TEXAS BOARD OF WATER ENGINEERS

BULLETIN 5602

PUMPAGE OF GROUND WATER AND CHANGES IN ARTESIAN PRESSURE IN THE HOUSTON DISTRICT AND BAYTOWN-LA PORTE AREA, TEXAS, 1953-55

By

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United States Geological Survey

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

February 1956

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ABSTRACT

Average daily ground-water withdrawals in the Houston district, Texas, reached an all-time high of 338,000,000 gallons in 1954. However, the increase in pumpage over that of 1953 was confined to the Katy rice-irrigation area, where a record high of about 67,000 acres was irrigated. The completion of Lake Houston Dam on the San Jacinto River and the resulting increased use of surface water in the heavily industrialized Houston-Pasadena area permitted the first decrease in ground-water pumping in that area since 1941. The average daily withdrawal in the Houston-Pasadena area in 1954 was about 180,000,000 gallons as compared with 186,000,000 gallons in 1953.

In the Baytown-La Porte area, which lies to the east of the Houston district, the average daily pumpage in 1954 was about 22,000,000 gallons as compared with 23,000,000 in 1953, and 25,000,000 in 1952.

As a result of the decrease in pumping in the Houston-Pasadena area in 1954, large recoveries of water levels have been observed in many wells throughout the area. The largest recoveries were noted in some of the wells of the city of Houston, where a maximum recovery of 31 feet was recorded in one well between spring measurements in 1954 and 1955.

Water levels in wells in the Katy area continued to decline at a slow rate. Declines in 57 observation wells averaged 4.9 feet during the 2-year period 1953-55.

Water levels in wells in the Baytown-La Porte area continued to decline at slow rates.

A quality-of-water observation program designed to detect salt-water encroachment into the heavily pumped sands has been in effect for many years. During this program substantial changes in quality have been observed in two test wells south of Pasadena. The chloride content of the water in one well increased by 28 parts per million between 1948 and 1955, and in another well it increased by 165 parts per million from 1950 to 1955.

As a result of the lowering of artesian pressures in the Houston district, a general subsidence of the land surface has taken place. For every 100 feet of decline in artesian pressure since 1943 about 1 foot of land-surface subsidence has occurred. Recent releveling indicates that the land surface in the vicinity of the ship channel has subsided more than 2 feet since 1943.

INTRODUCTION

Location

The Houston district, as used in this report, comprises an area of about 1,800 square miles and includes Harris County west of the San Jacinto River and adjoining parts of Fort Bend, Waller, and Montgomery Counties (fig. 1). The district can be subdivided on the basis of ground-water withdrawals into three main areas (fig. 2) as follows:

(1) The Katy area, composed of irrigated rice lands, occupying much of northern and western Harris County, northern Fort Bend County, and southeastern Waller County.

(2) The Houston area, consisting of the city of Houston and the closely adjoining territory.

(3) The Pasadena area, which includes the Ship Channel subarea, a heavily industrialized zone extending east from Houston along the Houston Ship Channel to the vicinity of Deer Park.

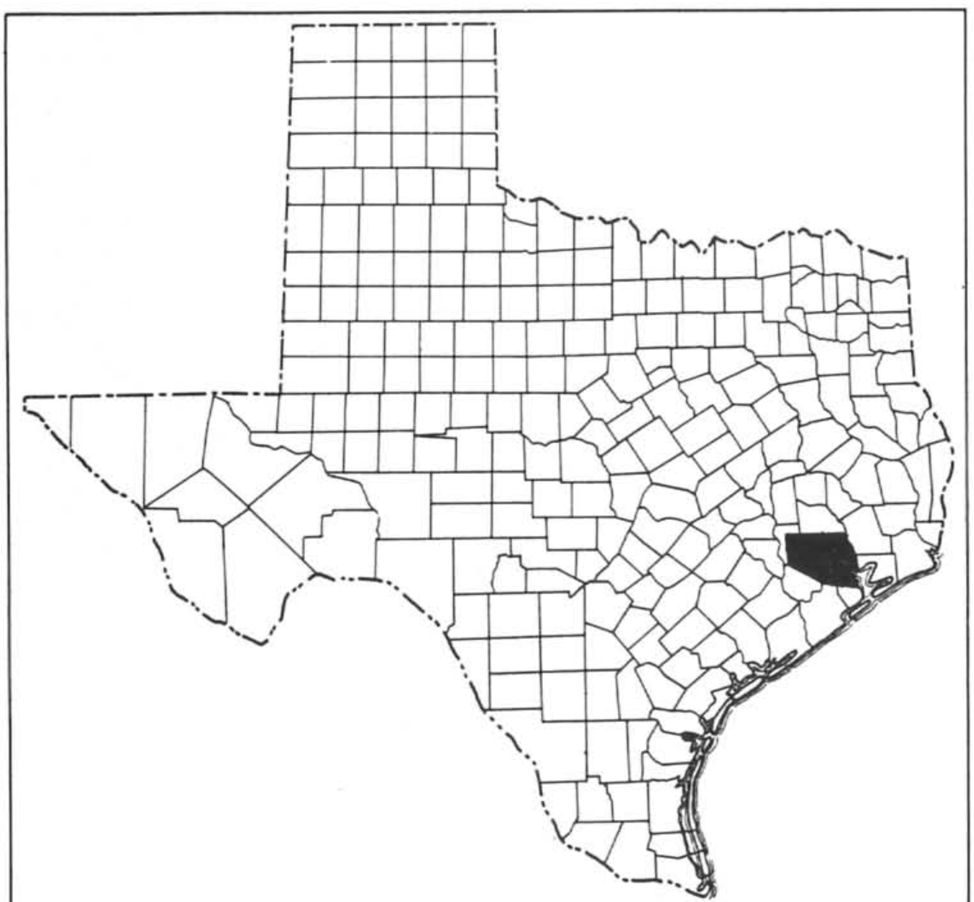

FIGURE 1.-Map of Texas showing location of the Houston district.

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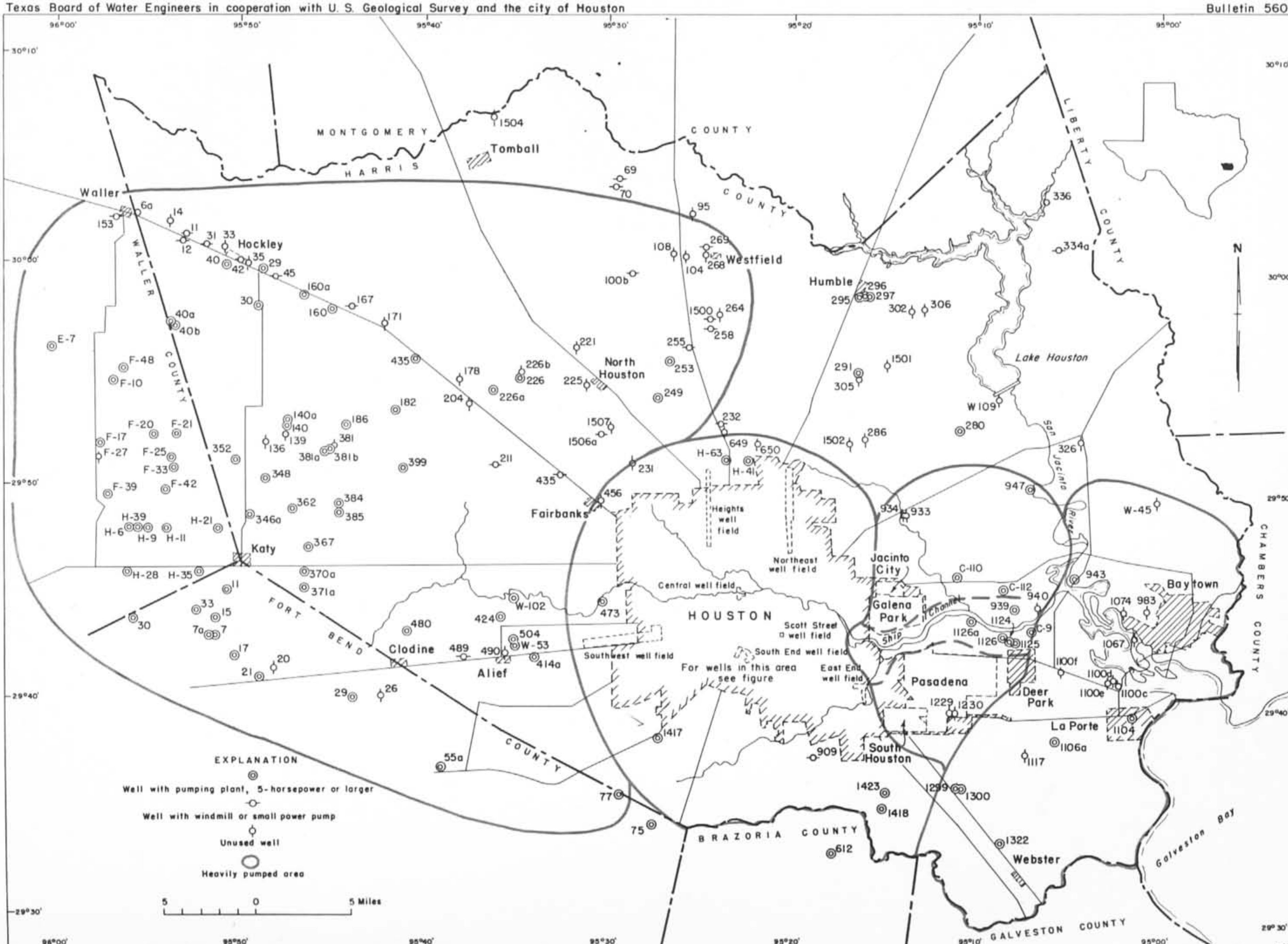

FIGURE 2.-Map of Houston district, Texas, showing location of observation wells and heavily pumped areas.

Data for the Baytown-La Porte area, which is not part of the Houston district but which is in that portion of Harris County east of the San Jacinto River and southeast of the Pasadena area, also are published in this report. Most of the ground water used in the Baytown-La Porte area is obtained from wells screened in the "Alta Loma" sand (Rose, 1943) which is the principal aquifer in Galveston County.

Purpose and Scope of Report

This is one of a series of reports* presenting information regarding the ground-water resources of the Houston district obtained by the United States Geological Survey in cooperation with the Texas Board of Water Engineers and the city of Houston. The report presents data on pumpage, changes in artesian pressure, and related information compiled during the period 1953-55.

The geology, geography, and climate of the Houston district have been described in previous reports. The geology of the district was summarized by Lang and Winslow (1950), and the water resources of the Houston-Galveston region were discussed by Goines, Winslow, and Barnes (1951).

The fieldwork and preparation of this report were under the administrative direction of A. N. Sayre, Chief of the Ground Water Branch, U. S. Geological Survey, and under the direct supervision of R. W. Sundstrom, District Engineer in charge of ground-water investigations in Texas.

PUMPAGE

Houston District

A pumpage inventory has been made in the Houston district each spring covering the preceding calendar year. Pumpage data were obtained from all industries, municipalities, and water districts pumping more than 5,000 gallons of water per day. Although many of the smaller industries and municipalities do not meter the water pumped from wells, nearly all the larger water systems are metered, so that more than 80 percent of the water pumped in the Houston-Pasadena area is recorded by meters. It is necessary to estimate the remainder, which is less than 20 percent. Pumpage figures for the Katy area were based on the acreage irrigated, the duty of water per acre, the total rainfall during the pumping season, and the total amount of power consumed by irrigation pumps each season.

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* See bibliography.

The total pumpage in the Houston district in 1953 averaged 306,000,000 gallons per day (gpd), and in 1954 averaged 338,000,000 gpd, compared with 308,000,000 gpd in 1952. Figure 3 shows the average daily pumpage from 1930 to 1954, inclusive, and shows the continued upward trend of rates of withdrawal of ground water in the Houston district.

Katy area

The Katy area, as used in this report, is the rice-irrigation area in northern and western Harris County, eastern Waller County, and northern Fort Bend County (fig. 2). The number of acres of rice irrigated by ground water in the Katy area increased from approximately 55,000 in 1952 and 58,000 in 1953 to approximately 67,000 in 1954. About 225 wells ranging in depth from 200 feet to 1,600 feet were in use in 1954. The average pumpage in the Katy area was about 120,000,000 gpd in 1953 and 160,000,000 gpd in 1954, as compared with 128,000,000 gpd in 1952. Figure 3 shows the average daily pumpage for the period 1930-54. Daily withdrawals during the 5-month pumping season (about 400,000,000 gpd) are more than twice as high as the average daily pumpage given above, which is averaged for the whole year.

Houston-Pasadena area

The completion of Lake Houston Dam on the San Jacinto River early in 1954 made larger amounts of river water available to the industries along the ship channel during the last half of the year. As a result of the completion of the dam and treatment plant, surface water was supplied to the Houston municipal mains in May 1954 for the first time since 1904. The year 1954 was the first since 1941 during which less water was pumped from wells in the Houston-Pasadena area than during the preceding year. By the end of 1954 the treatment plant was supplying more than 16,000,000 gpd of water from Lake Houston. The average use by the Houston Water Department in 1954 was 8,800,000 gpd of treated surface water and 72,500,000 gpd of ground water. This compares with 77,300,000 gpd of ground water in 1953 and 73,700,000 gpd in 1952.

Ground-water withdrawals from the industrial wells in the Pasadena area averaged 75,000,000 gpd in 1954, as compared with 80,000,000 gpd in 1953 and 75,000,000 gpd in 1952. During the latter part of 1954, because of increased use of surface water, the rate was appreciably less than the figure quoted above, which is the average for the full year. The average daily pumpage in the Houston-Pasadena area is shown in figure 4.

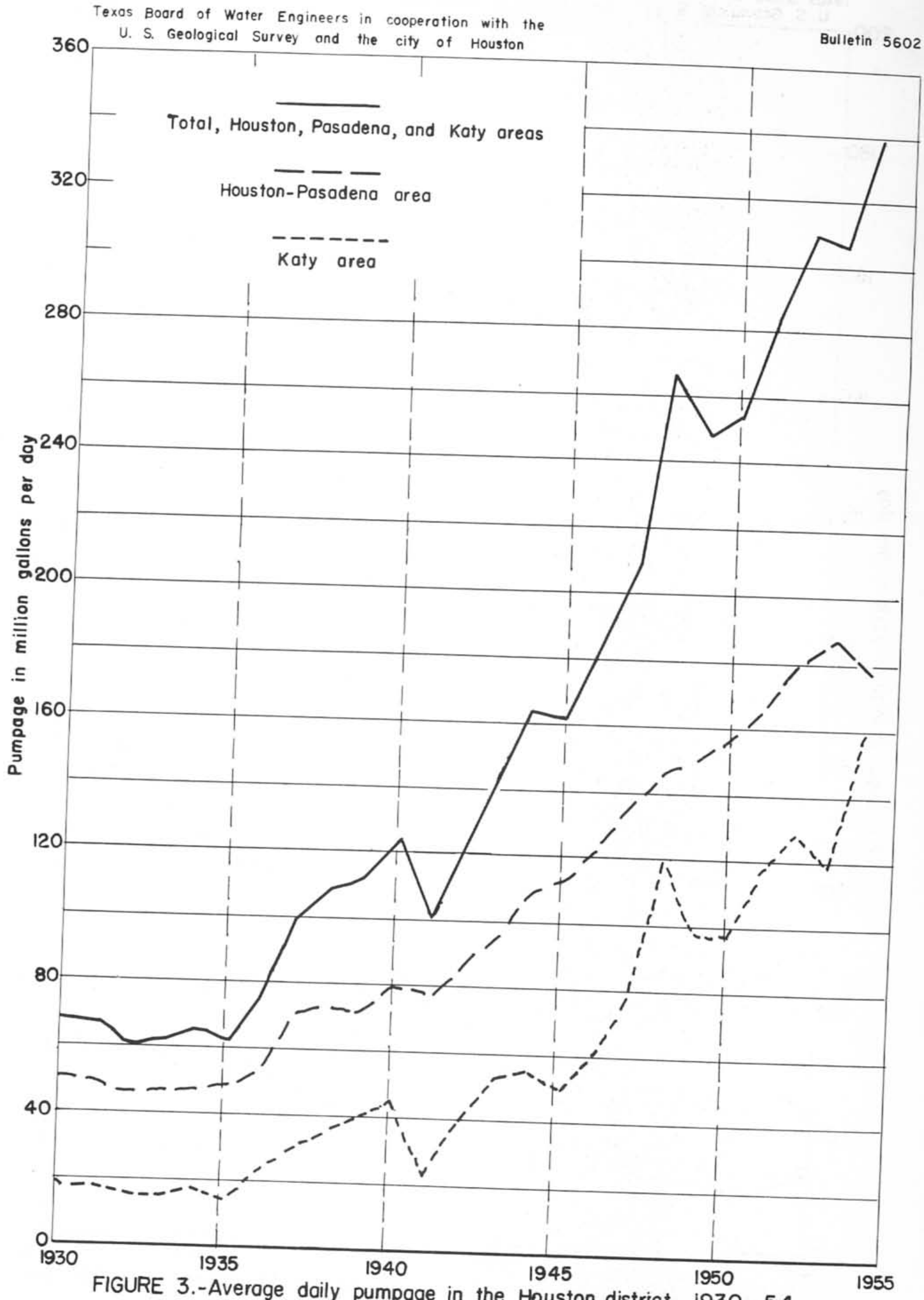

FIGURE 3.-Average daily pumpage in the Houston district, 1930-54.

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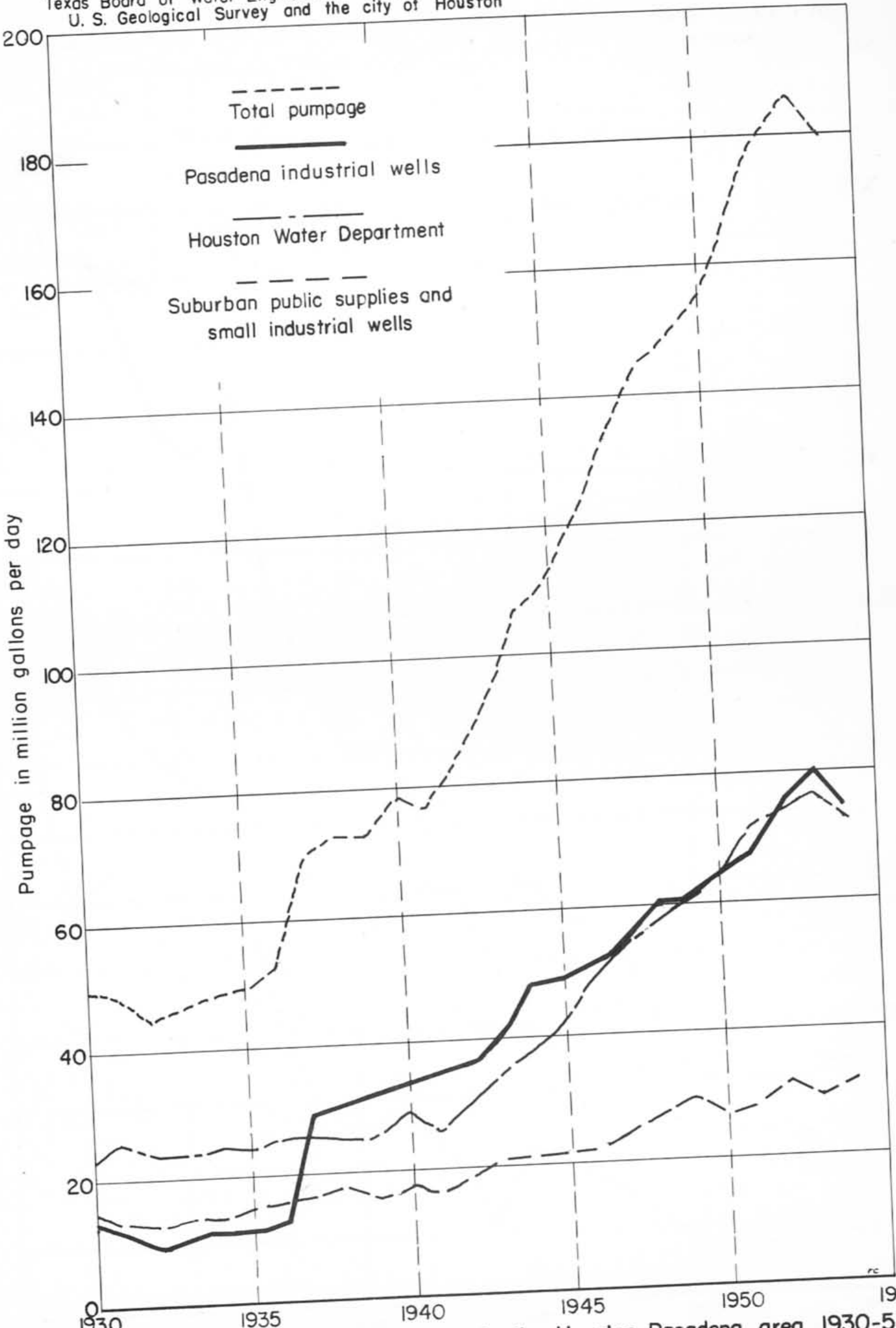

FIGURE 4.-Average daily pumpage in the Houston-Pasadena area, 1930-54.

Most of the ground-water withdrawal in the Pasadena area takes place in the Ship Channel subarea (fig. 2) where many industrial plants are located on both banks of the Houston Ship Channel. Table 1 shows that more than 80 percent of the ground-water pumpage in the Pasadena area is concentrated in the comparatively small Ship Channel subarea. This is also where the greatest lowering of artesian pressure has taken place (fig. 14).

Table 1.- Estimated average daily pumpage in the Pasadena area in million gallons per day.

	1952	1953	1954
Pasadena area	83	87	83
Ship Channel subarea	73	74	67

The average daily pumpage of ground water during the years 1952, 1953, and 1954, by different classes of users in the Houston and Pasadena areas, is shown in table 2. The chemical plants have replaced the oil refineries as leading industrial users of ground water because one of the oil refineries has reduced its use of ground water as increased surface-water supplies became available. The paper mill also has reduced its consumption of ground water, by increasing its use of river water from Lake Houston. Other industries are constructing pipelines and other facilities for the use of river water, so that the pumpage of ground water in the Pasadena area should be less, or certainly no greater, in the immediate future.

Table 2.- Estimated average ground-water pumpage for public, industrial, and miscellaneous supplies in the Houston-Pasadena area, in million gallons per day, 1952-54.

	1952	1953	1954
Public supplies			
Houston Water Department	73.7	77.3	72.5
Suburban	12.9	13.0	15.8
Industrial supplies			
Chemical plants	18.2	21.0	25.7
Oil refineries	24.1	27.0	22.7
Power plants	10.1	12.0	13.5
Paper mill	22.0	19.0	13.0
Steel mills	6.0	6.1	5.5
Tool companies	1.9	1.7	1.6
Ice plants	1.9	1.5	1.5
Railroads and allied plants	1.7	1.6	1.3
Food manufacturers and processors	1.5	.9	1.1
Cement plants	.7	.7	.8
Meat-packing plants	.6	.5	.5
Miscellaneous supplies			
Office buildings, hotels, laundries, country clubs, and other plants that use more than 5,000 gallons per day	4.8	4.3	3.4
TOTAL	180.1	186.6	178.9

Electric-power generating plants have become the third largest industrial user of ground water in the Houston-Pasadena area. Ground-water withdrawals by other classes of industrial users remained about the same or decreased slightly in the period 1952-54.

In 1954, the Houston Water Department obtained about 95 percent of its ground water from 45 wells in 7 well fields within and adjacent to the city. Figures 5 and 6 show the average daily pumpage from each well field and the hydrograph of a representative well in each field. The reductions in pumping rates in most fields and in the Houston-Pasadena area have permitted a recovery of artesian pressure in each well field for the first time in many years. Both the South End and Southwest well fields were pumped at higher rates in 1954 than in 1953, but each had two new wells in 1954 which distributed the pumpage over a larger area.

In addition to the wells in the seven fields, smaller wells were operated by the Water Department in several areas annexed to the city since 1949. Several one-well plants were constructed during 1954 and 1955, at the following locations: Afton Village, Airport, Linkwood, Meyerland, and South Park (fig. 11).

Baytown-La Porte Area

The average daily pumpage in the Baytown-La Porte area during the period 1920-54, and hydrographs of representative wells, are shown graphically in figure 7. Ground-water withdrawals averaged about 23,000,000 gpd in 1953 and 22,000,000 gpd in 1954. The withdrawal in 1952 was about 25,000,000 gpd. The decreases in total pumpage were due to conservation practices at the various plants and to an increased use of surface water by the largest user of ground water in the area. Table 3 shows the average amount of ground water withdrawn by the different types of users.

Table 3.- Estimated average pumpage in the Baytown-La Porte area, 1952-54, in million gallons per day.

	1952	1953	1954
Industries	20.1	17.8	15.2
Public supply	2.7	3.0	4.1
Rice irrigation	2.0	2.0	2.5
TOTAL	24.8	22.8	21.8

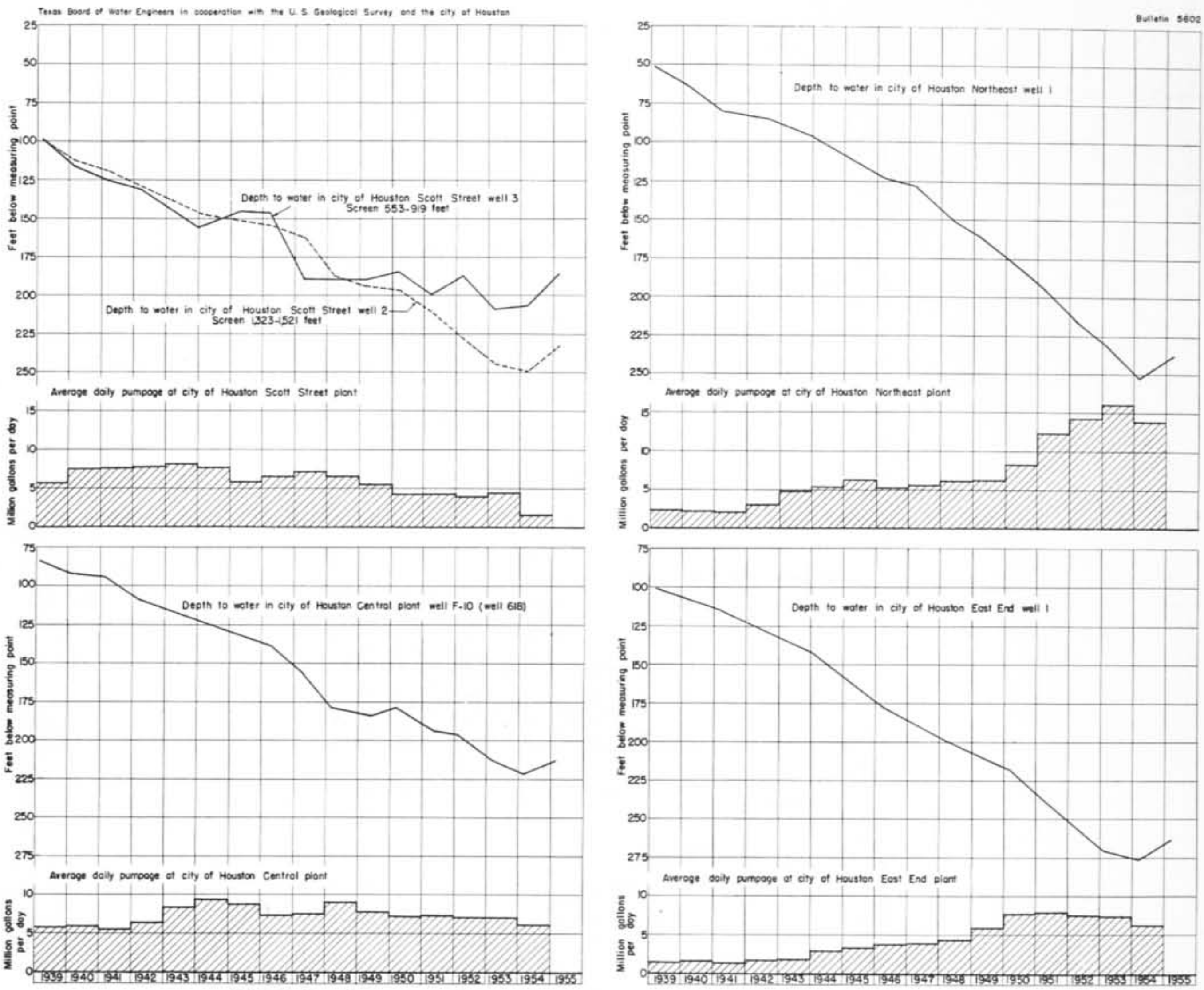

FIGURE 5.-Relation of pumpage to artesian pressure in the Central, Scott Street, Northeast, and East End well fields of the city of Houston.

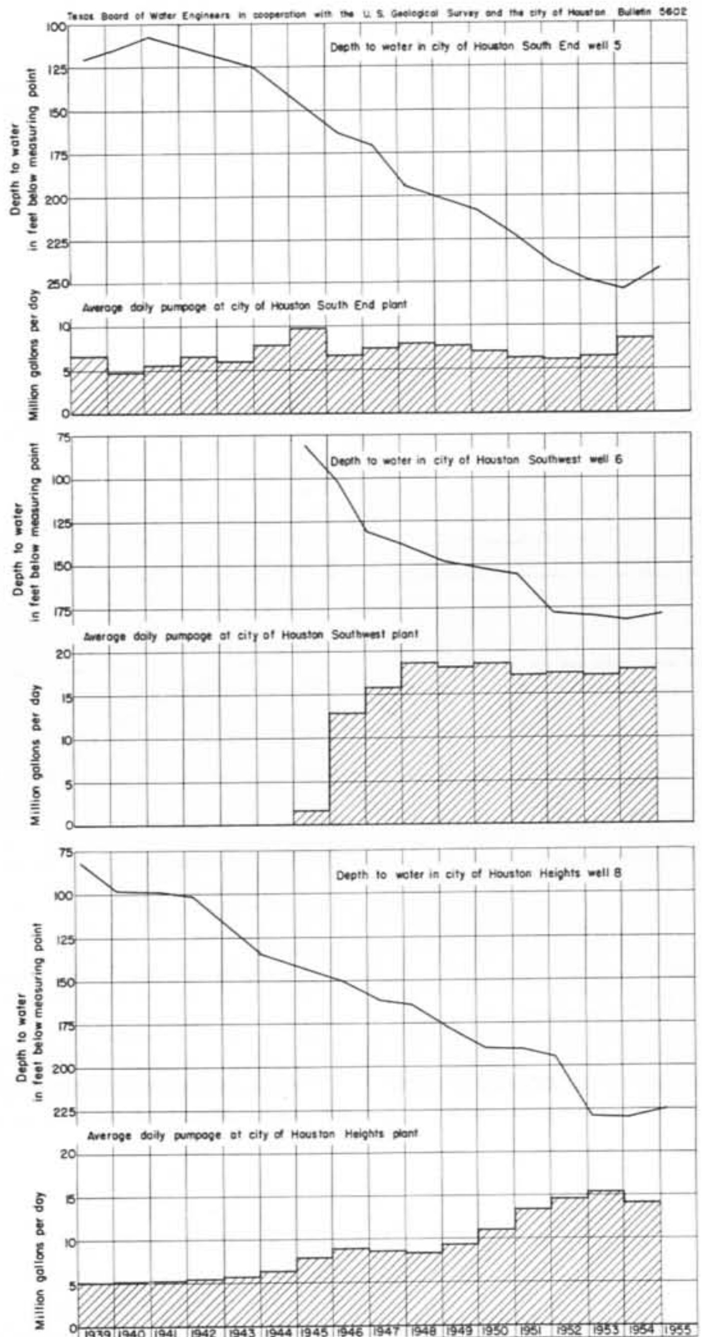

FIGURE 6.-Relation of pumpage to artesian pressure in the Heights, Southwest, and South End well fields of the city of Houston.

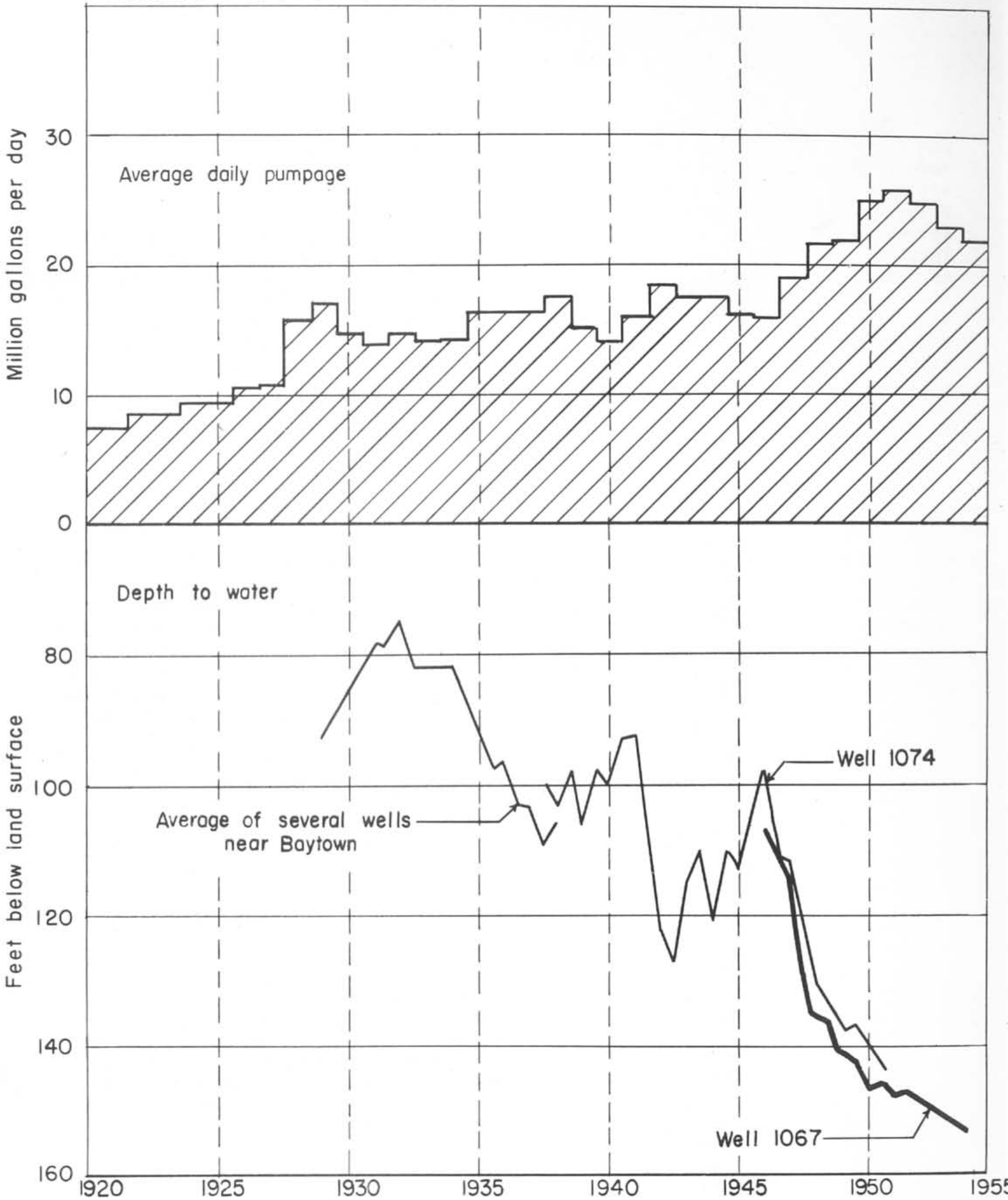

FIGURE 7.- Average daily pumpage, 1920-54, and changes in artesian pressure in the most heavily pumped sand, Baytown-La Porte area.

CHANGES IN ARTESIAN PRESSURE

Houston District

The water-bearing formations in the Houston district may be thought of as one hydraulically connected unit. The sand zones, which transmit water many times more rapidly than the clay zones, tend to be continuous in a lateral direction but are interrupted in the vertical direction by more or less continuous beds of clay. Prior to 1910, when ground-water withdrawals were small, the artesian pressure increased with depth, because the outcrop areas of the deeper sand horizons are farther inland and at a higher elevation than are those of the shallower sands. As the distance from the outcrop area increased, the artesian pressure (with respect to sea-level datum) in a given sand zone decreased, because this water lost head in percolating slowly down the dip, as well as upward through the clay zones into a zone of lower pressure above. Heavy withdrawals from deep sand horizons have changed the pressure gradients so that, locally at least, water is percolating from shallow zones to deeper zones. This vertical percolation of water accounts for only a small percentage of the water being withdrawn from the heavily pumped areas. Most of the water entering the wells moves laterally toward the wells through the permeable sand zones from areas several miles distant.

The withdrawal of water from a well lowers the artesian pressure in the immediate area, establishing a new hydraulic gradient within the aquifer. The gradient is controlled by the physical characteristics of the aquifer and the rate of withdrawal of water. Because at any one place the physical characteristics of the aquifer are constant, the hydraulic gradient is proportional to the rate of withdrawal. In the Houston-Pasadena area, the rate of withdrawal from wells increased each year from 1941 through 1953, so that the artesian pressure declined and the gradient became steeper. When the amount of water withdrawn from an aquifer decreases, the gradient becomes smaller and water levels rise. The increased use of surface water in 1954 and the resulting decrease in ground-water withdrawal in the Houston and Pasadena areas caused a marked recovery of water levels in some parts of the areas by March 1955. The largest increases in artesian pressure (rises in water levels) were noted in the city of Houston's well fields. Figure 8 outlines the areas where artesian pressures in the most heavily pumped sands increased from the spring of 1954 to the spring of 1955. Table 4 (p. 28) shows static (nonpumping) levels in city of Houston municipal wells for several years and the changes in artesian pressure for various intervals. From the table it can be seen that the recovery of artesian pressure in the Northeast well field averaged more than 20 feet from March 1954 to March 1955.

Figure 9 shows a comparison of the yearly change in average daily pumping rate in the Houston-Pasadena area with the yearly change in water level in Harris County well 1170, which is near the point of lowest artesian pressure. Figure 10 is a hydrograph of Harris County well 1170 for the period 1931 to 1955. By inspecting figure 4 and figure 10, it can be seen that ground-water withdrawals and water levels were fairly constant from 1930 through 1936. The large increase in withdrawal in 1937 resulted in a correspondingly large decrease in artesian pressure. Except for 1939 and 1941, the pumpage increased each year from 1937 through 1953, although the rate of increase slackened at the end of World War II in 1945 and during the slight business recession in 1949.

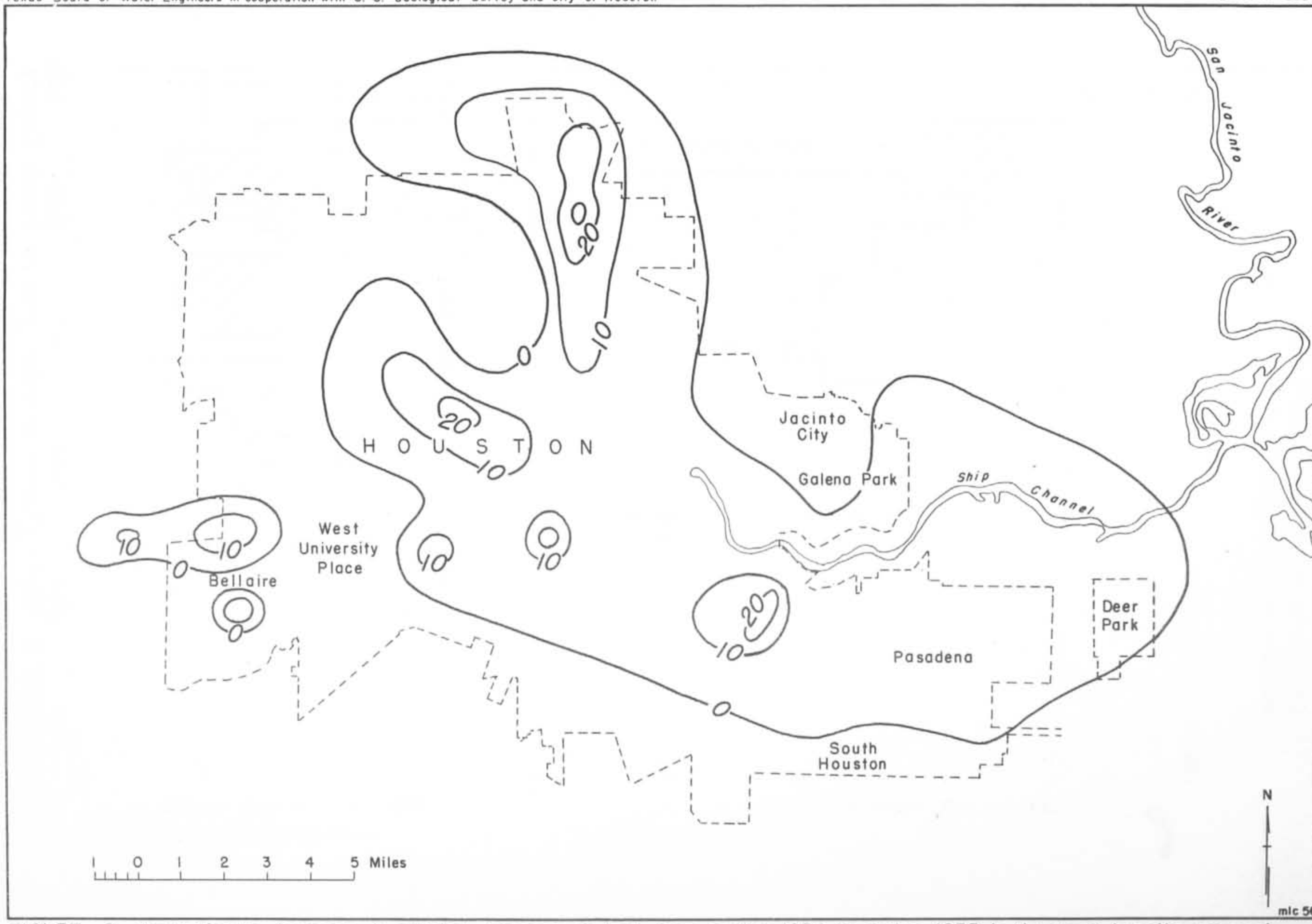

FIGURE 8.-Approximate increases in artesian pressure, in feet, from spring 1954 to spring 1955 in the most heavily pumped sands in the Houston-Pasadena area.

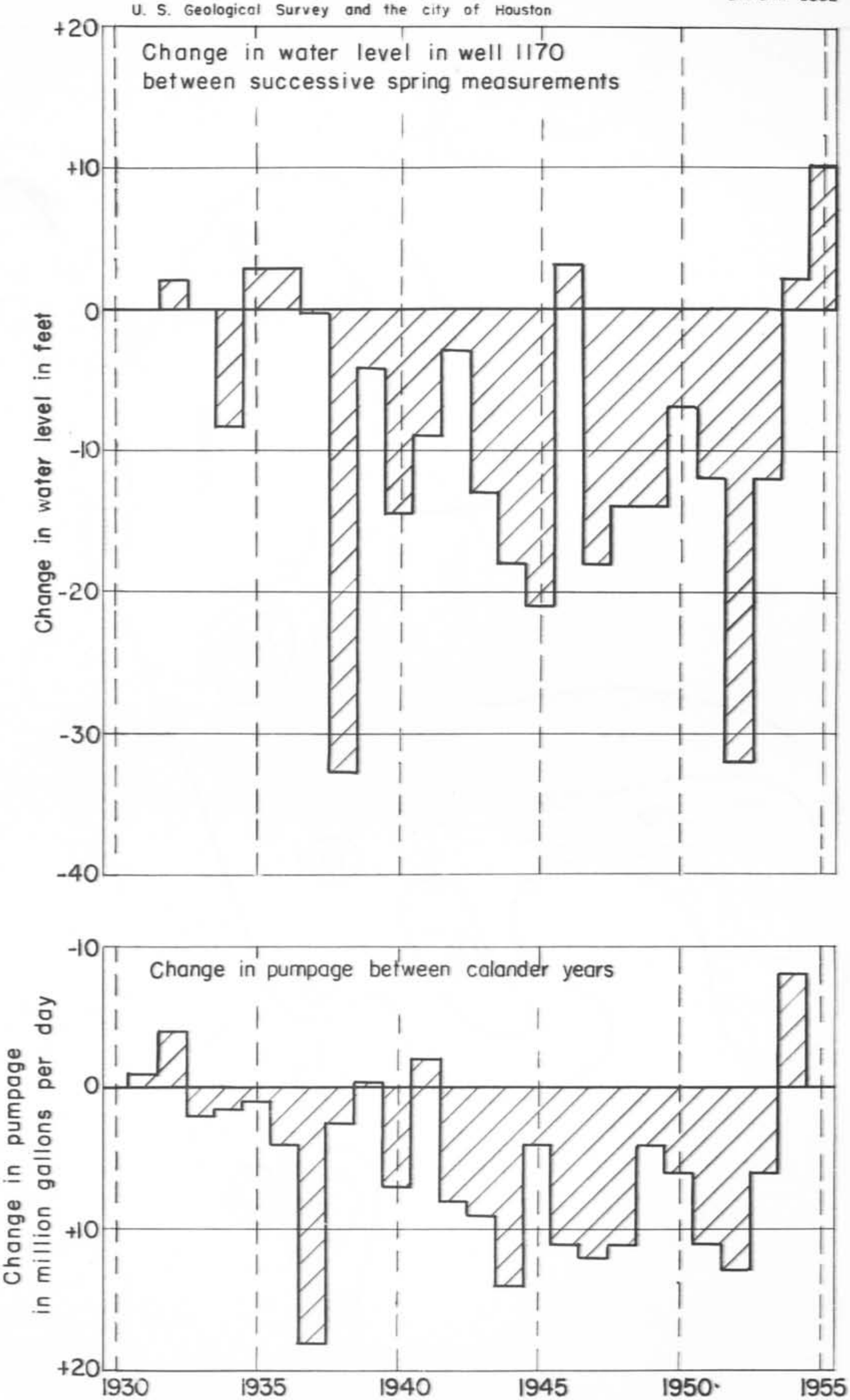

FIGURE 9.- Yearly change in water level in Harris County well 1170 and yearly change in average daily pumpage in the Houston-Pasadena area.

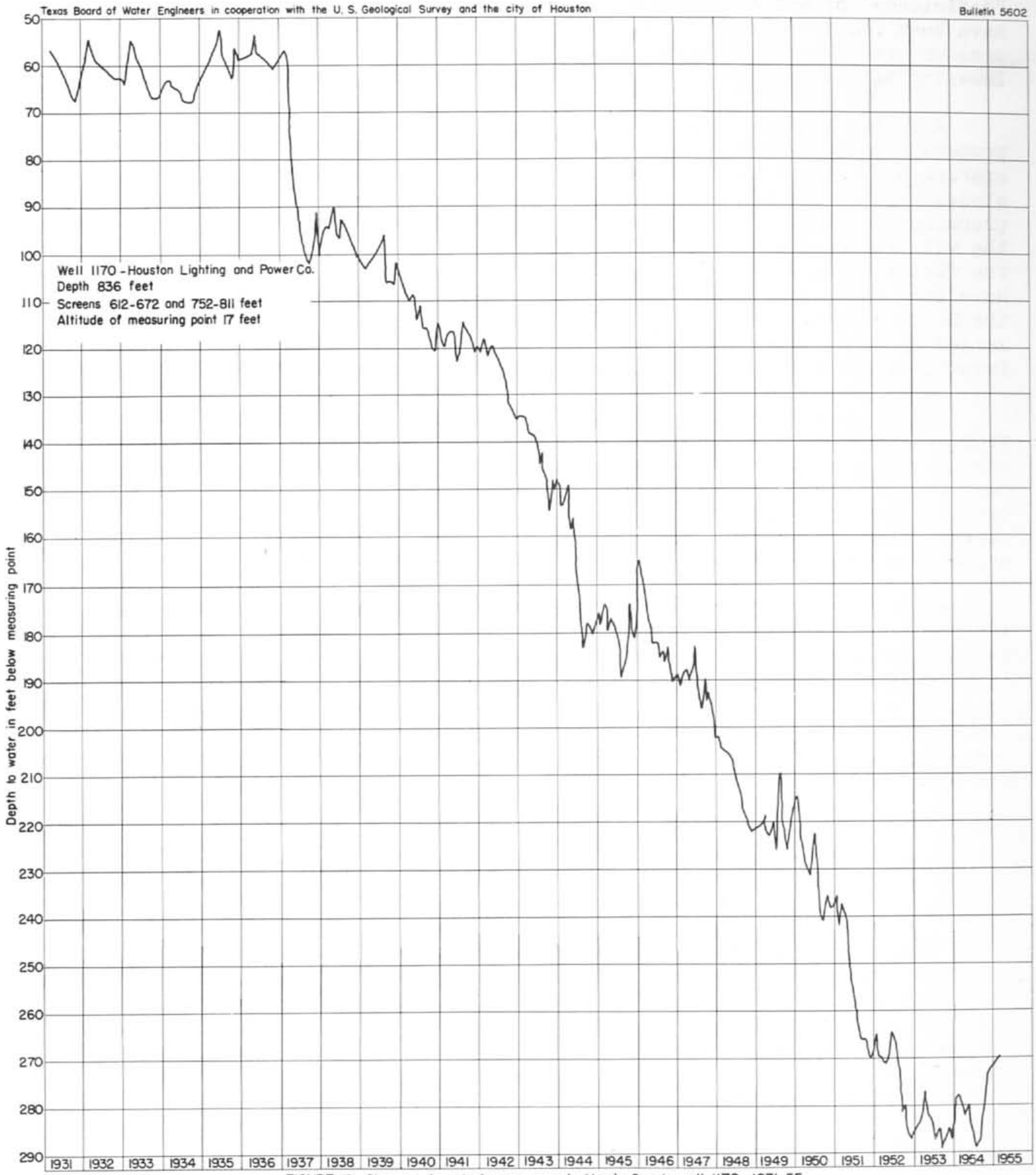

FIGURE 10.-Changes in artesian pressure in Harris County well 1170, 1931-55.

From a study of the records of pumpage and water levels, it is apparent that there is no "deficiency" of ground water in the Houston district, only a "deficiency" of artesian pressure in the areas where withdrawals of ground water have been concentrated. It would require a tremendous lowering of the artesian pressure to dewater the sands, but other unwanted effects may accompany further lowering of artesian pressure. These effects are discussed later in this report.

Artesian pressures can be maintained at the maximum possible levels by properly spacing wells and well fields. Excellent examples of proper and improper spacing are seen in the Houston district. In the Pasadena area, the wells are closely spaced and high pumping rates have caused excessive lowering of artesian pressures. In the Houston area, where the principal user is the city of Houston, the well fields are dispersed throughout the city and the individual wells within the fields are widely spaced. As a result, the declines in artesian pressures have been much less than in the Pasadena area, even though more water is pumped in the Houston area. In the Katy area, the irrigation wells are spread over a still larger area, and even though nearly as much water is pumped as in the Houston and Pasadena areas combined, declines in artesian pressures have been relatively small.

The largest part of the ground water pumped in the Houston-Pasadena area is from wells screened in sands 500 to 1,800 feet below the surface, although many smaller wells are screened shallower than 500 feet and some wells are screened as deep as 2,550 feet below the surface. Nearly all the larger wells are screened opposite more than one sand, and most are screened opposite several sands. In the larger wells the screens are surrounded by a gravel envelope, which provides a connection between all sands below the surface casing.

Water levels in more than 300 observation wells are measured at various intervals in the Houston district (figs. 2 and 11). As many of the wells are of the multiple-screen, gravel-pack type, and as artesian pressures differ with depth, it is very difficult to construct a piezometric map for any particular sand or group of sands. Figures 12, 13, and 14 show the approximate altitude of water levels in wells in the Houston district in January 1941, March 1951, and March 1955, respectively. As is pointed out in the figures, the levels upon which the contours are based are from wells screened in the most heavily pumped sands.

Katy area

Figure 15 shows hydrographs, for the period 1931-55, of two wells in the rice-irrigation area (Harris County well 186, and Waller County well F-25). Although the water-level trend is downward, it is at a very slow rate compared to the declines experienced in the Houston-Pasadena area during the same period, because the pumping is spread over a larger area. Declines of water level in 57 observation wells in the area between the spring measurements of 1953 and 1955 ranged from 0.1 to 10.2 feet and averaged 4.9 feet. In one well the water level rose 0.8 foot.

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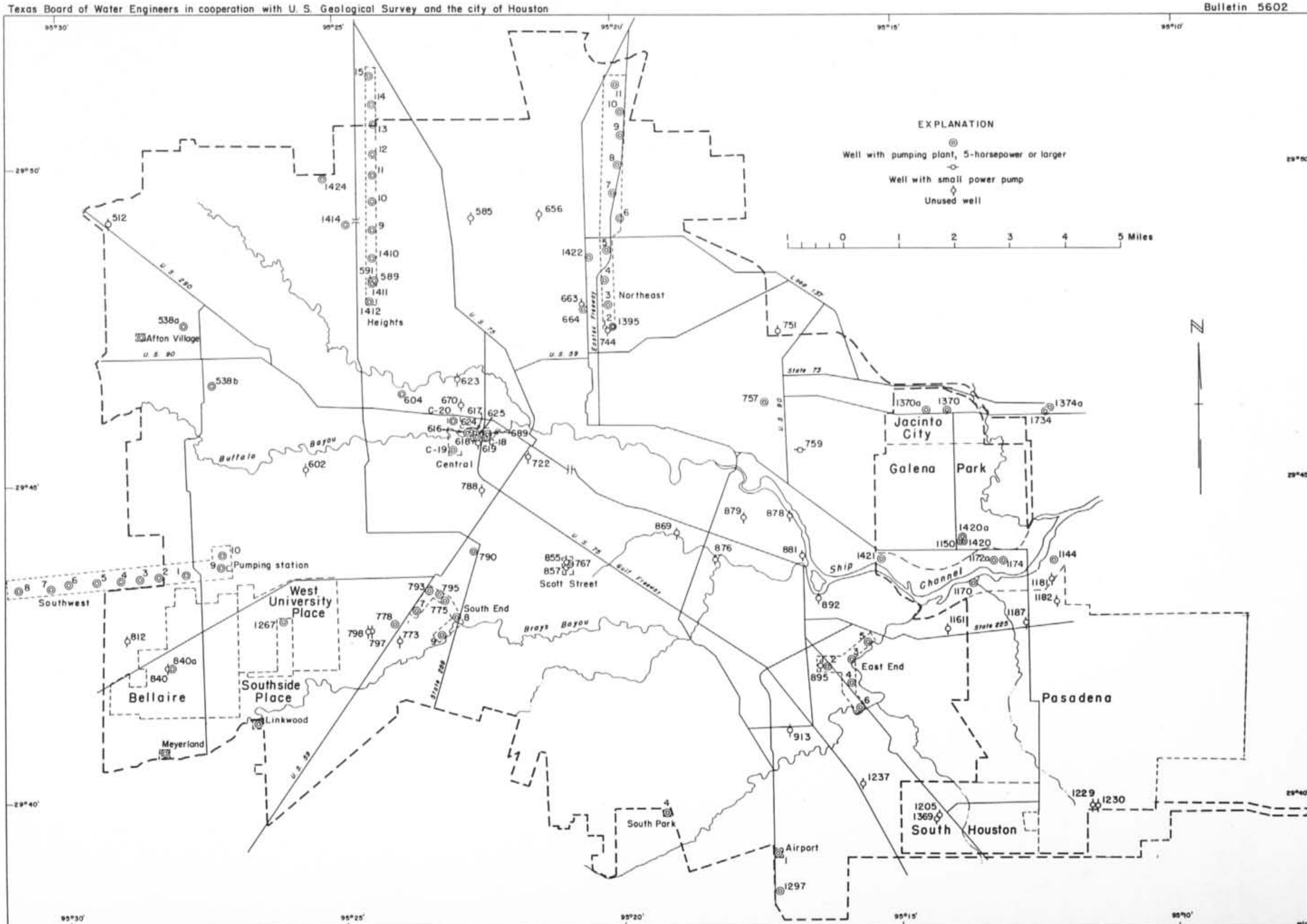

FIGURE 11.- Observation wells and location of municipal well fields in Houston.

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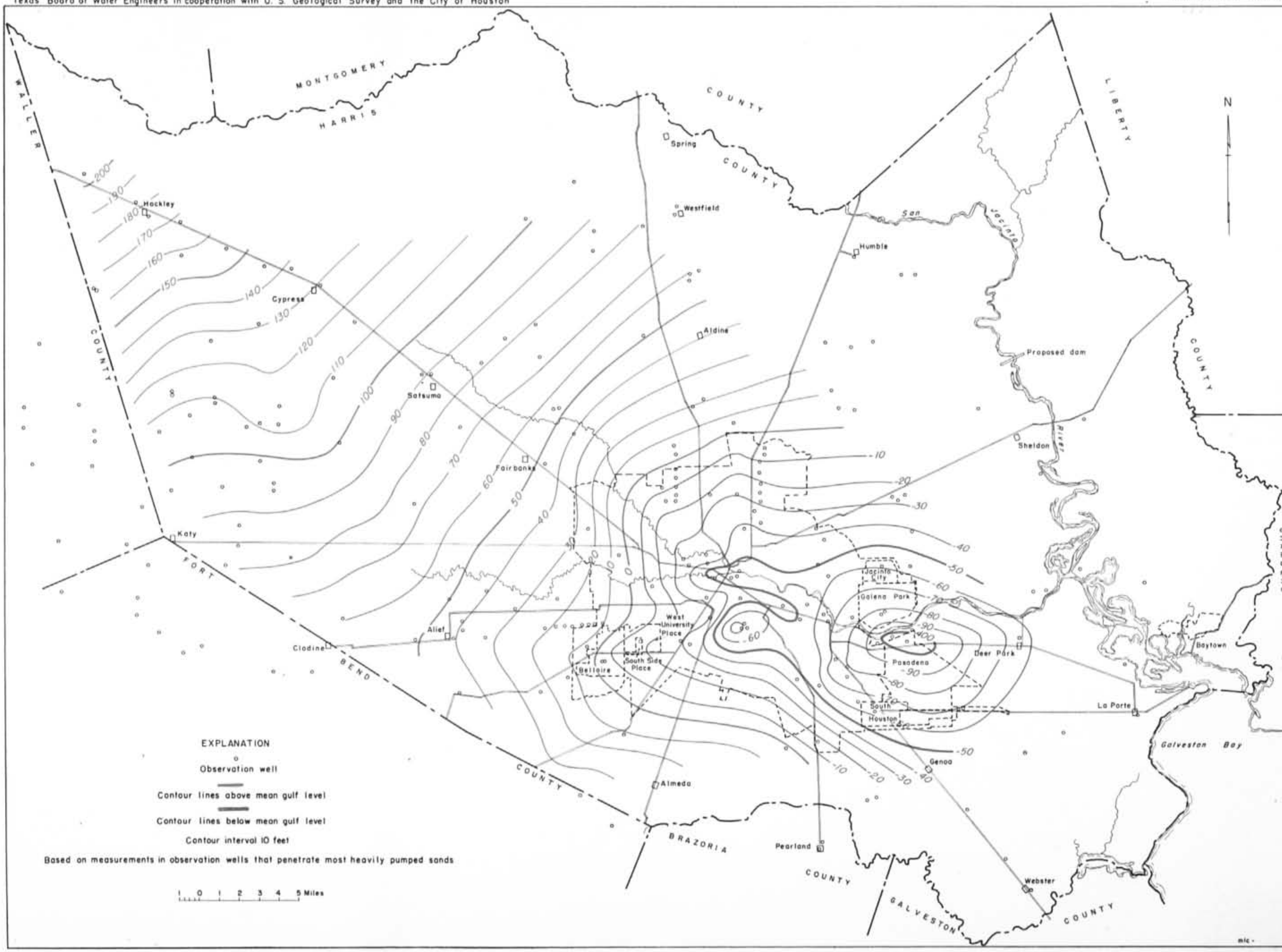

FIGURE 12.- Approximate altitude of water levels, in feet, in wells in the Houston district, Texas, January 1941.

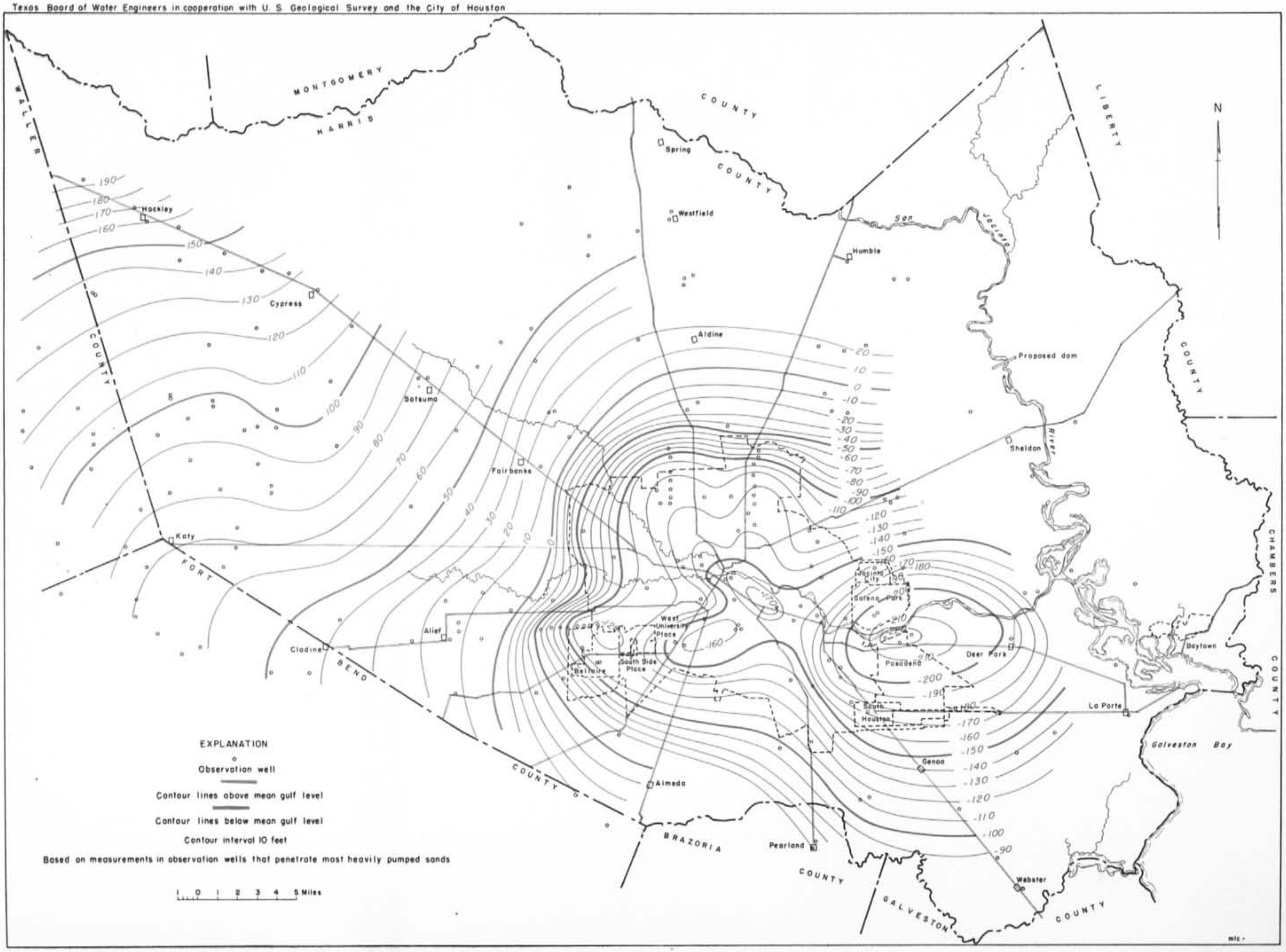

FIGURE 13.- Approximate altitude of water levels, in feet, in wells in the Houston district, Texas, March 1951.

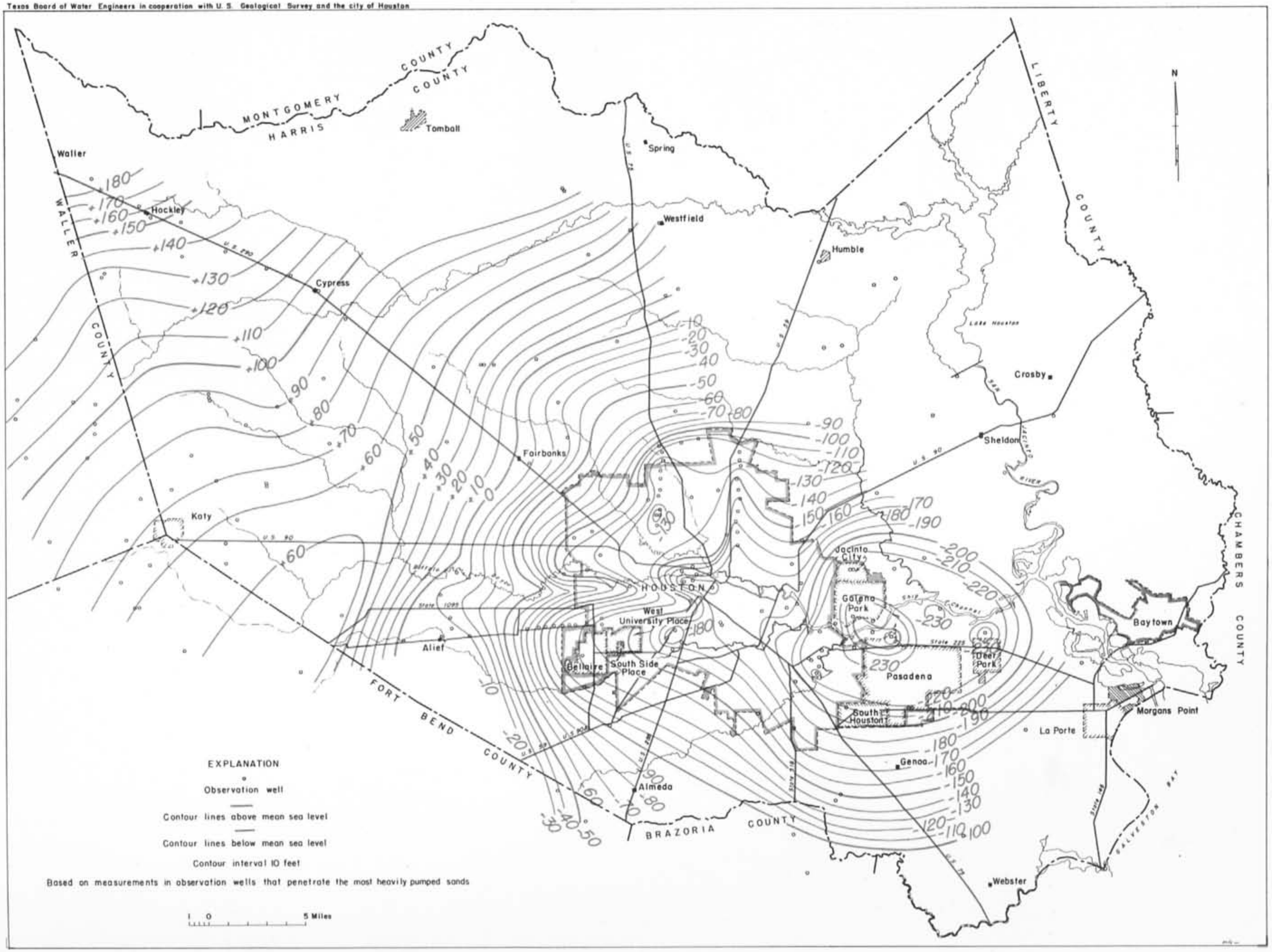

FIGURE 14 .- Approximate altitude of water levels, in feet, in wells in the Houston district, Texas, March 1955.

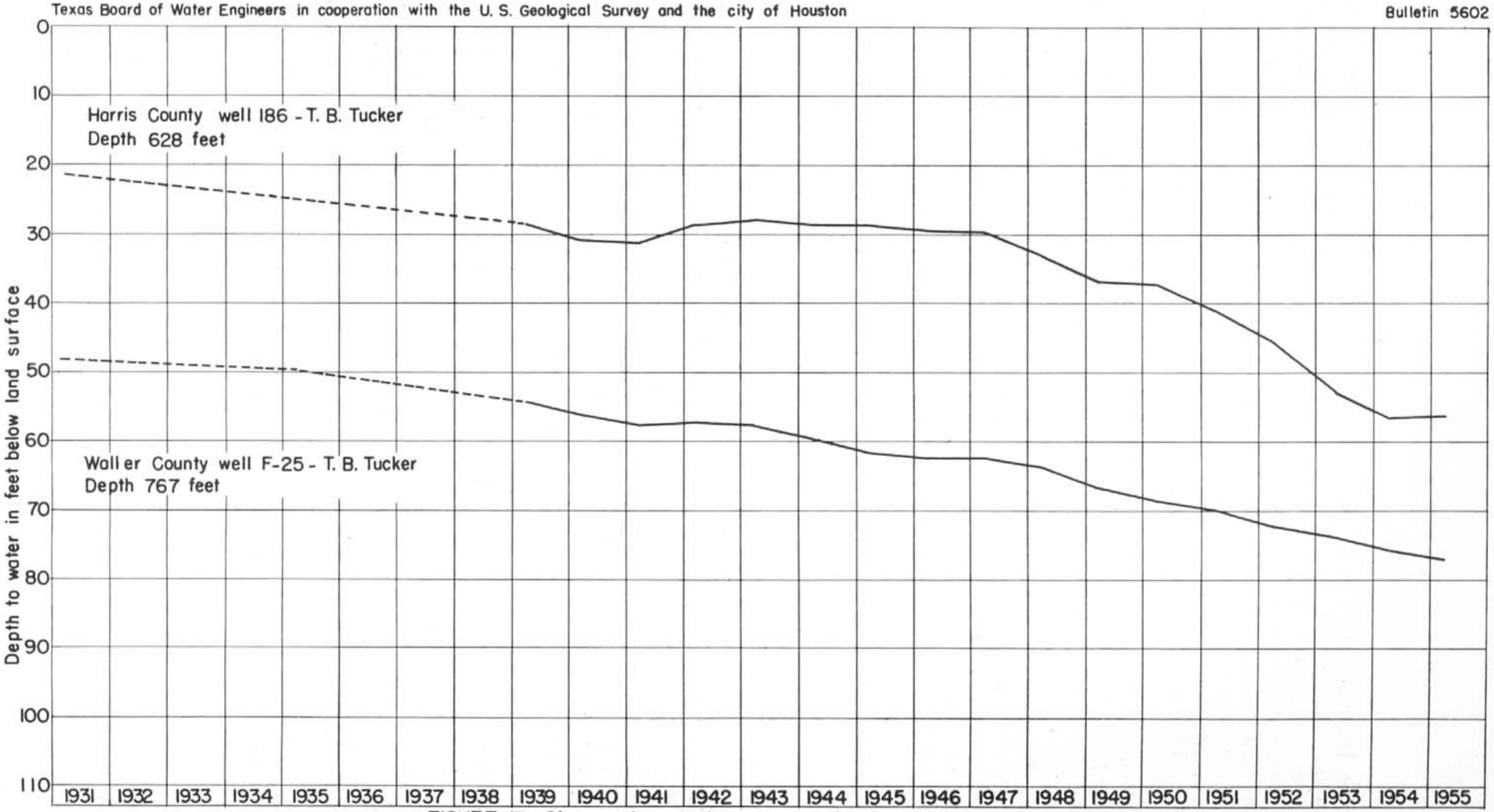

FIGURE 15.-Changes in artesian pressure in the Katy area.

Pasadena area

In the Pasadena area most of the ground water is obtained from wells screened more than 600 feet below the surface. Water levels in these deeper wells were generally several feet lower in the summer of 1953 than in the summer of 1952. However, because of changes in rates of ground-water withdrawal in 1954, the water levels in these wells were higher or only a little lower in the summer of 1954 than in the summer of 1953. By March of 1955 water levels in some wells were higher than in either 1953 or 1954. Figures 10, 16, 17, and 18 show examples of water-level fluctuations in representative wells in the Pasadena area.

In the area from eastern Pasadena to Deer Park, several of the large-capacity wells are about 500 feet deep. These wells are screened in the "Alta Loma" sand, which is the principal aquifer in Galveston County and in the Baytown-La Porte area of Harris County. The hydrograph of the shallow well shown in figure 17 is representative of wells screened in this sand. Both the wells represented in figure 17 are quickly affected by increases and decreases in nearby ground-water withdrawals, as is shown by the substantial recovery of water levels during the early summer of 1952, when several oil refineries were shut down. The water levels declined as pumping was resumed in July.

Houston area

The largest user of ground water in the Houston area is the Houston Water Department. Several industries in the eastern part of the area also use large quantities of ground water from their own wells, and some industrial, suburban public-supply, and other users withdraw water from wells in many parts of the Houston area. Water levels in the city wells recovered more than those in other wells during late 1954 and early 1955 because of the decreases in ground-water pumping that the city scheduled in order to utilize as much surface water as possible (table 4). Nearly all wells in the Houston area had higher water levels in March 1955 than in March 1954, except those on the south and west sides of the area (fig. 8).

In eastern Houston, artesian pressures in 9 observation wells declined an average of 1.4 feet from the spring of 1953 to the spring of 1954. From the spring of 1954 to that of 1955, the pressures in the same wells rose an average of 3.1 feet, so that the average change in artesian pressure was a rise of 1.7 feet between the spring of 1953 and the spring of 1955. This compares with an average decline of 25.8 feet in the same wells from the spring of 1951 to the spring of 1953. Figure 19 shows hydrographs for three industrial wells in eastern Houston.

Hydrographs showing water-level changes in wells in northern Houston and in central and western Houston are shown in figures 20 and 21, respectively.

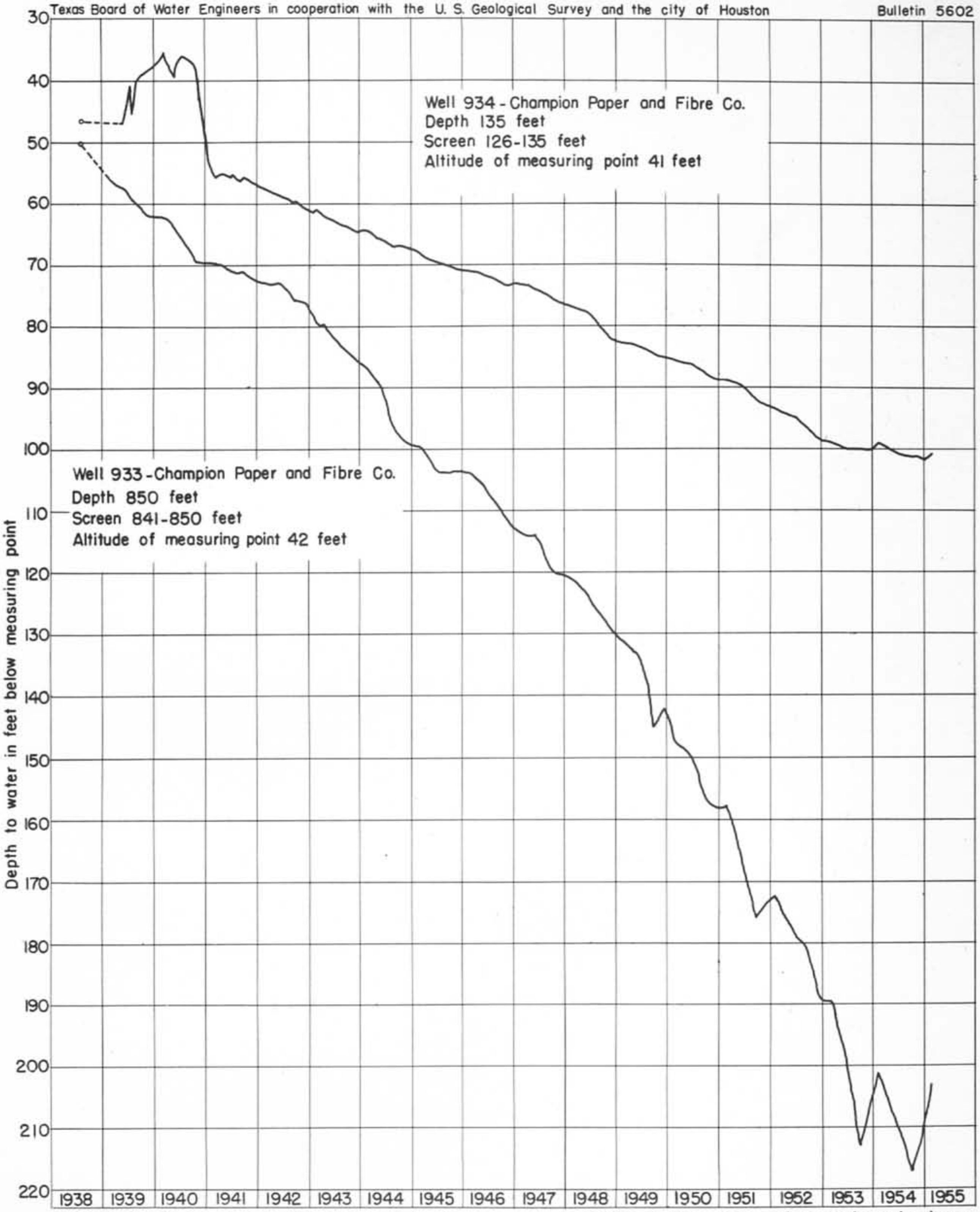

FIGURE 16.- Comparison of changes in artesian pressure in a very shallow well and a moderately deep well in the northern part of the Pasadena area.

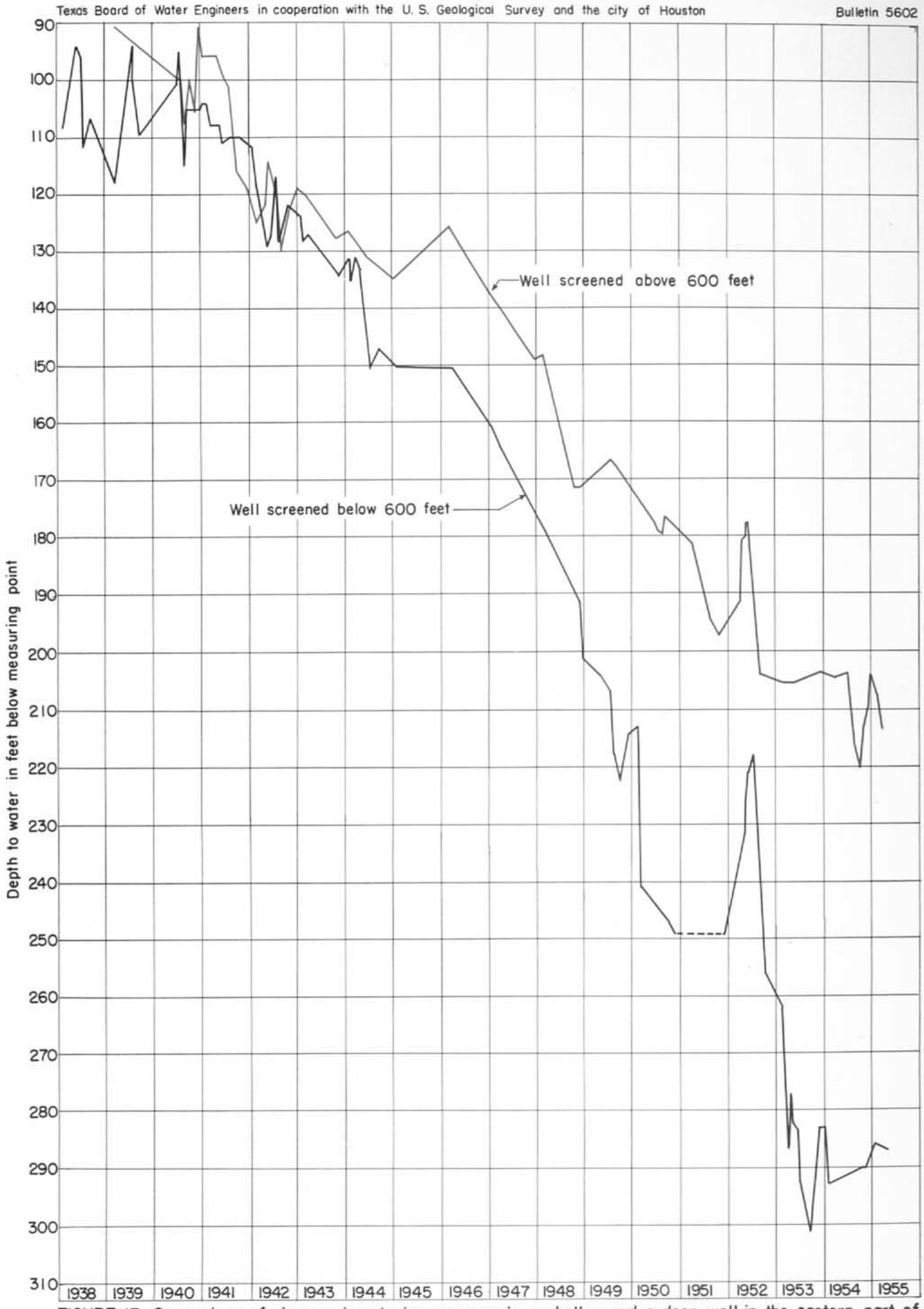

FIGURE 17.-Comparison of changes in artesian pressure in a shallow and a deep well in the eastern part of the Pasadena area on the Ship Channel.

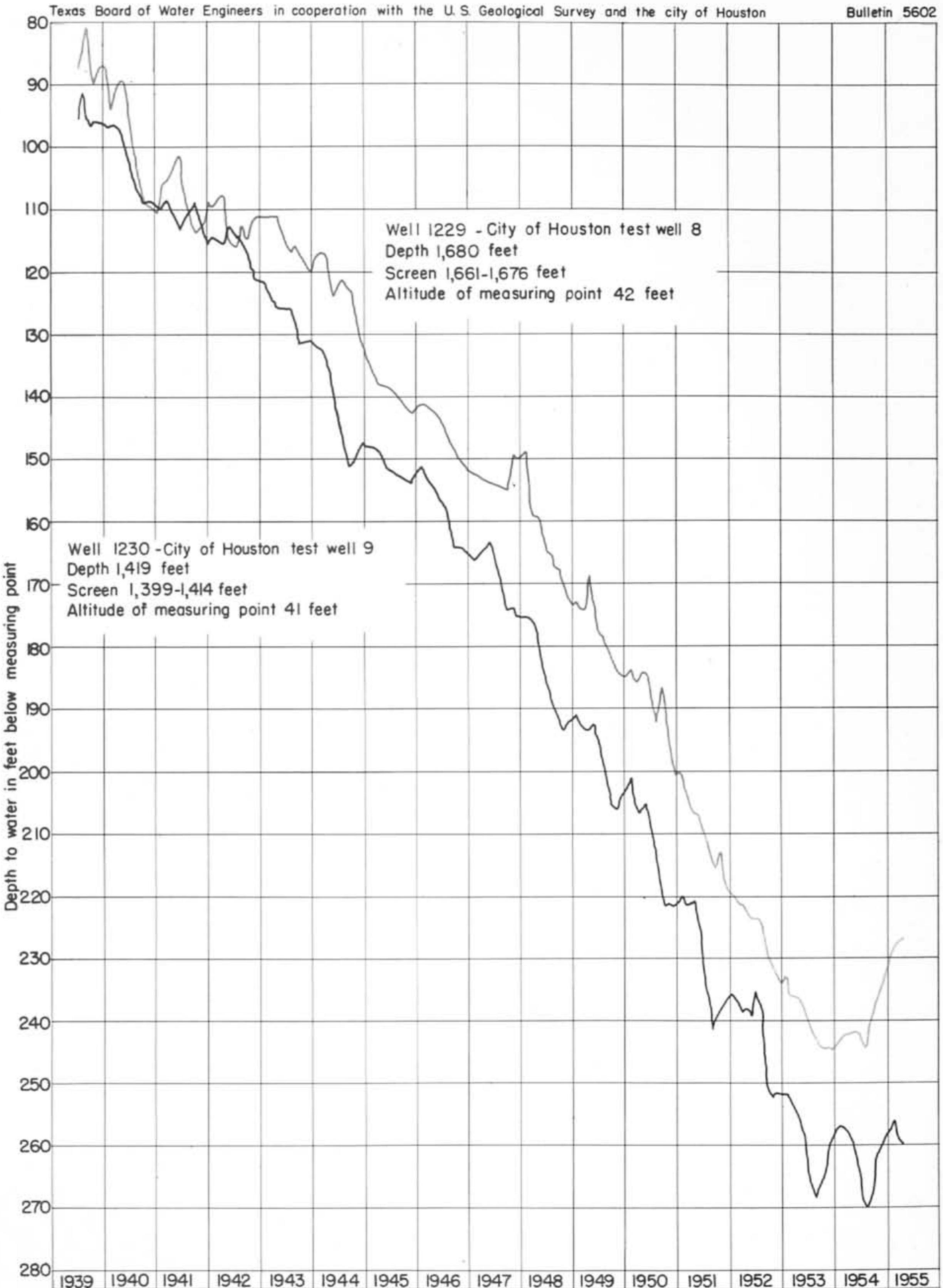

FIGURE 18.-Comparison of changes in artesian pressure in two single-screened deep wells in the southern part of the Pasadena area.

Table 4.- Net changes in artesian pressure, in feet, in active Houston municipal wells

Plant	Office no.	City well no.	Screened at intervals between (feet)	Date (1953)	Depth to water	Date (1954)	Depth to water	Date (1955)	Depth to water	Change in water level (feet)					
										1951-1953	1953-1954	1954-1955	1939-1953	1950-1955	1953-1955
Central		D-17	708- 978	Mar. 3	219.71	Mar. 3	228.24	Mar. 9	220.51	-23	- 8.5	+ 7.7	-132.6	-39.3	- 0.8
		C-18	884-1,989	12	223.73	3	239.07	9	219.46	-27.4	-15.3	+19.6	-	-37.8	+ 4.3
		C-19	1,160-1,960	3	245.39	3	265.02	9	244.75	-21.1	-19.6	+20.3	-	-35.0	+ 0.6
		C-20	1,015-1,940	12	239.61	3	257.31	3	232.64	-22.0	-17.7	+24.7	-	-38.2	+ 7.0
East End		2	1,222-2,050	-	-	-	-	Feb. 28	260	-	-	-	-	-52	-
		3	1,190-2,350	9	269.74	10	282.97	Mar. 8	264.92	-33.3	-13.3	+18.1	-	-62.4	+ 4.8
		4	1,001-2,510	9	261.22	10	276.76	7	255.70	-32.3	-15.5	+21.1	-	-52.6	+ 5.5
		5	1,469-2,560	Feb. 27	243.76	5	253.59	Feb. 28	232.29	-24.0	- 9.8	+21.3	-	-54.0	+11.5
		6	950-2,075	-	-	10	282	Mar. 3	271	-	-	+11	-	-	-
Heights	589	5	410-1,856	Feb. 26	177.8	Feb. 23	178.72	8	185.53	-22.5	- 0.9	- 6.8	-116	-53	- 7.7
	1410	6	581-1,226	Mar. 13	216.3	Mar. 9	219.79	4	223.69	-32.8	- 3.5	- 3.9	-137.8	-37.1	- 7.4
	1412	7	561-1,424	2	215.50	Feb. 23	221.39	1	215.74	-29.2	- 5.9	+ 5.7	-126.7	-35.7	- 0.2
	1411	8	556-1,240	Feb. 26	228.68	23	229.48	9	225.00	-38.8	- 0.8	+ 4.5	-145.8	-36.5	+ 3.7
		9	610-1,710	Mar. 2	197.24	Mar. 5	208.43	4	208.93	-15.1	-11.2	- 0.5	-	-69.8	-11.7
		10	600-1,860	2	202.68	9	208.68	Feb. 25	215.05	-26.0	- 6.0	- 6.4	-	-60	-12.4
		11	700-1,760	13	217.19	10	218.83	Mar. 9	221.64	-43.9	- 1.6	- 3.8	-	-59	- 4.5
		12	900-1,750	13	229.99	Feb. 23	221.22	9	222.18	-31.4	+ 8.8	- 1.0	-	-76	+ 7.8
		13	890-1,800	Feb. 26	192.36	23	217.95	9	217.95	-	-25.6	- 0.0	-	-88	-25.6
		14	950-1,790	26	192.07	Mar. 10	221.42	Feb. 25	213.65	-	-29.4	+ 7.8	-	-89	-21.6
		15	700-1,680	26	184.66	Feb. 23	205.36	25	199.35	-50.1	-20.7	+ 6.0	-	-66	-14.7
Northeast	1395	2	451-1,279	26	208	Mar. 4	210	-	-	-19	- 2	-	-126	-	-
		3	1,143-1,990	27	228.82	4	247.52	Mar. 8	233.83	-33.7	-18.7	+13.7	-	-56.7	- 5.0
		4	1,030-2,060	26	228.98	4	248.42	8	233.58	-36.5	-19.4	+14.8	-	-65.4	- 4.6
		5	1,060-1,960	Mar. 4	221.98	4	243.28	Feb. 25	222.13	-32.1	-21.3	+21.2	-	-78.9	- 0.2
		6	1,017-1,819	Feb. 26	220.94	Feb. 26	246.09	25	225.22	-24.6	-25.2	+20.9	-	-	- 4.3
		7	1,001-1,880	26	225.7	Mar. 4	252.71	Mar. 10	221.40	-33.9	-27.0	+31.3	-	-	+ 4.3
		8	1,010-1,950	-	-	Feb. 26	243.39	Feb. 25	223.07	-	-	+20.3	-	-83.0	-
		9	1,020-1,920	-	-	26	236.98	25	215.23	-	-	+21.5	-	-76.5	-
		10	700-1,830	Mar. 2	214.32	Mar. 4	224.48	25	202.29	-42.9	-10.2	+22.2	-	-66.2	+12.0
		11	710-1,960	2	199.76	Feb. 26	214.40	25	194.44	-39.1	-14.6	+20.0	-	-64.8	+ 5.3
Scott St.	857	3*	553- 919	11	208.00	Mar. 2	205.82	28	185.33	- 9	+ 2.2	+20.5	-109.7	- 1.4	+22.7
South End	793	5	1,275-1,595	10	249.64	2	256.84	28	242.22	-26	- 7.2	+14.6	-135	-32.2	+ 7.4
		7	1,425-1,932	10	256.32	8	260.56	-	-	-40.4	- 4.2	-	-171	-	-
		8	710-1,650	-	-	9	227.82	-	-	-	-	-	-	-	-
		9	680-1,795	-	-	-	-	28	215.53	-	-	-	-	-	-
Southwest		1	726-1,498	10	194.89	4	209.86	Mar. 1	193.86	- 8.0	-15.0	+16.0	-	-34.1	+ 1.0
		2	675-1,473	10	190.41	4	202.90	1	185.24	-10.0	-12.5	+17.7	-	-	+ 5.2
		3	686-1,396	9	194.51	4	202.28	1	187.23	-10.0	- 7.8	+15.1	-	-28.0	+ 7.3
		4	692-1,490	9	194.20	4	201.52	1	192.04	-12.5	- 7.3	+ 9.5	-	-33.3	+ 2.2
		5	652-1,379	4	192.70	4	194.69	4	188.81	-16.4	- 2.0	+ 5.9	-	-	+ 3.9
		6	548-1,360	4	179.75	3	182.55	4	179.90	-19.2	- 2.8	+ 2.7	-	-	- 0.2
		7	490-1,431	3	162.70	3	180.68	9	169.40	-10.0	-18.0	+11.3	-	-18.9	- 6.7
		8	559-1,445	3	148.91	2	161.48	9	154.38	-13.7	-12.6	+ 7.1	-	-	- 5.5
		9	520-1,030	-	-	10	176.20	9	176.06	-	-	+ 0.1	-	-	-
		10	1,070-1,945	-	-	2	207	4	214.05	-	-	- 7	-	-	-

*Abandoned - compares with no. 5

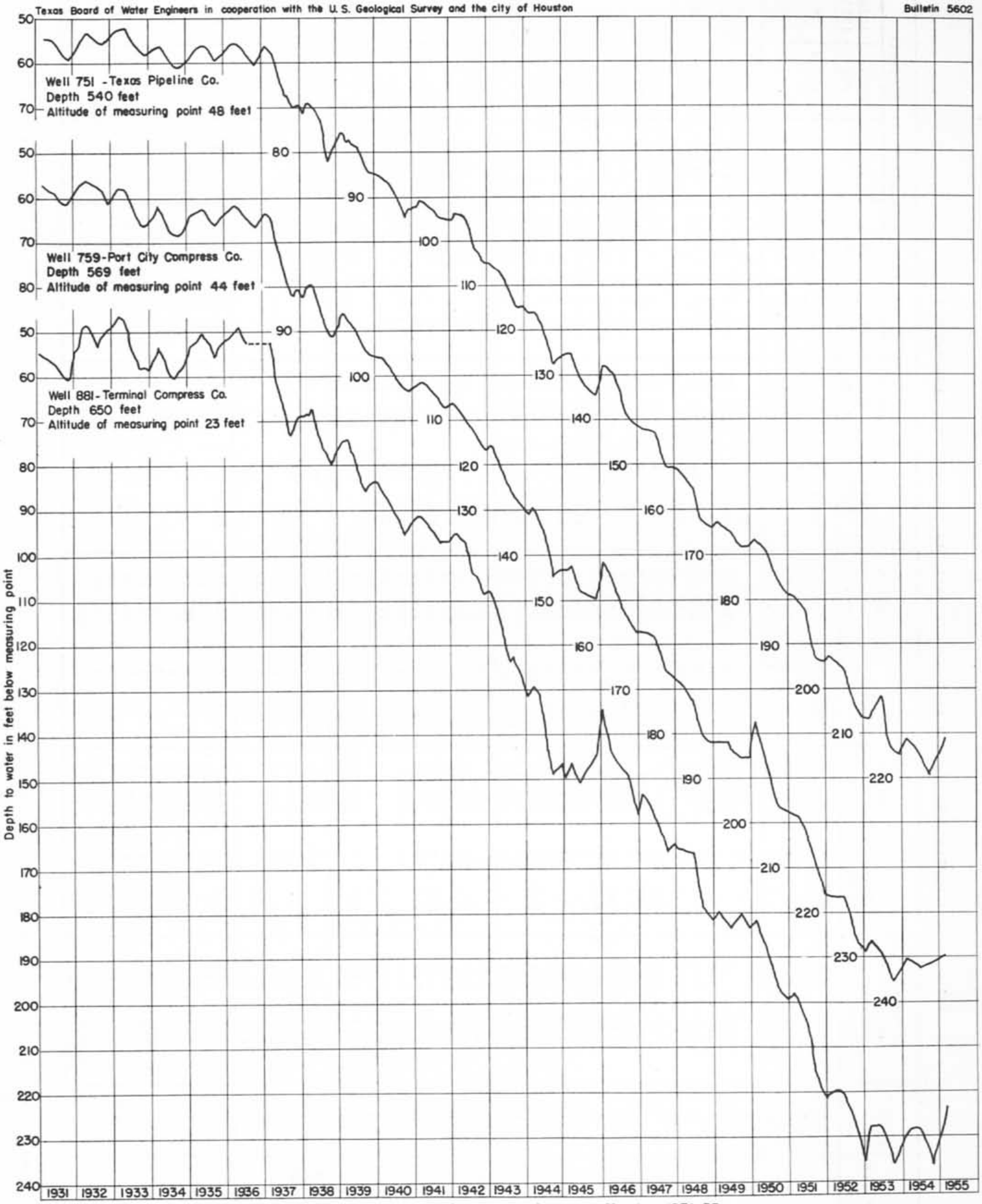

FIGURE 19.- Changes in artesian pressure in eastern Houston, 1931-55.

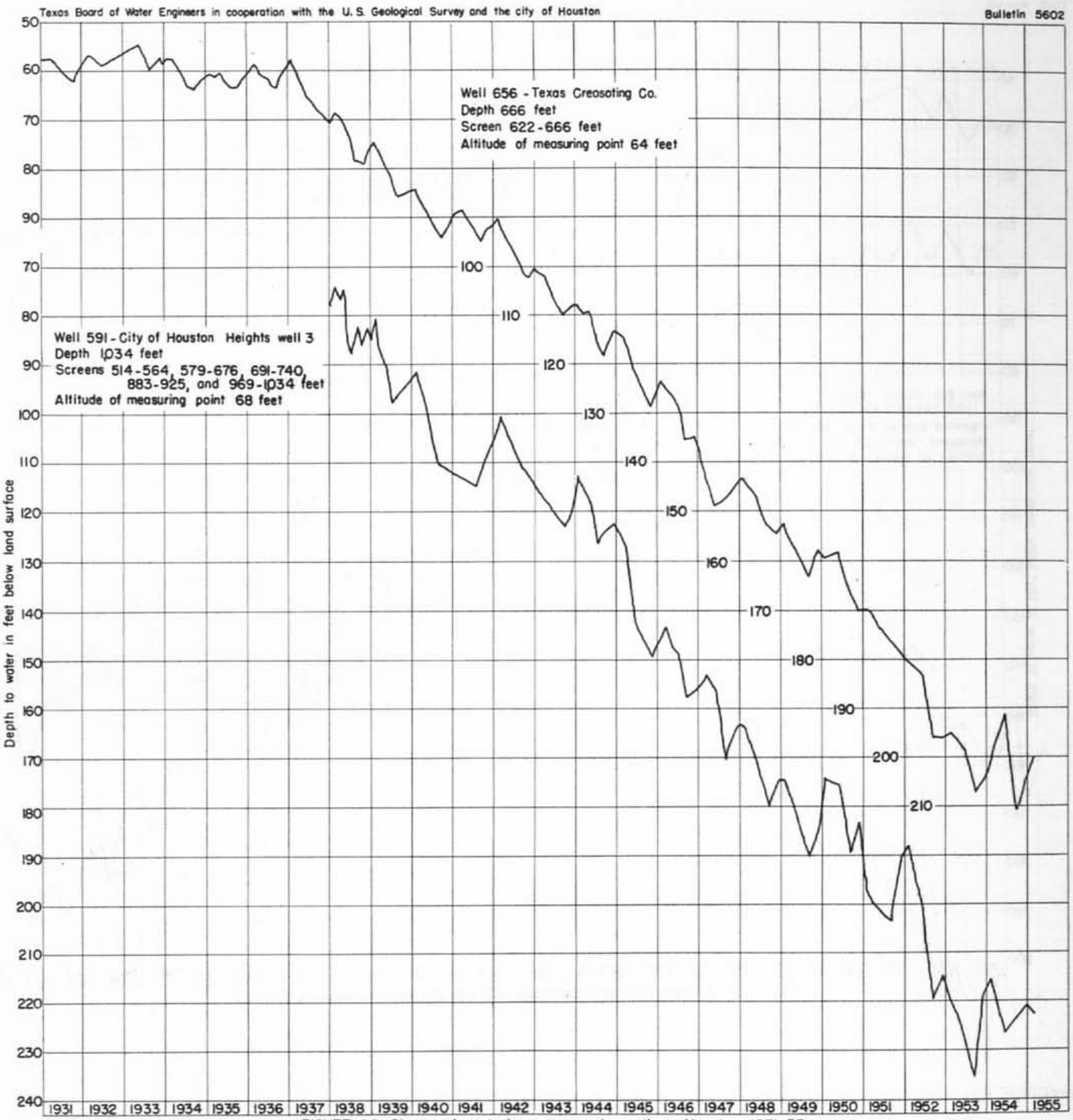

FIGURE 20.-Changes in artesian pressure in northern Houston, 1931-55.

FIGURE 21.-Changes in artesian pressure in central and western Houston, 1931-55.

Baytown-La Porte Area

Fluctuations of water levels in wells in the Baytown-La Porte area in response to changes in pumping rates are shown graphically in figure 7.

The water levels recovered in 1929-32, 1940-41, and 1945-46 because of decreases in the rate of withdrawal, and declined during periods of increased withdrawals. Decreases in the pumping rate during 1953 and 1954 in the Baytown-La Porte area are not reflected as increases of artesian pressure because the rate of withdrawal from the "Alta Loma" sand in the adjacent Pasadena area was increased during the period 1950-54. The net decline of water levels in wells in the "Alta Loma" sand in both the Baytown-La Porte area and the Pasadena area has been much less than the decline of water levels in wells in the deeper sands in a comparable period.

CHANGES IN CHEMICAL QUALITY

The heavily pumped sands in the Houston-Pasadena area contain salt water a few miles down the dip, or southeast of the area of large ground-water withdrawals (Winslow and Doyel, 1954b). Because the water in the sands moves from areas of higher head to areas of lower head (down the hydraulic gradient), salt water must be moving from the southeast toward the Houston-Pasadena area. The individual sands vary in their ability to transmit water and the hydraulic gradient is different in each sand; therefore, the rates of movement of the salt water in the sands are different. Because of their physical characteristics, some sands were not flushed of salt water as far down the dip as were other sands. The necessary data to locate accurately the contact zone or "interface" between the fresh and the salt water in each of the many sands are not available. The "interface" in some sands may be closer to the Houston-Pasadena area than is suspected, although present information places the nearest salty ground water 5 or 6 miles from the areas of heavy pumping, or about 80 years away at the current apparent rate of movement through the sands.

Approximately 70 wells have been sampled periodically in the Houston district to detect any incursion of salt water. Except for two wells, partial chemical analyses of water samples have failed to indicate any significant changes in the quality of the water. Water from city of Houston test wells 8 and 9 (Harris County wells 1229 and 1230) has changed considerably since 1948 (fig. 22). The chloride content of water from well 1229, which is screened between 1,661 and 1,676 feet and is about $3\frac{1}{2}$ miles south of the Pasadena city hall, increased 28 parts per million (ppm) from March 1948 to March 1955. The chloride content of water from well 1230, at the same location and screened between 1,399 and 1,414 feet, increased by 165 ppm from March 1950 to March 1955.

Texas Board of Water Engineers in cooperation with the U. S. Geological Survey and the city of Houston

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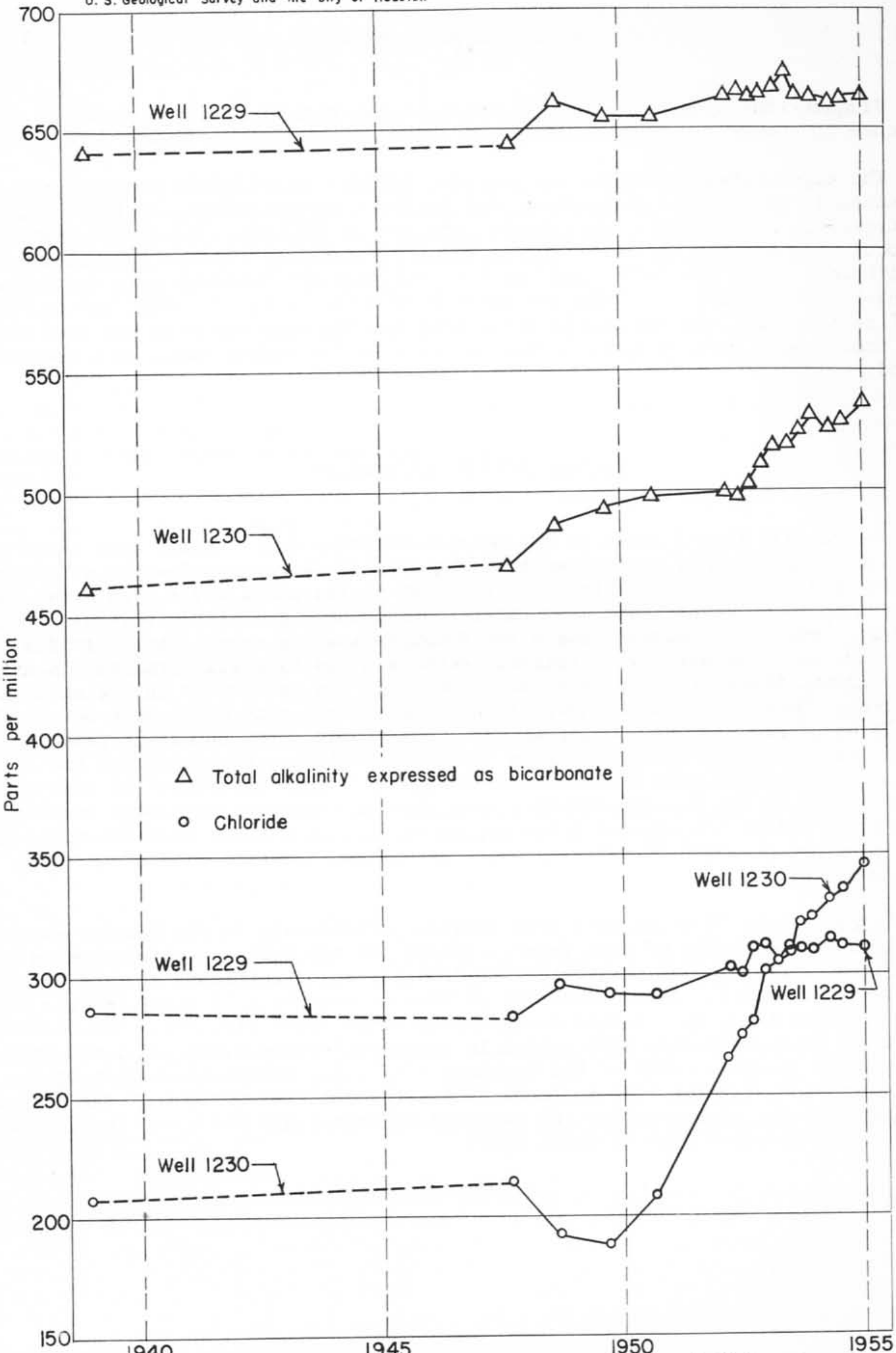

FIGURE 22.-Graph showing chloride content and total alkalinity of water from Harris County wells 1229 and 1230.

In many areas in southeastern Harris County no wells are screened at the proper depth to detect changes in the quality of water. Test wells should be located at strategic points in these areas and screened at the proper depths so that the fresh water-salt water "interface" can be mapped and the rate of movement of the salt water down the hydraulic gradient in the different sands can be observed. Winslow and Doyel concluded that such wells are particularly needed in the area between La Porte and Deer Park, where the fresh water-salt water "interface" is probably closest to the areas of large ground-water withdrawal.

SUBSIDENCE OF THE LAND SURFACE

Declines in artesian pressures resulting from heavy pumping have caused a general subsidence of the land surface throughout a large part of the Houston district. Precise releveling of certain bench marks by the U. S. Coast and Geodetic Survey in 1942-43 and in 1950-51 indicated a regional settling or subsidence of the land surface which was proportional to the decline of artesian pressure during that period. A subsidence of about 1 foot for each 100 feet of decline of artesian pressure was noted (Winslow and Doyel, 1954a).

More extensive leveling done during the 1953-54 field season shows that about 2 feet of land-surface subsidence took place in part of the Pasadena area near the ship channel between the 1942-43 releveling and the 1953-54 releveling. Contours through points of equal subsidence based on the observed elevations of 1953-54 (unadjusted) show a shallow depression in the land surface which coincides in location with the depression in the artesian-pressure surface.

The principal cause of the subsidence is believed to be a compaction of the clay beds associated with the water sands. As the head is lowered in the sands by concentrated ground-water withdrawal, part of the water contained in the clays overlying and underlying the sands drains into the sands. The weight of the overlying sands and clays, which are poorly consolidated, causes the clays to become more compact when the artesian head, which supports a part of the weight, is reduced. Winslow and Doyel (1954a) estimated that one-sixth of the water pumped from wells between 1943 and 1951 was derived from the clays. Figure 23 shows a striking comparison between the hydrograph of a well near downtown Houston and the "subsidograph" of a bench mark about 6,000 feet from the well.

In the Houston district the subsidence to date has been relatively uniform, so far as each small locality is concerned, so that its effect on manmade structures has been measurable only with precise instruments. However, in the Texas City area of Galveston County, where large quantities of water have been pumped from shallower sands, the differential settling in places has disturbed buried pipelines, reversed the flow of sewers, and warped some large structures.

Releveling by the U. S. Coast and Geodetic Survey every 5 years has been planned for the Houston district. Further study of the relation of subsidence to artesian pressure is necessary in order to determine: Which clay beds are being compacted; how much time lag occurs in adjustment of the pressure in the clay to that in the sand; how much additional subsidence can be expected if artesian pressures remain at present levels; and how much subsidence will occur if the artesian pressures are lowered further.

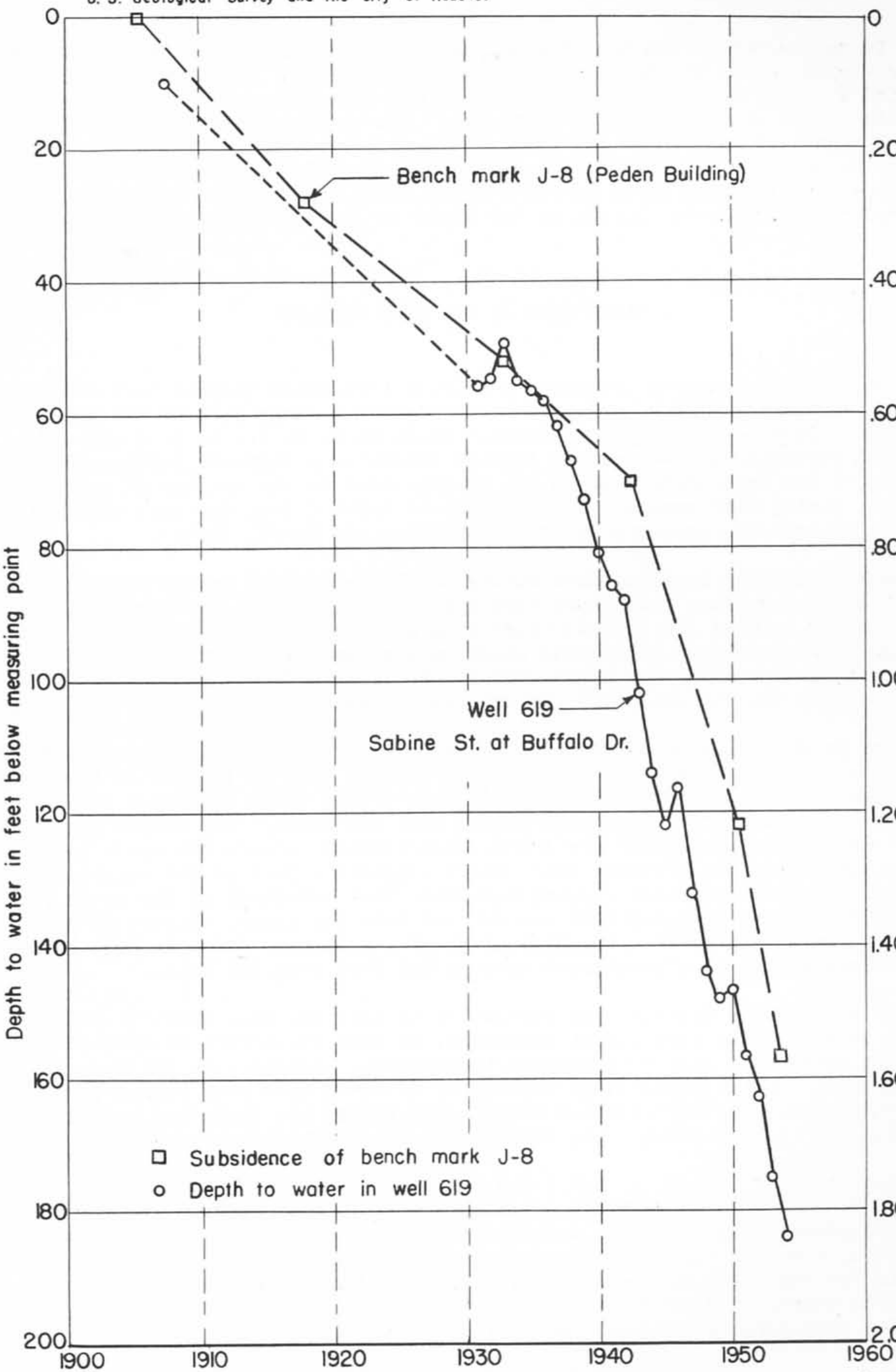

FIGURE 23.-Comparison of depth to water and subsidence of the land surface near downtown Houston, based on observed elevations.

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Year	Water-supply paper no.	Year	Water-supply paper no.
1935	777	1945	1026
1937	840	1946	1074
1939	886	1947	1099
1940	909	1948	1129
1941	939	1949	1159
1942	947	1950	1168
1943	989	1951	1194
1944	1019	1952	1224
		1953	1268