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TEXAS BOARD OF WATER ENGINEERS

GROUND-WATER RESOURCES
OF THE
HOUSTON DISTRICT, TEXAS
PROGRESS REPORT FOR 1946

BY

J. W. LANG

WITH SECTION ON RESULTS OF PUMPING TESTS AT
NEW SOUTHWEST PUMPING PLANT

BY

J. W. LANG AND R. W. SUNDSTROM

PREPARED IN COOPERATION WITH THE UNITED STATES
DEPARTMENT OF THE INTERIOR, GEOLOGICAL SURVEY,
AND THE CITY OF HOUSTON

DECEMBER 1946

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INTRODUCTION

Location of the area and history of ground-water studies

The Houston district, as the term is used in this report, comprises Harris County west of the San Jacinto River and adjoining parts of Montgomery, Waller, and Fort Bend Counties (see fig. 1). In this district large quantities of ground water are pumped from three areas as follows: The Houston pumping area, which includes the City of Houston and the adjoining territory, except that to the east; the Pasadena pumping area, which includes the industrial section that extends along the ship-channel from the Houston city limits eastward to Deer Park; and the Katy pumping area, an irregularly-shaped area of several hundred square miles in the western part of Harris County, northern part of Fort Bend County and southeastern part of Waller County in which water is pumped from wells for the irrigation of rice.

Beginning in December 1930 the Geological Survey, U. S. Department of the Interior, in cooperation with the Texas State Board of Water Engineers, has carried on a program of ground-water studies in the Houston district when available funds have permitted. These studies have been under the direction of W. N. White, district 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 studies was begun, the work has been carried on in cooperation with the City of Houston.

Field operations since December 1944

Field operations in the Houston district since the last progress report was issued in November 1944 are briefly described below:

Records of the volume of water pumped from wells throughout the district were collected for 1944, 1945 and 1946.

Measurements of water levels in 241 observation wells (see maps, figs. 1 and 2) were made at intervals ranging from one month to six months. Ninety-two of the wells, including 26 belonging to the Houston municipal system, are in the Houston and Pasadena-Ship Channel areas, 41 in the Katy rice-growing area, 12 in the areas south and west of Houston, and 96 in areas north and northwest of Houston, including the outcrop area of the water-bearing sands.

Maps were prepared for 1945 and 1946, 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 30 selected observation wells were collected each year and analyzed.

Pumping tests were made in November 1945 on six wells constructed by the City of Houston in its new Southwest well field, to determine coefficients of storage and transmissibility of the sands from which the wells draw water. By using average values for the coefficients obtained from the tests, computations were made of the future pumping levels to be expected under various assumed conditions of pumping.

From December 1944 to September 1945 the field operations were directed by N. A. Rose, who was then with the Geological Survey, but he has since resigned to go into private practice at Houston. Since September 1945 the work has been under the direction of the writer.

Previous reports

Fifteen reports and technical papers have been published, giving the results of investigations in the Houston district by the Geological Survey in cooperation with the State Board of Water Engineers and the City of Houston, as follows:

Water-supply papers

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

Mimeographed progress reports

Ground-water resources of the Houston-Galveston area, Texas, U. S. Department of the Interior, 1932.

Progress reports on the ground-water resources of the Houston district, Texas, State Board of Water Engineers, 1937, 1939, 1940, 1942, and 1944.

Special reports and technical papers

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. 1081-1101, Aug. 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), May 1943.

Special reports and technical papers -- Continued

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.: Bull. Amer. Assoc. Petrol. Geol., vol. 29, No.3, pp. 253-279, Mar. 1945.

Quantitative studies of some artesian aquifers in Texas, by W. F. Guyton and N. A. Rose: Econ. Geol., vol. 40, No. 3, pp. 193-226, May 1945.

Results of pumping test at new Southwest plant, Houston, Texas, by J. W. Lang and R. W. Sundstrom; U. S. Geol. Survey and Texas State Board of Water Engineers (typewritten), Feb. 1946.

In addition, the results of water-level measurements in observation wells of the Houston district from 1931 to 1943 have been published in Water-Supply Papers 777, 840, 886, 909, 939, 947, and 989 of the U. S. Geological Survey.

RECENT DEVELOPMENT OF GROUND WATER

From December 1944 to June 1946, 49 new wells of large capacity were drilled in the Houston district, of which 14 were drilled for industrial use, 20 for rice irrigation, and 15 for the public supply of districts and municipalities. Of the 14 industrial wells 10, including four replacements, were drilled to supply existing industrial plants and four were drilled to supply two new plants. Of the 20 new irrigation wells 17, including four replacements, were drilled in the Katy district and the other three were drilled in widely-separated areas southwest, southeast, and northwest of Houston. Of the 15 wells developed for public supply seven were drilled for the City of Houston and eight for water districts and small municipalities in the suburban areas around Houston and Pasadena. Six of the city wells were drilled and developed in the Southwest well field and one at the Central plant. One well (no. 1) at the Southwest field was put into regular operation in July 1945. The other six were put into operation in the winter or early spring of 1946.

In developing the six new wells at the Southwest field, an exploratory hole first was sunk at each well site and an electrical log was made for each to check the driller's log and serve as a guide for completing the well. These holes, identified as numbers 1 to 6, inclusive, were sunk to depths of 2,474, 1,505, 1,502, 1,500, 1,397, and 2,515 feet, respectively. Samples of water from the deeper sands in test holes 1 and 6 were collected and analyzed. The production wells were then drilled to depths ranging from 1,380 to 1,520 feet. Finally the wells were cased and screened. An average of about 400 feet of sands was screened in each well, all below a depth of 550 feet. Each well is equipped with a pump designed to produce 2,100 gallons a minute, which is believed by the city engineers to be the most economical rate of operation. Pumping tests have shown, however, that the wells are capable of yielding considerably more than that amount.

A similar procedure was followed in constructing the new well at the Central plant. An exploratory hole was sunk to a depth of 2,495 feet, and the production well was completed at 2,025 feet. The well yields about 2,300 gallons a minute.

In connection with its program of new development the City has awarded a contract for the drilling of two additional wells at the Southwest well field, extending the present line of wells westward. An exploratory hole will be drilled to a depth of about 2,500 feet at the site of proposed well No. 8, about 5,000 feet west of well 6 at the west end of the present line, and samples of water will be collected from the deeper sands for analysis. Electrical logs will be made for each well.

Prior to 1940 most of the irrigation wells of the Katy area were within 10 or 12 miles of Katy. In recent years, however, the boundaries of the district have expanded materially, reaching north and northwest beyond the Houston-Hempstead highway, for example. One of the new irrigation wells, about 10 miles northwest of Katy, was drilled to a depth of 2,350 feet. The owner reports that all the sands penetrated by the well are screened and that it has a yield of 3,200 gallons a minute.

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 yield more than 5,000 gallons a day have been compiled for the years 1930, 1935, 1937, and 1939 to 1946 inclusive.

In 1946 practically all the ground water used in the Houston and Pasadena areas was pumped from about 300 wells. Accurate production figures were obtained from meter records for 72 wells, which contributed about 65 percent of the supply. Less accurate but fairly good figures for 85 of the wells were obtained from discharge ratings and the length of time the pumps were operated. These wells contributed about 20 percent of the supply. Records for the remaining wells were poor and the pumpage had to be estimated.

In the Katy area the estimates of pumpage from the irrigation wells since 1930 have been based on the number of acres irrigated from each well, on the amount of current used by the electrically-operated wells, and on the results of measurements of discharge of water from about 30 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 1946, 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	1945	1946
Houston Water Department (from City records)	25.8	24.5	25.2	27.2	28.8	27.2	30.5	35.2	39.5b/	43.2	51.3d/
Houston independent public water supplies and industrial wells	11	14	16	16	17	16	18	20	21	21	21d/
Pasadena industrial wells	10	10	29	29	33	34	36	39	47b/	48	47d/
Total for the Houston and Pasadena areas	50	49	70	72	79	77	85	94	108b/	112	119d/
Katy irrigation wells	18	14	30	40	45	23	38	52	55c/	50c/	58c/
Total for the district	68	63	100	112	124	100	123	146	163b/	162	177

a/ The rice wells are pumped only during the season that 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 compilation and in order that comparisons may be made the total withdrawals in all three areas are given as daily averages for the entire year.

b/ Figures in 1944 progress report as corrected.

c/ For the Katy area the figures are based on a pumpage in 1944 of 1.9 acre-feet per acre for 31,740 acres and on the current used by 58 electrically operated wells; in 1945 a pumpage of 1.6 acre-feet per acre for 34,324 acres and the current used by 68 electrically operated wells; and in 1946 an estimated pumpage of 1.8 acre-feet per acre for 37,530 acres.

d/ Figures for 1946 are based on records of pumpage through November and estimates for December. The Houston City pumpage in 1946 included 1,024 acre-feet sold at the Southwest plant to irrigate rice.

HOUSTON AND PASADENA PUMPING AREAS

Pumpage

As shown by the above table the estimated average withdrawal of ground water in the Houston and Pasadena areas reached 119,000,000 gallons a day in 1946, as compared with 112,000,000 gallons in 1945, 108,000,000 gallons in 1944, 94,000,000 gallons in 1943, 85,000,000 gallons in 1942, and 77,000,000 gallons in 1941. In the spring and summer of 1945 the rate of withdrawal was higher than it was during the corresponding seasons in 1944 but in the fall and early winter the pumpage declined considerably owing to a curtailment of activity in several large plants producing war goods, and to industrial disturbances. Starting with the spring of 1946, however, industrial activity was again accelerated, industrial and municipal demands for water increased, and the total withdrawals for the year were higher than ever before.

Pumpage by the city, which is included in the above figures, averaged 51,300,000 gallons a day through November 1946 as compared with 43,200,000 gallons in 1945, 39,500,000 gallons in 1944, 35,200,000 gallons in 1943, 30,500,000 gallons in 1942, and 27,200,000 gallons in 1941. The daily average during August amounted to 66,241,000 gallons of which 9,087,000 gallons a day was sold by the city for the irrigation of rice. This surpassed the average for any previous month on record.

In 1946 the Water Department of the City of Houston operated 26 wells in seven well fields widely spaced over the city (see fig. 2, p. 36). The average daily pumpage from the wells of each well field in 1935 and from 1938 to 1946, inclusive, is given in the following table:

Average daily pumpage by Water Department of the City of Houston

Well Field	1935	1938	1939	1940	1941	1942	1943	1944	1945	1946a/
	Thousands of gallons a day									
Central	5,122	5,977	5,780	5,997	5,380	6,320	8,408	9,367	8,642	7,437
Heights	5,159	4,218	5,142	5,242	5,220	5,460	5,743	6,408	7,925	8,925
Scott Street	7,822	4,998	5,653	7,587	7,600	7,620	8,350	7,657	5,777	6,466
South End	4,651	5,817	6,600	6,143	5,550	6,330	6,019	7,862	9,809	6,725
East End	-	1,451	1,417	1,517	1,350	1,600	1,724	2,789	3,220	3,678
North East	510	2,380	2,417	2,321	2,170	3,110	4,789	5,413	6,244	5,221
Magnolia Park	1,104	128	221	49	210	-	114	-	-	-
Southwest	-	-	-	-	-	-	-	-	1,570	12,880
TOTAL	24,362	24,969	27,200	28,800	27,200	30,500	35,147	39,495	43,187	51,315

a/ Through November. The pumpage at Southwest includes 1,024 acre-feet sold to a private individual for the irrigation of rice.

The Magnolia Park well field was discontinued after 1943. The average daily pumpage at the new Southwest plant in 1945 was low because the plant was not completed until late in the summer, only one well was in operation from July 1 to October 16, the plant was shut down for repairs from October 16 to November 20, and only two wells were pumped during the remainder of the year.

The estimated total average daily withdrawal of ground water for public water supply and industrial use in the Houston and Pasadena areas during 1945 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 different classes of industries that use the most water.

Estimated average daily pumpage for public and industrial supply in the Houston and Pasadena areas in 1945

	Number of plants	Number of wells	Daily pumpage (million gallons a day)
Houston Water Department	7	26	43.2
Paper mill	1	8	18.1
Oil refineries 1/	9	24	17.8
Independent public water supplies	42	64	4.7
Ice plants	18	26	4.4
Railroads and allied plants	12	16	2.3
Tool and armament plants	5	8	2.7
Synthetic rubber plants 2/	2	3	3.4
Office buildings, hotels and theatres	24	26	1.7
Ship yards	2	5	1.2
Steel mill	1	7	4.9
Power plants	3	5	2.1
Country clubs	6	9	1.0
Meat packing plants	4	7	1.1
Laundries	12	12	0.8
Miscellaneous industrial plants using more than 5,000 gallons a day	46	52	3.4
Total	194	298	112.8

1/ Three refineries used a total average of about 3.5 million gallons a day of surface water, which was supplied from the San Jacinto River.

2/ 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

With the increase in pumping in the Houston and Pasadena areas from 77,000,000 gallons a day in 1941 to 112,000.000 in 1945 (see p. 5) the general decline of water levels in the wells, which began in 1937, continued at an accelerated rate during 1942, 1943, 1944, and the first eight months of 1945. During the fall of 1945 and the winter of 1945-46, however, following some curtailment in the operation of several of the industrial plants, a marked reduction in the average rate of decline occurred in the Pasadena and eastern Houston areas and a pronounced rise occurred in several wells (see hydrographs, figs. 3, 4, and 5, pp. 37, 38, and 39).

In the observation wells that are screened opposite the heavily-pumped sands at Houston and Pasadena and in the area west of Houston the average decline from the spring of 1942 to the spring of 1945 was 27.5 feet. The largest average decline, amounting to 39 feet in 22 observation wells, occurred in the eastern Houston and Pasadena - Ship Channel areas, where the increase in pumping was the heaviest. As a result of the decrease in pumping in the fall and winter of 1945-46, mentioned above, 10 of the wells had only a small net decline and 12 of them had a pronounced rise between spring measurements in 1945 and 1946, the mean for the 21 wells showing a rise of 2.0 feet. The net average decline for the 21 wells in this area, therefore, amounted to 37 feet between 1942 and 1946. In the northern, central, and western parts of Houston, and in the locality west of the City, there was an average decline of 7.5 feet between spring measurements in 1945 and 1946, as compared to an average decline of 5.5 feet during the corresponding period in 1944-45. In the locality north of Houston the water level had an average decline of 5.2 feet between 1945 and 1946, as compared with 4.2 feet between 1944 and 1945. Therefore, although there was some recovery during 1945-46 in the deeper parts of the cone of depression centering around Pasadena, the water levels in the surrounding areas along the periphery of the cone continued to drop and the cone continued to expand (see maps, figs. 9, 10,and 11, pp. 43, 44, and 45).

With renewal of pumping activity in 1946 resulting in an all time record breaking average pumpage of 119,000,000 gallons a day, the decline in water levels has been resumed at an accelerated rate, and the spring measurements in 1947 are expected to show a substantial net decline below those of 1946.

The decline of water levels from 1931 to the spring of 1946 in observation wells screened opposite the heavily pumped sands in Houston, Pasadena and the adjacent localities is shown in the table that follows:

Decline of water levels in wells screened opposite the heavily-pumped sands in the Houston, Pasadena and adjacent localities, in feet, 1931-1946, (based on spring measurements) (For location of wells, see figs. 1 and 2)

Vicinity of Pasadena

Well	Distance from Pasadena (miles)	Depth of well (ft.)	1931 to 1937	1937 to 1940	1940 to 1941	1941 to 1942	1942 to 1943	1943 to 1944	1944 to 1945	1945 to 1946	1940 to 1946	1937 to 1946	1931 to 1946	1946 to 1947
1182	½ N	685	-	-	20.9	2.8	13.8	21.8	26.3	+12.5	67.6	-	-	20.9
1170	1½ NW	836	-	51.0	6.5	4.5	16.0	14.0	26.0	+ 9.0	45.0	108.8	110.2	
1161	2 W	1,228	-	38.5	13.9	+0.3	14.6	16.2	24.3	+ 5.5	63.2	111.5	-	
1150	2½ NW	680	-	-	13.0	2.7	12.9	20.3	22.4	+ 7.9	64.4	100.2		18.1
1420	2½ NW	740	-	-	-	-	-	-	20.7	+ 7.4	-	-	-	18.8
883	3½ W	841	-	11.2	12.4	3.8	12.1	20.7	22.6	+10.4	61.1	-	-	21.2
1374	4 N	753	-	-	-	-	-	-	21.7	-	-	-	-	~~XX~~
1229	4 S	1,680	-	-	14.6	2.0	3.3	6.3	15.4	8.7	52.4	-	-	10.7
1230	4 S	1,419	-	-	13.0	6.3	7.2	9.8	16.7	3.8	53.0	-	-	13.7
1124	5½ E	1,329	-	-	-	8.0	12.0	7.0	19.2	0.4	-	-		
1126	5½ E	509	-	-	-	19.0	3.0	7 5	8.0	+ 9.2	-	-		
936	6 N	619	-	-	-	-	8.0	7.0	14.5	2.4	-	-		
1302	6½ S	832	-	27.3	7.5	4.0	6.7	12.2	11.9	4.8	46.6	-	78.8	6.8
933	7½ N	850	-	-	7.4	3.2	3.4	9.5	13.3	4.6	41.4	-	-	8.4
1100	7 E	900	-	-	2.9	10.4	11.0	5.6	6.2	+0.6	35.6	-	72.4	6.5
905	7½ SW	1,900±	-	3.1	-	-	-	-	-	-	37.3	-	51.5	~~[illegible]~~
1117	9 SE	526	-	-	-	-	-	-	6.9	0.3	28.5	-	-	3.5
1121	9 SE	580	-	-	-	-	-	-	4.8	0.7	27.4	-	-	4.1
943	9 NE	434	-	-	-	-	-	-	4.4	+0.2	-	-	-	3.3
1418	9½ S	1,348	-	-	-	-	-	-	9.8	4.8	-	-	-	7.6
947	10½ NE	312	-	-	-	-	-	-	3.6	2.0	14.2	-	-	1.6
1104	12 SE	570	-	-	-	3.4	15.4	2.7	5 0	1.0	-	-	54.5	4.0
1360	13½ SE	659	-	6.8	1.9	-	-	-	7.5	2.5	31.6	-	55.2	0.5
1019	14 E	450	-	0.8	2.2	11.9	-	-	4.7	0.0	28.7	-	-	2.5
Eastern Houston														
881	4½ W	650	7.5	30.8	7.8	4.0	13.0	20.7	17.6	+12.1	51.1	72.5	80.0	19.0
878	5 W	905	10.4	37.7	8.7	3.0	12.7	16.0	16.8	+ 1.8	53.2	76.6	87.0	16.4
913	5½ W	876	-	13.6	8.0	3.9	10.0	14.0	13.7	+ 1.7	46.1	64.0	-	15.5
759	5½ NW	569	14.8	32.3	5.8	4.7	9.6	13.7	13.3	+ 0.9	46.3	70.1	84.9	15.6
879	5½ W	-	-	7.3	1.7	1.6	-	-	-	+ 7.9	48.8	-	-	15.4
876	6½ W	- -	8.1	15.2	5.8	3.5	13.6	15.4	12.0	+ 4.4	44.9	61.4	69.5	15.7
757	6½ NW	676	12.0	29.7	4.2	3.0	15.6	13.0	10.3	1.9	44.9	68.8	80.8	14.1
751	7 NW	540	8.7	29.1	6.2	2.9	11.1	9.8	10.6	3.1	43.6	65.4	74.1	12.9
748	7½ NW	721	-	-	6.1	2.5	10.2	11.2	10.0	4.8	44.8	-	72.4	13.5
Northern Houston														
662	10 NW	834	-	25.9	+0.3	2.2	20.8	5.4	-	-	22.2	-	54.9	30.0
663	10 NW	740	-	7.4	1.3	3.7	2.8	1.0	5.2	2.6	16.7	-	31.9	3.3
1422	11 NW	-	-	-	-	-	-	-	2.5	5.2	-	-	-	14.0
1398	11 NW	574	-	-	-	-	-	-	3.4	4.8	-	-	-	~~XX~~
656	11½ NW	665	5.4	27.0	3.9	1.5	10.2	6.2	5.8	10.3	38.9	60.5	65.9	11.3 ~~XX~~
591	13½ NW	1,039	-	17.1	-	-	-	11.9	8.7	18.7	54.3	-	-	9.5
1414	14 NW	834	-	-	-	-	-	-	4.9	11.7	-	-	-	9.2
538	15½ NW	481	-	-	-	-	-	-	4.1	7.5	24.3	-	-	9.7

Decline of water levels in wells screened opposite the heavily-pumped sands in the Houston, Pasadena and adjacent localities, in feet, 1931-1946, (based on spring measurements) (For location of wells see figs. 1 and 2) -- Continued

Central and western Houston

Well	Distance from Pasadena (miles)	Depth of well (ft.)	1931 to 1937	1937 to 1940	1940 to 1941	1941 to 1942	1942 to 1943	1943 to 1944	1944 to 1945	1945 to 1946	1940 to 1946	1937 to 1946	1931 to 1946	1946 to 1947
853	9 W	650±	10.6	17.4	+0.5	3.5	20.3	3.5	6.7	0.4	33.9	45.8	56.4	0.5
854	9 W	919	-	6.0	-	3.3	4.6	26.0	8.1	2.3	-	-	-	4.8
711	10 W	884	-	-	-	-	10.8	2.5	6.9	+3.4	16.7	-	31.9	17.4
619	10½ NW	625	13.5	18.4	4.0	4.0	9.8	16.0	7.3	+2.0	35.1	46.7	60.0	16.1
623	11 NW	900±	-	6.0	3.5	5.0	3.2	6.4	8.3	2.9	29.4	-	-	7.1
607	12 W	571	-	-	-	-	-	4.0	8.4	2.8	-	-	37.5	5.6
787	12 W	701	-	4.6	0.7	0.5	7.1	10.9	9.5	+ 1.6	27.2	-	-	10.5
779	12 W	584	-	4.8	3.6	3.4	4.1	4.4	8.5	-	-	-	-	XX
609	12 W	825	-	7.1	2.8	2.7	7.0	13.4	6.1	+0.7	31.3	-	37.9	12.2
790	10 W	606	4.2	17.6	3.6	6.9	3.5	5.8	-	-	26.5	39.6	43.8	XX
602	13½ W	1,038	2.5	10.7	4.6	1.4	9.4	5.4	8.0	10.6	38.3	52.7	55.2	14.4
1266	14 W	998	-	-	-	-	-	-	11.1	9.0	-	-	-	
1267	14 W	894	-	-	-	-	-	-	7.7	12.5	-	-	-	6.1
812	17 W	400±	-	-	-	-	-	-	5.1	6.6	-	-	-	8.4

Locality west of Houston

Well	Distance from Pasadena (miles)	Depth of well (ft.)	1931 to 1937	1937 to 1940	1940 to 1941	1941 to 1942	1942 to 1943	1943 to 1944	1944 to 1945	1945 to 1946	1940 to 1946	1937 to 1946	1931 to 1946	1946 to 1947
1417	15 SW	1,007	-	-	-	-	-	-	1.7	8.2	-	-	-	9.4
783	15½ W	350±	-	12.2	2.4	1.9	2.8	3.7	6.2	6.9	23.9	35.2	-	9.7
809	16 W	1,100±	0.2	16.9	7.0	0.6	4.7	7.7	9.7	23.4	51.3	70.2	70.4	19.0
473	18½ W	416	-	3.9	3.0	0.6	2.3	4.0	3.9	7.0	20.8	-	-	7.7
496	19 SW	315	-	2.0	2.1	+0.5	0.6	2.2	2.3	4.4	11.1	-	-	3.0
498	19½ W	787	-	3.7	2.6	0.8	0.6	6.0	3.8	6.4	20.1	-	-	7.4
490	23½ W	1,272	-	-	2.6	2.3	2.9	3.5	2.5	10.4	24.3	-	-	12.8
489	25½ W	472	-	-	1.2	+0.8	1.0	3.0	1.2	3.5	9.1	-	-	4.2

Locality north of Houston

Well	Distance from Pasadena (miles)	Depth of well (ft.)	1931 to 1937	1937 to 1940	1940 to 1941	1941 to 1942	1942 to 1943	1943 to 1944	1944 to 1945	1945 to 1946	1940 to 1946	1937 to 1946	1931 to 1946	1946 to 1947
280	12 N	390	-	-	-	-	-	-	3.6	0.6	-	-	-	1.3
286	13½ N	250	-	-	-	-	-	-	2.7	3.1	-	-	-	2.1
650	14 NW	468	-	5.8	3.7	1.4	5.0	3.1	5.3	8.8	27.3	-	-	5.9
287	14½ N	355	-	-	-	-	-	-	5.8	6.5	-	-	-	3.4
649	16 NW	367	-	4.8	3.1	1.1	3.6	0.4	5.4	9.5	22.9	-	-	5.6
648	16 NW	301	-	-	2.9	0.5	3.1	0.5	5.0	8.3	20.3	-	-	XX
291	17 N	1,308	-	-	-	-	-	-	1.6	2.3	-	-	27.5	1.7
1501	17 N	200±	-	-	-	-	-	-	1.8	1.3	-	-	-	0.9
290	17½ N	296	-	-	-	-	-	-	1.8	2.7	-	-	-	2.1
302	18 N	1,000±	-	2.7	2.4	1.2	1.9	0.4	1.4	8.1	15.4	-	-	4.2
456	20 NW	230	-	1.1	1.1	1.5	1.3	0.7	3.8	5.5	10.9	-	22.1	4.1
264a/	21 NW	950±	19.4	17.2	0.0	+1.5	2.0	+8.1	7.2	6.6	5.5	22.8	42.2	2.3
1506	21 NW	600±	-	-	-	-	-	-	6.9	2.4	-	-	-	3.9
225a/	23½ NW	616	-	2.5	0.3	+0.6	+8.4	+22.3	25.5	21.6	17.9	-	-	5.0
268a/	24½ N	815	-	-	1.3	+0.3	+7.6	+26.4	6.7	37.6	8.5	-	-	9.2
269	24½ N	1,051	-	-	-	-	-	-	7.9	3.0	17.2	-	-	4.8
221a/	24½ NW	208	-	2.6	+2.7	+1.3	0.5	+13.5	9.6	10.8	3.4	-	-	1.3
226a/	25 NW	740	-	-	-	+9.5	-	-	10.5	12.1	-	-	-	3.7
205	27 NW	625	-	2.3	0.7	+1.8	+1.1	+5.7	-	-	3.7	-	6.0	4.5

1/ Water level affected by defective gas well in Bammel gas field.

Summary of decline of water levels in wells in Houston and Pasadena areas

A summary of the more significant figures on the decline of water levels in wells that are screened opposite the heavily-pumped sands in the Houston and Pasadena areas, with special reference to the decline from 1942 to 1946, is given below. The figures are based on measurements made in the spring of each year.

Vicinity of Pasadena. - In 14 observation wells within a radius of 8 miles from Pasadena the decline in water levels between spring measurements in 1942 and 1945 ranged from 18.5 to 61.9 feet and averaged 39 feet (see table on page 9). The average decline by years was as follows: 1942-43, 9.5 feet; 1943-44, 12.1 feet; 1944-45, 17.4 feet. Between 1945 and 1946 seven of the observation wells that are nearest the center of heavy pumping showed rises that ranged from 0.6 foot to 12.5 feet and averaged 7.9 feet; and the remaining seven showed declines that ranged from 0.4 foot to 8.7 feet and averaged 3.6 feet. The average change in the 14 wells from 1945 to 1946 was a rise of 2.7 feet. In three of the 14 wells for which comparable records are available (nos. 1150, 1161, and 1170), the decline in water levels between 1937 and 1946 was 100.2, 111.5 and 108.8 feet. These wells are located in the most intensively pumped part of the industrial area. In four widely spaced wells within a radius of 8 miles from Pasadena only one of which (no. 1170) is near the center of heavy pumpage, the decline between 1931 and 1946 ranged from 51.5 to 100.2 feet and averaged 70.4 feet. In one well (no. 1104), 12 miles southeast of Pasadena the decline was 54.5 feet and in another (no. 1360), 13½ miles southeast of Pasadena the decline was 55.2 feet between 1931 and 1936. The hydrographs in figure 3 show the fluctuation of water levels in well 1170, in the deepest part of the cone of depression,and in well 1230, about five miles southeast of the center of that section (see fig. 1).

Eastern Houston. - In eight observation wells in eastern Houston the declines in water levels between 1942 and 1945 ranged from 31.4 to 51.3 feet and averaged 39.1 feet, of which 12.0 feet occurred between 1942 and 1943, 14.2 feet between 1943 and 1944, and 12.9 feet between 1944 and 1945. Between 1945 and 1946 five of the wells showed rises ranging from 0.9 foot to 12.1 feet and averaging 4.8 feet, and three wells showed small declines averaging 3.3 feet. The average change during the year was a rise of 1.8 feet. In seven of these wells the declines between 1937 and 1946 ranged from 61.4 to 76.6 feet and averaged 68.4 feet. The hydrographs of water levels in three of the wells are shown in figure 4, page 38 .

Northern Houston. - In five wells in northern Houston the declines between 1940 and 1946 ranged from 16.7 to 54.0 feet and averaged 31.3 feet. In seven wells the declines between 1944 and 1945 ranged from 2.5 to 8.7 feet and averaged 4.9 feet, and between 1945 and 1946 ranged from 2.6 to 18.7 feet and averaged 8.9 feet. One well had a total decline of 60.5 feet between 1937 and 1946. In three wells the declines between 1931 and 1946 were 31.9, 54.9, and 65.9 feet. The record of one of the wells, No. 656, is shown graphically in figure 5, page 39 .

Central and western Houston. - In eight wells in central and western Houston for which records are available each spring, the declines in water level between 1942 and 1946 ranged from 20.8 to 41.0 feet and averaged 30.1 feet. The average decline by years was as follows: 1942-43, 9.0 feet; 1943-44, 10.5 feet; 1944-45, 7.6 feet; 1945-46, 3.0 feet. In four wells the declines from 1937 to 1946 ranged from 39.6 to 52.7 feet and averaged 46.2 feet. In seven wells the declines from 1931 to 1946 ranged from 31.9 to 60.0 feet and averaged 46.1 feet. The decline in one representative observation well, No. 619, is shown graphically in figure 5, page 39 .

Locality west of Houston. - In six wells in the area west of Houston the declines between 1943 and 1946 ranged from 8.7 to 19.6 feet and averaged 15.2 feet. The decline by years was a follows: 1942-43, 1.7 feet; 1943-44, 3.7 feet; 1944-45, 3.3 feet; 1945-46, 6.5 feet. Another well (no. 809) near the new Southwest well field showed a decline of 45.5 feet between 1943 and 1946, of which 23.4 feet occurred in 1945-46. The sharp decline in this well during 1945-46 was mostly due to pumping in the Southwest field, which was started late in 1945. The well had a net decline of 46.8 feet between 1937 and 1945. The record is shown graphically in figure 5, page 39 .

Locality north of Houston. - In 10 wells north of Houston the net decline between 1942 and 1946 averaged 12.5 feet. In several of these wells the water levels rose abnormally between spring measurements in 1942 and 1944, following the invasion of gas into the water-bearing sands from a leaky gas well near Bammel. In the same wells a corresponding decline occurred after the gas leak was repaired, as shown by a comparison of 1944 and 1946 measurements. The abnormal rise and fall is illustrated by the hydrographs for wells 225 and 268 in figure 13, page 47. The subject is discussed on pages 28 to 30 in the progress report for 1944 and on page 22 of this report.

Wells screened opposite the lightly-pumped sands. - In the observation wells that are screened opposite the comparatively shallow, lightly-pumped sands the decline in water levels continued during 1942-45, but at a considerably slower rate than the decline in wells in the deeper, more heavily-pumped sands. In five representative wells the declines between spring measurements in 1942 and 1946 ranged from 2.7 to 17.4 feet and averaged 11.8 feet. The decline by years occurred as follows: 1942-43, 1.8 feet; 1943-44, 3.9 feet; 1944-45, 3.8 feet; 1945-46, 2.3 feet. In three other wells for which comparable measurements are available the declines from 1931 to 1946 were 21.7, 29.9, and 31.1 feet.

Decline of water levels in wells screened opposite the lightly-pumped sands in the Houston, Pasadena, and adajcent localities, in feet, 1931-1946

Well	Distance from Pasadena (miles)	Depth (feet)	Spring measurements									
			1939-1940	1940-1941	1941-1942	1942-1943	1943-1944	1944-1945	1945-1946	1940-1946	1931-1946	
1154	2 NW	720	-	3.7	2.8	2.6	6.0	6.6	-	-	-	
1234	4½ S	316	-	-	-	-	4.3	16.1	8.3	-	-	
1209	4½ S	650±	2.3	4.3	2.8	2.3	4.7	0.0	+4.3	9.8	-	+ 13.7
934	7 N	135	-	18.1	3.3	3.6	3.2	2.9	3.6	34.7	-	3.9
909	8 SW	900±	-	1.5	1.4	0.4	4.0	0.8	3.6	11.7	29.9	2.1
778	11½ W	404	3.8	1.1	3.7	2.5	5.0(?)	20.0	+10.5	12.8	-	10.7
608	12 NW	350	4.4	4.1	4.0	1.8	4.0	8.4	2.8	25.1	31.1	4.8
604	12½ NW	340	4.9	2.2	5.5	0.7	4.0	7.0	5.7	25.1	21.7	3.3

Houston municipal wells. - In the table on page 14 the decline in "static" water levels in the Houston municipal wells is shown for the periods 1942 to 1946 and 1939 to 1946. The measurements do not, as a whole, reflect the true static levels, because most of the wells did not remain unpumped long enough to permit the levels to recover fully before the measurements were made, and because no control was exercised over the rate or time of pumping of other wells in the fields. The water levels measured in the same well at two different times therefore are not strictly comparable. However, the average of the individual declines at each plant gives the approximate magnitude of the decline at that plant, because individual discrepancies tend to be equalized if all the measurements are combined. The measurements in the Magnolia Park well represent static conditions more closely than those in any of the others because of the long periods of shut-down before the measurements were made.

The average decline in water level at each of the Houston Municipal well fields from 1939 to 1946 was as follows: Central, 47.7 feet; Heights, 59.7 feet; Northeast, 56.1 feet; Magnolia Park (abandoned in 1944), 59.5 feet; East End, 79.1 feet; Scott Street, 53.5 feet; and South End, 31.8 feet.

Decline of water levels, in feet, recorded in Houston municipal wells, 1939 to 1946

Plant	Well	1942			1946			Decline from 1942 to 1946	Decline from 1939b/ to 1946
		Date	Depth to water (ft.)	Time of shutdown a/	Date	Depth to water (ft.)	Time of shutdown a/		
Central	F- 1	Sept. 9	132.65	35 min.	–	–	–	–	
do.	F- 5	Mar. 5	118.10	30 min.	Mar. 15	147.21	3½ months	29.11	54.13
do.	F-10	do.	108.07	-- days	Apr. 20	138.20	7⅓ hours	30.13	54.98
do.	F-11	do.	101.50	30 min.	Apr. 13	118.80	16 hours	17.30	32.80
do.	F-12	do.	94.0	-- days	May 7	130.0	2+ days	36.00	45.35
do.	C-16	do.	116.21	30 min.	Apr. 12	148.98	6 months	32.77	51.15
do.	D-17	do.	106.56	-- months	--	--	--	--	--
(Installed in 1945-46)	C-18	--	--	--	Apr. 12	130.28	Not used	--	--
Heights	3	Mar. 6	101.25	Unused	Mar. 16	144.60	Unused	43.35	58.13
do.	5	do.	85.0	30 min.	Mar. 18	146.30	1½ hours	61.30	66.30
do.	6	do.	96.89	-- days	Mar. 16	139.90	2½ hours	43.01	61.40
do.	7	do.	106.28	30 min.	do.	144.02	1⅓ hours	37.74	54.71
do.	8	do.	101.53	-- days	Mar. 18	149.80	1 hour	48.27	57.88
Northeast	1	Mar. 6	92.92	30 min.	Mar. 22	122.92	12 hours	30.00	73.02
do.	2	do.	100.71	-- days	do.	132.10	1⅓ months	31.39	39.22
(Installed in 1944)	3	--	--	--	Mar. 23	127.90	1 hour	--	--
Magnolia Park (Abandoned in 1944)	2	Mar. 5	92.65	6 months	Apr. 23	143.03	Unused	50.38	59.54
East End	1	Mar. 5	125.08	30 min.	Mar. 16	176.63	9 hours	51.55	79.09
(Installed in 1943)	2	--	--	--	do.	184.35	1 hour	--	--
Scott Street	2	Mar. 5	122.87	30 min.	Mar. 19	153.80	Unused	30.93	58.93
do.	3	do.	131.70	30 min.	do.	146.40	1½ hours	14.70	48.09
do.	4	Mar. 3	127.70	10 min.	Mar. 20	147.65	12 hours	19.95	54.19
do.	5	Mar. 5	126.50	30 min.	Mar. 19	150.0	1¾ hours	23.50	52.64
South End	2	Mar. 6	95.42	30 min.	Mar. 15	109.35	48 hours	13.93	27.28
do.	4	do.	86.07	30 min.	do.	93.60	48 hours	7.53	14.56
do.	5	Mar. 5	128.97	30 min.	Apr. 12	167.82	1 hour	38.85	53.63
do.	6	(No comparative measurements)							

a/ Length of time pump was idle before measurement was taken. b/ See Water-Supply Paper 889-C, 1944, p. 158

Maps illustrating the altitudes of water levels in wells

The approximate altitudes of water levels in wells in the Houston district that draw from the more heavily-pumped sands, based on measurements made each year in January, are shown in figures 6 to 11, for 1941 to 1946, inclusive. These maps give an areal picture of the spread and deepening of the depressions in water levels produced by the increase in pumping from 1941 to 1945. They also illustrate the approximate hydraulic gradient and the direction of movement of the ground water, which is approximately at right angles to the contours. In order that the spread of the main depression can be followed easily from year to year the area in which the water levels in January were more than 40 feet below sea level have been crosshatched. Of particular interest are the maps for 1941 and 1942, following two years, 1940 and 1941 in which the volume of withdrawals for the Houston and Pasadena areas did not change materially. These maps show very little spread and deepening of the depression between 1941 and 1942. The maps for 1943, 1944, and 1945 show a considerable expansion and deepening during each succeeding year, caused by the large increases in the rate of pumping. The map for January 1946 is of interest because it shows that, although the total area in which the water levels were more than 40 feet below sea level widened considerably during the year, the depression around Pasadena was not quite as deep as it was in January 1945. This was the result of the curtailment of pumpage by many of the industrial plants around Pasadena in the fall and winter of 1945-46.

KATY RICE-GROWING AREA

Pumpage

In the Katy rice-growing area it is estimated that 37,530 acres was irrigated in 1946, as compared with 34,230 acres in 1945; 31,740 acres in 1944; 24,200 acres in 1940; 13,750 acres in 1937; and 8,000 acres in 1935.

The following table shows the number of wells that were used for rice irrigation; the number of acres irrigated; the total amount of water pumped, in acre-feet; and the amount of water in acre-feet, including rainfall, applied to the land per acre per season in 1930, 1935, and 1937 to 1946, inclusive.

The records show that the pumpage in acre-feet per acre usually varies inversely with the rainfall during the rice growing season, the total amount of water (pumped water plus rainfall) applied to the irrigated land during the season in most of the years of the period being remarkably uniform. In 1946, although the rainfall during the growing season was the second highest on record, the storm water caused considerable damage to irrigation levees with a consequent loss of water from the rice fields, and it was necessary to pump about as many acre feet per acre on the average as had been pumped during several preceding years. The total pumpage in the area in 1946 is estimated as about 67,000 acre-feet. Expressed as a daily average for the entire year the total pumpage amounted to 58,000,000 gallons a day in 1946, as compared with 50,000,000 gallons a day in 1945, 55,000,000 gallons a day in 1944, 45,000,000 gallons a day in 1940, 30,000,000 gallons a day in 1937, and 14,000,000 gallons a day in 1935.

Pumpage and rainfall in the Katy rice-growing area

	1930	1935	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946
Number of wells	45	40	61	71	78	88	95	103	112	115	123	125
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	34,320	37,530
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	56,000	67,000
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	1.6	1.8
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	2.2	2.5
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	3.8	4.3

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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, except figures given for 1946 which is the average for automatic recording stations at Katy, Barker, Pattison, Hockley, Satsuma, Addicks, and Alief. No record for Hempstead in 1938 or Sealy in 1939.

Decline of water levels in the Katy area

As shown by spring measurements the water levels in observation wells of the Katy district declined slowly but persistently from 1931 to 1941. The maximum decline was 20.3 feet, the minimum 5.1 feet, and the average 11.3 feet in the 12 wells for which comparative records are available. This was at the average rate of about 1.1 feet a year. Between the spring of 1941 and the spring of 1942 the water levels in 44 observation wells showed an average rise of 2.1 feet, owing to the small demands for irrigation in 1941 and the unusually large amount of recharge from the heavy rains of November 1940 to October 31, 1941. In 1942-43 little net change occurred, some wells showing a slight decline and others a slight rise. From the spring of 1943 to the spring of 1946 an average decline of 3.5 feet was recorded, of which 1.6 feet occurred in 1943-44, 1.4 feet in 1944-45, and 0.5 foot in 1945-46. For the 15-year period from 1931 to 1946 the 11 wells for which comparative measurements are available showed an average decline of 13.6 feet.

The following table gives the annual net changes in water levels in observation wells in the Katy area (see fig. 1, p. 35) between 1931 and 1946.

Annual net changes in water levels in wells in Katy rice-growing area, based on spring measurements

Harris County

Well	Depth of well (ft.)	1931 to 1933	1933 to 1939	1939 to 1940	1940 to 1941	1941 to 1942	1942 to 1943	1943 to 1944	1944 to 1945	1945 to 1946	1931 to 1941	1941 to 1946	1931 to 1946
40	497	-	-	-	-	+4.1	-	-	1.1	+1.4	-	+2.7	-
134	274	-	-	3.8	2.5	+2.3	+0.6	2.5	1.2	0.4	20.3	1.2	21.5
136	138	2.6	6.6	4.8	3.0	+3.3	-	-	1.6	0.5	17.0	1.2	18.2
139	134	-	6.2	4.0	2.6	+3.3	+0.2	2.8	1.7	0.1	-	1.1	-
140	359	-	-	4.0	2.5	+3.3	+0.3	2.8	1.4	0.4	-	1.0	-
160	499	-	-	3.4	+2.3	+3.1	0.1	+1.2	0.0	1.5	-	+2.7	-
182	239	-	-	6.3	-	-	+0.5	0.1	0.3	+0.1	-	-	-
186	628	-	-	2.5	0.5	+2.6	+0.7	0.4	0.1	0.8	9.7	+2.0	7.7
352	470	-	-	3.5	3.9	+3.3	+0.4	-	-	0.8	-	1.6	-
357	-	2.0	3.8	1.7	9.6	+3.4	+0.4	4.4	2.5	0.5	17.1	3.6	20.7
362	500	2.9	4.8	3.1	1.8	+2.8	+0.2	2.6	1.9	0.7	12.6	2.2	14.8
367	535	-	-	2.5	1.2	+2.4	0.0	1.6	1.7	0.8	-	1.7	-
370	625	-	-	2.2	1.1	+2.5	0.2	2.0	-	-	9.4	-	-
371	374	-	-	0.7	1.0	+2.0	0.1	2.1	1.6	0.9	-	2.7	-
380	50±	-	-	0.4	0.3	+1.7	0.2	+2.1	4.1	+0.9	-	+0.4	-
381	95	2.5	3.1	1.5	0.9	+1.9	+0.9	-	-	+1.3	8.0	+2.0	6.0
382	185	-	-	2.8	1.2	+2.2	+0.2	1.1	1.7	1.8	-	2.2	-
384	505	-	5.2	2.8	1.7	+1.3	+1.0	1.3	1.1	1.9	-	1.0	-
385	359	-	2.7	2.3	0.8	+2.1	+0.5	1.4	1.1	0.7	-	0.6	-
399	326	-	-	1.8	3.7	+1.3	+1.0	0.3	1.0	0.5	-	+0.5	-
480	512	-	-	-	-	+2 4	1.8	2.4	1.3	2.2	-	5.1	-

Fort Bend County

Well	Depth of well (ft.)	1931 to 1933	1933 to 1939	1939 to 1940	1940 to 1941	1941 to 1942	1942 to 1943	1943 to 1944	1944 to 1945	1945 to 1946	1931 to 1941	1941 to 1946	1931 to 1946
7	653	0.1	3.2	1.9	1.6	+1.6	2.2	+0.9	0.8	1.1	6.8	1.6	8.4
11	170±	-	2.3	2.3	5.2	+1.9	+0.1	1.7	2.5	+0.4	-	1.8	-
15	172	1.8	3.6	2.2	2.2	+2.1	+0.4	3.1	2.6	4.1	5.8	7.3	17.1
17	586	-	-	-	-	+2.0	-	-	0.6	0.9	-	1.0	-
20	250	-	2.2	2.3	0.4	+2.0	2.0	+0.7	1.1	0.1	-	0.5	-
21	-	0.8	1.8	1.9	0.6	+2.5	0.5	1.1	0.7	0.0	5.1	+0.2	4.9
26	657	-	-	0.3	1.2	+1.9	0.7	0.9	+1.7	0.8	-	+1.1	-
29	500	-	-	-	-	+1.7	0.5	1.3	1.0	+0.8	-	0.3	-
30	334	-	-	-	-	+1.6	+0.6	0.5	0.5	+0.7	-	+1.9	-
33	346	-	-	1.7	1.8	+1.0	+0.2	3.0	+0.2	0.3	-	1.9	-

Waller County

Well	Depth of well (ft.)	1931 to 1933	1933 to 1939	1939 to 1940	1940 to 1941	1941 to 1942	1942 to 1943	1943 to 1944	1944 to 1945	1945 to 1946	1931 to 1941	1941 to 1946	1931 to 1946
223	767	1.6	4.2	2.1	1.5	+0.5	0.2	2.1	2.0	0.8	9.4	4.6	14.0
225	643	-	-	-	-	+2.1	0.8	3.2	5.4	0.8	-	8.1	-
234-5	170± 545	2.2	6.6	3.5	1.6	+1.2	+2.8	4.3	0.6	1.0	13.9	1.9	15.8
239	-	-	-	-	-	+2.0	+0.9	3.0	5.3	+1.9	-	3.5	-
240	290	-	-	-	-	+0.4	+0.5	1.2	0.5	0.4	-	1.2	-
242	555	-	-	-	-	1.6	0.7	1.2	2.0	+1.1	-	4.4	-
245	482	-	-	-	-	+0.7	+0.4	1.9	1.5	0.4	-	3.7	-
246	900	-	-	-	-	+0.5	0.4	1.9	1.5	0.4	-	3.7	-
247	641	-	-	2.0	1.4	+0.6	-	-	2.3	0.0	-	3.7	-
252	246	-	-	-	2.4	+1.6	0.1	2.4	1.7	1.0	-	3.6	-

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

From 1941 to the summer of 1946 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 than they were in 1938-40 (see fig. 12, well 29, p. 46 , and the table on pp. 27 and 28), and in the few wells for which comparable measurements are available the water levels were as high or higher than they were in 1931-34. In localities affected by pumpage from nearby rice irrigation wells a decline of 5 to 15 feet occurred each pumping season (see fig.12, well 35, p. 46) which, however, was recovered during the winter. The water levels have, in general, continued to rise during the spring and early summer of 1946, partly as a result of the above-average rainfall during this period, which has contributed materially to the recharge of the sands, and partly to the delay in the start of heavy pumping for rice irrigation as a result of the rains. 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 moved down the dip toward the pumped areas. A proportionally large part of the recharge occurred during the abnormally wet year November 1940 to October 1941, and during periods of above-average rainfall in 1945 and the spring of 1946.

Fluctuation of water levels in wells in the outcrop area of the water-bearing sands of the Houston district

	Hockley area			Westfield - Tom Ball - Conroe area							
	Harris County			Harris County				Montgomery County			
Well	J-1	35a/	171	95	103	1503	1504	29	45	46	57
Depth (ft.)	27	35	66	30	29	41	29	29	30	35	48
Date		Depth to water in feet below measuring point b/									
Feb. 1938	-	23.03	15.40	-	17.63	-	-	24.81	23.56	32.35	-
May	-	19.35	11.30	-	15.16	-	-	25.14	23.70	32.19	-
Nov.	-	27.09	16.86	-	19.28	-	-	26.98	26.17	32.79	46.84
Dec.	-	27.27	17.41	-	21.71	-	-	27.30	25.53	32.73	46.39
Jan. 1939	-	27.38	15.56	-	18.86	-	-	24.98	24.27	31.90	46.96
Mar.	-	27.34	14.53	-	18.15	-	-	24.11	24.01	31.73	-
May	-	26.07	17.37	-	17.70	-	-	25.85	24.56	33.01	46.84
Aug.	-	26.65	20.66	-	16.17	-	-	26.15	25.55	32.92	47.70
Sept.	-	27.48	20.56	-	19.20	-	-	26.96	26.15	33.55	-
Dec.	-	27.32	20.30	26.44	20.10	-	-	27.80	25.80	33.38	-
Feb. 1940	-	27.72	19.61	26.77	20.05	-	-	27.54	25.40	32.44	-
May	26.90	26.89	19.08	26.97	19.84	35.28	-	27.26	26.02	31.52	-
June	27.05	27.28	18.65	27.23	20.40	35.10	26.82	26.76	26.10	33.64	-
July	27.13	-	-	-	-	35.49	25.97	-	-	-	-
Aug.	27.08	27.20	18.78	27.54	-	35.52	25.64	27.02	26.40	33.96	-
Oct.	27.10	27.51	19.09	27.78	21.26	35.75	26.05	27.60	26.40	33.78	46.70
Dec.	26.75	26.43	18.29	27.32	20.82	35.85	25.18	26.50	24.15	32.62	46.50
Jan. 1941	25.18	25.21	17.18	25.42	17.65	35.69	22.62	23.75	25.30	32.68	45.87
Feb.	24.82	22.72	16.51	24.67	16.45	35.51	22.48	23.10	23.86	30.90	45.65
Mar.	24.78	-	-	-	-	35.15	21.96	-	-	-	-
Apr.	-	19.80	11.75	23.20	14.10	-	-	21.53	25.32	33.30	44.83
May	25.11	17.84	10.78	-	-	35.16	20.65	-	-	-	-
June	24.73	-	-	23.85	12.83	34.80	20.38	20.43	25.81	32.97	44.46
July	24.47	15.79	9.80	22.71	-	34.98	20.90	19.50	26.38	33.45	44.12
Aug.	24.30	19.90	9.60	23.80	13.60	-	-	-	-	33.75	44.23
Sept.	24.63	22.01	9.73	23.47	14.03	34.65	23.24	23.03	25.20	33.05	44.32
Nov.	23.87	15.70	9.40	17.72	9.66	34.43	20.62	16.46	22.59	31.52	42.97
Dec.	23.73	16.47	9.49	12.79	11.18	33.91	20.81	18.21	23.10	32.97	42.75
Jan. 1942	24.00	16.57	9.41	18.96	11.11	33.75	21.52	19.56	22.78	33.37	42.37
May	23.71	14.68	8.91	15.48	10.90	33.35	21.85	16.76	23.60	32.82	41.40
July	23.30	18.07	8.68	16.91	-	33.01	22.51	17.87	21.02	33.04	41.35
Aug.	23.10	20.80	-	-	-	32.97	22.64	-	-	-	-
Sept.	22.98	20.31	8.98	18.75	15.94	32.83	22.92	18.40	21.23	32.25	41.02
Nov.	23.44	23.73	-	-	-	32.91	-	-	-	-	-
Jan. 1943	23.45	14.15	9.98	14.66	14.56	32.83	23.36	17.73	19.16	32.29	41.11
Mar.	-	14.90	-	15.55	12.25	32.37	23.19	19.31	20.43	31.96	41.83
Apr.	22.88	16.60	9.93	-	-	-	-	-	-	-	-
June	23.04	18.70	9.80	18.76	15.54	31.97	23.64	21.35	23.46	32.12	41.83
Aug.	22.74	25.75	10.17	18.91	15.13	32.01	22.99	22.13	22.63	32.35	41.96

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a/ Well 35 is in a locality affected by pumpage from nearby rice irrigation wells during the summer months. See hydrograph, figure 12.

b/ Additional measurements, not shown in this table, are in files of the Geological Survey office in Houston.

Fluctuation of water levels in wells in the outcrop area of the water-bearing sands of the Houston district -- Continued

	Hockley area			Westfield - Tom Ball - Conroe area							
	Harris County			Harris County				Montgomery County			
Well	J-1	35a/	171	95	103	1503	1504	29	45	46	57
Depth (ft.)	27	35	66	30	29	41	29	29	30	35	48
Date	Depth to water, in feet, below measuring point b/										
Jan. 1944	23.76	18.20	11.17	-	7.40	31.53	23.43	22.34	22.87	31.53	42.82
May	22.55	16.05	9.58	10.40	9.00	29.72	21.20	17.88	21.29	31.30	42.37
July	-	-	-	17.26	13.50	29.64	21.80	21.05	22.98	31.73	42.78
Sept.	23.35	32.92	9.58	20.73	16.40	29.32	22.65	23.70	22.69	31.56	42.93
Dec.	24.04	28.36	9.88	17.90	15.13	28.99	22.98	22.50	19.61	31.41	43.24
Jan. 1945	22.35	18.65	9.57	13.17	-	28.11	21.77	19.98	18.75	30.98	42.63
Mar.	21.76	17.43	9.19	13.53	9.96	27.57	21.08	18.88	18.93	31.16	41.86
June	22.08	20.33	8.36	15.47	10.42	27.70	20.38	17.96	19.96	31.27	41.46
Jan. 1946	22.77	14.38	9.05	11.80	8.26	29.88	22.86	23.40	17.11	30.52	42.06
May	21.93	15.05	8.09	10.09	9.13	28.83	21.43	18.01	16.63	30.56	41.35

a/ Well 35 is in a locality affected by pumpage from nearby rice irrigation wells during the summer months. See hydrographs, figure 12.

b/ Additional measurements, not shown in this table, are in files of the Geological Survey office in Houston.

WATER LEVELS IN THE BAMMEL GAS FIELD AREA

An abnormal rise in water levels began in December 1942 and continued for several months in the Bammel gas field and the surrounding territory to the northwest of Houston (see fig. 1, p. 35). The rise was caused by the escape of large quantities of gas into the water-bearing sands. It has been discussed by Rose and Alexander in the Houston progress report for 1944 1/, and in a paper printed by the American Association of Petroleum Geologists 2/.

In an area roughly about 25 miles long and 10 miles wide the water levels in most of the observation wells showed a sharp upward trend, and many wells in and near the gas field began to flow and continued flowing for several months (see fig. 13, p. 47). Most of the wells in and near the gas field ceased to flow in April 1944. In wells less than 400 feet deep the water levels declined steadily from April to the latter part of July 1944,rose slowly from July to October 1944, and then declined until January 1946. In the deeper wells the levels rose steadily from December 1942 to September 20, 1944, except in a short period in the fall of 1943. The greatest total rise was 61 feet in well 268 at Westfield (see fig. 13, p. 47). From September 1944 to January 1946 the water levels declined steadily. Measurements made in January and May 1946 indicate that most of the water levels in the Bammel area have returned to, or are approaching, the normal stage.

CHEMICAL CHARACTER OF THE GROUND WATER

Since 1931 samples of water collected periodically from 30 to 60 selected widely-spaced wells 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 January and February 1946, there has been no significant change in the composition of the ground water pumped in the Houston district.

In general, the mineral content of the ground water increases with depth in this district, and it therefore determines the maximum depth to which wells are drilled. The higher mineralization of the water from the deep sands is due largely to increased amounts of sodium chloride. The analyses of samples of water from wells and drill-stem tests in exploration holes show that water of low chloride content can be obtained at depths of about 1,900 to about 2,000 feet at Houston, about 1,900 feet at Pasadena, 1,850 feet in test well 8 near South Houston, 1,600 feet at the Shell Oil Company refinery near Deer Park, 2,000 feet in test well 2 on the Houston-Clodine road, and about 1,700 feet in test well 6 at Clodine, 20 miles west of Houston. However, samples of water with sufficient chloride to be objectionable for public use have been obtained from sands at about 2,100 feet at Houston, 2,000 feet at Clodine, about 1,000 feet at Baytown and about 1,000 feet at Webster.

1/ Rose, N. A., and Alexander, W. H., Jr., Progress report on the ground-water resources of the Houston district, U. S. Geol. Survey and Texas State Board of Water Engineers, (mimeographed release), pp. 28-30, November 1944.

2/ Rose, N. A., and Alexander, W. H., Jr., Relation of phenomenal rise of water levels to a defective gas well, Harris County, Texas: Bull. Amer. Assoc. Petrol. Geol., vol. 29, No. 3, March 1945.

During 1943, 1944, and 1945, in an effort to obtain more information concerning the depth to which water of good quality occurs at Houston, eight samples of water were obtained from six test holes by the drill-stem method at depths ranging from about 1,900 to about 2,300 feet. These test holes were drilled in connection with the development of eight new city wells at the East End, Northeast, South End, Southwest and Central well fields. The well field, the number of the well, the depth from which the sample was taken, and the contents of chloride, bicarbonate, sulfate, and total hardness as $CaCO_3$ in the water, in parts per million, are given in the following table:

Partial analyses of water taken by drill-stem sampling in City of Houston test wells, in parts per million

Well field	Well No.	Date	Depth of sampling	Chloride (Cl)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Hardness as $CaCO_3$
East End	2	1943	1,915 to 1,965	89	486	4	16
East End	2	1943	1,995 to 2,050	104	392	2	20
Northeast	3	1944	2,025 to 2,050	100	376	3	25
South End	7	1944	1,892 to 1,930	87	380	4	40
South End	7	1944	2,315 to 2,350	364	377	2	48
Southwest	1	1945	2,080 to 2,099	1,011	172	8	146
Southwest	6	1945	1,925 to 1,940	206	314	13	27
Central	C-18	1945	1,970 to 1,990	60	306	48	46

RESULTS OF PUMPING TESTS AT NEW SOUTHWEST PLANT, HOUSTON, TEXAS

By Joe W. Lang and R. W. Sundstrom

In 1945 six wells were brought into production by the City of Houston in its new Southwest well field. The wells range in depth from 1,380 to 1,520 feet and about 400 feet of water sand is screened in each, all below a depth of about 550 feet. The wells are in a locality where withdrawals of ground water from these sands has been relatively light. Although they were drilled and developed during the first half of 1945, only one well (No. 1) was placed in operation, being connected with the City mains on July 1. The remaining wells were idle until the pumping tests in November. Well 1 was shut down about October 20. For these reasons, an exceptionally good opportunity was offered late in November 1945 for pumping tests by the Theis method. Such tests were made by the writers during the period November 20-28, inclusive.

The main purpose of thetests was to determine the coefficients of storage and transmissibility of the sands from which the wells draw water. These coefficients can be used for computing future pumping levels in the well field, which in turn serve as a guide for planning future well installations.

History of the tests

The six new wells are situated southwest of the city in a line along the north side of the Houston-Clodine road and are numbered consecutively from east to west, beginning with well 1 on the east. The position of the wells and distances between them, which range from 1,560 to 2,703 feet, are shown in figure 14.

The static water levels in the wells were measured each day for 5 days preceding the tests. The tests were started November 20, 1945, at 10:35 a.m. First, well 1 was started and pumped continuously for 192 hours, while frequent measurements of the water levels were made in all the wells to determine the drawdowns produced by the pumping. At the end of 72 hours well 4 was turned on and pumped for 72 hours, while water-level observations were continued in the other wells and the drawdowns produced by pumping the two wells were determined. At the end of 144 hours well 4 was shut down, while pumping was continued in well 1, and the resulting recovery in water levels in all the wells was observed for 48 hours.

The measurements of depth to water were made by means of a steel tape in all except the pumped wells. In the pumped wells the water levels were measured by means of a pressure gage on an air line and were checked occasionally with tape measurements. The amount of water discharged from the pumped wells was measured in the storage reservoirs at the Southwest pumping station.

Analysis of data obtained from the pumping tests

The Theis 3/non-equilibrium formula was used for computing coefficients of transmissibility and storage from the results of the tests. These coefficients form a measure of the ability of the aquifer to transmit and to store water and, in combination with data on the length of time of pumping, distance from the pumped well, and rate of pumping, are the factors that determine the amount and rate of drawdown of the water levels caused by pumping from wells. Differences in field conditions from those assumed in the computations, the most important assumption being that the aquifer is of infinite extent, affect the results, but the effect of these differences is not great in aquifers as extensive as those of the Houston district.

The coefficient of transmissibility may be expressed as the number of gallons of water that will move in one day through a vertical strip of the aquifer one foot wide and the full height of the aquifer under unit hydraulic gradient (one foot per foot).

The coefficient of storage, expressed as a decimal fraction, is the volume of water, measured in cubic feet, released from storage in each column of the aquifer having a base area of one square foot and a height equal to the thickness of the aquifer, when the artesian head is lowered one foot.

The non-equilibrium formula is:

$$s = \frac{114.6\ Q}{T} \int_{\frac{1.87\ r^2 S}{Tt}}^{\infty} \frac{e^{-u}}{u}\, du$$

in which s is the drawdown in feet at any point in the vicinity of a well pumped at a uniform rate, Q is the discharge of the well in gallons a minute, T is the coefficient of transmissibility of the aquifer in gallons a day, r is the distance from the pumped well to the point of observation in feet, S is the coefficient of storage of the aquifer, and t is the time the well has been pumped in days.

Wenzel 4/discusses the application of the non-equilibrium formula as follows:

3/ Theis, C. V., The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans. 1935, pp. 519-524.

4/ Wenzel, L. K., Methods for determining permeability of water-bearing materials: U. S. Geol. Survey Water-Supply Paper 887, pp. 88-89, 1942.

"The formula may be used in two ways. If the coefficient of transmissibility and the coefficient of storage are known, the drawdown can be computed for any time and any point on the cone of depression. If the drawdowns are known, the coefficients of transmissibility and storage can be computed. If the drawdown is known T and S can be computed either from the drawdown curve of one well or from the drawdowns that are observed at any one time in a line of wells -- that is, from the form of the cone of depression.

"As the coefficient of transmissibility appears on both sides of the equation, the formula cannot be solved directly for T and S. However, T and S may be conveniently determined by the following graphical method suggested by Theis. The non-equilibrium formula may be written

$$s = \frac{114.6\ Q}{T} W(u)$$

in which W (u) may be read as 'well function of u' and the other terms as previously defined.

$$W(u) = -0.577216 - \log_e u + u - \frac{u^2}{2 \cdot 2!} + \frac{u^3}{3 \cdot 3!} - \frac{u^4}{4 \cdot 4!} \quad . \quad . \quad . \quad . \quad . \quad .$$

and

$$u = \frac{1.87\ r^2 S}{Tt}$$

"When T and S are to be determined from observations on the drawdown in one well, the log of the drawdown is plotted against the log of the reciprocal of the time since pumping began (s against $\frac{1}{t}$). When T and S are to be determined from the drawdowns in a line of wells, the log of the drawdown is plotted against the log of $\frac{r^2}{t}$. If the formation was entirely homogeneous and the water was discharged instantaneously with the fall in pressure, all points so plotted, for all times and all wells, would fall on a smooth curve. The curve so determined is a segment of the type curve produced by plotting the log of the value of the integral, W(u), against the log of the quantity u. If, therefore, (1) the type curve is plotted on logarithmic paper and (2) the observed drawdown values are plotted on transparent paper against $\frac{1}{t}$ for one observation well of $\frac{r^2}{t}$ for a line of observation wells to a logarithmic scale the same as that used for plotting the type curve, (3) the observed curve can be fitted to the type curve in only one place. Then (4) from this fit the value of W(u) and the corresponding value of u may be determined from the type curve for any selected point on the observed curve, which (5) may be used in conjunction with the observed values for that point to determine T and S.

"The coefficient of transmissibility is then computed by the formula

$$T = 114.6Q\ \frac{W(u)}{s}$$

"The coefficient of storage is computed by the formula

$$S = \frac{uTt}{1.87r^2}$$

In accordance with the foregoing discussion, computations were made for s and $\frac{r^2}{t}$ for wells 2, 3, 4, and 5 during the pumping of well 1, and for wells 5 and 6 during the pumping of wells 1 and 4. These computations were plotted on logarithmic paper and matched with the type curve, and values for the coefficients of transmissibility (T) and storage (S) were determined for wells 2, 3, 4, 5, and 6. Finally the coefficient of transmissibility for well 4 was determined by the recovery method, using the formula $T = \frac{264Q}{s} \log_{10} \frac{t}{t'}$; in which $\frac{t}{t'}$ is plotted against s (t is the time since pumping started, t' the time since pumping stopped, and s the residual drawdown). The results are given in the table below:

Coefficients of transmissibility and storage computed from pumping tests in the Southwest well field, Houston, Texas, November 20 to 28, 1945

Well No.	Coefficient of transmissibility T, gpd/ft	Coefficient of storage S	Remarks
1	----	----	Pumped continuously throughout test.
2	156,000	.00089	T and S obtained during pumping of well 1.
3	139,000	.0012	Do.
4	152,000	.0012	Do.
5	145,000	.0011	Do.
5	140,000	.00095	T and S obtained during pumping of wells 1 and 4.
6	146,000	.0012	Do.
4	141,000	----	From recovery of well 4.
Average	145,000	.001	

As shown by the above table, the coefficients of transmissibility in the individual wells range from 139,000 to 156,000 gpd/per ft and average 145,000 gpd/per ft. The coefficients of storage determined from the pumping tests range from 0.00089 to 0.0012 and average about 0.001. In the computations of future drawdown given on pages 29 to 32 the figures 140,000 and 0.001 were used for the coefficients of transmissibility and storage, respectively.

The specific capacity of a well is the discharge drawdown ratio (generally expressed as the number of gallons a minute a well will yield for each foot of drawdown). The specific capacities of wells 1 and 4, 35.1 and 35.6 gpm per ft respectively, were obtained by dividing the average yield of the wells by the drawdown at the end of the 72-hour periods of pumping. The specific capacities of the other wells, except that for well 6 were obtained during pumping tests ranging in length from 24 to 48 hours each in April, May, and June 1945, that for well 6 was estimated from a short preliminary test. The following table gives the average rate of pumping and the drawdown in water level in each well during the tests, the lengths of the tests in hours and the dates on which they were run and, finally, the specific capacity, computed or estimated from the results of the tests.

Specific capacities of wells in the Southwest well field, Houston, Texas, 1945; computed or estimated from results of pumping tests

Well	Pumping level (feet below pump base)	Rate of pumping (gpm)	Drawdown of water level (feet) 1/	Duration of test (hours)	Date of test (1945)	Specific capacity (gpm per foot)	Remarks
1	174	2,600	74	72	Nov. 20	35.1	
2	204	3,080	109	48	Apr. 23	28.2	Test by Layne-Texas Co.
3	215	3,040	120	24	May 5	25.2	Do.
4	167	2,660	75	72	Nov. 23	35.6	
5	182	3,490	90	48	June 15	38.8	Test by Layne-Texas Co.
6	129	1,470	43	6(?)	Feb. 23	34.2	Estimated from preliminary test by Layne-Texas Co.

1/ In computing the drawdown for each well the static water level as of November 20, 1945 was used.

Computed future pumping levels

As previously stated, six wells thus far have been drilled in the Southwest well field and screened in sands at depths between about 550 and 1,500 feet. A contract has been let by the City for the installation of two additional wells in the autumn or winter of 1946, to penetrate the same sands. These two wells will be situated along the present line extended toward the west -- well 7 at a distance of about 2,200 feet from well 6 and well 8 about 2,950 feet from well 7.

According to Mr. G. L. Fugate, chief designing engineer in the City Water Department, it is proposed to pump an average of about 15,000,000 gallons a day from the eight wells, representing an average of 1,300 gallons a minute per well.

In computing the drawdowns in the pumped wells themselves, it was assumed that in actual practice the pumps will be operated at or near their full capacity of 2,100 gallons a minute and that the average rate of 1,300 gallons a minute will be maintained by intermittent pumping. The figures on drawdowns in the pumped wells shown in the tables, therefore, were obtained by dividing 2,100 by the specific capacity of each well. The following tables give the computed drawdown in each well, at the end of 1 year and at the end of 5 years, that would be produced by its own pumping plus the drawdown in the well produced by pumping the other seven wells at an average rate of 1,300 gallons a minute each, or a total of nearly 15,000,000 gallons a day. The figures on drawdown in wells 7 and 8 caused by their own pumping are based on estimated specific capacitities of 30 (gpm) per foot.

Computed future drawdown and pumping level in 8 wells (6 completed and 2 proposed), at the end of 1 year, that will be produced by pumping an average of 15 million gallons a day from the 8 wells at the Southwest plant, Houston, Texas

Coefficient of transmissibility, T = 140,000 gpd/ft
Coefficient of storage, S = 0.001

End of 1 year (each well pumping an average of 1,300 gpm continuously)

Well causing drawdown	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8
	Drawdown (in feet) caused by pumping other wells							
Well 1	-	8.2	7.1	6.5	5.8	5.2	4.8	4.4
Well 2	8.2	-	9.1	7.7	6.6	5.7	5.2	4.7
Well 3	7.1	9.1	-	9.3	7.3	6.2	5.6	5.0
Well 4	6.5	7.7	9.3	-	8.3	6.8	6.0	5.3
Well 5	5.8	6.6	7.3	8.3	-	8.1	6.9	5.9
Well 6	5.2	5.7	6.2	6.8	8.1	-	8.6	6.8
Well 7	4.8	5.3	5.6	6.0	6.9	8.6	-	7.9
Well 8	4.4	4.7	5.0	5.3	5.9	6.8	7.9	-
Total drawdown caused by other wells	42.0	47.3	49.6	49.9	48.9	47.4	45.0	40.0
Drawdown caused by pumped well itself a/	64.9	80.0	89.6	64.1	59.6	76.3	76.3	76.3
Static water level Nov. 1945 (ft. below surface)	100.5	94.9	94.1	92.0	91.6	86.3	84.0b/	83.0b/
Computed pumping level after pumping 1 year (ft. below surface)	207.4	222.2	233.3	206.0	200.1	210.0	205.3	199.3

a/ Based on pumpage of 2,100 gallons a minute per well, and estimated specific capacities of 30 gpm/ft for wells 6, 7, and 8.

b/ Estimated.

Computed future drawdown and pumping level in 8 wells (6 completed and 2 proposed), at the end of 5 years, that will be produced by pumping an average of 15 million gallons a day from the 8 wells at the Southwest plant, Houston, Texas

Coefficient of transmissibility, T = 140,000 gpd/ft
Coefficient of storage, S = 0.001

End of 5 years (each well pumping an average of 1,300 gpm continuously)

Well causing drawdown	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8
	(Drawdown (in feet) caused by pumping other wells)							
Well 1	-	9.9	8.9	8.2	7.5	6.9	6.5	6.1
Well 2	9.9	-	10.8	9.4	8.3	7.4	7.0	6.4
Well 3	8.9	10.8	-	11.1	9.1	7.9	7.3	6.7
Well 4	8.2	9.4	11.1	-	10.2	8 5	7.8	7.0
Well 5	7.5	8.3	9.1	10.2	-	9.9	8.6	7.6
Well 6	6.9	7 5	7.9	8.5	9.9	-	10.3	8.5
Well 7	6.5	7.0	7.3	7.8	8.6	10.3	-	9.7
Well 8	6.1	6.4	6.7	7.0	7.6	8.5	9.7	-
Total drawdown caused by other wells	54.0	59.3	61.8	62.2	61.2	59.3	57.2	52.0
Drawdown caused by pumped well itself a/	66.6	81.8	91.3	65.8	61.4	80.0	80.0	80.0
Static water level Nov. 1945	100.5	94.9	94.1	92.0	91.6	86.3	84.0 b/	83.0 b/
Pumping level after pumping 5 years	221.1	236.0	247.2	220.0	214.2	225.6	221.2	215.0

a/ Based on pumpage of 2,100 gallons a minute per well, and estimated specific capacities of 30 gpm/ft for wells 6, 7, and 8.

b/ Estimated.

For convenience in making further computations, the following table has been prepared. This table gives, in feet, the computed drawdowns that would be produced in each well by pumping continuously 100 gallons a minute from the well itself or from any other well in the field.

Computed decline, in feet, for each 100 gallons a minute pumped continuously from each of wells 1, 2, 3, 4, 5, 6, 7 and 8, for periods of 1 month, 3 months, 6 months, 1 year, 2 years and 5 years. (Assuming well losses to vary directly with discharge).

Well 1

	Computed decline, in feet, for each 100 gpm pumped continuously from well 1							
	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8
1 month	3.04	0.428	0.345	0.295	0.242	0.197	0.169	0.139
3 months	3.13	0.518	0.437	0.384	0.330	0.284	0.255	0.223
6 months	3.19	0.576	0.492	0.442	0.387	0.341	0.311	0.279
1 year	3.21	0.633	0.549	0.502	0.444	0.398	0.368	0.335
2 years	3.29	0.692	0.606	0.555	0.503	0.454	0.424	0.391
5 years	3.38	0.764	0.681	0.630	0.577	0.529	0.503	0.466

Well 2

	Computed decline, in feet, for each 100 gpm pumped continuously from well 2							
	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8
1 month	0.428	3.77	0.495	0.390	0.302	0.240	0.203	0.165
3 months	0.518	3.86	0.584	0.479	0.392	0.328	0.290	0.251
6 months	0.576	3.91	0.642	0.537	0.449	0.385	0.347	0.307
1 year	0.633	3.97	0.699	0.593	0.504	0.442	0.404	0.364
2 years	0.692	4.02	0.756	0.642	0.563	0.503	0.460	0.420
5 years	0.764	4.10	0.831	0.726	0.638	0.574	0.535	0.495

Well 3

	Computed decline, in feet, for each 100 gpm pumped continuously from well 3							
	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8
1 month	0.345	0.495	4.25	0.512	0.362	0.277	0.231	0.186
3 months	0.437	0.584	4.34	0.602	0.452	0.366	0.319	0.273
6 months	0.492	0.642	4.40	0.659	0.508	0.423	0.376	0.329
1 year	0.549	0.699	4.46	0.716	0.565	0.480	0.433	0.386
2 years	0.606	0.756	4.50	0.773	0.628	0.537	0.490	0.442
5 years	0.681	0.831	4.59	0.853	0.698	0.612	0.565	0.517

Well 4

	Computed decline, in feet, for each 100 gpm pumped continuously from well 4							
	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8
1 month	0.295	0.390	0.512	3.00	0.445	0.320	0.262	0.208
3 months	0.384	0.479	0.602	3.09	0.527	0.410	0.351	0.295
6 months	0.442	0.537	0.659	3.15	0.593	0.467	0.408	0.352
1 year	0.503	0.593	0.716	3.20	0.649	0.524	0.465	0.409
2 years	0.555	0.642	0.773	3.25	0.706	0.581	0.522	0.466
5 years	0.630	0.726	0.853	3.34	0.781	0.656	0.597	0.541

Well 5

	Computed decline, in feet, for each 100 gpm pumped continuously from well 5							
	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8
1 month	0.242	0.302	0.362	0.445	2.80	0.422	0.325	0.249
3 months	0.330	0.392	0.452	0.527	2.89	0.512	0.414	0.338
6 months	0.387	0.449	0.508	0.593	2.95	0.569	0.472	0.395
1 year	0.444	0.504	0.565	0.649	3.00	0.626	0.529	0.452
2 years	0.503	0.563	0.628	0.706	3.05	0.683	0.585	0.508
5 years	0.577	0.638	0.698	0.781	3.14	0.758	0.660	0.583

Well 6

	Computed decline, in feet, for each 100 gpm pumped continuously from well 6							
	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8
1 month	0.197	0.240	0.277	0.320	0.422	3.61	0.459	0.317
3 months	0.284	0.328	0.366	0.410	0.512	3.70	0.545	0.406
6 months	0.341	0.385	0.423	0.467	0.569	3.76	0.603	0.464
1 year	0.398	0.442	0.480	0.524	0.626	3.82	0.660	0.521
2 years	0.454	0.503	0.537	0.581	0.683	3.86	0.717	0.577
5 years	0.529	0.574	0.612	0.656	0.758	3.95	0.792	0.652

Well 7

	Computed decline, in feet, for each 100 gpm pumped continuously from well 7							
	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8
1 month	0.169	0.203	0.231	0.262	0.325	0.459	3.61	0.408
3 months	0.255	0.290	0.319	0.351	0.414	0.545	3.70	0.497
6 months	0.311	0.347	0.376	0.408	0.472	0.603	3.76	0.555
1 year	0.368	0.404	0.433	0.465	0.529	0.660	3.82	0.612
2 years	0.424	0.460	0.490	0.522	0.585	0.717	3.86	0.669
5 years	0.503	0.535	0.565	0.597	0.660	0.792	3.95	0.744

Well 8

	Computed decline, in feet, for each 100 gpm pumped continuously from well 8							
	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8
1 month	0.139	0.165	0.186	0.208	0.249	0.317	0.408	3.61
3 months	0.223	0.251	0.273	0.295	0.338	0.406	0.497	3.70
6 months	0.279	0.307	0.329	0.352	0.395	0.464	0.555	3.76
1 year	0.335	0.364	0.386	0.409	0.452	0.521	0.612	3.82
2 years	0.391	0.420	0.442	0.466	0.508	0.577	0.669	3.86
5 years	0.466	0.495	0.517	0.541	0.583	0.652	0.744	3.95

In computing the future drawdowns no account was taken of the current downward trend of the water levels throughout the Houston-Pasadena area, which is due to a large increase in the regional pumpage in recent years. From recent water-level measurements it is roughly estimated that the amount of decline at the Southwest plant due to this general increase, plus the effect of seasonal increase in the regional pumpage, may be of the magnitude of 6 or 8 feet between November 1945 and September 1946. The regional decline due to past pumpage doubtless will continue for more than a year, but if there is no further increase in the regional pumpage the rate of decline should gradually lessen until equilibrium is reached.

Also, the effect of recharge on the outcrop of the water-bearing sands was not taken into account. This recharge should, in time, reduce the rate of drawdown shown by the computations. However, the outcrops are at a considerable distance from the Southwest plant, probably about 30 miles on the average, and the effect in 1 to 5 years would be relatively small.

SUMMARY

The total pumpage from wells in the Houston and Pasadena areas in 1946 was the highest on record, amounting to an average of about 119,000,000 gallons a day. The pumpage in 1945 was the second highest, with an average of 112,000,000 gallons a day, and in 1944 was third highest, with an average of 108,000,000 gallons a day. The daily average for 1943 was 94,000,000 gallons and for 1942 was 85,000,000 gallons. During the period 1930 to 1936, inclusive, it was nearly constant at about 50,000,000 gallons a day.

Pumpage by the City of Houston, included in the above figures, averaged 51,300,000 gallons a day through November, 1946 as compared with 43,200,000 gallons a day in 1945, 39,500,000 gallons in 1944, 35,200,000 gallons in 1943, 30,500,000 gallons in 1942, and 27,200,000 gallons in 1941.

As was to be expected, the large increase in the rate of ground-water withdrawals in the Houston and Pasadena areas from 1941 to 1945 (see table, p.5) caused the general decline of water levels, which began in 1937, to proceed at an accelerated rate during 1942, 1943, 1944, and the first 8 months of 1945. In the observation wells that are screened opposite the heavily-pumped sands at Houston and Pasadena and in the area west of Houston, the average decline from the spring of 1942 to the spring of 1945 was 27.5 feet; the largest average decline, amounting to 39.0 feet in 21 observation wells, occurred in the eastern Houston and Pasadena-Ship Channel areas. During the autumn of 1945 and the winter of 1945-46, the pumping in the industrial areas was curtailed to some extent. As a result of this reduction 10 of the observation wells in the eastern Houston and Pasadena areas had only a small net decline and 12 showed a pronounced rise in water levels between spring measurements in 1945 and 1946 (see hydrographs, figs. 3, 4, and 5, pp.37-39). In the northern, central, and western parts of Houston the decline from 1945 to 1946 was greater than it was from 1944 to 1945. This decline, it is believed was due in part to the spread of the cones of depression produced at Pasadena and elsewhere by heavy pumping during 1943 and 1944 and the first 8 months of 1945. With renewed pumping activity starting in the spring of 1946 and resulting in an all time record of withdrawals the water levels which had shown rises or decreased declines in preceeding months again started downward. It is expected that the levels in the spring of 1947 will show a substantial decline below those recorded in the spring of 1946.

In the Katy area it is estimated that 37,530 acres of rice was irrigated in 1946 as compared with 34,230 acres in 1945, 31,740 acres in 1944, 24,200 acres in 1940, 13,750 acres in 1937 and 8,000 acres in 1935. The records show that the pumpage in acre-feet per acre usually varies inversely with the rainfall during the growing season, the total amount of water(pumped water plus rainfall) applied to the irrigated land during the season in most of the years of the period being remarkably uniform (see table, p.16). In 1946, however, although the rainfall during the growing season was the second highest on record, the storm water caused considerable damage to irrigation levees with a consequent loss of water from the rice fields. Therefore, it was necessary to pump on the average about as much water per acre as the average pumped during several preceeding years. Expressed as a daily average for the entire year, the total pumpage amounted to about 58,000,000 gallons a day in 1946 as compared with 50,000,000 gallons in 1945 and 55,000,000 gallons in 1944.

The water levels in the observation wells of the Katy area showed an average decline of 3.5 feet from the spring of 1943 to the spring of 1946, of which 1.6 feet occurred in 1943-44, 1.4 feet in 1944-45, and 0.5 foot in 1945-46. During the 15-year period from 1931 to 1946, the 11 wells for which comparative measurements are available showed an average decline of 13.6 feet.

The outcrop areas of the water-bearing sands that supply the wells of Houston and Pasadena include the Katy pumping district. Except in this district the water levels in water-table observation wells in the outcrops north and northwest of Houston were from 5 to 10 feet higher during the period from 1941 to the autumn of 1946 than they were in 1938-40, and in the few wells for which comparable measurements are available they were as high or higher than they were in 1931-34. This indicates that recharge to the sands in a large part of the outcrop has been greater than the amount of water transmitted down the dip toward the heavily-pumped areas. A large proportion of the recharge was contributed during the abnormally wet year November 1940 to October 1941 and during periods of above average rainfall in 1945, and during the abnormally wet year 1946.

In the Bammel gas field and the surrounding territory to the northwest of Houston, an abnormal rise in water levels began in December 1942 and continued for several months. This rise was caused by the escape of large quantities of natural gas from a leaky gas well into the water-bearing sands. Many water wells in and near the gas field began to flow and continued to flow for several months. The greatest total rise recorded between December 1942 and September 1944 was 61 feet in well 268 at Westfield. Since September 1944 the water levels have declined steadily, and measurements made since January 1946 indicate that in most of the wells of the area the water levels have returned to, or are approaching, the normal stage.

The periodic analyses of water samples from selected observation wells, the latest of which were made in January and February of 1946, show no significant change in the chemical composition of the ground water of the Houston district.

In connection with the cooperative investigation a series of pumping tests were made in November 1945 on the six wells at the new Southwest well field of the City of Houston. Analyses of the results of the tests by the Theis non-equilibrium method gave values for transmissibility of the water-bearing sands ranging from 139,000 to 156,000 and averaging 145,000 gpd/ft, and coefficients of storage ranging from 0.00089 to 0.0012 and averaging 0.0010. Using these figures, and a figure of 15,000,000 gallons a day from eight wells as the assumed average rate of pumping, future pumping levels in the eight wells were computed for periods of 1 year and 5 years. The decline in each of the eight wells for each 100 gallons a minute pumped per well was also computed for periods ranging from 1 month to 5 years.

It is concluded that the ground-water reservoir of the Houston district has made a most satisfactory showing during the recent period of heavy demand. Thus far, nothing can be seen in the record to show that the economic pumping yield has been exceeded; nevertheless, practical considerations point to the desirability of permanently reducing the present draft in the most heavily pumped areas. With the decline in water levels in these areas and adjacent territory the cost of pumping has advanced, the pumping levels have fallen below the top of the pump bowls in some wells and are near that level in others. This necessitates lengthening of the pump column and, in some wells, costly replacement of pump and power equipment. In wells whose diameter is reduced a short distance below the present pump setting it may be impossible to lower the pump, and the wells may have to be abandoned.

With the recent addition of the Southwest well field in a locality comparatively remote from other areas of heavy pumping, and with improved pipe line facilities, the City Water Department appears to be in an excellent position for meeting public requirements during the coming year.

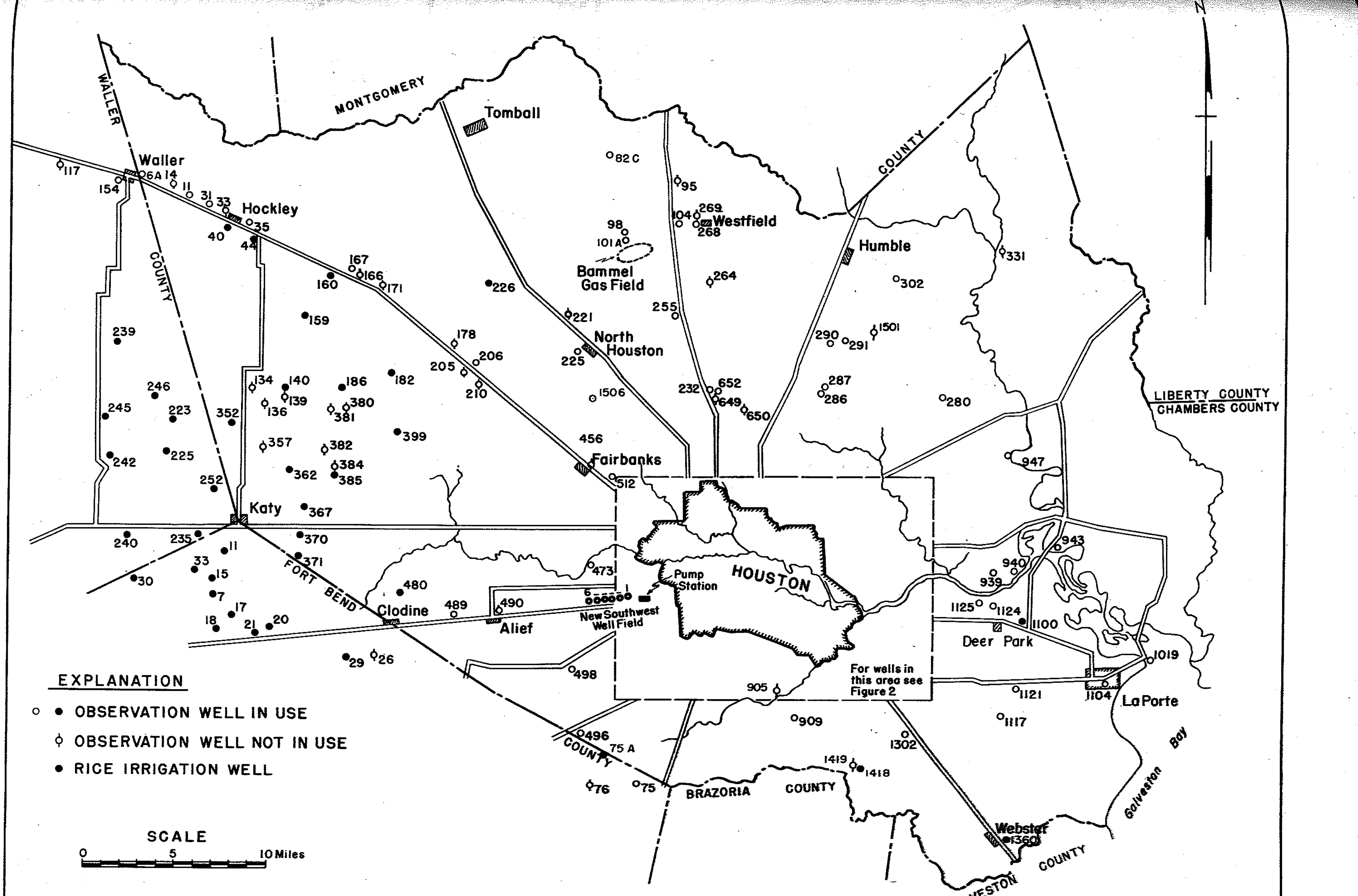


Figure 1 - MAP OF HOUSTON DISTRICT, TEXAS SHOWING OBSERVATION WELLS.

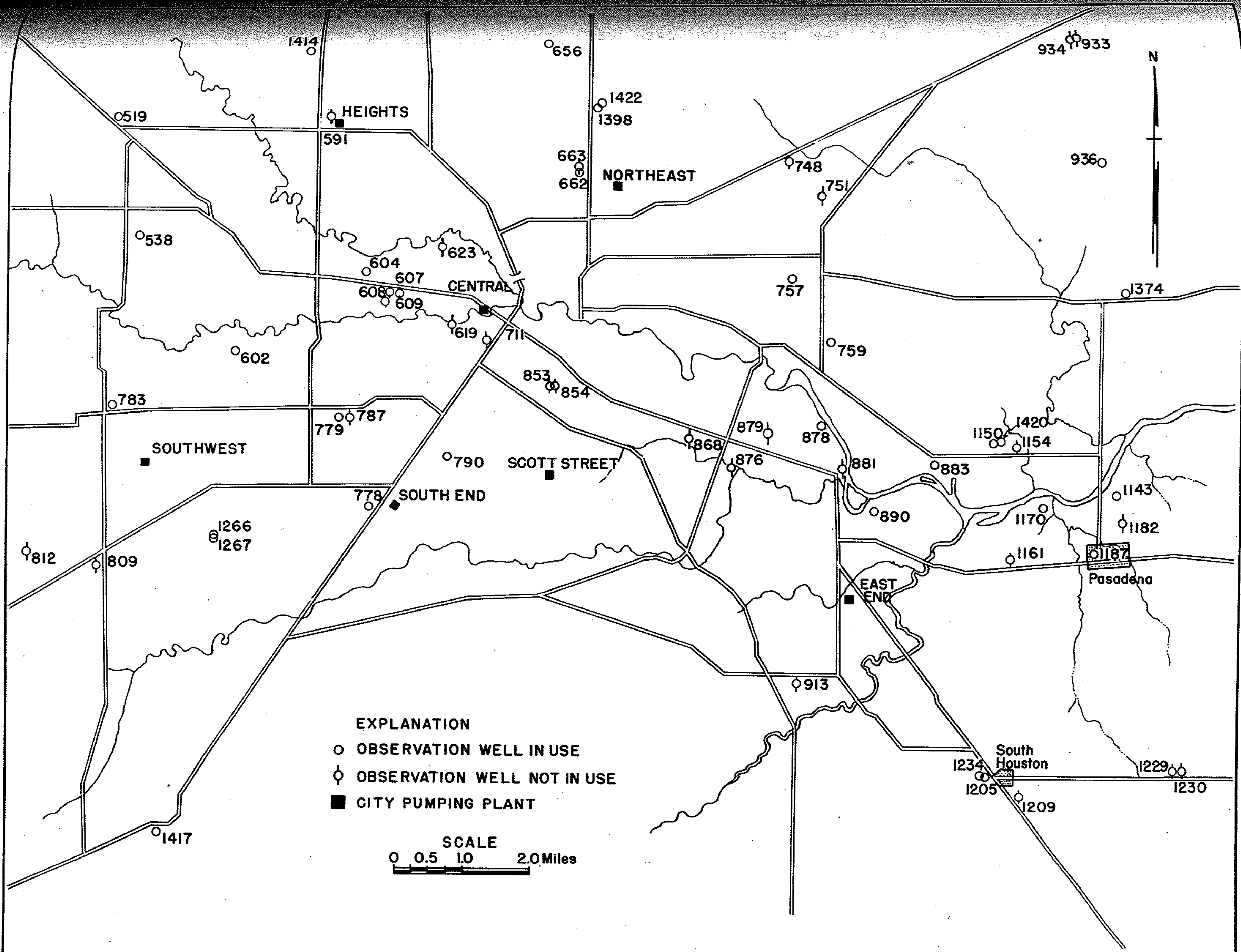


Figure 2– MAP OF HOUSTON AND VICINITY, TEXAS SHOWING OBSERVATION WELLS & CITY PUMPING PLANTS

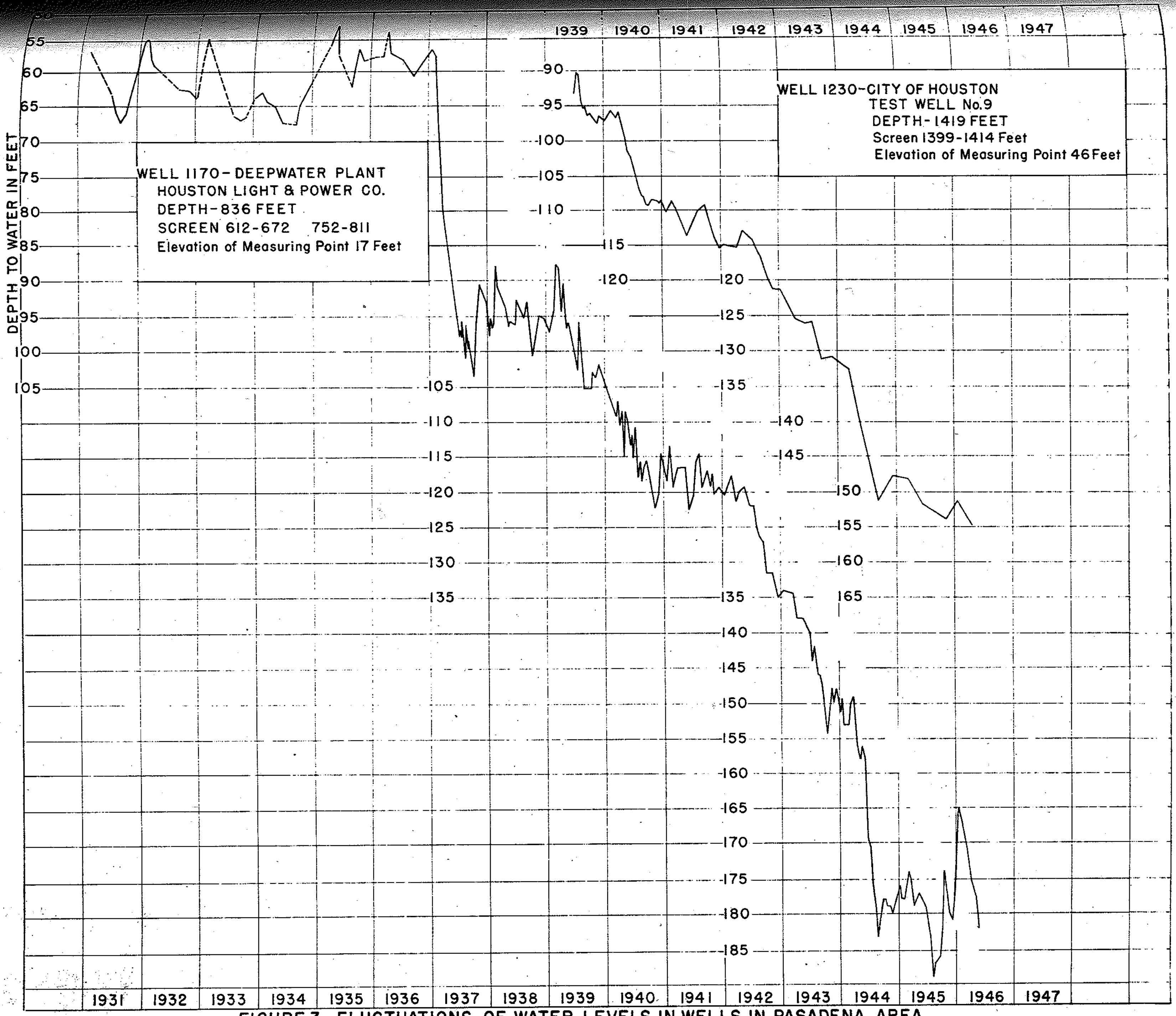


FIGURE 3-FLUCTUATIONS OF WATER LEVELS IN WELLS IN PASADENA AREA

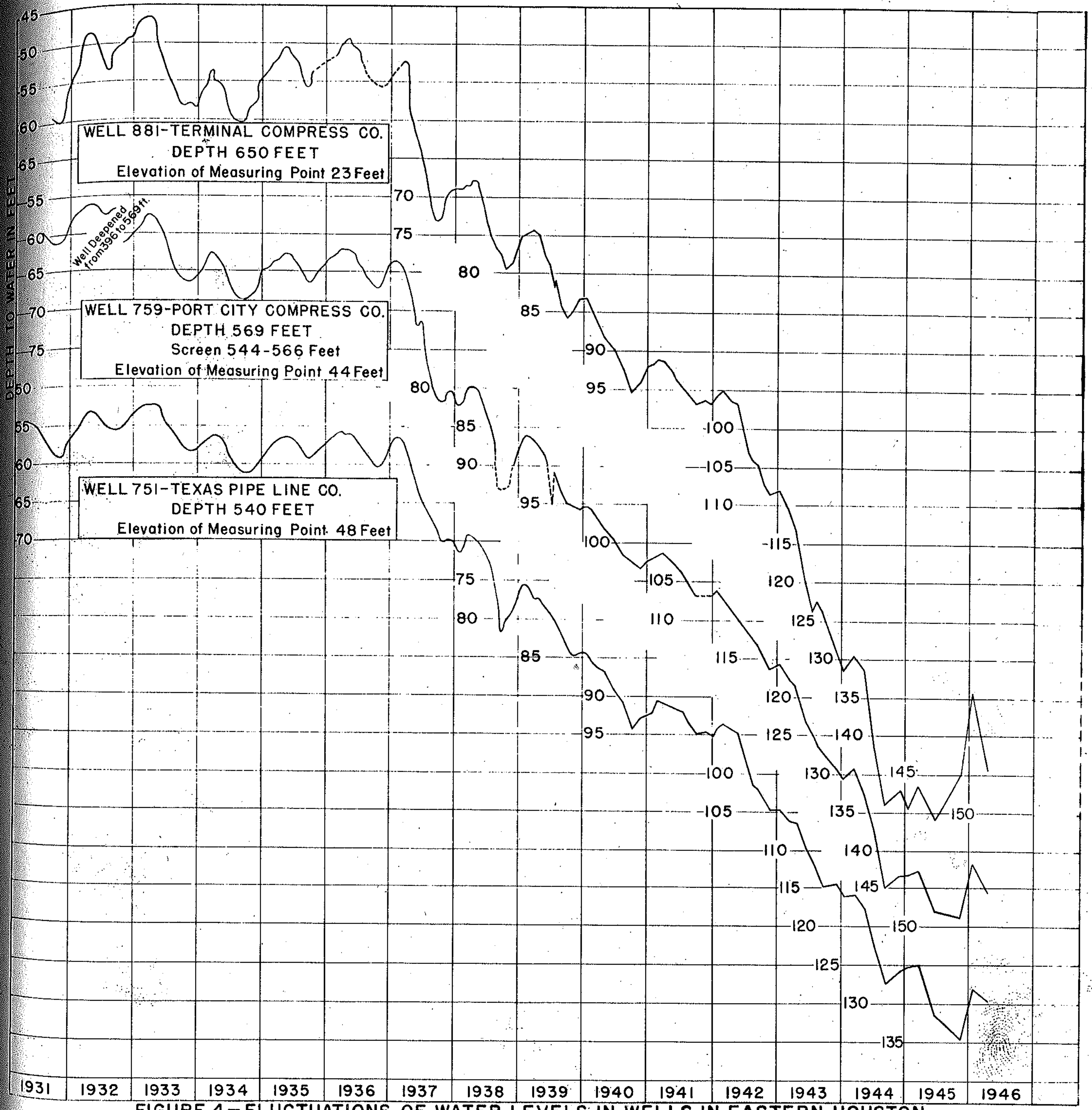


FIGURE 4—FLUCTUATIONS OF WATER LEVELS IN WELLS IN EASTERN HOUSTON

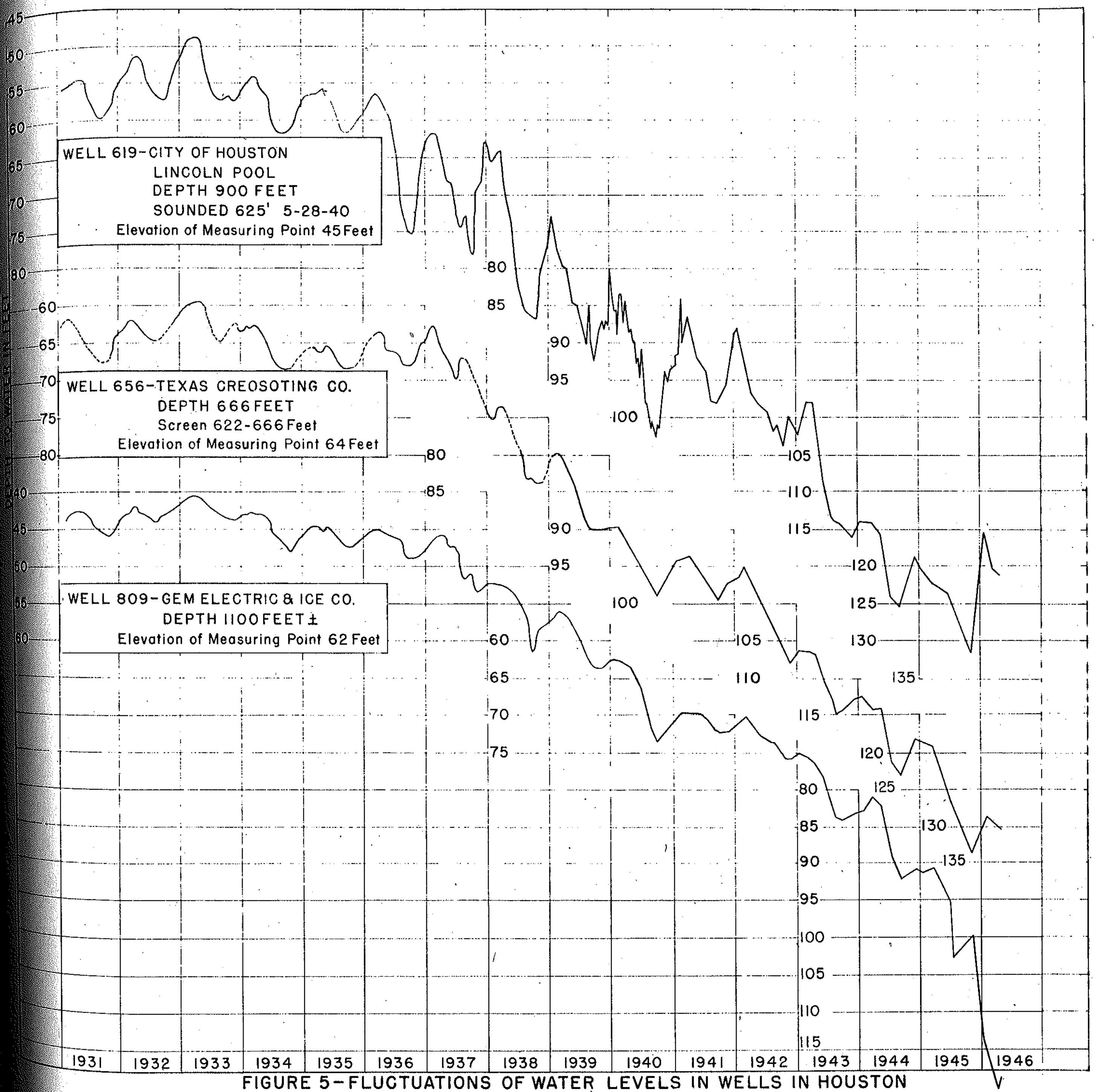
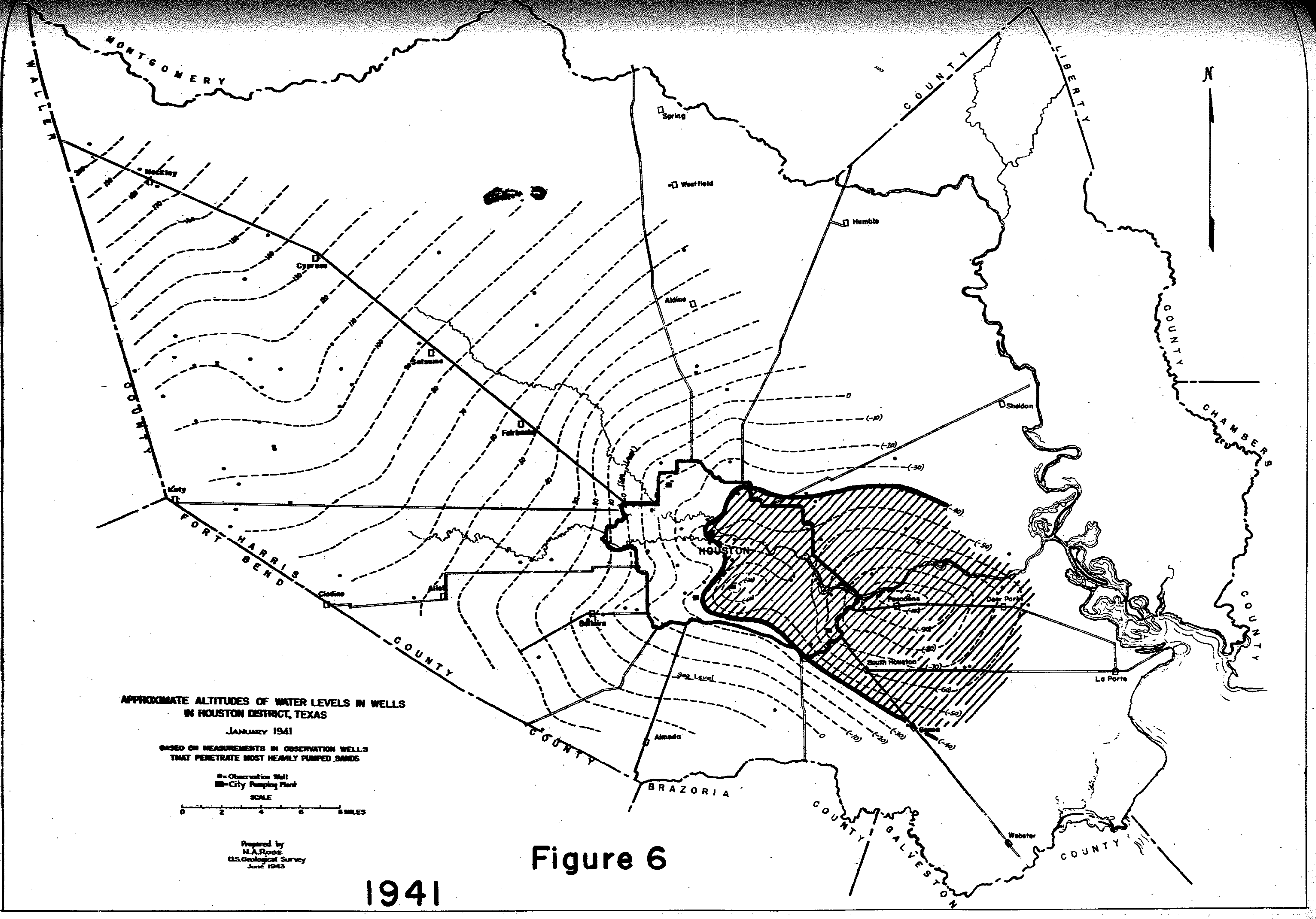


FIGURE 5—FLUCTUATIONS OF WATER LEVELS IN WELLS IN HOUSTON



APPROXIMATE ALTITUDES OF WATER LEVELS IN WELLS
IN HOUSTON DISTRICT, TEXAS

January 1941

BASED ON MEASUREMENTS IN OBSERVATION WELLS
THAT PENETRATE MOST HEAVILY PUMPED SANDS

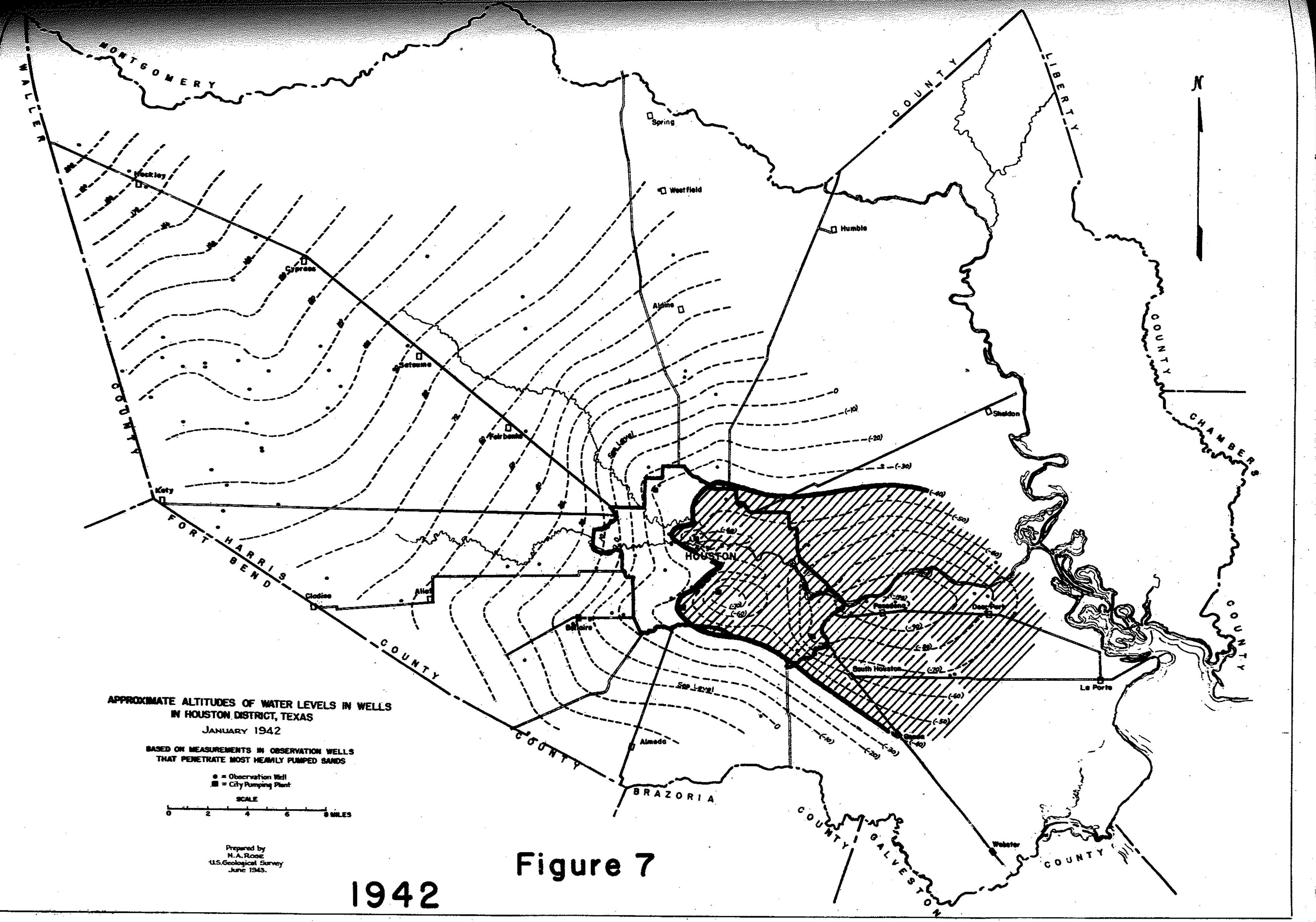
● = Observation Well
■ = City Pumping Plant

SCALE
0 2 4 6 8 MILES

Prepared by
N. A. Rose
U.S. Geological Survey
June 1943

Figure 6

1941



APPROXIMATE ALTITUDES OF WATER LEVELS IN WELLS
IN HOUSTON DISTRICT, TEXAS
JANUARY 1942

BASED ON MEASUREMENTS IN OBSERVATION WELLS
THAT PENETRATE MOST HEAVILY PUMPED SANDS

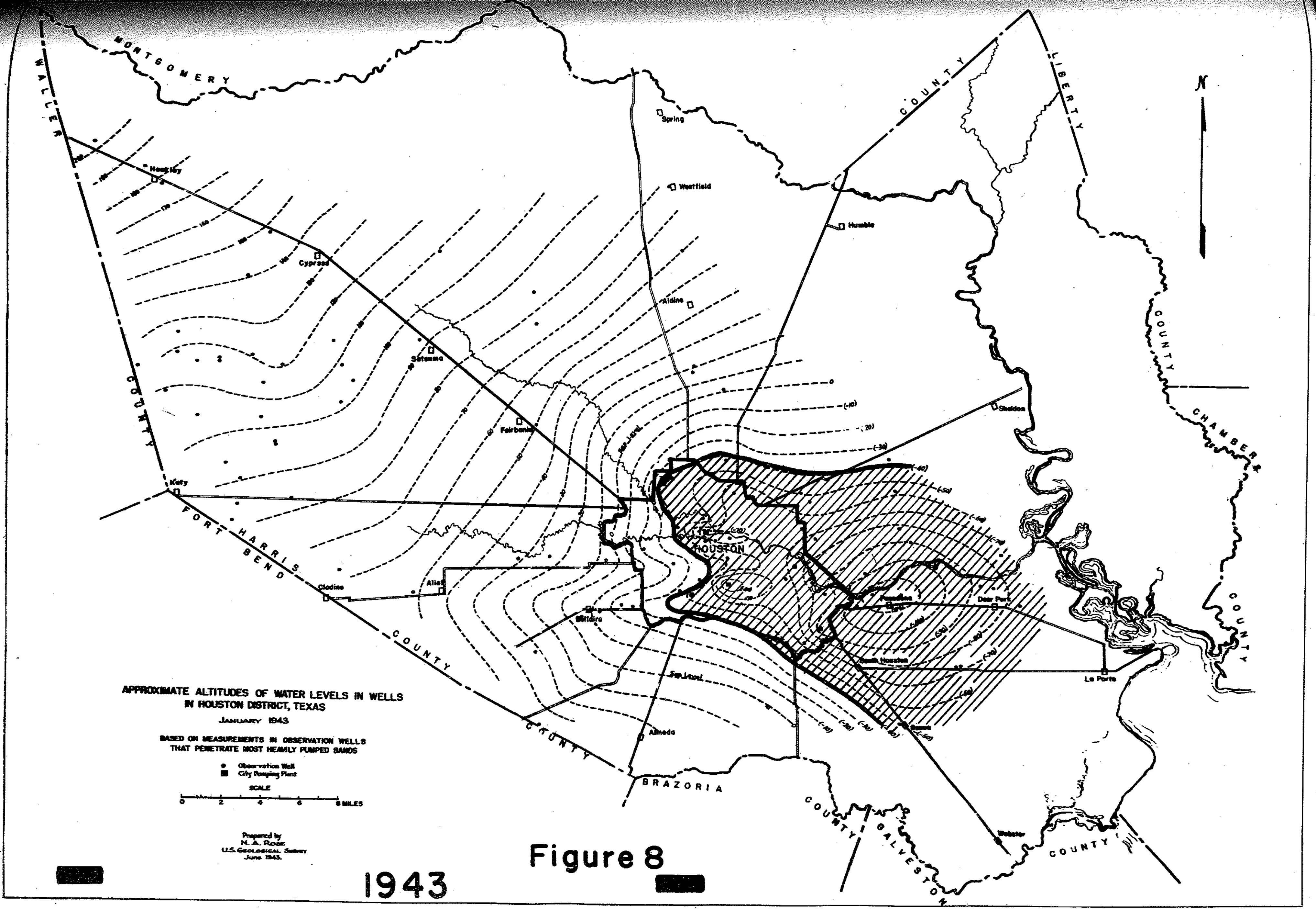
● = Observation Well
■ = City Pumping Plant

SCALE
0 2 4 6 8 MILES

Prepared by
N. A. Rose
U.S. Geological Survey
June 1943.

Figure 7

1942



APPROXIMATE ALTITUDES OF WATER LEVELS IN WELLS
IN HOUSTON DISTRICT, TEXAS

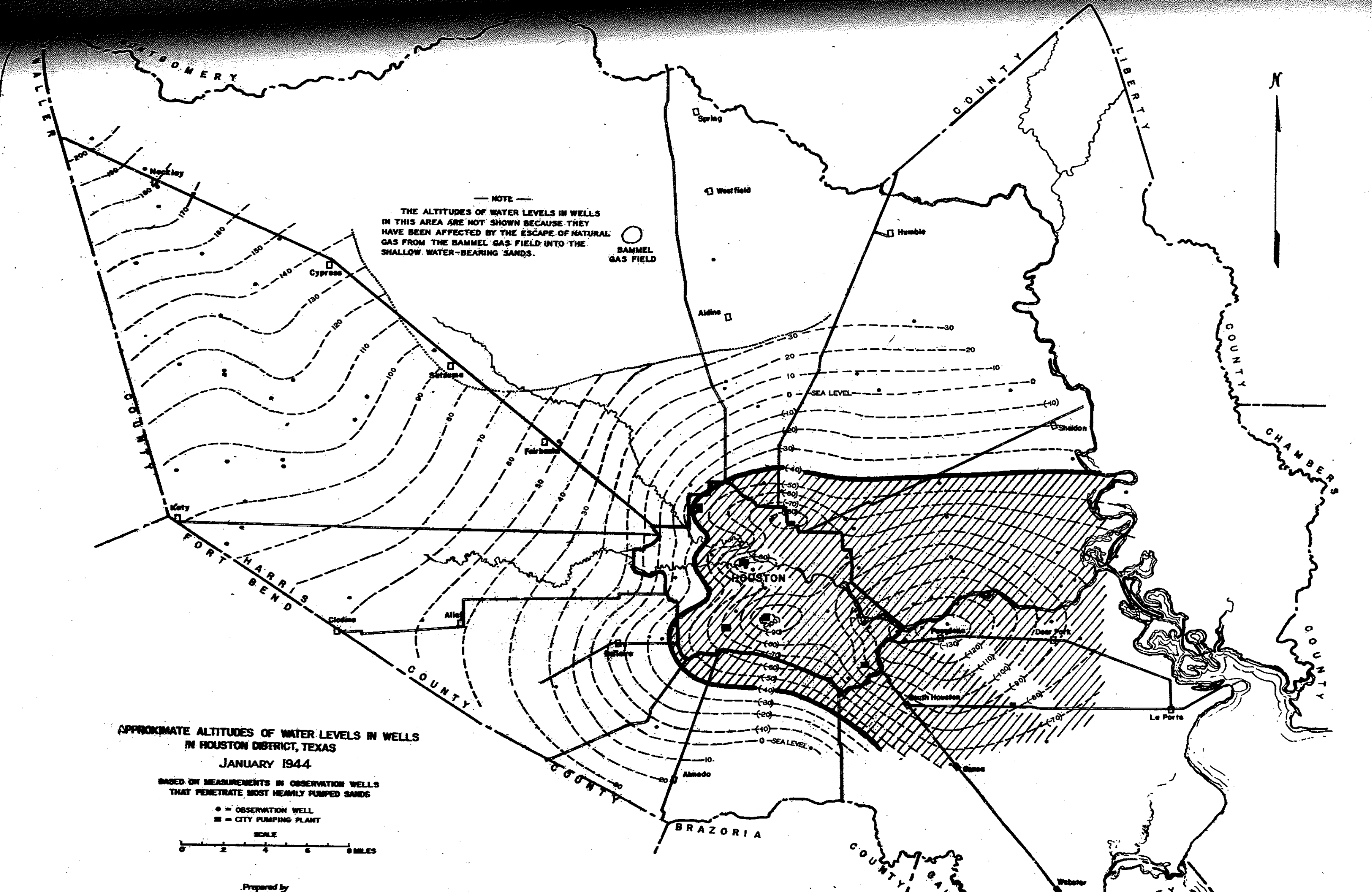
JANUARY 1943

BASED ON MEASUREMENTS IN OBSERVATION WELLS
THAT PENETRATE MOST HEAVILY PUMPED SANDS

Prepared by
N. A. Rose
U.S. Geological Survey
June 1943.

Figure 8

1943



— NOTE —

THE ALTITUDES OF WATER LEVELS IN WELLS IN THIS AREA ARE NOT SHOWN BECAUSE THEY HAVE BEEN AFFECTED BY THE ESCAPE OF NATURAL GAS FROM THE BAMMEL GAS FIELD INTO THE SHALLOW WATER-BEARING SANDS.

APPROXIMATE ALTITUDES OF WATER LEVELS IN WELLS
IN HOUSTON DISTRICT, TEXAS
JANUARY 1944

BASED ON MEASUREMENTS IN OBSERVATION WELLS
THAT PENETRATE MOST HEAVILY PUMPED SANDS

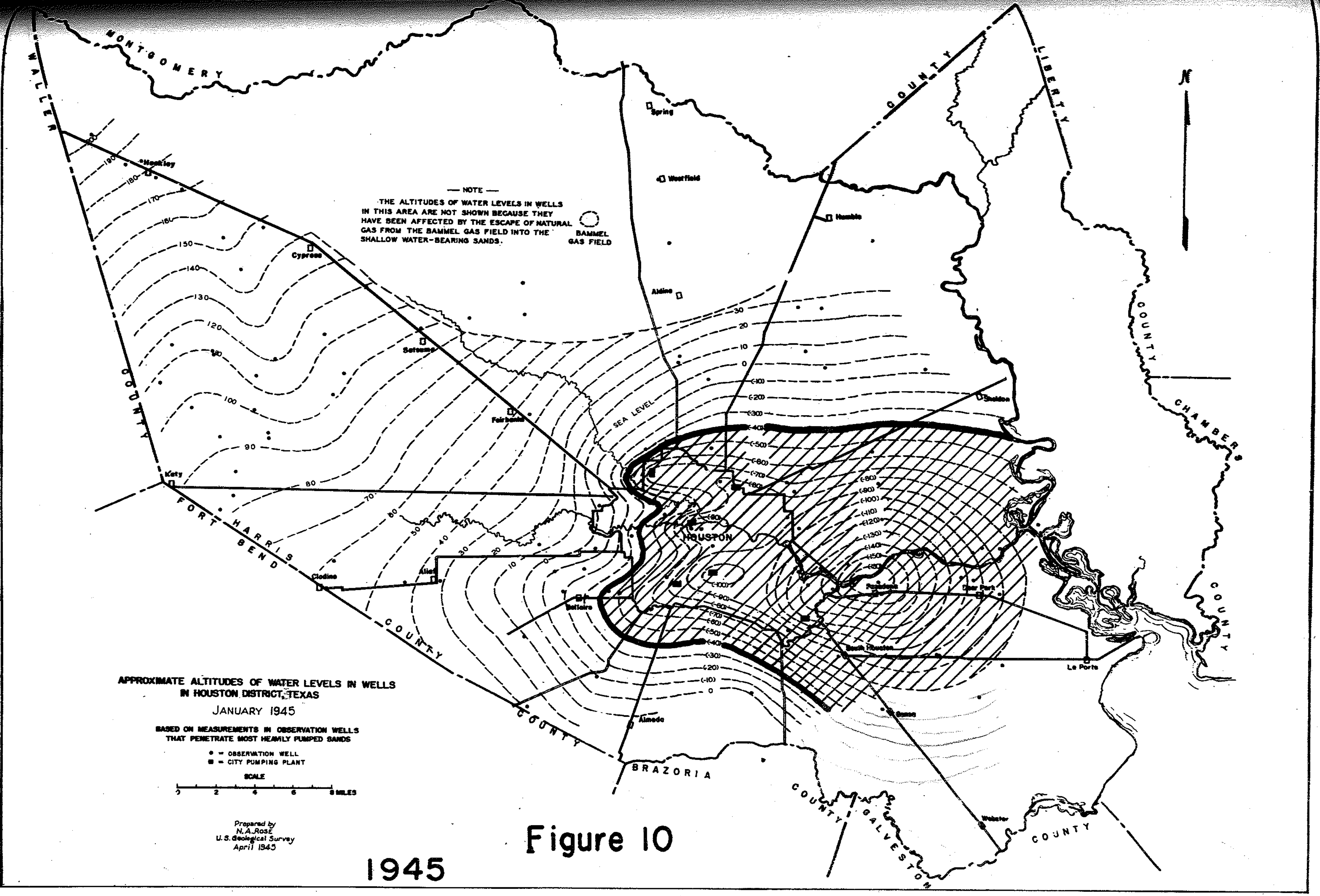
● = OBSERVATION WELL
■ = CITY PUMPING PLANT

SCALE
0 2 4 6 8 MILES

Prepared by
N. A. Rose
U.S. Geological Survey
March 1944

Figure 9

1944



APPROXIMATE ALTITUDES OF WATER LEVELS IN WELLS
IN HOUSTON DISTRICT, TEXAS

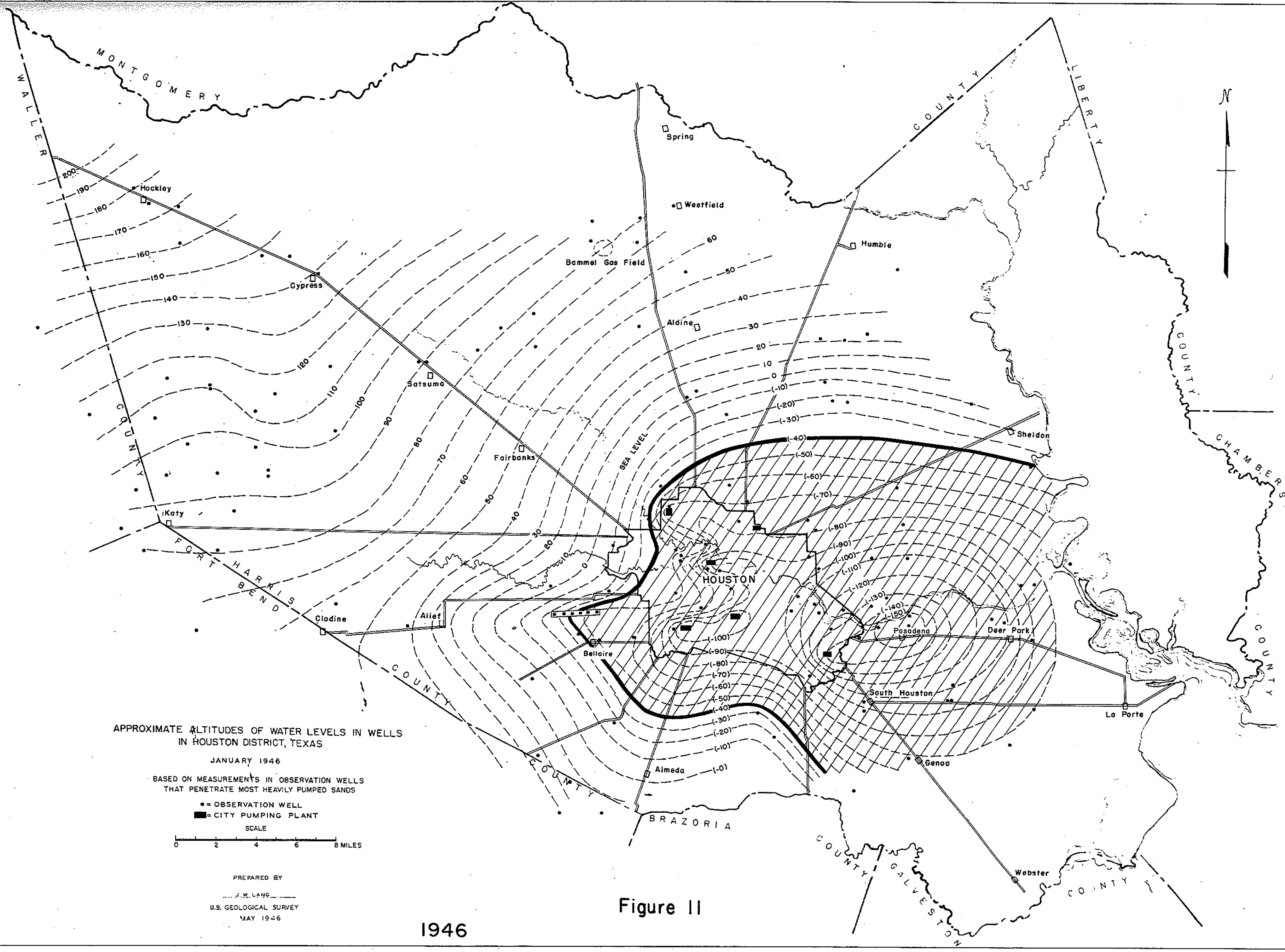
JANUARY 1945

BASED ON MEASUREMENTS IN OBSERVATION WELLS
THAT PENETRATE MOST HEAVILY PUMPED SANDS

Prepared by
N. A. Rose
U.S. Geological Survey
April 1945

Figure 10

1945



APPROXIMATE ALTITUDES OF WATER LEVELS IN WELLS
IN HOUSTON DISTRICT, TEXAS

JANUARY 1946

BASED ON MEASUREMENTS IN OBSERVATION WELLS
THAT PENETRATE MOST HEAVILY PUMPED SANDS

PREPARED BY
J. W. LANG
U.S. GEOLOGICAL SURVEY
MAY 1946

Figure 11

1946

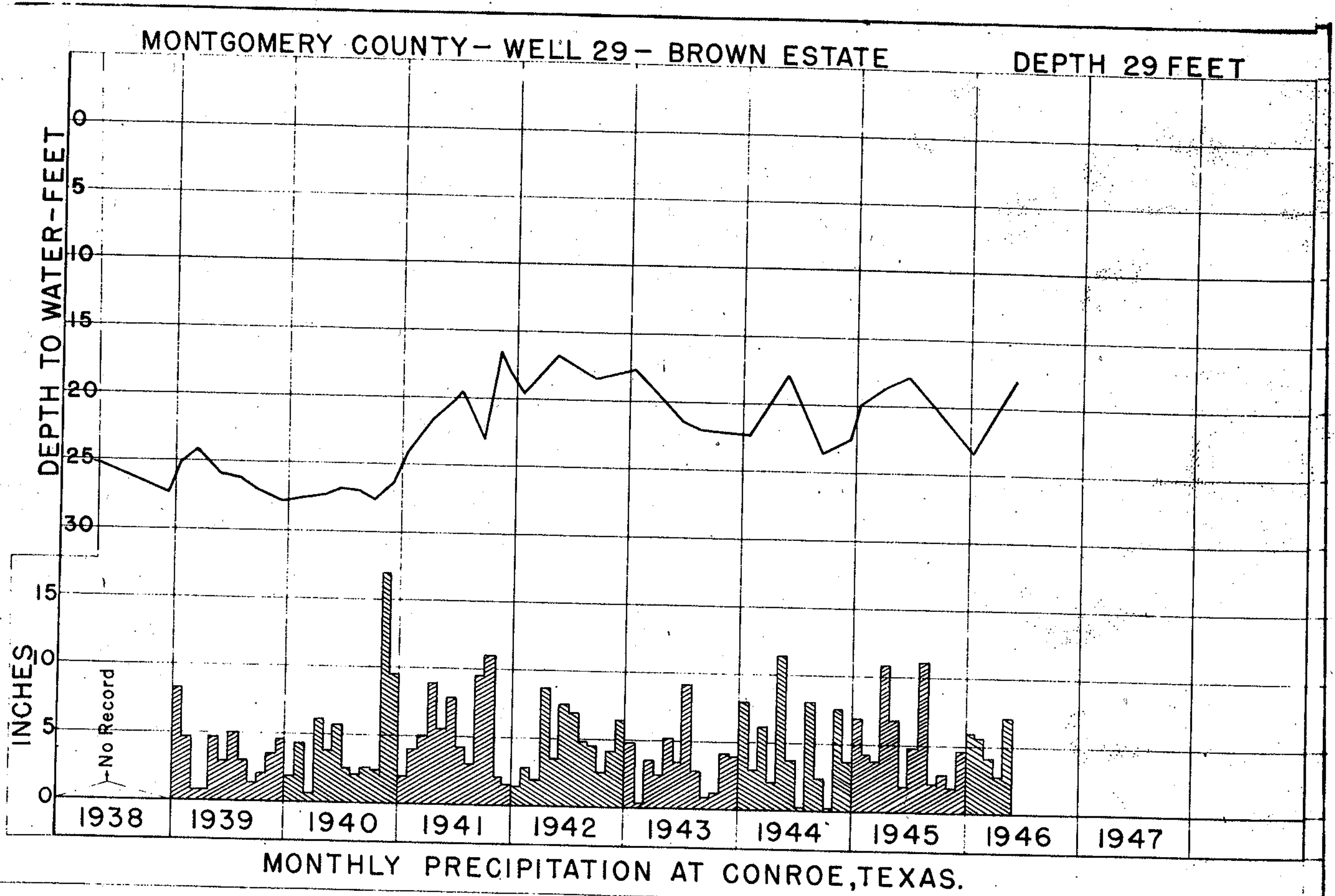
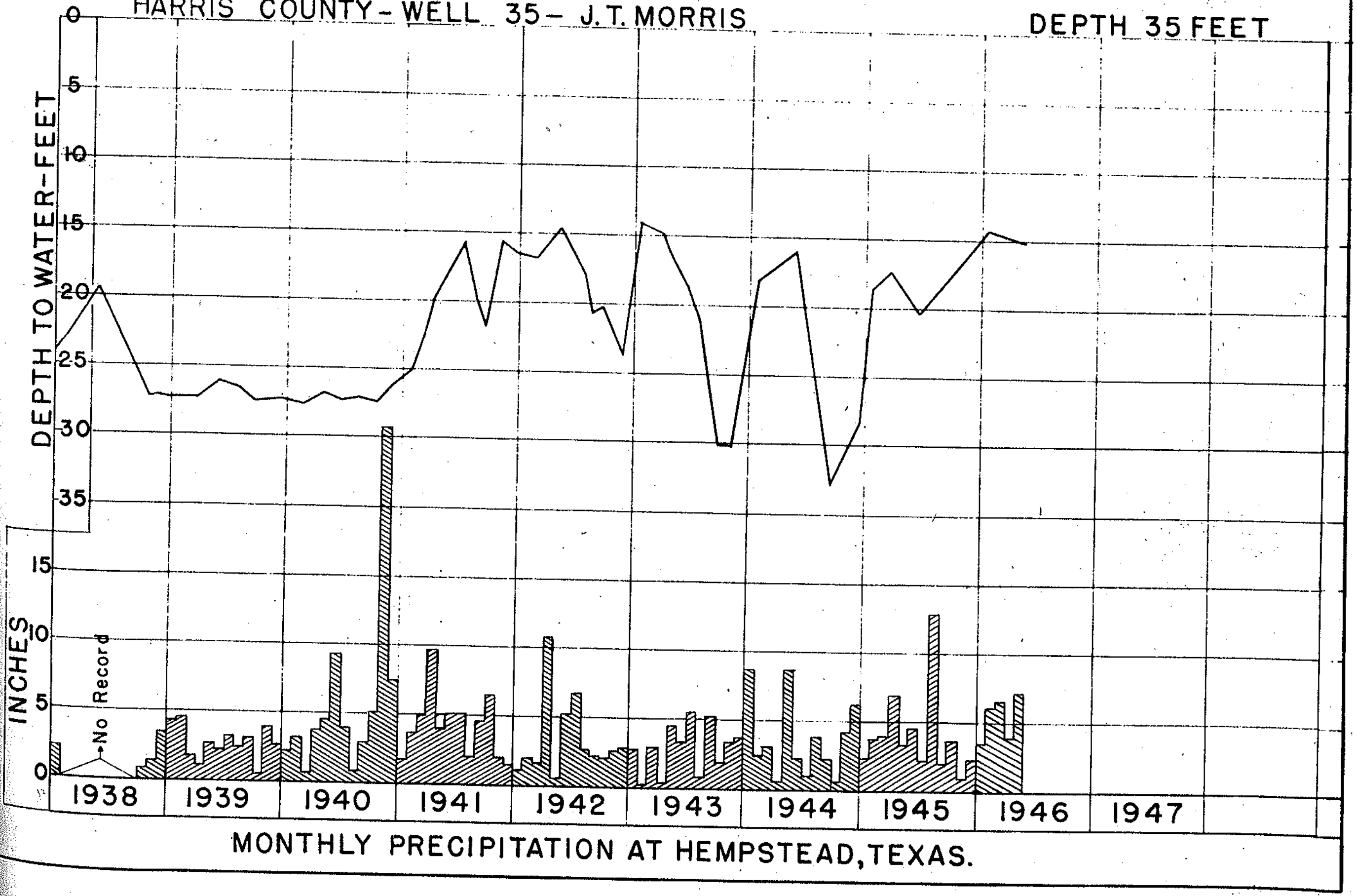


Figure 12 – FLUCTUATIONS OF WATER LEVELS IN SHALLOW WELLS AND PRECIPITATION IN OUTCROP AREA N. AND N.W. OF HOUSTON.



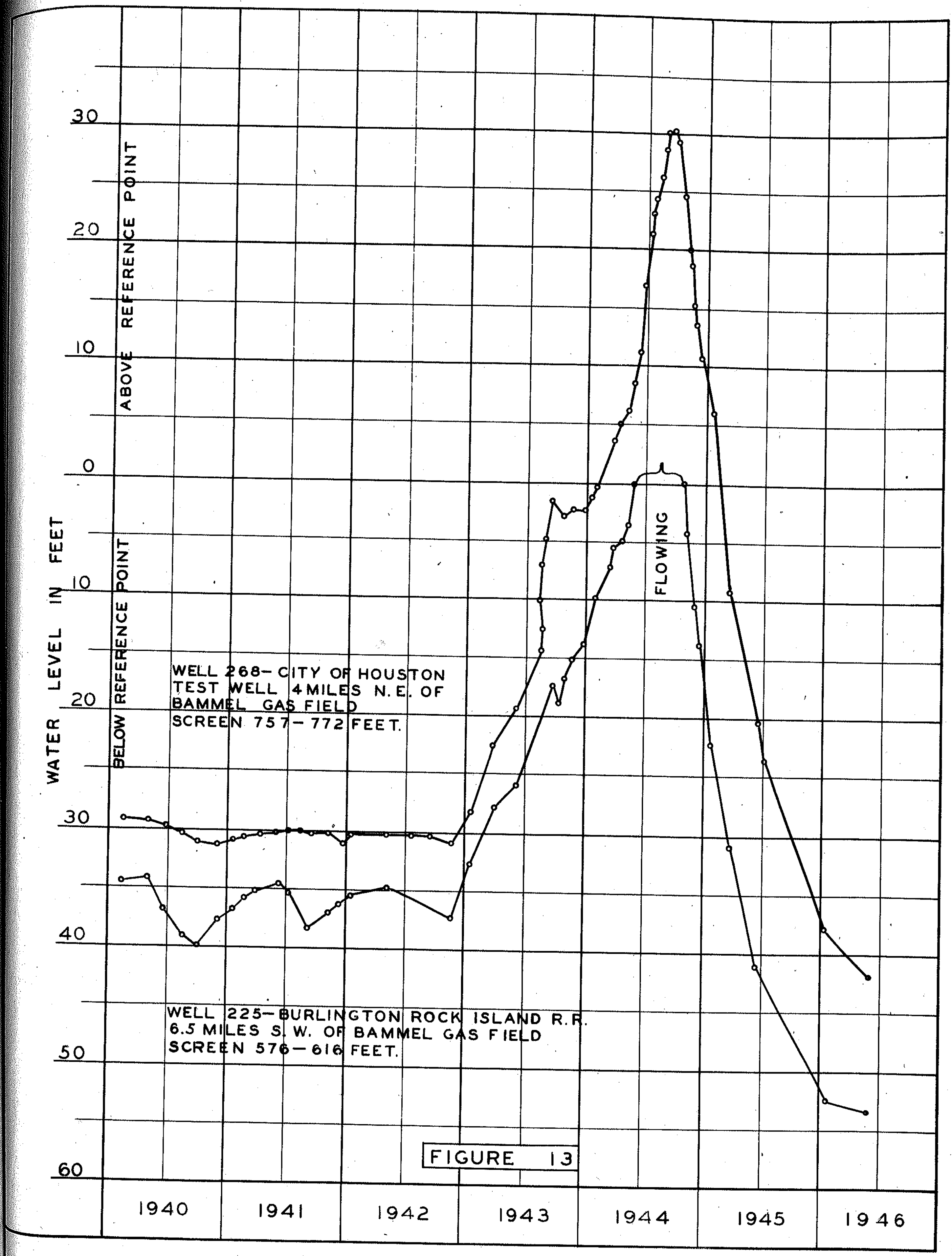

WATER LEVEL IN FEET
ABOVE REFERENCE POINT
BELOW REFERENCE POINT
30
20
10
0
10
20
30
40
50
60
FLOWING
WELL 268- CITY OF HOUSTON
TEST WELL 4 MILES N.E. OF
BAMMEL GAS FIELD
SCREEN 757-772 FEET.
WELL 225-BURLINGTON ROCK ISLAND R.R.
6.5 MILES S.W. OF BAMMEL GAS FIELD
SCREEN 576-616 FEET.
1940
1941
1942
1943
1944
1945
1946

FIGURE 13

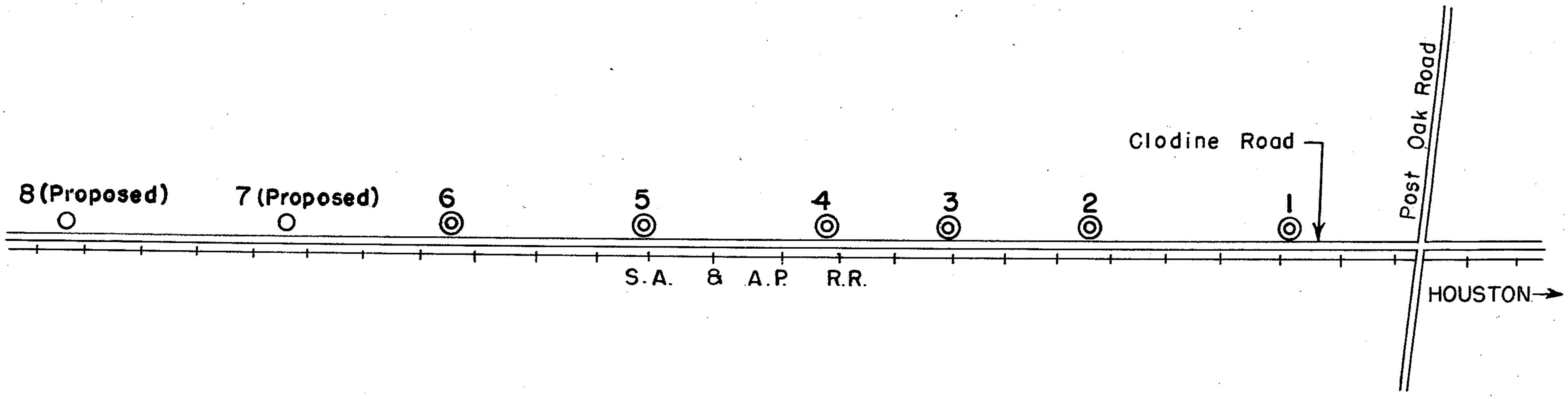
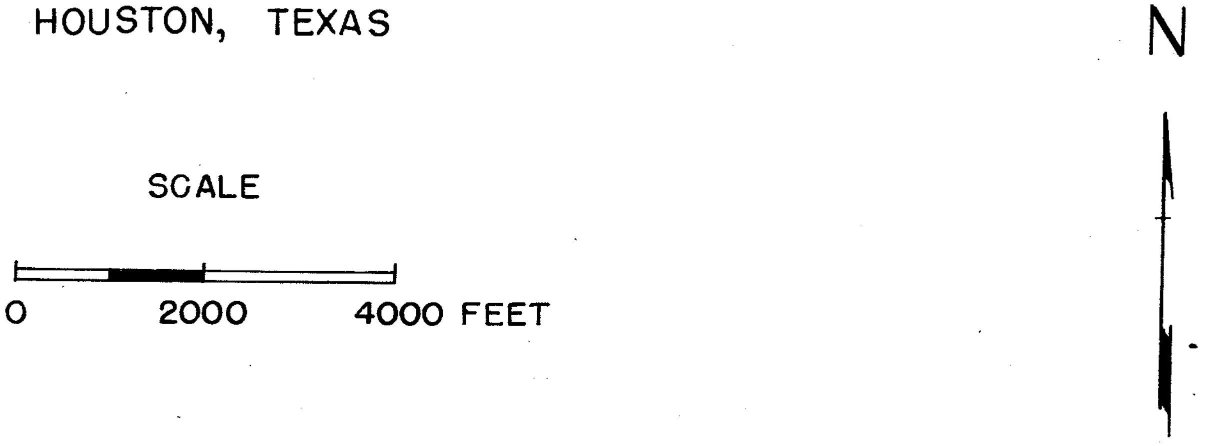


FIGURE 14-SKETCH SHOWING SPACING OF WELLS AT SOUTHWEST WELL FIELD, HOUSTON, TEXAS



MLC 2-20-4