TEXAS STATE BOARD OF WATER ENGINEERS

PROGRESS REPORT ON THE GROUND-WATER RESOURCES OF THE HOUSTON DISTRICT

By

N. A. Rose and W. H. Alexander, Jr.

Prepared in cooperation with the United States Department of the Interior, Geological Survey, and the City of Houston

November 1944

C O N T E N T S

ILLUSTRATIONS

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INTRODUCTION

History of investigation

An investigation of the supply of ground water available for the Houston district, comprising all of Harris County and parts of adjoining counties, has been in progress since December 1930 as part of a survey of the ground-water resources of Texas by the Geological Survey, U. S. Department of the Interior in cooperation with the Texas State Board of Water Engineers. This investigation from the beginning has been under the direction of W. N. White, principal hydraulic engineer, and under the general supervision of O. E. Meinzer, geologist in charge of the Division of Ground Water in the Geological Survey. Since the fall of 1938, when the current phase of the investigation was begun, the work has been carried on in cooperation with the City of Houston.

Field studies in 1942-44

From January 1942 to November 1944 measurements of water levels in 220 observation wells (see figs. 1 and 2, pp. 2-3) were made at intervals ranging from one month to six months; 66 of the wells are in the Houston and the Pasadena-Ship Channel areas; 44 in the Katy rice-growing area; 10 in the areas south and west of Houston; and 100 north and northwest of Houston in the outcrop area of the water-bearing sands. Records of the volume of water pumped from wells throughout the district were collected annually. A series of maps were prepared for 1941, 1942, 1943, and 1944 based on January measurements, showing the approximate altitude of water levels in wells that draw from the heavily pumped sands of the district. Samples of water from about 60 selected observation wells were obtained each year and analyzed. Records of new wells brought into operation for municipal and industrial use, and for rice irrigation were collected. The geothermal gradient of the water-bearing sands in the district was computed from a subsurface temperature survey in two unused deep wells and from observations of the temperature of the discharge from about 20 pumped wells that are screened at only one horizon.

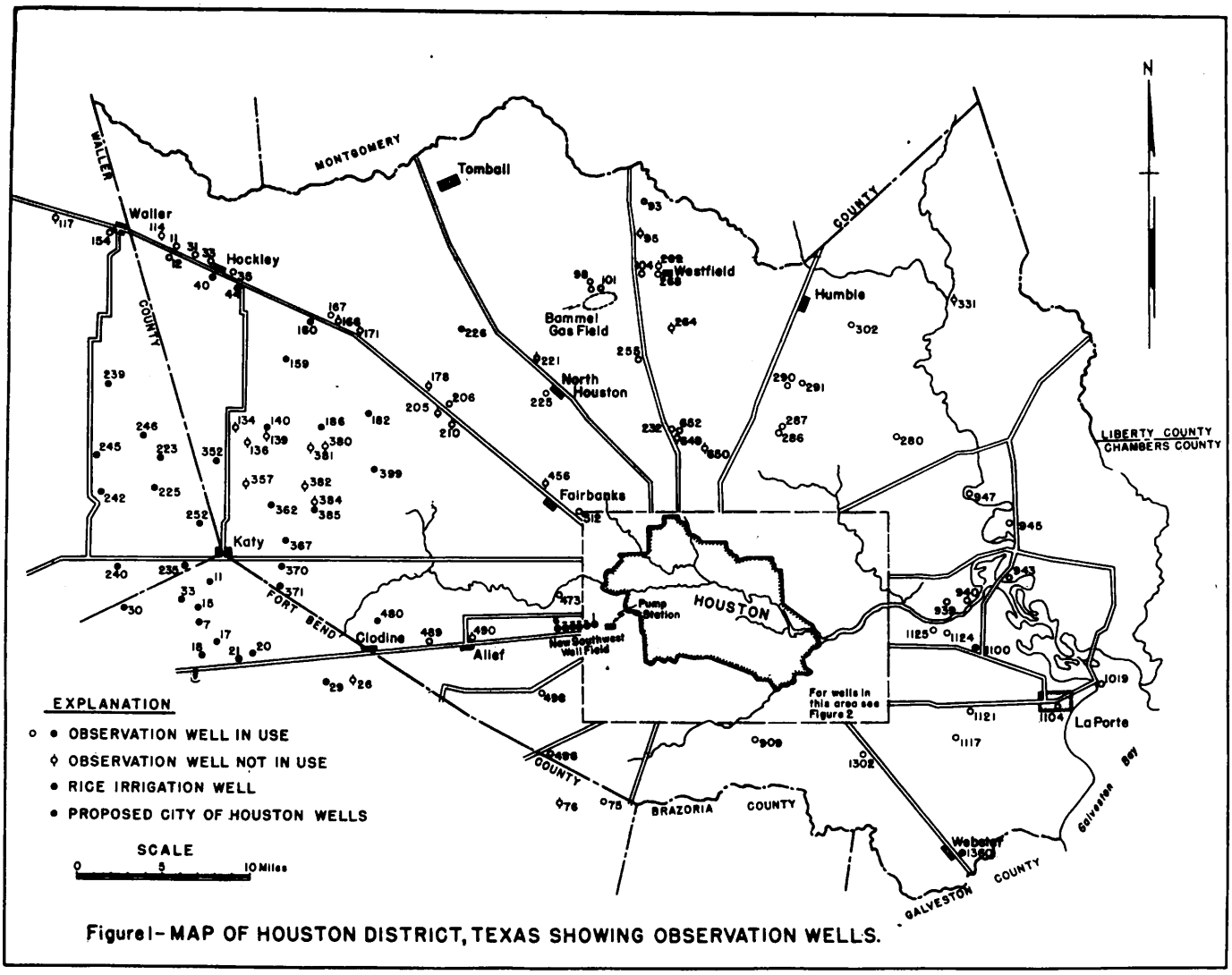


Figure 1 - MAP OF HOUSTON DISTRICT, TEXAS SHOWING OBSERVATION WELLS.

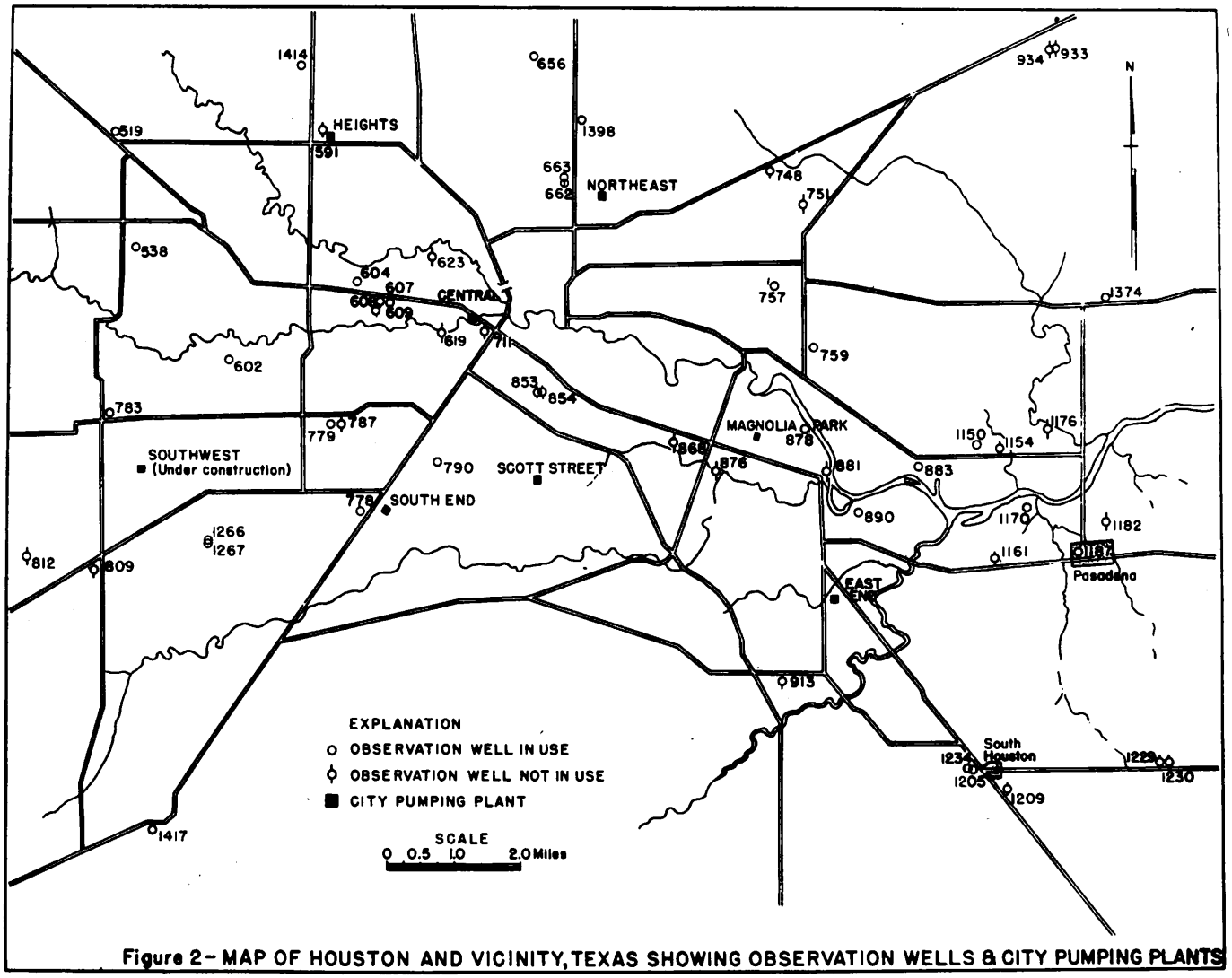


Figure 2- MAP OF HOUSTON AND VICINITY, TEXAS SHOWING OBSERVATION WELLS & CITY PUMPING PLANTS

During the drilling and finishing of three new wells by the City of Houston the writers served in an advisory capacity regarding the sampling of the water-bearing sands, interpretation of electrical logs, and the selection of screen settings. In connection with plans for future development of ground water by the City recommendations were made as to the location of a new well field, the spacing of wells within that field, the approximate depth to which the wells should be drilled, and the rate at which the wells should be pumped. These recommendations were based on studies made in cooperation with the engineering staff of the Utilities Department of the City of Houston. A study was also made of the relative merits of various plans for the distribution of pumpage by the City based on data obtained from pumping tests and the use of the non-equilibrium formula.

In response to a request by the War Production Board a study of the pump settings and pumping levels in industrial and municipal wells in the Houston and Pasadena Ship Channel areas was made to determine the probable effect of an increase in the rate of pumping on the operation of the wells, and to estimate the number of pumps that would have to be lowered due to the anticipated decline in water levels. Also at the request of the War Production Board surveys of the water supply for several of the industrial plants in the district were made, in order to make suggestions as to the feasibility of new ground-water developments proposed for these plants and whether the additional supply could be obtained by reworking existing wells or whether it would be advisable to drill new wells.

A study was made of a phenomenal rise of water levels in observation wells north and northwest of Houston in relation to the discharge of gas into the water-bearing sands from a defective gas well in the Bammel field, about 15 miles north of Houston.

Previous reports

Two water supply papers based on the investigation have been published by the Geological Survey as follows:

Ground-water resources of the Houston district, Texas, by W. N. White, N. A. Rose, and W. F. Guyton, U. S. Geol. Sur. Water-Supply Paper 889-C, 1944.

Exploratory water-well drilling in the Houston district, Texas, by N. A. Rose, W. N. White, and Penn Livingston, U. S. Geol. Sur. Water-Supply Paper 889-D, 1944.

The results of the investigation have been summarized in several progress reports that have been published in mimeographed form by the State Board of Water Engineers. The first of these reports was released in October 1932, and the last in January 1942. Periodic measurements of water levels in observation wells before December 1941 have been published in U. S. Geol. Sur. Water-Supply Papers 777, 840, 886, 909, and 939. In addition to these reports, five reports covering certain phases of the investigation have been published. These special reports are listed below:

Coefficients of storage and transmissibility obtained from pumping tests in the Houston district, Texas, by C. E. Jacob, Trans. Amer. Geophys. Union, pp. 744-756, 1941.

Application of coefficients of transmissibility and storage to regional problems in the Houston district, Texas, by W. F. Guyton, Trans. Amer. Geophys. Union, pp. 756-770, 1941.

Ground water and relation of geology to its occurrence in Houston district, Texas, by N. A. Rose, Bull. Amer. Assoc. Petrol. Geol., Vol. 27, No. 8, pp. 1,081-1,101, August 1943.

Pump settings and pumping levels in Houston district, Texas, by N. A. Rose and W. T. Stuart, U. S. Geol. Survey and Texas State Board of Water Engineers, mimeographed release, May 1943.

Relation of phenomenal rise of water levels to a defective gas well in Harris County, Texas, by N. A. Rose and W. H. Alexander, Jr., manuscript report, U. S. Geol. Survey and Texas State Board of Water Engineers, November 1944.

NEW DEVELOPMENT OF GROUND WATER 1942-44

Since January 1942 about 66 new wells with yields ranging from about 300 to about 2,500 gallons a minute have been drilled in the Houston district, of which 34 were for industrial plants, 24 for rice irrigation, and 8 for the public supply of districts and municipalities. Of the 34 industrial wells 14 were drilled to supply existing industrial plants and 20 to supply 12 new plants, of which 26 are in the Pasadena area and 8 in the Houston area. Of the 24 new irrigation wells 20 were drilled in the Katy area, 2 near La Porte, one near Webster and one about 10 miles north of Houston. Of the 8 municipal wells 3 were drilled for the City of Houston and 5 for water districts and small municipalities in the Pasadena area.

The first of the 3 new City wells was drilled at the East End well field in 1943. It was completed at a depth of 2,060 feet, yields approximately 2,000 gallons a minute, and is the deepest water well in the district. The second City well was drilled at the North East well field in 1944, is 1,995 feet in depth, and yields about 2,500 gallons a minute. The third was drilled at the South End well field in 1944, is 1,750 feet in depth, and yields about 2,150 gallons a minute.

In connection with the program of new development by the City of Houston a contract has been awarded for the drilling of six wells at the new Southwest well field (see fig. 1, p. 2). The pump station will be at the intersection of the S. A. A. P. and Southern Pacific Railroad tracks, on the Alief road 3,100 feet east of the Post Oak Road. Well 1 will be 5,050 feet west of the pump station, well 6 about 11,000 feet west of well 1, and the other four wells will be spaced at more or less regular intervals between wells 1 and 6. Two rigs will be used and it is expected that the drilling of wells 1 and 6 will begin about December 1, 1944. Exploratory holes will be put down to a depth of 2,500 feet at these two sites, and samples of water will be collected from all the deeper sands. An electrical log will be run on each of the six wells. From these data the proper depth and position of the screen in all six wells can be determined. It is planned to draw about 2,100 gallons a minute from each well.

VOLUME AND DISTRIBUTION OF PUMPAGE IN HOUSTON, PASADENA, AND KATY AREAS

Records of the pumpage from all the wells in the Houston, Pasadena, and Katy areas that produce over 5,000 gallons a day have been obtained and compiled for the years 1930, 1935, 1937, and 1939 to 1944, inclusive.

In 1943 practically all the ground water used in the Houston and Pasadena areas was pumped from 284 wells. It was found that the discharge was metered from 67 of the wells that yielded about 60 percent of the total supply, and good records of the time of operation and rate of discharge of the pumps were kept on about 45 other wells that yielded about 25 percent of the supply. The records were poor and the pumpage had to be estimated for the remaining 172 wells from which about 15 percent

of the total withdrawals were made. Approximately 10 new wells were added in 1944 and the total pumpage for the year was about 12 percent greater than it was in 1943.

In 1944 about 115 wells were used for rice irrigation in the Katy area. The estimates of pumpage from the irrigation wells since 1930 have been based on the number of acres that are irrigated by each well, on the amount of electrical current used by the electrically operated wells, and on the results of measurements of discharge of water from about 30 selected representative wells.

The estimated average quantities of water, in millions of gallons a day, withdrawn by wells in the Houston, Pasadena, and Katy pumping areas in 1930, 1935, 1937, and 1939 to 1944 inclusive are given in the following table:

Estimated average daily withdrawal of ground water in the Houston, Pasadena, and Katy areas (million gallons a day) a/

	1930	1935	1937	1939	1940	1941	1942	1943	1944 b/
Houston Water Department (from City records)	25.8	24.5	25.2	27.2	28.8	27.2	30.5	35.2	39
Houston independent public water supplies and industrial wells	14	14	16	16	17	16 c/	18	20	21
Pasadena industrial wells	10	10	29	29	33	34	36	39	46
Total for the Houston and Pasadena areas	50	49	70	72	79	77	85	94	106
Katy irrigation wells	18	14	30	40	45	23	38	52	55
Total for the district	68	63	100	112	124	100	123	146	161

a/ The rice wells are pumped only during the season which begins about May 1 and lasts approximately 130 days and the pumpage in the Houston and Pasadena areas although continuous is much heavier in the summer than it is during the remainder of the year. Therefore, for convenience in compiling and in order that comparisons may be made the total withdrawals in all three areas are given as a daily average for the entire year.

b/ For the Houston and Pasadena areas the figures for 1944 are based on records of pumpage through September and estimates of pumpage during the remainder of the year. For the Katy area the figures are based on a pumpage of 1.9 acre feet per acre for 31,740 acres and the kilowatt hours used by 58 electrically operated wells.

c/ Figure in 1942 progress report corrected.

HOUSTON AND PASADENA PUMPING AREAS

Pumpage

In the Houston and Pasadena areas in 1942 the total average rate of withdrawals by wells was 85,000,000 gallons a day. This represented an increase of 8,000,000 gallons a day, or a little over 10 percent, above the average in 1941. In 1943 the pumpage continued to increase at about the same rate as in the previous year, and the estimated average withdrawals was 94,000,000 gallons a day. During the first nine months of 1944 the rate of increase was slightly accelerated, and it is estimated that the pumpage for the year will average about 106,000,000 gallons a day or about 12,000,000 gallons a day greater than it was in 1943. This represents an increase of about 56,000,000 gallons a day, or about 115 percent, over the pumpage in 1935. About 29,000,000 gallons a day of this increase occurred in the Pasadena area.

The war is mainly responsible for the increase in pumping since 1941. Several new industrial plants, including synthetic rubber plants, shipbuilding yards, an ordnance depot, a gun plant, and a steel mill have been put in operation during the last three years and the facilities of oil refineries, tool manufacturing plants, and many other of the old established industries have been greatly expanded. The population of Houston and surrounding municipalities has increased sharply with the new industrial development and this has materially increased the requirements for public supply.

In 1944 the Water Department of the City of Houston operated 26 wells in seven well fields widely spaced over the city (see fig. 2, p. 3). The average daily pumpage from the wells of each well field in 1935 and from 1937 to October 1, 1944, inclusive is given in the following table.

AVERAGE DAILY PUMPAGE CITY OF HOUSTON

Well Field	1935	1937	1938	1939	1940	1941	1942	1943	1944 (through Sept.)
	Thousands of gallons a day								
Central	5,122	6,182	5,977	5,780	5,997	5,380	6,320	8,408	9,770
Heights	5,159	4,506	4,218	5,142	5,242	5,220	5,460	5,743	6,980
Scott-St	7,822	5,865	4,998	5,653	7,587	7,600	7,620	8,350	8,020
South End	4,651	4,833	5,817	6,600	6,143	5,550	6,330	6,019	6,550
East End	-	1,671	1,451	1,417	1,517	1,350	1,600	1,724	2,820
North East	510	2,140	2,380	2,417	2,321	2,170	3,110	4,789	5,170
Magnolia Park	1,104	13	128	221	49	210	-	114	-
TOTAL	24,368	25,210	24,969	27,200	28,800	27,200	30,500	35,147	39,310

The estimated total average daily withdrawal of ground water for public water supply and industrial use in the Houston and Pasadena areas during 1943 is given in the following table. The table is subdivided to show separately the pumpage by the Houston Water Department, by independent public water supply agencies, and by the 12 classes of industries that use the most water.

Estimated average daily pumpage for public and industrial supply in the Houston and Pasadena areas in 1943

	Number of plants	Number of wells	Daily pumpage (million gallons a day)
Houston Water Department	7	24	35.1
Paper mill	1	8	18.2
Oil refineries	6	21	13.8
Independent public water supplies	24	44	4.2
Ice plants	18	24	3.5
Railroads and allied plants	10	16	2.7
Tool and armament plants	4	7	2.7
Synthetic rubber plants *	2	3	1.8
Office buildings, hotels and theatres	26	29	1.7
Ship yards	2	6	1.5
Power plants	3	7	1.5
Country clubs	5	8	1.3
Meat packing plants	3	6	1.0
Laundries	13	13	0.9
Miscellaneous industrial plants using more than 5,000 gallons a day	57	68	4.5
Total	181	284	94.4

* One synthetic rubber plant used between 5 and 10 million gallons a day of surface water which was supplied from the San Jacinto River.

Decline of water levels in wells in Houston and Pasadena areas

The general decline of water levels in wells in the Houston and Pasadena areas, which began in 1937, continued during 1942, 1943, and 1944. In the observation wells that are screened opposite the heavily pumped sands at Houston, Pasadena, and in the area west of Houston the average decline between the springs of 1941 and 1942 was 3.2 feet, as compared with 6.1 feet during the preceding year. This reduction in the rate of decline was caused by a small decrease in pumpage which was about 2,000,000 gallons a day less in 1941 than it was in 1940 (see pp.10-11). With the large increases in the rate of pumping in 1942 and 1943 the average rate of decline was again accelerated being 8.7 feet from the spring of 1942 to the spring of 1943 and 10.3 feet from the spring of 1943 to the spring of 1944. The water levels between the springs of 1944 and 1945 will probably show a still greater rate of decline because of the large increase in withdrawals during 1944 which are estimated to be about 12,000,000 gallons a day more than they were in 1943 (see pp.10-11).

A comparison of the September measurements in observation wells shows an average decline of 12.2 feet from 1942 to 1943 and 13.6 feet from 1943 to 1944.

The decline of water levels between 1937 and 1944 in observation wells screened opposite the heavily pumped sands in Houston, Pasadena, and adjacent localities is shown in the following table.

Decline of water levels in wells screened opposite the heavily-pumped sands in the Houston, Pasadena, and adjacent localities, in feet, 1937-1944

Vicinity of Pasadena

Well	Distance from Pasadena (miles)	Depth (feet)	Spring measurements								Fall (Sept.) measurements	
			1937-38	1938-39	1939-40	1940-41	1941-42	1942-43	1943-44	1937-44	1942-43	1943-44
1182	½ W	685	--	--	--	20.9	+2.8	13.8	21.8	--	22.9	39.3
1187	1 W	834	--	+0.1	18.9	7.6	--	--	--	--	--	--
1231	1 W	834	--	+1.5	19.3	6.9	--	--	--	--	--	--
1176	2 NW	1,134	29.0	2.9	+1.5	6.0	8.7	6.1	7.8	59.0	--	--
1170	2 W	836	31.0	+0.5	19.5	6.5	4.5	16.0	14.0	91.0	20.5	31.0
1161	2½ W	1,228	25.0	3.5	10	13.9	+0.3	14.6	16.4	82.9	21.3	27.8
1150	2½ NW	680	--	--	--	13	2.7	12.9	20.3	--	20.8	29.8
883	3½ W	841	--	--	11.2	12.4	3.8	12.1	20.7	--	21.7	28.5
1229	4 S	1,680	--	--	--	14.6	2.0	3.3	6.3	--	3.2	5.3
1230	4 S	1,419	--	--	--	13.0	6.3	7.2	9.8	--	14.4	20.1
890	4½ W	1,284	22.1	--	--	10.0	--	--	21.9	85.0	21.8	--
1124	5½ E	913	--	--	--	--	8.0	12.0	7.0	--	--	--
1302	6½ S	832	18.0	4.5	4.8	7.5	4.0	6.7	12.2	57.7	10.4	14.7
936	6 N	619	--	--	--	--	--	8.0	7.0	--	14.2	17.0
933	7 N	850	--	--	--	7.4	3.2	3.4	9.5	--	7.8	14.7
1100	7 E	900	--	--	--	2.9	10.4	11.0	5.6	--	--	--

Eastern Houston

881	5 W	650	15.9	6.0	8.9	7.8	4.0	13.0	20.7	76.3	19.0	25.1
878	5 W	905	24.6	4.5	8.6	8.7	3.0	12.7	16.0	78.1	15.8	21.2
913	5½ W	876	--	6.4	7.2	8.0	3.9	10.0	14.0	--	13.9	15.7
759	5½ NW	569	16.5	6.0	9.8	5.8	4.7	9.6	13.7	66.1	13.0	18.4
876	6½ W	--	--	5.6	9.6	5.8	3.5	13.6	15.4	--	14.4	16.2
757	6½ NW	676	13.2	6.6	9.9	4.2	3.0	15.6	13.0	65.5	16.9	13.4
751	7 NW	540	12.6	6.6	9.9	6.2	2.9	11.1	9.8	59.1	12.6	12.6
748	7½ NW	721	--	--	--	6.1	2.5	10.2	11.2	--	12.6	13.6

Northern Houston

662	10 NW	834	12.2	7.2	15.6	+0.3	2.2	20.8	5.0	62.7	--	--
663	10 NW	740	--	--	7.4	1.3	3.7	2.8	1.0	--	2.6	4.1
656	11½ NW	665	10.8	6.1	10.1	3.9	1.5	10.2	6.2	48.8	11.2	8.6
591	13½ NW	1,039	--	5.8	11.3	--	--	--	11.9	--	12.6	1.1

Plus indicates rise in the water levels.

Decline of water levels in wells screened opposite the heavily-pumped sands in the Houston, Pasadena, and adjacent localities, in feet, 1937-1944

Central and western Houston

Well	Distance from Pasadena (miles)	Depth (feet)	Spring measurements								Fall (Sept.) measurements	
			1937-38	1938-39	1939-40	1940-41	1941-42	1942-43	1943-44	1937-44	1942-43	1943-44
853	9 W	650±	--	7.0	10.4	+0.5	3.5	20.3	3.5	--	7.4	8.7
854	9 W	919	--	6.0	--	--	3.3	4.6	26.0	--	23.7	--
711	10 W	884	--	--	--	--	--	10.8	2.5	--	11.1	14.1
790	12½ W	606	+1.1	10.3	6.2	3.6	6.9	3.5	5.8	35.2	--	--
619	10½ NW	625	2.2	8.7	7.5	4.0	4.0	9.8	16.0	52.2	13.1	11.1
623	11 NW	900+	--	--	6.0	3.5	5.0	3.2	6.4	--	6.0	9.4
787	12 W	701	--	--	4.6	0.7	0.5	7.1	10.9	--	15.7	1.6
779	12 W	584	--	--	4.8	3.6	3.4	4.1	4.4	--	--	--
606	12 NW	575	4.6	7.7	7.6	2.9	3.4	5.8	--	--	--	--
609	12 NW	825	--	--	7.1	2.8	2.7	7.0	13.4	--	10.7	9.3
607	12 W	--	--	--	--	--	--	--	4.0	--	5.2	10.0
602	13½ W	1,038	7.7	5.8	6.2	4.6	1.4	9.4	5.4	40.5	9.4	7.8

Locality west of Houston

783	15½ W	350+	2.7	5.2	4.3	2.4	1.9	2.8	3.7	23.0	4.8	5.8
809	16 W	1,100±	6.4	3.9	6.6	7.0	0.6	4.7	7.7	36.9	4.0	8.1
473	18½ W	416	--	--	3.9	3.0	0.6	2.3	4.0	--	4.3	4.3
498	19½ W	787	--	--	3.7	2.6	3.8	0.6	6.0	--	4.7	3.8
490	23½ W	1,272	--	--	--	2.6	2.3	2.9	3.5	--	3.9	1.4
489	25½ W	472	--	--	--	1.2	+0.8	1.0	3.0	--	3.9	2.0

Locality north of Houston

650	14 NW	468	--	--	5.8	3.7	1.4	5.0	3.1	--	4.8	4.8
649	16 NW	367	--	--	4.8	3.1	1.1	3.6	0.4	--	4.0	3.4
648	16 NW	301	--	--	--	2.9	0.5	3.1	0.5	--	3.7	2.6
302	18 N	1,000	--	--	2.7	2.4	1.2	1.9	0.4	--	--	--
264	21 NW	--	11.8	2.5	2.9	0.0	+1.5	2.0	+8.1	--	+3.7	1.9
225	23½ NW	616	--	--	2.5	0.3	+0.6	+7.1 (?)	+22.3	--	+19.8	--
268	24½ N	815	--	--	--	1.3	+0.3	+7.6 (?)	+26.4	--	+28.9	+31.9
221	24½ NW	208	--	--	2.6	+2.7	+1.3	0.5	+13.2	--	+8.0	0.9

Plus indicates rise in the water levels.

A summary of the more important declines in water level in observation wells from 1943 to 1944 and from 1937 to 1944, based on spring measurements, is as follows:

Vicinity of Pasadena - In 14 observation wells near Pasadena the decline in water level between 1943 and 1944 ranged from 5.6 to 21.8 feet and averaged 12.8 feet. In five wells, for which comparable records are available, the decline between 1937 and 1944 ranged from 57.7 to 91.0 feet and averaged 75.0 feet (see fig. 3, p. 13).

Eastern Houston - In eight wells in eastern Houston the decline between 1943 and 1944 ranged from 9.8 to 20.7 feet and averaged 14.2 feet. In five wells the decline between 1937 and 1944 ranged from 59.1 to 78.1 feet and averaged 69.0 feet (see fig. 4, p. 14).

Northern Houston - In four wells in northern Houston the decline between 1943 and 1944 ranged from 1.0 foot to 11.9 feet and averaged 6.0 feet. In two wells the decline between 1937 and 1944 was 48.8 and 62.7 feet (see fig. 5, well 656, p. 15).

Central and western Houston - In 11 wells in central and western Houston the decline between 1943 and 1944 ranged from 2.5 to 26.0 feet and averaged 8.9 feet. In three wells the decline from 1937 to 1944 was 35.2, 40.5, and 52.2 feet (see fig. 5, well 619, p. 15).

Locality west of Houston - In six wells in the area west of Houston the decline between 1943 and 1944 ranged from 3.0 to 7.7 feet and averaged 4.6 feet. In two wells the decline from 1937 to 1944 was 23.0 and 36.9 feet (see fig. 5, well 809, p. 15).

Locality north of Houston - In four wells north of Houston the decline between 1943 and 1944 ranged from 0.4 to 3.1 feet and averaged 1.1 feet. In four other observation wells immediately north of Houston the water levels have risen abnormally since January 1942 in common with the water levels in a large number of wells in an area extending 12 miles or more to the north and northwest of the city. This is discussed on pp. 28 to 30 .

Graphs portraying decline of water levels in eight wells in the Pasadena and Houston areas are shown in figures 3, 4, and 5 on pages 13 to 15.

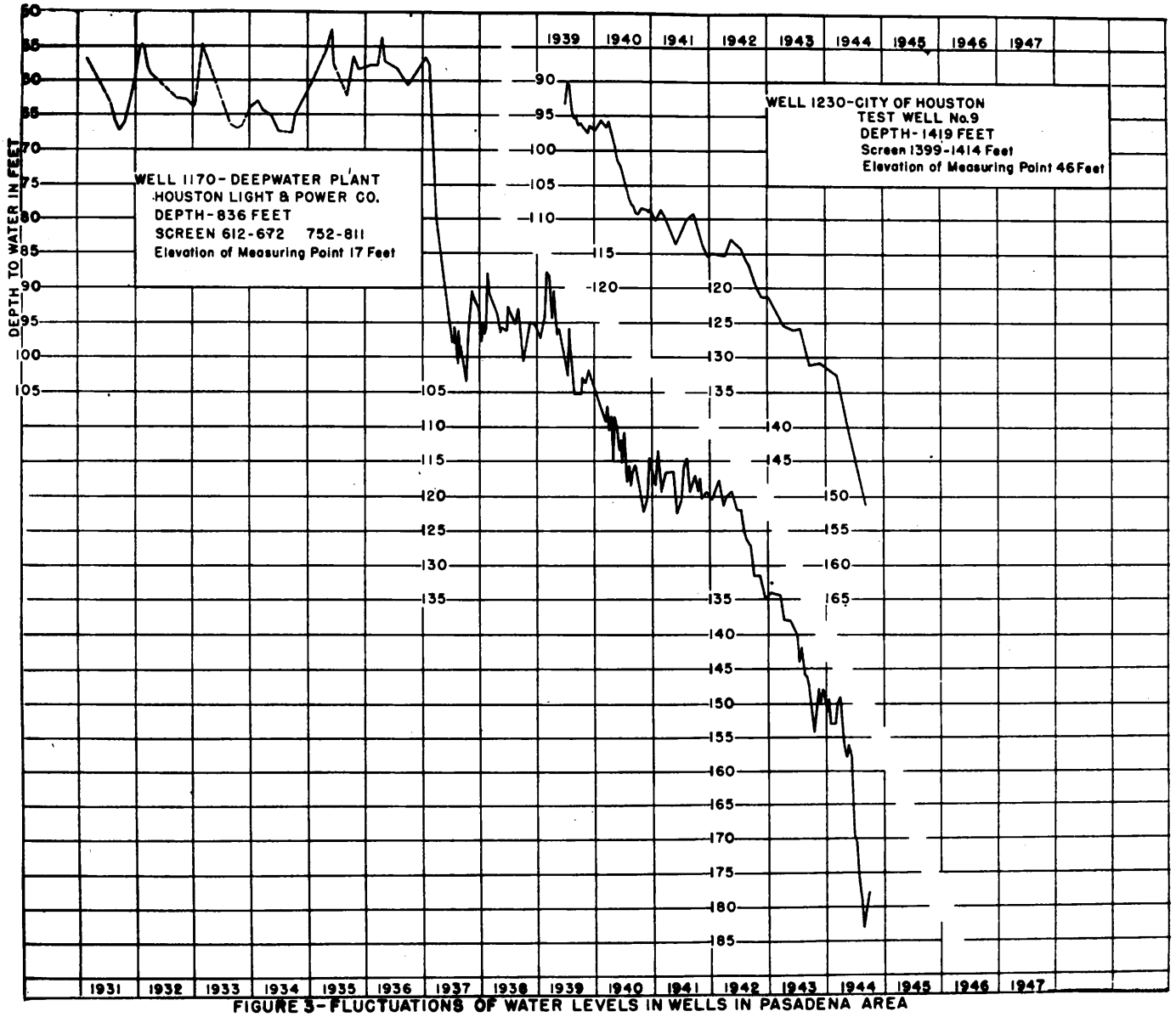


FIGURE 3- FLUCTUATIONS OF WATER LEVELS IN WELLS IN PASADENA AREA

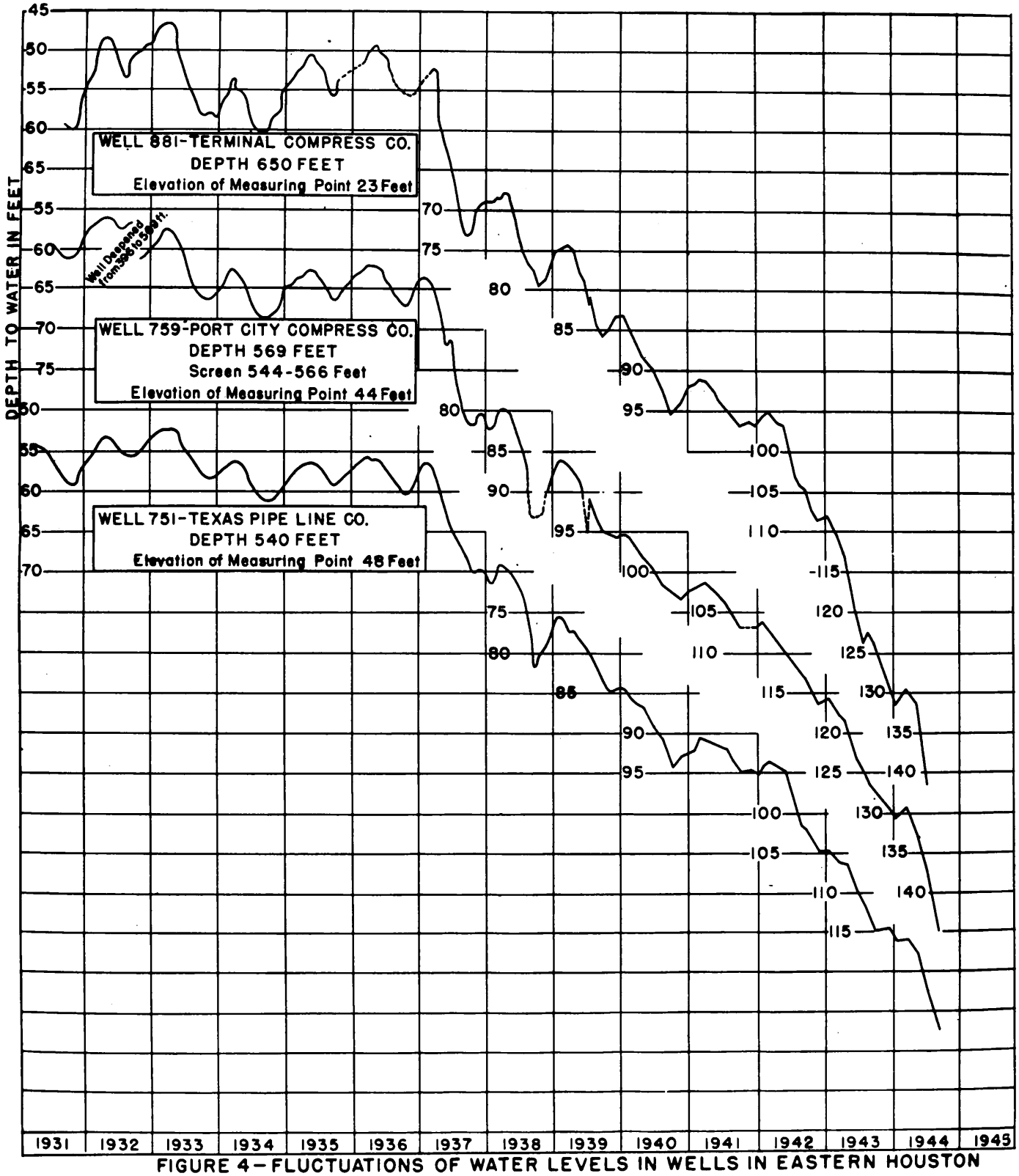


FIGURE 4 – FLUCTUATIONS OF WATER LEVELS IN WELLS IN EASTERN HOUSTON

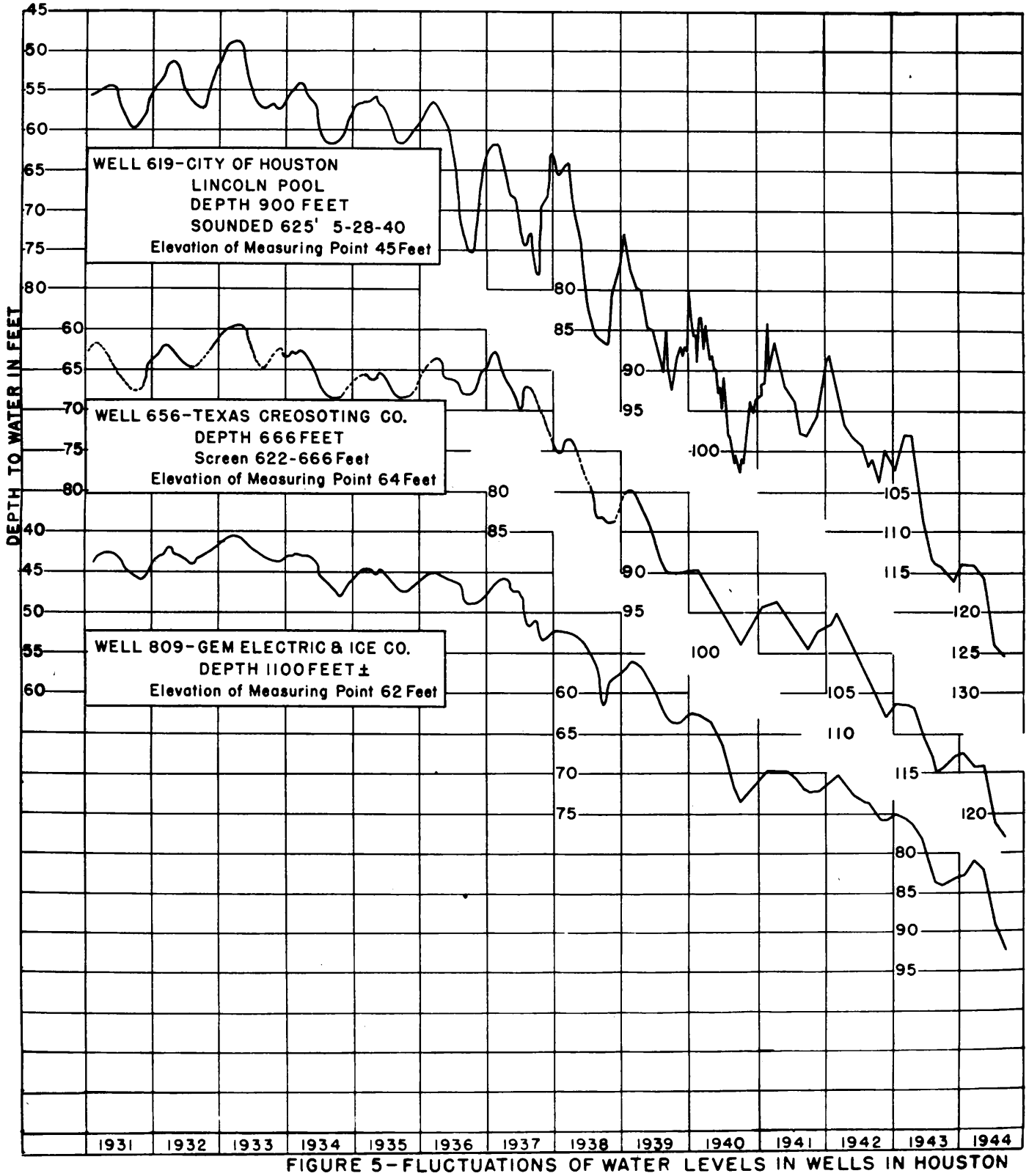


FIGURE 5-FLUCTUATIONS OF WATER LEVELS IN WELLS IN HOUSTON

Wells screened opposite lightly pumped sands - In the observation wells that are screened opposite the comparatively shallow lightly pumped sands the decline continued during 1942 and 1943 but at a decreasing rate. During 1944, however, the rate was accelerated. Based on spring measurements the average decline was 3.4 feet from 1941 to 1942, 2.2 feet from 1942 to 1943, and 4.5 feet from 1943 to 1944. A comparison of September measurements shows a decline of 5.5 feet from 1942 to 1943 and a decline of 5.8 feet from 1943 to 1944. In two wells the decline from 1937 to 1944 was 16.9 and 27.1 feet.

Decline of water levels in wells screened opposite the lightly pumped sands in the Houston, Pasadena and adjacent localities, in feet, 1937-44

Well	Distance from Pasadena (miles)	Depth (feet)	Spring measurements								Fall (Sept.) measurements	
			1937-38	1938-39	1939-40	1940-41	1941-42	1942-43	1943-44	1937-44	1942-43	1943-44
1154	1½ NW	720	-	-	-	3.7	2.8	2.6	6.0	-	8.9	5.0
1234	4½ S	316	-	-	-	-	-	-	4.3	-	4.8	-
1209	4½ S	650±	6.5	4.2	2.3	4.3	2.8	2.3	4.7	27.1	3.8	5.6
934	7 N	135	-	-	-	18.1	3.3	3.6	3.2	-	3.6	3.3
778	11½ W	404	-	-	3.8	1.1	3.7	2.5	5.0(?)	-	5.8	9.8
608	12 NW	350	-	-	4.4	4.1	4.0	1.8	4.0	-	8.9	5.2
604	12½ NW	340	0.6	+1.0	4.9	2.2	5.5	0.7	4.0	16.9	2.9	-

A series of maps showing the approximate altitudes of water levels in wells that draw from the heavily pumped sands of the district, based on January water level measurements, has been prepared for 1941, 1942, 1943, and 1944 (see figs. 6, 7, 8, and 9, pp. 17 to 20). The direction of movement of the ground water, which is approximately at right angles to the contours, and the approximate hydraulic gradient are shown by the maps. The maps also show the spread and deepening of the large cone of depression that encircles the areas of heavy withdrawal. The area within the contour 40 feet below sea level has been cross hatched so that the spread of the cone of depression can be easily followed from year to year. It should be noted that the maps for 1941 and 1942, two years in which the volume of withdrawals for the Houston and Pasadena areas was more or less comparable, show very little change in the spread and deepening of the cone. However, the maps for 1943 and 1944 show considerable expansion and deepening due to the large increases in the rate of pumping.

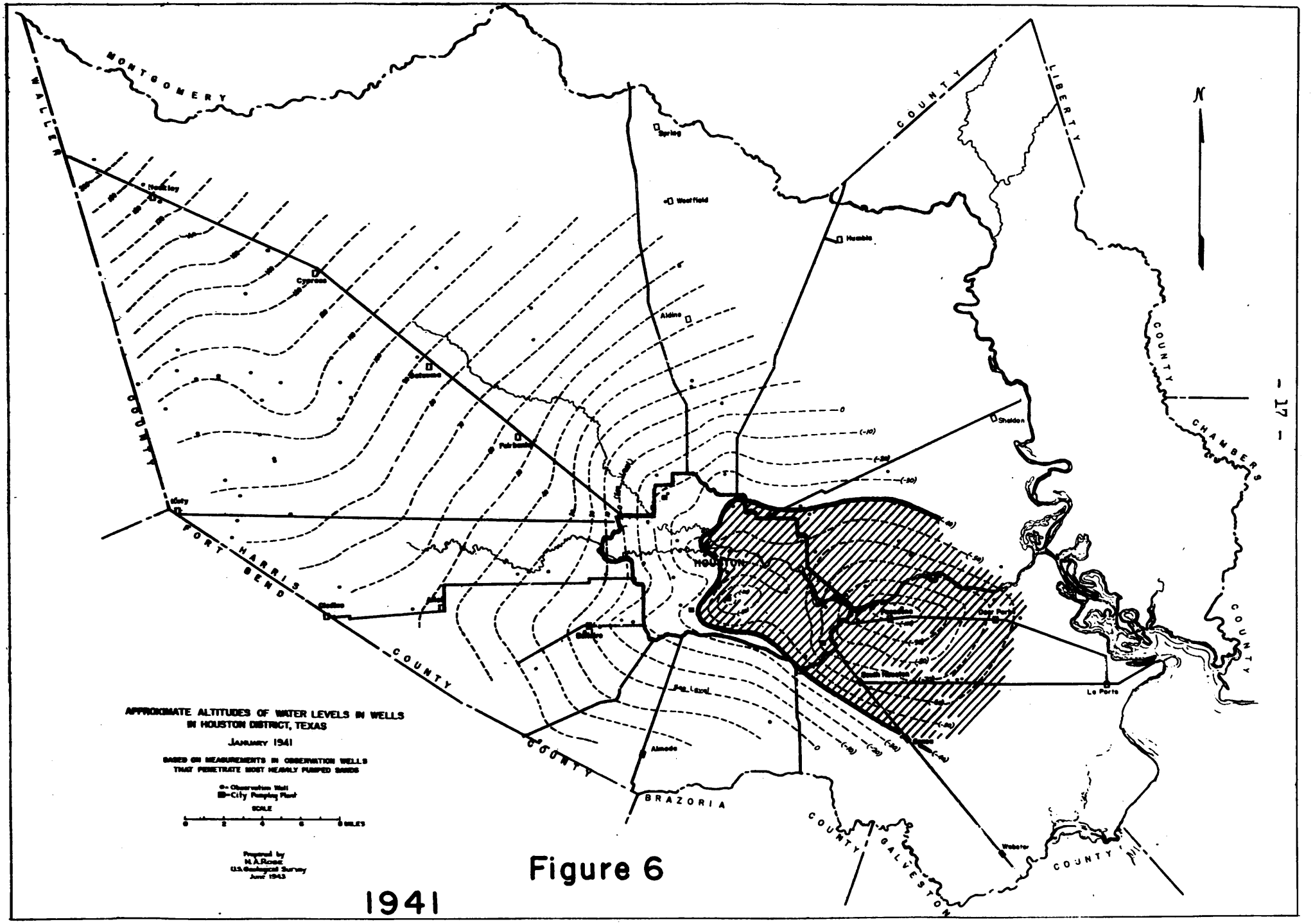


Figure 6

1941

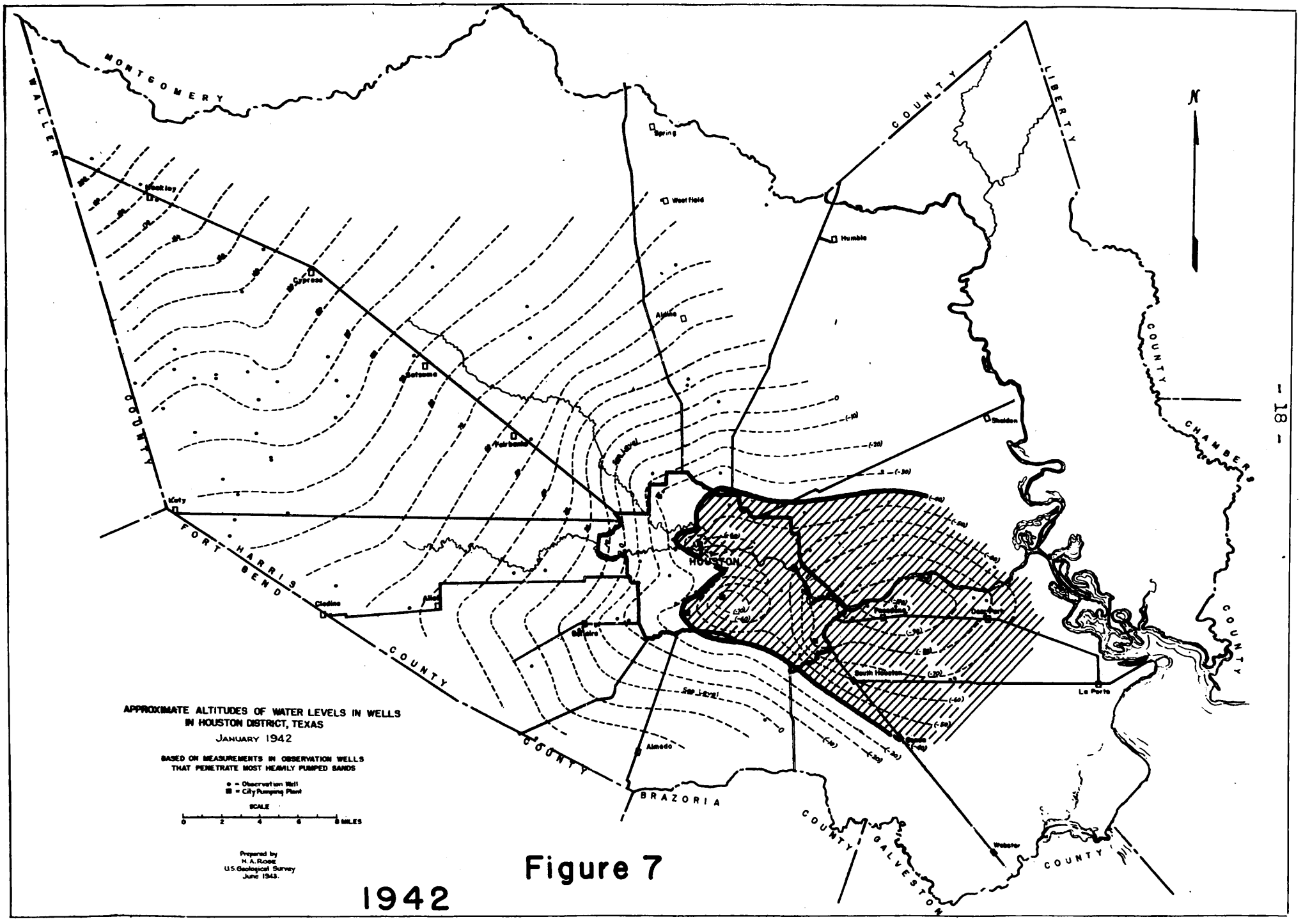


Figure 7

1942

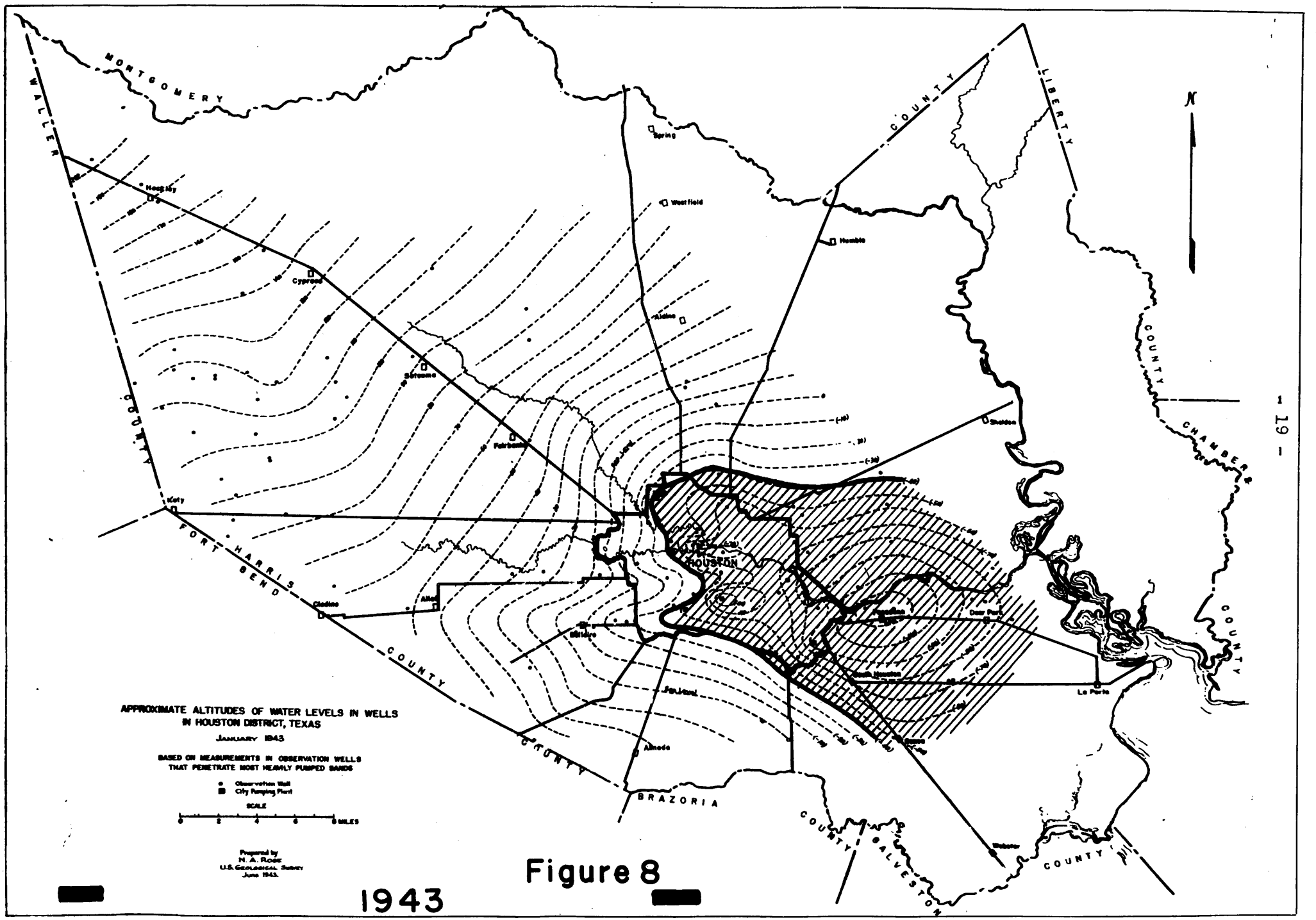


Figure 8

1943

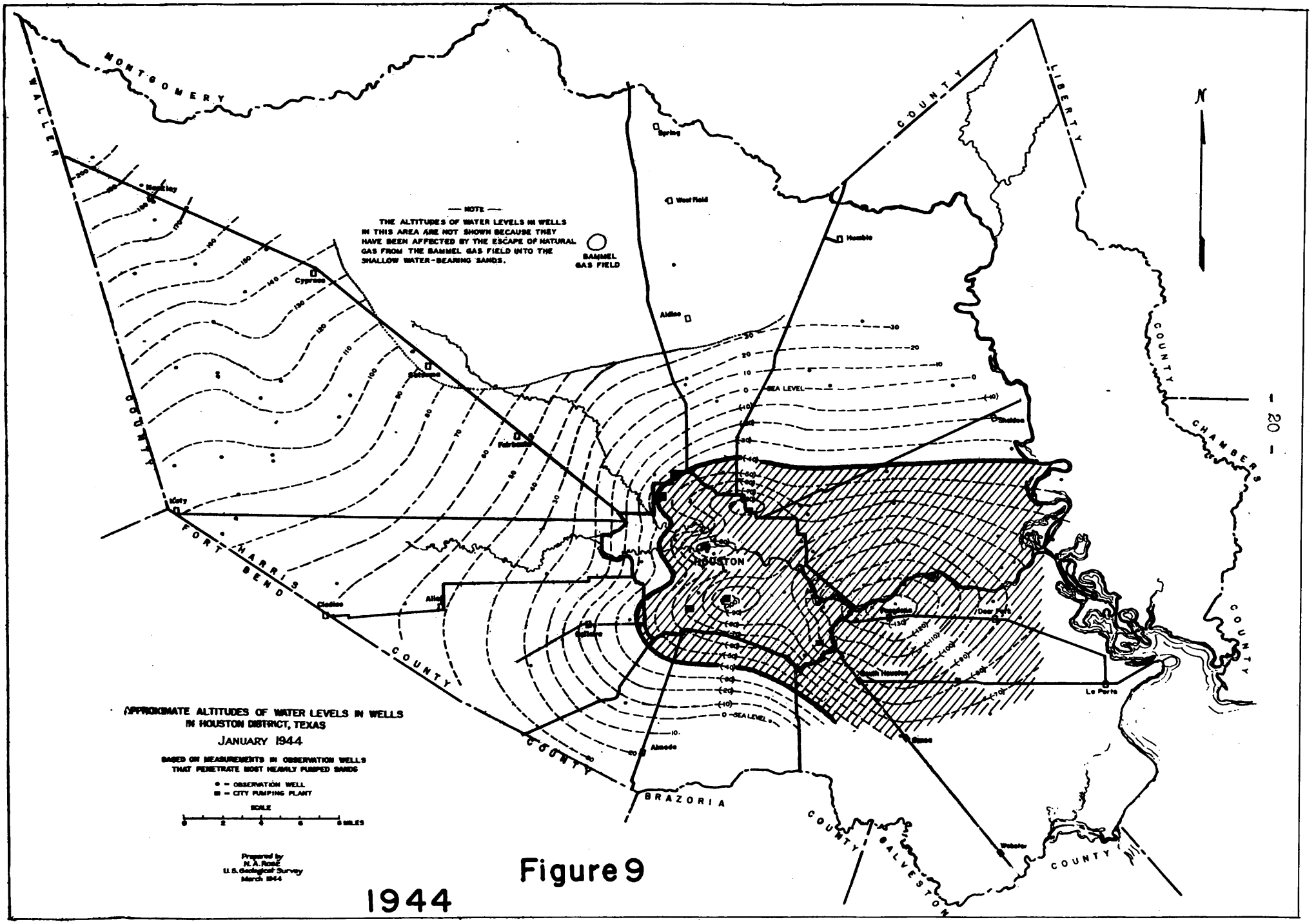


Figure 9

1944

KATY RICE-GROWING AREA

Pumpage

From 1941 to 1944 the number of acres of rice that were planted in the Katy area increased only about 4,400 acres, but the boundaries of the rice-growing district expanded materially. Most of the new acreage was in the northern part of the area, northwest, south, and southeast of Hockley, where 10 new irrigation wells were put into operation. These wells, in general, are more widely spaced than those in the central and southern part of the area and being up the dip draw in part from sands that are stratigraphically deeper than the sands drawn upon in the southern part.

The following table shows the number of wells that were used for the irrigation of rice in the area; the number of acres irrigated; the total amount of water pumped, in acre feet; and the amount of water, including rainfall, applied to the land per acre per season in 1930, 1935, and 1937 to 1944, inclusive.

Pumpage and rainfall in the Katy rice-growing area

	1930	1935	1937	1938	1939	1940	1941	1942	1943	1944
Number of wells	45	40	61	71	78	88	95	103	112	115
Total number of acres irrigated a/	9,400	8,000	13,750	16,370	19,950	24,200	27,350	30,418	30,416	31,740
Total amount of water pumped, in acre-feet b/	20,200	15,700	33,600	28,000	44,900	50,400	25,800	43,000	58,000	64,000
Acre-feet of water pumped per acre	2.2	1.9	2.5	1.7	2.2	2.1	0.9	1.4	1.9	1.9
Rainfall, in feet (May through September) c/	0.9	1.9	0.9	1.9	1.6	1.4	2.6	1.9	1.9	1.8
Total amount of water applied to the land (irrigation + rainfall), in acre-feet per acre	3.1	3.8	3.4	3.6	3.8	3.5	3.5	3.3	3.8	3.7

a/ Records of the American Rice Growers Co-Operative Association.
b/ One-acre foot equals approximately 326,000 gallons.
c/ Average of rainfall recorded by U. S. Weather Bureau at Hempstead, Houston, Sealy, and Sugarland.
No record for Hempstead in 1938 or Sealy in 1939.

As shown by the table the number of acres under irrigation in the Katy area has increased each year from about 8,000 acres in 1935 to about 31,740 acres in 1944. All of this land was irrigated from wells. The total amount of water received by the irrigated land per acre each year of this period for which pumpage inventories are available, including the rainfall during the irrigation season, was remarkably uniform, but due to variations in the rainfall the pumpage per acre varied widely. In 1941 the rainfall during the growing season was abnormally heavy and the pumpage was comparatively small, averaging only 0.9 acre foot per acre. In 1942 the rainfall during the season was only slightly above the average for the ten years covered by the table, but it was unusually well distributed throughout the season. This tended to reduce irrigation demands and the pumpage was again light, averaging 1.4 acre feet per acre. In 1943 and 1944 an average of 1.9 acre feet per acre was pumped and the total of pumpage in the area reached 58,000 and 64,000 acre feet, respectively, the equivalent of 52,000,000 and 55,000,000 gallons a day throughout the year. The pumpage in both of these years was greater than that of any previous year.

Decline of water levels in wells in Katy area

From 1931 to 1941 the water levels in wells in the Katy area declined persistently, although the amount of the decline was only a fraction of that experienced in the Houston and Pasadena areas during the same period. Between the spring of 1941 and the spring of 1942 there was a general rise of water levels in the area as a result of the relatively small pumpage for rice irrigation and the unusually large recharge from the heavy rains of November 1940 to October 1941, the average rise in 44 observation wells being 2.1 feet. From the spring of 1942 to the spring of 1943 there was little net change, some of the wells showing a slight decline and others a slight rise. From the spring of 1943 to the spring of 1944 the water levels showed an average decline of 1.6 feet as a result of the increase in the rate of withdrawal in 1943 over that in 1942. From November 1943 to October 1944 the water levels in 32 wells showed an average net decline of 4.2 feet although the rate of pumping in 1944 was only slightly greater than it was in 1943. This comparatively large decline with a small increase in pumping was due in part to the unequal distribution of rainfall during the growing season in 1944, almost 50 percent of it occurring in May with a corresponding shortage in the latter part of the season. As a result practically all of the wells were idle in May and June but were operated continuously during July, August, September, and the first two weeks in October. The water levels should recover considerably during the winter of 1944-45.

The following table shows the decline and rise of water levels in observation wells in the Katy area (see fig. 1, p. 2) between 1931 and 1944.

Decline of water levels in wells in Katy rice-growing area

Harris County

Well	Depth of well (feet)	Spring measurements					Fall measurements	
		1931 to 1944	1939 to 1944	1941 to 1942	1942 to 1943	1943 to 1944	Oct. 1942 to Nov. 1943	Nov. 1943 to Oct. 1944
134	274	--	5.9	+2.3	+0.6	2.5	1.6	2.1
136	138	16.1	6.9	+3.3	--	--	1.1	2.1
139	134	a/12.1	5.9	+3.8	+0.2	2.8	--	3.3
140	359	--	5.7	+3.3	+0.2	2.8	--	3.7
146	250	--	--	+3.1	--	--	--	--
159	590	--	--	+3.2	0.3	0.1	--	--
160	499	--	--	+2.8	0.1	+1.2	2.4	1.3
182	239	--	2.1	--	+0.5	0.1	1.1	2.2
183	284	--	--	+2.5	--	--	--	--
186	628	7.3	0.1	+2.6	+0.7	0.4	0.9	2.5
205	615	3.4	+7.0	+1.6	+0.7	+5.7	--	--
206	450±	2.0	+3.0	+2.5	1.0	+1.6	--	--
352	470	--	--	+3.3	+0.4	--	0.9	3.9
357	--	17.7 (?)	11.9	+3.3	+0.4	4.4	4.3	11.2
362	500	12.2	4.5	+2.8	+0.2	2.6	2.9	6.6
367	535	--	2.9	+2.3	0.0	1.6	2.2	7.0
370	625	--	3.0	+2.6	0.2	2.0	--	--
371	374	--	1.9	+2.1	0.1	2.1	+0.9	8.0
380	55±	--	+2.9	+1.6	0.2	+2.1	1.0	+0.2
381	95±	--	--	+1.8	+0.9	--	0.4	2.3
382	185	--	2.6	+2.2	+0.2	1.0	5.3	9.2
384	505	a/ 7.6	2.5	+2.3	+1.1	1.4	3.6	4.4
385	359	a/ 4.6	1.9	+2.1	+0.5	1.4	2.0	5.4
399	326	--	--	+1.3	+1.0	0.3	0.4	2.4
400	258	--	--	+2.1	+0.6	--	--	--
480	512	--	--	+2.3	1.8	2.2	2.0	5.3

Fort Bend County

6	596	--	--	+2.0	1.2	--	--	--
7	337	--	--	+1.6	--	+0.9	1.1	4.3
11	170	a/ 9.5	7.2	+2.0	+0.1	1.8	0.5	3.3
15	172	10.4	5.0	+2.0	+0.5	3.1	0.3	2.5
20	250	a/ 4.2	2.0	+2.1	--	+0.6	0.3	--
21	--	4.7	1.6	+2.5	0.5	1.1	0.6	6.3
26	657	--	1.2	+1.9	0.7	0.9	0.0	5.9
29	500	--	--	+1.7	0.5	1.4	--	--
30	334	--	--	+1.6	+0.6	0.4	0.6	0.4
33	346	--	5.3	+1.0	+0.2	3.0	0.0	4.5

Plus (+) indicates rise in water levels

a/ Decline between 1933 to 1944.

Decline of water levels in wells in Katy rice-growing area

Waller County

Well	Depth of well (feet)	Spring measurements					Fall measurements	
		1931 to 1944	1939 to 1944	1941 to 1942	1942 to 1943	1943 to 1944	Oct. 1942 to Nov. 1943	Nov. 1943 to Oct. 1944
223	767	11.9	5.4	+0.6	0.2	2.1	2.3	5.5
225	643	--	--	+2.1	0.8	3.1	7.1	26.3
235	175	14.3	5.4	+1.2	0.0	1.6	3.4	1.6
239	828	--	--	+2.0	+0.9	3.0	--	18.7
240	290	--	--	+0.4	+0.6	1.2	0.2	1.7
245	482	--	--	+0.7	+0.4	1.9	+2.2	27.4
246	926	--	--	+0.5	0.4	1.9	3.6	7.4
247	641	--	--	+0.7	--	--	2.5	7.0
252	246	--	--	+1.5	0.1	2.4	1.3	2.3

Plus (+) indicates rise in water levels.
a/ Decline between 1933 to 1944.

FLUCTUATION OF WATER LEVELS IN SHALLOW WELLS IN THE OUTCROP AREA OF WATER-BEARING SANDS

North and northwest of Houston in the outcrop area of the water-bearing sands the water levels in very shallow wells that draw from perched water respond quickly to heavy rains, especially in winter, an abrupt rise frequently being observed within a few hours after the rain. Such wells are also quickly affected by hot weather and drought, the water levels declining persistently and at a comparatively rapid rate during hot dry periods. On the other hand, the water levels in wells that are somewhat deeper and draw from the true water table are affected to some extent by rainfall and drought, but respond much more slowly, no material rise occurring in most cases for several weeks or months after a period of heavy rainfall; moreover, the rise is likely to be maintained for a considerable period of time thereafter even during moderate droughts. The water table wells are usually affected by heavy pumping of nearby irrigation wells whereas the perched water wells are not. Neither water table nor perched water wells have been affected by the discharge of gas into the water-bearing sands from the defective gas well in the Bammel field (see next section).

From 1941 to the fall of 1944 the water levels in the water table wells in the outcrop area north and northwest of Houston were from 5 to 10 feet higher than they were in 1939-40 (see fig. 10, well 29, p. 27), and in the few wells for which comparable records are available were as high or higher than they were in 1931-34. In localities affected by pumpage from nearby rice irrigation wells there was a decline of 5 to 15 feet during the summer months (see fig. 10, well 35, p. 27), which however was recovered during the winter. This indicates that during the period of record more water has been contributed to storage in the outcrop area (the ultimate source of the ground water supply of the Houston district) than has been withdrawn by movement down the dip toward the pumped area. A proportionately large part of the recharge occurred however during the abnormally wet year November 1940 to October 1941.

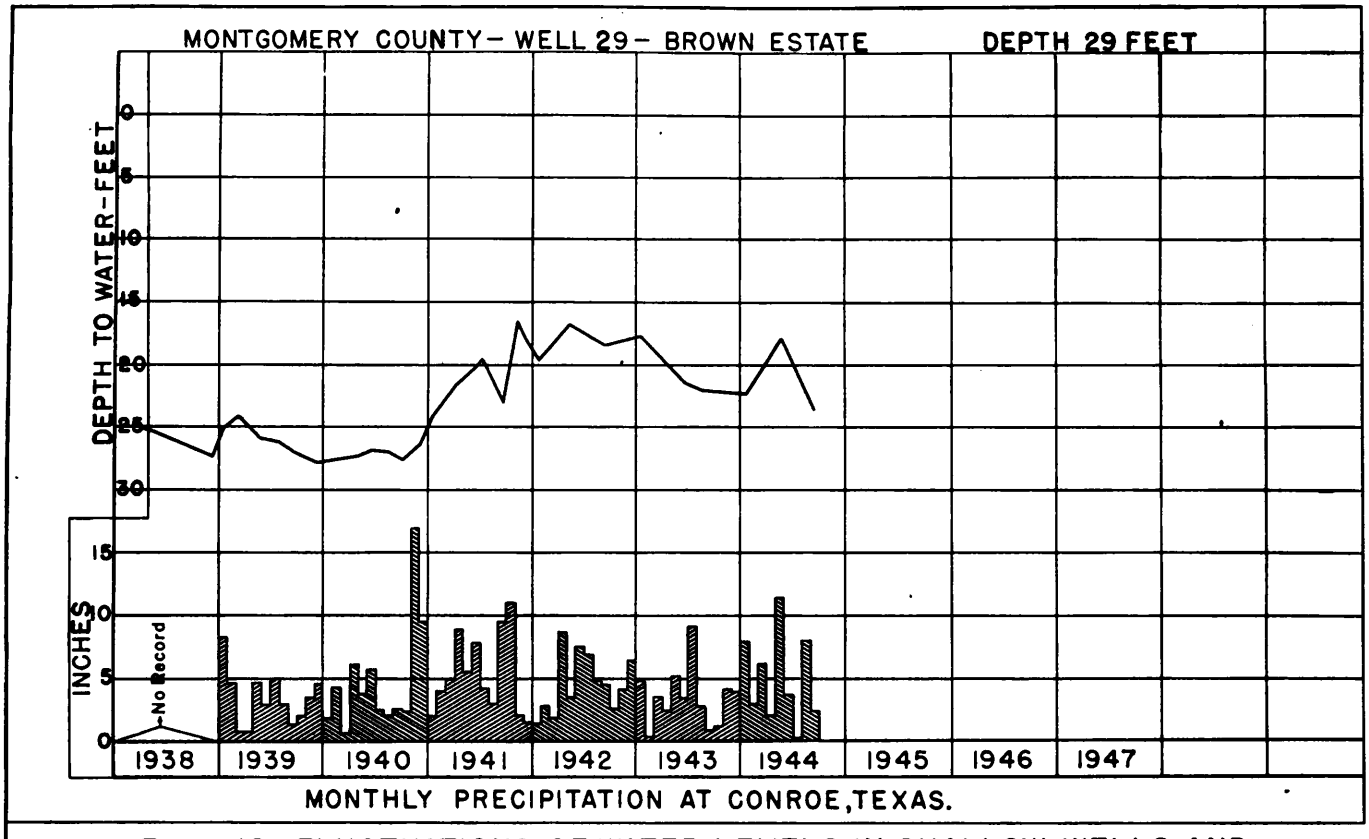
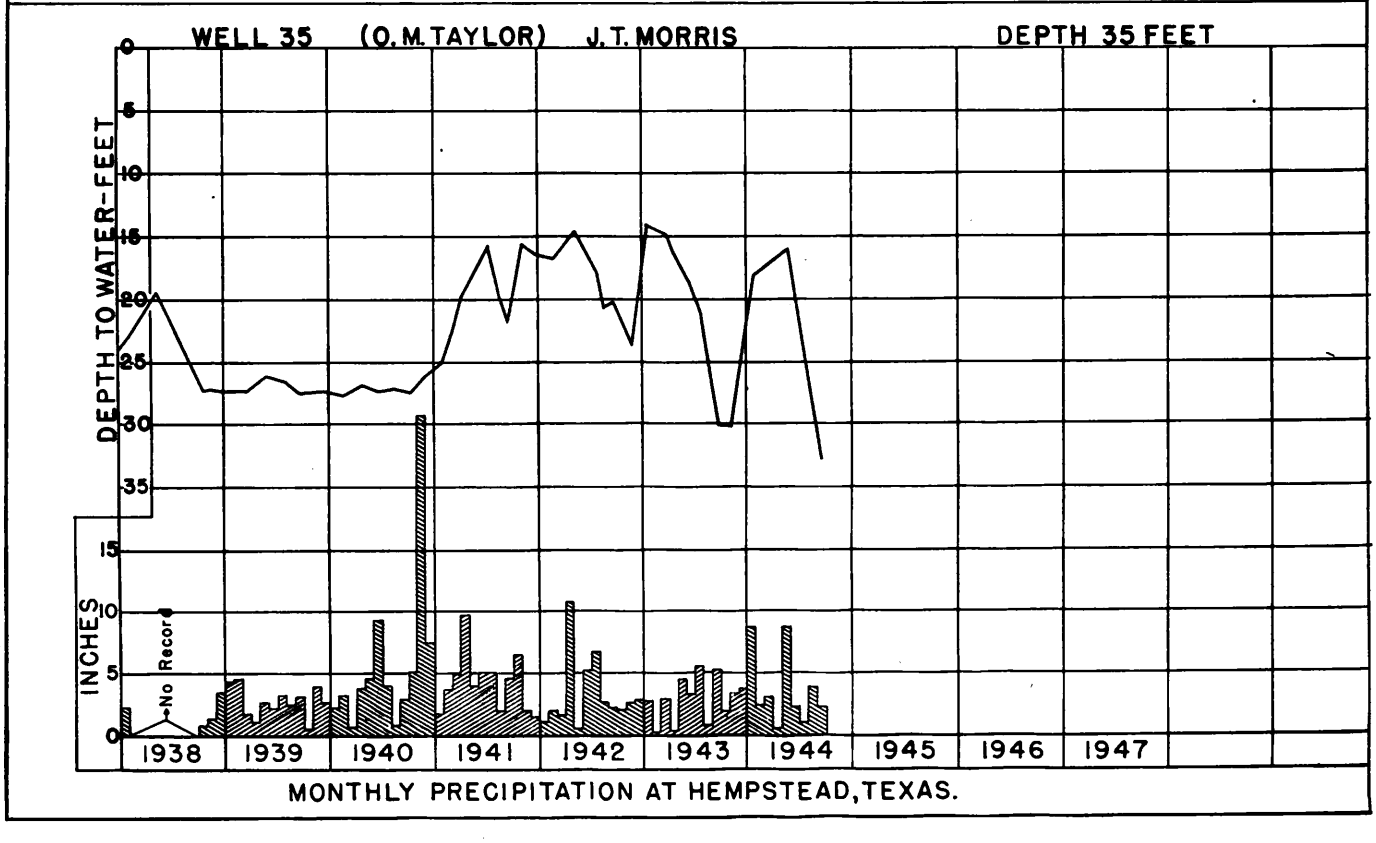


Figure 10 – FLUCTUATIONS OF WATER LEVELS IN SHALLOW WELLS AND PRECIPITATION IN OUTCROP AREA N. AND N.W. OF HOUSTON.



RELATION OF RISE IN WATER LEVELS TO THE ESCAPE OF GAS FROM A DEFECTIVE GAS WELL IN THE BAMMEL FIELD

The outstanding exception to the general downward trend of water levels in deep wells in the Houston district has occurred in an area roughly about 25 miles long and about 10 miles wide northwest of Houston where the water levels in most of the observation wells have shown a sharp upward trend since December 1942 (see fig. 1, p. 2). The rise in water levels was first noted in well 225 (depth 616 feet) at North Houston and well 268 at Westfield (depth 815 feet) when the measurements of December 1942 and January 1943 were compared, the net rise during the intervening period being 4.5 and 3.7 feet, respectively. A rise was next noted in August 1943 in well 221, 1.2 miles north of North Houston (depth 208 feet) and in well 264, 3.2 miles south of Westfield (screened at about 900 feet).

In August 1943 when about 50 water wells in northern Harris County were investigated it was found that several wells in and near the Bammel gas field which theretofore had been pumped were flowing and the water level in most of the wells within a radius of several miles of the gas field had risen sharply. Within a few days after the start of the investigation five water wells in the field started to crater. It was reported that one of the gas wells in the field had developed a leak in the casing at approximately 600 feet below the surface and was discharging gas into the water-bearing sands.

Most of the water wells in and near the field continued to flow for several months. They ceased flowing about April 1, 1944, and from then until the latter part of July 1944 the water levels in wells in the affected area that are less than 400 feet in depth steadily declined. (None of these wells are true water table wells. As mentioned on p.26 , neither perched-water nor true water-table wells were affected by the intrusion of gas.) From the latter part of July to November 2, 1944, the date of the latest measurement, the water level in wells less than 400 feet in depth have risen slowly. In the deeper wells the water levels rose steadily from December 1942 to September 20, 1944, except for a short period during the fall of 1943, and since September 1944 they have declined rapidly. The greatest total rise recorded from December 1942 to November 1944 was 61 feet in well 268 at Westfield (see fig. 11, p. 29).

Fairly complete records of water levels in wells 225 and 268 are available. Therefore, hydrographs of these two wells have been used as a basis for computing the relative amount of water that would have been required as recharge into the zone of water-bearing sands at a depth of about 400 to 750 feet at Bammel to have caused the rises in artesian pressure recorded in the two wells. Computations by means of the Theis non-equilibrium formula indicate that about 6 billion gallons of water would have been required as recharge to the sands to produce the rise in water level recorded in well 268 from December 1, 1942 to November 7, 1944. This amount of water is the equivalent of about 14 billion cubic feet of gas at a pressure of 250 pounds per square inch, which was the approximate pressure measured in a "relief" well about 300 feet west of the defective gas well. The computations show that the amount of gas discharged into this zone of sands increased from an average of about 7 million cubic feet a day from December 1, 1942 to April 1, 1943 to an average of about 39 million cubic feet a day from July 24 to August 30, 1944. The amount of gas being discharged into the "affected zone" has decreased sharply since August 30 and averaged only about 10 million cubic feet a day from November 2 to 7, 1944.

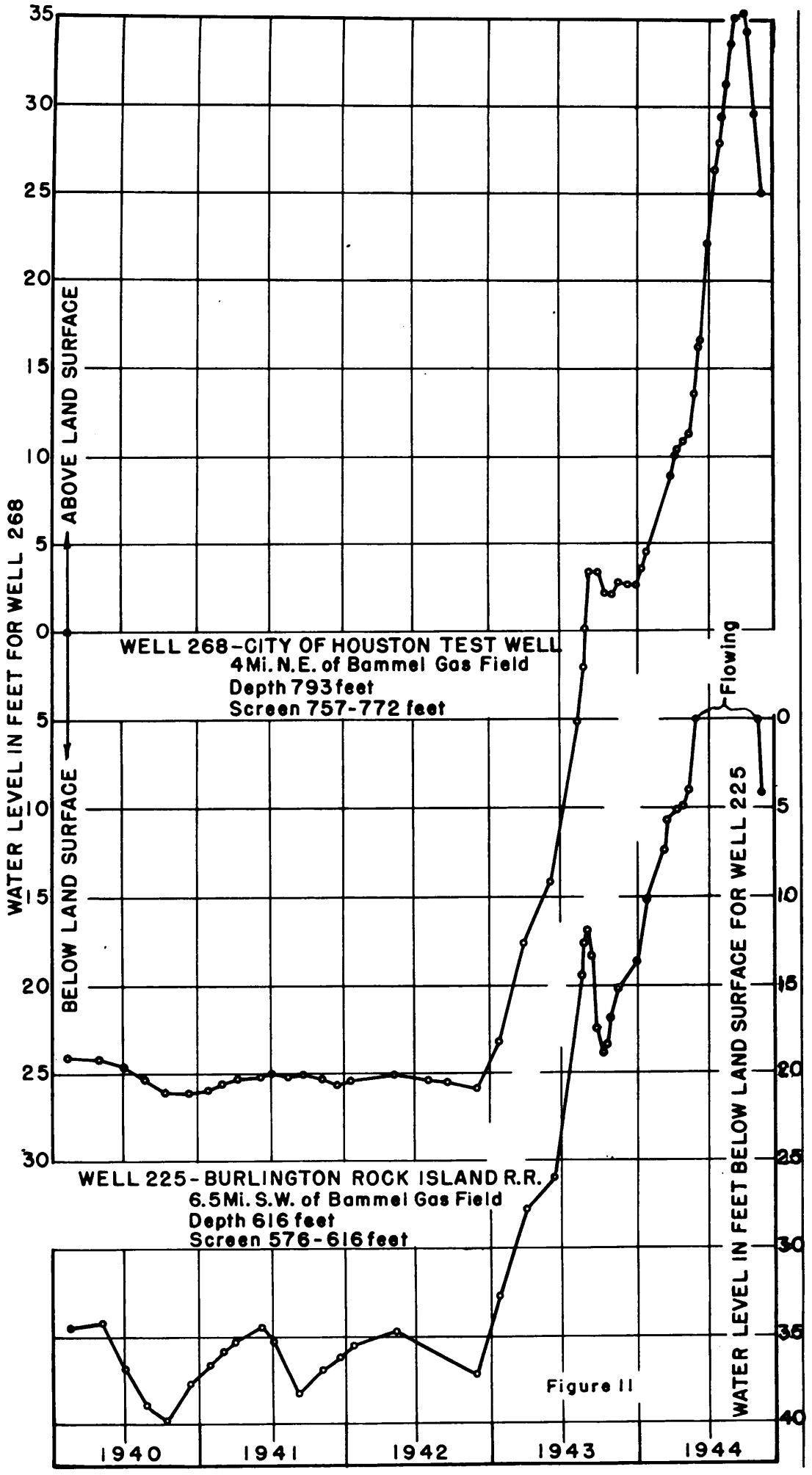

WELL 268-CITY OF HOUSTON TEST WELL
4 Mi. N.E. of Bammel Gas Field
Depth 793 feet
Screen 757-772 feet
WELL 225-BURLINGTON ROCK ISLAND R.R.
6.5 Mi. S.W. of Bammel Gas Field
Depth 616 feet
Screen 576-616 feet
ABOVE LAND SURFACE
BELOW LAND SURFACE
WATER LEVEL IN FEET FOR WELL 268
WATER LEVEL IN FEET BELOW LAND SURFACE FOR WELL 225
Flowing
35
30
25
20
15
10
5
0
5
10
15
20
25
30
0
5
10
15
20
25
30
35
40
1940
1941
1942
1943
1944

Figure 11

If 6 billion gallons of water has been completely displaced, the gas would have traveled about 2,400 feet from the defective well. It is believed, however, that complete displacement of the water and unwatering of the sands has occurred only to a limited extent, perhaps principally in the upper part of each sand.

The only effect that the leakage of gas at Bammel has had or is expected to have on the water-supply of the Houston and Pasadena areas is an increase in the artesian pressure in the zone of sands into which the gas has been discharged. This zone of sands extends down dip into the two areas and the depth to the top of the zone ranges from about 950 to 1,400 feet in Houston. The water level in an observation well at the Heights well field in Houston showed a rise of 4.5 feet from August 1943 to July 1944. The increase in pressure has probably reached other wells in Houston that draw from the "affected zone", but inasmuch as these wells are affected by their own pumping and that of nearby wells the amount of the increase due to the gas leakage cannot be estimated.

The discharge of gas into this zone of sands has disrupted to a degree the program of study in this part of the Houston district which has depended in considerable part upon the correlation of fluctuations in water levels with the pumpage. Inasmuch as recent water-level measurements indicate that gas is still being discharged into the water-bearing sands in the Bammel area it is impossible to estimate the length of time that will elapse before the water levels in the area return to normal.

CHEMICAL CHARACTER OF THE GROUND WATER

Samples of water have been collected periodically since 1931 from selected widely spaced wells and have been analyzed to determine whether there has been any change in the chemical character of the water, particularly any increase in chloride. According to these analyses, the latest of which were made in September 1943, there has been no significant change in the composition of the water in any of the wells from which the district obtains its supply.

In an effort to obtain more information concerning the depth to which water of good quality occurs at Houston, five samples of water were taken by the drill stem method in the test holes drilled in connection with the three city wells that were completed in 1943 and 1944. The well field, the number of the well, the depth from which the sample was taken, and the chloride, bicarbonate, sulphate, and total hardness as $CaCO_3$ in the water, in parts per million, are given in the following table:

Well field	Well	Depth of sampling (feet)	Chloride (Cl)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Hardness (as $CaCO_3$)
			In parts per million			
East end	2	1,915 to 1,965	89	486	4	16
East end	2	1,995 to 2,050	104	392	2	20
South end	7	1,892 to 1,930	87	380	3.9	40
South end	7	2,315 to 2,350	364	377	2	48
North East	3	2,025 to 2,050	100	376	3	25

The occurrence of fresh water in the deep sands, especially the comparatively low chloride to a depth of 2,350 feet, indicates that salt encroachment through vertical movement or from down dip through the sands tapped by wells in the heavily pumped area is rather remote.

TEMPERATURE OF GROUND WATER

The temperature of ground water has become increasingly important in the last few years because of the very large amount of water used for cooling and air conditioning. The temperature of the water from many of the wells in the Houston district has been recorded, but prior to 1944 no attempt had been made to determine the rate of increase in temperature with increasing depth.

Data presented by Darton 1/ and Van Orstrand 2/ show that the geothermal gradient of ground water varies widely from place to place and that the gradient may vary in rate at different depths. Some of the possible causes for these variations are: transfer of heat by migration of water near the surface of the ground, and in deep sands; variations in radioactivity, and in thermal conductivity of rocks; proximity to crystalline rocks; and proximity to geological structures, such as salt domes. Records of temperature of water from 61 artesian wells in Texas that range in depth from 403 to 3,330 feet show a variation in the rate of temperature increase from one degree to 21 1/2 feet to one degree to 271 feet. The mean annual temperatures were used as a basis for calculation 3/. The temperature of water from wells 25 to 50 feet or so in depth is usually about the same or slightly higher than the mean annual temperature of the locality.

1/ Darton, N. H., Geothermal data of the United States, U. S. Geol. Sur. Bulletin 701, 1920.

2/ Van Orstrand, C. E., Temperature gradients, Problems of petroleum geology, Amer. Assoc. Petr. Geol., pp. 989-1,021, 1934.

3/ Darton, N. H., op. cit., pp. 82-86.

A temperature survey of ground water in the Houston district was made in May 1944. A subsurface thermometer was run to obtain thermal gradients in two observation wells, wells 1229 and 1230. These two wells, which are about 135 feet apart, and were drilled by the City of Houston as test wells in 1939, are southeast of the city on the South Houston-La Porte highway, about three miles east of the town of South Houston. The casing in both wells has an outside diameter of 3 1/2 inches and the screens are set at 1,661 to 1,676 feet in well 1229 and at 1,339 to 1,414 feet in well 1230. The water level at the time of the survey was 139 feet below the land surface in well 1229 and 124 feet below the land surface in well 1230. The wells have not been pumped since 1939. The temperature readings in both wells were obtained with a Humble automatic recording instrument and were made by an engineer of the Production Department of the Humble Oil and Refining Company. The readings were recorded by a stylus on a chart that is enclosed in the instrument and is made to revolve by clockwork. The instrument was calibrated before and after the surveys were made and the maximum readings recorded were compared with the readings of three maximum registering thermometers encased in the end of the instrument. The temperatures thus recorded are believed to be within 1/2°F. of the true values. The readings were obtained by stopping the instrument at depth intervals of 50 feet and making one stop per minute while it was being lowered into the well and repeating the process while it was being withdrawn. The first and last reading was taken at a depth of 150 feet, which was a short distance below the water level. The temperatures given on graph 1 in figure 12, page 35 are the mean of the going-in and coming-out readings.

As shown by graph 1 in figure 12, page 35 there is a close agreement between the temperature gradients in the two wells. Based on a standard of mean annual temperature of air at Houston which is 69.2°F, plus (+) a constant of 1°F to correct for soil temperature over air temperature 4/ the gradient from an average of the readings taken in well 1229 is 97.4 feet in depth to one degree increase in temperature and in well 1230 is 96.0 feet in depth to one degree increase in temperature.

4/ Van Orstrand, C. E., Temperature in some springs and geysers in Yellowstone National Park, The Journal of Geology, vol. 32, no. 3, pp. 221 and 215, April-May, 1924.

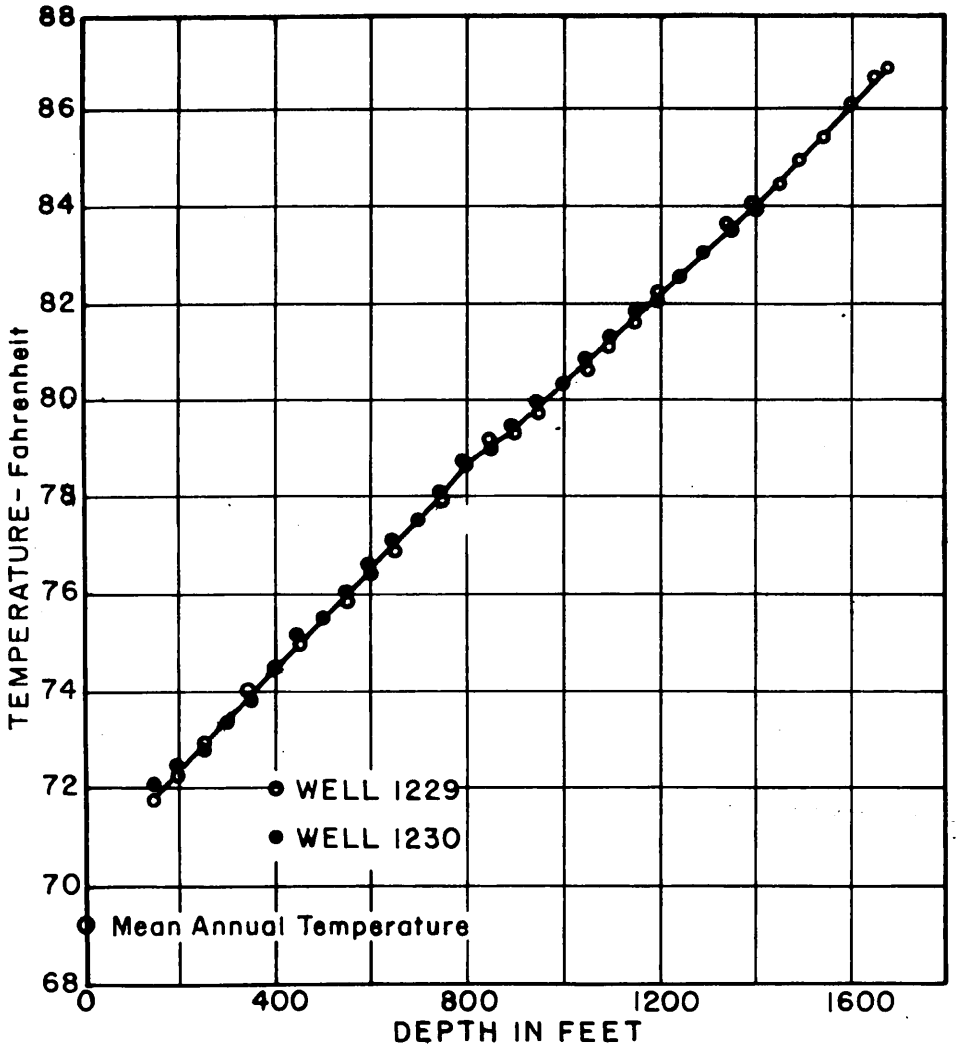
In an effort to correlate the temperature gradients in these wells with those of water discharged from pumped wells, observations were made on 26 pumped wells in the district ranging in depth from 65 to 1,618 feet. Most of these wells (about 20) have only one section of screen, and in calculating the thermal gradient the middle of the screen section was considered to be the point of entry of the water into the well. The wells were pumped for at least 20 minutes before the temperature readings were made. Two mercury thermometers were used, a standard chemical thermometer with enclosed paper scale and a standard 6-inch thermometer. Both thermometers were readable to half a degree; the chemical thermometer is considered accurate to 1/2 degree and the other to one degree.

The following table gives the well number; the name of the owner; depth of the well; depth to the top and bottom of the screen section; observed temperature of the water pumped from the well, in degrees Fahrenheit; and geothermal gradient, in depth in feet for one degree increase in temperature. The gradients are based on 70.2°F. (mean annual air temperature of 69.2°F. plus (+) 1°F.).

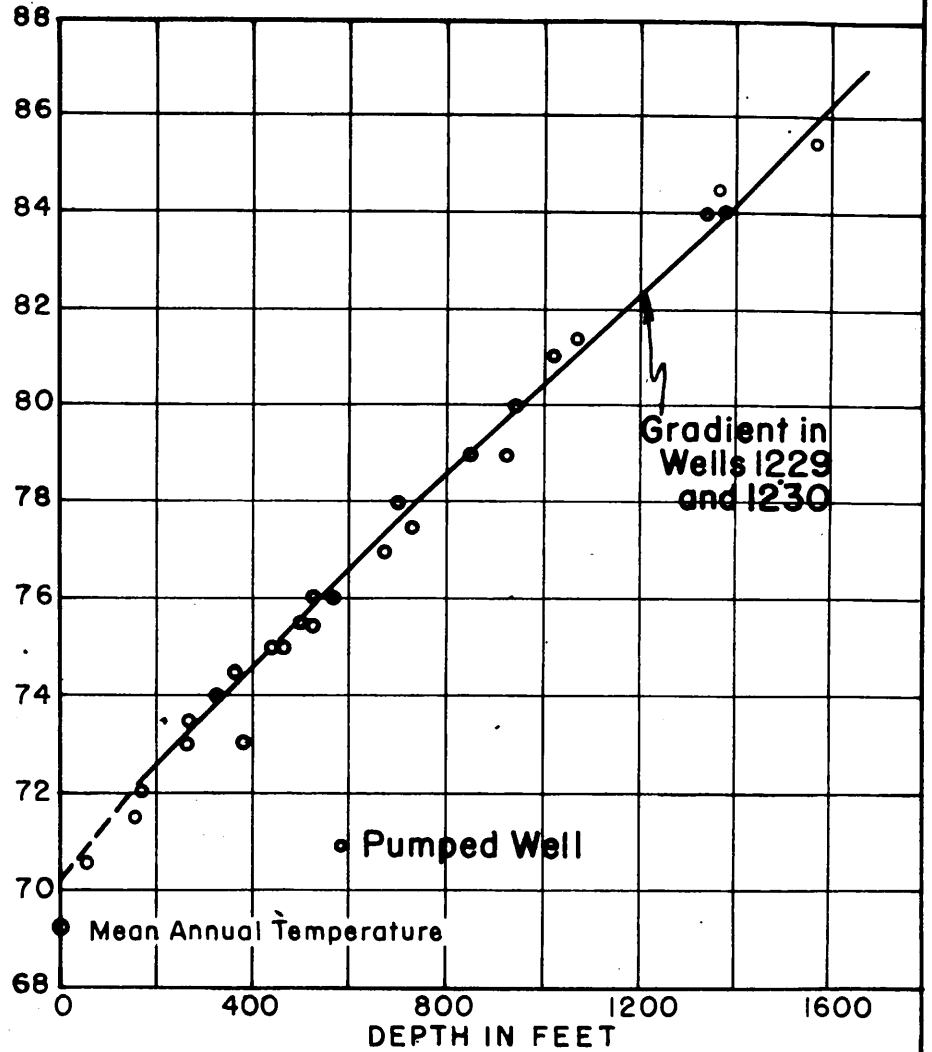
Temperature 3

Well	Owner	Total depth (feet)	Depth to top and bottom of screen (feet)	Observed temperature	Depth in feet for one degree increase in temperature above 70.2° a/
--	R. H. Goodrich	65	55 to 65	70.5	200.0
80a	Victor Theiss	165	16[illegible] to 165	71.5	125.3
534	R. H. Goodrich	186	166 to 186	72.0	97.8
65	City of Tomball	293	248 to 293	73.0	96.5
1409	Texas Water Company	411	372 to 411	73.0	140.0
865	Texas Ice and Fuel Company	272	252 to 272	73.5	79.4
866	do.	401	252 to 401	74.0	85.6
765	Seven-up Bottling Company	388	340 to 386	74.5	84.5
1242	Foster Place	475	427 to 455	75.0	92.0
1241	Hinderliter Tool Company	457	437 to 457	75.0	93.2
1243	Foster Place	531	500 to 530	75.5	97.2
1277	Texas Water Company	544	494 to 544	75.5	98.0
1104	City of LaPorte	570	500 to 570	76.0	92.3
1387	Pittsburg Plate Glass Company	638	514 to 626	76.0	98.3
840	City of Bellaire	827	651 to 708	77.0	100.5
1406	Harris County Water Control District No. 2	853	626 to 843	77.5	99.8
780	Hollyfield Laundry	727	686 to 724	78.0	90.5
644	Esperson Building	900	825 to 885	79.0	97.1
640	Oil and Gas Building	986	903 to 966	79.0	106.2
1266	City of Southside Place	998	911 to 988	80.0	97.0
269	City of Houston	1,031	1,016 to 1,031	81.1	94.9
--	City of Pasadena	1,203	934 to 1,199	81.5	94.5
728	Burkhardt Laundry	1,402	1,358 to 1,402	84.0	100.0
620	Public Laundries	1,379	1,310 to 1,377	84.0	97.4
732	Gould Laundry	1,391	1,347 to 1,391	84.5	95.8
736	Houston Packing Company	1,618	1,537 to 1,617	85.5	103.0

a/ Mean annual air temperature plus one degree.



GRAPH-A: Geothermal gradient from subsurface temperature readings in wells 1229 & 1230



GRAPH-B: Relation of observations of temperature from 26 pumped wells with the geothermal gradient in wells 1229 & 1230

Figure 12

In general the geothermal gradients of the wells shown in the table are rather uniform. A few of the wells that are less than 400 feet in depth show a rather large variation from the average. This may be explained in part by the fact that a fraction of a degree of temperature, which is beyond the accuracy of the readings, would make a substantial difference in the calculated gradient. The variations of the gradients in the wells over 400 feet in depth are relatively small. The average temperature gradient of 25 of the 26 wells is 98.0 feet per degree of increase in temperature, and is closely comparable with the average gradient of 96.7 recorded in wells 1229 and 1230 (see graph B, figure 12). The shallow well that has a gradient of 200 was not included in the average because a fraction of a degree in temperature could cause too great a change in the calculated gradient. Based on the results of these studies a geothermal gradient of approximately 97 feet in depth per degree of increase in temperature should be applicable to the water-bearing sands in the Houston district to a depth of 1,800 feet.

SUMMARY

The results of the investigation of the ground-water resources of the Houston district since January 1942 are consistent with those recorded in former years and discussed in considerable detail in previous reports.

Since January 1942 about 66 new wells have been drilled in the district for municipal and industrial supply, and for the irrigation of rice. In connection with the program of new development of the public supply by the City of Houston the drilling of six new wells at the new Southwest well field will begin about December 1, 1944. These wells will be spaced about 1,800 feet apart in an east-west line. It is planned to draw about 2,100 gallons a minute from each well.

There has been a general increase in the withdrawals by wells in the Houston and Pasadena areas since 1942. The average daily pumpage in those areas was 85,000,000 in 1942 and 94,000,000 in 1943, and is expected to be about 106,000,000 gallons in 1944. This large increase in the rate of pumping has caused an acceleration in the decline of water levels throughout both areas, the average decline in the observation wells based on measurements in the spring being 8.7 feet in 1942-43 and 10.3 feet in 1943-44. From September 1943 to September 1944 the decline averaged 13.6. A comparison of the water levels in the spring of 1945 with those of the corresponding period in 1944 is expected to show a still higher rate of decline because of the large increase in withdrawals in 1944 which are estimated to be about 12,000,000 gallons a day more than they were in 1943.

In the Katy rice-growing area the number of acres under irrigation has steadily increased from about 8,000 in 1935 to about 31,740 in 1944. The total amount of water applied to the land per acre each year during this period, including rainfall during the growing season, has been remarkably uniform, but due to the variations in the rainfall the pumpage in acre feet per acre varied widely. The total annual pumpage for rice irrigation in 1941, 1942, 1943, and 1944 was 25,800, 43,000, 58,000, and 64,000 acre feet, respectively. As a result of the relatively small pumpage and the unusually heavy recharge in 1941 there was an average rise of water levels in the irrigation wells of 2.1 feet between the springs of 1941 and 1942. The water levels in the spring of 1943 showed little change from those in the spring of 1942. From the spring of 1943 to the spring of 1944 the water levels showed an average decline of 1.6 feet as the result of the increase in the rate of withdrawal in 1943 over that in 1942. There was an average decline of 4.2 from the fall of 1943 to the fall of 1944.

The water levels in the water-table wells in the outcrop area of the water-bearing sands north and northwest of Houston were from 5 to 10 feet higher from 1941 to the fall of 1944 than they were in 1939-40, and in the few wells for which comparable records are available were as high or higher than they were in 1931-34. This indicates that during the period of record more water has been contributed to storage in the outcrop area (the ultimate source of the water pumped from the wells of the Houston district) than has been withdrawn by movement down dip toward the pumped areas. A proportionately large part of the recharge occurred, however, during the abnormally wet year November 1940 to October 1941.

The outstanding exception to the general downward trend of water levels in deep wells of the Houston district has occurred in an area roughly about 25 miles long and 10 miles wide northwest of Houston where the water levels in most of the observation wells have shown a sharp upward trend since December 1942. This phenomenal rise in water levels is due to the discharge of gas into the water-bearing sands from a defective gas well in the Bammel field. Computations by means of the non-equilibrium formula show that about 6 billion gallons of water or an equivalent of 14 billion cubic feet of gas at a pressure of 250 pounds per square inch would be required as recharge to the water-bearing sands to produce the rise recorded in an observation well at Westfield from December 1, 1942 to November 7, 1944. The only effect that this discharge of gas into the water-bearing sands has had or is expected to have on the water supply of the Houston, Pasadena, and Katy areas is an increase in the artesian pressure in the zone of sands into which the gas has been discharged.

The periodic analyses of water samples from selected observation wells in September 1943, like those of former years, show no significant change in the chemical character of the water and give no evidence of the intrusion of salt water into the fresh water-bearing sands of the district.

The compilation of data from a subsurface temperature survey in two unused deep wells and from observations of temperature of the discharge from 26 pumped wells show that a geothermal gradient of approximately 97 feet in depth to one degree increase in temperature should be applicable to the water-bearing sands in the district to a depth of about 1,800 feet.