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TEXAS BOARD OF WATER ENGINEERS

BULLETIN 5805

PUMPAGE OF GROUND WATER AND FLUCTUATIONS OF WATER LEVELS IN THE HOUSTON DISTRICT AND THE BAYTOWN-LA PORTE AREA, TEXAS, 1955-57

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

December 1958

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ABSTRACT

Withdrawals of ground water averaged 298,000,000 gallons per day (gpd) during 1956 in the Houston district. Although this rate was about 10 percent higher than in 1955, it was lower than the 1954 rate of 338,000,000 gpd. The decrease in 1955 was due to a greater use of surface water which became available to the Houston-Pasadena area upon completion of Lake Houston dam and to fewer acres of rice being irrigated in the Katy area. The increase in ground-water withdrawals in 1956 over 1955 was caused by a greater demand for municipal supplies in the Houston-Pasadena area and by the need for more water per acre of irrigated rice because of the lesser rainfall and greater evaporation during 1956.

Lower pumping rates during the years 1954-56 resulted in rises in water levels in wells near the ship channel and in several Houston municipal wells. Elsewhere in the Houston district water levels continued to decline and were lower in March 1957 than in any previous March. Water levels in wells in the Katy area continued to decline comparatively slowly, averaging 4.3 feet of decline between the spring measurements of 1955 and 1957. Water levels declined about 7 feet in wells in eastern Houston and about 15 feet in southwestern Houston during the same period.

The primary source of water pumped in the Houston district is precipitation; however, there are several routes by which the water might reach the wells. Possibly one-sixth of the water pumped from wells is water of compaction which drains from the clays as the pressure head is reduced. Some of the water pumped has leaked vertically through the silty and clayey materials from higher and lower beds. Much of the water moves laterally through the sands toward the wells.

Changes in quality of water have been observed in 3 of about 70 wells that are sampled each year in order to detect salt-water encroachment into the heavily pumped sands. The chloride content of the water from one well increased 46 parts per million (ppm) from March 1948 to June 1957, and in another well at the same location it increased 184 ppm between March 1950 and May 1956. The chloride content of water from a well north of La Porte increased 52 ppm between July 1947 and June 1957.

In the Baytown-La Porte area the average pumpage of ground water was about 28,000,000 gpd in 1956 as compared to 25,000,000 gpd in 1955 and 22,000,000 gpd in 1954. Water levels in wells in the Baytown-La Porte area continued to decline at about the same rate--slightly more than 5 feet per year.

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 is east of the Houston area and west of the San Jacinto River. The Pasadena area 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, 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 Houston and Pasadena areas, are also 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 member of the Beaumont clay which is the principal aquifer in Galveston County.

PURPOSE AND SCOPE OF REPORT

This is one of a series of reports (see bibliography) 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. This report presents data on pumpage, changes in artesian pressure, and related information compiled during the period 1955-57.

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 was discussed by Rose (1943a) and by Lang, Winslow, and White (1950), and others. The water resources (both ground and surface) of the Houston-Galveston region were reported on by Goines, Winslow, and Barnes (1951). Additional data may be found in other reports that are listed in the bibliography at the end of this report.

The field work 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.

HOUSTON DISTRICT

PUMPAGE

Pumpage data for the preceding calendar year for the Houston district is obtained each spring. All industries, municipalities, and water districts pumping more than 5,000 gallons per day supply records or estimates of their pumpage. More than 80 percent of the water pumped from wells in the Houston-Pasadena area is recorded by meters; the remainder is estimated. Pumpage figures for the Katy area are based on the acreage irrigated, the duty of water per acre, the total rainfall during the irrigation season, and the total amount of power consumed by irrigation pumps each season.

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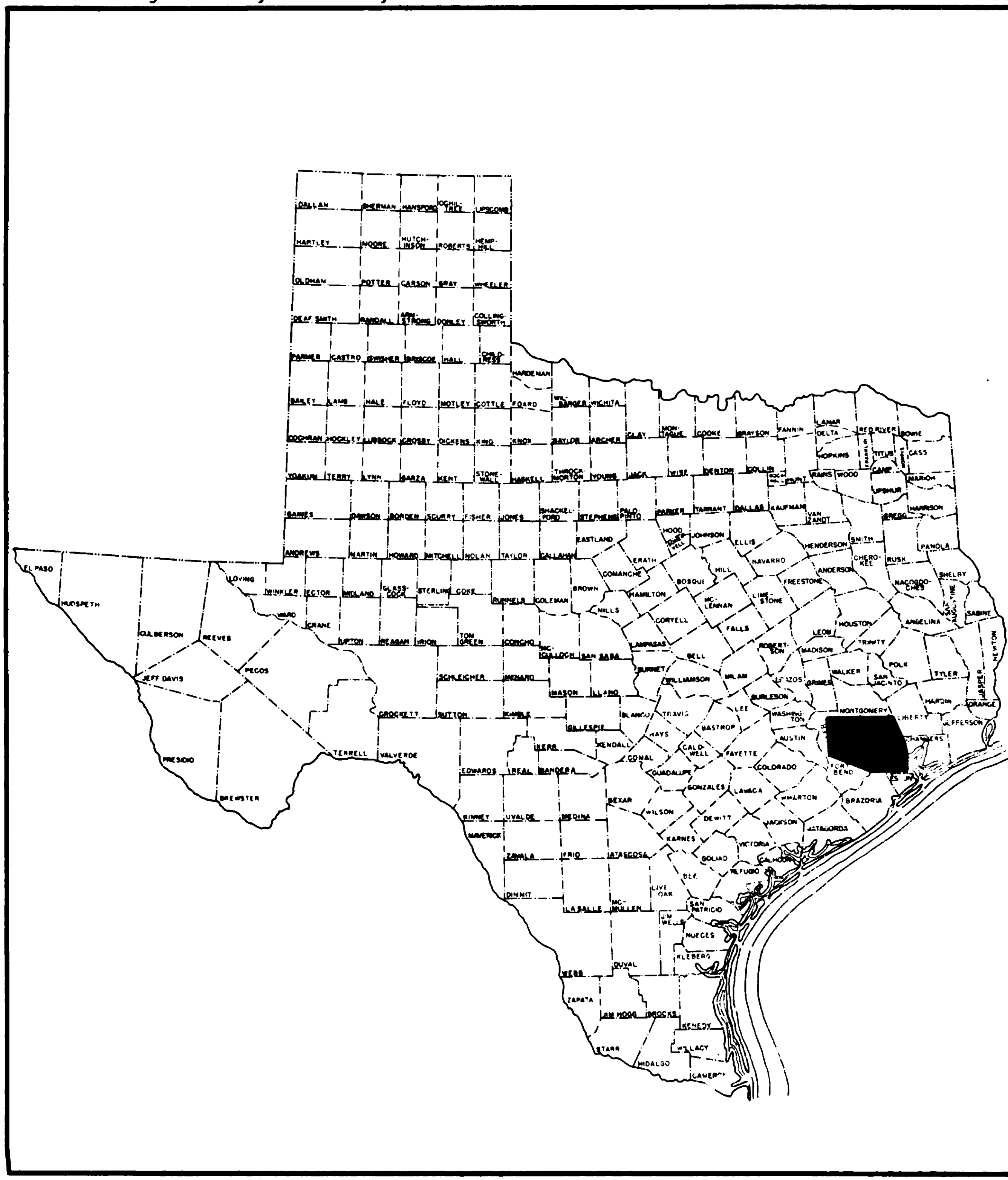

FIGURE 1. - Map of Texas showing location of the Houston district and the Baytown - La Porte area.

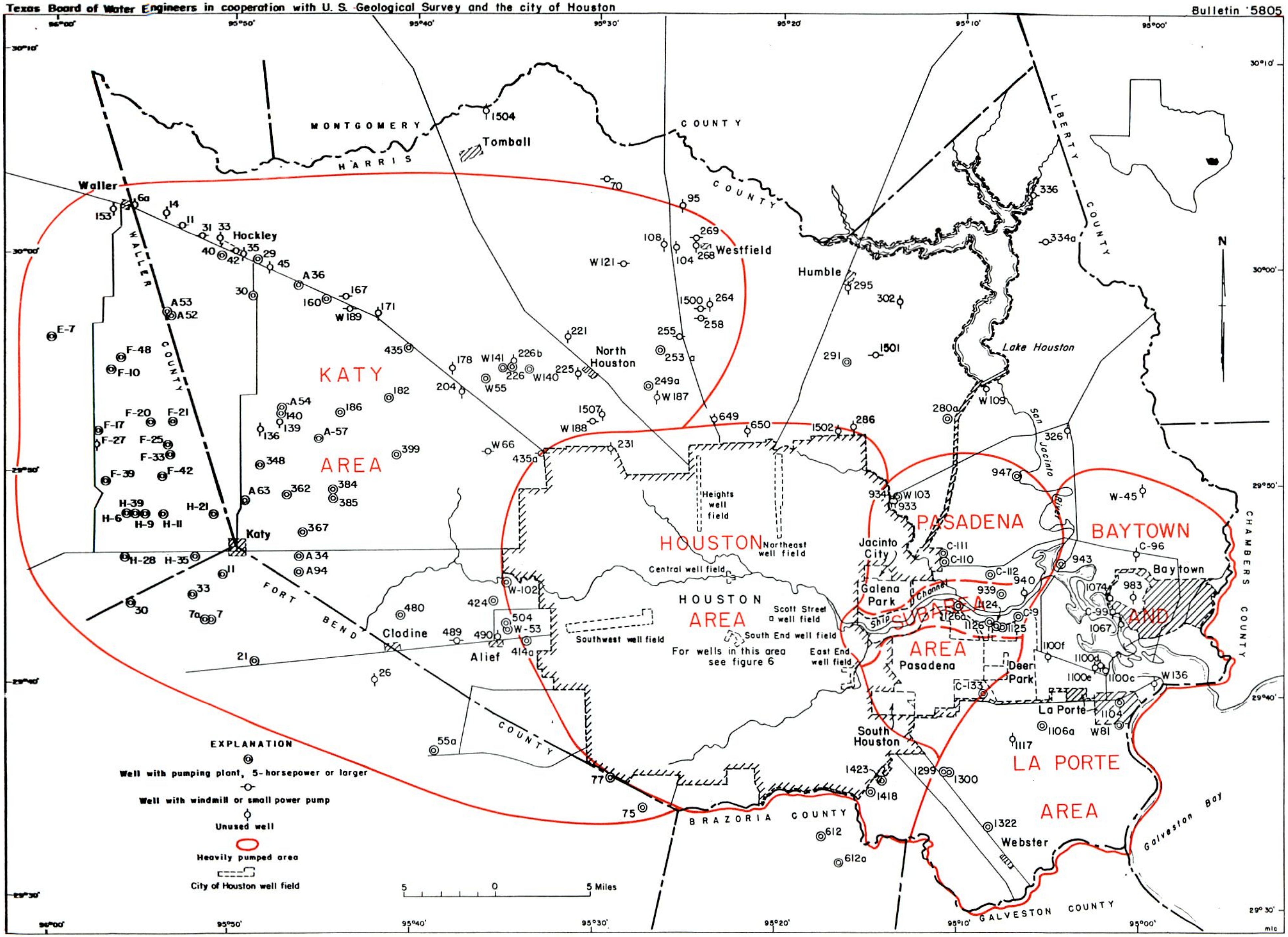

FIGURE 2.- Map of Houston district and the Baytown-La Porte area, Texas, showing location of observation wells and heavily pumped areas.

The ground-water pumpage in the Houston district declined from the all-time high average of 338,000,000 gallons per day (gpd) in 1954 to 270,000,000 gpd in 1955. In 1956 the pumpage increased to 298,000,000 gpd. Figure 3 shows the average daily pumpage from 1930 to 1956. It shows the change in pumping rates as larger quantities of surface water became available for industrial and municipal purposes in the Houston-Pasadena area. It also shows the decreased demand for irrigation water in the Katy area because of limitations of rice acreage.

KATY AREA

Pumpage in the Katy area is principally for the irrigation of rice. The number of acres of rice irrigated by ground water in the Katy area decreased from about 65,000 in 1954 to about 46,000 in 1955 and 41,000 in 1956. The smaller acreages in 1955 and 1956 resulted from acreage limitations instituted under the price-support program for rice which was begun by the U. S. Department of Agriculture in 1955. Less ground water per acre was applied to rice in 1955 than in 1954 or in 1956 because 7 to 9 more inches of rain fell during the 1955 irrigation season. The average pumpage in the Katy area was 104,000,000 gpd in 1955 and 125,000,000 gpd in 1956, as compared to 160,000,000 gpd in 1954. (See fig. 3.) Daily withdrawals during the 5-month pumping season are more than twice as great as indicated by the figures given above, which represent averages for the whole year.

HOUSTON-PASADENA AREA

The average daily pumpage of ground water in the Houston-Pasadena area has been less during 1954-56 than it was in 1953 (fig. 4). The reasons for this change in trend are (1) the increased availability of surface water from the San Jacinto River since the completion of Lake Houston in 1954; and (2) the construction of surface-water treatment plants and pipe-line facilities which were placed in use by the city of Houston in 1954 and by private industry in 1954, 1955, and 1956. The total use of surface water in the Houston-Pasadena area increased from an average of 18,200,000 gpd in 1953 to 32,800,000 gpd in 1954, 54,400,000 gpd in 1955, and 66,900,000 gpd in 1956 (fig. 5). The city of Houston began pumping treated surface water into the municipal distribution system in May 1954. The average use of treated surface water by the Houston Water Department was 8,800,000 gpd in 1954, 19,100,000 gpd in 1955 and 19,600,000 gpd in 1956.

Table 1 shows that the principal source of municipal water is from wells although the average daily pumpage from wells in 1954, 1955, and 1956 was less than in the peak year of 1953 when 77,300,000 gpd of ground water was pumped.

Table 1.- Average use of water by the Houston Water Department, in million gallons per day, 1953-56

	1953	1954	1955	1956
Treated surface water	0	8.8	19.1	19.6
Ground water	77.3	72.5	61.9	73.9
TOTAL	77.3	81.3	81.0	93.5

Ground-water withdrawals from the industrial wells in the Pasadena area averaged 71,000,000 gpd in 1955 and 62,000,000 gpd in 1956, as compared with 75,000,000 gpd in 1954 and 80,000,000 gpd in the peak year, 1953. Most of the ground water pumped in the Pasadena area is from wells in the ship-channel subarea . However, it is in this subarea that the substitution of surface water has caused the largest reduction in withdrawals.

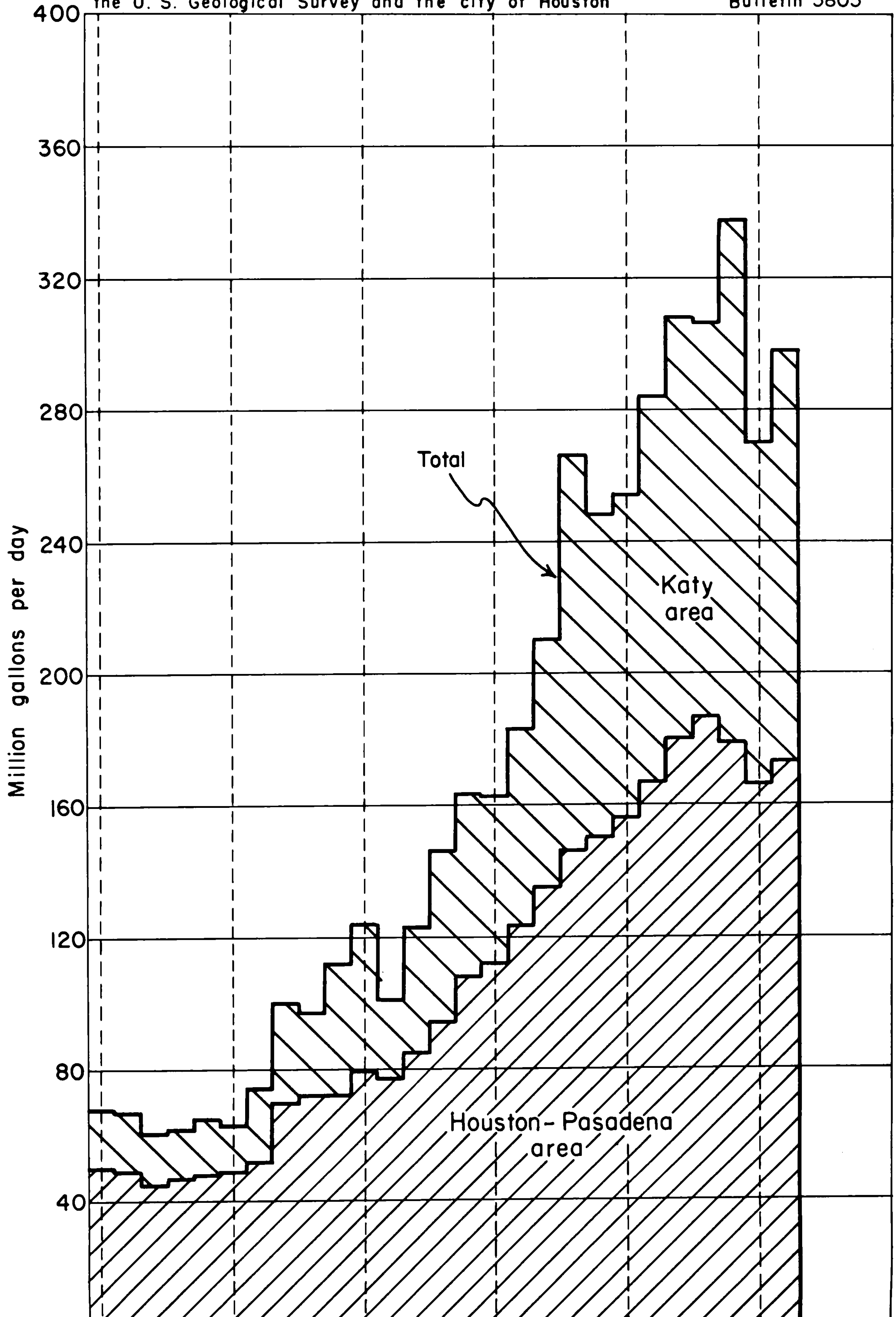

FIGURE 3.- Average daily pumpage of ground water in the Houston district, 1930-56.

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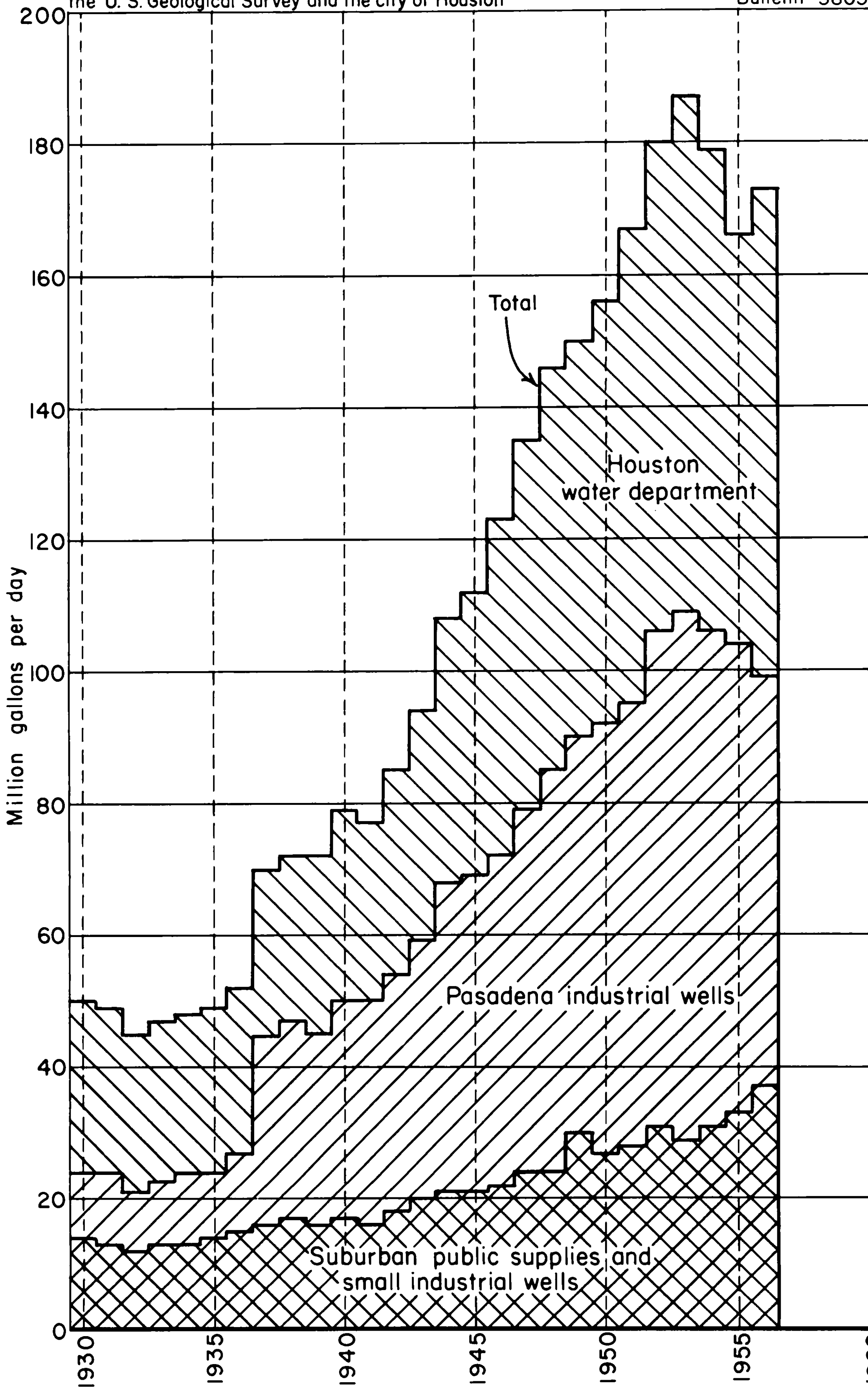

FIGURE 4. - Average daily pumpage of ground water in the Houston-Pasadena area, 1930-56.

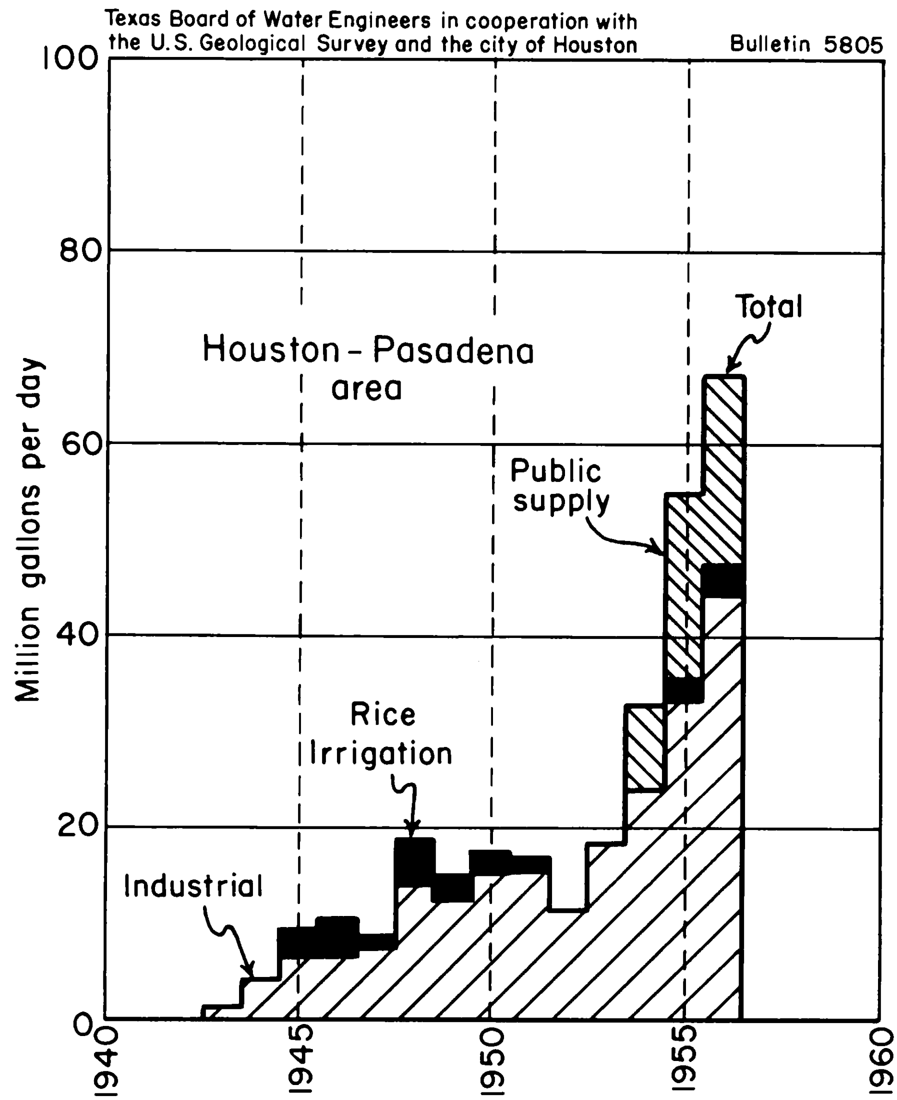

FIGURE 5. - Average daily use of surface water in the Houston - Pasadena area, Texas.

Table 2 shows that in 1956 only 57,000,000 gpd or about 78 percent of the ground water used in the Pasadena area was from wells in the relatively small ship-channel subarea as compared to 74,000,000 gpd or about 85 percent in 1953.

Table 2.- Average pumpage of ground water in the Houston-Pasadena area, in million gallons per day, 1953-56

	1953	1954	1955	1956
Ship-channel subarea	74	67	66	57
Balance of Pasadena area	13	16	14	16
Pasadena area total	87	83	80	73
Houston area	100	96	86	100
Houston-Pasadena area total	187	179	166	173

The average daily pumpage of ground water during 1953, 1954, 1955 and 1956, by different classes of users in the Houston-Pasadena area, is shown in table 3.

Table 3.- Average ground-water pumpage for public, industrial, and miscellaneous supplies in the Houston-Pasadena area, in million gallons per day, 1953-56

	1953	1954	1955	1956
Public supplies:				
Houston Water Department	77.3	72.5	61.9	73.9
Suburban	13.0	15.8	17.5	23.9
Subtotal	90.3	88.3	79.4	97.8
Industrial supplies:				
Chemical plants	21.0	25.7	29.0	27.8
Oil refineries	27.0	22.7	23.7	19.6
Power plants	12.0	13.5	11.0	9.2
Steel mills	6.1	5.5	5.9	7.0
Paper mill	19.0	13.0	6.9	2.5
Food manufacturers and processors	1.4	1.6	1.6	1.9
Ice plants	1.5	1.5	1.4	1.3
Tool companies	1.7	1.6	1.9	1.0
Railroads and allied plants	1.6	1.3	1.1	.8
Cement plants	.7	.8	.8	.8
Subtotal	92.0	87.2	83.3	71.9
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
TOTAL	186.6	178.9	165.7	173.0

The largest industrial users of ground water are the chemical plants and oil refineries although the use by the refineries has decreased materially since 1953 owing to the increased use of surface water. Steam-powered electric-generating plants and steel mills are the other large classes of users of ground water in the Houston-Pasadena area. The use by the power plants in the Houston-Pasadena area has decreased considerably since 1954 because part of the load was transferred to two new plants in the Baytown-La Porte area where saline surface water is used for cooling. The paper mill, which was the largest single industrial user of ground water until 1954, pumps only enough ground water to keep the wells in standby condition; most of the supply is surface water.

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

HOUSTON AREA

The Houston Water Department is the largest user of ground water in the Houston area; suburban villages and water districts (mostly within the area annexed in 1957 by the city of Houston) are the next largest users. More than 86,000,000 gpd or 86 percent of the ground water withdrawn from wells in this area during 1956 was used for public supply. Although the Houston Water Department also used nearly 20,000,000 gpd of treated surface water in 1956, the increased demands of both city and suburban customers caused the rate of withdrawal from wells in the Houston area to equal the rate in 1953 (table 2). The wells supplying small industries and miscellaneous users have been pumped at about the same rate for several years.

More than 87 percent of the ground water pumped by the Houston Water Department in 1956 came from 47 wells in the well fields which serve the six major distribution plants (fig. 6). Figures 7 and 8 show the average daily pumpage from each well field and a hydrograph showing the change in water level in a representative well in each field. An additional 10 percent of the ground water used by Houston in 1956 came from seven wells at six smaller distribution stations. The remainder of the ground-water supply for the city was obtained from several wells that formerly were operated by water districts and private water companies in areas annexed prior to 1956.

The average ground-water pumpage in the Houston and Pasadena areas decreased from 186,600,000 gpd in 1953 to 178,900,000 gpd in 1954 and to 165,700,000 gpd in 1955 but increased to 173,000,000 gpd in 1956. The increase in 1956 in the Houston area was 14,000,000 gpd which was about twice the decrease in the Pasadena area, causing a net increase of 7,300,000 gpd from 1955 to 1956 in the Houston and Pasadena areas.

CHANGES IN WATER LEVELS IN WELLS

Water levels declined in all wells in the Houston district except in those in and near the ship-channel subarea and in several Houston municipal wells during the period March 1955 to March 1957. The decrease in pumpage in the Houston-Pasadena area in 1954 and 1955 (table 3) caused rises in water levels from March 1954 to March 1955 in part of the Houston-Pasadena area (Wood, 1956, p. 14-15). Although the increased use of surface water caused further reductions in ground-water withdrawals in the ship-channel subarea and in the eastern part of the Houston area, the overall rate of withdrawal in the Houston area was about the same in 1956 as it was in 1953. Figures 9 and 10 show profiles of the water levels in the most heavily pumped sands in the Pasadena area for the years 1953, 1955, and 1957. The profiles were constructed from measurements made in March of each year. The profiles show that the water levels have continued to decline since 1953 except in and near the ship-channel subarea where reductions were made in ground-water withdrawals.

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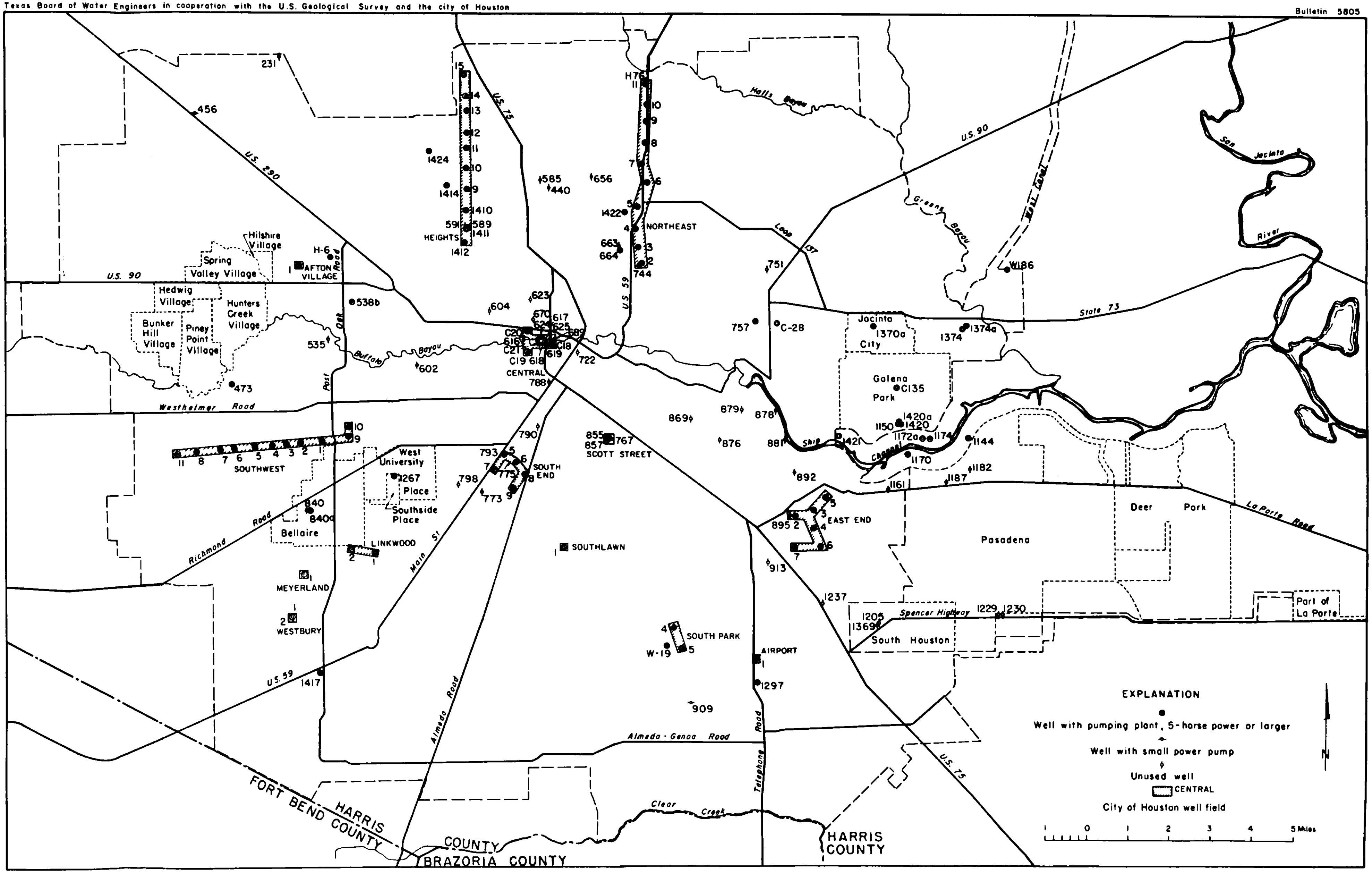


FIGURE 6. - Observation wells and location of municipal well fields in Houston.

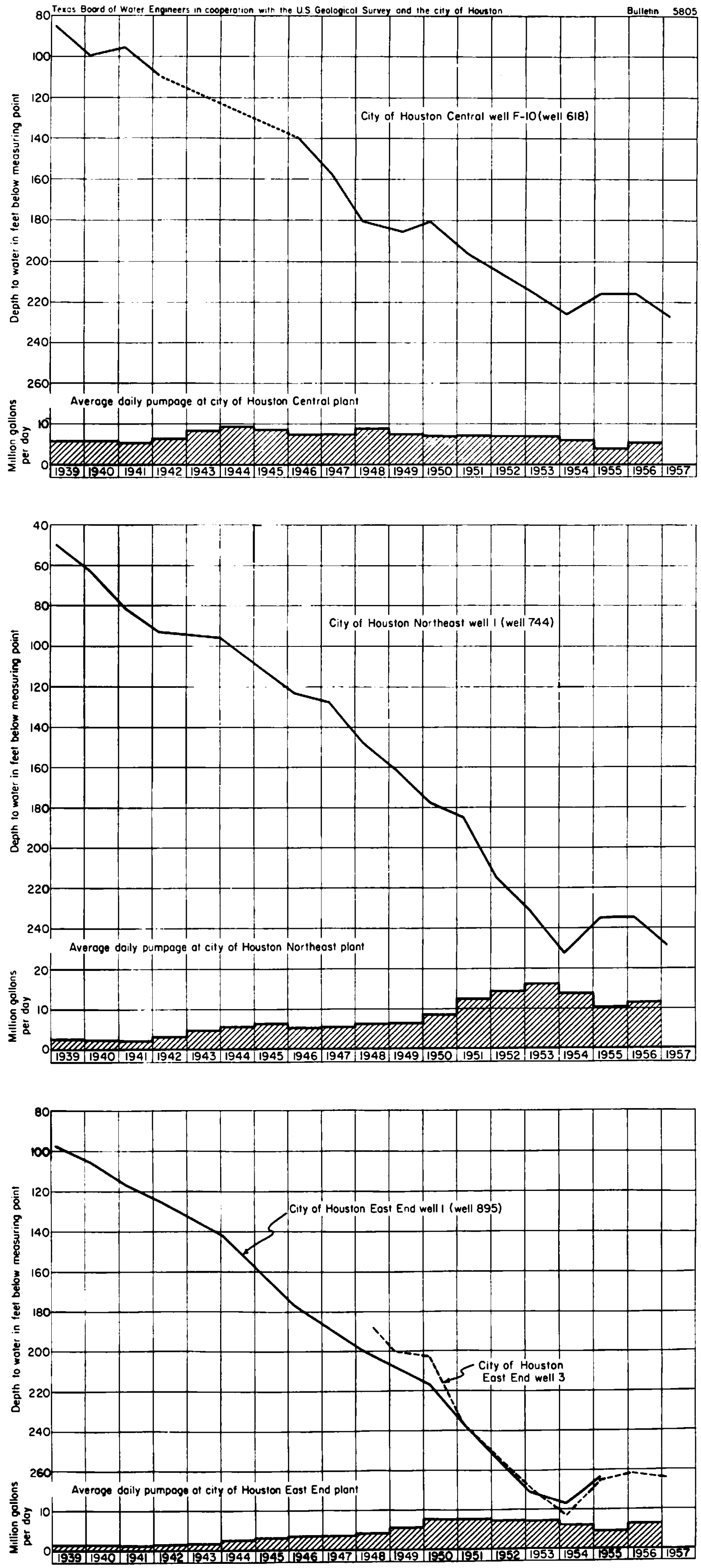


FIGURE 7.- Relation of pumpage to depth to water in the Central, Northeast, and East End well fields of the city of Houston.

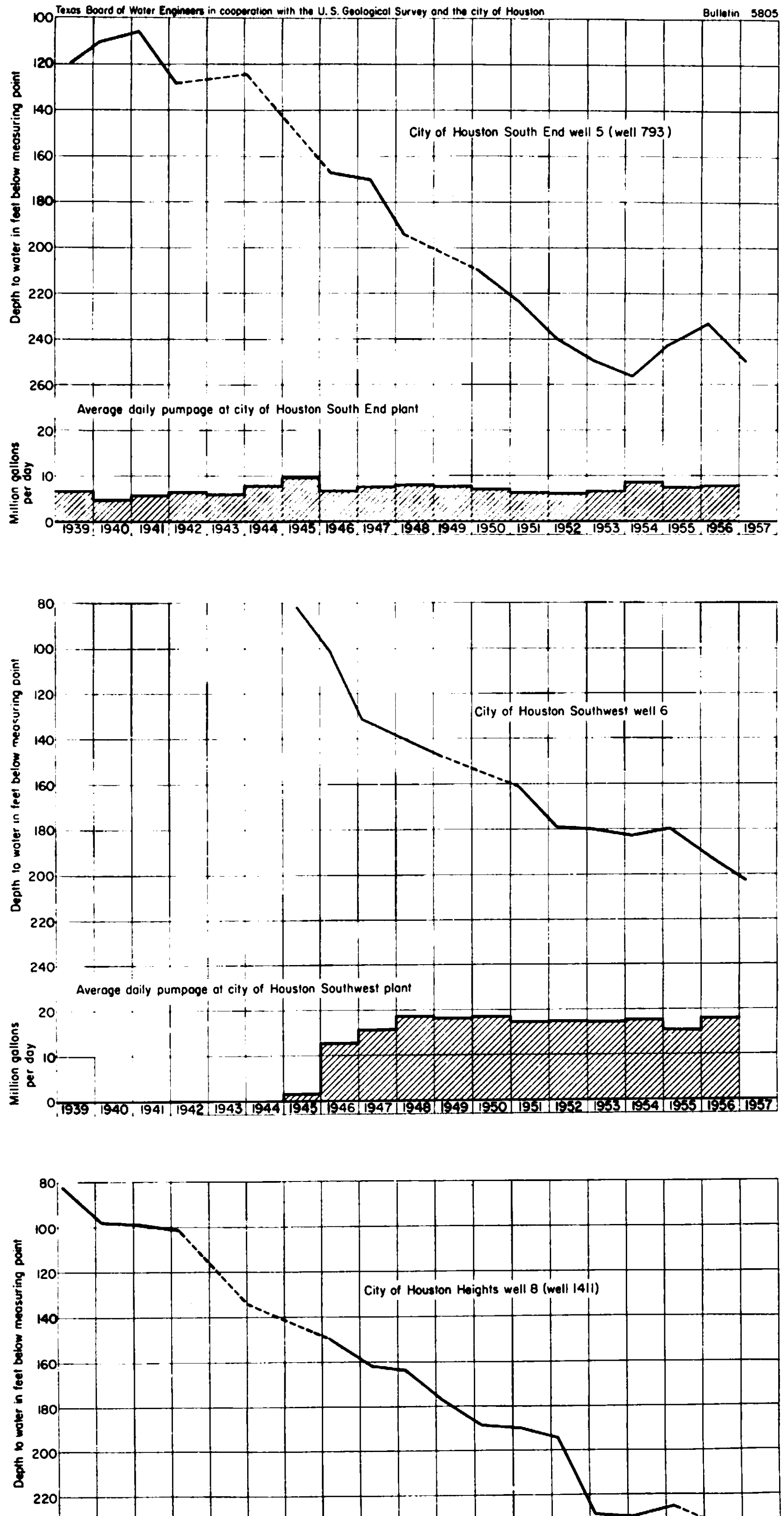


FIGURE 8.- Relation of pumpage to depth to water in the South End, Southwest, and Heights well fields of the city of Houston.

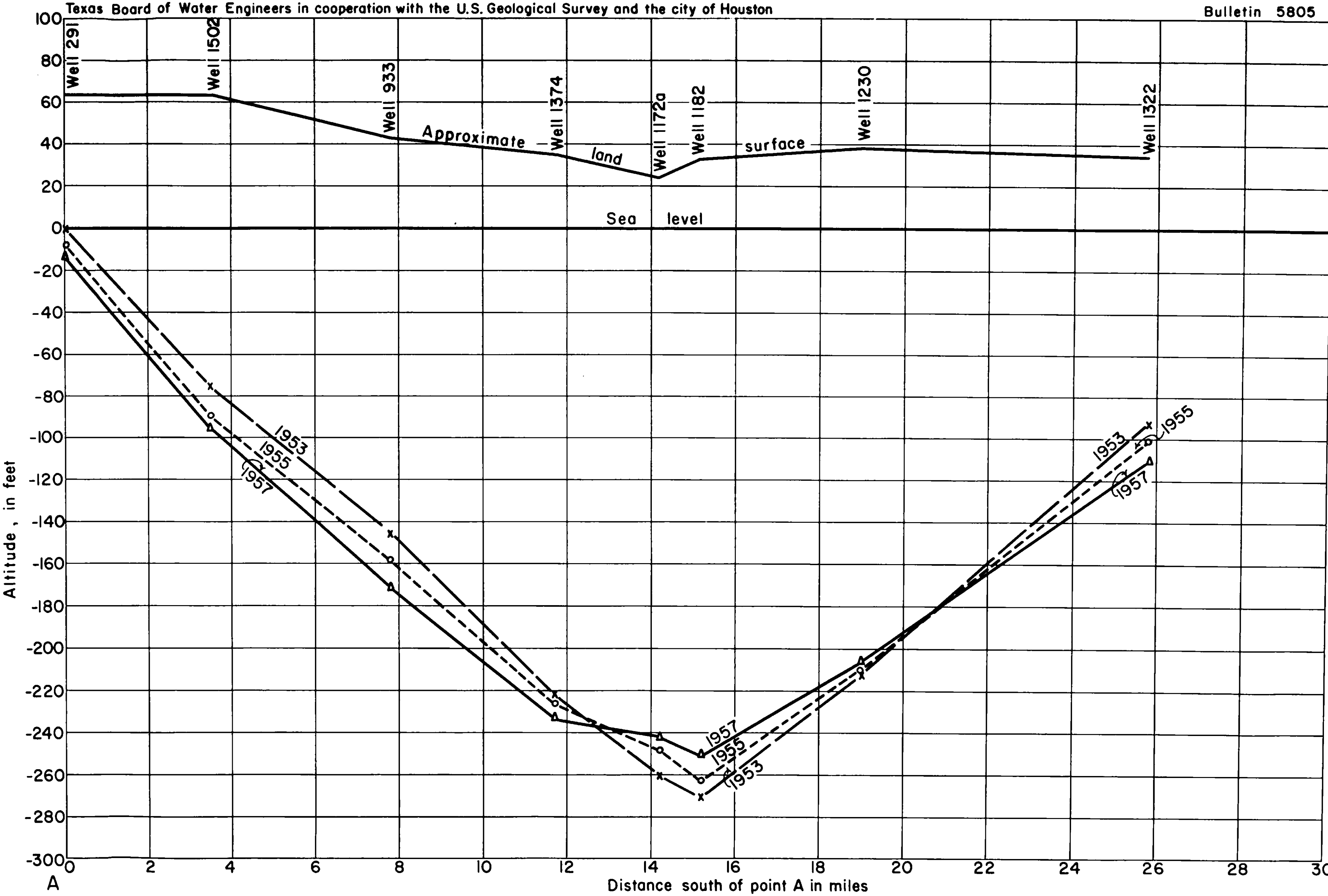


FIGURE 9.- Profile A-A' showing water levels in the Pasadena area, March 1953, 1955, and 1957. (Location of profile shown on figure 13.)

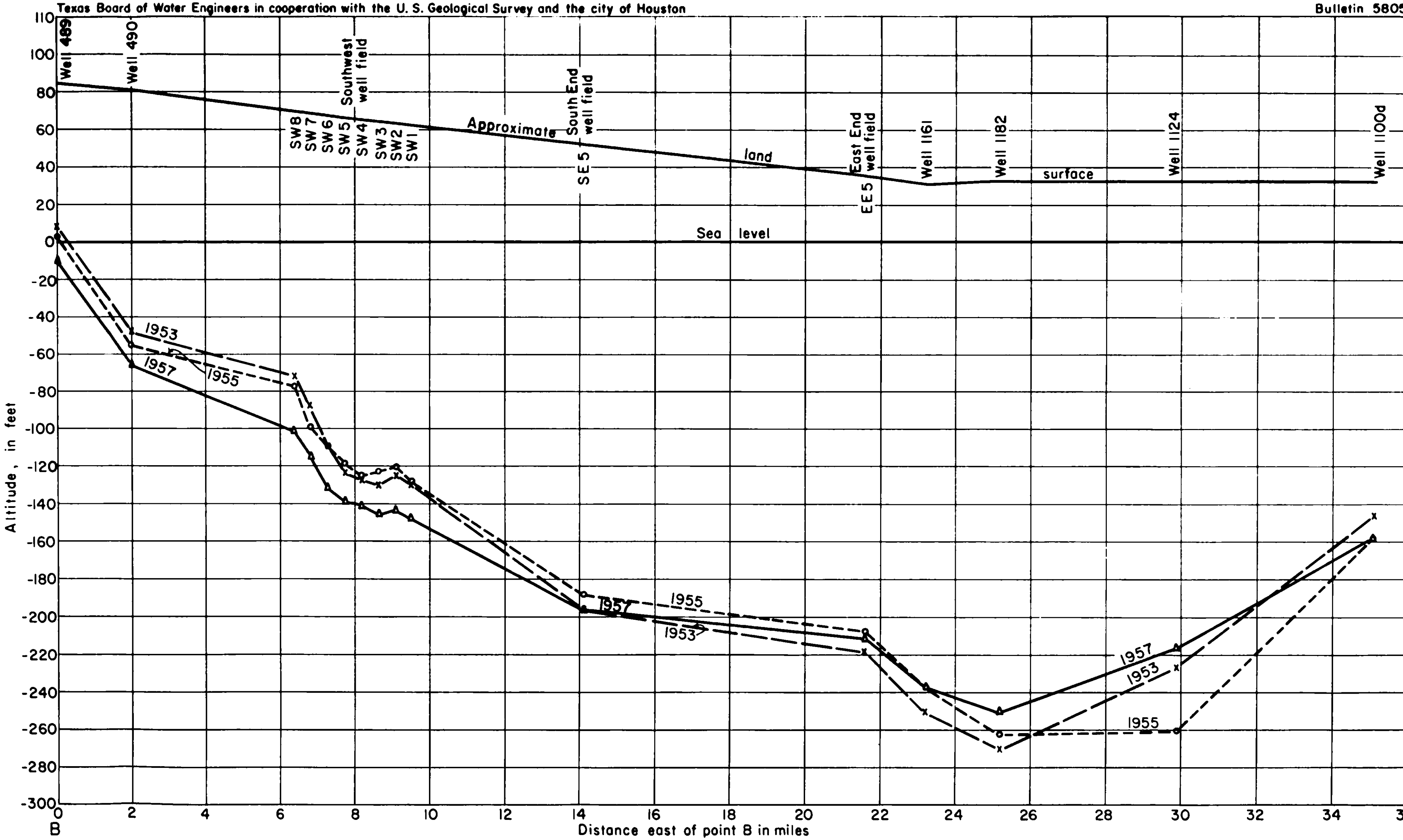
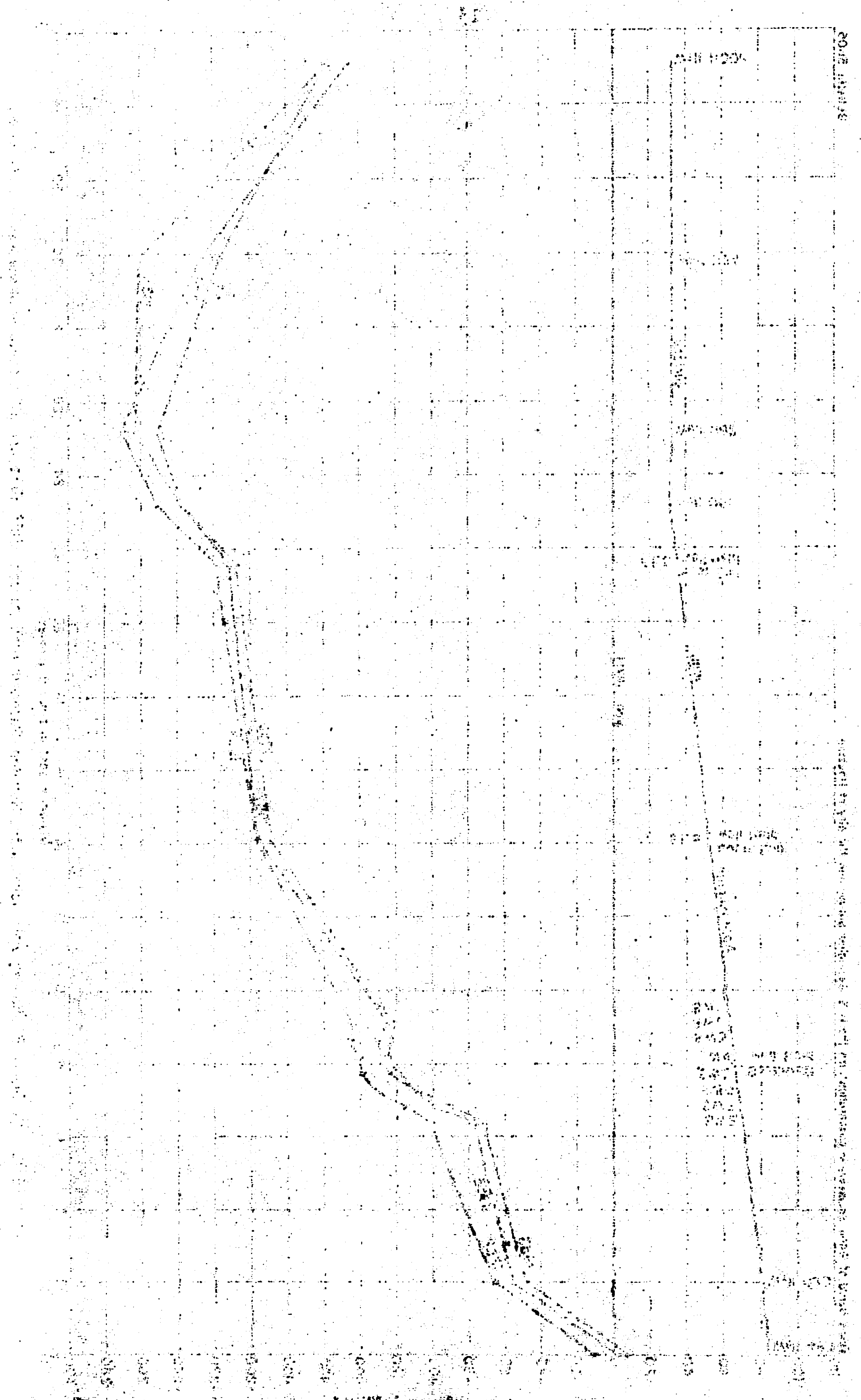


FIGURE 10.- Profile B-B' showing water levels in the Houston-Pasadena area, March 1953, 1955, and 1957. (Location of profile shown on figure 13.)



Most 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 at depths shallower than 500 feet and some wells are screened as deep as 2,550 feet. 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 and the blank casing between the screens are surrounded by a gravel envelope which provides a connection between all the sands below the surface casing.

Water levels are measured periodically in more than 300 observation wells in the Houston district (figs. 2 and 6). Most of the wells are of the multiple-screen, gravel-pack type, and artesian pressures differ with depth, consequently the data are insufficient for the preparation of a piezometric map for any particular sand or group of sands. Figures 11, 12, and 13 show the approximate altitudes of water levels in wells in the Houston district in January 1941, March 1951, and March 1957, respectively. As is pointed out in the figures, the observation wells are screened in the most heavily pumped sands.

KATY AREA

Fluctuations of water levels in two wells in the Katy area (Harris County well 186 and Waller County well F-25) are shown in figure 14. Although the water-level trend is downward, it is at a very slow rate compared to that in the Houston-Pasadena area during the same period, principally because in the Katy area the wells are distributed over a larger area. Declines of water level in 44 observation wells in the Katy area ranged from 0.5 to 6.9 feet and averaged 4.3 feet between measurements in 1955 and 1957. Most of the declines took place during the period March 1956 to March 1957. During the 1956 irrigation season rainfall was less and evaporation was greater than in 1955 and consequently pumpage increased, and the accompanying declines were greater even though the acreage irrigated was smaller than in 1955.

PASADENA AREA

Water levels in the deeper wells in the ship-channel subarea were generally higher in March 1957 than they were in March 1955. The rises in water levels were caused by a reduction in pumpage; the greatest rises occurred in the area where ground-water withdrawals have been reduced the most. Water levels in 5 observation wells in the ship-channel subarea rose an average of 5.4 feet from March 1955 to March 1957.

In the remainder of the Pasadena area the water levels in March 1957 were below those in March of previous years. Water levels in 8 observation wells in the northern part of the Pasadena area declined an average of 3.6 feet during the period March 1955 to March 1957. Figures 15, 16, 17, and 18 show examples of water-level fluctuations in representative wells in the Pasadena area.

In the area south of the ship channel 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 (in the Beaumont clay), which is the principal aquifer in Galveston County to the south and in the Baytown-La Porte area of Harris County. The hydrograph of the shallow well in figure 17 is representative of wells in the Pasadena area screened in this sand. The water level in the "Alta Loma" sand has continued to decline about 5 to 6 feet per year in this area as there has been no reduction in withdrawals from the "Alta Loma" and a small increase in withdrawal rate has been recorded from similar wells in the adjacent Baytown-La Porte area.

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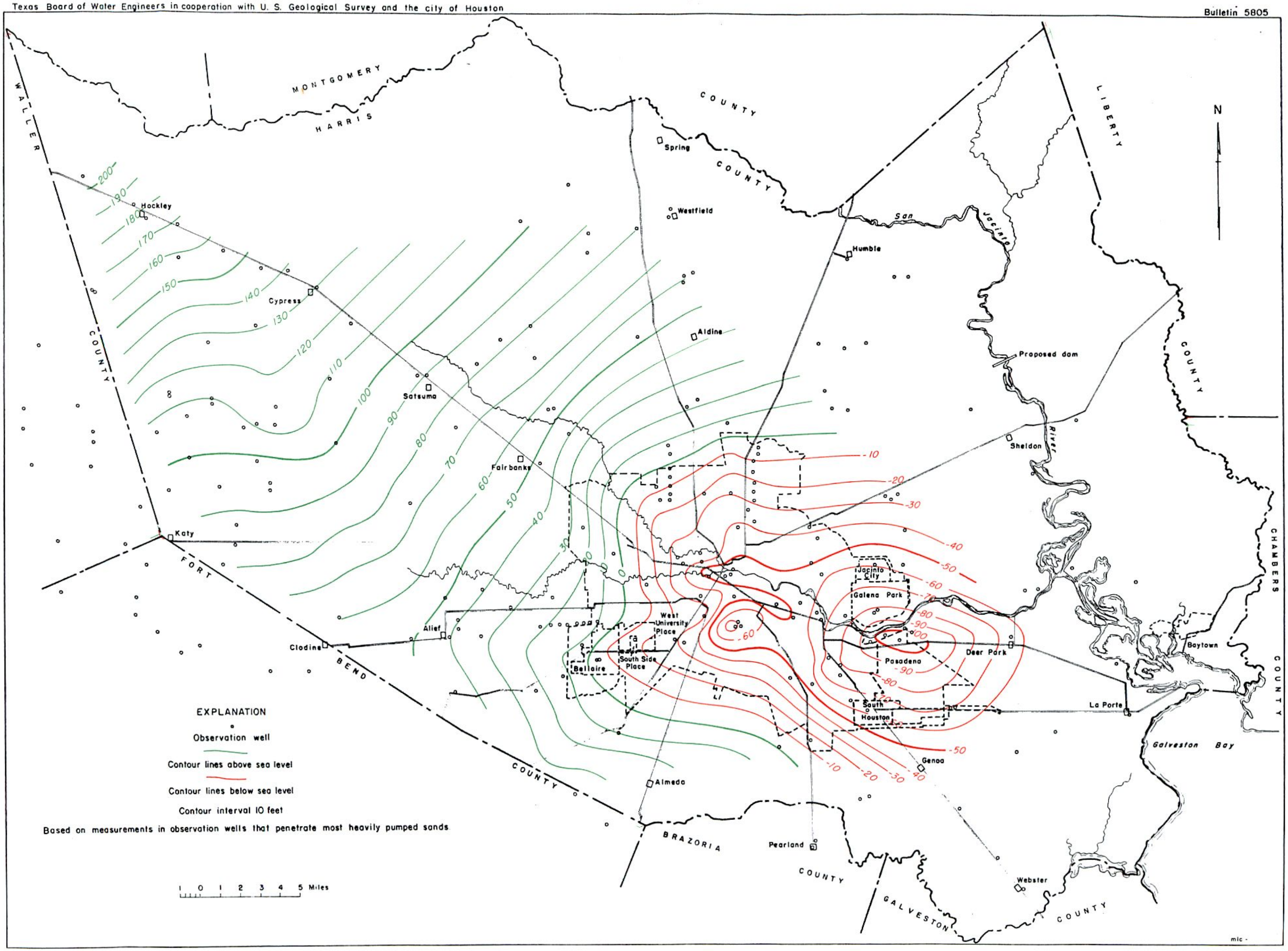
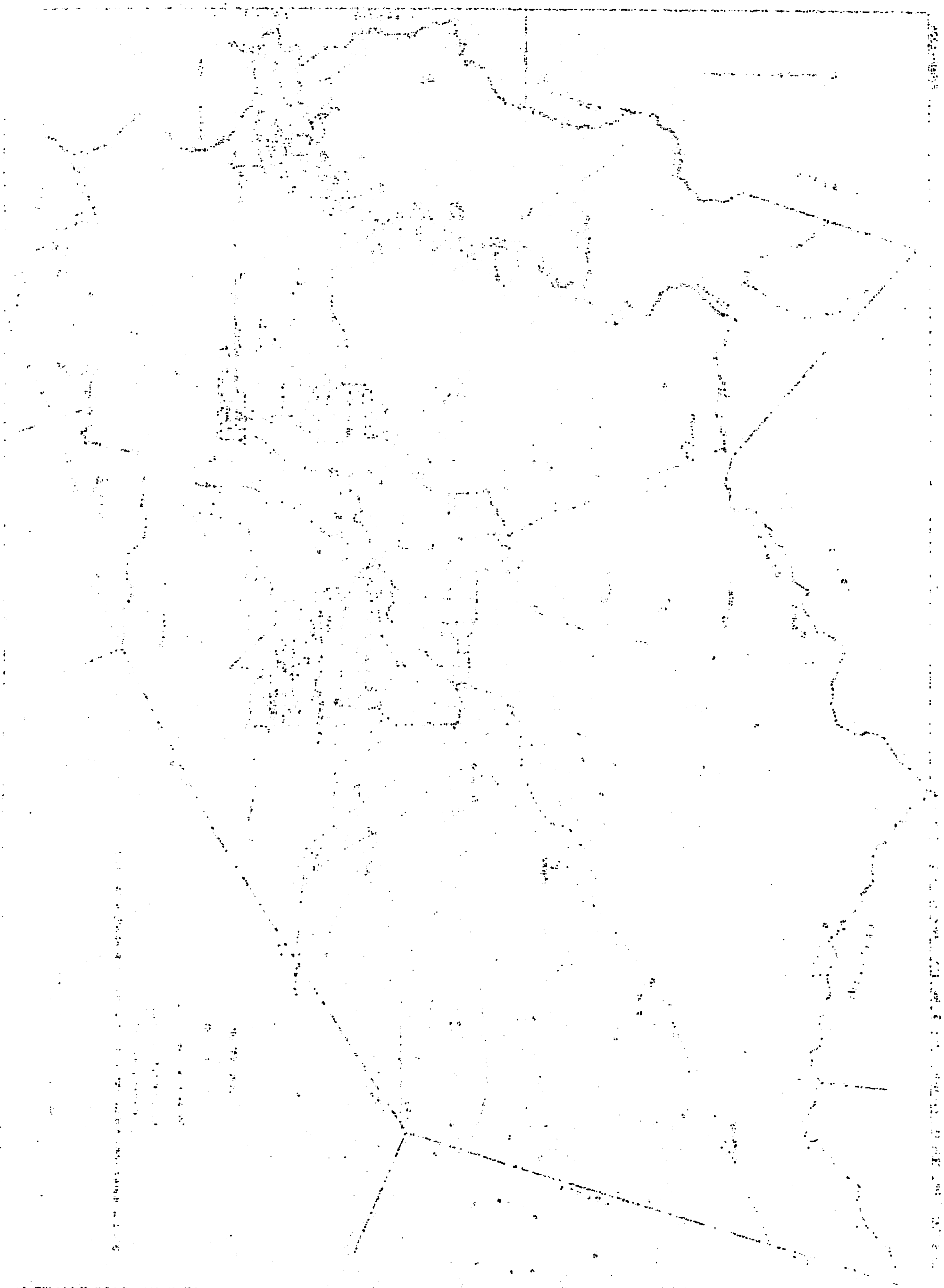


FIGURE 11 - Approximate altitude of water levels, in feet, in wells in the Houston district, Texas, January 1941.



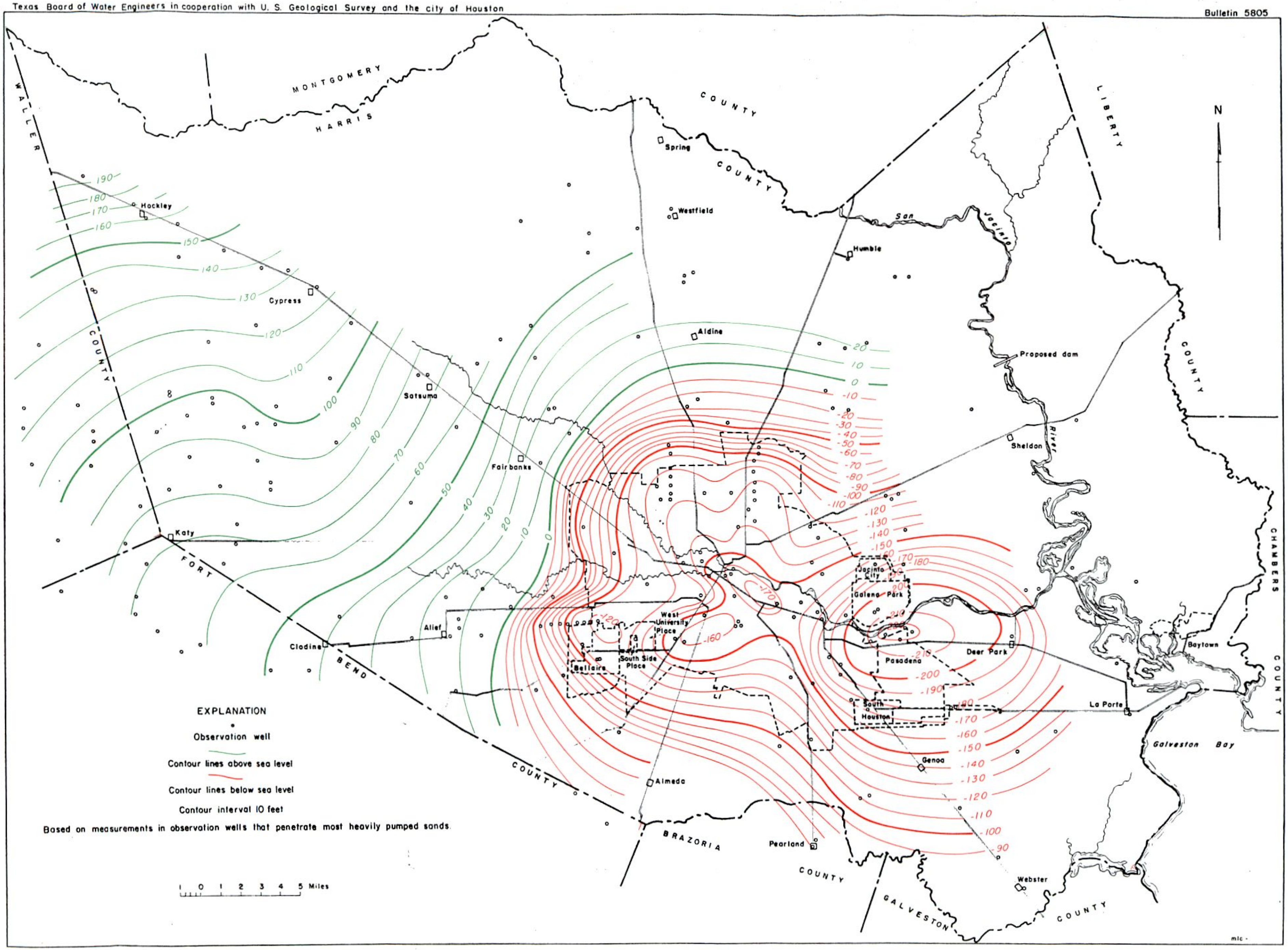


FIGURE 12.- Approximate altitude of water levels, in feet, in wells in the Houston district, Texas, March 1951.

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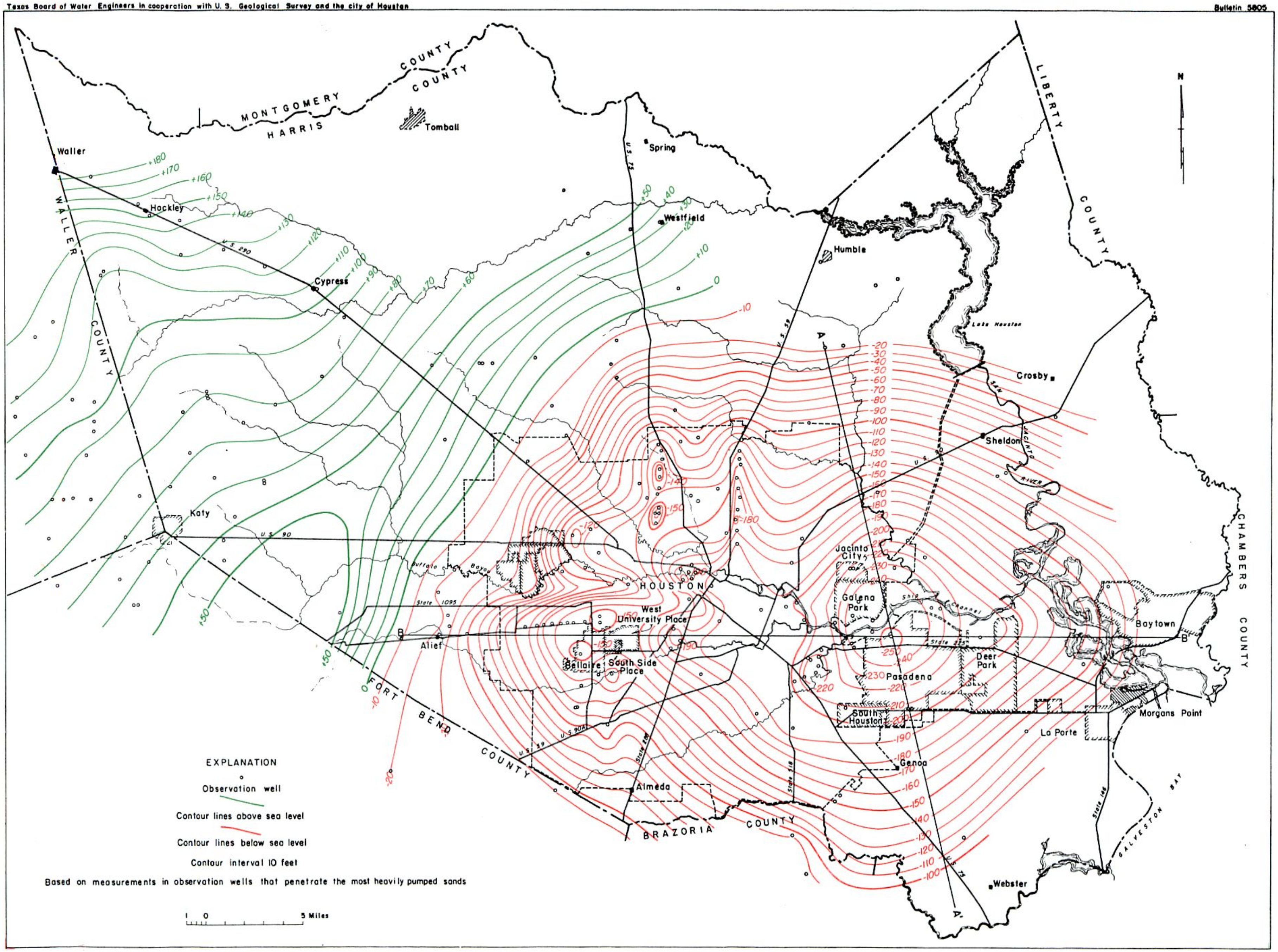

FIGURE 13.- Approximate altitude of water levels, in feet, in wells in the Houston district, Texas, March 1957.

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FIGURE 14.- Changes in water levels in wells in the Katy area.

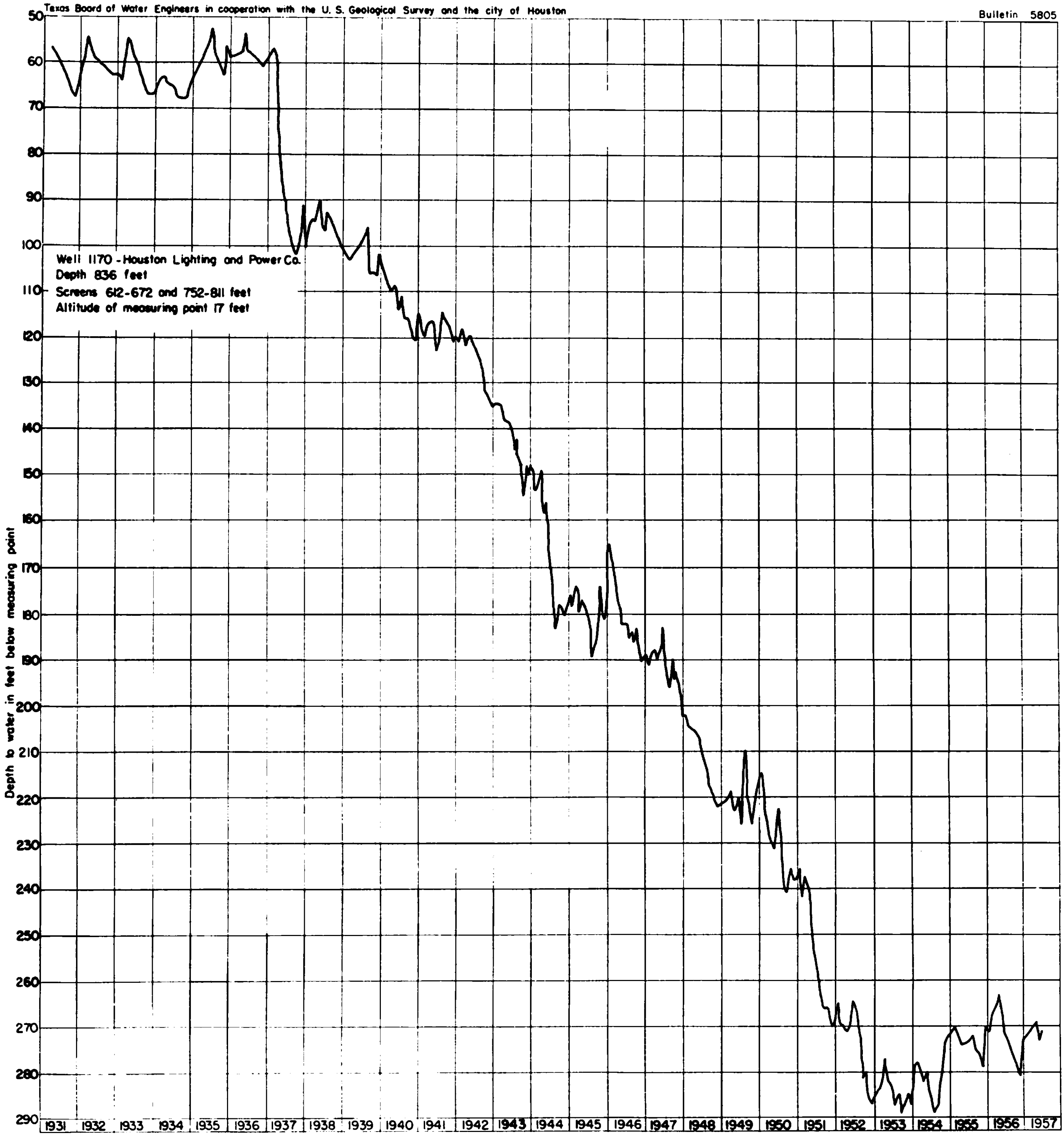
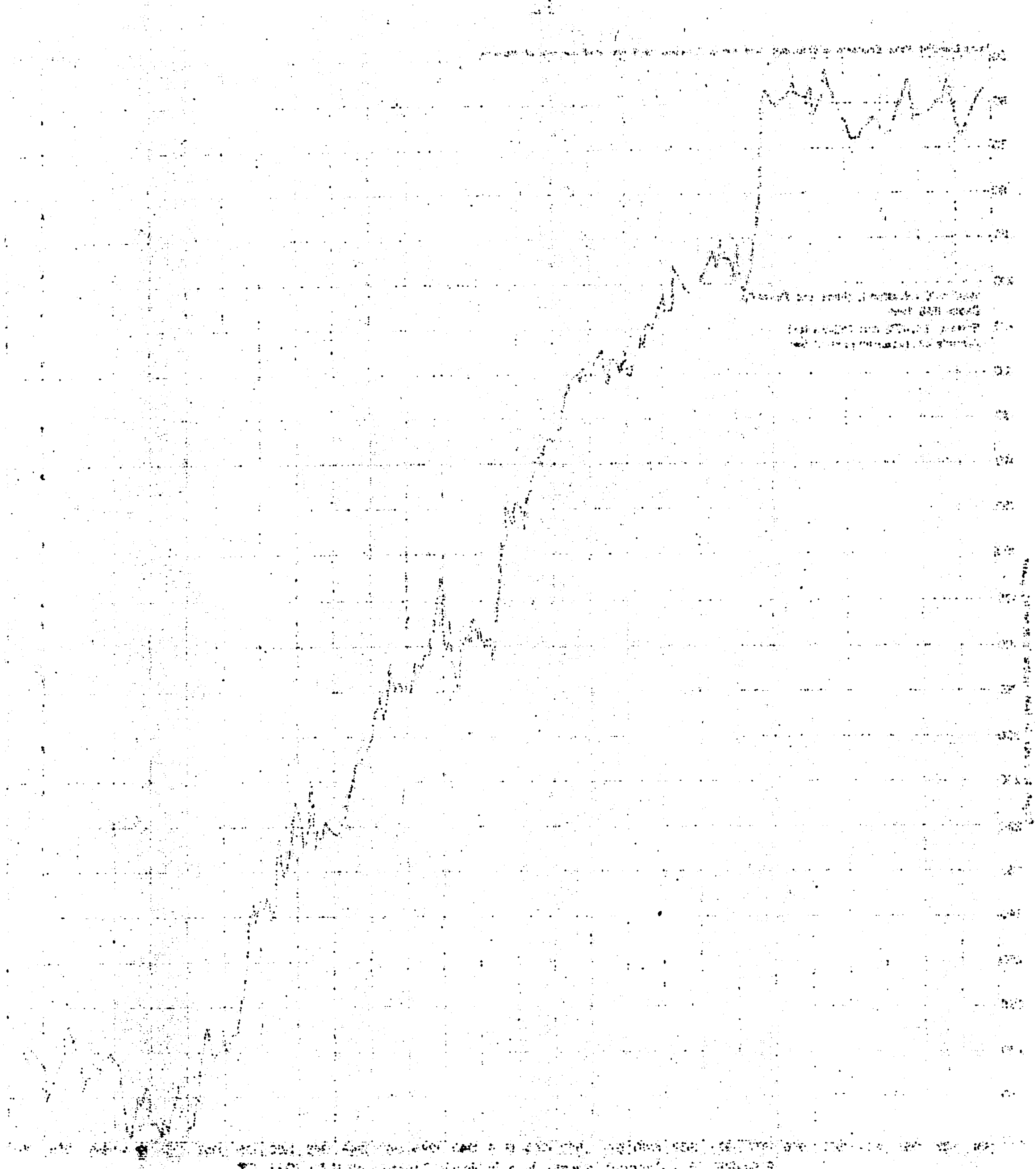


FIGURE 15. - Changes in water level in Harris County well 1170, 1931-57.



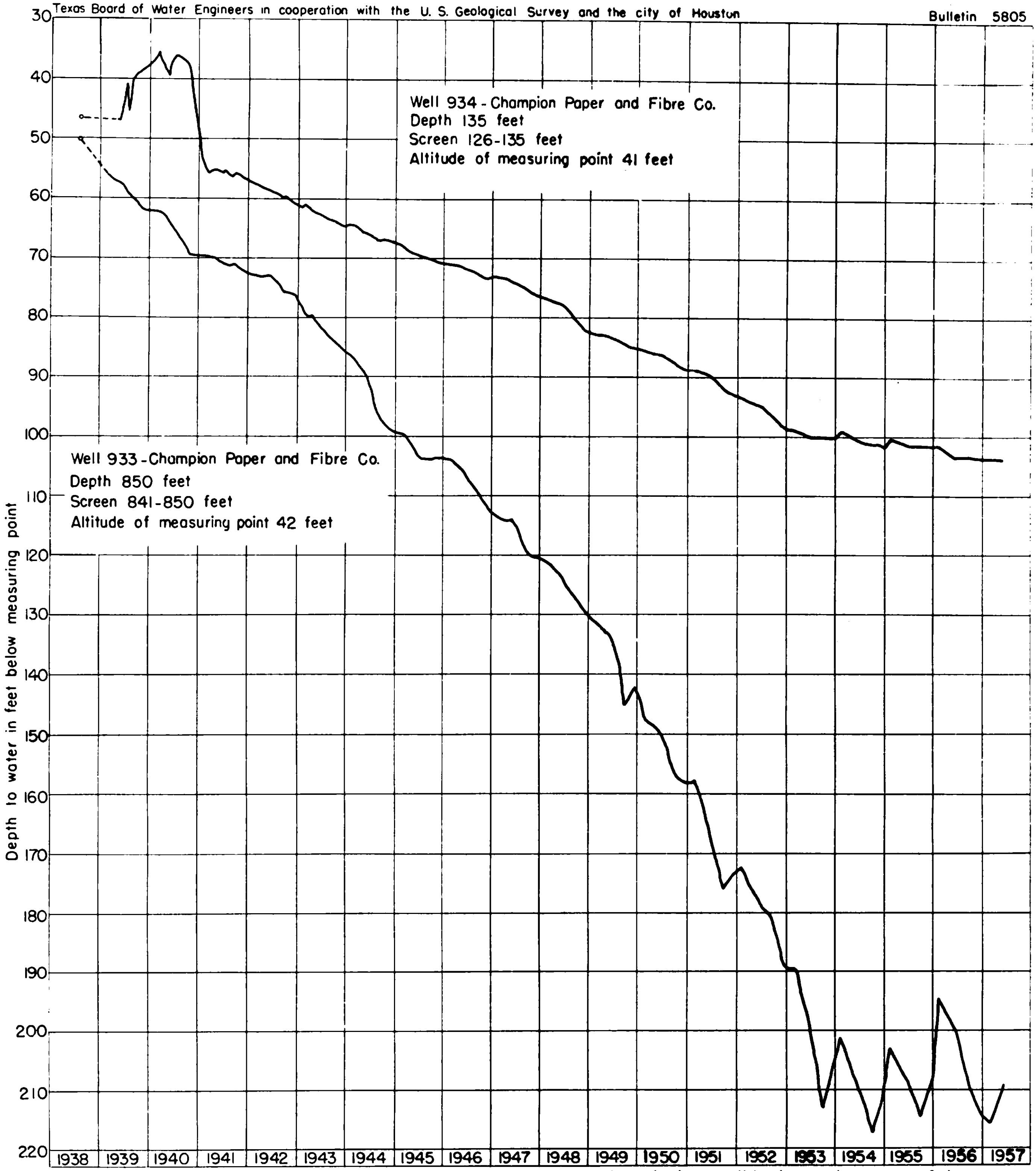


FIGURE 16.- Changes in water levels in a very shallow well and a moderately deep well in the northern part of the Pasadena area.

FIGURE 17. - Changes in water levels in a shallow well and a deep well in the eastern part of the ship-channel subarea.

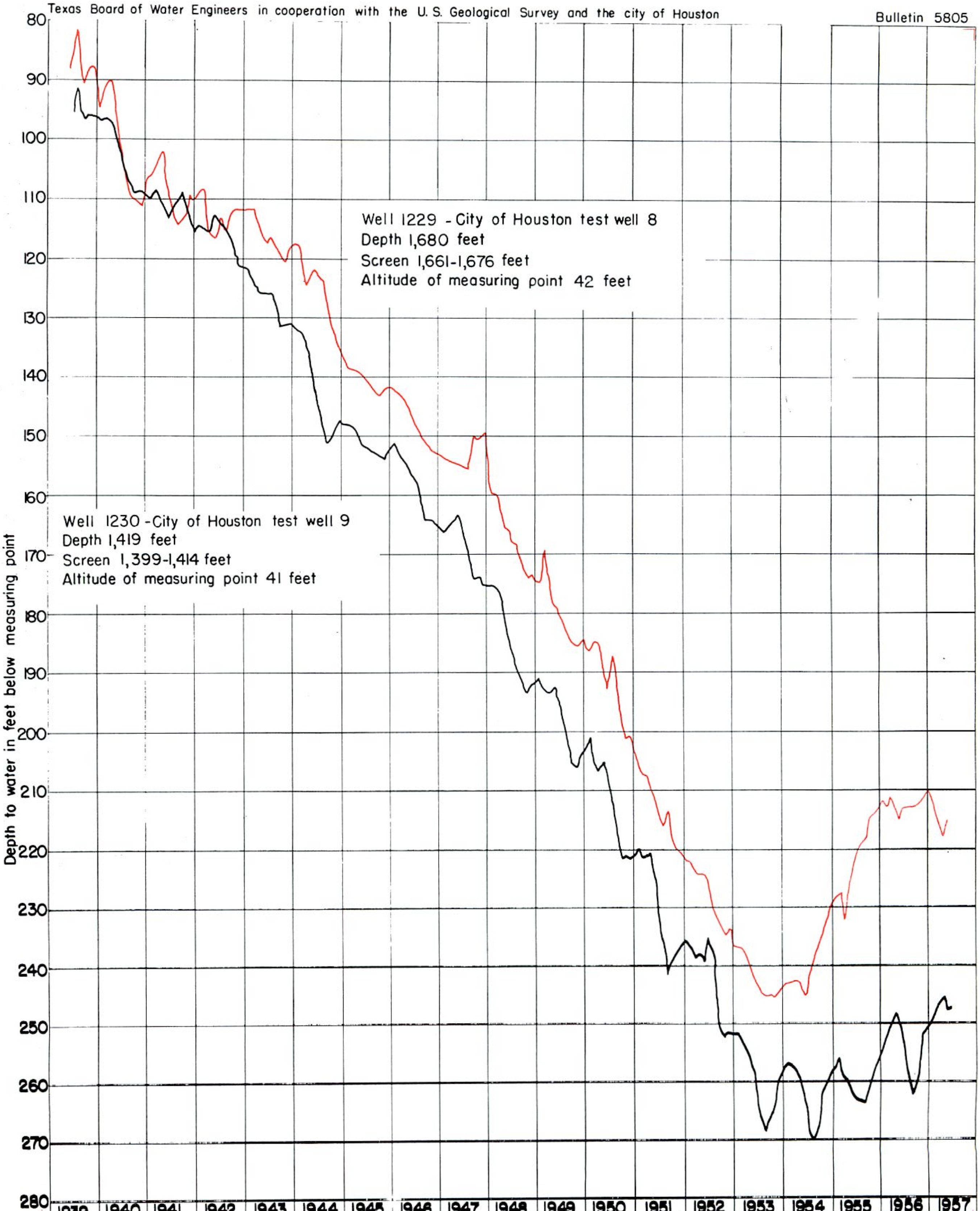


FIGURE 18.- Changes in water levels in two single-screened deep wells in the southern part of the Pasadena area.

HOUSTON AREA

Water levels declined generally throughout the Houston area during the period 1955 to 1957 largely because of the increase in pumpage for public supplies. Water levels in 11 observation wells in eastern Houston declined an average of 7.1 feet from March 1955 to March 1957, while water levels in 24 observation wells in southwestern Houston declined an average of 15.1 feet. Water levels in 8 observation wells in central Houston declined an average of 10.3 feet and water levels in 24 wells in northern Houston declined an average of 7.7 feet from March 1955 to March 1957. Figures 19, 20, 21, and 22 show examples of fluctuations of water levels in wells in the Houston area. Table 4 shows net changes in water levels in active Houston municipal wells for the period 1953 to 1957.

SOURCE OF WATER TO WELLS IN THE HOUSTON DISTRICT

The source of all the fresh ground water in the Houston district is precipitation that percolates downward to the water table. The materials that make up the water-bearing formations were deposited, at least in part, in brackish or salt water, but precipitation on the outcrop has moved downdip flushing the saline ground water from the updip portions of the formations (Winslow, Doyel, and Wood, 1957, p. 13-17). The water that is pumped from wells in the Houston district has moved laterally or vertically and is taken from storage both in the sands and in the clays.

Water in transient storage principally in the sands--that is, water moving from areas of recharge to areas of discharge, has been thought to be the most important source of water to wells in the Houston district. As water moves down the dip from the outcrop area, precipitation percolating into the sands adds to the ground water in transient storage. 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 of water transmitted downdip, the surplus recharge is rejected to the streams, consumed by plants as transpiration, and lost by evaporation. If the amount of recharge is less than is transmitted downdip, water levels decline in the outcrop.

Water is also taken from storage in both overlying and underlying beds by vertical leakage. The clayey beds that separate the heavily pumped zones from the sands above and below, are only slightly permeable. Because of the method of deposition, the individual beds of sand and clay are not continuous, but thicken and thin so that any individual layer generally cannot be traced for long distances, not even a few hundred feet in some areas. Beds of sand that are separated by several tens of feet of clay at the site of one well may be connected by another bed of sand or by the thickening of the sand beds as the clay bed lenses out at a well site a short distance away. Beds of well-sorted sand may be separated by beds of poorly sorted sand, silt, and clay, which do not give up water freely to wells but which do have the ability to transmit large quantities of water considering the large area and head differential involved. The area of the surface in the Houston-Pasadena area, as shown in figure 2, is about 500 square miles and the difference in head between the very shallow sands and the sands in the heavily pumped zone is in excess of 100 feet in most of the area (fig. 16). The volume of water that would move through 150 feet of material having an effective coefficient of permeability of only 0.002 gallon per day per square foot under a head differential of 100 feet, would be almost 40,000 gpd per square mile, or 20,000,000 gpd in an area of 500 square miles. Assuming 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 are not necessarily correct for the Houston-Pasadena area, but are intended to show the possible order of magnitude of vertical leakage.

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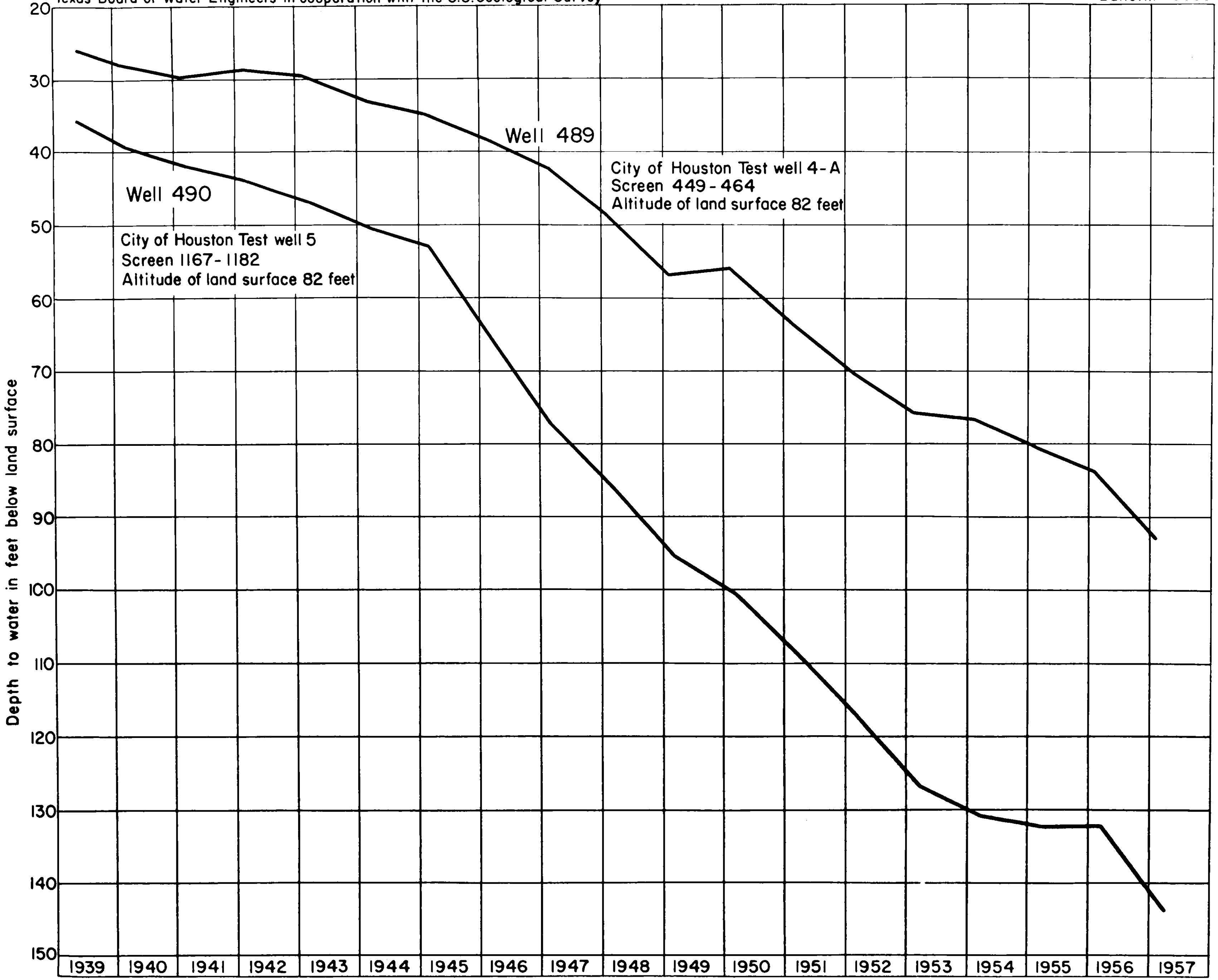

FIGURE 19. - Changes in water levels in two single-screened wells of different depths near Alief.

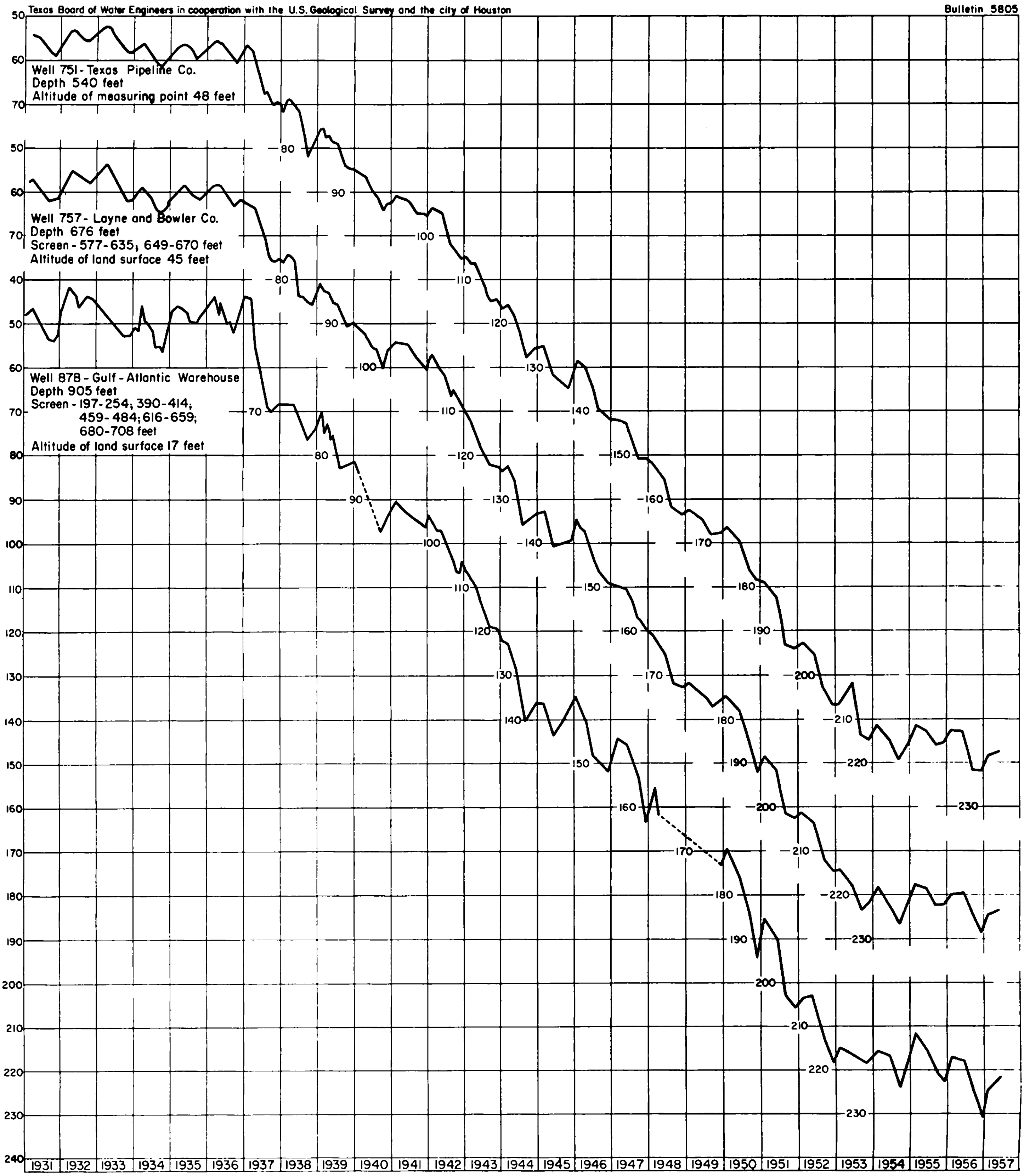

FIGURE 20. - Changes in water levels in wells in eastern Houston, 1931-57.

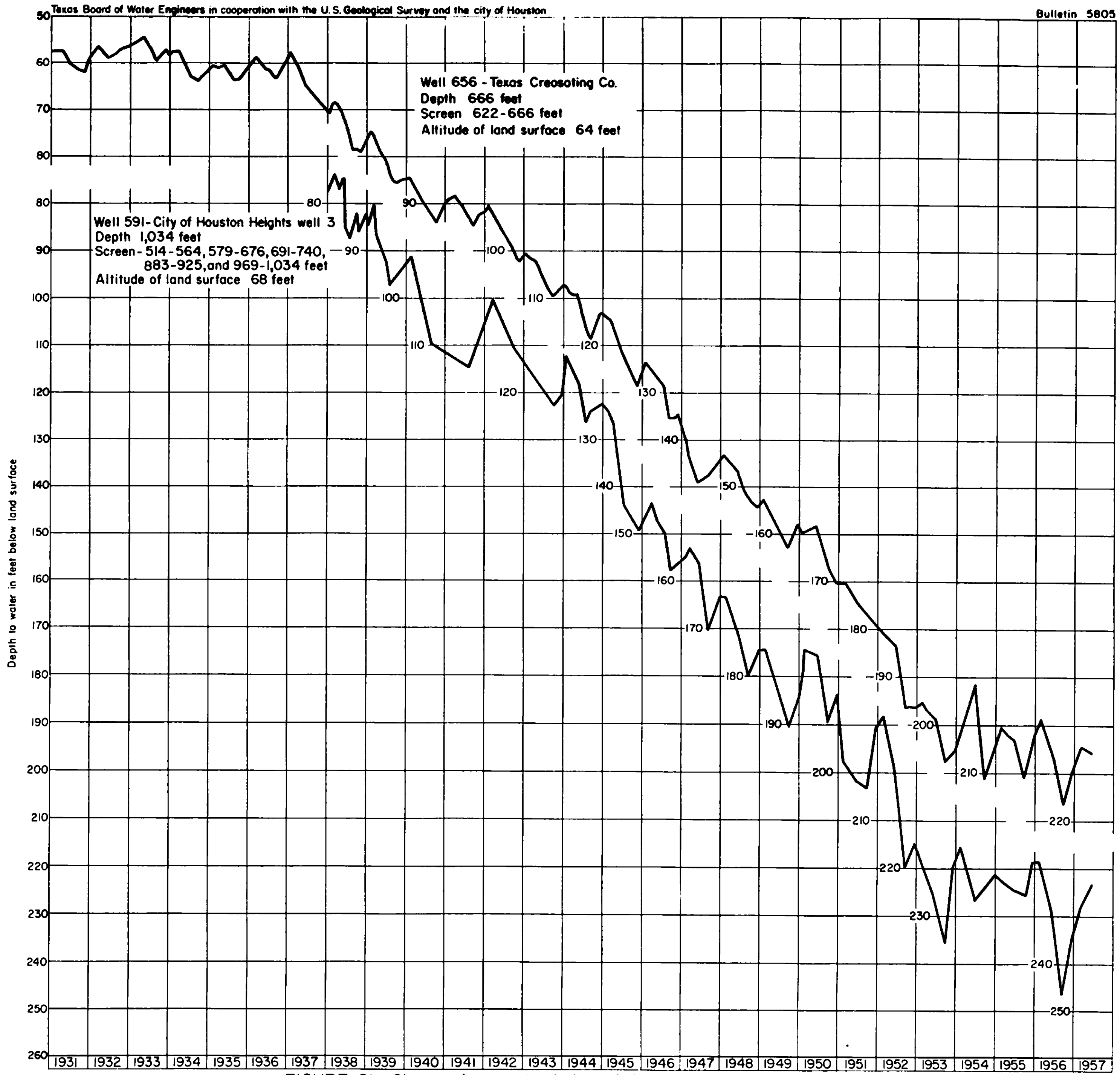

FIGURE 21.- Changes in water levels in wells in northern Houston, 1931-57.

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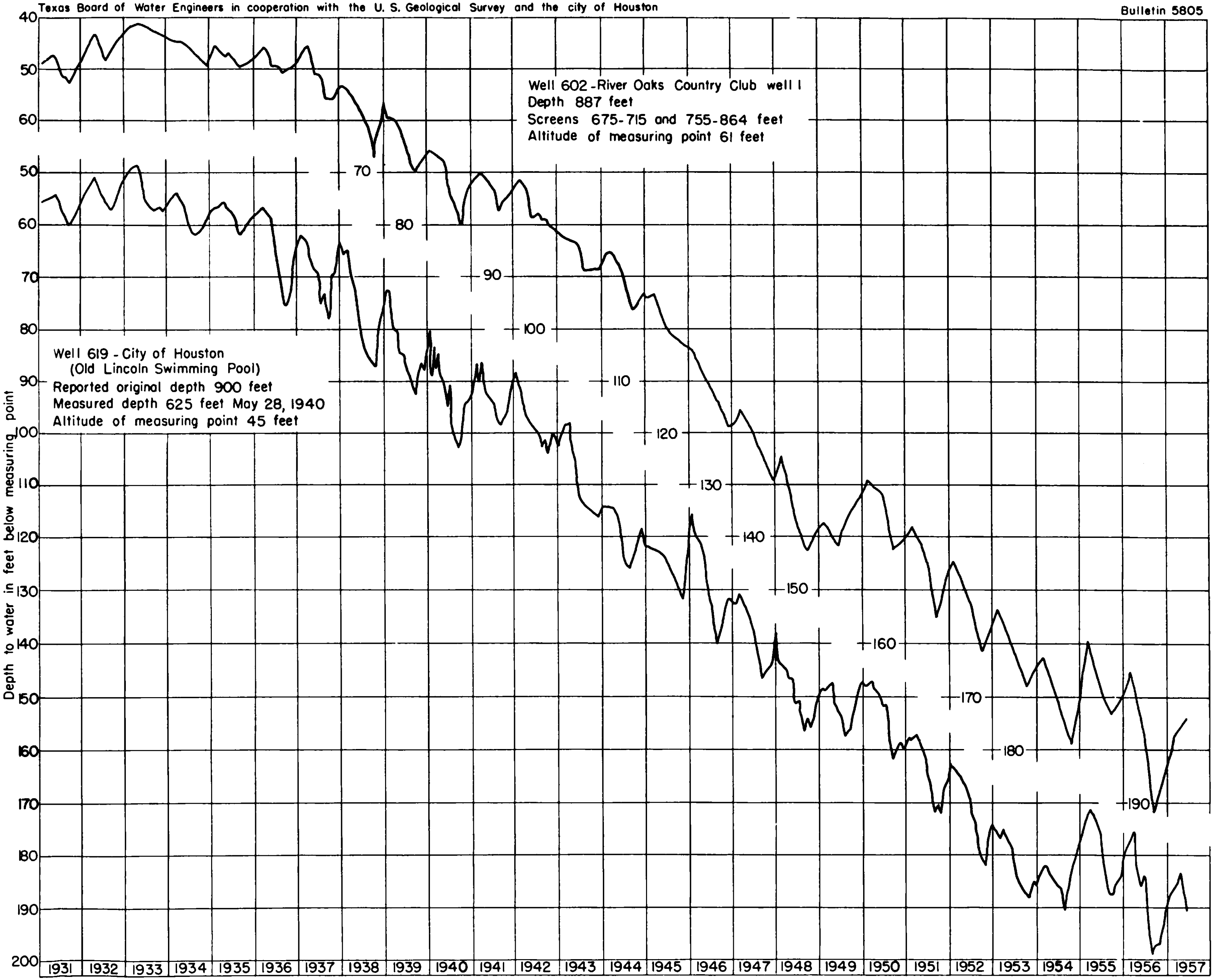
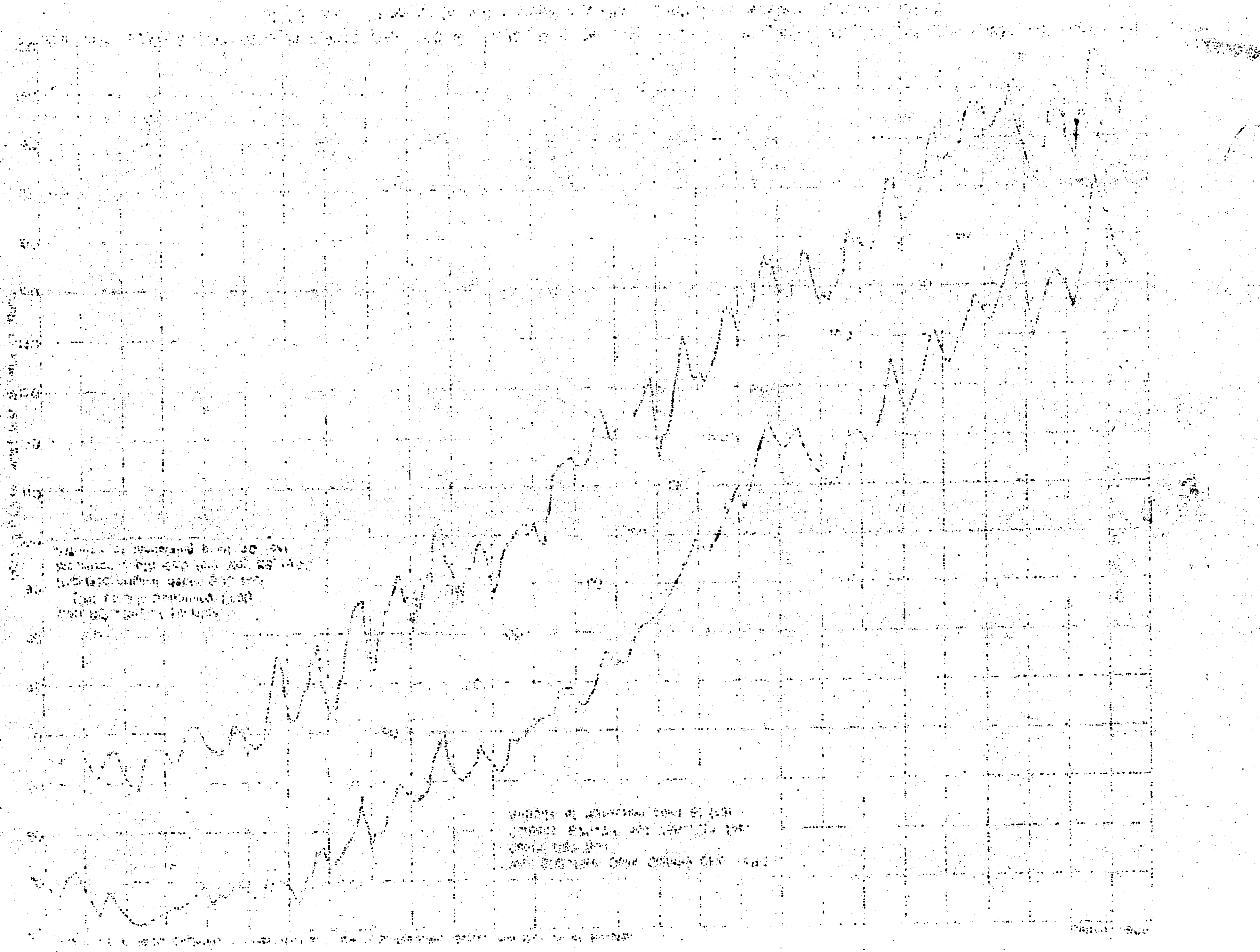


FIGURE 22. - Changes in water levels in wells in central and western Houston, 1931 - 57.



Water levels in shallow wells in the outcrop area in northern Harris County and in Montgomery County respond to changes in rainfall (fig. 23). Most, if not all, of the decline in water levels since 1950 in the outcrop area 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. Streams in Montgomery County have continued to drain ground water during the period of deficient rainfall, indicating that water in excess of the amount moving downdip to the Houston-Pasadena area is available for recharge to the lower sands. However, the streams and bayous in northern and western Harris County, which drain the outcrop area of the upper sands, have been dry for varying periods in recent years except during time of storm runoff. It is probable that the water table has declined to a level below the stream beds in those areas. It is also probable that the water table has declined in the clayey materials as well as in the sandy materials throughout the area of decline of artesian head.

Ground water is also moving laterally updip in the sands from southeast of the Houston-Pasadena area. This too is water that is in transient storage and is being followed by salty ground water which occurs in the downdip portions of all the sands (Winslow, Doyel, and Wood, 1957).

A considerable amount of water is released from artesian storage. As the artesian pressure head declines in the sands a small amount of water is released because of the elastic compression of the sand and because of the slight expansion of the water. A much larger amount is released as water of compaction or water that has drained from the interbedded clays as the artesian pressure head is lowered in the sands (Winslow and Doyel, 1954a, p. 421). The resultant compaction of the clays has caused subsidence of the land surface.

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 amount of subsidence to be expected from compaction of interbedded clays or dewatered shallow clays; (3) the rate of movement of salty ground water toward the heavily pumped area; (4) the amount of recharge entering the outcrop to become ground water in transient storage; and (5) the rate and amount of possible lowering of the water table. Such a study would require the establishment of observation wells screened in individual sand beds to observe changes in head and in water quality in the heavily pumped sands, and establishment of additional very shallow wells to observe fluctuations of the water table in the shallow sands; the determination of the physical properties of water-bearing materials; and a comprehensive evaluation of the historic hydrologic data in the Houston district.

CHANGES IN CHEMICAL QUALITY

Salt water is present in the heavily pumped sands a few miles down the dip (southeast) from the area of large ground-water withdrawals in the Houston-Pasadena area (Winslow, Doyel, and Wood, 1957). 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 the 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 the interface in some sands may be closer to the Houston-Pasadena area than is suspected.

Salty ground water is moving from the southeast toward the Houston-Pasadena area because the water in the sands moves from areas of higher head to areas of lower head or in the direction of the hydraulic gradient (fig. 13). The individual sands differ 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. At the current apparent rate of movement, the interface may be many years away from areas of heavy withdrawal.

The chemical quality of the water from city of Houston test wells 8 and 9 (Harris County wells 1229 and 1230) has changed considerably since 1948 (fig. 24). The chloride content of water from well 1229, which is screened between 1,661 and 1,676 feet and is 3½ miles south of the Pasadena

Table 4.- Net changes in water levels, in feet, in active Houston municipal wells, 1953-57

Plant	Office no.	City well no.	Screened at intervals between (feet)	Date (1954)	Depth to water	Date (1955)	Depth to water	Date (1956)	Depth to water	Date (1957)	Depth to water	Change 1953-1954	Change 1954-1955	Change 1955-1956	Change 1956-1957
Central		C-18	844-1,989	Mar. 3	239.07	Mar. 9	219.46	Mar. 2	219.50	Mar. 11	228.5	-15.3	+19.6	- 0.04	- 9
		C-19	1,160-1,960	3	265.02	9	244.75	2	240.73	7	254.93	-19.6	+20.3	+ 4.02	-14.20
		C-20	1,015-1,940	3	257.31	3	232.64	5	238.19	5	241.41	-17.7	+24.7	- 5.55	- 3.22
East End		3	1,190-2,350	10	282.97	8	264.92	Feb. 29	261.83	Feb. 28	263.97	-13.3	+18.1	+ 3.09	- 2.14
		4	1,001-2,510	10	276.76	7	255.70	Mar. 6	258.88	Mar. 6	259.20	-15.5	+21.1	- 3.18	- .32
		5	1,469-2,560	5	253.59	Feb. 28	232.29	6	237.09	Feb. 28	235.84	- 9.8	+21.3	- 4.80	+ 1.25
		6	950-2,075	10	282	Mar. 3	271	Feb. 29	271	Mar. 6	271.8	-	+11	.0	- .8
		7	785-1,755	-	-	-	-	29	249.56	Feb. 28	258.34	-	-	-	- 8.78
Heights	589	5	410-1,856	Feb. 23	178.72	8	185.53	29	194.63	27	196.27	- .9	- 6.8	- 9.10	- 1.64
	1410	6	581-1,226	Mar. 9	219.79	4	223.69	Mar. 7	230.58	Mar. 12	245.26	- 3.5	- 3.9	- 6.89	-14.68
	1412	7	561-1,424	Feb. 23	221.39	1	215.74	7	229.66	-	-	- 5.9	+ 5.7	-13.92	-
	1411	8	556-1,240	23	229.48	9	225.00	-	-	7	240	- .8	+ 4.5	-	-
		9	610-1,710	Mar. 5	208.43	4	208.93	1	211.75	Feb. 27	214.29	-11.2	- .5	- 2.82	- 2.54
		10	600-1,860	9	208.68	Feb. 25	215.05	8	211.70	27	219.20	- 6.0	- 6.4	+ 3.35	- 7.50
		11	700-1,760	10	218.83	Mar. 9	221.64	8	220.00	Mar. 12	232.99	- 1.6	- 3.8	+ 1.64	-12.99
		12	900-1,750	Feb. 23	221.22	9	222.18	8	217.82	12	232.46	+ 8.8	- 1.0	+ 4.36	-14.64
		13	890-1,800	23	217.95	9	217.95	1	202.65	Feb. 27	213.46	-25.6	.0	+15.30	-10.81
		14	950-1,790	Mar. 10	221.53	Feb. 25	213.65	Feb. 29	206.74	27	214.09	-29.4	+ 7.8	+ 6.91	- 7.35
		15	700-1,680	Feb. 23	205.36	25	199.35	29	195.51	-	-	-20.7	+ 6.0	+ 3.84	-
Northeast		3	1,143-1,990	Mar. 4	247.52	Mar. 8	233.83	27	226.68	Mar. 7	238.58	-18.7	+13.7	+ 7.15	-11.90
		4	1,030-2,060	4	248.42	8	233.58	27	225.90	12	243.76	-19.4	+14.8	+ 7.68	-17.86
		5	1,060-1,960	4	243.28	Feb. 25	222.13	Mar. 2	220.66	Feb. 27	229.36	-21.3	+21.2	+ 1.47	- 8.70
		6	1,017-1,819	Feb. 26	246.09	25	225.22	Feb. 28	228.46	Mar. 7	230.93	-25.2	+20.9	- 3.24	- 2.47
		7	1,001-1,880	Mar. 4	252.71	Mar. 10	221.40	Mar. 2	227.85	Feb. 27	233.79	-27.0	+31.3	- 6.45	- 5.94
		8	1,010-1,950	Feb. 26	243.39	Feb. 25	223.07	Feb. 28	228.61	27	230.3	-	+20.3	- 5.54	- 1.7
		9	1,020-1,920	26	236.98	25	215.23	Mar. 2	219.82	27	225.48	-	+21.8	- 4.59	- 5.66
		10	700-1,830	Mar. 4	224.48	25	202.29	Feb. 28	209.35	27	213.31	-10.2	+22.2	- 7.06	- 3.96
		11	710-1,960	Feb. 26	214.40	25	194.44	28	201.58	27	212.66	-14.6	+20.0	- 7.14	-11.08
Scott St.	857	3	553- 919	Mar. 2	205.82	28	185.33	29	188.72	Feb. 28	200.15	+ 2.2	+20.5	- 3.39	-11.43
South End	793	5	1,275-1,595	2	256.84	28	242.22	Mar. 1	232.85	Mar. 4	249.84	- 7.2	+14.6	+ 9.37	-16.99
		9	680-1,795	-	-	28	215.53		-	4	227.83	-	-	-	-
Southwest		1	726-1,498	Mar. 4	209.86	Mar. 1	193.86	Feb. 29	190.17	Mar. 1	213.31	-15.0	+16.0	+ 3.69	-23.14
		2	675-1,473	4	202.90	1	185.24	29	190.68	1	208.64	-12.5	+17.7	- 5.44	-17.96
		3	686-1,396	4	202.28	1	187.23	29	189.28	1	210.70	- 7.8	+15.1	- 2.05	-21.42
		4	692-1,490	4	201.52	1	192.04	Mar. 1	198.21	5	208.46	- 7.3	+ 9.5	- 6.17	-10.25
		5	652-1,379	4	194.69	4	188.81	1	200.16	1	209.26	- 2.0	+ 5.9	-11.35	- 9.10
		6	548-1,360	3	182.55	4	179.90	1	191.60	5	202.71	- 2.8	+ 2.7	-11.70	-11.11
		7	490-1,431	3	180.96	9	169.68	1	187.70	5	192.48	-18.0	+11.3	-18.02	- 4.78
		8	559-1,445	2	161.48	9	154.38	1	172.53	5	179.05	-12.6	+ 7.1	-18.15	- 6.52
		9	520-1,030	10	176.20	9	176.06	Feb. 29	176.66	1	189.87	-	+ .1	- .60	-13.21
		10	1,070-1,945	2	207	4	214.05	29	203.51	4	227.93	-	- 7	+10.54	-24.42
		11	705-1,552	-	-	-	-	Mar. 1	180.30	1	185.99	-	-	.	- 5.69
Afton Oaks		1	680-1,645	-	-	Jan. 18	177.28	1	173.77	1	195.29	-	-	+ 3.51	-21.52
Airport		1	820-1,830	-	-	Mar. 3	236.5	6	234.3	5	247.94	-	-	+ 2.2	-13.6
Linkwood		1	770-1,840	-	-	-	-	2	183.20	11	205.50	-	-	-	-22.30
Meyerland		1	710-1,770	-	-	-	-	1	167.14	4	183.43	-	-	-	-16.29
South Park		4	820-1,790	May 20	221.40	-	-	7	221.5	Feb. 28	237.6	-	-	-	-16.1
		5	755-1,820	-	-	-	-	Apr. 23	222.67	-	-	-	-	-	-

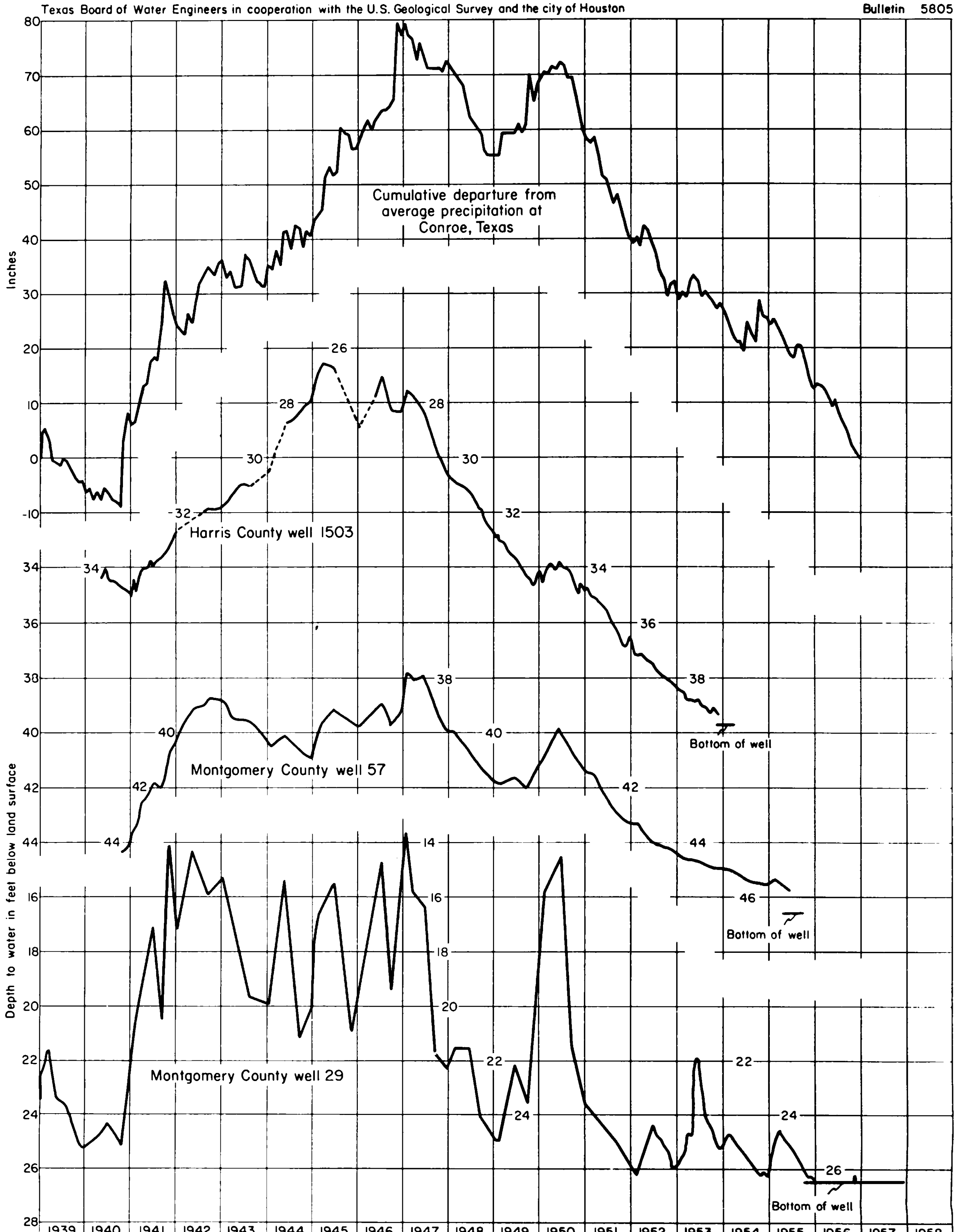


FIGURE 23.- Changes in water levels in shallow wells in northern Harris and southern Montgomery Counties and cumulative departure from average monthly precipitation at Conroe, Tex., 1939-56.

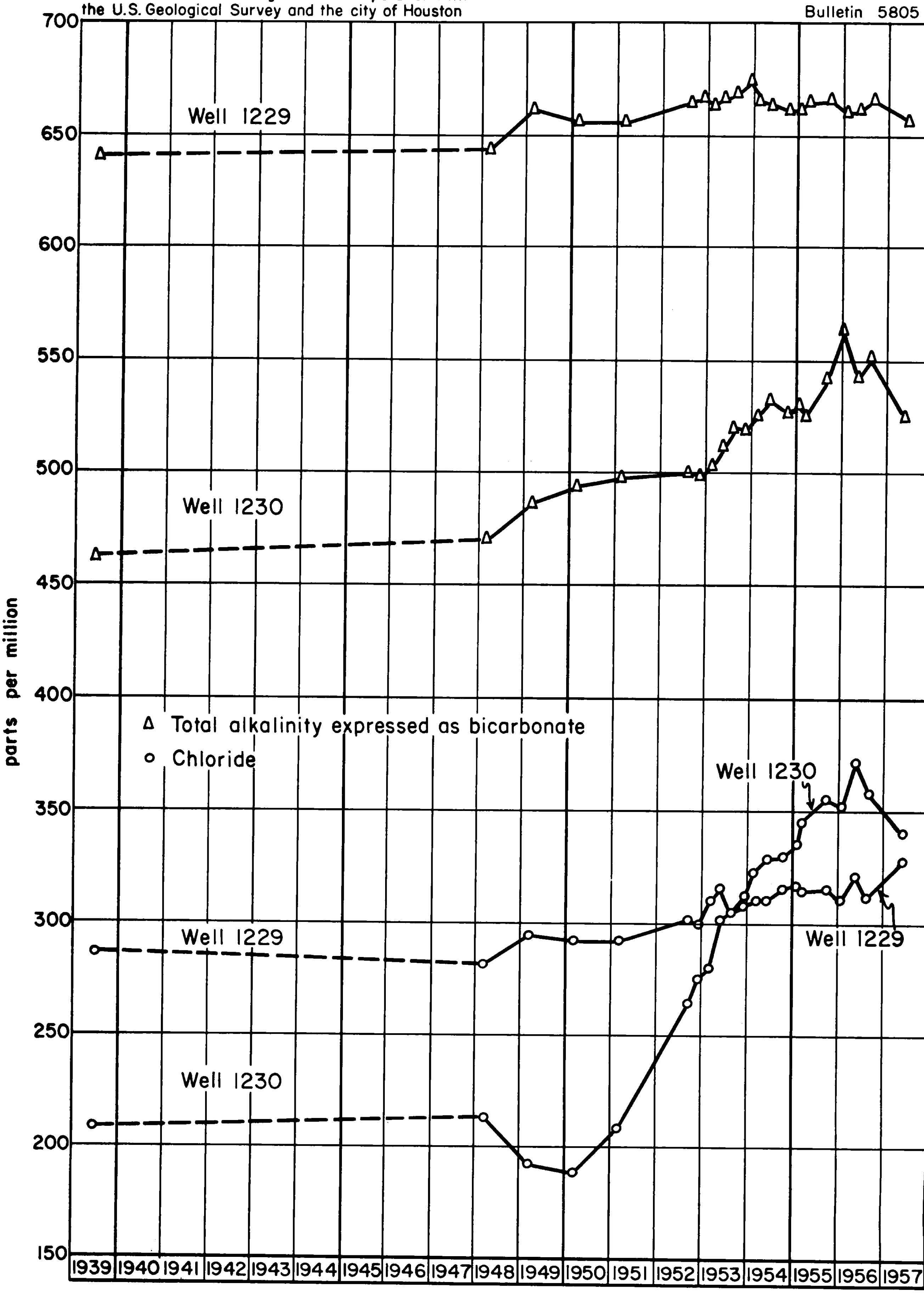
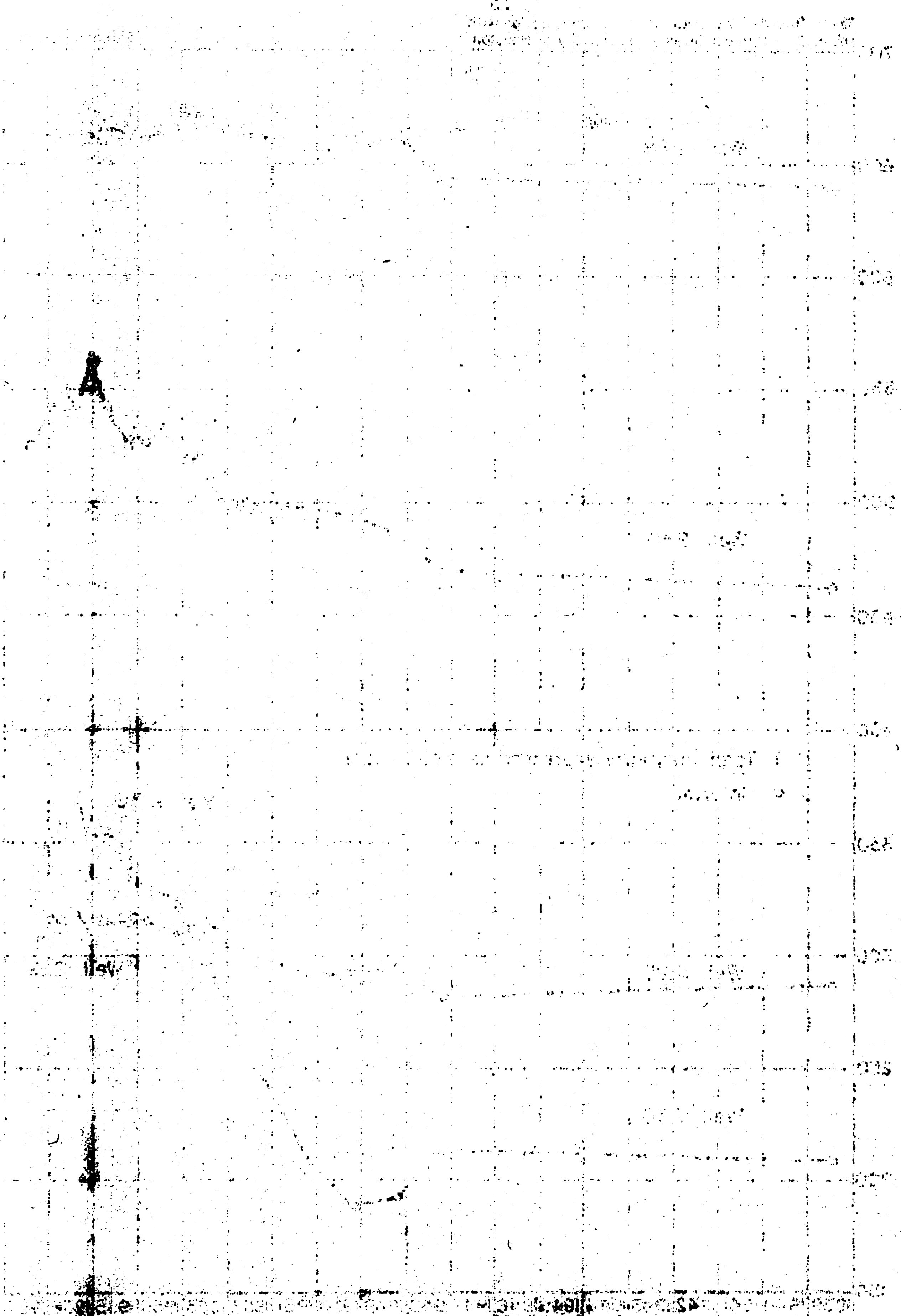


FIGURE 24.- Chloride content and total alkalinity of water from Harris County wells 1229 and 1230.



city hall, increased 46 parts per million (ppm) from March 1948 to June 1957. The chloride content of water from well 1230, at the same location and screened between 1,399 and 1,414 feet, increased 184 ppm between March 1950 and May 1956 and decreased 32 ppm by June 1957. The decrease in chloride content in well 1230 has occurred since the reduction of ground-water pumpage in the Pasadena area and the resultant increases in artesian pressure. The decrease in chloride content may be caused by circulation from connected higher or lower sands some distance from the well due to unequal changes in artesian head (fig. 18) or it may be the result of a slight change in the direction of the hydraulic gradient in the sand. A change in direction would not necessarily be evident in figure 13 because of the generalized nature of the contours.

A change in chemical quality of the water has been observed in a well 3 miles northwest of La Porte and 5 miles east of Deer Park. This well was completed as an observation well and is screened between 980 and 990 feet. In July 1947 the chloride content of the water was 65 ppm and in June 1957 it was 117 ppm.

Although nearly 70 wells are sampled periodically in the Houston district, in many areas of southeastern Harris County no wells are screened at the proper depth to detect changes in the quality of water. Of the wells sampled, only those discussed above have shown any significant changes. Test wells should be constructed at strategic points south and southeast of Pasadena and screened at the proper depth so that the interface can be mapped and the rate of movement down the hydraulic gradient in the different sands can be observed. These wells are particularly needed where the interface is closest to the areas of large ground-water withdrawals.

BAYTOWN-LA PORTE AREA

The Baytown-La Porte area is that part of Harris County east and southeast of the Pasadena area (fig. 2). Nearly all the wells in the Baytown-La Porte area are less than 600 feet deep and withdraw water from the "Alta Loma" sand of the Beaumont clay (Rose, 1943b; Petitt and Winslow, 1957). The "Alta Loma" sand is also the principal aquifer in Galveston County.

PUMPAGE

The average daily pumpage of ground water in the Baytown-La Porte area during the period 1928-56 is shown graphically in figure 25. Withdrawals of ground-water averaged about 25,000,000 gpd in 1955 and 28,000,000 gpd in 1956 and the average daily rate for the period 1950-56 was more than 24,000,000 gpd. Figure 26 shows the average daily use of surface water in the Baytown-La Porte area. Table 5 shows the average amount of ground water withdrawn by the different type of users.

Table 5.- Estimated average pumpage from wells in the Baytown-La Porte area, in million gallons per day, 1953-56

	1953	1954	1955	1956
Industries	17.8	15.2	17.7	18.0
Public supply	3.0	4.1	4.5	4.5
Rice irrigation	2.0	2.5	3.0	5.4
TOTAL	22.8	21.8	25.2	27.9

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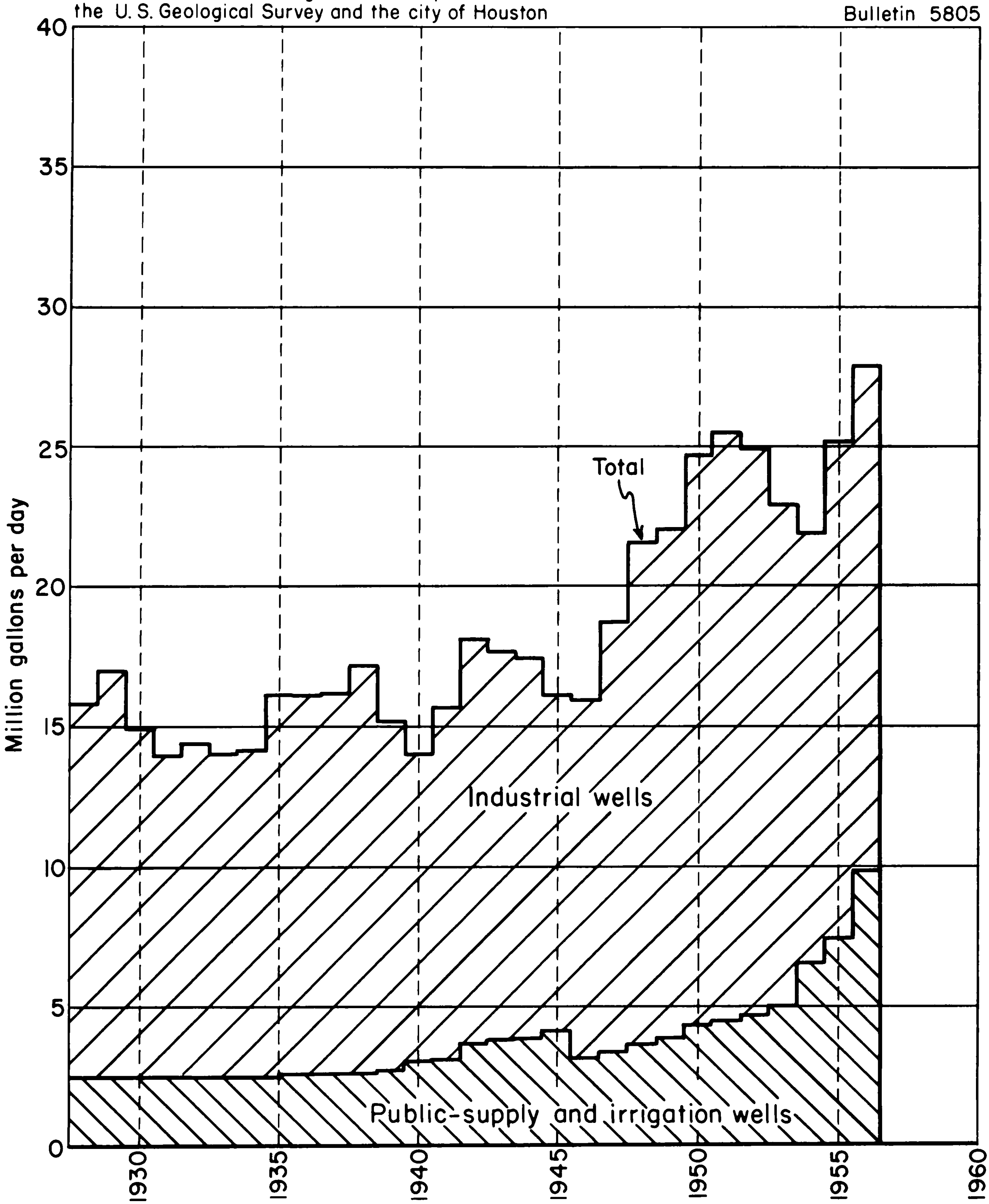

FIGURE 25.- Average daily pumpage of ground water in the Baytown - La Porte area, 1928-56.

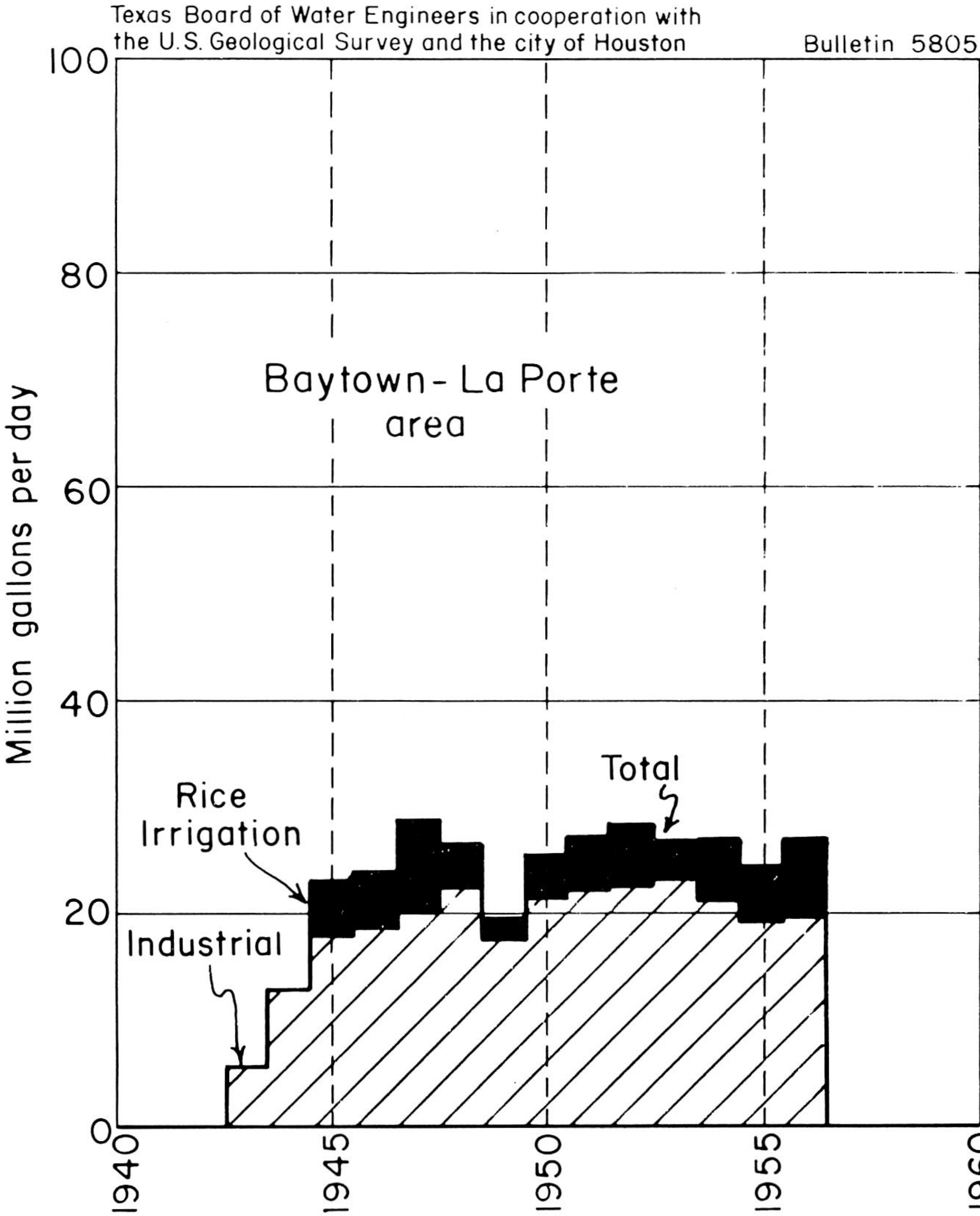

FIGURE 26.- Average daily use of surface water in the Baytown - La Porte area, Texas.

CHANGES IN WATER LEVELS IN WELLS

Figure 27 shows the fluctuations of water levels in two wells in the Baytown-La Porte area (Harris County wells 1067 and 1117). The hydrographs are based on spring measurements only and do not show seasonal variations, and because of no measurements in 1941, 1942, and 1943, do not show changes during those years. Both wells are screened in the "Alta Loma" sand and well 1067 is also screened in a shallower sand. Although the wells are more than 8 miles apart, the long-term rate of decline is about the same--slightly more than 5 feet per year.

The hydrograph of the shallow well in figure 17 is representative of changes in artesian head in the "Alta Loma" sand in the eastern part of the Pasadena area, south of the ship channel. Heavy pumping from wells in the "Alta Loma" sand in the Pasadena area is responsible for part of the decline of water levels in the Baytown-La Porte area.

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FIGURE 27. - Changes in water levels in the "Alta Loma" sand of the Beaumont clay in the Baytown - La Porte area, 1929 - 57.

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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.
1935	777	1946	1074
1937	840	1947	1099
1939	886	1948	1129
1940	909	1949	1159
1941	939	1950	1168
1942	947	1951	1194
1943	989	1952	1224
1944	1019	1953	1268
1945	1026	1954	1324
		1955	1407