TEXAS WATER DEVELOPMENT BOARD

REPORT 63

DEVELOPMENT OF GROUND WATER IN THE HOUSTON DISTRICT, TEXAS, 1961-65

By

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ABSTRACT

Total withdrawals of ground water in the Houston district increased from about 311 mgd (million gallons per day) in 1960 to about 421 mgd in 1965. Large increases in pumpage occurred in the Katy, Houston, and Pasadena areas. Pumpage increased only slightly in the Baytown-La Porte and Texas City areas and remained almost constant in the Alta Loma area.

Water-levels significantly declined throughout most of the Houston district. The area of maximum decline still is centered in the Pasadena area, where rate of decline is about 9.5 feet per year.

Chemical quality of ground water has changed most in the city of Galveston's "old" well field at Alta Loma. Chloride content is increasing steadily in water from the most southeasterly well in the field. The few increases noted in other areas in the district are small.

Subsidence of land surface continues as water levels decline. As much as 5 feet of subsidence has occurred in the Pasadena area in the period 1943-64. Rate of subsidence in the Pasadena area has been about 0.2 foot per year for the period 1954-64.

DEVELOPMENT OF GROUND WATER
IN THE HOUSTON DISTRICT, TEXAS, 1961-65

INTRODUCTION

Collection of data needed to define the ground-water resources in and around Houston was begun by U.S. Geological Survey on a more or less continuing basis about 1929. Data collection in the Houston district is part of a program of the Geological Survey's Water Resources Division to investigate and evaluate the nation's water resources. The present program of collection and dissemination of data is a cooperative effort by U.S. Geological Survey, Texas Water Development Board, and the cities of Houston and Galveston.

Many reports have been published on the geology and ground-water resources of the Houston district. Perhaps the most significant of these are the reports by Lang, Winslow, and White (1950); Petitt and Winslow (1955, 1957); and Wood and Gabrysch (1965). These sources were used extensively in preparation of this report.

The Houston district, as described in this report, includes all of Harris and Galveston Counties and parts of Chambers, Liberty, Montgomery, Waller, Fort Bend, and Brazoria Counties (Figure 1). Previous reports described the same areas, but the boundary of the Houston district was more restrictive because ground-water conditions in Galveston County were reported separately. Galveston County is now included in the Houston district because of the related effects of extensive ground-water development in southeastern Harris County.

The purpose of this report is to summarize the geology and hydrology of the Houston district, to update records of pumpage and water-level changes, and to present the most recent data on subsidence of land surface. The summary of general geology and hydrology is taken from previous reports. No attempt has been made to revise the previous interpretations, but recent reports on ground water in Orange County (Wesselman, 1965) and in Jasper and Newton Counties (Wesselman, 1967) and studies under way in Austin and Waller, San Jacinto, and Liberty Counties indicate that a revised interpretation of certain aspects of the ground-water geology of the Houston district may be required.

The author wishes to express his appreciation to the well drillers, industrial plant officials, municipal officials, and many well owners who contributed data used in this report. The cooperation and assistance of D. E. Van Buskirk, chief engineer of the city of Houston, greatly facilitated collection of data and preparation of this report.

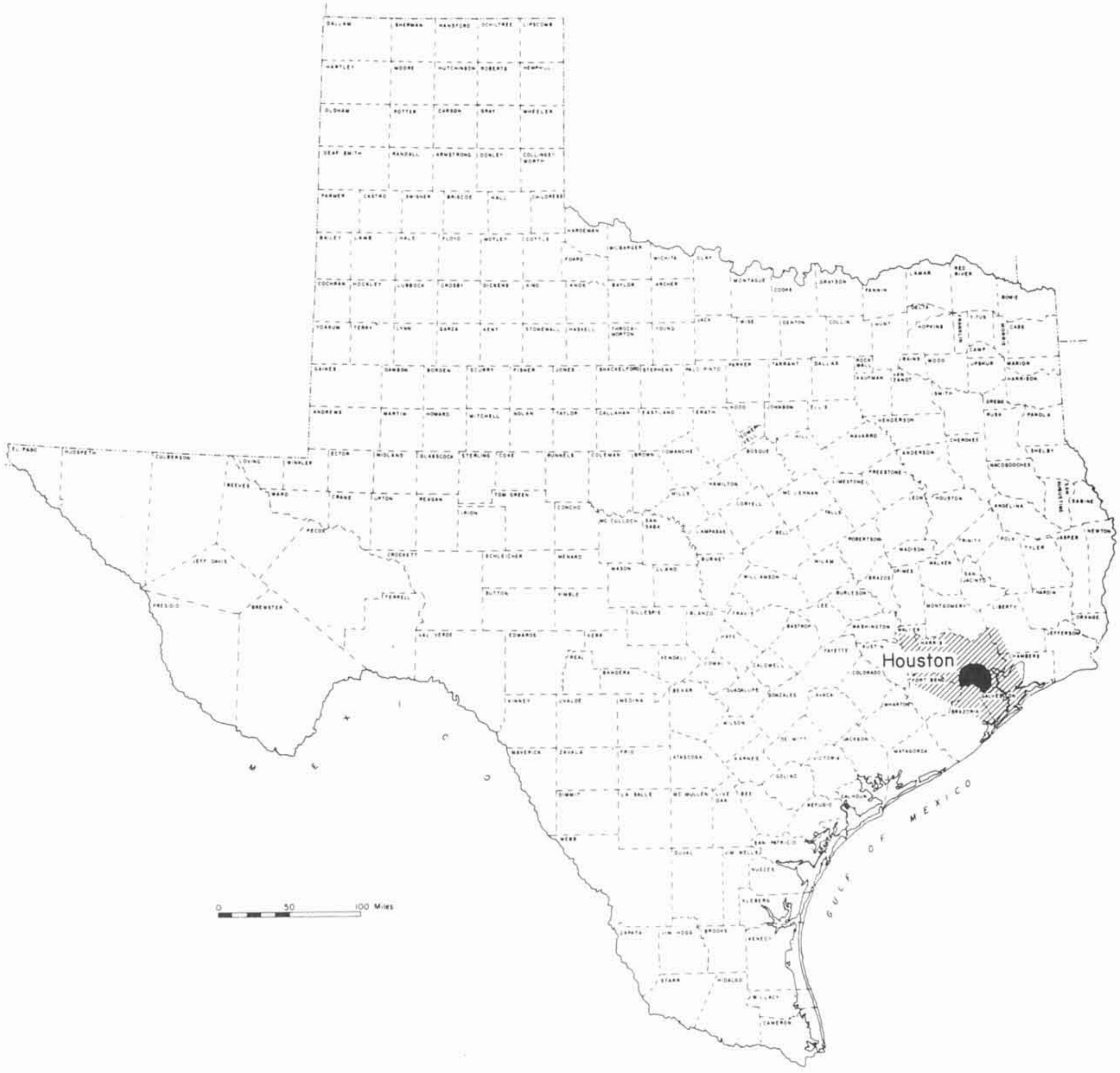

Figure 1

Index Map Showing Area of Report

U.S. Geological Survey in cooperation with the Texas Water Development Board and the cities of Houston and Galveston

GENERAL GEOLOGY AND HYDROLOGY

Aquifer System

The geology and hydrology of the Houston district have been described in detail by various authors. Wood and Gabrysch (1965, p. 7) described the general geology based on previous studies as follows:

> The formations from which the Houston district obtains its water supply are composed of sediments derived from older Tertiary and Cretaceous formations and consist of sand, gravel, silt, and clay. The formations were built up by rivers as coalescing fans on and near the continent and as marine and lagoonal deposits along the coast.
>
> The water-bearing formations in the Houston district are as follows, from oldest to youngest: The Catahoula Sandstone of Miocene(?) age, the Oakville Sandstone of Miocene age, the Lagarto Clay of Miocene(?) age, the Goliad Sand of Pliocene age, the Willis Sand of Pliocene(?) age, the Lissie Formation and Beaumont Clay of Pleistocene age, and the alluvium of Recent age.... The formations crop out in belts roughly parallel to the coast, the oldest formation farthest inland and each younger formation cropping out successively nearer the coast.... The estimated dip of the older beds is from 50 to 60 feet per mile and of the younger beds 15 to 20 feet per mile. All the formations thicken downdip so that the older formations dip more steeply than the younger ones. Localized structures, such as faults and salt domes, cause reversals of dip or thickening or thinning of beds. The faults may have several hundred feet of displacement in the older Tertiary formations, but the displacement tends to decrease toward the surface so that faulting generally is not apparent at the surface, and the fresh-water-bearing beds generally are not displaced enough to disrupt hydraulic connections.

The faults referred to above are deep-seated. Many small faults are in evidence in the Houston district, but they are likely shallow and may be a result of subsidence caused by ground-water extraction.

Because of their origin and method of deposition, the sand and clay beds underlying the Houston district are not persistent in lithology or thickness. The sand and clay beds grade into each other both laterally and vertically within short distances; consequently, differentiation of geologic formations on drillers' and electrical logs is almost impossible. However, White and others (1944, p. 146-147) and Lang and others (1950, p. 37) divided the aquifer system into 7 zones based on the predominance of sand or clay. Zone 2 is a clay zone that underlies the heavily-pumped part of the aquifer system in the Houston district. It contains some of the most continuous beds in the area but is probably not a completely confining layer.

The Alta Loma Sand of Rose (1943b), the major aquifer of Galveston County and southern Harris County, is an exception in that it can be traced in the subsurface for great distances. The Alta Loma Sand is massive and about twice as permeable as the underlying sands. It has been described as a basal sand of the Beaumont Clay, but recent work by Wesselman (1965) indicates that the Alta Loma Sand is older than the Beaumont and is equivalent to at least part of the Chicot aquifer as named in Louisiana.

In a study of the ground-water resources of Jasper and Newton Counties in the eastern part of the Gulf Coast region, Wesselman (1967) observed a marked difference in hydraulic properties (especially hydraulic head) between sands above and below a clay zone in the two-county area. Wesselman named the clay zone the Burkeville aquiclude. Based on studies in the Houston district, the Jasper-Newton study, an analog model study of the ground-water system of eastern Texas and western Louisiana, and investigations presently underway, stratigraphic zone 2 of the Houston district is probably equivalent to the Burkeville aquiclude.

The heavily pumped layer, as defined by Wood and Gabrysch (1965), is the thick sequence of interfingering sand and clay between the land surface and zone 2 in part of the Houston district, between the top screens in the large city of Houston water-production wells and zone 2 in part of the district, and between the base of the Alta Loma Sand and zone 2. The heavily pumped layer of the Houston district is probably equivalent to the Evangeline aquifer as named in Louisiana.

Source of Water

Approximately 45 inches of precipitation fall on the Houston district annually. About 11 inches run off into streams; most of the remaining 34 inches either evaporates or is transpired by plants. A small amount percolates downward to the water table and then toward the areas of ground-water withdrawal.

Rate of recharge to the aquifers in the Houston district is not known, but it probably is less than pumpage, which is equivalent to about 3 inches of precipitation over the entire district.

The sands underlying the Houston district contain water that is in transient storage. The water moves very slowly, on the order of 1 foot per day, from the areas of recharge to the areas of discharge.

The water in most of the aquifer is under artesian pressure even though the large withdrawals of water have lowered the pressure head to a great extent. There is no evidence that the sands themselves are being dewatered. Most of the water pumped probably comes from storage, either artesian or compaction. A small part of the water released from storage is due to expansion of the water, but more is due to elastic compression of the aquifer skeleton as the pressure is released.

DEVELOPMENT OF GROUND WATER IN THE HOUSTON DISTRICT

For discussion, the Houston district has been divided into areas on the basis of the concentration of pumpage and type of water use (Figures 2, 3, 4, 5, and 6).

Areas of major ground-water development outlined in this report are as follows: Houston, Pasadena, Katy, Baytown-La Porte, Texas City, and Alta Loma.

Records of pumpage of ground water in some cities in the Houston district date back to the late 19th century. Wood and Gabrysch (1965, p. 20) presented data in graphic form on pumpage of ground water from 1890 to 1960. Only the data on pumpage since 1960 are presented in this report. Tables 1, 2, and 3 show the amounts of ground water pumped in each of the areas within the district during the period 1960-65.

Before the beginning of heavy withdrawals of ground water in the Houston district, water pressure in the sands was generally much greater than it is now, and water would flow from many of the wells. Since development of large supplies of ground water, water levels have been lowered considerably. The amount of lowering is described by area.

Table 1.--Average pumpage of ground water in areas principally in Harris County, in million gallons per day.

Area	Use	1960	1961	1962	1963	1964	1965
Houston	Public Supply						
	City of Houston	78.1	83.1	96.3	105.2	109.4	115.7
	Suburban	10.7	9.8	10.6	12.4	12.9	13.6
	Industrial	9.1	8.1	8.4	7.8	8.2	8.1
	Irrigation	.5	.6	1.0	1.0	1.3	1.2
	Subtotal	98.4	101.6	116.3	126.4	131.8	138.6
Pasadena	Public Supply	8.6	8.8	10.0	11.0	10.7	11.5
	Industrial	70.0	75.1	73.1	72.9	79.2	82.4
	Irrigation	*	*	*	.1	.1	.1
	Subtotal	78.6	83.9	83.1	84.0	90.0	94.0
Katy	Public Supply	1.6	1.6	1.7	1.9	1.6	2.5
	Industrial	5.8	5.8	9.4	9.8	10.6	10.0
	Irrigation						
	Rice	80	89	141	136	128	126
	Other	.4	.4	.5	.7	.6	.6
	Subtotal	88	97	153	148	141	139
Baytown-La Porte	Public Supply	4.6	4.9	5.6	6.3	7.4	8.7
	Industrial	18.2	18.9	18.2	19.8	18.6	16.7
	Irrigation	.1	.1	.2	.2	.2	.1
	Subtotal	22.9	23.9	24.0	26.3	26.2	25.5
	TOTAL	288	306	376	385	389	397

*Less than 50,000 gpd.

Table 2.--Average pumpage of ground water in Galveston County, in million gallons per day.

Area	Use	1960	1961	1962	1963	1964	1965
Texas City	Public Supply	3.7	3.9	4.4	4.5	4.5	4.7
	Industrial	6.1	5.1	5.2	5.4	6.2	5.9
	Subtotal	9.8	9.0	9.6	9.9	10.7	10.6
Alta Loma	Public Supply	11.9	10.7	10.9	11.5	11.5	11.3
Miscellaneous Galveston County	Public Supply	1.4	1.5	1.5	1.6	1.8	1.9
	TOTAL	23.1	21.2	22.0	23.0	24.0	23.8

Table 3.--Average pumpage of ground water in the Houston district, in million gallons per day.

Use	1960	1961	1962	1963	1964	1965
Public Supply	121	124	141	154	160	170
Industrial	109	113	114	116	123	123
Irrigation	81	90	143	138	130	128
TOTAL	311	327	398	408	413	421

Records of water levels and water-level declines in a large part of the Houston district are based on measurements in wells that have multiple screens. The screened sands are likely to contain water under different pressure heads, so the measured water level is a composite of pressure heads of water in all sands screened. Because no observation well in the Houston district completely penetrates and screens the aquifer referred to as the heavily pumped layer, water-level measurements in a particular well represent the hydraulic head in only that part that is screened. The maps of altitudes of water levels in the heavily-pumped layer are regional approximations and may not be correct at any particular location or particular depth.

Water-level measurements in wells tapping the Alta Loma Sand are much more representative of the true pressure within the aquifer. Most wells producing water from the Alta Loma have only one or two screens because the formation is massive and contains little clay. It is likely that there is very good vertical hydraulic permeability within the formation.

Maps showing the altitudes of water levels in both the heavily-pumped layer and the Alta Loma Sand are given in Figures 3, 4, 5, and 6. Figures 3 and 5 show the altitudes of water levels in the early part of 1957, and Figures 4 and 6 show altitudes in the early part of 1966. Both sets of maps are presented so that regional water-level patterns can be compared after the latest 9 years of pumping.

Houston Area

The Houston area is in the central and south-central parts of Harris County (Figure 2) and consists of most of the city of Houston and closely adjoining territory. The Houston area, as designated in this report, is slightly larger than in previous reports. Because of the growth of the city of Houston, a small part of the area to the north and northwest has been included in the Houston area.

Pumpage

Pumpage in the Houston area is principally for municipal use, but minor amounts of ground water are furnished to small industries. The city of Houston is the largest single user of ground water in the district. Pumping by the city dates back to 1887 when the city purchased a private water-supply company. The demand for water then was only about 1 or 2 mgd (million gallons per day). The demand has grown steadily to about 142.3 mgd in 1965. Since 1954, however, part of the demand has been met by water furnished from Lake Houston. In 1954, pumpage from the ground was 72.5 mgd and pumpage from Lake Houston for municipal supply was 0.9 mgd. Average pumpage from Lake Houston for municipal use has remained almost constant between about 24 and 25 mgd since 1959. The increase in demands has been met by increasing draft from the ground. Even in 1960, more water was being pumped from the ground than just before the introduction of Lake Houston water. Pumpage from the ground in the Houston area in 1965 was 138.6 mgd (Table 1); 115.7 mgd was for the city of Houston.

Decline of Water Levels

A comparison of Figures 3 and 4 shows that the greatest decline of water levels (as much as 70 feet) during the past 9 years in the Houston area was in the eastern part. Much of the decline there is caused by pumpage in the heavily industrialized Pasadena area to the east. The lowest water level, 290 feet below sea level, is in the eastern part of the area. Localized cones of depression occur at most wells but are more pronounced at groups of wells where large quantities of ground water are pumped.

The history of water-level decline in the Houston area is demonstrated by the hydrographs of wells 602 and 619 (Figure 7). The hydrographs indicate a rate of decline of about 7 feet per year for the period before 1954. After 1954, the year of the introduction of water from Lake Houston, pumping of ground water was decreased and the city of Houston cut back pumping in the east and northeast parts of the area. This caused a reduction in the rate of water-level decline during the period 1954-59. However, growth of water usage soon overshadowed the supply from the lake and the rate of water-level decline in the Houston area has been about 5 feet per year in recent years.

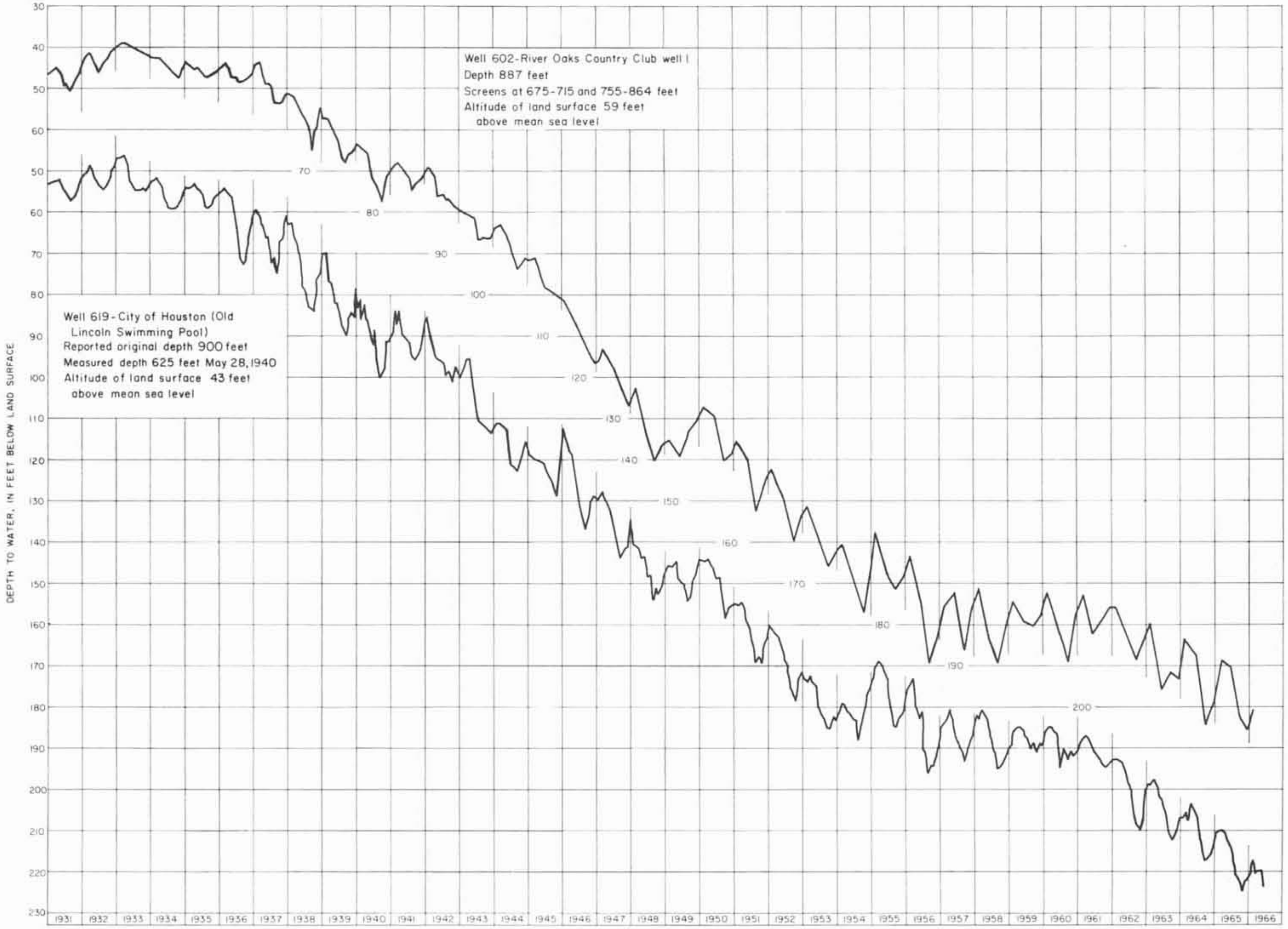

Figure 7

Changes in Water Levels in Wells in the Houston Area

U.S. Geological Survey in cooperation with the Texas Water Development Board and the cities of Houston and Galveston

Pasadena Area

The Pasadena area lies to the east of the Houston area and west of the San Jacinto River (Figure 2). It includes a heavily industrialized zone along the Houston Ship Channel. Large ground-water extractions began in the Pasadena area after 1937.

Pumpage

The principal use of water in the Pasadena area is industrial. Of about 154 mgd (surface and ground water) pumped in 1965 for all uses in the area, 142 mgd was for industrial use.

Before 1942, all water used in the area was pumped from the ground. Surface water from Lake Sheldon and the San Jacinto River was brought into the area in 1942, but the amount of surface water used was less than 20 mgd until Lake Houston was completed. In 1954, 83 mgd of ground water and 33 mgd of surface water was used in the area. In 1965, 94 mgd of ground water and 59.6 mgd of surface water was used. In 1965, the rate of ground-water pumping was 7 mgd more than before the introduction of water from Lake Houston.

Decline of Water Levels

The Pasadena area is the area of most heavily concentrated ground-water withdrawals in the district. Because of this, the area has the lowest water levels and the greatest rate of water-level decline. Figure 4 shows that the water level in the heavily-pumped layer early in 1966 was more than 330 feet below sea level in the center of the cone of depression. A composite hydrograph of water levels in wells 1170 and C-66 near the ship channel (Figure 8) indicates a rate of decline of about 14 feet per year from 1937 to 1953. The hydrograph also shows very clearly the rise in water levels as a result of the introduction of Lake Houston water in 1954. As soon as the supply from Lake Houston was exceeded by demand, more ground water was pumped than before and the hydrograph indicates a recent rate of water-level decline of almost 9 feet per year.

Figure 9 shows hydrographs of water levels in wells 1229 and 1230, which are screened in two different sands in the heavily-pumped layer. The center of concentrated withdrawals in the Pasadena area is several miles from these wells and the effect of changes in daily pumping is dampened by this distance. Seasonal patterns of pumping, however, are reflected in the water levels in the two wells.

The water level in the deeper sand is higher than in the shallower sand, but this relation between the water levels is normal in the heavily-pumped layer even though pumpage has lowered the water levels more than 300 feet from the original static level (water level before pumpage began). Rate of decline in the southern part of the Pasadena area, as indicated by these hydrographs, was about 13 feet per year before 1954. Since 1961, the rate of decline has been about 9.5 feet per year.

Pumping from the Alta Loma Sand has also caused large water-level declines in the Pasadena area. Figure 4 shows water levels to be as low as 270 feet below sea level in 1966. Figure 10 shows hydrographs of two wells completed in

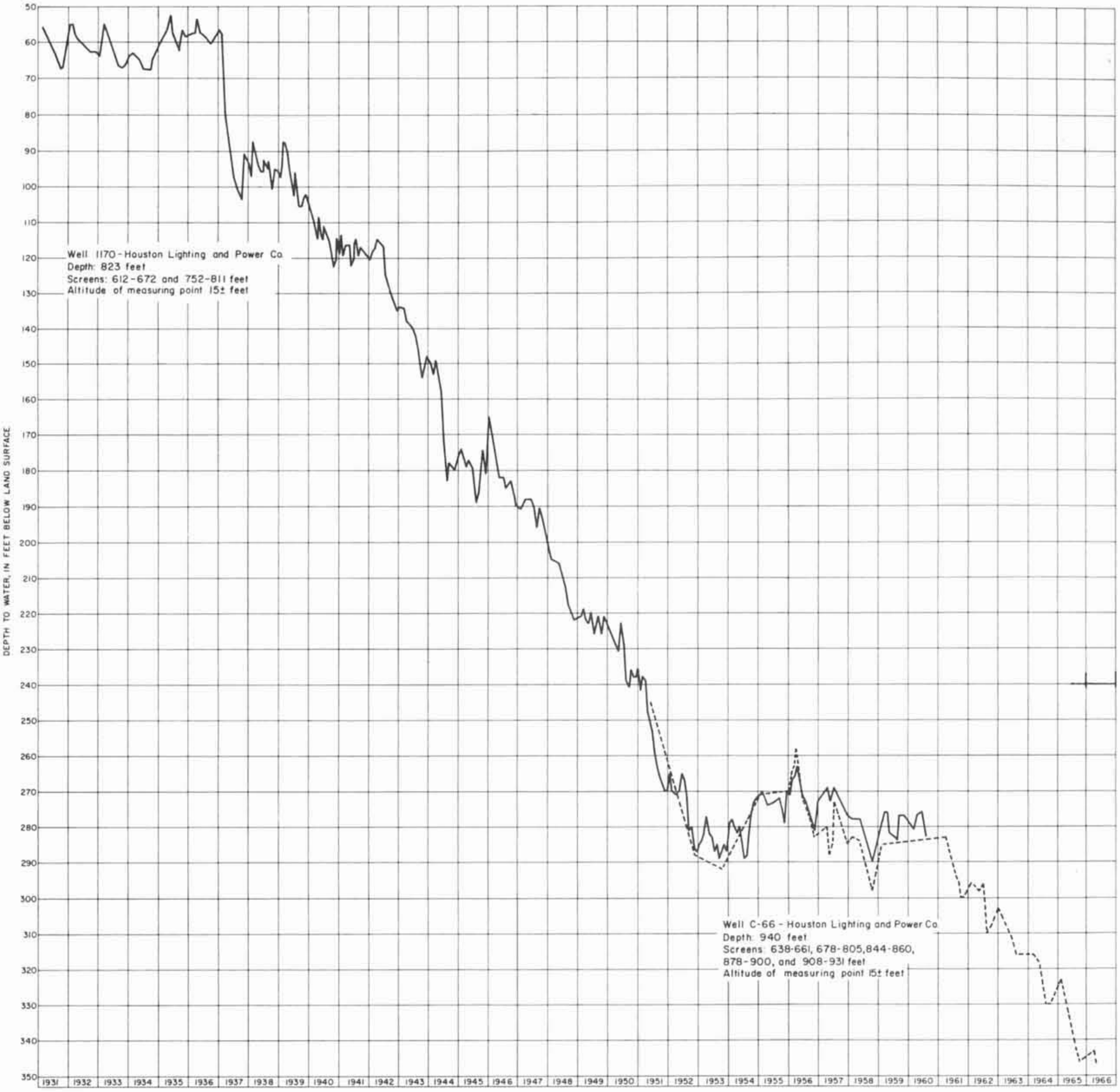

Figure 8

Changes in Water Levels in Harris County Wells 1170 and C-66

U. S. Geological Survey in cooperation with the Texas Water Development Board and the cities of Houston and Galveston

Figure 9

Changes in Water Levels in Two Single-Screened Deep Wells in the Southern Part of the Pasadena Area

U.S. Geological Survey in cooperation with the Texas Water Development Board and the cities of Houston and Galveston

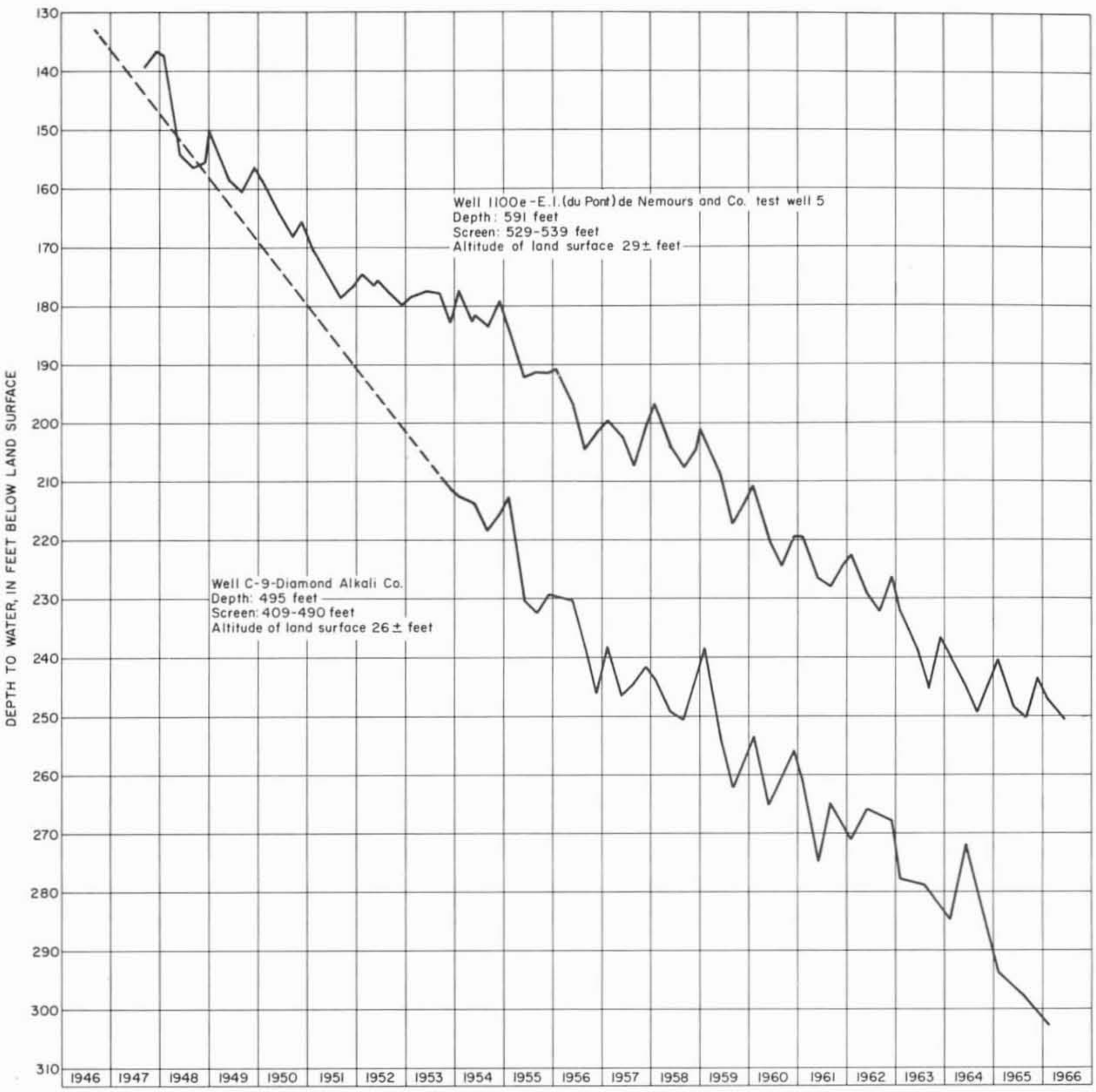

Figure 10

Changes in Water Levels in Wells Completed in the Alta Loma Sand of Rose (1943) in the Pasadena Area

U.S. Geological Survey in cooperation with the Texas Water Development Board and the cities of Houston and Galveston

the Alta Loma Sand. The hydrographs show an average rate of water-level decline of about 6-1/2 feet per year in recent years. The hydrographs do not show any effect on water levels resulting from supply from Lake Houston.

Katy Area

The Katy area is composed of much of the northern and western parts of Harris County, southeastern Waller County, and northern Fort Bend County (Figure 2). The area, which is principally agricultural, is the largest in the district.

Pumpage

All water used in the Katy area is pumped from the ground, and more than 95 percent of the water is used for the irrigation of rice. Pumping for rice irrigation began in the area in the 1890's; it increased gradually until about 1935 and then rapidly until 1954, when it was about 160 mgd. Acreage limitations imposed by the U.S. Department of Agriculture in 1955 caused a decline in the acreage of rice planted from 1955 until about 1960. Since 1960, the acreage planted has remained fairly constant. Fluctuations in water usage now mostly reflect climatic conditions, but recently it has become common practice to apply irrigation water after the first cutting of the rice to attempt to get a second crop. More water is used by this practice. Total acreage planted each year within the Katy area for the period 1960-65 based on records of the U.S. Department of Agriculture was as follows:

Year	Acreage
1960	52,153
1961	39,299
1962	45,453
1963	45,754
1964	46,206
1965	46,227

During the 1965 irrigation season, 330 well-yield and power-consumption tests were run on 96 wells in the Katy area. Total pumpage from the 96 wells was determined and, with figures for acreage planted, the average amount of water applied was computed to be 3.05 acre-feet per acre. This amount was multiplied by the entire acreage irrigated to obatin total usage for the area. Using records of precipitation, the irrigated acreage, and the results of the tests, estimates of pumpage for the years 1960 through 1966 were made.

Pumping for irrigation occurs during a period of about 150 days, but for comparison, the annual pumpage was divided by 365 days to obtain an average daily rate on a 12-month basis. Pumpage estimates for the years 1960-65 are part of Table 1.

Decline of Water Levels

Although the pumpage of ground water in the Katy area is greater than pumpage in any other area in the Houston district, the rate of water-level decline has been less than that in any other area. There are at least two principal reasons for the lesser rate of water-level decline:

1. The combination of hydraulic properties of the aquifer in the Katy area is more favorable for ground-water withdrawal than elsewhere in the district. The coefficient of storage, even though still in the artesian range, is greater than in the other areas. Therefore, larger amounts of water can be withdrawn with lesser decline of pressure. The permeability of the sands in the area is also greater than the permeability of sands of the heavily-pumped layer in the other areas. The permeability in the Katy area is not, however, greater than that of the Alta Loma Sand but the transmissibility is greater. Thus, because of the greater capacity to transmit water, the declines are less.

2. Pumping in the Katy area is not as concentrated as in other areas of the district. Each well can furnish enough water for the irrigation of large plots of land, therefore the wells are generally spaced so that they cause only minor interference.

Figure 11 illustrates the decline of water levels in the Katy area. The hydrographs of the water levels indicate a nearly steady decline of about 1.5 feet per year.

Baytown-La Porte Area

The Baytown-La Porte area extends from the eastern edge of the Pasadena area eastward to the Chambers County line and southward to the Galveston County line (Figure 2). It contains the cities of Baytown and La Porte. Recently, the National Aeronautics and Space Administration established the Manned Spacecraft Center in the southern part of the area.

Pumpage

Ground-water pumpage in the Baytown-La Porte area is about 65 percent industrial and 34 percent municipal. Large-scale withdrawals of ground water for industrial use began about 1919. Pumpage averaged about 5 mgd in 1919 but averaged 25.5 mgd in 1965 (Table 1). Practically all withdrawals in the area are from the Alta Loma Sand.

Decline of Water Levels

Very little data on water levels and water-level declines in the heavily-pumped layer of the Houston district are available in the Baytown-La Porte area because practically all development of ground water is from the Alta Loma Sand. Water-level decline in the heavily-pumped layer is due to pumping to the west of Baytown. Figure 5 shows that the Baytown-La Porte area is on the east and southeast side of the cone of depression in the Alta Loma Sand. Figure 12, a hydrograph of water levels in well 1117, shows that the rate of water-level decline in the Alta Loma Sand has been about 5 feet per year.

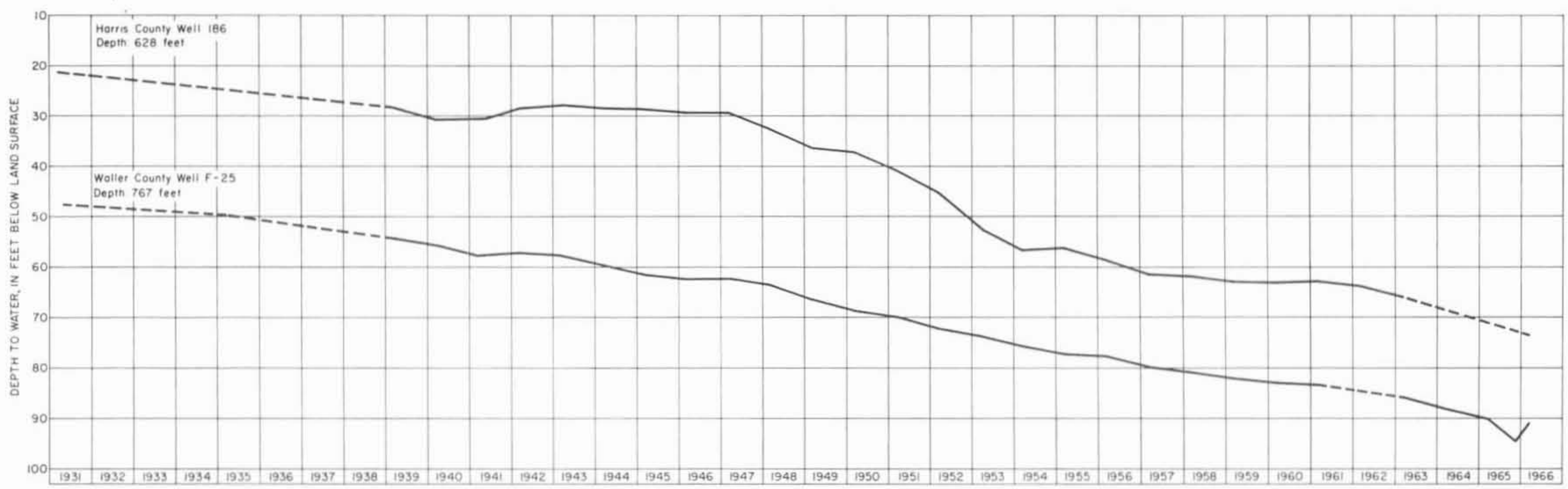

Figure 11

Changes in Water Levels in Wells in the Katy Area

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Figure 12

Changes in Water Levels in a Well Completed in the Alta Loma Sand of Rose (1943) in the Baytown - La Porte Area

U.S. Geological Survey in cooperation with the Texas Water Development Board and the cities of Houston and Galveston

Texas City Area

The Texas City area is in the southeastern part of Galveston County (Figure 2). It includes the cities of Texas City and La Marque and adjoining area. The economy of the area is industrial. The aquifers in the area are the Alta Loma Sand and the sands above the Alta Loma.

Pumpage

Pumpage in the Texas City area was about 2 mgd in 1930. It increased to about 11 mgd in 1940, and to about 24 mgd in 1944 and 1945. In 1948, surface water from the Brazos River was brought into the area, and the use of ground water decreased. Ground-water pumpage averaged about 10 mgd from 1950 to 1965. During 1944 and 1945, about 70 percent of the ground water was extracted from the Alta Loma Sand. Since then, 50 percent or more of the water was extracted from the sands above the Alta Loma. In 1965, 60 percent of the 10.6 mgd of water pumped in the area came from the upper sands.

Decline of Water Levels

Water levels in wells completed in the Alta Loma Sand in the Texas City area declined rapidly between 1940 and 1945 as shown by the hydrograph of water levels in well F-50 (Figure 13). The declines were less rapid between 1945 and 1948, and water levels recovered between 1948 and 1951. Recovery was due to decreased ground-water pumpage resulting from the use of surface water from the Brazos River. Between 1951 and 1958, water levels remained fairly constant but since 1958 water levels have declined at the rate of about 2 feet per year.

Hydrographs of water levels in well F-42 (Figure 13) in Texas City and M-15, southwest of Texas City, show about the same pattern of decline as does the hydrograph of well F-50. Both wells F-42 and M-15 are completed in sands above the Alta Loma.

Alta Loma Area

The Alta Loma area is in the west-central part of Galveston County about 18 miles northwest of the city of Galveston (Figure 2). The town of Alta Loma and the city of Galveston well fields are in this area.

Pumpage

The city of Galveston began pumping water from a well field at Alta Loma as early as 1894. Pumpage in the area increased slowly from about 2 mgd in 1896 to about 5 mgd in 1937. Between 1937 and 1944, pumpage increased to about 13 mgd. It remained at about 13 mgd until 1949, then decreased to about 11 mgd in 1950. Pumpage has fluctuated between 10.6 and 12.9 mgd since that time; in 1965, it was about 11.3 mgd.

The city of Galveston has been the only major developer of ground water in the Alta Loma area. Before 1964, the town of Alta Loma purchased water from the city of Galveston, but in 1964 Alta Loma drilled a well for its supply.

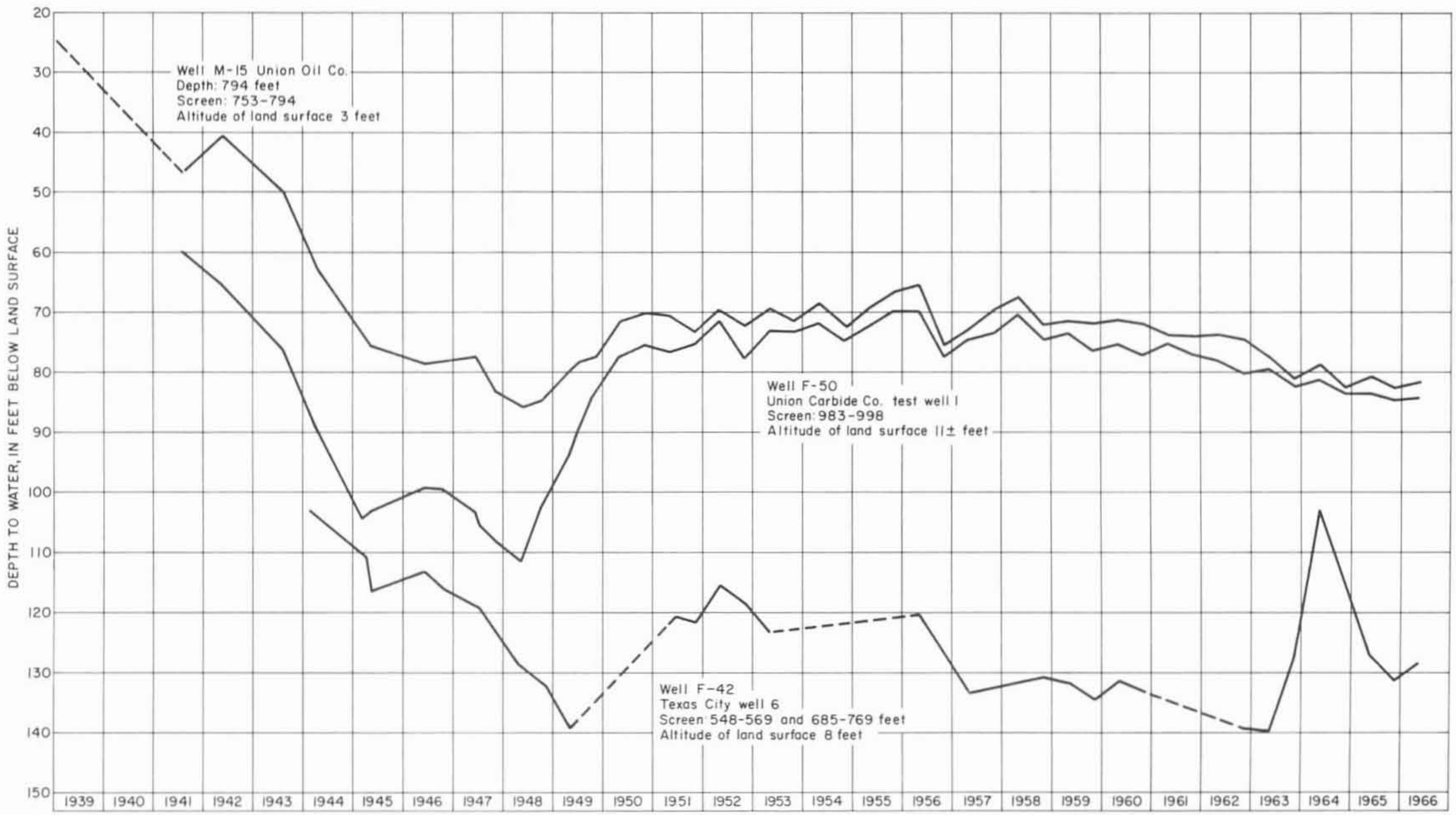

Figure 13

Changes in Water Levels in Wells in the Texas City Area

U.S. Geological Survey in cooperation with the Texas Water Development Board and the cities of Houston and Galveston

All major wells in the area are completed exclusively in the Alta Loma Sand except the well owned by the town of Alta Loma, which is completed in both the Alta Loma Sand and in sands above.

Decline of Water Levels

The increase in pumpage from 5 to 13 mgd between 1937 and 1944 caused water levels to decline rapidly until about 1948. Figure 14, the hydrograph of the water level in well E-93, shows an average rate of decline between 1943 and 1948 of about 8.5 feet per year. Since 1948, the rate of decline has varied in accordance with pumping patterns in the area; from 1961 to 1966, the rate was about 2 feet per year. Figure 6 shows that the water level in the Alta Loma Sand is about 130 feet below sea level in the deepest part of the cone of depression in the Alta Loma area.

CHEMICAL QUALITY OF GROUND WATER

In general, ground water of good chemical quality can be obtained in most of the Houston district. Sands containing fresh water are present at greater depths in the Houston area than elsewhere in the district. Electrical logs and test holes indicate that practically no fresh water occurs in subsurface sands along the coast.

In reference to the general quality of ground water in the district, Lang, Winslow, and White (1950, p. 48) state..."The shallow aquifers as a rule contain calcium bicarbonate type waters that are hard, whereas the deep aquifers contain sodium bicarbonate type waters that are soft. Waters from these aquifers contain only moderate amounts of mineral matter." Several reports have presented maps of the approximate base of fresh water in the district. The latest map of the base of fresh to slightly saline water prepared by U.S. Geological Survey appears as Plate 5 in the report by Wood, Gabrysch, and Marvin (1963). Analyses of water from many wells in the district are presented in the report by White, Rose, and Guyton (1944) and Petitt and Winslow (1955). The reader is referred to these and more recent publications for more specific information on quality of water.

The fresh water-salt water interface in the sands of the heavily-pumped layer lies along a line approximately parallel to the coastline in the southern part of Harris County. In the Alta Loma Sand, the interface is probably along a line between Alta Loma and Texas City. The lower part of the Alta Loma Sand at Texas City and at Alta Loma contains more highly mineralized water than does the upper part. There are not enough monitoring points in either the Alta Loma Sand or the heavily-pumped layer to determine the exact location of the interfaces or the rate of updip movement of the saline water toward the centers of the cones of depression.

Figure 15 shows the chloride content and total alkalinity of water in two single-screen wells in Pasadena southeast of Houston (Figure 2). Well 1229 is screened from 1,661 to 1,676 feet, and well 1230 is screened from 1,399 to 1,414 feet. Chloride content in water from both wells has increased during the period of record; however, the increase in the shallower well has been greater. Water from well 1229, the deeper well, had a chloride content of about 285 ppm

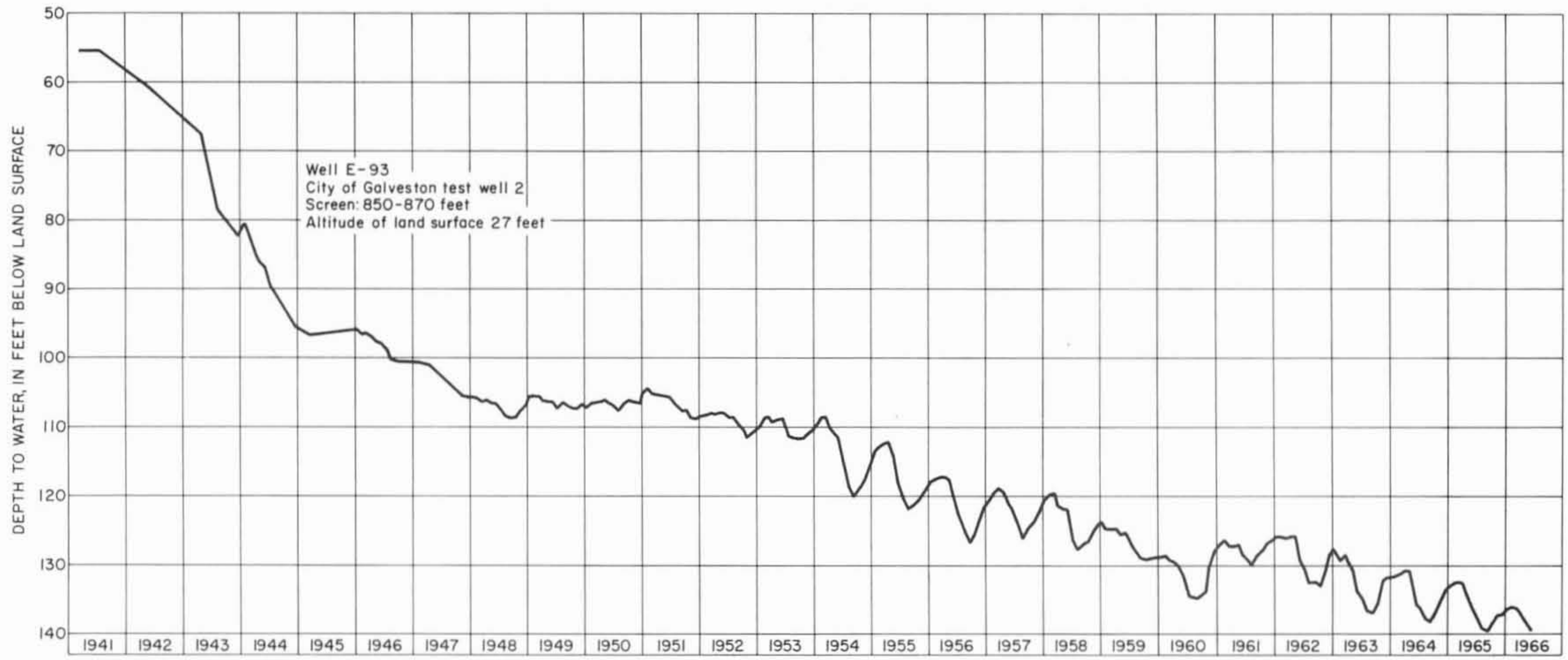

Figure 14

Changes in Water Levels in Well E-93 in the Alta Loma Area

U. S. Geological Survey in cooperation with the Texas Water Development Board and the cities of Houston and Galveston

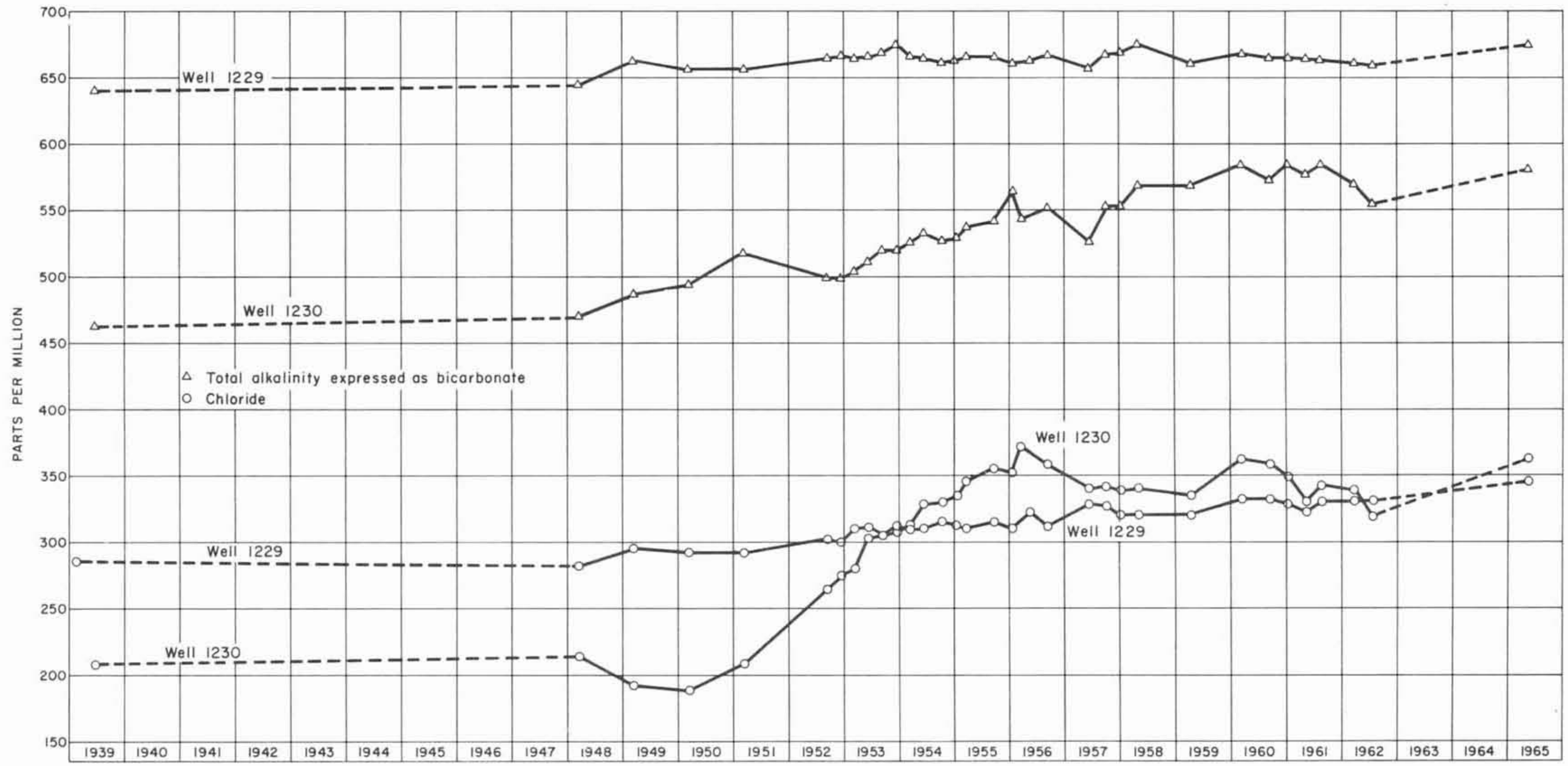

Figure 15

Chloride Content and Total Alkalinity of Water from Harris County Wells 1229 and 1230 in Pasadena

U. S. Geological Survey in cooperation with the Texas Water Development Board and the cities of Houston and Galveston

(parts per million) when drilled in 1939, and water from well 1230 had a chloride content of about 208 ppm. In 1965, water from the deeper well had about 345 ppm of chloride while water from the shallower well had about 365 ppm.

Total alkalinity in water from well 1229 has increased from about 640 ppm to about 675 ppm, while alkalinity in water from well 1230 has increased from about 465 ppm to about 580 ppm since 1939. From 1960 to 1965, however, there was practically no increase in total alkalinity in water from either well.

Figure 16 shows the increase in chloride in water from the city of Galveston's "old" well field at Alta Loma. These graphs show that the chemical quality of water from the Alta Loma Sand has deteriorated considerably since 1934. The chloride content in water from city well 8 (L-68), the most southeasterly well, has continued to increase steadily. Wide fluctuations in chloride content of the water can be accounted for principally by changes in pumpage patterns. The fluctuations are also related to locations of the individual wells in respect to presence of absence of a discontinuous clay bed separating the main body of the Alta Loma Sand from an underlying sand containing water that is more saline.

Figure 17 shows that chloride content of water from wells in the "new" well field north of Alta Loma has remained nearly constant since about 1945, with the major exception of water from well 10 (E-78). Increased mineralization at well 10 can be explained by its location in respect to the cone of depression at the "new" field. Wood (1958b, p. 18) indicated that the chloride content of water in the Alta Loma Sand becomes progressively higher west of the well field. This is substantiated by the higher concentration of chloride in water from well 14 (E-92) on the west side of the field. Well 10 (E-78) is on the northwest side of the cone of depression caused by pumping at Alta Loma; therefore, the more highly mineralized water moving toward the cone of depression from the northwest would reach well 10 before reaching any other wells.

Figure 18 shows the changes in chloride content of water from wells in the Alta Loma Sand and from sands above the Alta Loma at Texas City. The decrease in chloride concentration from about 1,080 ppm in 1953 to 970 ppm in 1966 in water from well M-37 is probably due to the decrease in pumping from the sand in the area. There has been no significant increase in chloride concentration in water from sands above the Alta Loma at Texas City, as indicated by Figure 18 (well M-36).

Because salt-water encroachment is an ever-present threat to ground-water supplies in coastal areas, care should be exercised in developing well fields. Fortunately, the movement of water in sands is slow. With proper monitoring points, it would be possible to determine location of the interface of fresh water and salt water and to estimate rate of movement of the salt water. Adequate monitoring points are not available, however, and much needs to be done on the problem of salt-water encroachment in the Houston district.

SUBSIDENCE OF LAND SURFACE

Subsidence of land surface has occurred in most of the Houston district. Locally, subsidence may be due in part to the extraction of oil and gas; regionally, however, the principal cause of subsidence is lowering of the pressure head by ground-water pumping.

Figure 16

Changes in Chloride Content of Water from Wells in the City of Galveston's "Old" Well Field in the Vicinity of Alta Loma

U.S. Geological Survey in cooperation with the Texas Water Development Board and the cities of Houston and Galveston

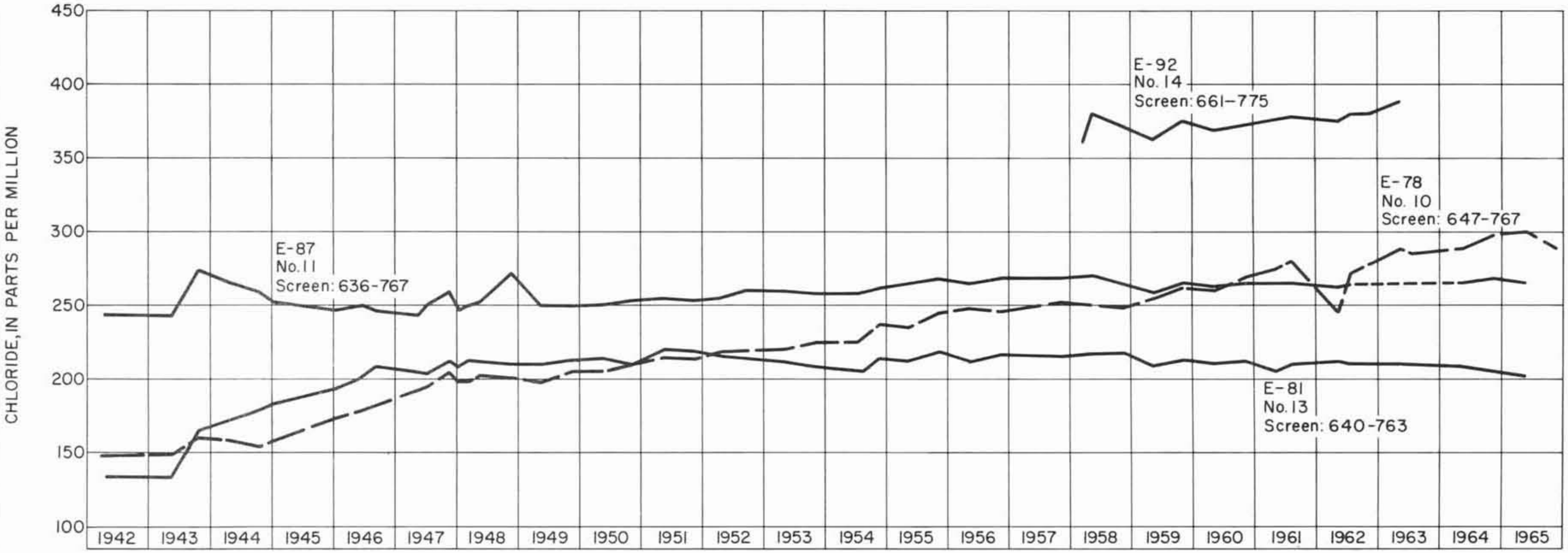

Figure 17

Changes in Chloride Content of Water from Wells in the City of Galveston's "New" Well Field North of Alta Loma

U.S. Geological Survey in cooperation with the Texas Water Development Board and the cities of Houston and Galveston

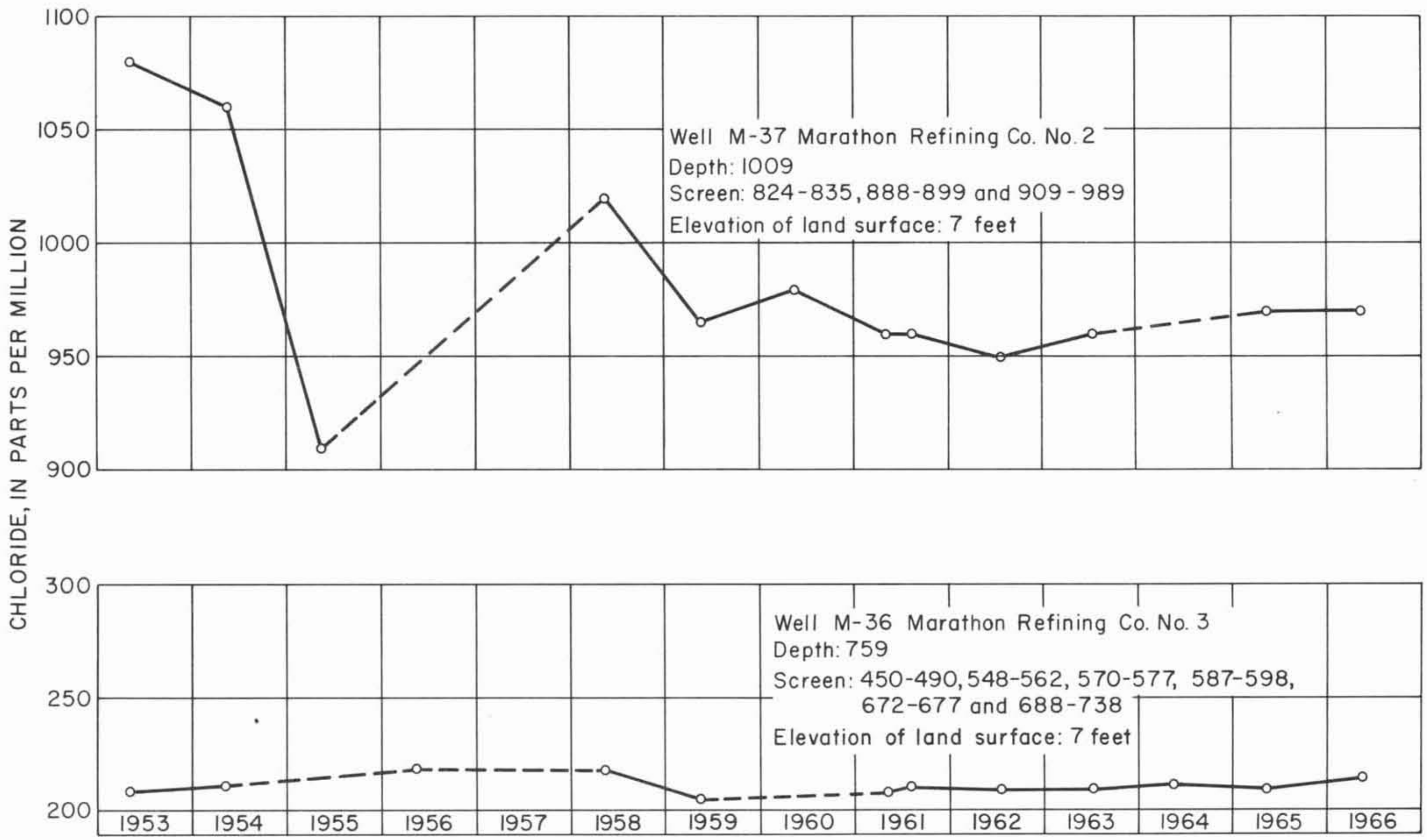

Figure 18

Changes in Chloride Content of Water from Wells in the Texas City Area

U.S. Geological Survey in cooperation with the Texas Water Development Board and the cities of Houston and Galveston

Hydraulic or artesian pressure in the ground-water system partially supports the weight of the overburden. With reduction in pressure, an additional load is transferrred to the skeleton of the aquifer. The lowering of pressure in the sands creates a pressure difference between the sands and clays, forcing water to move from the clays to the sands. The entire process tends to compact the saturated material, with most of the compaction taking place in the clays.

Figure 19 shows the extent of subsidence in the Houston district during the period 1943-64 based on releveling by the U.S. Coast and Geodetic Survey. The locations of areas of maximum subsidence, the Texas City area, the Pasadena area, and the Baytown-La Porte area are also the areas of major water-level decline. Relation between amount of subsidence and water-level decline ranges from less than 0.5 foot subsidence per 100 feet of water-level decline in the Katy area to about 1.3 feet per 100 feet in the Pasadena area. The difference can probably be attributed to variations in the amount of clay present in the zone affected by pressure decline, as the Katy area is underlain by a greater percentage of sand.

Between 1943 and 1964, the maximum subsidence, based on U.S. Coast and Geodetic Survey releveling data, has been in the Pasadena area, where as much as 5 feet occurred just north of the Houston Ship Channel. Leveling by private industries indicate that the subsidence at Texas City has been greater than that shown on Figure 19, possibly about 8 feet.

Maximum rate of subsidence has been about 0.2 foot per year for each of two periods of releveling, 1954-59 and 1959-64. Even though there have been fluctuations in the rate of water-level decline, the subsidence rates apparently have not been affected. There seems to be a substantial lag in the time between water-level decline and subsidence. It is likely that compaction and subsidence will continue for some time after any stabilization of water levels.

SUMMARY

Withdrawal of ground water in the Houston district increased from about 311 mgd in 1960 to about 421 mgd in 1965. In the Texas City area of Galveston County and the Baytown-La Porte area of Harris County, ground-water withdrawals increased only slightly. Large increases in the pumping rate were noted in the Houston, Pasadena, and Katy areas during the 1960-65 period. Population growth in the Houston area and increased use by industry in the Pasadena area accounted for most of the increase in ground-water pumping. Subnormal rainfall and double cropping of rice accounted for a large increase in ground-water use in the Katy area.

Water levels continue to decline throughout the district. The largest decline has occurred in the Pasadena area; the smallest decline is in the Alta Loma area where pumping is nearly stabilized.

Salt-water encroachment has caused significant changes in chemical quality in the city of Galveston's "old" well field at Alta Loma; lesser changes were noted in Harris County. Significant changes also may be occurring in the quality of water in the southeastern part of Harris County, but monitoring points are not available for verification.

Subsidence is continuing throughout most of the Houston district. The greatest amount of subsidence (about 5 feet), based on U.S. Coast and Geodetic Survey releveling data, has occurred in the Pasadena area where the land surface subsided at the rate of about 0.2 foot per year during the 1954-64 period.

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