TEXAS WATER COMMISSION

BULLETIN 6211

PUMPAGE OF GROUND WATER AND FLUCTUATION OF WATER LEVELS IN THE HOUSTON DISTRICT AND THE BAYTOWN-LA PORTE AREA, TEXAS, 1957-61

By

Robert B. Anders, Geologist
and
Wellborn L. Naftel, Engineering Technician
United States Geological Survey

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

June 1962

TABLE OF CONTENTS

TABLES

TABLE OF CONTENTS (Cont'd.)

ILLUSTRATIONS

Figures

TABLE OF CONTENTS (Cont'd.)

PUMPAGE OF GROUND WATER AND FLUCTUATION OF WATER LEVELS IN THE HOUSTON DISTRICT AND THE BAYTOWN-LA PORTE AREA, TEXAS, 1957-61

INTRODUCTION

Location of Areas

The area covered by this report is in southeast Texas and includes the Houston district and the adjoining Baytown-La Porte area.

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

(1) The Katy area, consisting primarily of irrigated ricelands, occupies much of northern and western Harris County, southeastern Waller County, and northern Fort Bend County.

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

(3) The Pasadena area, which is east of the Houston area and west of the San Jacinto River, includes the ship-channel subarea, a heavily industrialized zone extending east from Houston along the Houston ship channel to the vicinity of Deer Park.

Data for the Baytown-La Porte area (Figure 2), which is not part of the Houston district but is east of the San Jacinto River and southeast of the Houston and Pasadena areas, are included 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 of Rose (1943) of Pleistocene age. The Alta Loma sand is the principal aquifer not only in southeastern Harris County but also in Galveston County.

Purpose and Scope of Report

This report is one of a series (see Bibliography) containing information on the ground-water resources of the Houston district. It presents data on pumpage, changes in artesian pressure, and related information compiled during the period 1957-61 by the U. S. Geological Survey in cooperation with the Texas Water Commission [formerly the Board of Water Engineers] and the city of Houston.

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

Figure I

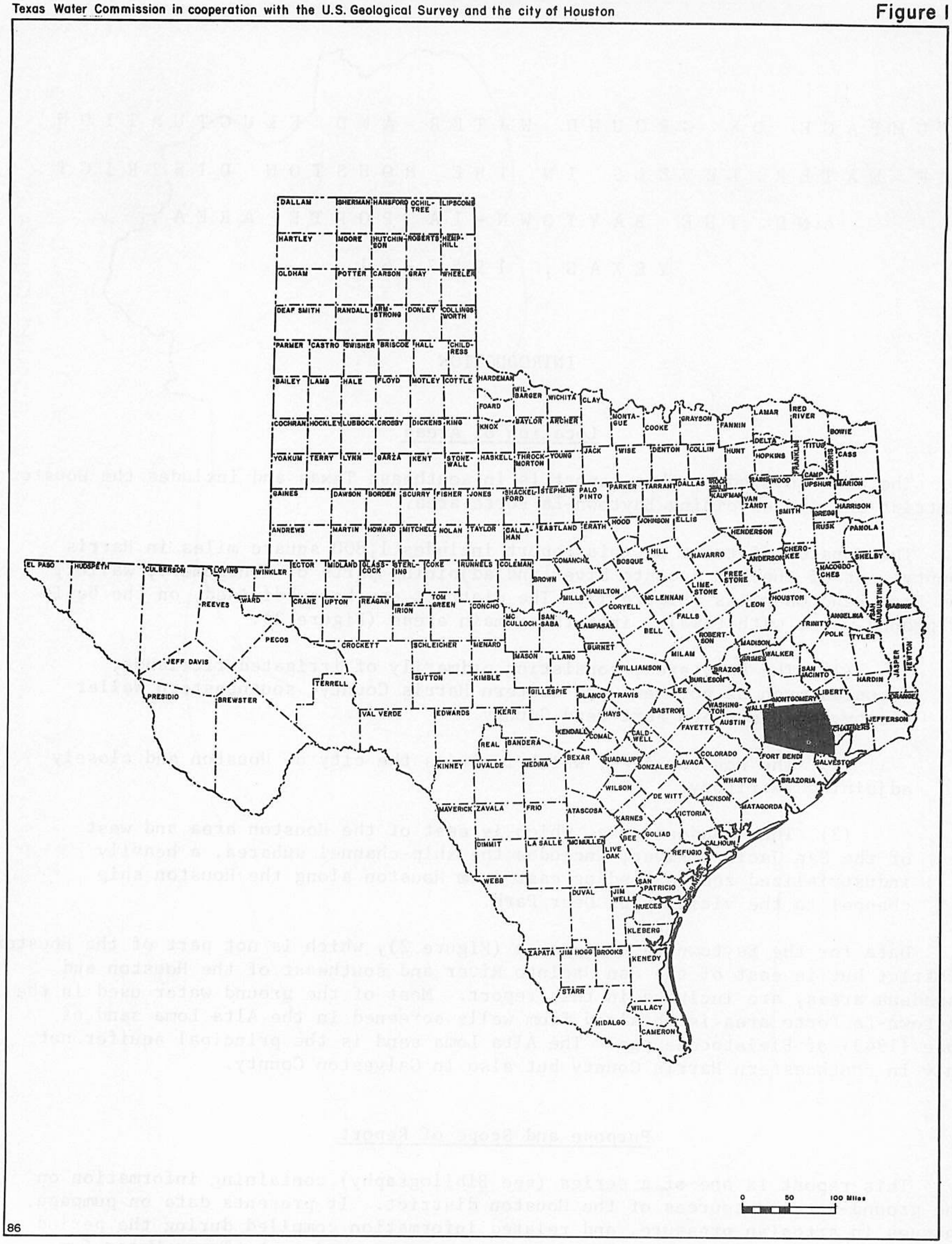


FIGURE I. – Map of Texas showing area of this report

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

Figure 2

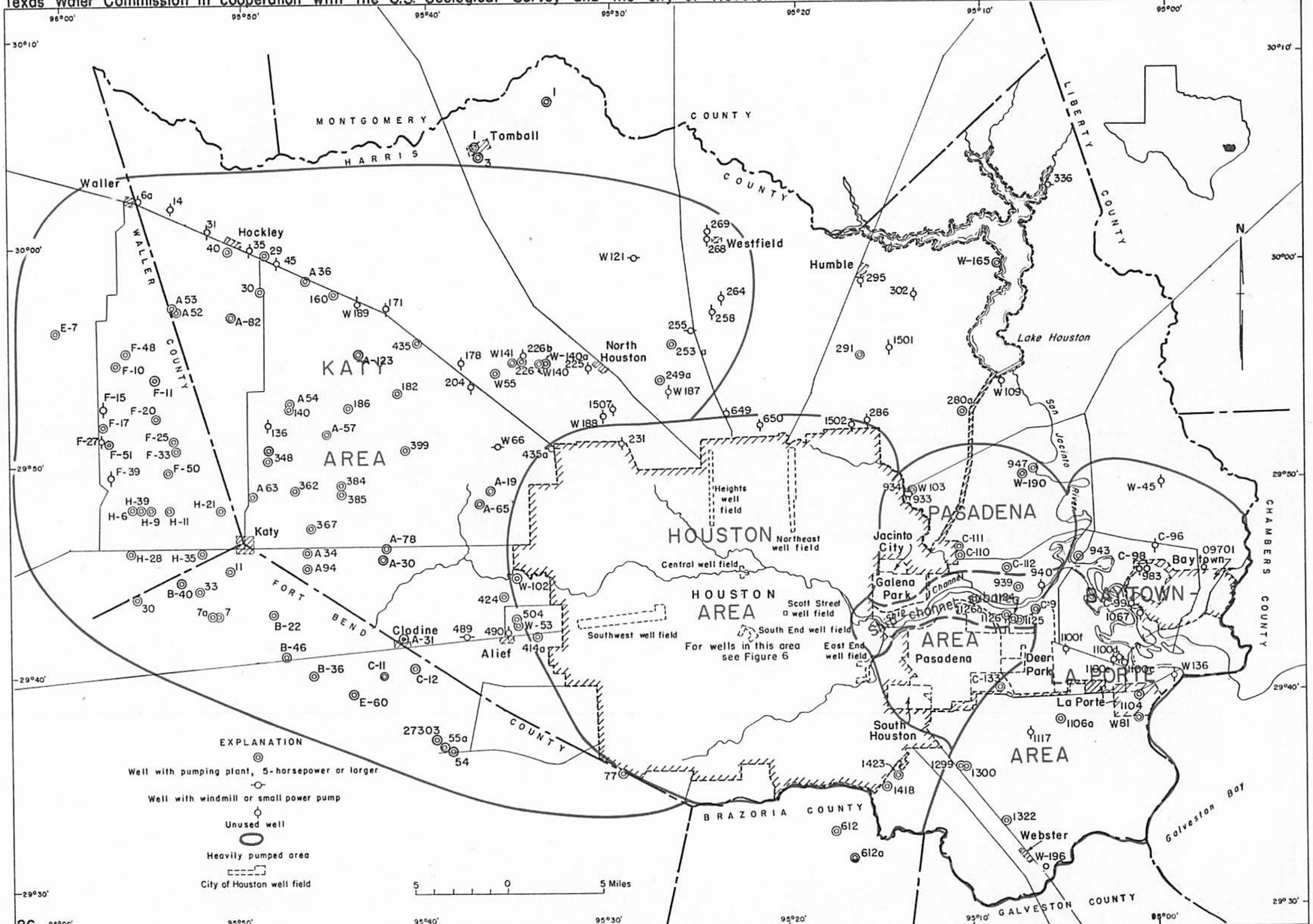


FIGURE 2.- Map of the Houston district and the Baytown-La Porte area, showing location of observation wells and heavily pumped areas

The geology, geography, and climate of the Houston district have been described in previous reports. The geology and its relation to the occurrence of ground water in the district were described by Rose (1943a), Lang, Winslow, and White (1950), and Winslow and Doyel (1954a). The water resources, both surface and ground, of the Houston-Galveston area were discussed by Goines, Winslow, and Barnes (1951).

The field work and preparation of this report were under the direct supervision of R. W. Sundstrom and A. G. Winslow, successively district engineer and district geologist in charge of ground-water investigations in Texas.

HOUSTON DISTRICT

Pumpage

Pumpage data for the preceding calendar year are obtained each spring for all industries, municipalities, and water districts pumping more than 5,000 gpd (gallons per day) in the Houston district. About 80 percent of the water pumped from wells in the Houston-Pasadena area is metered; the remainder is estimated. Pumpage figures for the Katy area are based on the consumption of electricity by irrigation pumps, the number of acres irrigated, distribution of rainfall during the irrigation season, and the duty of water per acre.

The rate of withdrawal of ground water in the Houston district decreased during the period 1957-60 as compared with the preceding period 1953-56. In 1960 the pumpage was 260 mgd (million gallons per day), an increase of 6 mgd over the pumpage in 1959, which was the lowest since 1953. The average pumpage in the areas that compose the Houston district and in the Baytown-La Porte area from 1953 to 1960 is shown in Table 1. The changes in pumping rates are due partly to an increase in the use of surface water and partly to a decrease in the demand for irrigation water in the Katy area because of limitations of rice acreage.

Katy Area

Ground water in the Katy area is used principally to irrigate rice; a small amount, probably less than 5 percent, is used for public supply and industrial purposes. During the period 1957-60, less ground water was pumped than during the preceding 4-year period, owing principally to acreage limitations instituted under the price-support program for rice and also to the generally greater precipitation; in 1958 however, rainfall during a large part of the growing season was below normal and pumpage was greater than in the other 3 years. The average daily pumpage of ground water in the Katy area is shown in Table 1 and Figure 3; in the 4 years (1957-61) it ranged between 80 mgd in 1960 and 110 mgd in 1958. The average amount of ground water applied per acre in 1960 was approximately half that applied in 1958, mainly because precipitation during the 1960 irrigation season was 9 inches greater than during the 1958 season. Actually, the daily withdrawals during the 5-month pumping season are more than twice as great as are indicated by the figures, which show averages for the whole year.

Table 1.--Average use of water in the Houston and Pasadena, Katy, and Baytown-La Porte areas, in million gallons per day, 1953-60

	1953	1954	1955	1956	1957	1958	1959	1960
Ground water								
Houston and Pasadena areas	187	179	166	173	175	186	169	180
Katy area	120	160	104	125	95	110	85	80
Total, Houston district	307	339	270	298	270	296	254	260
Baytown-La Porte area	23	22	25	28	26	25	27	29
TOTAL	330	361	295	326	296	321	281	289
Surface water								
Houston and Pasadena areas	18	33	54	67	68	71	79	81
Baytown-La Porte area	27	27	24	28	22	23	26	28
TOTAL	45	60	78	95	90	94	105	109
TOTAL, GROUND AND SURFACE WATER	375	421	373	421	386	415	386	398

Houston and Pasadena Areas

The average daily pumpage of ground water in the Houston and Pasadena areas for the period 1953-60 is shown in Tables 1 and 2 and for the period 1930-60 in Figures 3 and 4; as indicated, it was less during the period 1957-60 than in 1953. During 1957-60 it averaged about 177 mgd, as compared with 176 mgd in 1953-56. The decrease in pumpage since 1953 is attributed to the increased availability and use of surface water from the San Jacinto River since the completion of Lake Houston and the construction of distribution and treating facilities by the city of Houston and private industry.

Pumpage of ground water by industries in the Pasadena area during the period 1957-60 ranged between 67 mgd in 1959 and 73 mgd in 1958 and averaged 70 mgd (Table 2). This represents a slight decrease from the preceding 4-year period when the average pumpage was about 72 mgd. Most of the ground water used in the Pasadena area is from wells in the ship-channel subarea, where the increased use of surface water has caused the greatest reduction in ground-water withdrawals.

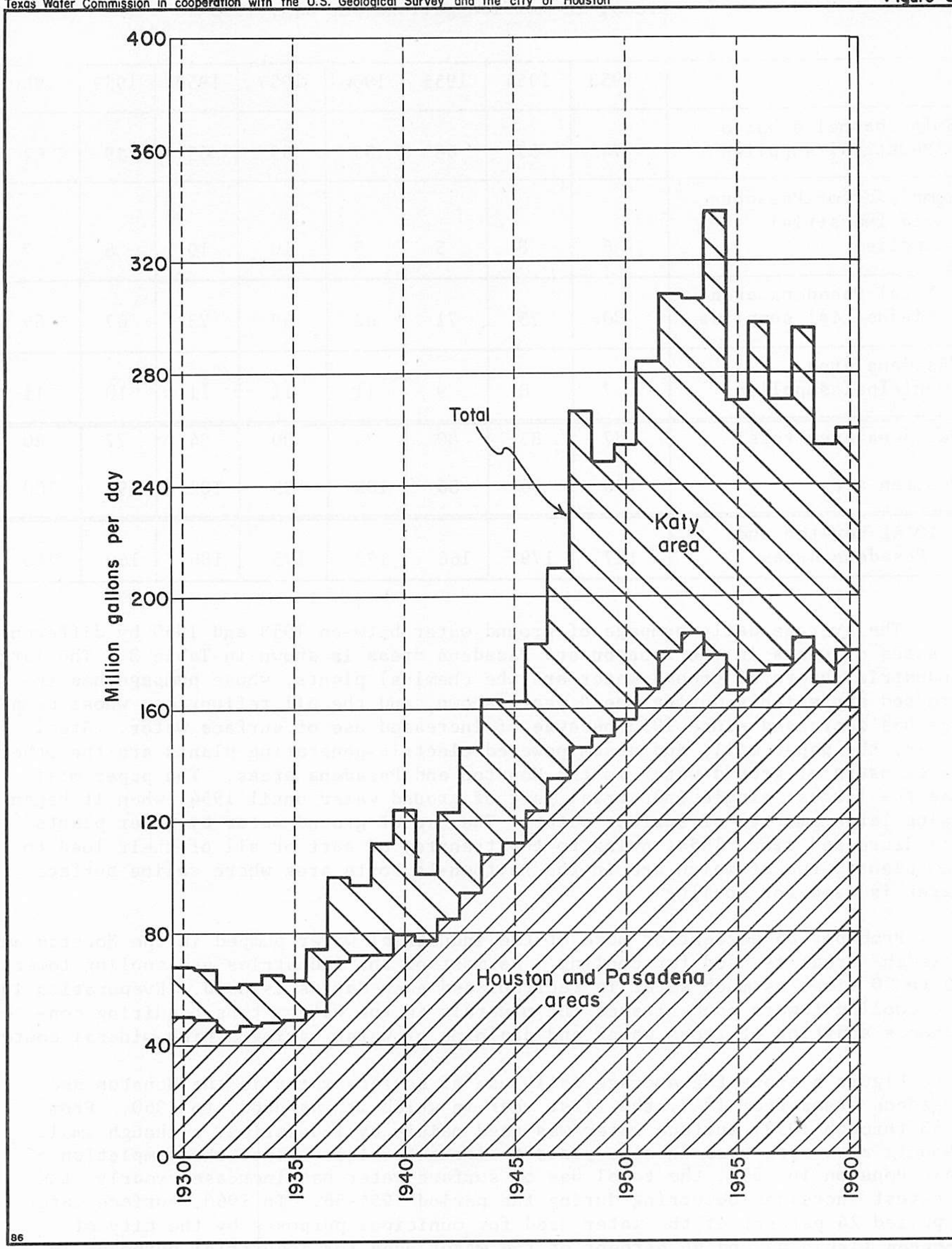


FIGURE 3.-Average daily pumpage of ground water in the Houston district

Table 2.--Average pumpage of ground water in the Houston and Pasadena areas, in million gallons per day, 1953-60

	1953	1954	1955	1956	1957	1958	1959	1960
Ship-channel subarea industrial supplies	74	67	66	57	59	63	59	62
Remainder of Pasadena area industrial supplies	6	8	5	5	10	10	8	7
Total Pasadena area industrial supplies	80	75	71	62	69	73	67	69
Pasadena area municipal supplies	7	8	9	11	11	11	10	11
Pasadena area total	87	83	80	73	80	84	77	80
Houston area	100	96	86	100	95	102	92	100
TOTAL Houston and Pasadena areas	187	179	166	173	175	186	169	180

The average daily pumpage of ground water between 1953 and 1960 by different classes of users in the Houston and Pasadena areas is shown in Table 3. The largest industrial users of ground water are the chemical plants, whose pumpage has increased appreciably during the 8 years shown, and the oil refineries, whose pumpage has decreased since 1953 because of increased use of surface water. Steel mills, the paper mill, and steam-powered electric-generating plants are the other large users of ground water in the Houston and Pasadena areas. The paper mill was the largest single industrial user of ground water until 1954, when it began using large amounts of surface water. The use of ground water by power plants has decreased since 1954, owing to the transfer of part or all of their load to new plants, two of which are in the Baytown-La Porte area where saline surface water is used for cooling.

Probably 85 percent or more of the industrial water pumped in the Houston and Pasadena areas is used for cooling. As most of the industries use cooling towers, 15 to 20 times as much water is recirculated each day as is used. Evaporation in the cooling towers concentrates the minerals in the water, thus requiring continuous addition of fresh water and draining of water having a high-mineral content.

Figure 5 shows the average daily use of surface water in the Houston and Pasadena areas from 1943, the first year in which it was used, to 1960. From 1943 through 1953, surface water was used mainly by industries, although small amounts also were used in some years to irrigate rice. Since the completion of Lake Houston in 1954, the total use of surface water has increased yearly, the greatest increases occurring during the period 1954-56. In 1960, surface water supplied 24 percent of the water used for municipal purposes by the city of Houston (Table 4) and 46 percent of the water used for industrial purposes in the ship-channel subarea.

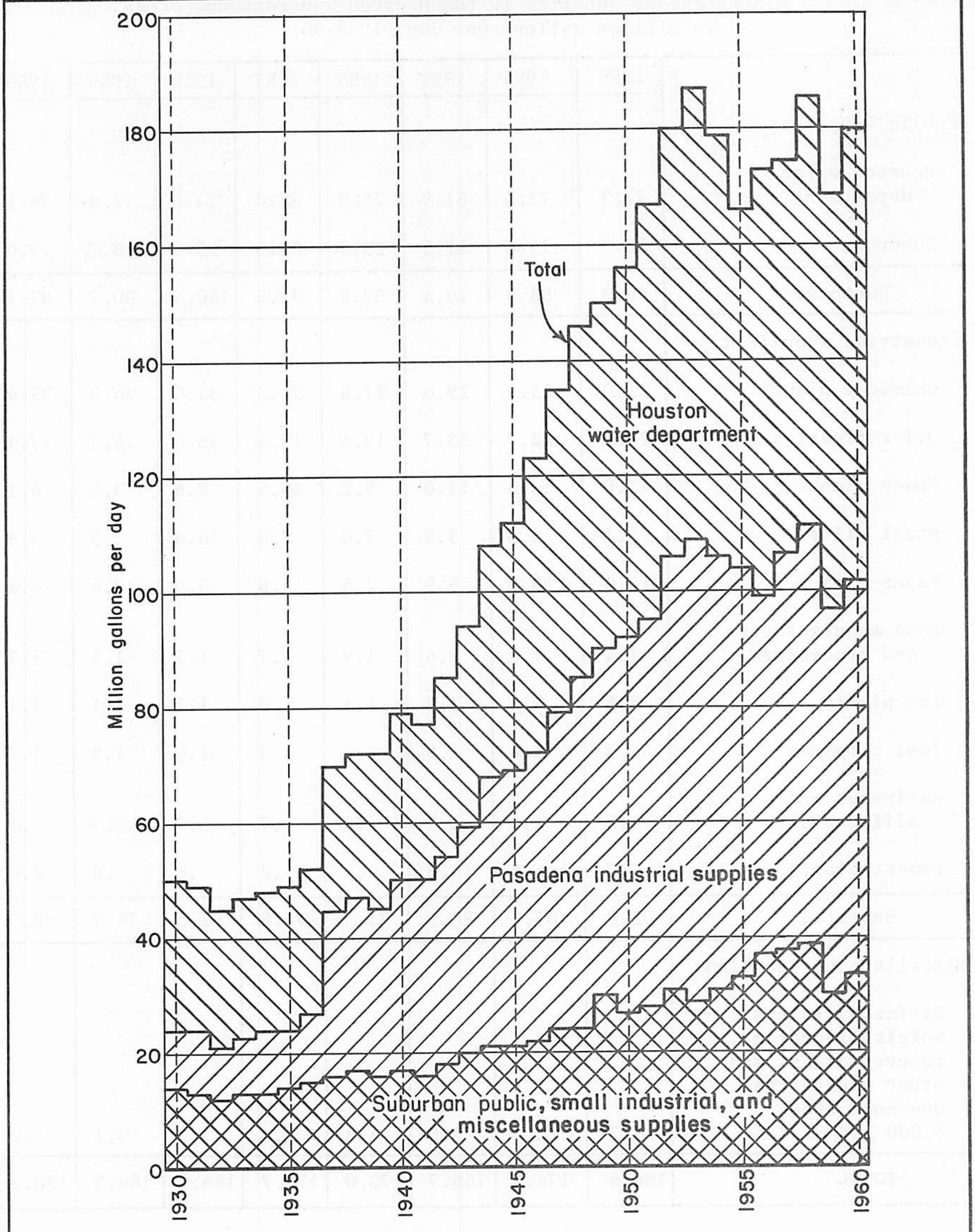


FIGURE 4.-Average daily pumpage of ground water in the Houston and Pasadena areas

Table 3.--Average pumpage of ground water for public, industrial, and miscellaneous supplies in the Houston and Pasadena areas, in million gallons per day, 1953-60

	1953	1954	1955	1956	1957	1958	1959	1960
Public supplies:								
Houston water department	77.3	72.5	61.9	73.9	68.0	74.8	72.0	78.1
Suburban	13	15.8	17.5	23.9	23.6	25.6	18.7	19.0
Subtotal	90.3	88.3	79.4	97.8	91.6	100.4	90.7	97.1
Industrial supplies:								
Chemical plants	21.0	25.7	29.0	27.8	31.2	31.0	34.0	35.4
Oil refineries	27.0	22.7	23.7	19.6	19.4	18.0	16.2	17.1
Power plants	12.0	13.5	11.0	9.2	10.5	7.8	3.8	4.1
Steel mills	6.1	5.5	5.9	7.0	7.6	10.4	7.5	9.5
Paper mill	19.0	13.0	6.9	2.5	5.6	9.0	7.6	6.8
Food manufacturers and processors	1.4	1.6	1.6	1.9	1.7	1.7	1.5	1.7
Ice plants	1.5	1.5	1.4	1.3	1.0	1.1	1.1	1.1
Tool companies	1.7	1.6	1.9	1.0	1.3	2.0	1.5	1.8
Railroads and allied plants	1.6	1.3	1.1	.8	.7	.7	.7	.6
Cement plants	.7	.8	.8	.8	.8	.8	.8	2.0
Subtotal	92.0	87.2	83.3	71.9	79.8	82.5	74.7	80.1
Miscellaneous supplies:								
Office buildings, hotels, laundries, country clubs, and other plants that use more than 5,000 gpd	4.3	3.4	3.0	3.3	3.3	3.3	3.1	3.0
TOTAL	186.6	178.9	165.7	173.0	174.7	186.2	168.5	180.2

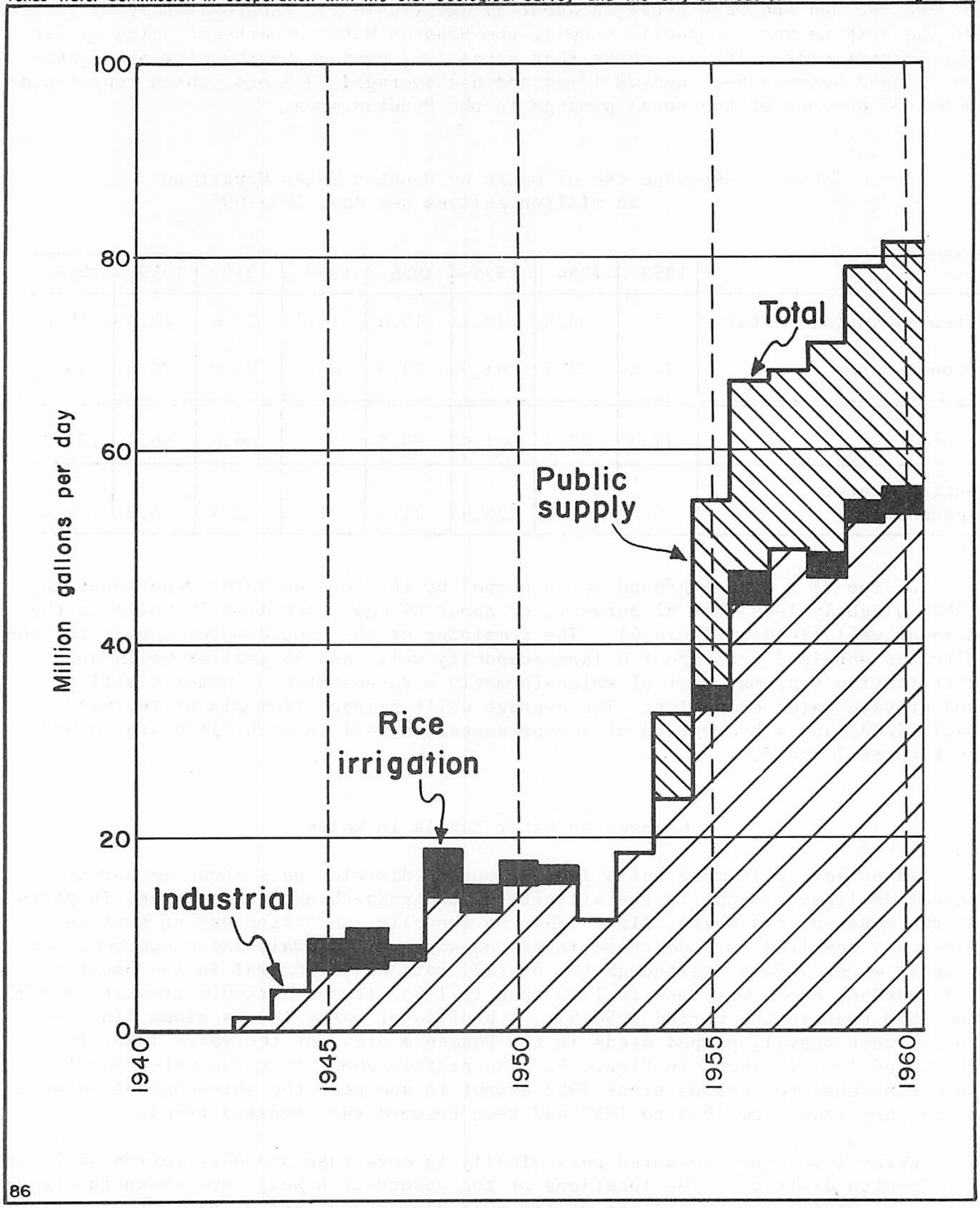


FIGURE 5.-Average daily use of surface water in the Houston and Pasadena areas

In the Houston area withdrawals of ground water since 1957 have ranged between 92 and 102 mgd and have averaged about 97 mgd (Table 2). Approximately 85 percent of the pumpage was for public supply, the Houston Water Department being by far the largest user. Table 4 shows that since 1957 pumpage by the city of Houston has ranged between 68.0 and 78.1 mgd and has averaged 73.2 mgd, which represents about 75 percent of the total pumpage in the Houston area.

Table 4.--Average use of water by Houston Water Department, in million gallons per day, 1953-60

	1953	1954	1955	1956	1957	1958	1959	1960
Treated surface water	0	8.8	19.1	19.6	18.2	21.6	24.4	25.2
Ground water	77.3	72.5	61.9	73.9	68.0	74.8	72.0	78.1
Total	77.3	81.3	81.0	93.5	86.2	96.4	96.4	103.3
Surface-water percentage	0	10.8	23.6	21.0	21.1	22.4	25.3	24.4

Of the 78.1 mgd of ground water pumped by the Houston Water Department in 1960, slightly less than 82 percent, or about 64 mgd, came from 52 wells in the 8 major well fields (Figure 6). The remainder of the ground-water supply for the city was obtained from about 6 large-capacity wells and 95 smaller wells and distribution systems, most of which formerly were operated by water districts and private water companies. The average daily pumpage from six of the major well fields and a hydrograph of a representative well in each field are shown in Figures 7 and 8.

Changes in Water Levels in Wells

Water levels in most wells in the Houston district have shown steady net annual declines, except in the vicinity of the ship-channel subarea and in parts of the Houston area where, since 1954, an annually increasing use of surface water has resulted in a decrease in ground-water withdrawals and a concommitant rise in water levels. Although the overall rate of withdrawal in the Houston and Pasadena areas was less in 1960 than in 1953, it was markedly greater in 1958 and 1960 than in the period 1954-57. A profile of water levels along line A-A' in the most heavily pumped sands in the Pasadena area for the years 1953, 1955, 1957, and 1961 is shown in Figure 9. The profile shows that the water levels have continued to decline since 1953 except in and near the ship-channel subarea where they rose from 1953 to 1957 and then resumed the downward trend.

Water levels are measured periodically in more than 300 observation wells in the Houston district. The locations of the observation wells are shown in Figures 2 and 6. Most of the wells are of the multiple-screen, gravel-pack type, and artesian pressures differ with depth; thus, the data are insufficient to prepare a piezometric map for any particular sand or group of sands. Figures 10, 11, and 12 show the approximate altitudes of water levels in wells in the Houston district in January 1941, March 1951, and March 1961, respectively. The observation wells

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

Figure 6

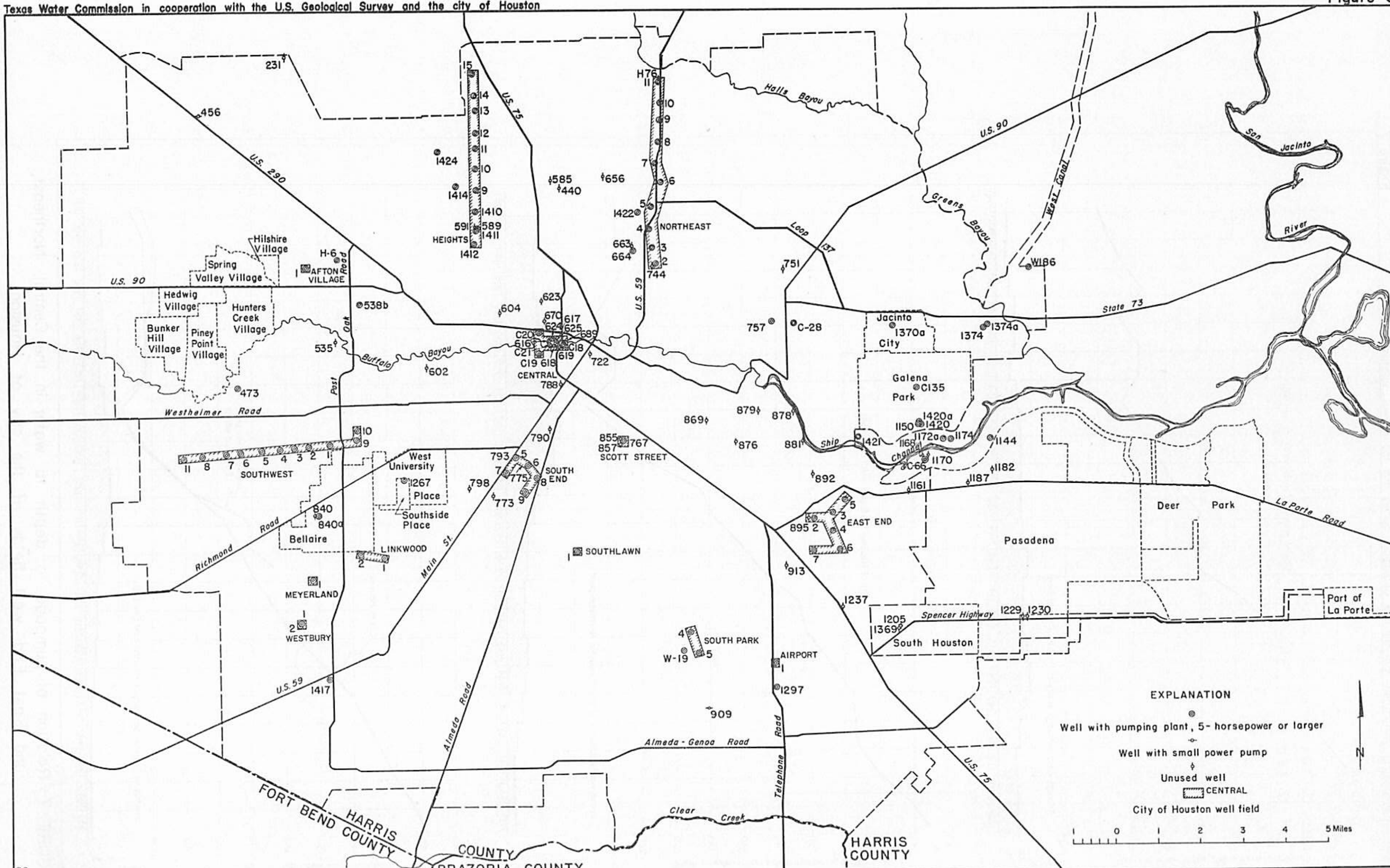


FIGURE 6. - Observation wells and location of municipal well fields in Houston

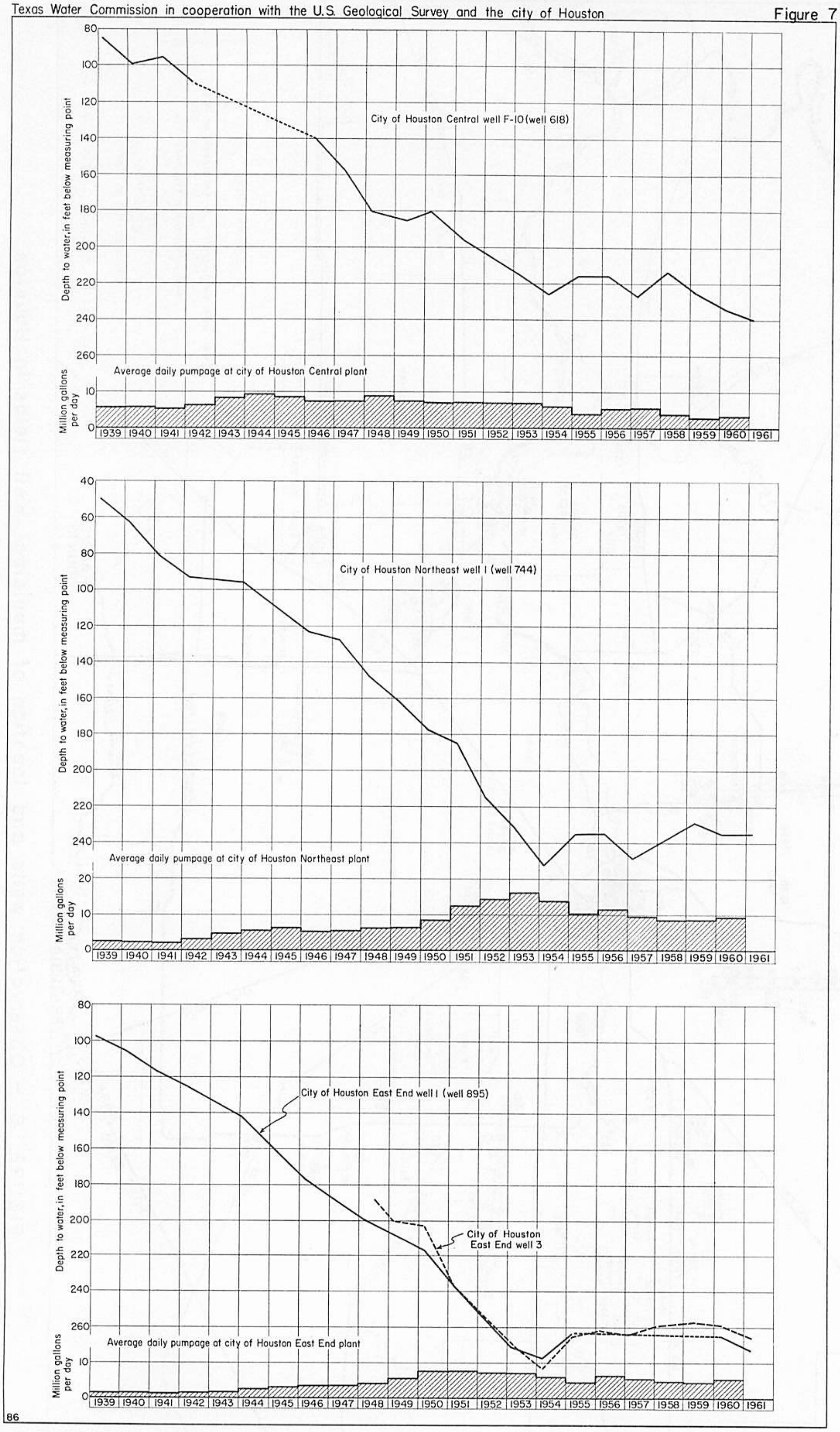


FIGURE 7.- Relation of pumpage to depth to water in the Central, Northeast, and East End well fields of the city of Houston

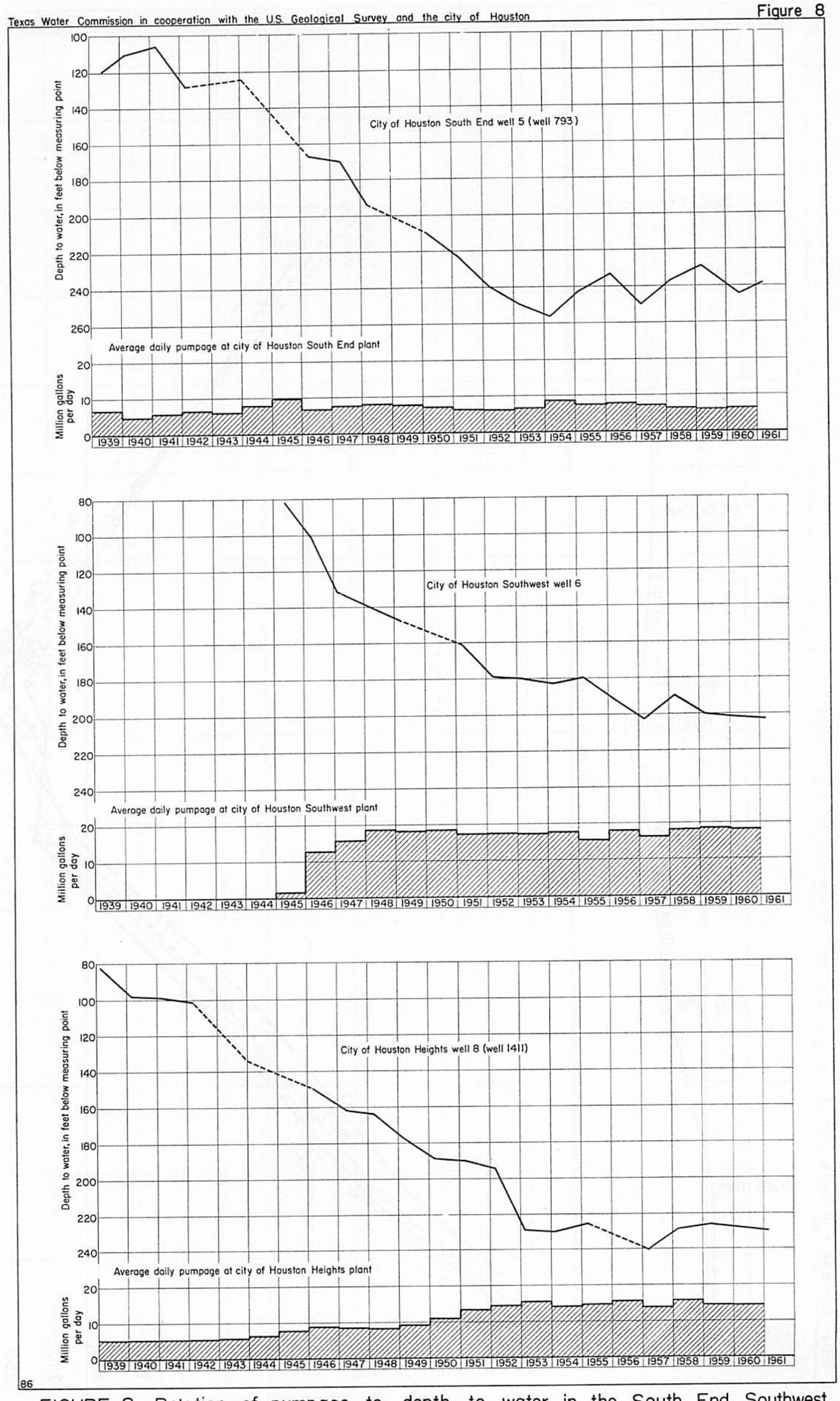
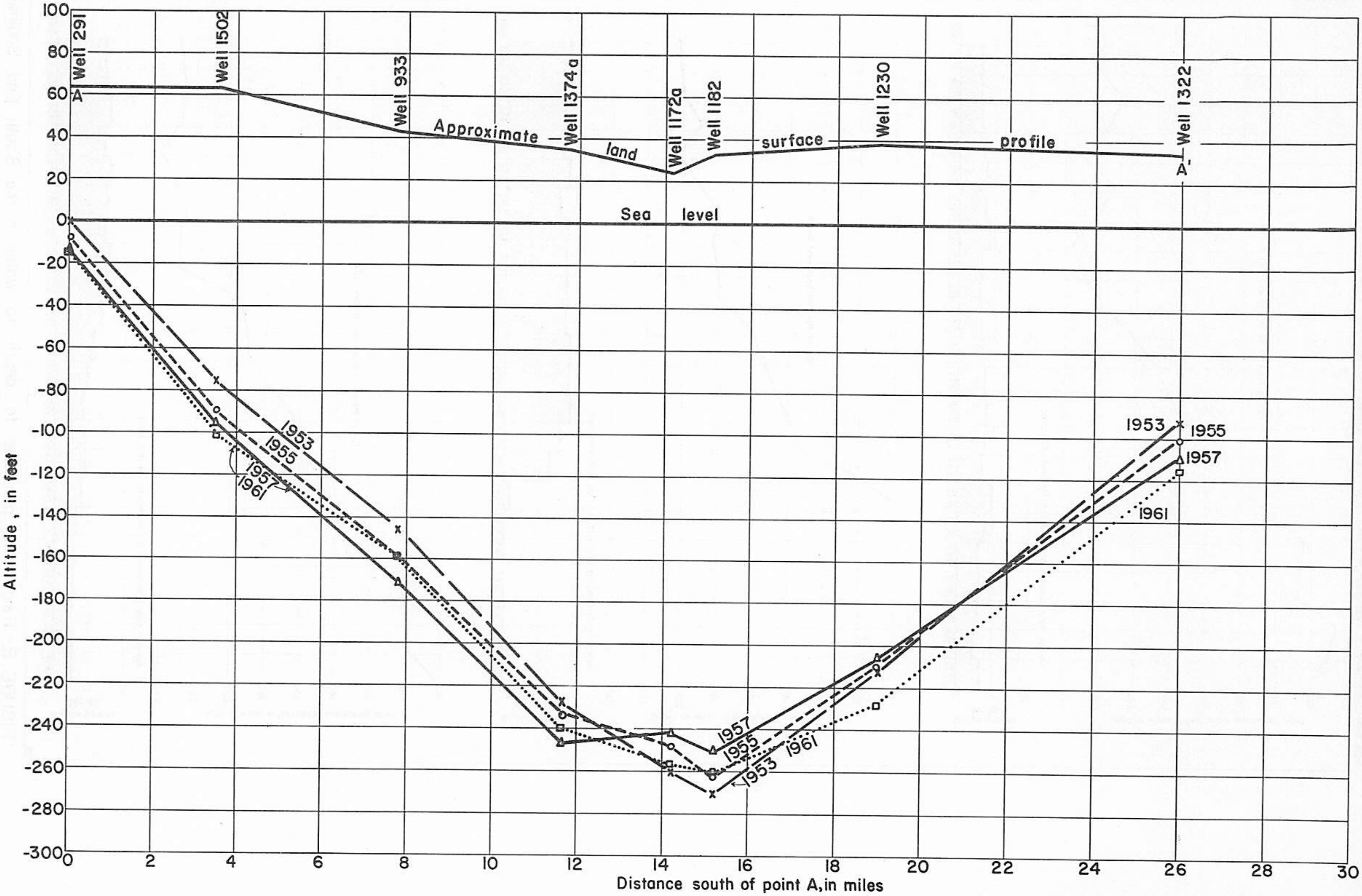


FIGURE 8.- Relation of pumpage to depth to water in the South End, Southwest, and Heights well fields of the city of Houston

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

Figure 9



86

FIGURE 9.- Profile A-A' showing water levels in eastern Harris County, March 1953, 1955, 1957, and 1961

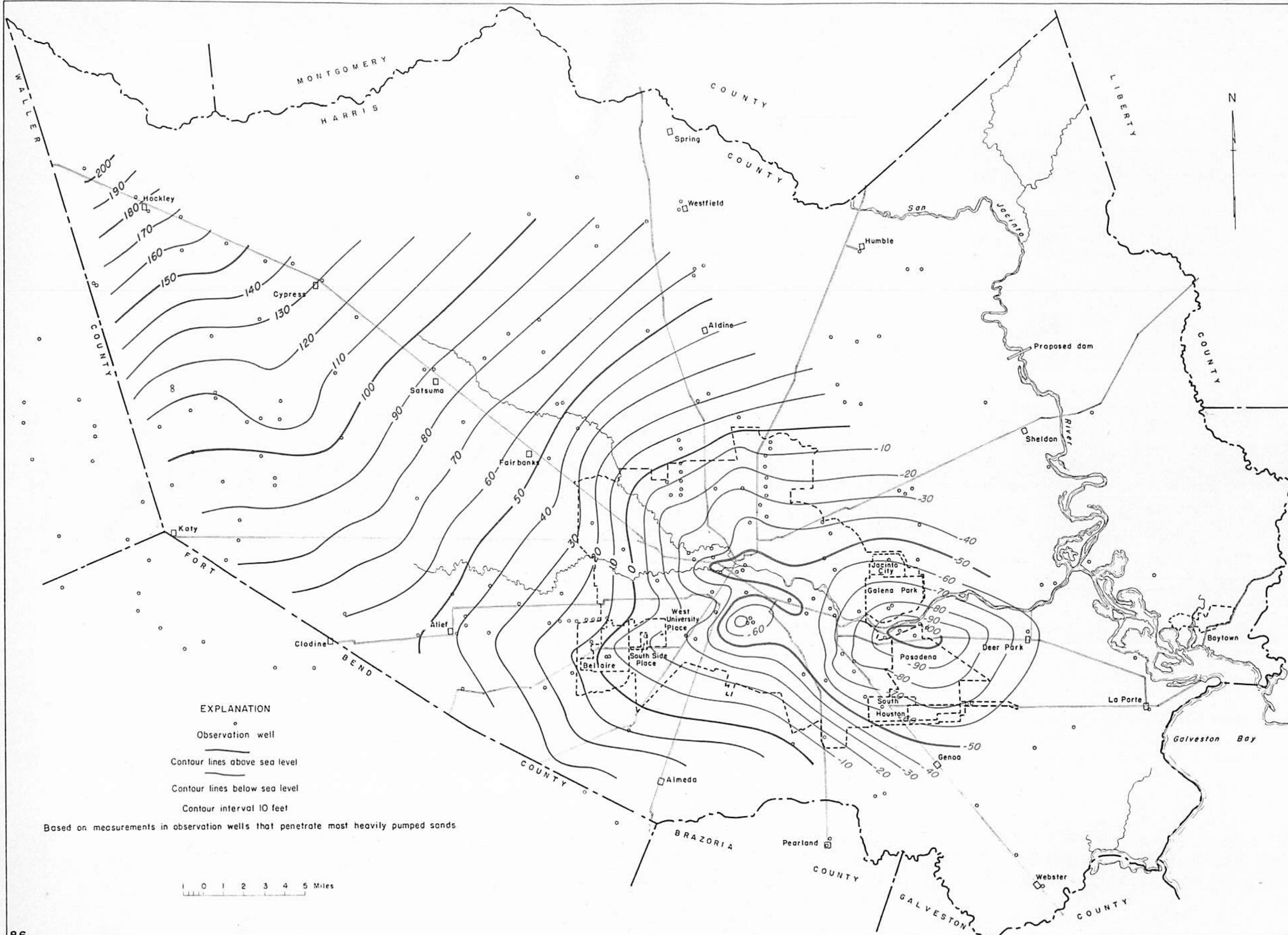


FIGURE 10.- Approximate altitude of water levels, in feet, in wells in the Houston district, January 1941

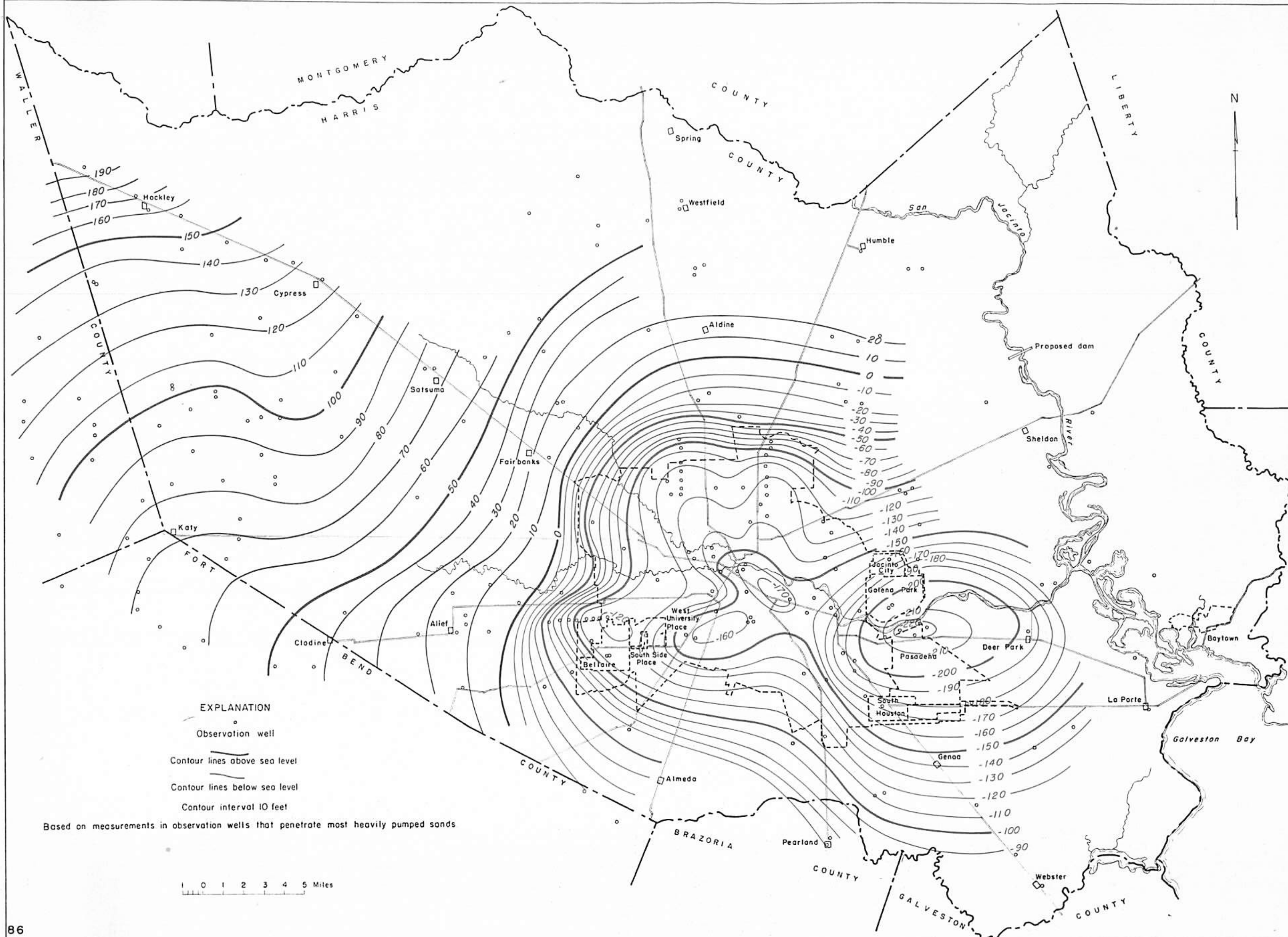


FIGURE 11.- Approximate altitude of water levels, in feet, in wells in the Houston district, March 1951

are screened in the most heavily pumped sands, and only approximate overall changes in water levels can be determined by comparing the figures.

The decrease in the withdrawals of ground water in the ship-channel subarea since 1951 is reflected in the slower rate of deepening of the depression in the water levels relative to the period between 1941 and 1951.

Katy Area

Fluctuations of water levels in two wells (Harris County well 186 and Waller County well F-25) in the Katy area are shown in Figure 13. Although the water-level trend is downward in the Katy area, the rate of decline is very slow compared to that in the Houston and Pasadena areas during the same period, mainly because the wells in the Katy area are distributed over a larger area. Since 1957 the rate of decline has decreased owing to a decrease in withdrawals resulting from a reduction in rice acreage allotments and a general increase in the rainfall during the growing season. During the period 1953-61 the water levels in 27 observation wells declined an average of 10.3 feet, whereas in the period 1957-61 they declined an average of only 1.6 feet.

Pasadena Area

The fluctuations of water levels in most wells in the Pasadena area during the period 1953-61 closely reflect the changes in rate of ground-water withdrawal. The hydrographs of representative wells in the Pasadena area are shown in Figures 14, 15, 16, and 17.

In the heavily pumped deep sands, water levels rose markedly during the period 1953-57, but since then they have resumed their downward trend, though at a considerably reduced rate compared to the rate of decline prior to 1953. However, in the northern part of the area, the water level in well 933 (the deep well on Figure 16) has been relatively stable since 1953 except for a sharp rise in 1956 and a decline in 1958 that reflect variations in local ground-water withdrawals.

In the eastern part of the ship-channel subarea, where several wells obtain water from the relatively shallow Alta Loma sand of Rose (1943), which is the principal aquifer in Galveston County and in the Baytown-La Porte area of Harris County, water levels have continued to decline about 4 feet per year since 1953 (Figure 17). This rate of decline which is slightly less than before 1953 is attributed to a local reduction in pumpage from the Alta Loma, although an increase in pumpage has been recorded in the adjacent Baytown-La Porte area.

Houston Area

Water levels in most wells in the Houston area declined during the period 1957-61. The hydrographs of eight wells in the Houston area, or that reflect the pumpage from the heavily pumped sands in the Houston area, are shown in Figures 18, 19, 20, and 21. In six wells the water levels declined an average of 1.4 feet per year during the 1957-61 period, the largest declines occurring in the eastern part of the area. In general, the declines were less than during the preceding 4-year period. In 48 Houston municipal wells the net changes in water levels for the period 1957-61 ranged between a rise of 18.1 feet and a decline of 20.5 feet (Table 5). The net decline was 2.6 feet, or 0.6 foot per year, considerably less than the 7 to 15 feet per year from March 1955 to March 1957 (Wood, 1958, p. 25).

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

Figure 13

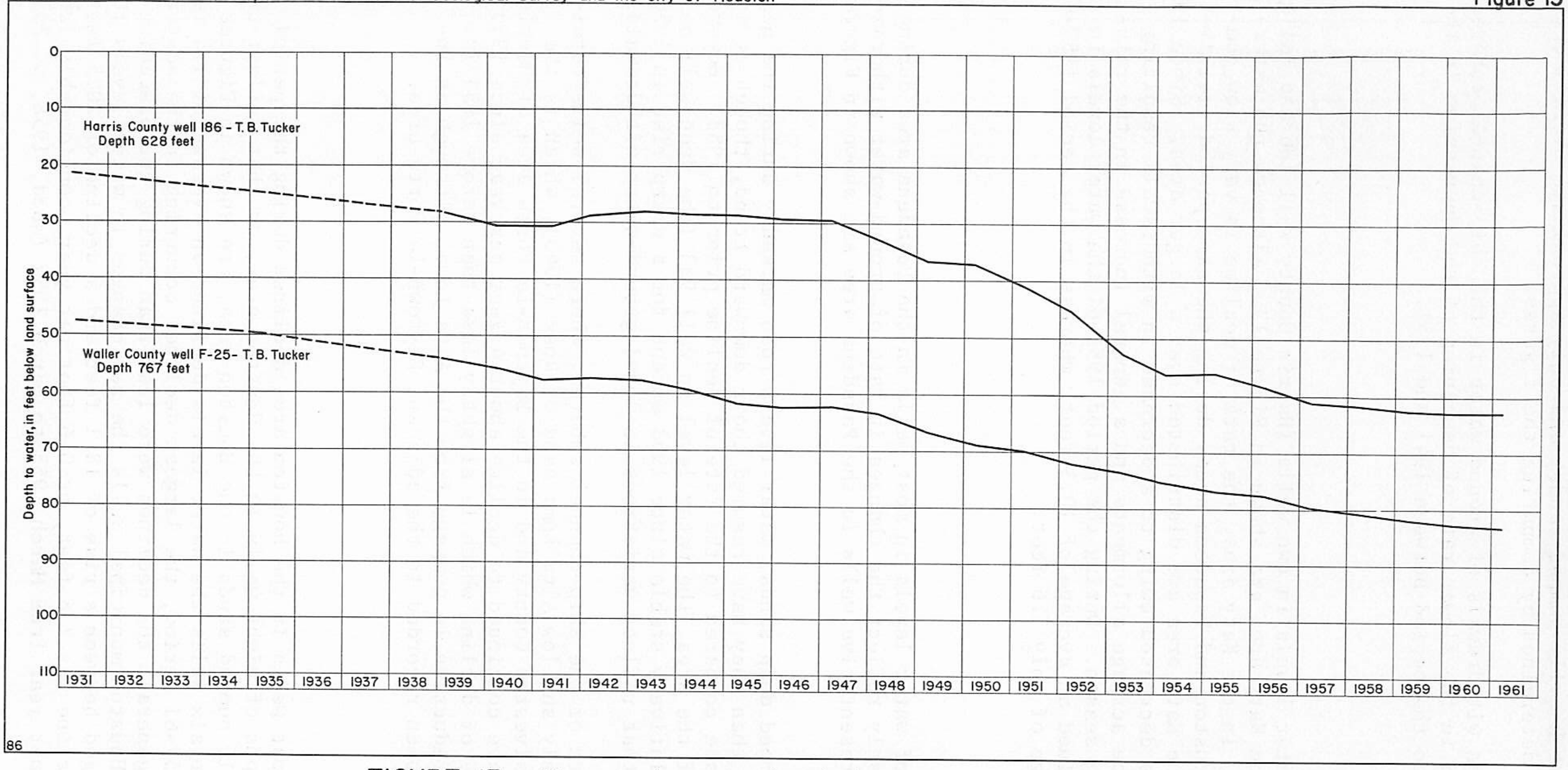
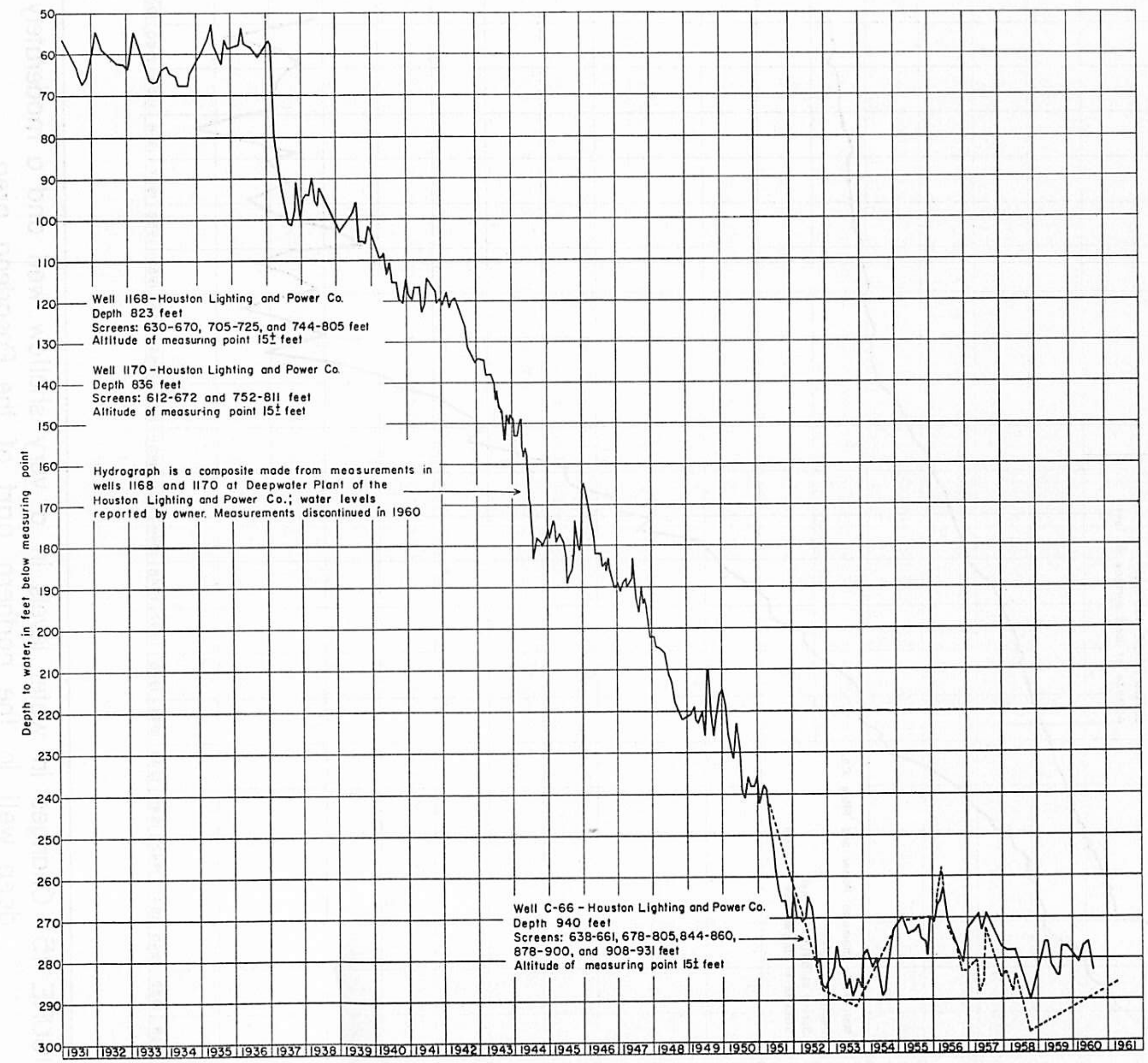


FIGURE 13.- Changes in water levels in wells in the Katy area

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

Figure 14



86

FIGURE 14.- Changes in water levels in Harris County wells 1168, 1170, and C-66

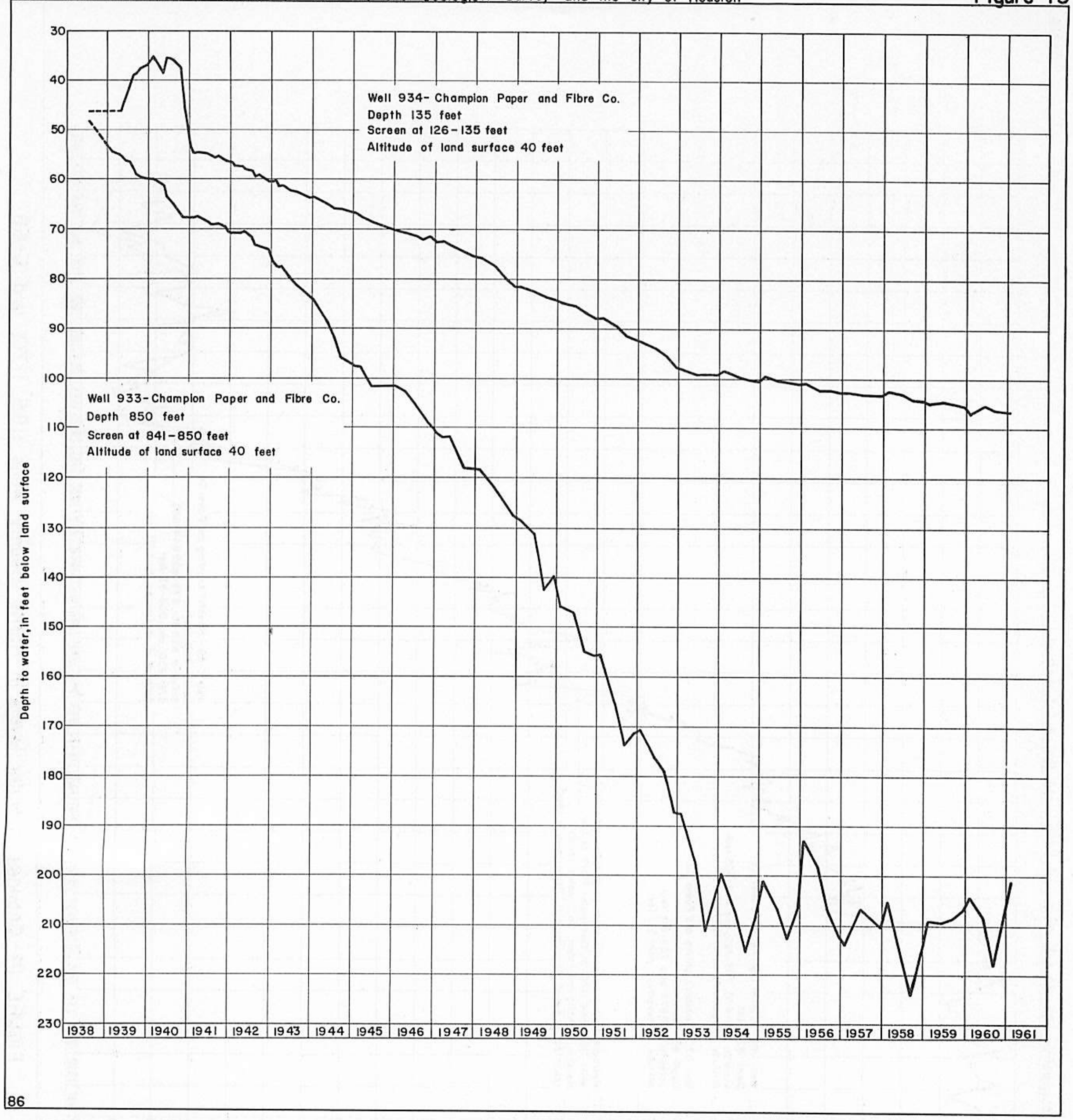


FIGURE 15.- Changes in water levels in a very shallow well and a moderately deep well in the northern part of the Pasadena area

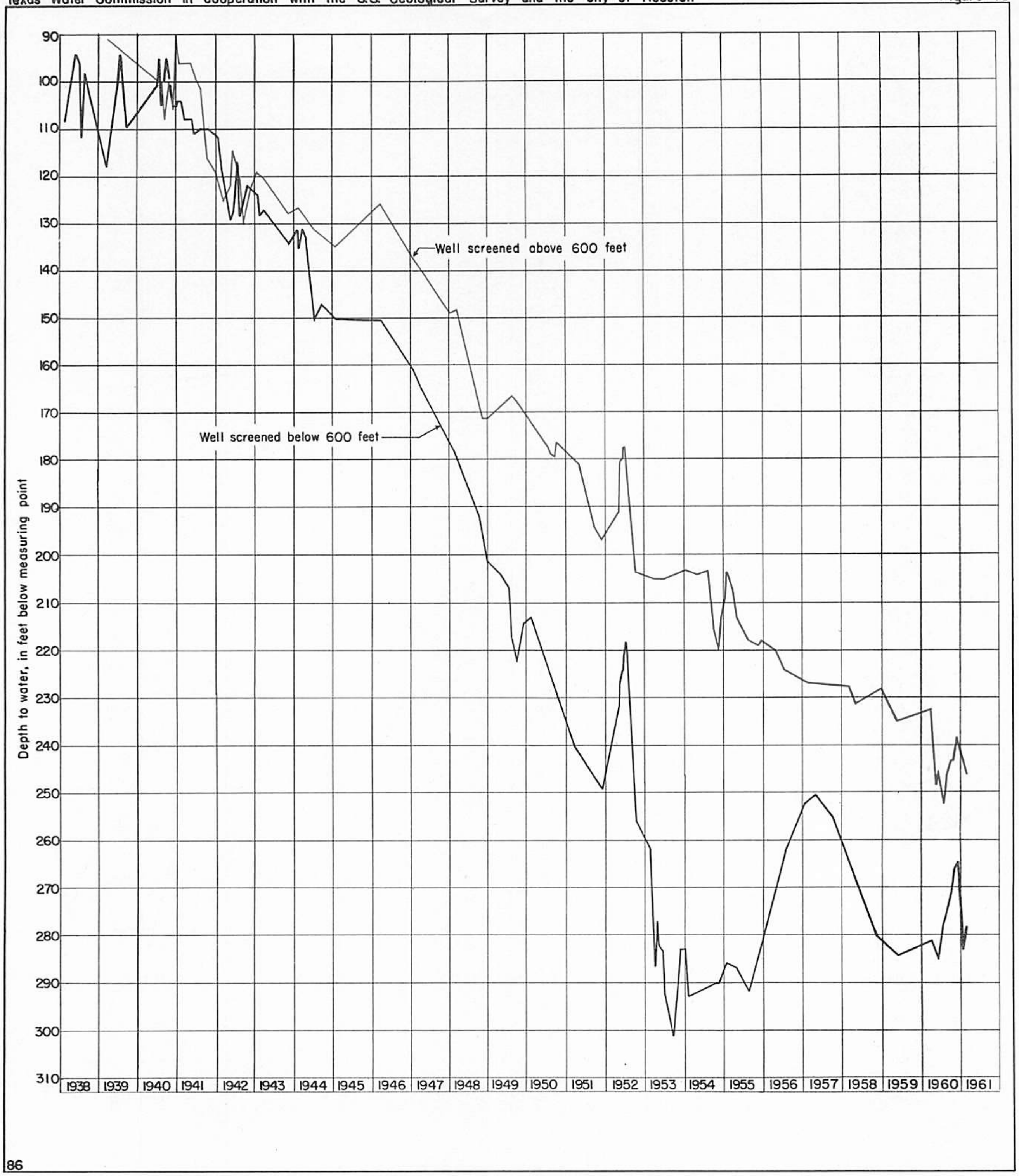
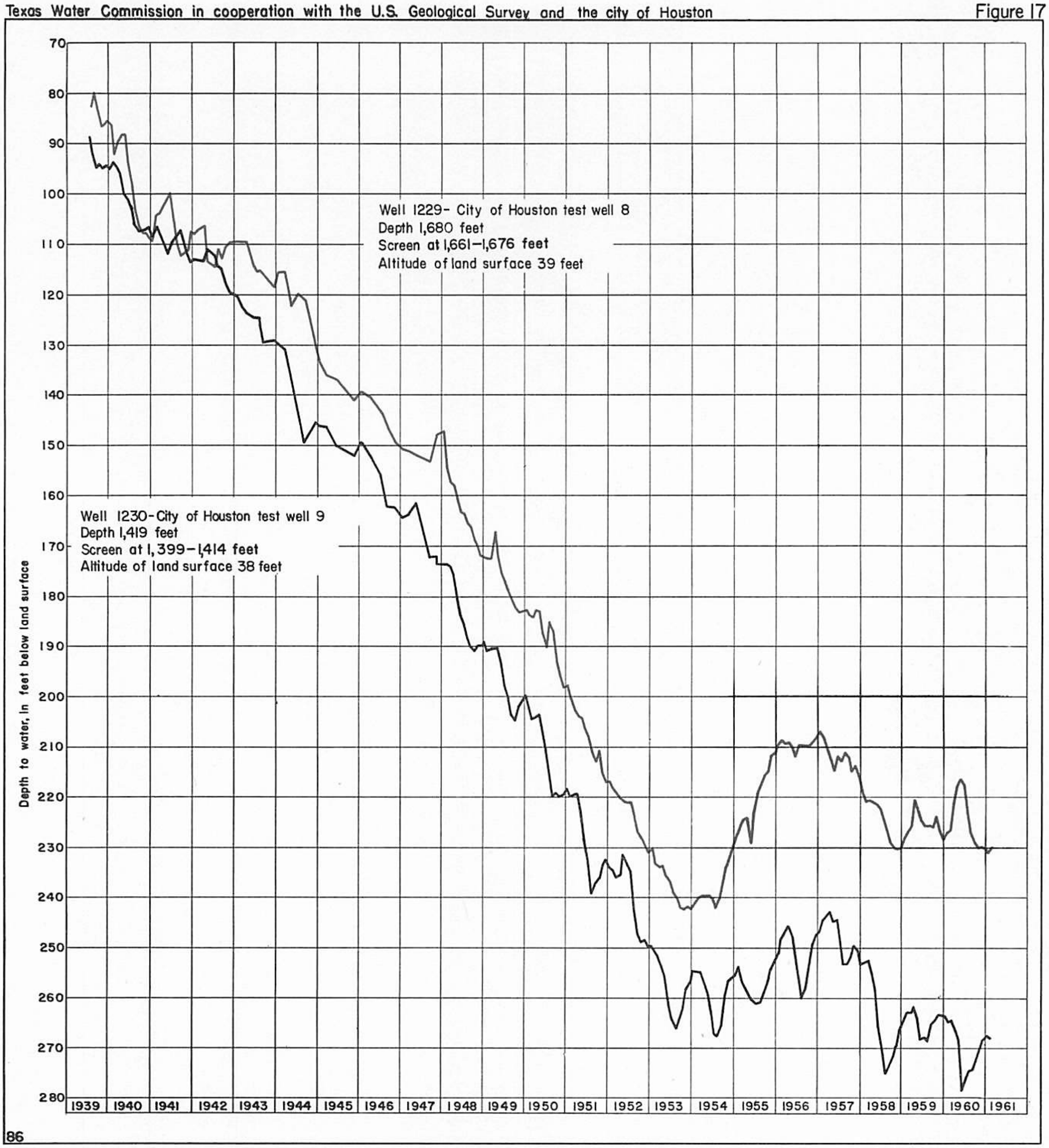


FIGURE 16.- Changes in water levels in a shallow well and a deep well in the eastern part of the ship-channel subarea



86

FIGURE 17.- Changes in water levels in two single-screened deep wells in the southern part of the Pasadena area

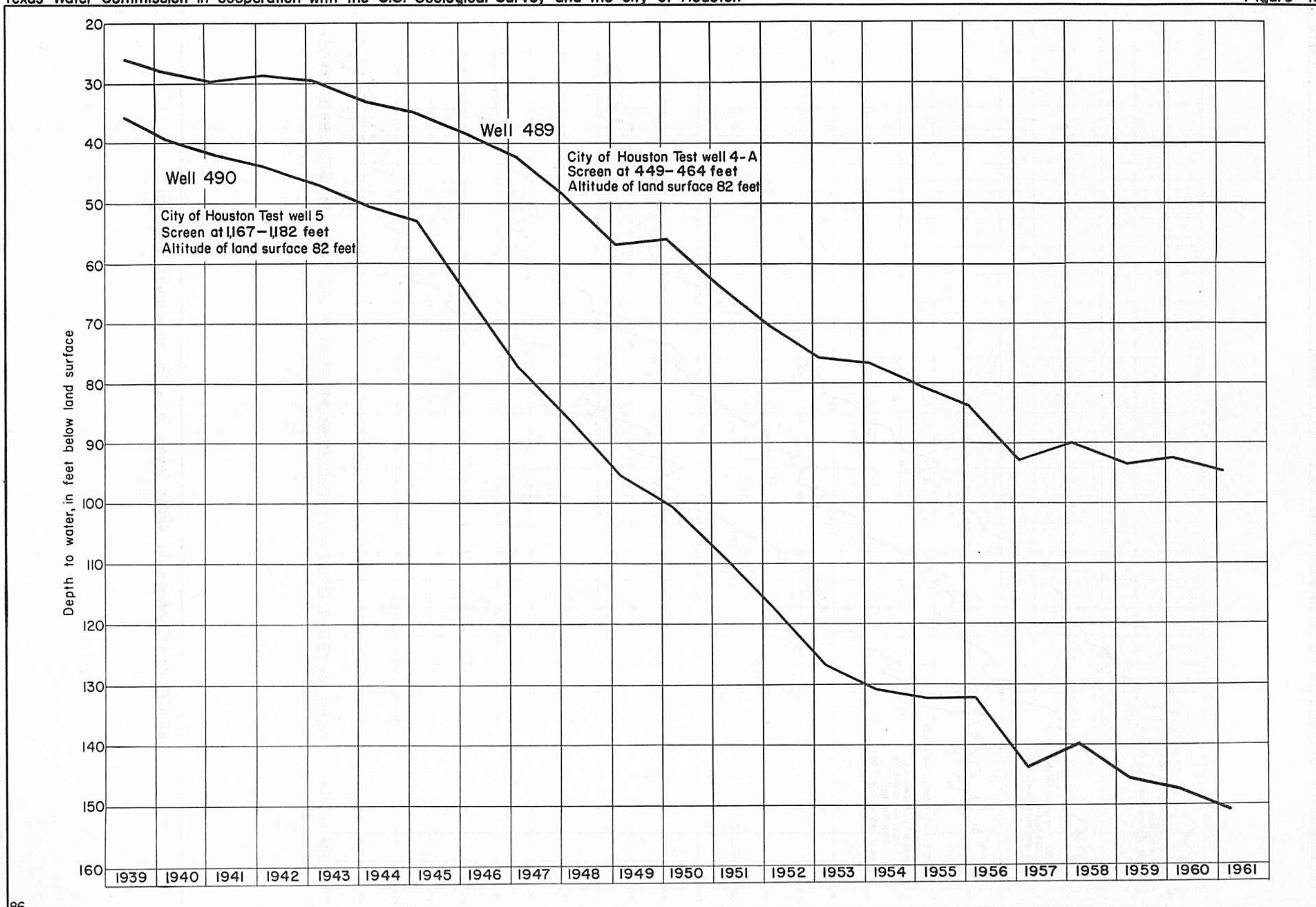
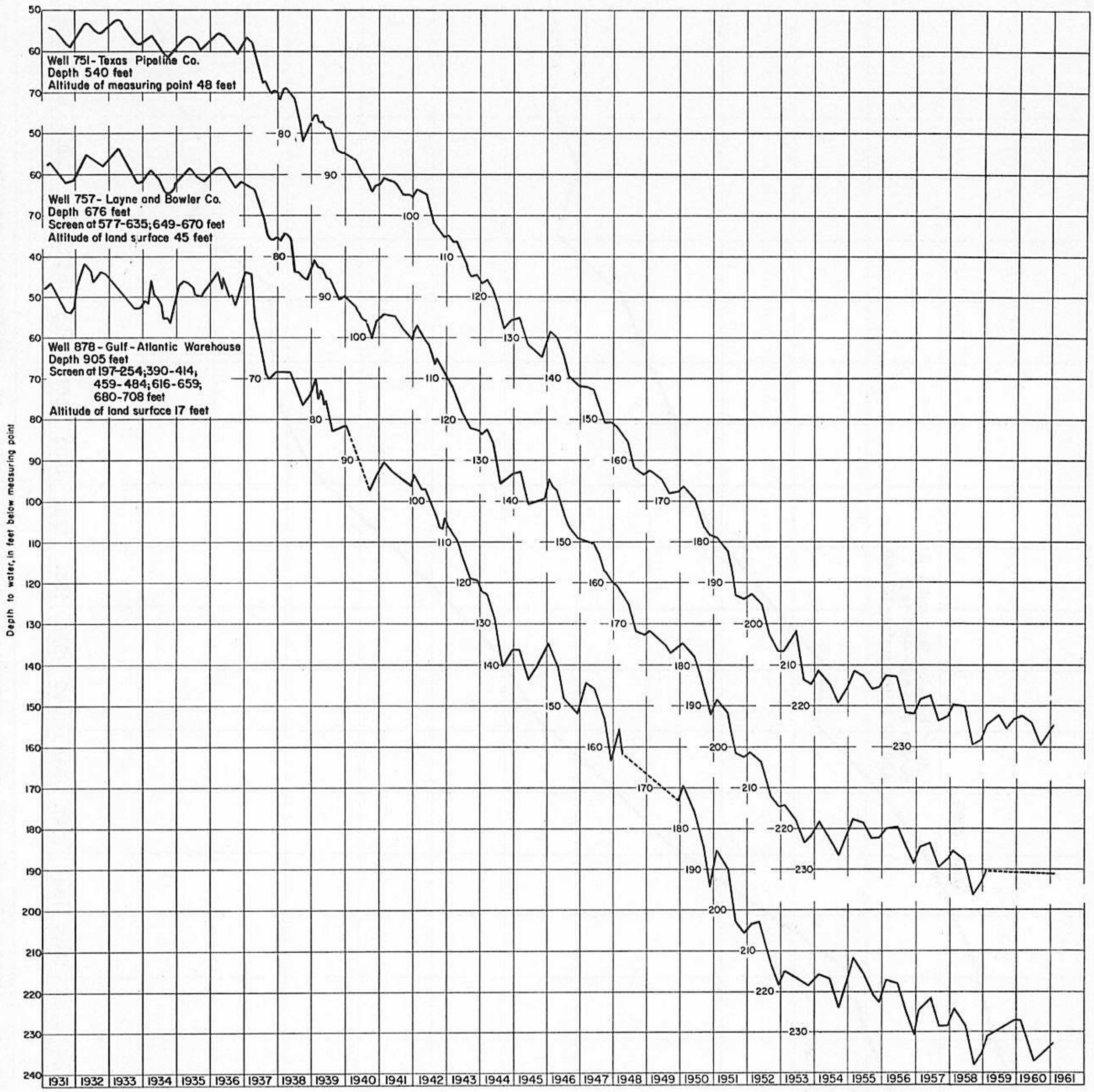


FIGURE 18.—Changes in water levels in two single-screened wells of different depths near Alief



86

FIGURE 19.- Changes in water levels in wells in eastern Houston

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

Figure 20

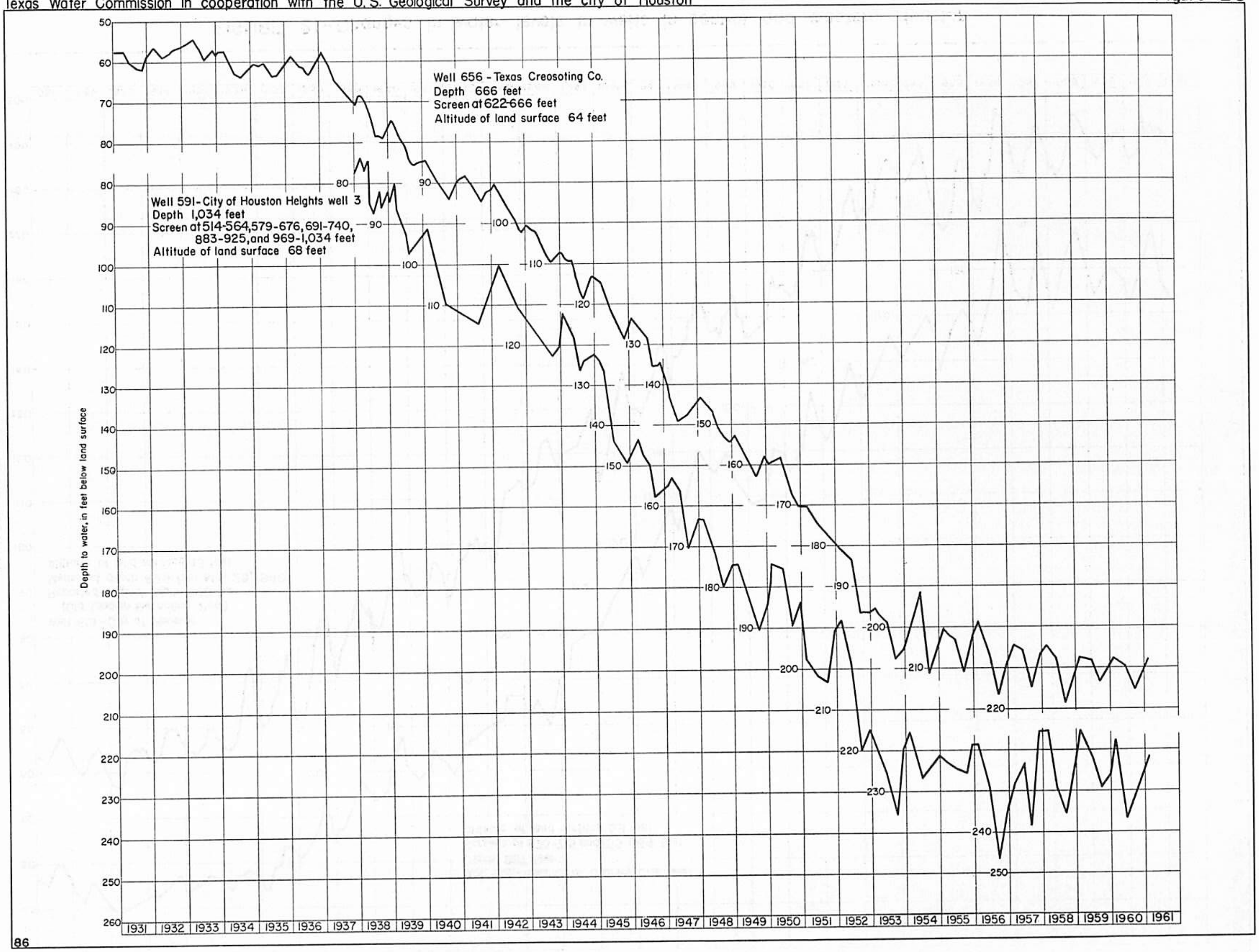


FIGURE 20.—Changes in water levels in wells in northern Houston

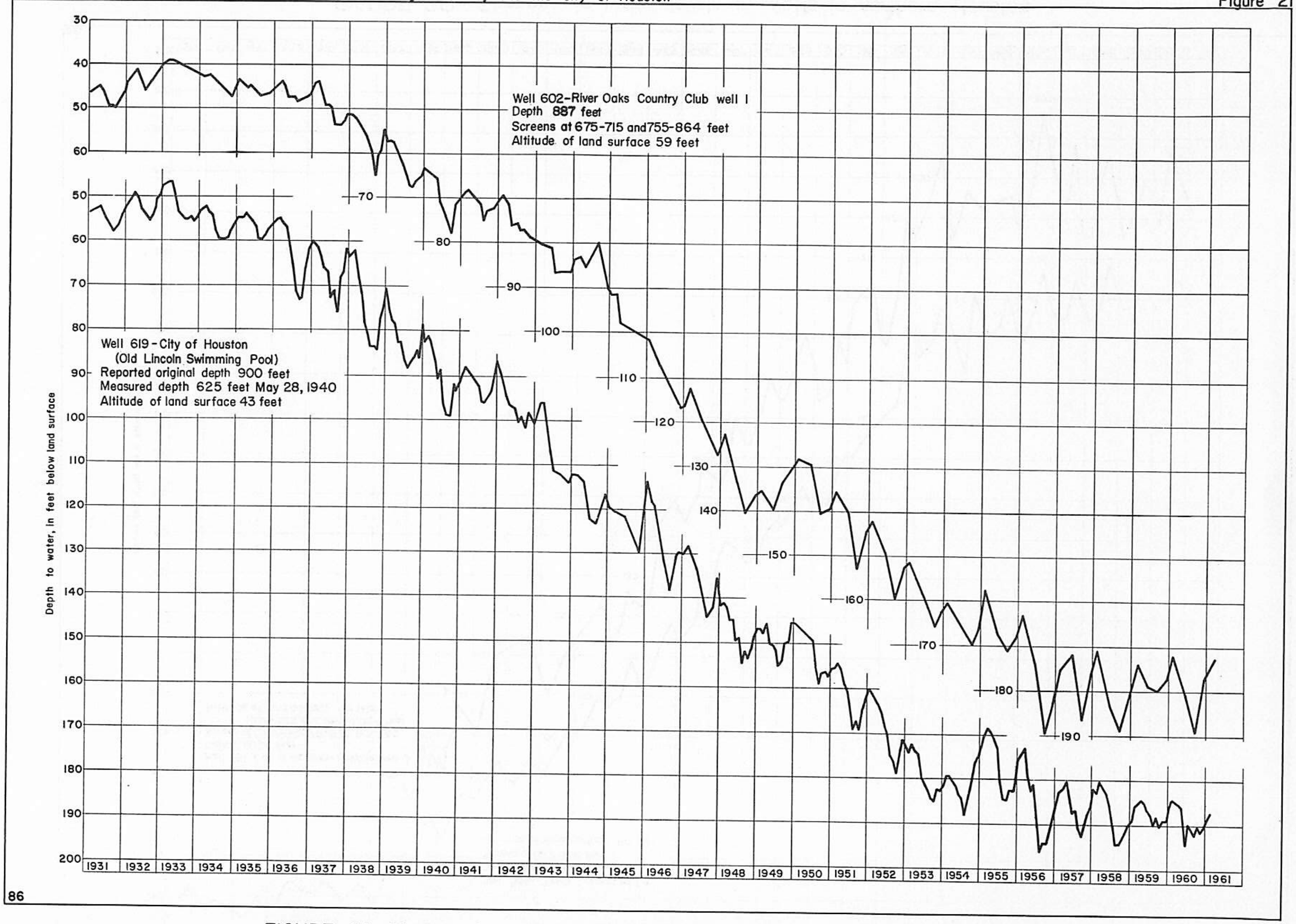


FIGURE 21.-Changes in water levels in wells in central and western Houston

Table 5.--Net changes in water levels in Houston municipal wells, 1957-61

Plant	U.S.G.S. no.	City well no.	Screened at intervals between (feet)	Date (1958)	Depth to water (feet)	Date (1959)	Depth to water (feet)	Date (1960)	Depth to water (feet)	Date (1961)	Depth to water (feet)	Change in water level (feet)				
												1957-1958	1958-1959	1959-1960	1960-1961	1957-1961
Central	616	F- 5	894-1,438	Mar. 7	205	Mar. 5	201	Mar.14	201	Mar.10	218	--	+ 4	0	-17	--
	618	F-10	889-1,320	Feb.25	217.52	5	225.35	Feb.25	217.73	Feb.24	240.01	--	-17.83	+ 7.62	-22.28	--
	624	F-11	460- 930	Mar. 7	181.59	5	184.35	Mar.14	182.77	Mar.10	186.82	+17.12	- 2.76	+ 1.58	- 4.05	+11.9
	--	C-18	844-1,989	7	222.7	5	212.28	14	214.57	14	226.2	+ 5.8	+10.4	- 2.3	-11.6	+ 2.3
	--	C-19	1,160-1,960	7	241.8	5	236.57	14	239.7	10	253.97	+13.1	+ 5.2	- 3.1	-14.37	+ 1.0
	--	C-20	1,015-1,940	7	233.16	5	239.53	15	233.70	13	238.82	+ 8.25	- 6.37	+ 5.83	- 5.12	+ 2.6
	--	C-21	745-2,000	10	221.89	5	223.28	14	224.32	14	239.98	+17.0	- 1.39	- 1.04	-15.66	- 1.1
East End	895	1	1,027-1,648	--	--	--	--	Mar.24	262.28	Feb.24	268.09	--	--	--	- 5.81	--
	--	3	1,190-2,350	Mar. 6	259.08	Mar. 2	257.47	3	259.24	Mar. 6	265.40	+ 4.89	+ 1.61	- 1.77	- 6.16	- 1.4
	--	4	1,001-2,510	6	256.61	2	256.26	3	259.24	6	262.63	+ 2.59	+ 0.35	- 2.98	- 3.39	- 3.4
	--	5	1,469-2,560	6	230.91	2	228.89	3	229.45	9	238.38	+ 4.93	+ 2.02	- 0.56	- 8.93	- 2.6
	--	6	950-2,075	6	261.27	6	272.8	15	272	6	277	+10.5	-11.5	- 1.	- 5	- 5
	--	7	785-1,755	7	256.6	6	259.40	15	261.18	10	270.41	+ 1.7	- 2.8	- 1.58	- 9.23	-12.1
Heights	591	3	514-1,034	Mar. 4	216.27	Feb.10	216.11	Feb.18	218.36	Feb.10	222.44	--	+ 0.16	- 2.25	- 4.08	--
	589	5	410-1,856	Mar. 4	193.24	Feb.26	193.67	Mar.11	193.74	Feb.27	198.06	+ 3.03	- 0.43	- 0.07	- 4.32	- 1.8
	1,410	6	581-1,226	4	220.15	24	218.88	Feb.29	220.60	Mar. 1	227.09	+25.11	+ 1.27	- 1.72	- 6.49	+18.1
	1,411	8	556-1,240	4	228	Mar. 9	225	Mar. 1	227	1	229	+12	+ 3	- 2	- 2	+11
	--	9	610-1,710	4	212.08	9	212.40	Feb.29	206.88	1	216.6	+ 2.21	- 0.32	+ 5.58	- 9.7	- 2.3
	--	10	600-1,860	11	214.10	5	221.85	26	212.4	Feb.27	219.98	+ 5.10	- 7.75	+ 9.5	- 7.6	- 0.8
	--	12	900-1,750	10	224.83	10	233.38	29	217.08	27	227.54	+ 7.63	- 8.55	+16.30	-10.42	+ 5.0
	--	13	890-1,800	4	221.63	Feb.26	224.86	26	210.36	Mar. 2	233.94	- 8.17	- 3.23	+14.50	-23.58	-20.5
	--	14	950-1,790	4	219.71	26	224.63	26	224.63	--	--	- 5.62	- 4.92	+ 7.68	--	--
Northeast	744	1	1,008-1,865	Mar.12	238	Feb.26	228.5	Mar.15	235	Mar. 3	233.65	+10	+10	- 6	+ 1	+14.9
	1,395	2	460-1,278	Feb. 2	219	Mar. 9	220	Feb.26	218	Feb.27	217	--	- 1	+ 2	+ 1	--
	--	3	1,143-1,990	28	225.68	13	226.37	Mar.17	235.6	27	234.25	+12.90	- 0.69	- 9.2	+13	+ 4.3
	--	4	1,030-2,060	28	223.16	Feb.26	225.99	Feb.26	230.63	27	232.57	+20.6	- 2.83	- 4.64	- 1.9	+11.2
	--	5	1,060-1,960	28	218.90	26	220.05	26	222.43	Mar. 3	225.20	+10.46	- 1.15	- 2.38	- 2.77	+ 4.2
	--	6	1,017-1,819	27	223.61	26	231.15	26	227.21	Feb.27	232.83	+ 7.32	- 7.54	+ 3.84	- 5.62	- 1.9
	--	7	1,001-1,880	28	229.04	26	226.31	Mar.16	223.20	27	236.15	+ 4.75	+ 2.73	+ 3.11	-12.95	- 2.3
	--	8	1,010-1,950	Mar.12	227.67	26	225.8	Feb.26	227.11	--	--	+ 2.6	+ 1.9	- 1.3	--	--
	--	9	1,020-1,920	12	228.98	26	222.81	26	221.84	Feb.27	230.94	- 3.50	+ 6.17	+ 0.97	- 9.10	- 5.4
	--	10	700-1,830	--	--	26	214.46	26	212.38	27	216.23	--	--	+ 2.08	- 3.85	- 2.9
	--	11	710-1,960	Feb.28	209.52	Mar.13	206.31	Mar.15	204.63	Mar. 9	211.2	+ 3.14	+ 3.21	+ 1.68	- 6.6	+ 1.5
Scott St.	857	3	553- 919	Mar. 5	201.17	Mar. 6	209.47	Mar.11	199.73	Mar. 9	204.16	- 1.02	- 8.30	+ 1.44	- 4.43	- 4.0
	767	5	470- 945	--	--	10	206	11	201	9	205	--	--	+ 5	- 4	--
South End	793	5	1,275-1,595	Mar.12	236.35	Mar. 2	228.54	--	--	--	--	+13.46	+ 7.79	--	--	--
	775	6	1,089-1,756	--	--	10	231.28	Mar.11	236.72	Mar. 7	243.44	--	--	- 5.44	- 6.74	--
	--	7	1,365-1,932	Mar. 5	240.73	Feb.25	237.40	11	234.69	7	245.70	--	+ 3.33	+ 2.71	-11.01	--
	--	9	680-1,795	5	222.40	Mar.10	219.38	11	219.13	--	--	+ 5.43	+ 3.02	+ 0.20	--	--
	--	10	794-2,180	4	240.11	Feb. 2	226.49	11	235.88	Mar. 7	237.27	--	+13.62	- 9.39	- 1.39	--

Table 5.--Net changes in water levels in Houston municipal wells, 1957-61--Continued

Plant	U.S.G.S. no.	City well no.	Screened at intervals between (feet)	Date (1958)	Depth to water (feet)	Date (1959)	Depth to water (feet)	Date (1960)	Depth to water (feet)	Date (1961)	Depth to water (feet)	Change in water level (feet) 1957-1958	1958-1959	1959-1960	1960-1961	1957-1961
Southwest	--	1	726-1,498	Mar. 5	212.70	Feb.27	213.16	Mar.16	217.3	Mar. 3	224.53	+ 0.61	- 0.46	- 4.1	- 7.2	-11.2
	--	2	675-1,473	11	202.98	Mar.10	219.99	3	221.6	3	208.06	+ 5.66	-17.01	- 1.6	+13.5	+ 0.5
	--	3	686-1,396	12	207.68	Feb.27	215.55	3	206.61	3	209.25	+ 3.02	- 7.87	+ 8.94	- 2.64	+ 1.4
	--	4	692-1,490	5	205.60	Mar.10	225.69	15	229.87	8	218.63	+ 2.86	-20.09	- 4.18	+11.24	-10.1
	--	5	652-1,379	5	199.90	Feb.29	205	15	213	3	212.50	+ 9.36	- 5	- 8	0	- 3.2
	--	6	548-1,360	5	189.54	29	199.15	15	201.8	3	203.02	+13.17	- 9.61	- 2.6	- 1.2	- 0.3
	--	7	490-1,431	5	186.18	Mar. 5	198.36	16	203.35	7	203.66	+ 6.30	-12.18	- 4.99	- 0.31	-11.2
	--	8	559-1,445	5	172.14	5	178.21	16	186.57	8	191.37	+ 6.91	- 6.07	- 8.36	- 4.80	-12.3
	--	9	520-1,030	11	197.16	10	197.98	3	191.52	8	201.20	- 7.29	- 0.82	+ 6.46	- 9.68	-11.3
	--	10	1,070-1,945	10	221.51	9	223.09	3	219.15	8	241.53	+ 6.42	- 1.58	+ 3.94	-22.38	-13.6
	--	11	705-1,552	11	184.60	6	186.50	16	201.00	8	199.51	+ 1.39	- 1.90	- 4.50	+ 1.49	-13.5
Afton Village		1	680-1,645	Feb.27	180.86	Feb.27	188.88	Mar.11	188.84	Mar. 1	198.29	+14.43	- 8.02	+ 0.04	- 9.45	- 3.0
Airport		1	820-1,830	Mar. 7	247.03	Mar. 9	249.05	14	249.66	7	256.93	+ 0.91	- 2.02	- 0.61	- 7.37	- 9.0
Garden Oaks		1	622-1,081	Feb.27	186.40	Feb.10	191.74	Feb.18	192.61	Feb.10	196.14	+ 6.0	- 5.34	- 0.87	+ 0.40	- 4.1
Greens' Bayou		1	790-1,105	--	--	9	290.22	16	291.6	7	292.21	--	--	- 1.4	- 0.6	--
Linkwood		1	770-1,840	Mar.10	206.80	Feb.27	204.65	Mar.11	205.05	Mar. 7	208.70	- 1.30	+ 2.15	- 0.40	- 3.65	- 3.2
		2	735-2,260	4	201.67	Mar. 5	207.60	17	212.80	8	215.45	--	- 5.93	- 5.20	- 2.65	--
Home Owned Estates		3	- 980?	Feb.13	249.83	Feb. 9	259.26	Feb.15	253.30	Feb. 7	254.09	- 6.75	- 9.43	+ 5.96	- 0.79	-11.0
Meyerland		1	710-1,770	Mar. 4	179.47	Mar. 5	188.10	Mar.11	187.24	Mar. 8	196	+ 3.96	- 8.63	- 0.86	- 9	-13
		2	618-1,198	--	--	5	165.05	11	164.99	3	164.31	--	--	+ 0.06	+ 0.58	--
O. S. T. Acres Add.		1	596- 930	--	--	Feb.20	236.10	Feb.11	233.98	Feb. 3	234.13	--	--	+ 2.12	- 0.15	--
South Park		5	755-1,820	Feb.18	235	Jan.--	236	Mar.--	232	Mar. 6	248	--	- 1	+ 4	-16	--
		4	820-1,790	Mar. 6	235.75	Mar. 2	238.98	14	241	6	243.5	+ 1.85	- 3.23	- 2	- 2.5	- 5.9
Southlawn		1	670-1,940	11	223.08	2	220.5	18	222.02	1	225	- 0.33	+ 2.4	- 1.52	- 3	- 2
Westbury		1	1,050-1,715	4	178.3	5	181.29	11	182.76	3	188.10	+ 3.79	- 3.0	- 1.47	- 5.34	- 6.0
		2	530-1,000	4	149.29	Feb.27	155.14	16	153.55	8	158.20	+ 7.29	- 5.85	+ 1.59	- 4.65	- 1.6

Source of Water to Wells in the Houston District

The source of all the fresh ground water in the Houston district is from precipitation that percolates downward to the water table. The sediments that carry the fresh water were originally deposited, at least in part, in brackish or salt water which was later flushed from the updip portions of the formations by precipitation that fell on the outcrop and that has moved downdip (Winslow, Doyel, and Wood, 1957, p. 383-388). Water moves both laterally and vertically toward the pumped wells in the Houston district and is taken from storage in both the sands and the clays.

The water in the aquifer is in transient storage--that is, it is moving from areas of recharge to areas of discharge. The water moves not only down the dip from the outcrop area, but also vertically from shallow beds. If the amount of recharge is equal to the amount of discharge, there is no net change in the total water in transient storage. If the amount of recharge is larger than the amount transmitted downdip, the surplus water is rejected to the streams, lost by evaporation, and consumed by plants as transpiration. If the amount of recharge in the outcrop area is less than the amount of water transmitted downdip, water levels decline in the outcrop area.

In the Houston district water is taken from storage not only from the heavily pumped sands but also from beds overlying and underlying the heavily pumped sands. The clayey beds that separate the heavily pumped sands from the sands above and below are only slightly permeable. Because of the method of deposition of the individual beds of sand and clay, the beds are not continuous but thicken and thin so that generally they cannot be traced for long distances, or even for a few hundred feet in many areas. Beds of sand that are separated by tens of feet of clay at one well site may be connected by another bed of sand or by the lensing out of the separating clay bed at another well a short distance away. Beds of well-sorted sand may be separated by beds of poorly sorted sand, silt, and clay, which do not yield water freely to wells but which can transmit large quantities of water considering the large area and, in many places, the large head differential involved. The area of the land surface in the Houston and Pasadena areas as shown in Figure 2 is about 500 square miles, and the difference in head between the shallow sands and the sands in the heavily pumped zone is more than 100 feet (Figure 15). The volume of water that would move through 150 feet of material having an effective coefficient of permeability of only 0.002 gpd (gallon per day) per square foot under a head differential of 100 feet is about 40,000 gpd per square mile, or 20,000,000 gpd in an area of 500 square miles. If there were a specific yield of 16 percent and no recharge, the removal of 20,000,000 gpd from storage would result in lowering the water table a little more than 0.4 foot per year. These figures probably are not correct for the Houston and Pasadena areas, but they serve to indicate the possible order of magnitude of vertical leakage.

Ground water is also moving laterally updip in the sands from southeast of the Houston and Pasadena areas in response to a decrease in artesian pressure head in the heavily pumped area. This, too, is water in transient storage and is being followed by salty ground water that occurs in the downdip portions of all the sands (Winslow, Doyel, and Wood, 1957, p. 395-397).

A considerable amount of water is released from artesian storage in the aquifers underlying the Houston district and the Baytown-La Porte area. As the artesian pressure head declines in the sands, a small amount of water is released because of elastic compression of the sand and the slight expansion of the water. Perhaps the largest amount of water is released from compaction of the interbedded clays as the artesian pressure head is lowered in the sands, thus increasing the pressure-head difference between the sands and clays. The resultant compaction of the clays caused a maximum subsidence of the land surface of about 2.5 feet in the Pasadena area between 1943 and 1954 (Winslow and Wood, 1959, p. 1030).

Releveling by the U. S. Coast and Geodetic Survey in 1958-59 showed an additional foot of subsidence in the Pasadena and Baytown areas since 1954.

In the outcrop areas in northern and northwestern Harris County and in Montgomery County water levels in shallow wells reflect the distribution and amount of rainfall (Figure 22). Most of the decline in water levels since 1950 is due to deficient rainfall, but part of the decline may be due to an increased rate of movement downdip to areas of large withdrawals. However, the rapid fluctuation of water levels in these wells also suggests that the ground water may occur under artesian conditions at times and under water-table conditions at other times. The sharp rise of water levels in 1960 indicates, at least in part, substantial recharge from precipitation on the outcrop area, but it also may reflect a rise in artesian pressure when the water table rose above a relatively impermeable layer.

Streams in Montgomery County have continued to receive ground-water discharge during the period of deficient rainfall, indicating that water in excess of the amount moving downdip toward the Houston and Pasadena areas is available to recharge the lower sands. However, streams and bayous in northern and western Harris County, which drain the outcrop of the upper sands, were dry for varying periods during the recent drought, except for storm runoff, indicating that the water table probably declined to a level below the streambeds in those areas.

Additional studies are needed in the Houston district in order to evaluate more fully the ground-water resources of the district. A study should be made of the rates of removal of water from the several ground-water reservoirs, because of their bearing on such important items as (1) future pumping levels, (2) the rate of movement of salty ground water toward the heavily pumped area, (3) the movement of salty water into the shallow aquifers adjacent to the ship channel, (4) the amount of recharge entering the outcrop to become ground water in transient storage, (5) the rate and amount of possible lowering of the water table, and (6) the amount of subsidence to be expected from compaction of the interbedded clays or dewatered shallow clays. These studies would require the establishment of observation wells screened in individual sand beds in which to observe changes in head and water quality in the heavily pumped sands, and the establishment of additional very shallow wells to observe water-table fluctuations and local changes in water quality. Also of importance are the determination of the physical properties of the water-bearing materials and a careful evaluation of the historic hydrologic data in the Houston district.

Changes in Chemical Quality

The encroachment of salt water into fresh-water aquifers is an ever-present threat in many coastal and near-coastal aquifers. Generally, encroachment of salt water is very slow, its progress depending upon the thickness and horizontal permeability of the aquifers, the density of the heavily pumped wells, the quantity and rate of pumping, the distance from the center of pumping to salt water, the amount and direction of the hydraulic gradients, the vertical separation between fresh- and salt-water-bearing formations, and the vertical permeability.

In the Pasadena and Baytown-La Porte areas, salt water is present in the heavily pumped sands a few miles downdip (southeast) from the area of large ground-water withdrawals (Winslow, Doyel, and Wood, 1957, p.394-395). Some sands were not flushed of salt water as far downdip as were other sands because of their different physical and hydrologic characteristics. The contact zone or interface between the fresh and salt water has not been accurately located in each of the many sands, because of insufficient data. The nearest salty ground water is probably 5 or 6 miles from the areas of heavy pumping, although it may be closer than suspected in some individual sands.

Salty ground water is moving from the southeast toward the Houston and Pasadena areas because water must move in the direction of the hydraulic gradient (Figure 12). As the individual sands differ in their ability to transmit water, the hydraulic gradients also are different and, therefore, the rates of movement of the salt water in the individual sands are different. At the current apparent rate of movement, the interface may be many years away from the areas of heavy withdrawals.

Samples of water from more than 70 wells in the Houston district are collected periodically to detect changes in chemical quality. No wells are screened at the proper depth to detect changes in the quality of water in most of the critical areas of southeastern Harris County, western Chambers County, and northern Galveston County. Of the wells sampled, only those discussed below have shown any significant changes. Water from a few other wells also has shown an increase in chemical content, but these changes appear to be due to casing failure.

The chemical quality of water from city of Houston test wells 8 and 9 (Harris County wells 1229 and 1230) has changed considerably since 1948 (Figure 23). Well 1229, which is about 250 feet west of well 1230 and about 3-1/2 miles south of the Pasadena city hall, is screened between 1,661 and 1,676 feet; well 1230 is screened between 1,399 and 1,414 feet. In both wells the chloride content was higher in 1960 than in 1957, and in well 1229 the chloride content in 1960 was the highest of record. The decrease in chloride content in well 1230 in 1956 and 1961 may have been caused by slight changes in the direction of the horizontal and vertical hydraulic gradients in the sands due to shifting of the centers of large withdrawals.

In order to evaluate properly the threat of salt-water encroachment, test wells should be constructed at strategic points and screened at appropriate depths to allow the interface to be mapped and to determine the rate of salt-water movement in the different sands down the hydraulic gradient toward the Houston and Pasadena areas. These wells are particularly needed where the interface is closest to the areas of large ground-water withdrawals.

BAYTOWN-LA PORTE AREA

Pumpage

The average daily pumpage of ground water from 1928 to 1960 and the average daily use of surface water from 1943 to 1960 in the Baytown-La Porte area are shown in Figures 24 and 25. The use of surface water was fairly constant between 1945 and 1960, averaging about 24 mgd, whereas the withdrawals of ground water increased from 16.2 mgd in 1945 to 28.6 mgd in 1960. The average pumpage of ground water for industry, public supply, and irrigation from 1953 to 1960 is shown in the table on the following page.

	1953	1954	1955	1956	1957	1958	1959	1960
Industries	17.8	15.2	17.7	18.0	17.3	16.9	18.4	18.2
Public supply	3.0	4.1	4.5	4.5	4.7	4.6	4.3	4.4
Irrigation	2.0	2.5	3.0	5.4	4.0	3.0	4.0	6.0
TOTAL	22.8	21.8	25.2	27.9	26.0	24.5	26.7	28.6

Changes in Water Levels in Wells

The fluctuations of water levels in three wells in the Baytown-La Porte area (Harris County wells 1067, 1117, and C-99) are shown in Figure 26. The hydrographs of these wells are based on measurements in the spring only and do not show seasonal fluctuations.

Wells 1117 and C-99 are screened in the Alta Loma sand; well 1067, in which measurements were discontinued in 1957, is screened in the Alta Loma and a shallower sand. The water levels in wells 1117 and 1067 have declined at a relatively uniform rate, about 5 feet per year since 1940, and the water level in well C-99, about 8 miles distant, has declined about 3 feet per year since 1952.

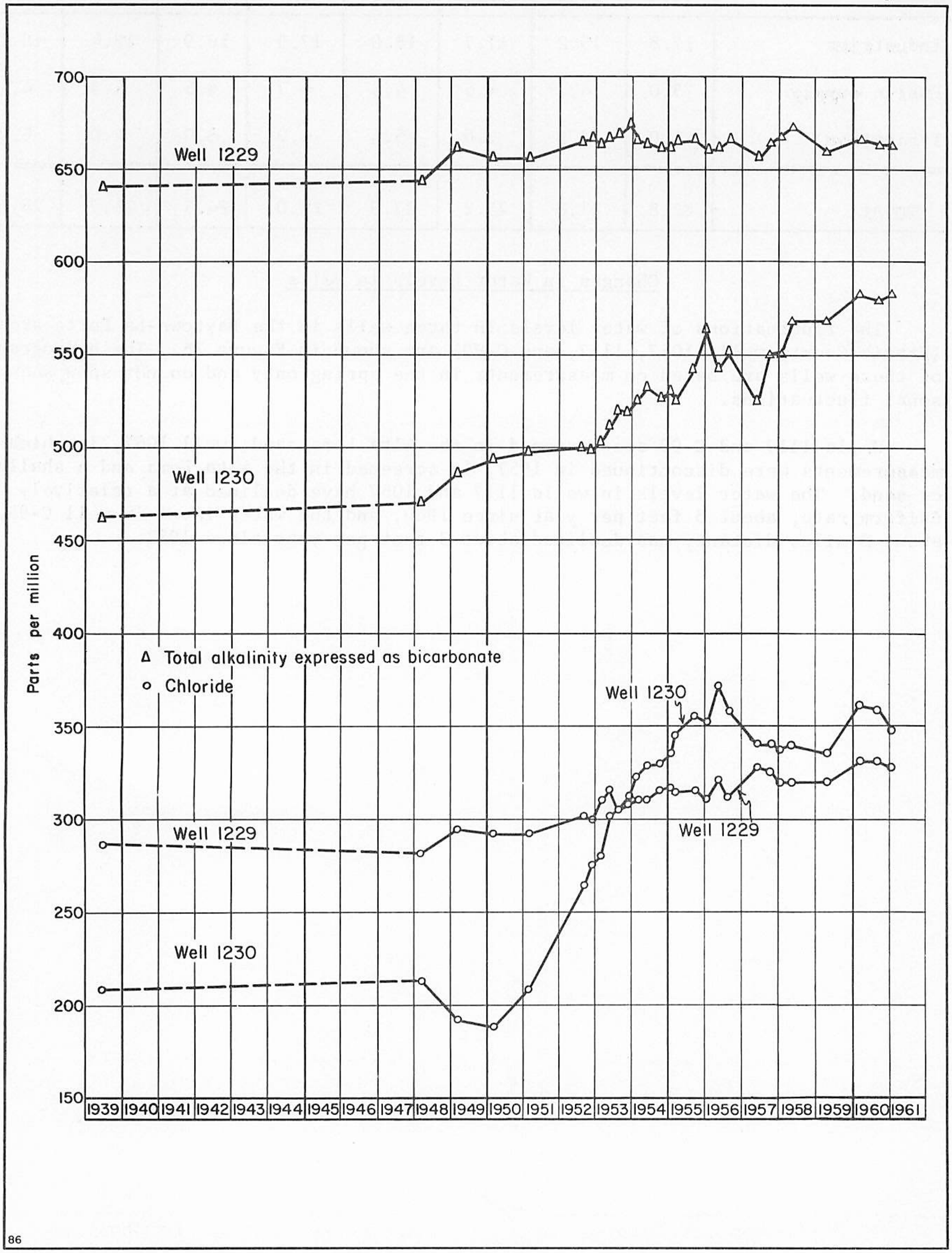


FIGURE 23.- Chloride content and total alkalinity of water from Harris County wells 1229 and 1230

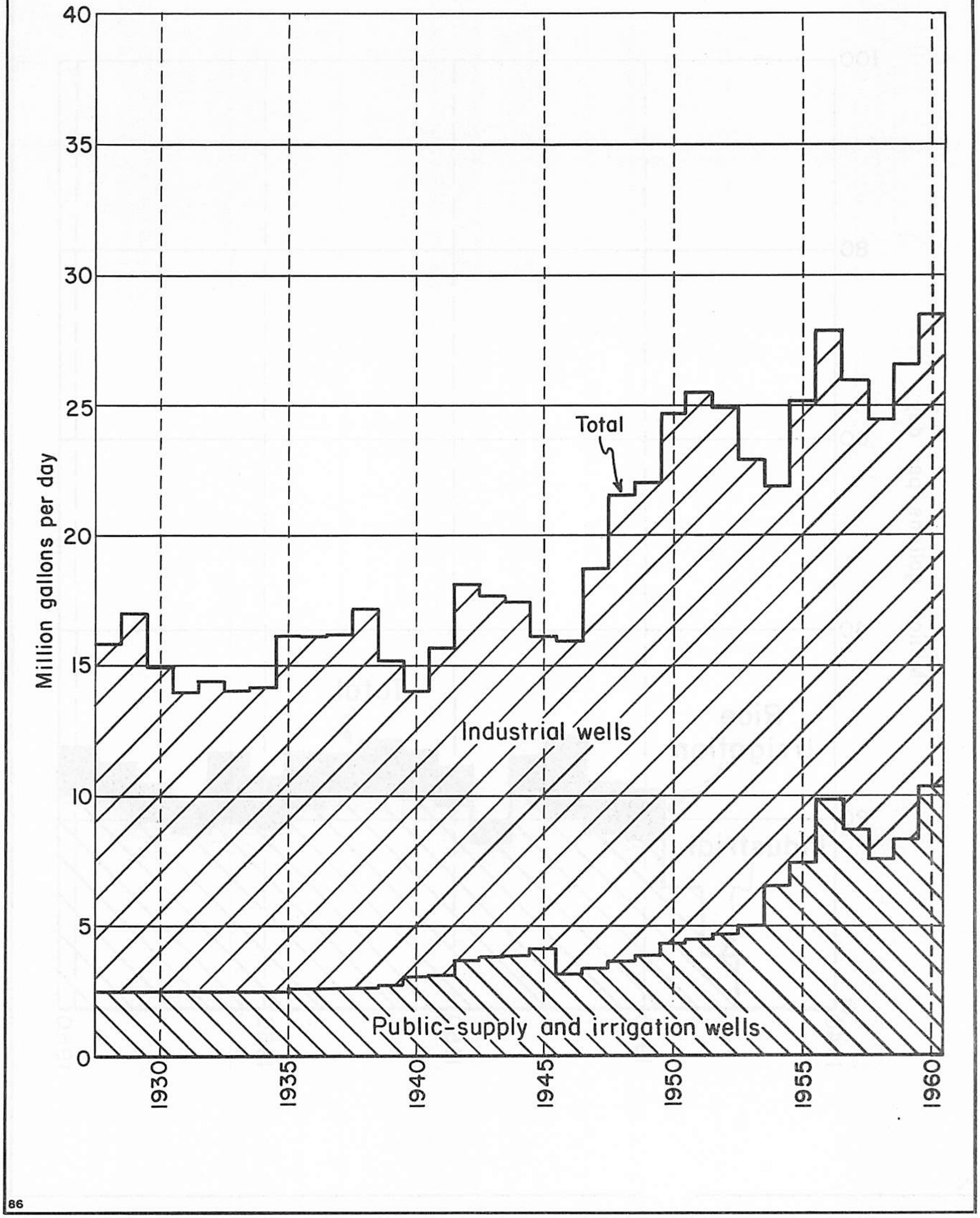


FIGURE 24.-Average daily pumpage of ground water in the Baytown – La Porte area

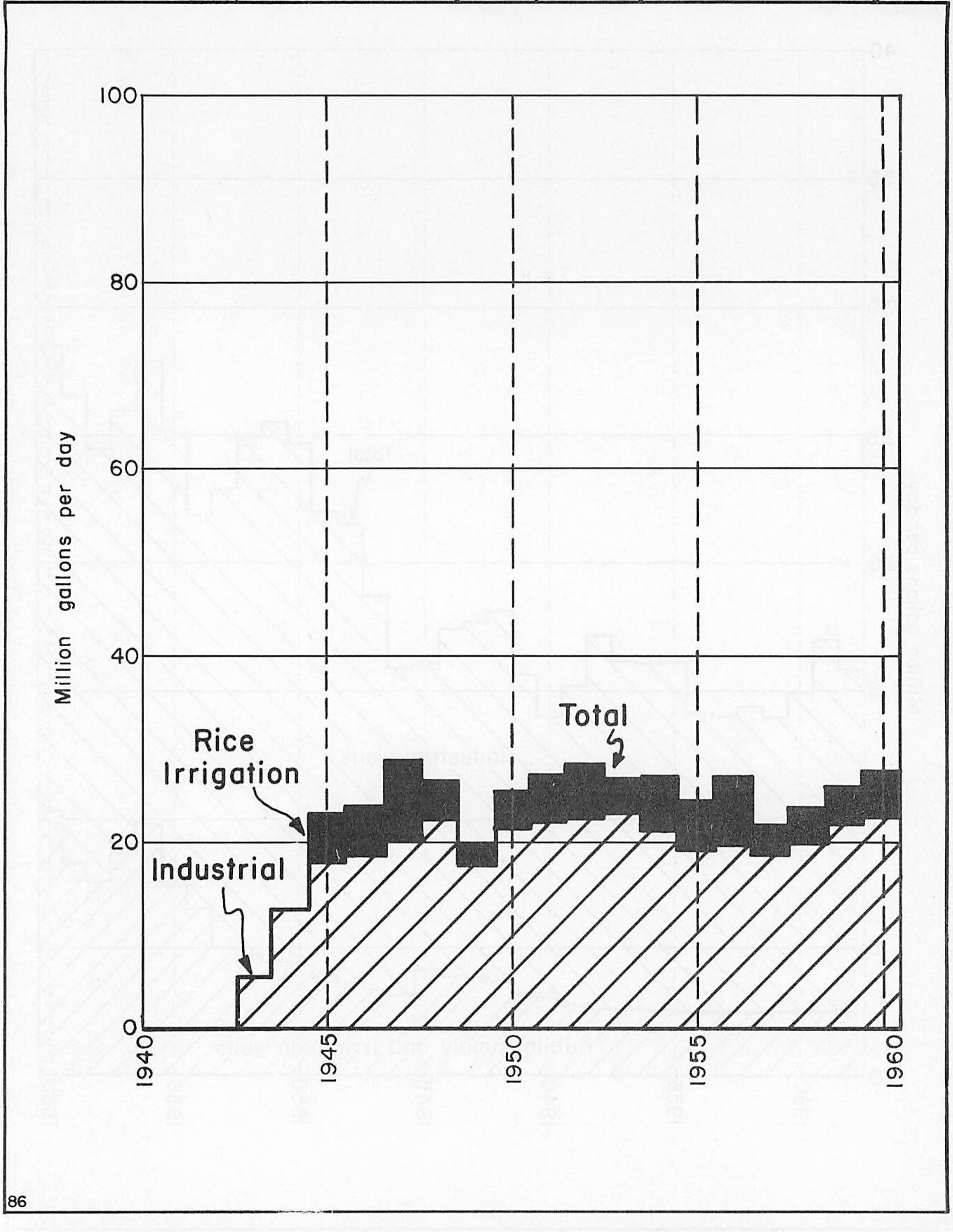


FIGURE 25.- Average daily use of surface water in the Baytown - La Porte area

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

Figure 26

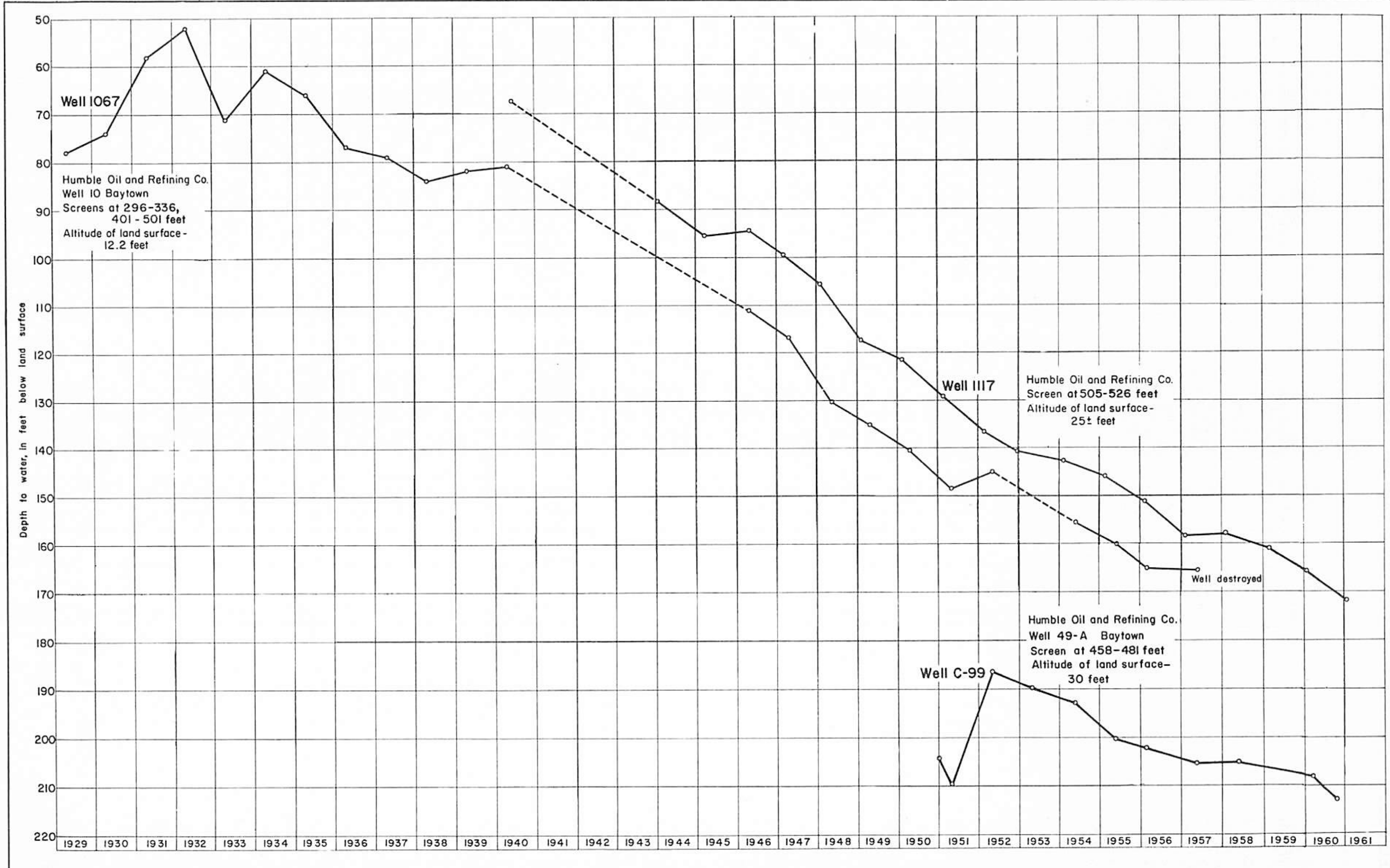


FIGURE 26.- Changes in water levels in the Alta Loma sand of Rose (1943) of Pleistocene age in the Baytown - La Porte area

BIBLIOGRAPHY

Barnes, B. A., 1941, Records of wells, drillers' and electrical logs, water-level measurements, and map showing location of wells in Galveston County, Texas: Texas Board Water Engineers* mimeo. rept.

Broadhurst, W. L., 1953, Coastal Plain near Houston, Texas: U. S. Cong., House Comm. Interior and Insular Affairs, Physical and Economic Foundation of Natural Resources, v. IV, p. 51-69.

Deussen, Alexander, 1914, Geology and underground waters of the southeastern part of the Texas Coastal Plain: U.S. Geol. Survey Water-Supply Paper 335.

Doyel, W. W., Winslow, A. G., and Naftel, W. L., 1954, Pumpage of ground water and decline of artesian pressure in the Houston district, Texas, during 1951 and 1952: Texas Board Water Engineers* Bull. 5401.

Fluellen, T. R., and Goines, W. H., 1952, Water resources of Waller County, Texas: Texas Board Water Engineers* Bull. 5208.

Foster, M. D., 1939, Ground waters of the Houston-Galveston area, chemical character and industrial utility: Ind. and Eng. Chemistry, v. 31, p. 1028.

Goines, W. H., Winslow, A. G., and Barnes, J. R., 1951, Water supply of the Houston Gulf Coast region: Texas Board Water Engineers* Bull. 5101.

Guyton, W. F., 1941, Application of coefficients of transmissibility and storage to regional problems in the Houston district, Texas: Am. Geophys. Union Trans., v. 22, pt. 3, p. 756-770.

Guyton, W. F., and Rose, N. A., 1945, Quantitative studies of some artesian aquifers in Texas: Econ. Geology, v. 40, no. 3, p. 193-226.

Hayes, C. W., and Kennedy, William, 1903, Oil fields of the Texas-Louisiana Gulf Coastal Plain: U.S. Geol. Survey Bull. 212.

Jacob, C. E., 1941, Coefficients of storage and transmissibility obtained from pumping tests in the Houston district, Texas: Am. Geophys. Union Trans., v. 22, pt. 3, p. 744-756.

Lang, J. W., and Sundstrom, R. W., 1946, Ground-water resources of the Houston district, Texas, progress report for 1946 with section on results of pumping tests at new southwest pumping plant: Texas Board Water Engineers* mimeo. rept.

Lang, J. W., Winslow, A. G., and White, W. N., 1950, Geology and ground-water resources of the Houston district, Texas: Texas Board Water Engineers* Bull. 5001.

Livingston, Penn, 1939, Records of wells, drillers' logs, water analyses, and map showing location of wells in Montgomery County, Texas: Texas Board Water Engineers* mimeo. rept.

Livingston, Penn, and Turner, S. F., 1939a, Records of wells, drillers' logs, water analyses, and map showing location of wells in Fort Bend County (east of Brazos River), Texas: Texas Board Water Engineers* mimeo. rept.

________1939b, Records of wells, drillers' logs, water analyses, and map showing location of wells in Galveston County, Texas: Texas Board Water Engineers* mimeo. rept.

Lockwood, M. G., 1954, Subsidence in the Houston area can no longer be ignored: Civil Eng., v. 24, no. 6, p. 370-372.

Petitt, B. M., Jr., and Winslow, A. G., 1955, Geology and ground-water resources of Galveston County, Texas: Texas Board Water Engineers* Bull. 5502.

________1957, Geology and ground-water resources of Galveston County, Texas: U.S. Geol. Survey Water-Supply Paper 1416.

Rorabaugh, M. I., 1949, Memorandum on multiple-step drawdown test, southwest well field, Houston, Texas: U. S. Geol. Survey dupl. rept.

Rose, N. A., 1943a, Ground water and relation of geology to its occurrence in the Houston district, Texas: Am. Assoc. Petroleum Geologist Bull., v. 27, no. 8, p. 1080-1101.

________1943b, Progress report on ground-water resources of the Texas City area, Texas: Texas Board Water Engineers* open-file rept.

________1943c, Records of wells, drillers' logs, water analyses, and map showing locations of wells in Montgomery County, Texas: Texas Board Water Engineers* mimeo. rept.

Rose, N. A., and Alexander, W. H., Jr., 1944, Progress report on the ground-water resources of the Houston district: Texas Board Water Engineers* mimeo rept.

________1945, Relation of phenomenal rise of water levels to a defective gas well in Harris County, Texas: Am. Assoc. Petroleum Geologists Bull., v. 29, no. 3, p. 253-279.

Rose, N. A., and Stuart, W. T., 1943, Pump settings and pumping levels in Houston district, Texas: Texas Board Water Engineers* mimeo. rept.

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

Singley, J. A., 1893, Preliminary report on the artesian wells of the Gulf Coastal slope: Texas Geol. Survey 4th Ann. Rept.

Taylor, T. U., 1907, Underground waters of the Coastal Plain of Texas: U.S. Geol. Survey Water-Supply Paper 190.

Turner, S. F., and Foster, M. D., 1934, A study of salt-water encroachment in the Galveston area, Texas: Am. Geophys. Union Trans., v. 15, pt. 2, p. 432-435.

Turner, S. F., and Livingston, Penn, 1935, Ground-water studies in the humid and semiarid parts of the Texas Coastal Plain: Am. Geophys. Union Trans., v. 16, pt. 2, p. 503-507.

________1939, Records of wells, drillers' logs, water analyses, and map showing location of wells in Waller County, Texas: Texas Board Water Engineers* mimeo. rept.

White, W. N., 1938, Progress report on the ground-water resources of the Houston district, Texas: Texas Board Water Engineers* mimeo. rept.

________1939, Progress report on the ground-water resources of the Houston district, Texas: Texas Board Water Engineers* mimeo. rept.

White, W. N., Livingston, Penn, and Turner, S. F., 1932, Ground-water resources of the Houston-Galveston area, Texas: Texas Board Water Engineers* mimeo. rept.

________1939, Ground-water resources of the Houston-Galveston area, Texas: Texas Board Water Engineers* mimeo. rept.

White, W. N., Rose, N. A., and Guyton, W. F., 1940, Progress report on the ground-water resources of the Houston district, Texas: Texas Board Water Engineers* mimeo. rept.

________1942a, Progress report on the ground-water resources of the Houston district, Texas: Texas Board Water Engineers* mimeo. rept.

________1942b, Ground-water resources of the Houston district; progress report with records of wells, pumpage, water-level fluctuations in wells, and water analyses, Harris County and adjoining parts of Fort Bend and Waller Counties, Texas: Texas Board Water Engineers* mimeo. rept.

________1944, Ground-water resources of the Houston district, Texas: U. S. Geol. Survey Water-Supply Paper 889-C.

White, W. N., Turner, S. F., and Livingston, Penn, 1937, Progress report on the ground-water resources of the Houston district, Texas: Texas Board Water Engineers* mimeo. rept.

Winslow, A. G., and Doyel, W. W., 1954a, Land-surface subsidence and its relation to the withdrawal of ground water in the Houston-Galveston region, Texas: Econ. Geology, v. 49, no. 4, p. 413-422.

________1954b, Salt water and its relation to fresh ground water in Harris County, Texas: Texas Board Water Engineers* Bull. 5409.

Winslow, A. G., Doyel, W. W., and Wood, L. A., 1957, Salt water and its relation to fresh ground water in Harris County, Texas: U. S. Geol. Survey Water-Supply Paper 1360-F.

Winslow, A. G., and Fluellen, T. R., Jr., 1952, The Houston district, Texas, pumpage and decline of artesian pressure during 1950-1951: Texas Board Water Engineers* Bull. 5201.

Winslow, A. G., and Wood, L. A., 1959, Relation of land subsidence to ground-water withdrawals in the upper Gulf Coast region, Texas: Mining Eng., p. 1030-1034.

Wood, L. A., 1956a, Pumpage of ground water and changes in artesian pressure in the Houston district and Baytown-La Porte area, Texas, 1953-55: Texas Board Water Engineers* Bull. 5602.

________1956b, Availability of ground water in the Gulf Coast region of Texas: U. S. Geol. Survey open-file rept.

________1958, Pumpage of ground water and fluctuations of water levels in the Houston district and the Baytown-La Porte area, Texas, 1955-57: Texas Board Water Engineers* Bull. 5805.

Records of water levels in wells in the Houston district are published in the following U. S. Geol. Survey Water-Supply Papers:

Year	Water-Supply Paper No.	Year	Water-Supply Paper No.	Year	Water-Supply Paper No.
1935	777	1944	1019	1951	1194
1937	840	1945	1026	1952	1224
1939	886	1946	1074	1953	1268
1940	909	1947	1099	1954	1324
1941	939	1948	1129	1955	1407
1942	947	1949	1159		
1943	989	1950	1168		

*Name of agency changed to Texas Water Commission January 30, 1962.