a contract with the taxing district on July 30, 1887, under the name of the Artesian Water Co., covering terms of public and private supply, and anticipating a consolidation of the interests of this company with those of the Memphis Water Co., then under contract for public supply.

Both water companies then proceeded to sink wells, but consolidation of their interests was consummated in April, 1889, shortly after which the Wolf River Plant was abandoned and dismantled, a temporary station having been erected near the present station (the Auction Avenue station), connecting with such wells as were then operative.

Forty-two wells were drilled during 1888 and 1889, and the Auction Avenue pumping station was put into operation in 1890. The Auction Avenue plant consisted of a tunnel 5 feet in diameter and smaller branching tunnels situated 75 to 80 feet below the surface. The wells discharged directly into these tunnels, and the water flowed by gravity to a central suction well at the pumping station, which is locally called the "wet well." Three Worthington vertical compound condensing high-duty pumping engines pumped the water from the central well and delivered it under pressure directly to the service mains.

In 1903 the interest of the Memphis Water Co. was purchased by the city, the Memphis Artesian Water Department was organized, and a Board of Water Commissioners was formed for its supervision.

New wells were drilled from time to time as old wells failed and as additional supplies of water were required, but no change was made in the system until 1907. By this time the Auction Avenue plant had become inadequate, and during 1907 and 1908 a new pumping station was built at Central Avenue. The Central Avenue plant

consisted of six wells pumped by compressed air and had a capacity of about 5,000,000 gallons in 24 hours.

Prior to 1907 the Artesian Water Department had done some experimenting with segregated pumps. By 1910 the feasibility of these pumps had been demonstrated and several installations were made at different points about the city. Ultimately 14 such installations were available for use. They served to handle peak loads and heavy local drafts.

Realizing that the existing plant was becoming inadequate and that the system was liable to pollution by seepage of sewage into the tunnels, the water commissioners contracted with Chester & Fleming, hydraulic engineers, in 1919, to make a thorough study of the water-supply system and to submit recommendations for future development. Chester & Fleming submitted their report in April, 1920. A further study was made by Fuller & McClintock, hydraulic engineers, who submitted a report to the commissioners in March, 1922. This report considered the various methods of developing a larger water supply and recommended a new plant that would obtain water from wells pumped by compressed air. The recommendations were approved by the water commissioners, and Fuller & McClintock undertook the construction of the new plant, which was put into operation in 1925.

The present supply is obtained from 23 wells 375 to 550 feet deep and 9 wells about 1,400 feet deep. The wells 375 to 550 feet deep are located at intervals of 500 feet along or near North Parkway and are numbered C–1 to C–24 (see pl. 1); the 1,400-foot wells are at the same well houses as wells C–1, C–2, C–3, C–4, C–5, C–21, C–22, C–23, and C–24. The wells are pumped by compressed air at a pressure of about 80 pounds to the square inch, which is delivered to the well houses by means of a duplicate system of pipe lines. The water flows by gravity through a duplicate system of mains to the pumping station at North Parkway and Dunlap Street, where it is aerated and filtered and pumped directly into the delivery mains.[2]

The first deep well in Memphis was drilled for the Bohlen-Huse Ice Co., in 1886, but no interest was aroused in the artesian-water supply until another well drilled for the same company in 1887 on Court Street proved to be a flowing well. Immediately wells were drilled for other industrial plants in Memphis, and Safford[3] reported 57 wells exceeding 185 feet in depth in the city in May, 1889. Of these wells, 32 were city wells and 25 private wells.

Although no records exist of the number of wells drilled or the quantity of water pumped by private concerns during subsequent years, information gathered from old drillers in the region indicates

[2] For a detailed description of the city water system see Municipal Engineering, vol. 64, pp. 47–51, 1923.
[3] Safford, J. M., The water supply of Memphis: Tennessee State Board of Health Bull., vol. 5, p. 102, 1890.

that practically every plant requiring a supply of water of more than 10,000 gallons a day was equipped with its own well. Chester & Fleming, in their report made in 1920, list 58 private plants having wells with large yields. The writer, in 1928, listed 86 private plants with wells. The location of these wells is shown on Plate 1, and data in regard to them are given in the accompanying table. From the drilling of the first well in Memphis to the present time pumpage from private wells has equaled or exceeded the pumpage of the Memphis Artesian Water Department.

Records of wells of the Memphis Artesian Water Department

[Measurements of depth to water were made on Mar. 15, 1929]

No.	Altitude above mean sea level (feet)	Depth of well (feet)	Diameter of well (inches)		Geologic horizon	Depth to water (feet)	Yield with air lift (gallons a day)
			Top	Bottom			
C-1		425	12	10	Wilcox group		1,440,000
C-2		453	12	10	do		1,440,000
C-3		409	12	10	do		1,440,000
C-4		519	12	10	do		1,440,000
C-5	359.4	1,400	10	8	Ripley formation	23.6	
C-6		504	12	10	Wilcox group		1,440,000
C-7		522	12	10	do		1,440,000
C-8					do		
C-9		544	12	10	do		1,440,000
C-10		495	12	10	do		1,440,000
C-11		525	12	10	do		1,440,000
C-12		518	12	10	do		1,440,000
C-13		510	12	10	do		1,440,000
C-14		479	12	10	do		1,440,000
C-15	355.8	495	12	10	do		1,440,000
C-16	356.0	527	12	10	do		1,440,000
C-17	356.5	522	12	10	do		1,440,000
C-18	356.6	527	12	10	do		1,440,000
C-19	357.1	371	12	10	do		1,440,000
C-20	356.6	371	12	10	do		1,440,000
C-21	358.3	345	12	10	do		1,440,000
C-22	358.7	357	12	10	do		1,440,000
C-23	358.4	393	12	10	do		1,440,000
C-24	358.1	369	12	10	do		1,440,000
C-25		2,656	10	8	Eutaw formation	22.3	
C-26	360.5	1,400	10	8	Ripley formation	24.9	
C-27	363.9	1,400	10	8	do	16.6	
C-28	355.7	1,400	10	8	do	11.4	
C-29	350.6	1,400	10	8	do	8.3	
C-30	357.5	1,400	10	8	do	9.2	
C-31	358.6	1,400	10	8	do	8.3	
C-32		1,400	10	8	do	6.4	
C-33		1,400	10	8	do		

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Records of drilled wells in Memphis, Tenn.

Section in Plate 1	No.	Owner	Location	Altitude above mean sea level (feet) [a]	Depth of well (feet)	Diameter of well (inches)		Depth to which well is cased (feet)	Water level		Method of lift	Capacity of pump (gallons a minute)	Drawdown (feet) [a]	Daily pumpage (gallons)	Source of data [b]	Quantity of water	
						Top	Bottom		Depth below surface (feet)	Date of measurement (1923) [b]						Date sampled (1923)	Content of dissolved iron (parts per million)
75?-	1	Fisher Lumber Co.	North Second St., well 1	220	422	12	12	422	33	Rept.	Centrifugal	300	13				
75-1/2	2	do	North Second St., well 2	220	414	16	16	414	43	do	do	850	19	450,000	Rept.		
132-2	3	James C. Clark	100 feet north of Plum Ave., 150 feet west of Illinois Central R. R.		445	6	6		35	Oct. 12	Air lift	80		125,000		Oct. 12	0.94
132-1	4	James E. Stark Co.	150 feet north of intersection of North Seventh St. and Illinois Central R. R., 20 feet west of track.	225	450	4	4	450			do						
	5	Turner, Faber & Lovel Co.	100 feet north of Seventh St., 75 feet east of Illinois Central R. R.	225	480	6	6	480			Reciprocating	70		30,000	Est.	Oct. 11	1.4
53-	6	Anderson Tully Co.	200 feet north of intersection of Illinois Central R. R. and North Second St.	230	450	4½	4½	450			Air lift	200		100,000	do.	do.	.64
52-2	7	American Snuff Co.	Front and Keele Sts.	235	388	10	6	388	33	Rept.	Reciprocating with steam head.			30,000	do.	do.	2.0
32-	8a	Bannon Ice & Coal Co.	190 feet west of Seventh St., 125 feet south of Auction Ave.	240	408	8	8	408	45	do.	Air lift					do.	.24
	8b	do	200 feet west of Seventh St., 75 feet south of Auction Ave.	240	396	10	10	396	45	do.	do.	600	10	860,000	Est.		
132-3	9	James E. Stark Co.	75 feet north of Plum Ave., 75 feet west of Illinois Central R. R.	230	445	6	6	445	28	do.	do.	350	9	125,000	do.		
	10	Kelsey Wheel Co.	725 feet north of Plum Ave., 25 feet west of Illinois Central R. R.	230	490	8	8	480			do.	500		700,000	do.	Oct. 11	1.3
102-1	11	Memphis Hardwood Flooring.	1,225 feet north of Plum Ave., 375 feet west of Thomas St.	230	412	4	4	412	34	Rept.	do.	150		200,000		do.	1.4
	12	Green River Lumber Co.	725 feet north of Plum Ave., 25 feet east of Belt Line track.	230	425	4	4	425			Reciprocating with steam head.			250,000		do.	1.2
60-1	13	E. L. Bruce Flooring Co.	400 feet east of Thomas St.	230	385	8	6	385			Air lift	350		200,000			

139-1, 2	14	Virginia Bridge Co.	550 feet west of Morehead Ave., 65 feet south of White St.	240	440	8	8				Reciprocating electric.	80		[c] 40,000	Rept.	Oct. 11	4.4
	15	Golf Shaft & Block Co.	200 feet east of Morehead Ave., 10 feet south of White St.	230	430	6	6	430			Air lift	50		15,000	do		
H																		
31559°—31—2 71-1	16	Electric Ice Co.	80 feet east of Waldran St., 200 feet from east-west alley.	250	492	16	10	430	90	Rept.	Centrifugal electric.	750		720,000	Est.	Oct. 9	1.1
	17	Valrath Outdoor Enterprise.	Nedra Ave.		267	3	3	267	100	do	Reciprocating						
	18	King Haase Furniture Co.	500 feet south of Chelsea Ave.	240	55	4	4	55	10	do	do			50,000	Est.		
	19	Urania Petroleum Co.	100 feet east of Hollywood St., 75 feet north of Union R. R.		530	6	6	530	30.5	Oct. 12	Air lift	340	41.5	500,000	do		
30-1	20	Hollywood Ice Co.	West of Hollywood St., 60 feet from Louisville & Nashville R. R.		377	8	6	377	35	Rept.	Turbine	325	15	470,000	Est.	Oct. 12	.94
	21	Alabama Fertilizer Co.	900 feet east of Hollywood St., 50 feet south of Louisville & Nashville R. R. siding.			6	6				Air lift	400		600,000		do	.20
83-1	22	Hartwell Bros.	25 feet west of Fairfax St.		395	6	6	395	19	Oct. 12	do	200	49	40,000			
11-	23	Forest Products Chemical Co.	Speed Ave.		565	10	10	565	23	Oct. 13	do	600	12	500,000	Est.	Oct. 11	.45
19-1	24	Dixie Cotton Oil Co.	775 feet west of Illinois Central R. R., 600 feet north of Speed Ave.		500	8	8	500	40	Rept.	Centrifugal	1,170					
III																		
12	25	Cudahy Packing Co.	500 feet north of Speed Ave.		438	8	8	438	20	do	do	550	45	400,000	Rept.	Oct. 11	.96
	26	Wood Lumber Co.	300 feet south of Speed Ave.		[d] 40			40			Reciprocating with steam head.	10		15,000	do		
97-1	27	Louisville & Nashville R. R.	500 feet east of Leewood St., 125 feet north of main track.		435	16½	12	435	25	Rept.	Centrifugal	400		500,000	Est.		
14-	28a	Buckeye Cotton Oil Co.	Raleigh Road, 50 feet east of Louisville & Nashville R. R.		✓377	24	24	377			do	1,500					
	28b	do	do		✓426	24	24	426			do	900					
	28c	do	do		✓290	24	24	290			do	1,800		2,500,000	Rept.		
67-7	29	Chickasaw Cooperage Co.	Scott St. near Phillips Ave.								Air lift	120		150,000	do	Oct. 12	.35
	30	Memphis Ice Co.	Summer Ave. and Union R. R.			4	4				do	250		360,000	do		

[a] Altitudes were determined from positions on the U. S. Geological Survey topographic map, which has a 10-foot contour interval.
[b] Rept., information given by engineer in charge of plant. Est., estimated; for water level and drawdown the figures given were determined from the shut-in pressure and the operation pressure of the air lift; for daily pumpage the figures given were computed from ice production or pounds of steam used.
[c] Drawdown when pumping at capacity of pump unless otherwise noted.
[d] Well ends in Pliocene gravel.

Records of drilled wells in Memphis, Tenn.—Continued

Section in Plate 1	No.	Owner	Location	Altitude above mean sea level (feet)	Depth of well (feet)	Diameter of well (inches)		Depth to which well is cased (feet)	Water level		Method of lift	Capacity of pump (gallons a minute)	Drawdown (feet)	Daily pumpage (gallons)	Source of data	Quantity of water	
						Top	Bottom		Depth below surface (feet)	Date of measurement (1928)						Date sampled (1928)	Content of dissolved iron (parts per millio
IV	31	Shelby County Workhouse.	Old Raleigh Road		520	8	6	520	36	Rept.	Double-acting reciprocating.	150					
200-1	32	National Cemetery	Old Raleigh Road at intersection with Louisville & Nashville R. R.		388	4	2	388	30	do	Reciprocating						
99-1	33	Memphis Cold Storage Co.	99 South Front St	270	510	8	8	510	60.5	do	Air lift	300	16	250,000	Rept.		
	34	Swift & Co	31-39 Union Ave	270	468			468	52	do	do			45,000			
79-1	35	Gayoso Hotel	75 feet east of Front St., 100 feet north of McCall St.	260	420	8	8	420	90	do	do	120	12	200,000	Rept.		
	36	Oliver Finnie Co	Vance Ave., under south sidewalk at west end.		500	8	8	500	60	do	do	110		60,000	do	Oct. 8	.71
136-1	37	Tennessee Brewing Co.	Tennessee St	280	520	10	10	520	70	do	do	400	20	450,000	Est.	Oct. 13	2.5
	38	Grand Central Station.	200 feet north of West Georgia Ave., west of South Main St.	275	498	12	12		80	do	Centrifugal	569		500,000	Rept.		
63-1	39	Chisca Hotel	Mulberry St., under east sidewalk, 75 feet south of Linden St.	255	490	6	6	490	70	do	Air lift	200		185,000	do	Oct. 8	.17
V	40	Orpheum Theater	McCall Ave., under south sidewalk, 50 feet north of Main St.	260	475	10	8	475	65	do	Turbine	400					
118-1	41	Hotel Peabody	Union Ave	250	448	10	10	448	50	do	Air lift	500	46	500,000	Est.		
116-1	42	Bank of Commerce & Trust Building.	Madison Ave. and Main St.	260	500			500	62	do	do		*12	60,000	Rept.	Oct. 9	.65
93-1	43	Loeb Steam Laundry.	282-290 Madison Ave	255	416	6	6	416	38	Oct. 9	do	200	12	100,000	do	Oct. 10	.42
	44	Southern United Ice Co.	308 Court St	250	480	10	10	480	35	Rept.	do	700	53	1,000,000	do	Oct. 12	.0
66-1	45	Coca Cola Bottling Co.	50 feet west of Fourth St., 100 feet north of Washington Ave.	245	450	8	6	450	45	do	Double-acting reciprocating.	53		25,000	Rept.	Oct. 9	.88

46	Memphis Union Station Co.	1,000 feet south of Calhoun Ave., 50 feet west of South Third St.	260	558	8	8	558	70	Rept.	Centrifugal	400		250,000	Rept.	Oct. 13	1.1
7a	Memphis Power & Light Co.	South Fourth St.	270	527	12	12	527	80.5	Oct. 15	Air lift					do	4.4
47b	do	do	270	485	10	10	485	76.9	do	do						
47c	do	do	270	503	16	16	503	75.7	do	do						
47d	do	do	270	501	16	16	501			do			360,000	Rept.		
48	Broadway Ice Co.	100 feet west of Lauderdale St., 50 feet south of railroad.	280	500	8	8	500	70	Rept.	do	600	20	860,000	do	Oct. 18	1.7
49	Consumers Coal & Ice Co.	75 feet north of Beale Ave., 100 feet west of its intersection with Southern Ry.	255	395	10	10	395	59	do	do	500	20	720,000	do	Oct. 10	.60
50	Lily Ice Cream Co.	658 Madison Ave.	260	453	8	8	453	89	do	do	300	11	400,000	do		
51	Kraus Cleaners Co.	726 Madison Ave.	255	473	6	6							30,000	do		
52a	Clover Farm Dairy.	Beale Ave. and Manassas St.	260	524	6	6	524	81.5	Oct. 19	Air lift	303	50			Oct. 10	2.3
52b	do	do	260	597	6	6	597	81.5	do	do	344	50	360,000	Rept.		
53	do	Union Ave. and Walnut St.	270	596	8	6	596	74	Rept.	do	345	41				
54	Southern United Ice Co. (formerly Valley Ice & Coal Co.).	100 feet north of Alston Ave., 200 feet east of Porter St.									600		800,000	Rept.		
55	Crescent Laundry Co.	Dunlap St. near Beale Ave.	275	390	6	6	390			Air lift	200		115,000	do	Oct. 10	.36
56	Baptist Hospital	Madison Ave.	265	490	6	6	490	77	Oct. 10	do	300	33	200,000	do	do	.80
57	Memphis Steam Laundry.	Jefferson Ave.	240	463	6	6	463	60.6	do	do	450	11.6	190,000	do	Oct. 18	.48
58	Success Steam Laundry.	Jefferson Ave. and Pauline St.	255	460	6	6	460	20	Est.	do	132	12	79,000	do	Oct. 10	.41
59	Memphis Furniture Manufacturing Co.	Dudley St.	300	417	4	4	417	35	Rept.	do	35	15	21,000	do	Oct. 17	.93
60	DeSoto Hardwood Flooring Co.	Sledge St.	305	[d] 90	5½	5½	90			Reciprocating			20,000	do	Oct. 18	.05
61	Model Bluff City Laundry.	Linden Ave. and Camilla St.	260		6	6				Air lift			80,000	do	Oct. 23	.94
62	Lamar Steam Laundry.	Lemar Ave. opposite Redcliffe Pl.	270	487	6	4	487			do	125		75,000	do	do	2.4
63	Southern Cotton Oil Co.	Williams Ave.	315	498	16	8	498	100	Rept.	do	450	25	186,000	do	do	2.1
64	Blumenfeld Ice & Coal Co.	Lamar Ave. and Haywood St.	305	495	10	8	495	76	do	Centrifugal	450		650,000	do	do	1.1
65	East End Ice & Coal Co.	Central Ave. and Cooper St.	295	400	8	8	400			Air lift	400		500,000	Rept.		
66	Virginia Carolina Chemical Corp.	Poplar Ave.		449	6	6				do	60	2	30,000	do	Oct. 12	.0

[d] Well ends in Pliocene gravel.
* Pumping 100 gallons a minute.

Records of drilled wells in Memphis, Tenn.—Continued

Section in Plate 1	No.	Owner	Location	Altitude above mean sea level (feet)	Depth of well (feet)	Diameter of well (inches)		Depth to which well is cased (feet)	Water level		Method of lift	Capacity of pump (gallons a minute)	Drawdown (feet)	Daily pumpage (gallons)	Source of data	Quantity of water	
						Top	Bottom		Depth below surface (feet)	Date of measurement (1928)						Date sampled (1928)	Content of dissolved iron (parts per million)
166-1	67	Clarence Saunders	Goodwyn St. and Lafayette Ave.	------	361	14	5	361	47	Rept.	------	------	------	------	------	------	------
62-1	68	Chickasaw Golf Club.	Galloway Ave.	------	100	8	8	100	------	------	Double-acting reciprocating.	80	------	50,000	Rept.	------	------
VIII																	
33-1	69a	West Tennessee State Normal School.	------	300	515	------	------	515	74	Oct. 28	Air lift	------	------	------	------	------	------
33-2	69b	---do---	------	300	461	8	8	461	74	---do---	---do---	------	------	175,000	Rept.	------	------
50-1	70	American Fork & Hoe Co.	Arkansas St. and Wisconsin Ave.	------	420	6	4	420	80	Rept.	---do---	120	20	40,000	---do---	Oct. 18	1.5
111-1	71	Weis & Lesh Plant Motorwheel Corp.	Wisconsin Ave. and Pennsylvania St.	285	580	6	6	580	------	------	---do---	355	------	118,000	---do---	Oct. 11	4.4
70-1	72	DeSoto Oil Co.	998 Kansas Ave.	285	548	6	6	548	60	Rept.	Reciprocating.	300	20	72,000	---do---	------	------
105-1	73	Memphis Power & Light Co.	McLemore Ave., 1,000 feet west of Florida St.	270	485	8	8	485	73	Est.	Air lift	408	25	600,000	---do---	Oct. 18	.48
	74	Liquid Carbonic Corp.	Florida St., 200 feet north of McLemore Ave.	295	435	8	6	435	90	---do---	---do---	200	------	150,000	---do---	------	------
IX																	
141-1	75	Wabash Screen Door Co.	Florida St. and Triggs Ave.	285	400	3½	3½	400	91	---do---	---do---	100	9	30,000	---do---	Oct. 18	1.3
	76	Ford Hardwood Lumber Co.	McGehee Ave. and Florida St.	285	[d] 85	6	6	85	------	------	Reciprocating.	30	------	40,000	---do---	---do---	.0
189-1	77	Gayoso Lumber Co.	Florida St. and Fay Ave.	260	460	4	4	460	60?	Rept.	Air lift	------	------	125,000	---do---	---do---	.42
186-1	78	Pioneer Pole & Shaft Co.	1197 South Third St., 200 feet west of street.	280	545	6	6	545	72	---do---	---do---	500	------	------	---do---	---do---	.02
X	79	Apex Steam Laundry.	Lamar Ave. and Kyle St.	285	[d] 90	6	6	90	60	---do---	Reciprocating.	95	------	35,000	---do---	------	------

134-1	80	Swift Co. Oil Mill		300	443	10	10	443	73	...do...	Air lift	300	15	75,000	...do...	Oct. 23	2.4
	81	Southern Ry., Forrest Yards.	Southern Ave	305	554	10	10	554			...do...	500		200,000	...do...	...do...	.05
78-1 XI	82	St. Louis-San Francisco Ry., Yale Yards.	Well 2		390	8	8	390	50	Rept.	Centrifugal	568					
78-2	83	...do...	Well 1		386	8	8	386	56	...do...	...do...	533					
100-1 XII	84	Memphis Country Club.	Southern Ave		392	8	6	392			Reciprocating			20,000			
181-1 XIII	85	Railway Ice Co	Peebles Ave	230	360	15	12	360	32	Rept.	...do...	300	12	430,000	Rept.	July 19	1.19
151-1	86	Illinois Central R. R., Nonconnah Yards.	1,500 feet west of Horn Lake Road.	235	361	10	10	361	51	...do...	...do...	400		548,000	...do...		

[a] Well ends in Pliocene gravel.

This table came from WRP 656

GEOLOGY

GENERAL CONDITIONS

Memphis is situated in what is known geologically as the Mississippi embayment of the Gulf Coastal Plain. This area is underlain by a series of beds of unconsolidated or slightly consolidated gravel, sand, and clay deposited in a broad, shallow syncline, or trough, which pitches gently to the south. The upper end of the trough is in southern Illinois, and its axis lies a few miles west of the Mississippi River; the beds dip toward the axis from both sides. The eastern edge of the syncline almost coincides with the Tennessee River. The east flank has a westward dip of about 30 feet to the mile near its edge, but the dip decreases toward the west. The formations of gravel, sand, and clay range in age from Upper Cretaceous to Recent; they rest on a floor of Paleozoic limestone, shale, and chert. In Tennessee the unconsolidated sediments (Upper Cretaceous and younger formations) are believed to attain about their maximum thickness at Memphis, where they are from 2,700 to 3,000 feet thick. These deposits, named in order from oldest to youngest, are the Tuscaloosa, Eutaw, Selma, and Ripley formations, of Upper Cretaceous age; the Clayton, Porters Creek, Ackerman, Holly Springs, Grenada, and Jackson formations, of Eocene age; Pliocene sand and gravel; and loess and alluvium of Quaternary age. These formations come to the surface east of Memphis. Starting just east of the Tennessee River, in Hardin County, and traveling to Memphis one traverses in succession the outcrops of the different formations, beginning with the oldest, the Tuscaloosa, and ending with the loess, which is the surface formation at Memphis. This is clearly shown in the map and section by Glenn.[4]

A section at Memphis, as determined from well C–25 of the Memphis Artesian Water Department, which was drilled to a depth of 2,656 feet, is shown in Figure 1.

The more important publications treating of the geology of western Tennessee are listed below.

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.

Wade, Bruce, The geology of Perry County: Tennessee Geol. Survey, Resources of Tennessee, vol. 4, pp. 150–151, 1914.

Stephenson, L. W., Geology and ground waters of northeastern Arkansas: U. S. Geol. Survey Water-Supply Paper 309, 1916.

Wade, Bruce, The gravels of west Tennessee Valley: Tennessee Geol. Survey, Resources of Tennessee, vol. 7, pp. 55–89, 1917.

Berry, E. W., Upper Cretaceous floras of the eastern Gulf region in Tennessee, Mississippi, Alabama, and Georgia: U. S. Geol. Survey Prof. Paper 112, 1919.

[4] 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, pl. 1 and Fig. 7, 1906.

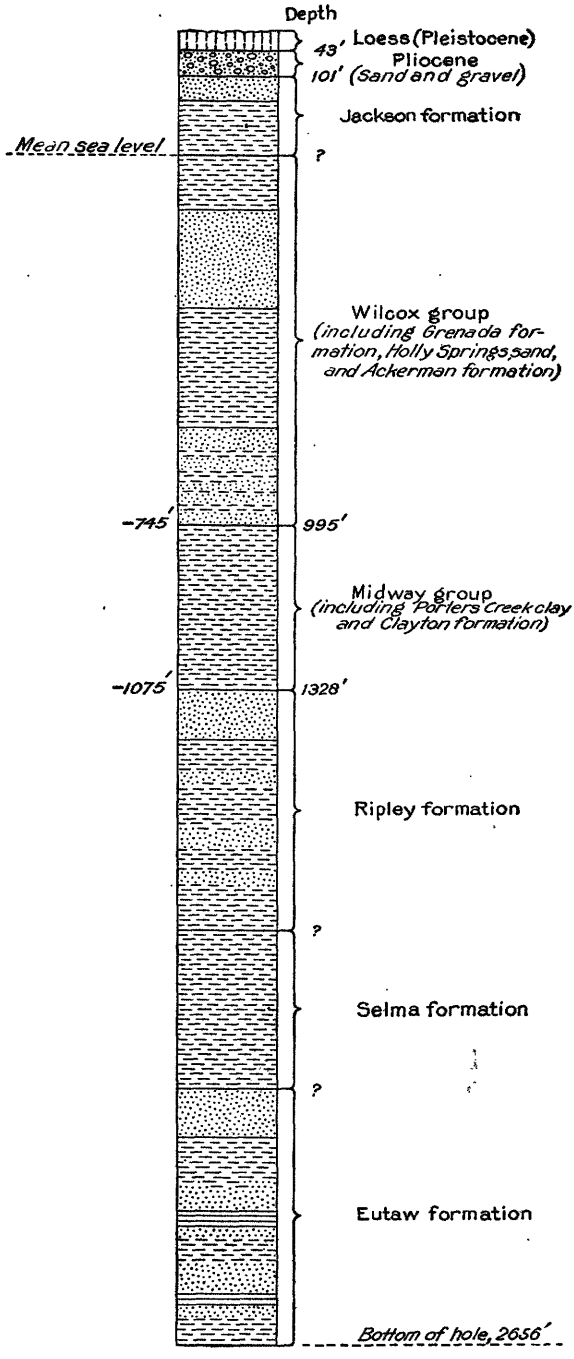


FIGURE 1.—Log of well C-25 of the Memphis Artesian Water Department

Roberts, J. K., The Tertiary of west Tennessee: Am. Jour. Sci., 5th ser., vol. 12, pp. 235–243, 1926.

Stephenson, L. W., Logan, W. N., and Waring, G. E., The ground-water resources of Mississippi: U. S. Geol. Survey Water-Supply Paper 576, 1928.

Roberts, J. K., The Tertiary geology and stratigraphy of west Tennessee (manuscript to be published by Tennessee Geol. Survey).

TUSCALOOSA FORMATION

The Tuscaloosa formation as found in scattered remnants just east of the Tennessee River consists of sandy gravel, but in Alabama it is variable in character, consisting of gravel, sand, and clay. Berry [5] shows that the Tuscaloosa formation is a delta deposit and postulates its thinning out or change to massive sediments toward the southwest. The character of the Tuscaloosa at Memphis is not known, as no well there has penetrated the formation, with the possible exception of well C–25, put down by the Memphis Artesian Water Department to a depth of 2,656 feet, the available log of which is not sufficiently detailed to make a positive correlation. To judge from the character of this formation in Alabama, where the conditions of sedimentation were probably more nearly like those at Memphis than those where the Tennessee River outcrops occur, the formation at Memphis is not a gravel deposit but rather a sand or clay. It would probably be encountered at a depth of 2,700 to 3,000 feet.

Though there is no definite information concerning the chemical character of the water from the Tuscaloosa formation at Memphis, owing to the fact that no well penetrates the formation, it seems probable that the water would have a high mineral content. The water from the overlying Eutaw formation contains over 1,500 parts per million of solid matter. In Mississippi analyses of water from the Tuscaloosa formation show increasing mineral content with increasing depth, though it should be noted that the overlying Eutaw formation is more saline than the underlying Tuscaloosa formation.[6] Without giving a discussion of all the factors in the problem, it seems probable that the fresh water in the Tuscaloosa formation, which, according to the principle of Badon Ghyben and Herzberg,[7] is in balance with a shorter column of salt water of equal weight, would not reach to a depth of 2,600 feet.

EUTAW FORMATION

The outcrop area of the Eutaw formation is 85 to 90 miles east of Memphis. Where the Eutaw occurs at the surface it is dominantly

[5] Berry, E. W., Upper Cretaceous floras of the eastern Gulf region in Tennessee, Mississippi, Alabama, and Georgia: U. S. Geol. Survey Prof. Paper 112, pp. 26–30, 1919.

[6] Stephenson, L. W., Logan, W. N., and Waring, G. A., The ground-water resources of Mississippi: U. S. Geol. Survey Water-Supply Paper 576, pp. 341–344, 364–365, 1928.

[7] Brown, J. S., A study of coastal ground water, with special reference to Connecticut: U. S. Geol. Survey Water-Supply Paper 537, pp. 16–17, fig. 2, 1925.

sand, although clay is always found with the sand. The most usual condition is a series of rapidly alternating layers of sand and clay, the sand occuring in layers from a quarter of an inch to 6 inches in thickness, interlaminated with sheets of white, gray, or black clay one-sixteenth to half an inch thick. Some of the sand is glauconitic. In some places large lenses of fissile carbonaceous clay are intercalated in the sand. The Eutaw formation has a maximum thickness in its outcrop area of 250 feet. It is probably much thicker at Memphis, but this can not be positively stated. At Memphis the static head of water in the Eutaw formation, as determined in the 2,656-foot well of the Memphis Artesian Water Department, the log of which is shown in Figure 1, is 360 feet above mean sea level. As much of Memphis is below an altitude of 360 feet, water fron this formation will overflow at the surface in many places. Water from the Eutaw formation generally contains a large quantity of dissolved mineral matter. At Memphis it contains considerable sodium chloride and is not suitable for domestic or industrial use.

SELMA FORMATION

The Selma formation of this region is a sandy or calcareous clay of a slate-blue color. It contains many fossils, some of which are large and conspicuous, such as *Inoceramus* and *Exogyra*. This formation is 300 feet thick near its outcrop to the east, but it is probably thicker at Memphis. The depth to the Selma formation at Memphis is not known definitely but is at least 1,800 feet. The Selma is not a water-bearing formation.

RIPLEY FORMATION

The Ripley formation in southern Tennessee has been divided into three lithologic units—the Coon Creek tongue, the McNairy sand member, and the Owl Creek tongue.

The Coon Creek tongue consists of sandy marl overlain by a series of stratified micaceous clays about 100 feet thick. The Owl Creek tongue is a series of micaceous sands and marls about 50 feet thick. The McNairy sand member as seen in outcrop consists of several hundred feet of medium to fine cross-bedded sands of various colors, including red, white, brown, yellow, and purple. Intercalated with the sands are lenses of clay, which at Memphis probably have considerable horizontal extent and may even be continuous beds. The Coon Creek and Owl Creek tongues are marine phases of the Ripley formation, and at Memphis, which was in the deep part of the embayment, marine conditions may have existed longer than they existed at the locality of the present outcrop of the Ripley formation. This would cause the Coon Creek and Owl Creek deposits to thicken and the McNairy sand member to thin toward Memphis.

Neither the Coon Creek tongue nor the Owl Creek tongue is a good aquifer. The McNairy sand member includes one bed of good water-bearing sand 100 feet thick, which is known to underlie at least a part of Memphis and furnish a part of the public water supply.

The Ripley formation is 600 feet thick near its outcrop in western Tennessee but may be somewhat thicker at Memphis. At Memphis the top of the formation, as determined in wells C–5, C–25, C–26, C–27, C–28, C–29, C–30, C–31, C–32, and C–33 of the Memphis Artesian Water Department, is at a depth of about 1,325 feet, or 1,085 feet below mean sea level. The static head of water in the Ripley is about 240 feet with reference to mean sea level.

At present the Ripley formation is being drawn upon only by the Memphis Artesian Water Department, pumping from wells C–5, C–26, C–27, C–28, C–29, C–30, C–31, C–32, and C–33. These wells, which are spaced 500 feet apart, have an average yield of about 800 gallons a minute each and are pumped continuously during the peak period of summer demand in order to lessen the amount of water pumped from the sand between 375 and 550 feet. During the remainder of the year these wells are pumped intermittently. The average daily pumpage from this Ripley sand is shown in Figure 2. From a small initial draft during the last months of 1925 the amount pumped has increased until it attained an average of 4,600,000 gallons a day in 1928.

MIDWAY GROUP

The Clayton, the basal formation of the Midway group, crops out over a very small area in Tennessee. In the southern part of the State it is a poorly consolidated limestone, but toward the north it changes to a glauconitic sand. The nature of the deposit at Memphis is not known.

The Porters Creek is a homogeneous dove-gray to black plastic clay that crops out about 70 miles east of Memphis, but at Memphis it is found 975 to 1,350 feet below the surface, or 750 to 1,085 feet below mean sea level. It is impervious to water and forms an effective confining bed for water in lower formations.

WILCOX GROUP

The Wilcox group of formations includes, from older to younger, the Ackerman formation, the Holly Springs sand, and the Grenada formation. All the wells in Memphis except the 1,400-foot wells of the Memphis Artesian Water Department obtain water from either the Grenada or the Holly Springs formation, but it is impossible to determine in which of these formations any well ends, because the basis of differentiation is fossil leaves, and these leaves are never present in well drillings.

The Ackerman formation does not crop out in Tennessee, its most northerly exposure occurring in the northwestern part of Tippah

County, Miss. The contact of the Ackerman formation with the Holly Springs sand probably swings to the northwest and is buried under younger deposits. If this is so the Ackerman formation would be found in depth at Memphis. The formation consists of stratified gray clay that is more or less lignitic. Many of the clay layers are sandy, and some sand beds are interstratified with the clay. The Ackerman formation will yield little if any water.

The Holly Springs formation is predominantly sand; it is strongly cross-bedded and includes material of all sizes from small gravel to the finest of sand, which is in many places mixed with clay. Lenses of clay covering an area of 1 to 8 acres and attaining a thickness as great as 200 feet are found intercalated in the sand in areas where the formation crops out, and similar or larger lenses are undoubtedly present at Memphis. The Holly Springs sand has a maximum thickness of at least 550 feet. The top of the formation is encountered at about 450 feet below the surface, or about 235 feet below mean sea level, and the formation continues to a depth of 1,000 feet, or 785 feet below mean sea level. It is a productive water-bearing formation.

The Grenada formation overlies the Holly Springs sand and is very much like it, but on the whole the sands are finer. The Grenada attains a maximum thickness of 400 feet, and yields large supplies of good water. It extends from about 75 to 450 feet below the surface, or from about 175 feet above to 220 feet below mean sea level. At Memphis several large lenses of blue clay occur near the top of the Grenada formation and serve to form an impermeable layer above the water-bearing sands.

JACKSON FORMATION

The Jackson formation, which overlies the Grenada, consists of fine sand, clay, and lignite. It contains little water.

PLIOCENE GRAVEL

In the vicinity of Memphis the Pliocene deposits consist of coarse sand and gravel. The gravel ranges from pebbles just coarser than grains of sand to cobbles over 5½ inches in diameter, but the common sizes range from a quarter of an inch to 1 inch. The distribution of the Pliocene gravel is very irregular; in some places the gravel is missing, but in others it attains a maximum thickness of 50 feet. The thick parts of the gravel occur in sinuous bands. The irregularities of distribution may result from the way in which the gravel was deposited or from erosion subsequent to deposition. Where the Pliocene gravel exceeds 20 feet in thickness it is a good water-bearing formation, but water from it is subject to pollution from the surface drainage.

LOESS

Overlying the Pliocene gravel and forming the general surface at Memphis is a deposit of loess, a fine-grained, structureless deposit of a light-buff color. It is typically exposed in the bluffs along the river, where it has a thickness of 50 feet. The loess is not a source of water, and shallow wells in the vicinity of Memphis must go as deep as the Pliocene gravel to obtain a supply.

PUMPAGE

The total pumpage from all the wells in both the Wilcox group and the Ripley formation in 1928 was about 38,600,000 gallons a day. There is no private pumping from the Ripley formation.

The daily pumpage of the Memphis Artesian Water Department during 1928 showed a maximum of 26,458,000 gallons in 24 hours, a minimum of 13,429,000 gallons, and an average of 17,600,000 gallons. These figures include the pumpage from the 1,400-foot stratum of the Ripley formation, which in 1928 amounted to a maximum of 8,876,000 gallons a day and an average of 4,616,000 gallons. The average daily pumpage during 1928 showed an increase of 2,708,000 gallons over the average for 1920. The population of Memphis in 1928, according to the estimate of the United States Census Bureau, was 190,200; the 1920 census gave a population of 162,351. As calculated from these figures the average daily per capita consumption of city water in 1928 was 92.5 gallons; in 1920, 91.7 gallons. This difference is negligible, the increase in total consumption being about proportional to the growth of population.

The pumpage of the Water Department represents only a part of the pumpage from the Wilcox group of formations in Memphis. Soon after the drilling of the first deep well in Memphis many of the local industrial plants developed private water supplies from deep wells. Owing to the ease of obtaining a good well and the cheapness of operation, private plants, even those with small water consumption, found it most economical to have their own wells. Private wells were in favor also because of the fact that air-lift pumping reduced the iron and carbon dioxide content of the water considerably, and the water so pumped was therefore superior to city water from the Auction Avenue plant. For these reasons virtually all the industrial plants and large buildings had private supplies.

As there are no records of the amount of water pumped by individual concerns in Memphis prior to 1920, it is impossible to determine whether this pumpage has steadily increased, whether it has reached a high point and remained constant, or whether it has reached a maximum and declined. The normal growth of the city would lead to an increase in the private pumpage, which might be assumed to parallel

the increase in city pumpage. The following factors, however, would tend to decrease the private pumpage:

1. The quality of the water furnished by the city waterworks since 1925 has been greatly improved by effective treatment, so that it is now better than that from wells privately pumped by air lift.

2. The necessity of renewing wells and pumping machinery has induced many small water consumers to use city water.

3. The need of having a city connection for fire protection involves a minimum fixed charge, and if the amount of water consumed is only slightly greater than that covered by the minimum charge it is not economical to have a private supply.

4. In many small steam-power plants one engineer had charge of both the plant and the pumping machinery. The substitution of electric power in such plants has displaced the engineer, as it is not profitable to employ one simply to supervise the pumps. Centrifugal pumps could be operated by electric motors without much supervision, but owing to the iron content of the water they are not so satisfactory as air lifts.

5. Formerly Memphis manufactured large quantities of ice to be shipped to outlying points, but the development of small, simple machines for producing ice has resulted in the establishment of local ice plants at these points, and the consumption of water in ice plants in Memphis has therefore decreased.

6. The use of spray ponds for cooling condenser water has diminished the amount of water so used. The quantity of water used for condensing by the Memphis Power & Light Co. (Memphis Electric Co. and Memphis Street Car Co.) has decreased about 10,000,000 gallons per 24 hours since 1920.

It is impossible to evaluate these factors. Factors 2, 3, and 4 represent small water supplies, and the total amount consumed was probably not large; the amount represented by factor 5 may be considerable. The decrease due to the combined influence of factors 1 to 5 probably did not compensate for the normal increase in consumption due to increase of population but only served to lessen the total increase. Factor 6 represents a considerable decrease.

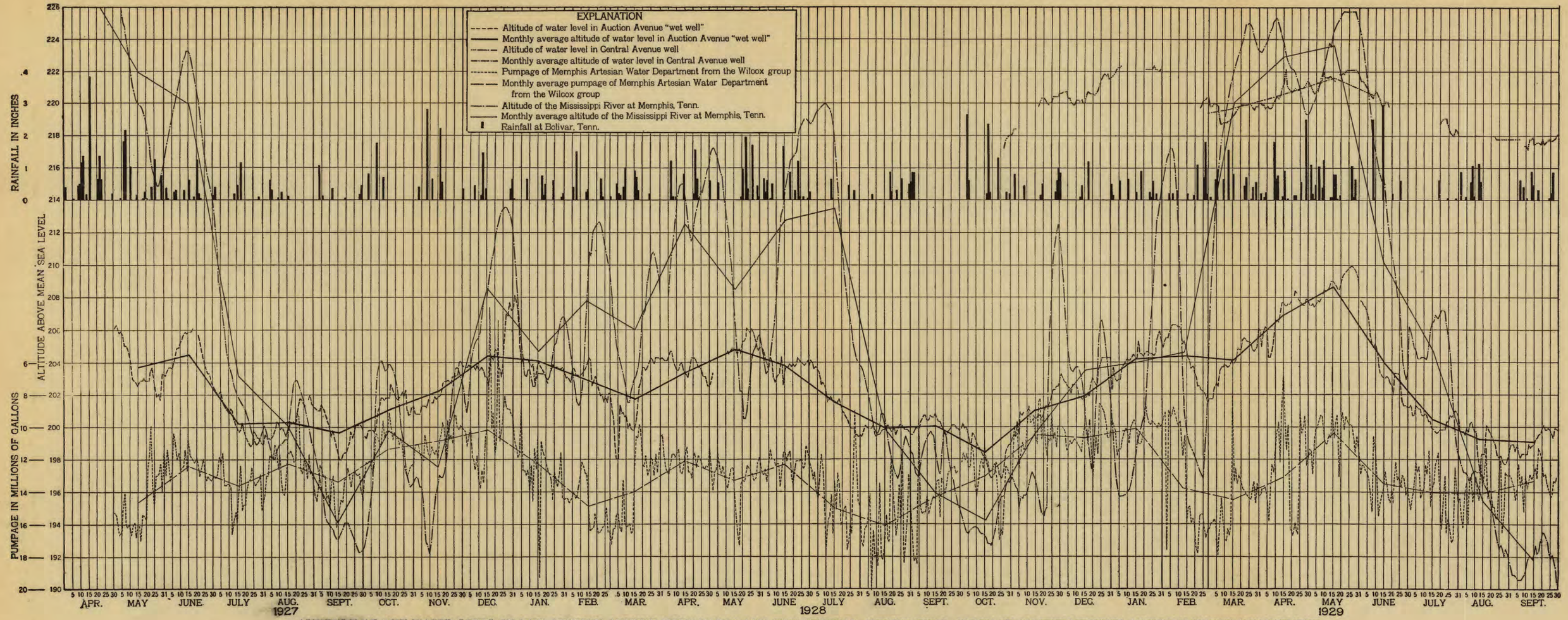
Chester & Fleming, in their report of 1920, list 58 private plants of large consumption, with an aggregate average daily pumpage of 21,740,000 gallons. The list of plants was not complete, and the pumpage given is an estimate, which is, however, sufficiently accurate for the present purpose.

The pumpage of private plants as here used is the estimated daily average for periods during which a plant was running continuously at full capacity. No correction has been made for days or weeks of shutdown or for periods when a plant was running at reduced capacity.

Therefore, the average given is probably considerably in excess of a daily average determined by dividing the total pumpage throughout the year by 365. Inasmuch as the estimates of private pumpage are derived by various methods, they are not exact, but any attempt to arrive at an average daily pumpage that would be a true daily average of the pumpage throughout the year would be attempting a precision that the data do not justify. In 1928 the writer listed 86 private plants, with an aggregate average daily pumpage estimated at 21,000,000 gallons. Although this list did not include every pumped well in greater Memphis it is believed to include every plant with a pumpage of 50,000 gallons or more in 24 hours. For many of the wells the pumpage is estimated. Of the wells listed in 1920 by Chester & Fleming, eight with a combined production of 290,000 gallons a day are no longer in operation. Of the wells listed in 1928, six, with a present combined production of 1,255,000 gallons a day, were in operation in 1920, but were not listed by Chester & Fleming. A study of 37 plants listed both by Chester & Fleming and the author shows an increase in pumpage of 32 per cent since 1920. As these plants are distributed among the various industries the increase in pumpage from their wells can be considered representative of the general trend of private pumping, other than the pumping which has been decreased for reasons previously given. On the assumption that there has been an increase of 32 per cent since 1920, the total pumpage in 1920 of the six wells not listed by Chester & Fleming was 853,000 gallons a day. This increases the estimated total pumpage by private plants in 1920 to 22,593,000 gallons a day.

The average daily pumpage of the city water supply from the Wilcox group of formations in 1920 was 14,982,000 gallons a day, which added to the private pumpage of 22,593,000 gallons made the total pumpage from the Wilcox group 37,575,000 gallons a day. In 1928 the city pumpage from the Wilcox group was 12,984,000 gallons a day, and the pumpage from private wells is estimated at 21,000,000 gallons a day, making a total of 33,984,000 gallons a day or 3,591,000 gallons less than in 1920.

The decrease in pumpage from the Wilcox group from 1920 to 1928 is due to two causes—the developing of wells in the sand of the Ripley formation by the Memphis Artesian Water Department, which began in 1925, and a cut of 10,000,000 gallons a day by the Memphis Power & Light Co. during the years 1920 to 1926. In 1928 the Memphis Artesian Water Department was pumping an average of 4,616,000 gallons a day from the Ripley formation. The cut made by the Memphis Power & Light Co. was effected as follows: The introduction of a spray pond in 1921 cut off 5,000,000 gallons a day; there was a gradual cut of 2,500,000 gallons a day in 1924; the shut-down of the Beach Street plant in January, 1926,



ALTITUDE OF THE WATER LEVEL IN THE AUCTION AVENUE "WET WELL" AND THE CENTRAL AVENUE WELL, PUMPAGE OF THE MEMPHIS ARTESIAN WATER DEPARTMENT FROM THE WILCOX GROUP, ALTITUDE OF THE MISSISSIPPI RIVER AT MEMPHIS, AND RAINFALL AT BOLIVAR, TENN.

resulted in an immediate cut of 1,500,000 gallons a day and a gradual cut of 1,000,000 gallons more. It is estimated that from 1920 to 1928 the other plants in the city increased their consumption 32 per cent, and in addition about 5,000,000 gallons a day was required by new plants. These increases nearly compensate for the cut of the Memphis Power & Light Co.

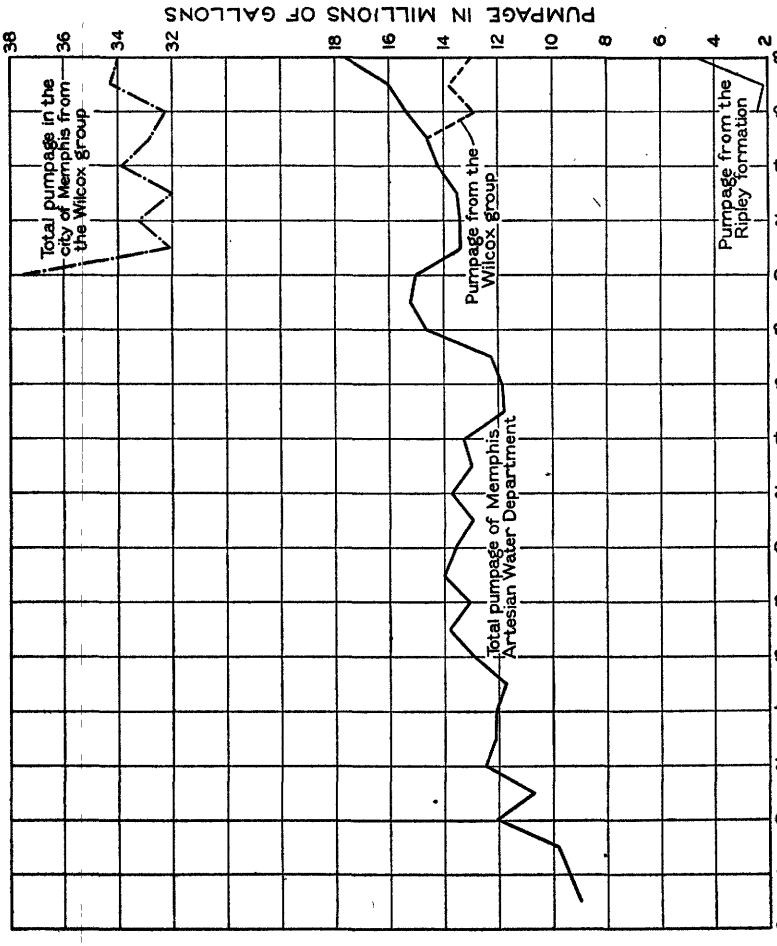


FIGURE 2.—Average daily pumpage of Memphis Artesian Water Department, 1897 to 1928 (all from the Wilcox group up to 1925); average daily pumpage of Memphis Artesian Water Department from the Wilcox group, 1925 to 1928, and from the Ripley formation, 1926 to 1928; and total average daily pumpage from the Wilcox group at Memphis, 1920 to 1928

The total daily average pumpage from the Wilcox group and the average daily pumpage of the Memphis Artesian Water Department from the Wilcox group and from the Ripley formation are shown in Figure 2. As the Memphis Artesian Water Department obtained all of its water from the Wilcox group prior to 1925, the curve in Figure 2 for its total pumpage and the curve for its pumpage from the Wilcox group coincide for the period 1897 to 1925. In 1925 a small amount of water was pumped from the Ripley formation

by the Memphis Artesian Water Department, and in succeeding years this pumpage has increased. In the curve indicating the total average daily pumpage from the Wilcox group in the city of Memphis from 1920 to 1928 only two points are definitely known—1920 and 1928; the intermediate points were determined by deducting the known cuts in pumpage and distributing the normal increase and new pumpage over the eight years. This curve, therefore, is not accurate, but it shows the general trend of the fluctuations in the total pumpage. The total pumpage from the Wilcox group reached its maximum in 1920, and the pumpage of the Memphis Artesian Water Department from the Wilcox group was also at its maximum in 1920. This is due to two facts—private pumpage, all of which is derived from the Wilcox group, was greater in 1920 than in 1928, and, whereas the total pumpage of the Memphis Artesian Water Department was groater in 1928 than in 1920, the amount pumped from the Wilcox group was less because an average of 4,616,000 gallons a day was obtained from the Ripley formation. These two facts should be borne in mind in any studies of the influence of pumping in lowering the water level.

SEASONAL FLUCTUATIONS OF HEAD IN WELLS

A continuous record of the altitude of the water level in any well will show fluctuations resulting from many causes. In order to determine the nature and magnitude of the fluctuations of the pressure head at Memphis and to deduce their causes, two continuous water-level recorders were installed in October, 1928, one in the Auction Avenue "wet well," the other in the Central Avenue well. The level of the water in the Auction Avenue "wet well" represents the static level in about 100 wells, all of which flow into tunnels leading to the "wet well." These wells are scattered over a rectangular area 5,000 by 3,000 feet, which is within 400 feet of the Wolf River at the nearest point and near the center of all pumpage that derives water from the Wilcox group. A record of the altitude of the water level in the Auction Avenue "wet well," taken at 8:30 a. m., has been kept since April, 1927, and the continuous recorder has been operating in the well since October, 1928. The Central Avenue well is at Wills Park, on Central Avenue. It is 4 miles from the river and 2 miles from the nearest pumping well of the Memphis Artesian Water Department and is in a section where there is but little private pumping. The record for this well is incomplete.

The data of water level in the Auction Avenue "wet well" and the Central Avenue well are shown graphically in Plate 2. Prior to October, 1928, the level given is the daily reading; after this date the level given is the lowest reading of the 24 hours, midnight to midnight, on the continuous recorders. For comparison, curves showing the

daily pumpage of the Memphis Artesian Water Department from the Wilcox group, the daily altitude of the Mississippi River, and the rainfall are also given. The monthly averages of the altitude of the water level in the two wells, the pumpage, the altitude of the Mississippi River, and the rainfall at Bolivar are given in Figure 3.

The pumpage of the Memphis Artesian Water Department from the Wilcox group is derived by subtracting from the total daily pumpage the pumpage from the Ripley formation. It is plotted in reverse sense—a larger pumpage being lower on the sheet than a small pumpage—in order to facilitate comparison with the water level.

It should be borne in mind that pumpage of the Memphis Artesian Water Department represents only 38 per cent of the total pumpage from the Wilcox group, the remainder being pumped by industrial plants. However, as the factors which necessitate an increase or decrease in the pumpage of the Memphis Artesian Water Department have somewhat similar effects on the industrial pumping, the total pumpage from the Wilcox group roughly parallels the pumpage for the city waterworks with two exceptions. Industrial pumping is cut by at least 3,440,000 gallons on Sundays in laundries, sawmills, and such plants as completely stop, and it is possible that other plants run at lower capacity, so that the total Sunday cut of industrial pumping is probably in excess of 3,440,000 gallons. The total pumpage of the Memphis Artesian Water Department shows no such Sunday cut but increases or decreases according to the weather. It is possible for the city to meet changes in the demand by increasing or decreasing the amount taken from the Ripley formation. This is illustrated by the increased pumpage from the Wilcox group during February and March in 1928 and in 1929, which was due to cessation of pumping from the Ripley formation and does not indicate an increase in total pumpage. Any sudden peak in pumpage, such as that for January 16, 1928, can be accounted for in this way. On the contrary, changes in total pumpage may not show in the graph of the pumpage from the Wilcox group. As a rule, however, the ratio of the pumpage from the Ripley formation to the pumpage from the Wilcox group remains about the same, and it can be assumed that the graph of the pumpage from the Wilcox group represents in a general way the variations of the total pumpage in all Memphis.

The stages of the Mississippi River at Memphis given by the Mississippi River Commission have been used in plotting the altitude of the river.

In plotting the rainfall the records at Bolivar, Tenn., have been used. Bolivar lies almost due east of Memphis in the outcrop area of the Wilcox group. With the exception of local summer rains, precipitation usually occurs over the whole of the outcrop area of the Wilcox group during the same day, so that when it rains at Bolivar rainy weather can be assumed throughout the area.

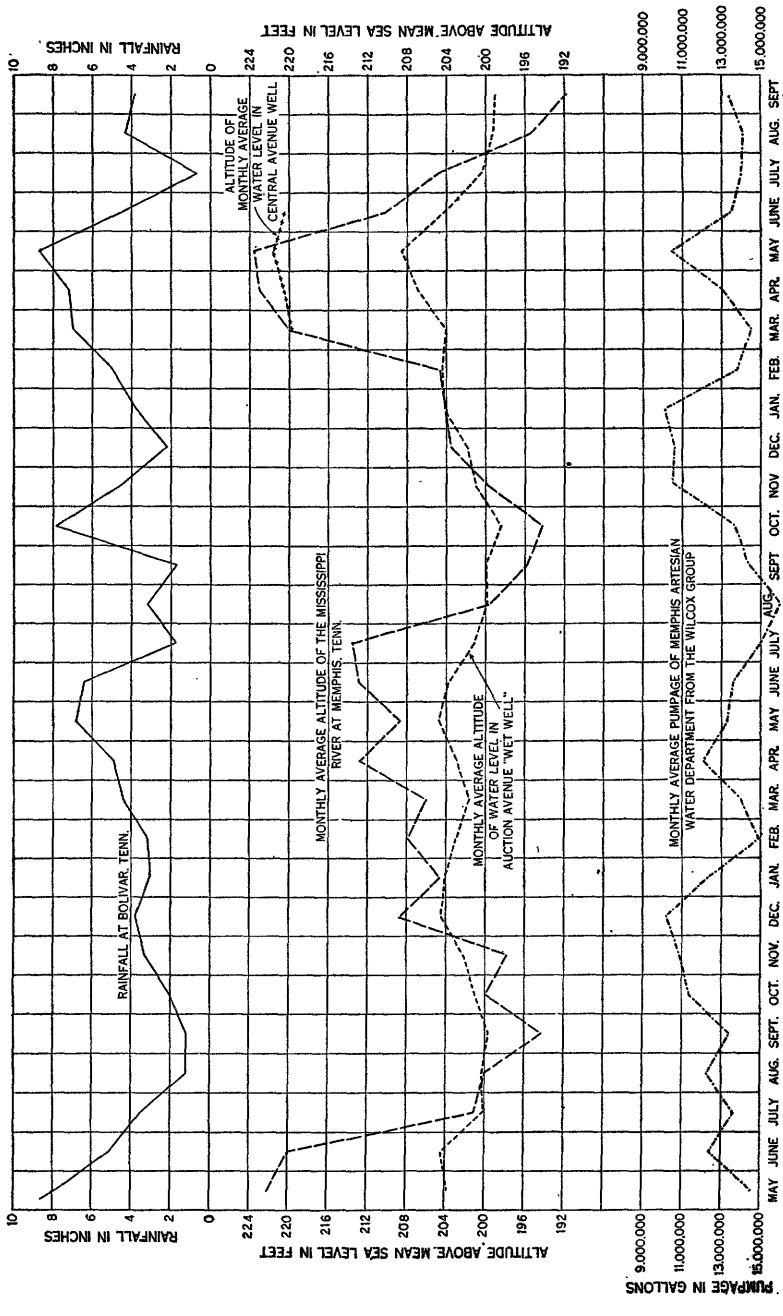


FIGURE 3.—Monthly averages for the period May, 1927, to September, 1929, of the altitude of the water level in the Auction Avenue "wet well" and the Central Avenue well, the pumpage of the Memphis Artesian Water Department from the Wilcox group, the altitude of the Mississippi River at Memphis, Tenn., and the rainfall at Bolivar, Tenn.

The water level in the Auction Avenue "wet well" attains its highest point early in the summer, either in May or in June. (See pl. 2 and fig. 3.) It drops off rapidly during the summer, reaching the lowest point in September, after which it rises continuously during the fall and early winter. It may drop a little in February and March before rising to its spring high point. The maximum variation from May 1, 1927, to October 30, 1929, was 13.2 feet. The yearly variation was 8.3 feet May 1, 1927, to May 1, 1928; 7.6 feet May 1, 1928, to May 1, 1929; and 12.6 feet for the period May 1 to October 1, 1929. The average yearly variation for the 2½-year period is 9.5 feet. Although the record of water level at the Central Avenue well is incomplete (see pl. 2), it parallels in a general way that of the Auction Avenue well, showing a high in May, after which it drops off rapidly to a low in September and October, and then rises rapidly in the fall and early winter; but unlike that of the Auction Avenue well it reaches its highest point in January.

Pumpage diminishes rapidly from September to December and remains small from January to April, the minimum occurring some time within this period. Pumpage rapidly increases again in May and June and reaches a maximum in August. Thus the time of greatest pumpage and lowest water level in the Auction Avenue "wet well" coincide, but the period of least pumpage and highest water level do not, as can be clearly seen in Figure 3 by comparing the pumpage and water level November, 1928, to February, 1929, with May, 1929. An explanation of this can be found by comparing the water level in the Auction Avenue "wet well" with the altitude of the Mississippi River. The river is at high stages from March until the end of June, the maximum usually occurring in April and May, although it may occur any time during these four months. The river falls rapidly in July and remains low until October, when it begins to rise. The curve indicating the river stage roughly parallels the water-level curve, and the maxima and minima are coincident. Further proof of the influence of the river on the water level is afforded by the record for March 15 to 22, 1929, given in Figure 4. The water level in the Auction Avenue "wet well" continued to rise as the river rose, although the pumpage increased. As there was no rain, the rise of nearly 2 feet in the water level in spite of the increased pumpage can only be attributed to the influence of the rise in the river level. This is shown also by the following table, which gives records for June and August, 1927, and June, 1928. Though the pumpage is nearly the same there is a difference of 4.2 feet in static level.

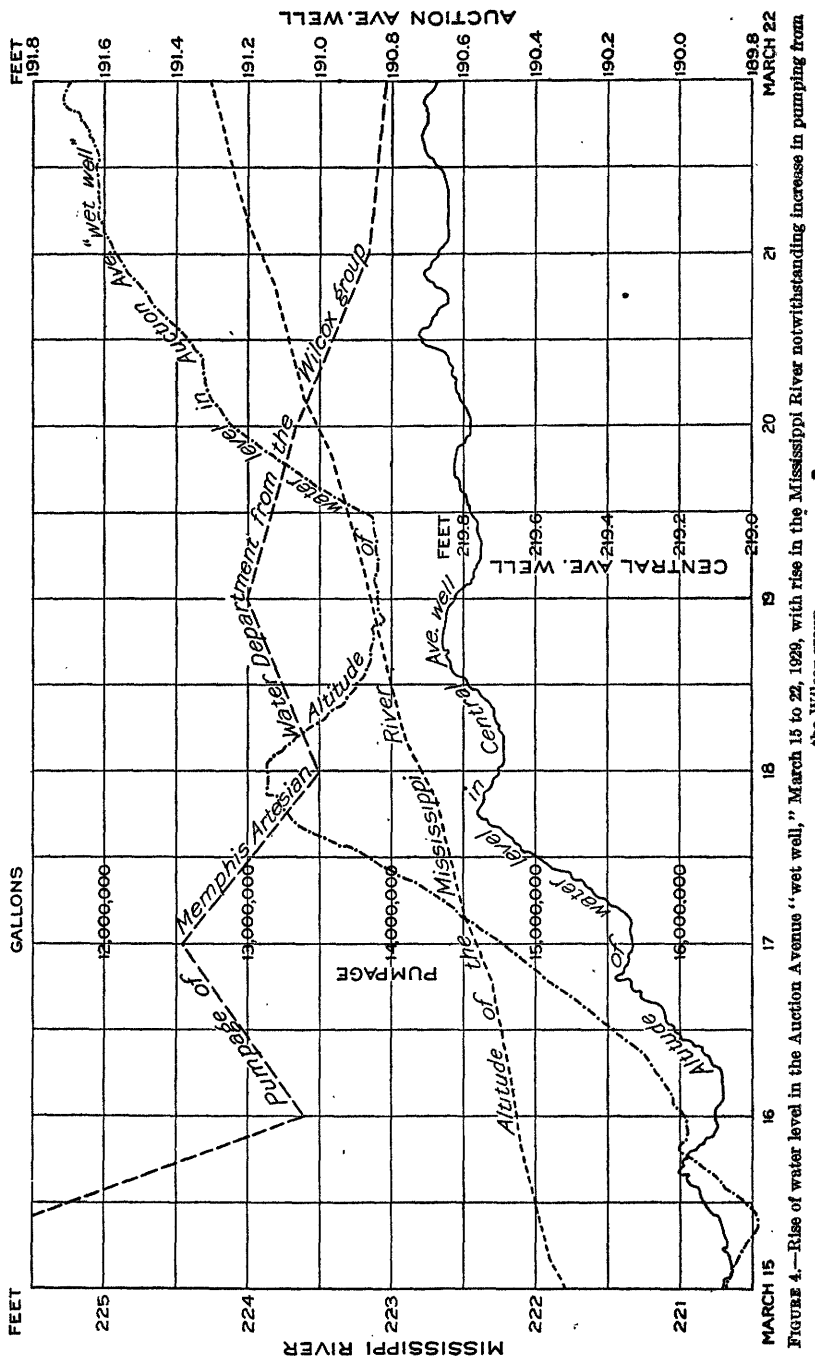


FIGURE 4.—Rise of water level in the Auction Avenue "wet well," March 15 to 22, 1929, with rise in the Mississippi River notwithstanding increase in pumping from the Wilcox group

. Relation of pumpage and altitude of Mississippi River to water level at Auction Avenue "wet well"

Month	Pumpage (gallons a day)	Water level at Auction Avenue well (feet above sea level)	Altitude of Mississippi River (feet above sea level)
June, 1927	12,350,000	204.5	220.0
August, 1927	12,280,000	200.3	200.1
June, 1928	12,270,000	203.8	212.8

The lack of synchronism between the drawdown and pumpage might be attributed to the effect of lag. It has been observed in other artesian areas that the water levels in wells do not respond immedi-

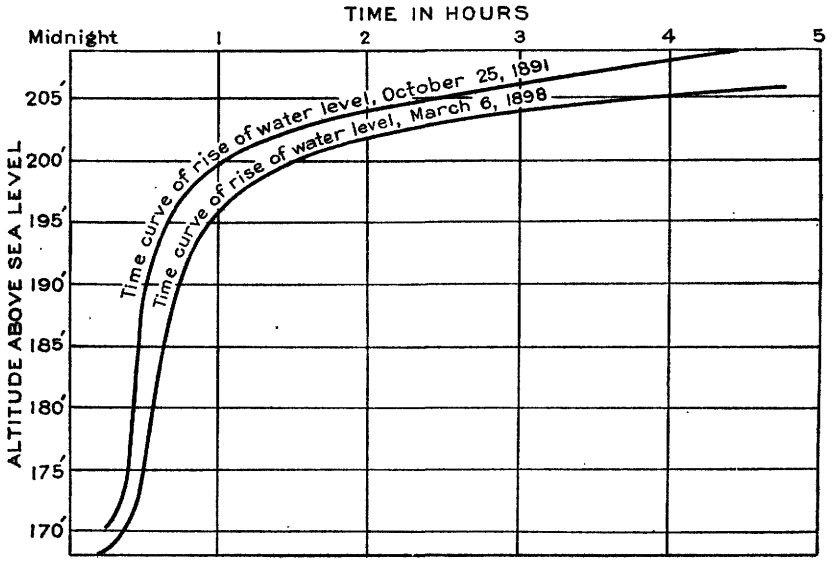


FIGURE 5.—Rate of rise of water level on shutting down pumps at the Auction Avenue station on October 25, 1891, and March 6, 1898. (After Lundie)

ately to the starting or stopping of pumpage in adjacent wells but that there is a time interval, or lag, before adjustment takes place. The curves given by Lundie [8] (see fig. 5) show that when pumpage was stopped at the Auction Avenue plant the recovery of the head was very rapid—for example, in the first hour of shut down on October 25, 1891, the head recovered 30 feet. Chester & Fleming state that the water level at the Central Avenue pumping station recovered to normal 35 minutes after the cessation of pumping. These facts would indicate that the static head responds very rapidly to changes in pumpage and that the failure of the water level to respond in the cases given can not be explained on the basis of lag.

[8] Lundie, John, op. cit., p. 19,

Another factor which may influence the water level is the rainfall over the outcrop area of the Wilcox group. A large part of the yearly precipitation occurs from January to June, and the period from July to October is relatively dry. During the growing season most of the precipitation is taken up by the vegetation, and therefore very little of the rainfall reaches the zone of saturation. Hence the period of principal recharge is from November until March, and it may be assumed that in the outcrop area the water level reaches its highest level in the early spring and its lowest in the late summer and early fall. These variations in water level at the outcrop represent variations of load on the confined portion of the water-bearing bed and should cause changes in the artesian head. Data are not available to prove this assumption, and the magnitude of the variations is such that it is possibly concealed by the more prominent factors.

It has been shown that the water level varies with pumpage, river level, and possibly rainfall. The records thus far obtained are so short that it is impossible to determine from them how much each factor contributes to the fluctuations of water level, but it is evident that the major factor is the pumping and that the other factors only modify its effect. In any consideration of drawdown or of specific yield these factors must be borne in mind.

ORIGINAL STATIC LEVEL

Glenn [9] gives the original static level at Memphis as 225 feet above mean sea level. Safford [10] was Glenn's authority, but Safford does not state definitely when the measurement was made, and it is probable that this figure is not the original static level but the level at the time Safford made his investigation, which was after several wells had been drilled. The altitude of the collar of the first successful well is not definitely known. This well was drilled for the Bohlen-Huse Ice Co. in the bayou at Court Street and had a large flow. The bayou is now 230 to 240 feet above sea level, and there is no evidence of filling. Chester & Fleming state that when the first well at Central Avenue was drilled, in 1908, the water level there from March to May 1908, averaged 232.7 feet above mean sea level. On October 28, 1928, the water level in the well at the West Tennessee State Normal School after a shutdown of 6 hours was 237 feet above mean sea level. This is doubtless less than the original static level in this well, but the West Tennessee State Normal School is 6½ miles east of the original well on Court Street, and owing to the hydraulic gradient its original static level was probably higher than the original level at Court Street. All

[9] 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, p. 110, 1906.

[10] Safford, J. M., op. cit., p. 102.

these facts indicate that the original static level in the vicinity of the Auction Avenue wells was considerably more than 225 feet, probably about 235 feet.

RELATION OF PUMPAGE TO REGIONAL DRAWDOWN

The average altitude of the water level at the Auction Avenue plant for the year 1928 was 202.0 feet above mean sea level. This is 33 feet lower than the assumed original 235 feet. Taking 34,000,000 gallons for the average daily pumpage from the Wilcox group in 1928 makes the yield of the formation about 1,000,000 gallons a day for each foot of drawdown as measured at the Auction Avenue well. This figure for yield must be accepted as only approximate, however, because the original static level is not known exactly, and the water level has a considerable seasonal variation, also because the figure for total pumpage is only an estimate and may be somewhat in error.

If a well in an artesian water-bearing bed is pumped at a given rate, the pressure-indicating surface, as determined by measuring the depth to water at the pumped well and in other wells located in various directions and at various distances from the pumped well, will be found to conform in shape to the surface of a solid of revolution determined by an exponential curve, the vertex of which is at the pumped well. Such a surface is called a cone of depression. A group of closely spaced wells distributed approximately uniformly throughout a circular area and having about the same pumpage can be likened to one well with a pumpage equal to the combined pumpage of the individual wells, and the pressure-indicating surface for such a group of wells is similar in a general way to the cone of depression of a single isolated well. Under most conditions the drawdown, or lowering of the pressure-indicating surface at a pumped well, is directly proportional to the rate of pumping; for instance, if the rate of pumping is doubled the drawdown is doubled. This is also true of the lowering of the pressure-indicating surface at any well in a group of wells, such as that described above, so long as the distribution of the wells remains the same and the rates of pumpage from each remain in the same ratio. If, however, new wells situated at a distance are pumped or if the ratio of pumpage of the wells relative to each other is changed, the drawdown in any well is not proportional to the total pumpage. Without changing the total pumpage, it is possible to change the drawdown in any given well in a group by changing the location of pumpage relative to the well. Also, total pumpage can be changed without changing the drawdown in any given well by changing the location of pumpage relative to the well.

Prior to 1907 most of the pumping in Memphis was concentrated in the down-town section of the city, and the pressure-indicating

surface was a conelike depression with its apex at the Auction Avenue "wet well." The slope of the cone was steep in the down-town section but was almost flat a short distance away. Increases in pumpage were all in the same area, and the drawdown at the Auction Avenue "wet well" was in general proportional to pumpage. This can be seen by comparing profiles of the water surface in 1898 and 1902 as given by Lundie and Hider.[11] (See fig. 6.)

In 1907 pumping for the city waterworks was started at the Central Avenue plant, and in 1910 pumping from segregated wells was started. Private pumping showed a similar scattering. The influence of scattering of pumpage on the water level in the Auction Avenue "wet well" can be seen by comparing the figures of pumpage and water level in the following table:

Influence of the scattering of pumpage on the water level in the Auction Avenue "wet well"

	Average water level in Auction Avenue "wet well" (feet above sea level)	Average daily pumpage of Memphis Artesian Water Department from Wilcox group (gallons)	
		At Auction Avenue	Total
1898	175.5	9,400,000	9,400,000
1923	175.7	5,697,000	13,510,000
1928	202.0	None.	13,000,000

Thus, though the pumpage has increased, the water level in the Auction Avenue "wet well" has risen, owing to a change in the location of the pumped wells. There has been a lowering of the pressure-indicating surface, however, over the rest of the city, as is clearly shown in Figures 6 and 7.

Further evidence is given in well 172, in which the water level had an altitude of 208.5 feet on September 13, 1916, and 204.9 feet on October 30, 1928. Chester & Fleming state that the wells drilled at Central Avenue in 1908 had water levels at an average altitude of 232.3 feet from March to May, inclusive. The water level in well 157, in the same location, had an altitude of 226.2 feet on April 10, 1916, and 225.4 feet on June 18, 1916; from March to May, 1929, its average was 220.6 feet.

In considering any figure for drawdown in Memphis such as that given above, or in estimating what effect increased pumpage will have on lowering the water level it should be borne in mind that the lowering of the water level is very largely dependent on the location of the pumpage. By distributing pumping over a large area the

[11] Hider, Arthur, Omberg, J. A., jr., and Bell A. T., Engineers' report on the waterworks system of Memphis, Tenn., Memphis, 1904.

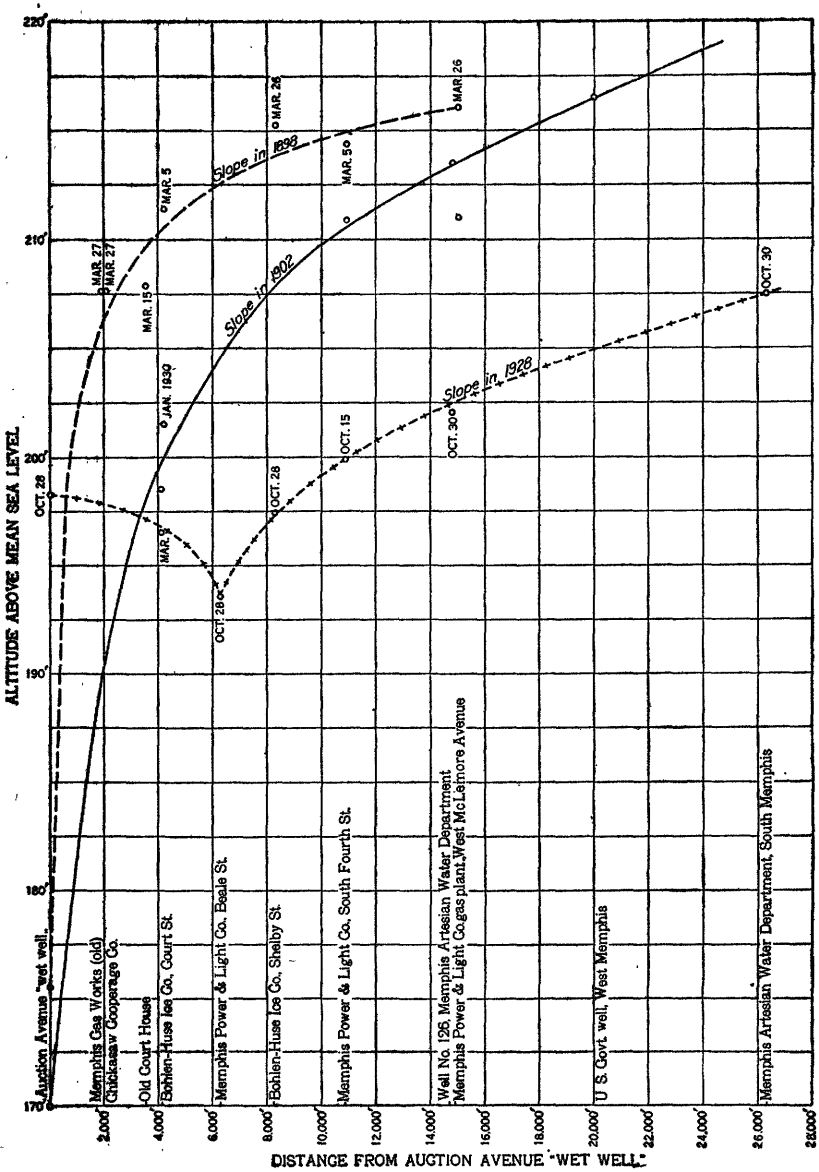


FIGURE 6.—Profiles of pressure-indicating surface along the line *A–A'* in Plate 1 in 1898, 1902, and 1926. Level of wells in 1898 from Lundie, in 1902 from Hider, both corrected to present datum. Distances are scaled from plat of Memphis and do not agree with distances given by Lundie and Hider

quantity pumped can be greatly increased with only slight lowering of the water level over the whole area.

The pressure-indicating surface has been considerably lowered over a large area, and its lowest point has moved slightly southeast from its former position at the Auction Avenue "wet well," but the maximum drawdown has not increased. The present pressure-indicating surface roughly resembles a trough, the sides and ends of which are determined by parabolas and the bottom of which is a level line. The long axis of the trough parallels the river. The drawdown has increased only slightly since about 1900. The farther north, south, or east a well is from this axis the higher is the static level in the well, and the less is the pumping lift. This

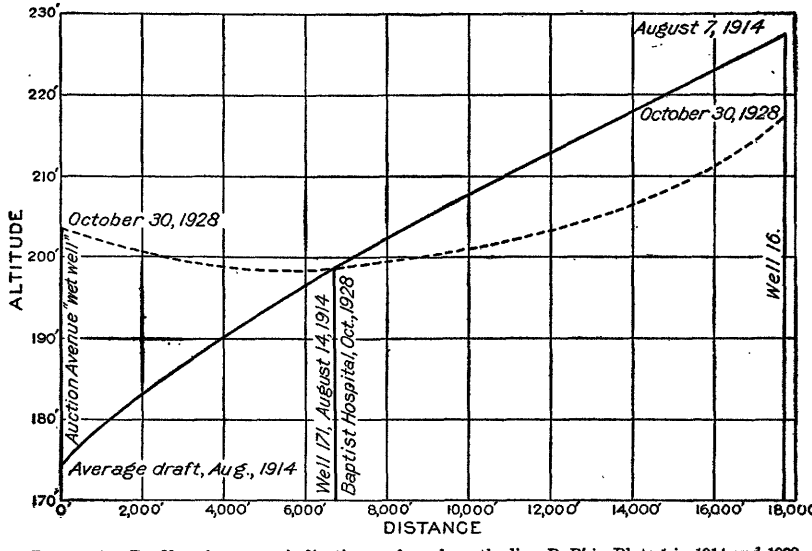


FIGURE 7.—Profiles of pressure-indicating surface along the line *B–B'* in Plate 1 in 1914 and 1928

fact shows that a wider distribution of pumping will allow increased pumpage without increasing the pumping lift.

The above discussion of the lowering of the pressure-indicating surface demonstrates that the present pumpage in the city of Memphis can be considerably increased in the outlying areas without materially increasing the drawdown in the down-town area. Also, in view of the large amount of pumping in the city, the drawdown at the Auction Avenue "wet well" is not great, and it is believed that additional supplies can be developed in the down-town part of the area. If more water is pumped the head will doubtless decline, but for any increase anticipated in the immediate future the decline will not be excessive.

CHEMICAL CHARACTER OF THE WATER

The analyses in the accompanying table are selected from about 100 analyses of samples collected from wells in southwestern Tennessee in connection with the present investigation. The statements in regard to the waters from the different formations are based on all the analyses, together with others reported in Water-Supply Paper 576 of the United States Geological Survey.

Water from wells in the Wilcox group is in general fairly soft and has a moderately low content of dissolved mineral matter. Analyses 1 and 2 are extremes and 3, 4, and 6 are more typical examples from 21 analyses of samples from wells in the Wilcox group in southwestern Tennessee. Samples were taken from 51 wells in this formation in Memphis and were examined for sulphate and iron to see if any relation could be found between the quantities of these two constituents and the location of the wells with reference to the Mississippi River. No such relation was found. Nearly all the samples had around 5 parts per million of sulphate and 0.4 to 2.5 parts per million of iron. This is considerably more iron than is desirable in a water supply for general use, but the excess is easily removed by aeration followed by filtration.

The water is pumped from many wells by air lift, which accomplishes the necessary aeration while raising the water. Separation of the iron may take place to some extent in the wells, with deposition on the casing. A sample from such a well will show less iron than is present in the water in the ground. Analyses 4 and 5 indicate the improvement in iron content resulting from the treatment of water for the public supply of Memphis. The reduction from 0.61 to 0.08 part per million of iron changes the character of the water completely as regards its appearance on standing and its suitability for laundry use.

Water from the Wilcox group anywhere in Memphis will be approximately the same as that represented by the analyses given.

Waters from the Ripley formation in Tennessee and in Mississippi have a rather wide range in composition. Analyses 7 and 8 are extremes found in southwestern Tennessee. Analysis 9 is about an average water from the formation; it has 124 parts per million of dissolved solids. The average for 27 analyses of waters from the Ripley formation in Georgia was 150, and for 21 analyses from the Ripley formation in Mississippi was 235. Many of the waters from the Ripley formation are soft, like Nos. 8 and 9, and some also contain sodium bicarbonate, like No. 9. Most of the waters from the Ripley formation also carry enough iron to make necessary some form of treatment for its removal.

Except for the slight trouble and expense involved in the removal of the iron, water from either the Wilcox group or the Ripley formation is likely to be thoroughly satisfactory for all ordinary uses.

Though water from the Eutaw formation in its outcrop area is fairly soft and has a moderately low content of dissolved solids, the water from the Eutaw formation in the 2,656-foot well at Memphis, represented by analysis 10, is a sodium bicarbonate water containing some chloride. The total dissolved solids amount to 1,466 parts per million. This water contains sufficient dissolved solids to be noticeable to the taste and is unsuitable for domestic or industrial use.

Analyses of ground waters in southwestern Tennessee

[Parts per million. Samples 1, 2, 4 to 7, and 9 analyzed by Margaret D. Foster, U. S. Geological Survey, Washington, D. C.; samples 3 and 8 by D. F. Farrar, Tennessee Geological Survey, Nashville, Tenn.; sample 10, by F. A. Mantel, Memphis Artesian Water Department, Memphis, Tenn. Samples 1 to 5 are from the Wilcox group; samples 7 to 9 from the Ripley formation; sample 10 from the Eutaw formation]

	1	2	3	4	5
Silica (SiO_2)	19	11	3.0	21	16
Iron (Fe)	.05	.07	.1	.61	.08
Calcium (Ca)	65	2.0	25	11	8.6
Magnesium (Mg)	35	1.4	3.0	5.5	4.3
Sodium (Na)	15	1.3	7.0	6.5	15
Potassium (K)	1.0	.9		1.6	1.3
Bicarbonate radicle (HCO_3)	387	13	86	74	80
Sulphate radicle (SO_4)	8.6	2.5	2.0	3.7	4.4
Chloride radicle (Cl)	5.0	.9	12	1.8	1.8
Nitrate radicle (NO_3)	.74	.39	.2	.0	.07
Total dissolved solids	333	27	94	83	87
Total hardness as $CaCO_3$ (calculated)	306	11	75	50	39
Date of collection	July 25, 1928	June 29, 1929	Feb. 15, 1928	July 26, 1928	July 26, 1928

	6	7	8	9	10
Silica (SiO_2)	13	27	4.0	20	16
Iron (Fe)	1.2	.35	.7	1.6	.4
Calcium (Ca)	15	40	7.0	3.0	3.2
Magnesium (Mg)	6.8	12	1.0	1.0	1.1
Sodium (Na)	6.8	6.6	2.0	35	422
Potassium (K)	1.6	4.9		2.7	71
Bicarbonate radicle (HCO_3)	89	137	17	104	925
Sulphate radicle (SO_4)	4.0	54	9.0	5.5	1.8
Chloride radicle (Cl)	3.6	2.7	.8	1.0	17
Nitrate radicle (NO_3)	.0	.0	1.2	.55	.03
Total dissolved solids	91	217	39	124	1,487.5
Total hardness as $CaCO_3$ (calculated)	65	149	22	12	15.4
Date of collection	July 19, 1928	June 22, 1928	Mar. 5, 1929	July 26, 1928	Sept. 26 1927

1. 250-foot well owned by town of Millington.
2. 335-foot well owned by Kentucky-Tennessee Power & Light Co., McKenzie.
3. 100-foot well owned by city of Covington.
4. 475-foot well, C-3, at southwest corner of pumping station, owned by city of Memphis.
5. Treated water from wells comprising public supply for city of Memphis.
6. 360-foot well, No. 85, owned by Railway Ice Co., Memphis.
7. 230-foot well owned by Hugh Carter, Bolivar.
8. 145-foot well owned by Harris Bros., Luray.
9. 1,400-foot well, C-27, at southeast corner of pumping station, owned by city of Memphis.
10. 2,656-foot well, C-25, of the Memphis Artesian Water Department, Memphis.