TEXAS DEPARTMENT OF WATER RESOURCES

REPORT 241

DEVELOPMENT OF GROUND WATER IN THE HOUSTON DISTRICT, TEXAS, 1970-74

By

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U.S. Geological Survey

This report was prepared by the U.S. Geological Survey under cooperative agreement with the Texas Department of Water Resources and the Cities of Houston and Galveston

January 1980

Published and distributed
by the
Texas Department of Water Resources
Post Office Box 13087
Austin, Texas 78711

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ABSTRACT

Total withdrawals of ground water in the Houston district increased 9 percent from about 488 million gallons per day (21.4 cubic meters per second) in 1970 to about 532 million gallons per day (23.3 cubic meters per second) in 1974. The average annual rate of increase from 1960 to 1969 was about 6.3 percent. During 1970-74, increases in pumpage occurred in the Houston, Katy, and NASA areas; decreases occurred in the Pasadena and Alta Loma areas; and the pumpage in the Baytown-La Porte and Texas City areas remained almost constant.

Water levels continued to decline throughout the district during 1970-74, but the rate of decline generally was not as great as in previous years. The greatest declines in the past several years were in the Houston area, but the center of decline is still in the Pasadena and Baytown-La Porte areas. The decrease in the rate of decline suggests that the aquifers in the Houston district could support the amount of pumping during 1970-74 with little, if any, further decline. Although salt-water encroachment has probably occurred in the district, particularly in Galveston County, no large increases in chloride were measured at the monitoring points.

DEVELOPMENT OF GROUND WATER IN THE HOUSTON DISTRICT, TEXAS, 1970-74

INTRODUCTION

Collection of data to define the ground-water resources in and around Houston, Texas, was begun by the U.S. Geological Survey about 1929. The present project of collection and dissemination of data is a cooperative program by the U.S. Geological Survey, the Texas Department of Water Resources, and the cities of Houston and Galveston. The purpose of this report is to update the published data on ground-water development in the Houston district.

The description of the ground-water hydrology of the district has changed with time as additional information from the data-collection and analysis program has been obtained. The construction of and analyses based on two analog models of the aquifers underlying the Houston district (Wood and Gabrysch, 1965, and Jorgensen, 1975), as well as studies of land-surface subsidence and salt-water encroachment, have greatly facilitated the understanding of the ground-water system.

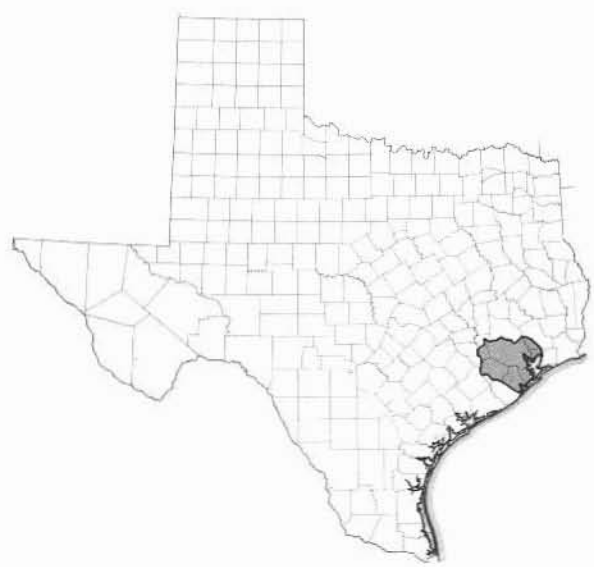

Figure 1.—Index Map Showing Area of Report

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 in this program described the same areas, but the 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.

For those readers interested in using the metric system, the metric equivalents of English units of measurements are given in parentheses. The English units used in this report may be converted to metric units by the following factors:

From	Multiply by	To obtain
acre-feet	0.001233	cubic hectometers (hm^3)
feet	.3048	meters (m)
million gallons per day (million gal/d)	.04381	cubic meters per second (m^3/s)

The author expresses his appreciation to the well drillers, industrial plant officials, municipal officials, and many well owners who contributed data used in this report.

AQUIFERS

Numerous reports on the ground-water hydrology of the Houston district have described the aquifers by using an interpretation of the subsurface geology. The reports have consistently stated that the structure and stratigraphy is very complex, and that delineation of the aquifers is extremely difficult. The first attempt to model the ground-water system in the early 1960's (Wood and Gabrysch, 1965) was partly successful, but probably the greatest benefit obtained from the first model was to develop a different approach to the analysis of the aquifers. Much more emphasis was placed on ground-water hydraulics, and as a result, the ground-water system was divided into two major aquifers, the Chicot and Evangeline, which are underlain by the Burkeville confining layer that is composed principally of clay. A second analog model (Jorgensen, 1975), which represents the system as presently defined, is much more adequate than the earlier model.

Table 1 shows the relationship between the aquifers and the geologic and hydrologic units as used in previous reports on the Houston district. The maps showing the bases of the Chicot and Evangeline aquifers were prepared by John Wesselman of the U.S. Geological Survey and presented in the report on the second analog model (Jorgensen, 1975, Figures 4 and 7). However, because of the importance of these maps to the analysis of ground-water development in the district, they are reproduced in this report as Figures 2 and 3.

A hydrogeologic section from Montgomery County to Galveston County (Jorgensen, 1975, Figure 3) is also presented as Figure 4 in this report to provide a better visual concept of the delineation of the aquifers. The Jasper aquifer as shown on Figure 4 is not used for water supply in the Houston district and will not be discussed in this report.

The Evangeline aquifer is the major source of ground water in the Houston district, but in Galveston County and southern Harris County, the Chicot aquifer is the major source of ground water because in these areas the Evangeline contains saline water.

The Alta Loma Sand of Rose (1943; hereafter referred to as the Alta Loma Sand) is the basal sand of the Chicot aquifer in some parts of the district. The Alta Loma Sand is the primary source of water in the Chicot aquifer except in the Texas City area. At Texas City, sand and gravel lenses in the middle part of the Chicot are the important sources of water, and the Alta Loma Sand contains highly mineralized water.

DEVELOPMENT OF GROUND WATER

The major areas of ground-water development discussed in this report are the Houston, Pasadena, Katy, Baytown-La Porte, NASA, Texas City, and Alta Loma areas (Figure 5). The history of development of ground water has been presented by Wood and Gabrysch (1965), Gabrysch (1972), and Jorgensen (1975).

Pumpage of ground water in the Houston district for 1970-74 is presented in Tables 2, 3, and 4. The altitudes of water levels in wells in the Chicot and Evangeline aquifers in the Spring of 1975 are shown on Figures 6 and 7. The maximum altitude below sea level of the water levels in 1975 in wells completed in the Chicot and Evangeline aquifers (Figures 6 and 7) were 290 feet (88 m) and 400 feet (122 m), respectively.

Figures 8 and 9 show the declines in water levels for the 10-year period from the Spring of 1965 to the Spring of 1975. The maximum declines in water levels in the Chicot and Evangeline aquifers during 1965-75 were 80 feet (24 m) and 130 feet (40 m), respectively (Figures 8 and 9).

Houston Area

The Houston area, which is in the central and south-central parts of Harris County, consists of most of the City of Houston and the closely adjoining areas (Figure 5).

Pumpage

Pumpage in the Houston area is principally for municipal supply, but minor amounts of ground water are used by small industries. Most of the pumpage is from the Evangeline aquifer. In 1970, ground-water pumping in the area was 170.7 million gal/d (7.5 m^3/s); pumping by the City of Houston was 141.7 million gal/d (6.2 m^3/s). The City of Houston also used 52.9 million gal/d (2.3 m^3/s) of treated water from Lake Houston in 1970.

Pumping of ground water in the area increased about 25.2 million gal/d (1.1 m^3/s) to 195.9 million gal/d (8.6 m^3/s) in 1971 and then decreased to about 189.6 million gal/d (8.3 m^3/s) in 1974. The average rate of increase in ground-water pumping between 1970 and 1974 was about 2 percent per year; however, there was nearly a 15-percent increase from 1970 to 1971, and except for 1973, there were decreases in other years. During 1970-74, surface-water usage by the City of Houston increased from 52.9 million gal/d (2.3 m^3/s) to 69.9 million gal/d (3.1 m^3/s); the total usage of water increased by an average of about 3 percent per year.

Table 1.--Geologic and hydrologic units used in this report and in reports on nearby areas

This report: System	This report: Series	This report: Stratigraphic unit	This report: Aquifer	Wood and Gabrysch (1965): Houston district	Sandeen and Wesselman (1973): Brazoria County	Wilson (1967): Austin and Waller Counties	Popkin (1971): Montgomery County	Lang, Winslow, and White (1950): Houston district	Petitt and Winslow (1957): Galveston County	Wesselman (1971): Chambers and Jefferson Counties	Anders and others (1968): Liberty County	Wessleman (1972): Fort Bend County
Quaternary	Holocene	Quaternary alluvium	Chicot aquifer: Upper unit	Confining layer and Alta Loma Sand of Rose (1943)	Chicot aquifer: Upper unit	Alluvium of the Brazos River	Chicot aquifer	Alluvial deposits	Beach and dune sand	Chicot aquifer: Upper unit	Chicot aquifer	Chicot aquifer: Upper unit
	Pleistocene	Beaumont Clay				Evangeline aquifer (May contain unidentifiable parts of basal Chicot aquifer along the edges of Brazos River flood plain or along southern part of both counties)		Beaumont Clay	Beaumont Clay			
		Montgomery Formation	Chicot aquifer: Lower unit		Chicot aquifer: Lower unit			"Alta Loma Sand"	"Alta Loma Sand"	Chicot aquifer: Lower unit		Chicot aquifer: Lower unit
		Bentley Formation										
		Willis Sand						Zone 7 Zone 6	Lissie Formation			
Tertiary	Pliocene	Goliad Sand	Evangeline aquifer	Heavily pumped layer	Evangeline aquifer		Evangeline aquifer	Zone 5		Evangeline aquifer	Evangeline aquifer	Evangeline aquifer
	Miocene	Fleming Formation	Burkeville confining layer	Zone 2		Burkeville aquiclude	Burkeville aquiclude			Burkeville aquiclude	Burkeville aquiclude	Burkeville aquiclude
			Jasper aquifer: Upper unit			Jasper aquifer	Jasper aquifer: Upper part of Jasper	Zone 4 Zone 3		Jasper aquifer	Jasper aquifer	Jasper aquifer
			Jasper aquifer: Lower unit				Jasper aquifer: Lower part of Jasper	Zone 2 Zone 1				

Table 2.—Average Pumpage of Ground Water in Areas Principally in Harris County, in Million Gallons Per Day

Area	Use	1970	1971	1972	1973	1974
Houston	Public supply:					
	City of Houston	141.7	158.7	163.5	156.1	156.6
	Surburban	18.3	23.9	19.6	21.6	23.4
	Industrial	9.6	12.4	10.6	10.3	9.0
	Irrigation	1.1	.9	.8	.6	.6
	Subtotal	170.7	195.9	194.5	188.6	189.6
Pasadena	Public supply	14.1	14.2	15.4	16.2	15.3
	Industrial	107.0	106.1	104.0	100.0	97.0
	Irrigation	.1	.1	.1	.1	.0
	Subtotal	121.2	120.4	119.5	116.3	112.3
Katy	Public supply	3.1	3.6	5.0	6.6	8.9
	Industrial	9.4	9.4	10.8	9.6	11.0
	Irrigation:					
	Rice farming	106.1	110.3	109.8	95.5	130.6
	Other	.4	.5	.3	.3	.2
	Subtotal	119.0	123.8	125.9	112.0	150.7
Baytown-La Porte	Public supply	7.0	7.3	7.9	8.0	8.3
	Industrial	21.0	21.1	23.9	22.3	19.7
	Subtotal	28.0	28.4	31.8	30.3	28.0
NASA	Public supply	5.6	5.7	6.4	6.2	6.4
	Industrial	9.1	8.9	11.9	12.4	13.7
	Irrigation	.9	.1	.1	.1	.1
	Subtotal	15.6	14.7	18.4	18.7	20.2
Other Harris County areas	Public supply	—	1.6	2.3	2.5	3.0
	Irrigation	3.0	2.1	2.2	.9	2.6
	Subtotal	3.0	3.7	4.5	3.4	5.6
Total (rounded)		458	487	495	469	506

Decline of Water Levels

Water levels in wells completed in the Chicot aquifer declined as much as 50 feet (15 m) between 1965 and 1975 (Figure 8), and water levels declined as much as 130 feet (40 m) in wells completed in the Evangeline aquifer (Figure 9). The rates of decline ranged from less than 2 feet (0.6 m) per year in the Chicot aquifer in the northeastern part of the area to about 5 feet (1.5 m) per year in the central part of the area. Water levels declined from less than 4 feet (1.2 m) per year in the Evangeline aquifer in the extreme southern part of the area to about 13 feet (4 m) per year in the western part of the area.

The history of water-level declines in the Houston area since 1950 is shown by the hydrographs on Figure 10. The rate of decline of the water level in well LJ-65-13-927 was about 7 feet (2.1 m) per year between 1965 and 1970. Since 1970, the water level in this well has been

Table 3.—Average Pumpage of Ground Water in Galveston County, in Million Gallons Per Day

Area	Use	1970	1971	1972	1973	1974
Texas City	Public supply	7.1	7.2	6.8	7.0	7.0
	Industrial	6.5	8.3	7.6	6.5	6.2
	Subtotal	13.6	15.5	14.4	13.5	13.2
Alta Loma	Public supply	11.9	12.5	13.0	10.2	6.8
Other Galveston County areas	Public supply and industrial	4.6	5.2	5.0	6.0	5.9
Total (rounded)		30	33	32	30	26

Table 4.—Average Pumpage of Ground Water in the Houston District, in Million Gallons Per Day

Use	1970	1971	1972	1973	1974
Public supply[1]	211	237	242	237	239
Industrial	165	169	171	164	159
Irrigation	112	114	113	98	134
Total (rounded)	488	520	526	499	532

[1] Other Galveston County pumpage from Table 3 is equally divided between public supply and industrial use.

declining at a lesser rate; the water level in 1976 was almost the same as in 1972. The rate of decline of the water level in well LJ-65-21-402 was about 9.9 feet (3.0 m) per year between 1965 and 1973 but only about 3.6 feet (1.1 m) per year between 1973 and 1976.

Pasadena Area

The Pasadena area, which is east of the Houston area and mostly west of the San Jacinto River (Figure 5), includes a heavily industrialized zone along the Houston Ship Channel. Large ground-water withdrawals began in the Pasadena area after 1937.

Pumpage

The principal use of water in the Pasadena area is industrial. Of about 190 million gal/d (8.3 m^3/s) of both surface water and ground water used in 1974 for all purposes, 174.7 million gal/d (7.7 m^3/s) was for industrial use.

The use of surface water in the Pasadena area has increased, and the use of ground water has decreased. In 1970, the use of surface water from Lake Houston was 74.4 million gal/d (3.3 m^3/s), while ground-water pumping was 121.2 million gal/d (5.3 m^3/s). In 1974, the use of surface water was 77.7 million gal/d (3.4 m^3/s), which was an increase of about 4 percent; ground-water pumping was

112.3 million gal/d ($4.9\ m^3/s$), or a decrease of about 7 percent. The decrease (about 9 percent) in water usage for industrial purposes (Table 2) was probably due to recycling of available supplies.

Decline of Water Levels

Water levels in wells completed in the Chicot aquifer in the Pasadena area declined as much as 50 feet (15 m) between 1965 and 1975 (Figure 8), while water levels in wells in the Evangeline aquifer declined as much as 100 feet (30 m) (Figure 9). The average rates of decline in the Chicot and Evangeline aquifers ranged from less than 2 feet (0.6 m) per year to 5 feet (1.5 m) per year, and about 6 feet (1.8 m) per year to about 11 feet (3.4 m) per year, respectively. However, the hydrographs of water levels in two wells shown on Figure 11 are a better presentation of the historical decline since 1951.

The water level in well LJ-65-23-220 declined about 25 feet (8 m) between 1965 and 1968, remained almost constant between 1968 and 1972, declined about 10 feet (3.0 m) in 1972, and has remained almost constant from 1972 to 1976. The water level in well LJ-65-23-219, completed in the upper part of the Evangeline aquifer, has a similar pattern. The water level declined about 50 feet

Figure 11.—Hydrographs Showing Changes in Water Levels in Wells in the Pasadena Area

(15 m) from 1965 to 1967, declined about 5 feet (1.5 m) between 1967 and 1971, declined about 33 feet (10 m) between 1971 and 1973, and remained almost constant between 1973 and 1976.

Figure 12 shows the hydrograph of water levels in well LJ-65-23-805, which is screened in a single sand unit in the Evangeline aquifer. Although there is no ground-water development near this well, the effects of pumping elsewhere in the area are reflected in the water levels. The rate of decline as shown by the hydrograph (Figure 12) was 10.4 feet (3.2 m) per year from 1961 to 1969, 6.2 feet (1.9 m) per year from 1969 to 1971, and 3.2 feet (1.0 m) per year from 1971 to 1976. The decrease in the rate of decline in water levels in the late 1960's and early 1970's reflects the decrease in ground-water pumping in the Pasadena area.

Katy Area

The Katy area includes much of the northern and western parts of Harris County, southeastern Waller County, and the northern part of Fort Bend County (Figure 5). This area, which is mostly agricultural, is the largest area in the Houston district.

Pumpage

All water used in the Katy area is ground water, and more than 90 percent of the water is used for the irrigation of rice. Estimates of the amount of water used for rice irrigation are based on the amount of water pumped per acre and the total acreage in cultivation. The amount of water pumped per acre was estimated from the results of tests using selected wells.

The yield of water per unit of power consumption was determined for each of the selected wells two or three times during the irrigation season. The average yield per unit of power times the total power used for the irrigation season provides a good estimate of the total pumpage. The number of acres planted in rice each year was obtained from the allotment records of the U.S. Department of Agriculture. The acreage planted and the estimated pumpage for 1966-74 are given in Table 5.

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. Estimates of pumpage for 1970-74 are given in Table 2.

Table 5.—Katy Area Rice Acreage and Ground-Water Pumpage

Year	Acreage	Pumpage (acre-feet per acre)	Total pumpage (acre-feet)
1966	55,131	2.12	116,878
1967	57,606	3.09	178,003
1968	67,426	2.44	164,519
1969	60,827	2.62	159,367
1970	48,508	2.45	118,845
1971	46,791	2.64	123,528
1972	48,797	2.52	122,968
1973	53,486	2.00	106,972
1974	55,426	2.64	146,325

Decline of Water Levels

Water-level declines in the Chicot and the Evangeline aquifers in the Katy area ranged from less than 2 feet to as much as 4 feet (0.6 to 1.2 m) and from 1 foot to more than 6 feet (0.3 to 1.8 m) per year between 1965 and 1975, respectively (Figures 8 and 9). Although pumping in the Katy area was greater than in any other area, the rate of water-level decline was less. There are at least two principal reasons for the lesser rate of water-level decline:

1. Hydraulic properties of the aquifer in the Katy area are more favorable for ground-water withdrawal with less decline in the water level than elsewhere in the district. The coefficient of storage, even though still in the artesian range, is greater than in the other areas; therefore, large amounts of water can be withdrawn with less decline in artesian pressure. The hydraulic conductivities of the sands in the Evangeline and Chicot aquifers in the Katy area are also greater than in the other areas. Because of the greater capacity to transmit water, the water-level 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 and short-term mutual interference.

Figure 13 illustrates the declines of water levels in the Katy area. Well LJ-65-03-705 is completed in the Chicot aquifer, and wells LJ-65-03-502 and LJ-65-10-902 are completed in both the Chicot and Evangeline aquifers. The rate of decline in well LJ-65-03-705 was about 2.6 feet (0.8 m) per year before 1970, and 0.3 foot (0.1 m) per year between 1970 and 1974. The rate of decline in well LJ-65-03-502 was about 2.0 feet (0.6 m) per year before 1972, and about 1.3 feet (0.4 m) per year from 1972 to 1976. Except for

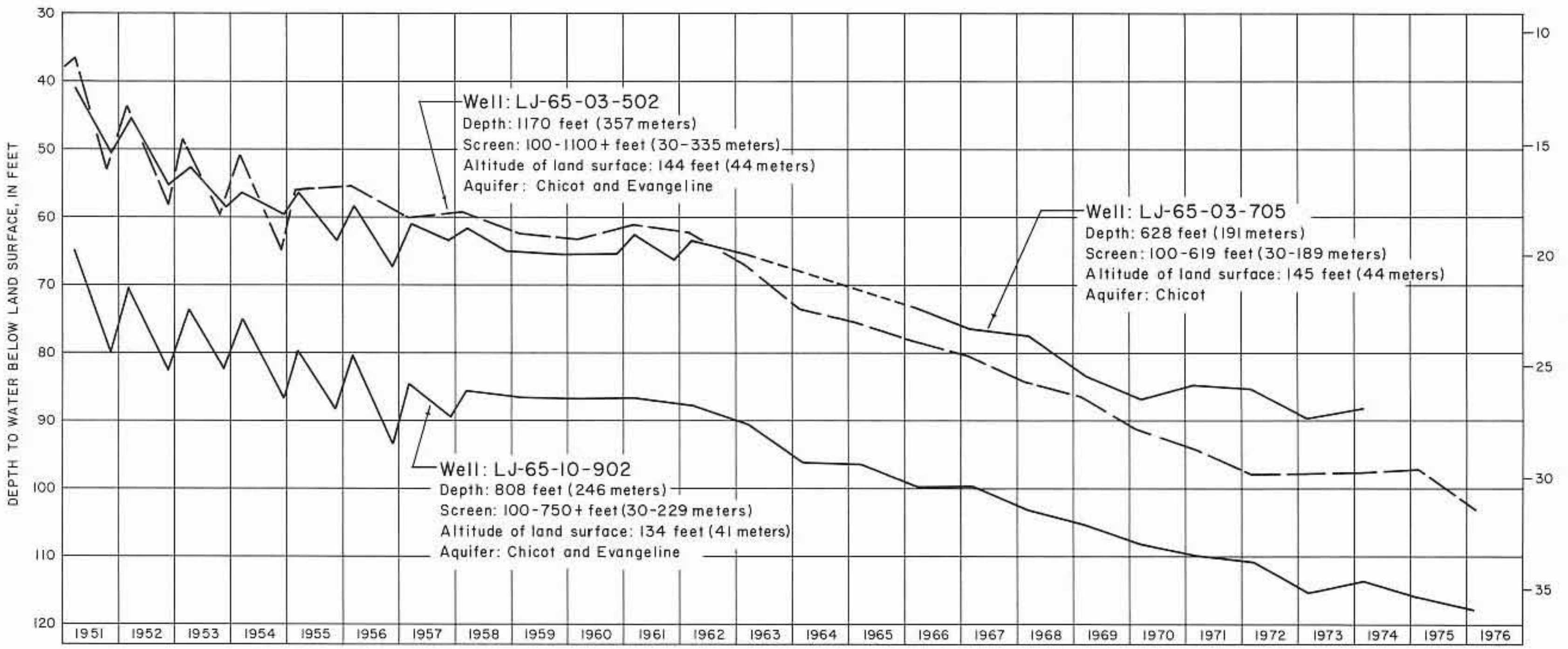

Figure 13

Hydrographs Showing Changes in Water Levels in Wells in the Katy Area short-term differences, the rate of decline in well LJ-65-10-902 has remained at about 2.2 feet (0.7 m) per year since about 1963. No observation wells are available that are completed only in the Evangeline aquifer; therefore, water levels and changes in water levels in the Evangeline can only be inferred.

Because of the large amount of sand in the aquifer units in the subsurface, the degree of hydraulic continuity is probably greater in the Katy area than anywhere else in the Houston district. Wells in the area are usually completed in both the Chicot and Evangeline, which allows ground-water flow between the aquifers and artesian pressures to generally equalize.

Baytown-La Porte Area

The Baytown-La Porte area extends eastward from the Pasadena area to the Chambers County line (Figure 5). Previously, the area was delineated southward to the Galveston County line; however, extensive ground-water development in the southern part of the area has necessitated a division into two parts. For purposes of discussion, the northern part is now called the Baytown-La Porte area and the southern part is called the NASA (National Aeronautics and Space Administration) area. Records have been reworked, and pumpage has been distributed to show separate development in the two areas since 1960.

Pumpage

Ground-water pumping in the Baytown-La Porte area is principally from the Alta Loma Sand, which is the basal sand of the Chicot aquifer. In 1974, about 70 percent of the ground water pumped was for industrial use and 30 percent was for municipal supply. Pumping of ground water from the area in 1974 was 28 million gal/d (1.2 m^3/s), which was the same as in 1970.

Decline of Water Levels

Water levels in wells in the Baytown-La Porte area have declined since 1965 and before. As much as 80 feet (24 m) of decline has occurred in wells completed in the Chicot aquifer (Figure 8), and as much as 100 feet (30 m) of decline has occurred in wells completed in the Evangeline aquifer (Figure 9) during 1965-75. The decline in water levels in wells in the Evangeline aquifer is due principally to pumping to the west of the Baytown-La Porte area. Water levels in wells in the Chicot and Evangeline aquifers are as much as 290 feet (88 m) and as much as 350 feet (107 m) below sea level, respectively (Figures 6 and 7).

The hydrograph of water levels in well LJ-65-24-501 (Figure 14) shows an increasing rate of decline between 1968 and 1973. A rise in water levels has occurred since 1973, and in February 1976 the water level was about 6 feet (1.8 m) higher than in February 1973. The slight recovery in water levels is probably due to the decrease in pumping in 1973 and 1974 from the peak rate in 1972 (Table 2).

NASA Area

The NASA area is bounded on the north by the Baytown-La Porte area, on the west by the Pasadena and Houston areas, on the south by Galveston County, and on the east by Galveston Bay (Figure 5). The NASA area was previously included as part of the Baytown-La Porte area, but because of the increased ground-water development, beginning in 1962 with construction of the Johnson Space Center of the National Aeronautics and Space Administration, the area is now considered separately.

Pumpage

Pumpage of ground water for 1970-74 is given in Table 2. All pumping for public supply, which has gradually increased from 5.6 million gal/d (0.25 m^3/s) in 1970 to 6.4 million gal/d (0.28 m^3/s) in 1974, is from the Alta Loma Sand. Pumping for industrial use, which has increased from 9.1 million gal/d (0.40 m^3/s) in 1970 to 13.7 million gal/d (0.60 m^3/s) in 1974, is from both the Evangeline and Chicot aquifers. Total pumping in the area has increased from 15.6 million gal/d (0.68 m^3/s) in 1970 to 20.2 million gal/d (0.88 m^3/s) in 1974. The increase has been at a rate of about 6 percent per year.

Decline of Water Levels

Water levels in wells completed in the Alta Loma Sand in the NASA area have declined as much as 80 feet (24 m) between 1965 and 1975 (Figure 8). Although observation wells are not available to provide positive data, the approximate decline in water levels in the Evangeline aquifer ranged from less than 40 to about 70 feet (12 to 21 m) during 1965-75 (Figure 9). The depth to water in wells in the Alta Loma Sand ranged from about 170 to about 260 feet (52 to 79 m) below sea level in 1975 (Figure 6). The depths to water in the Evangeline aquifer is estimated to range from 150 to more than 300 feet (46 to 91 m) below sea level.

Figure 15 is a hydrograph of water levels in well LJ-65-32-406. The graph shows a decline in water levels

Figure 14

Hydrograph Showing Changes in Water Levels in a Well Completed in the Alta Loma Sand in the Baytown-LaPorte Area

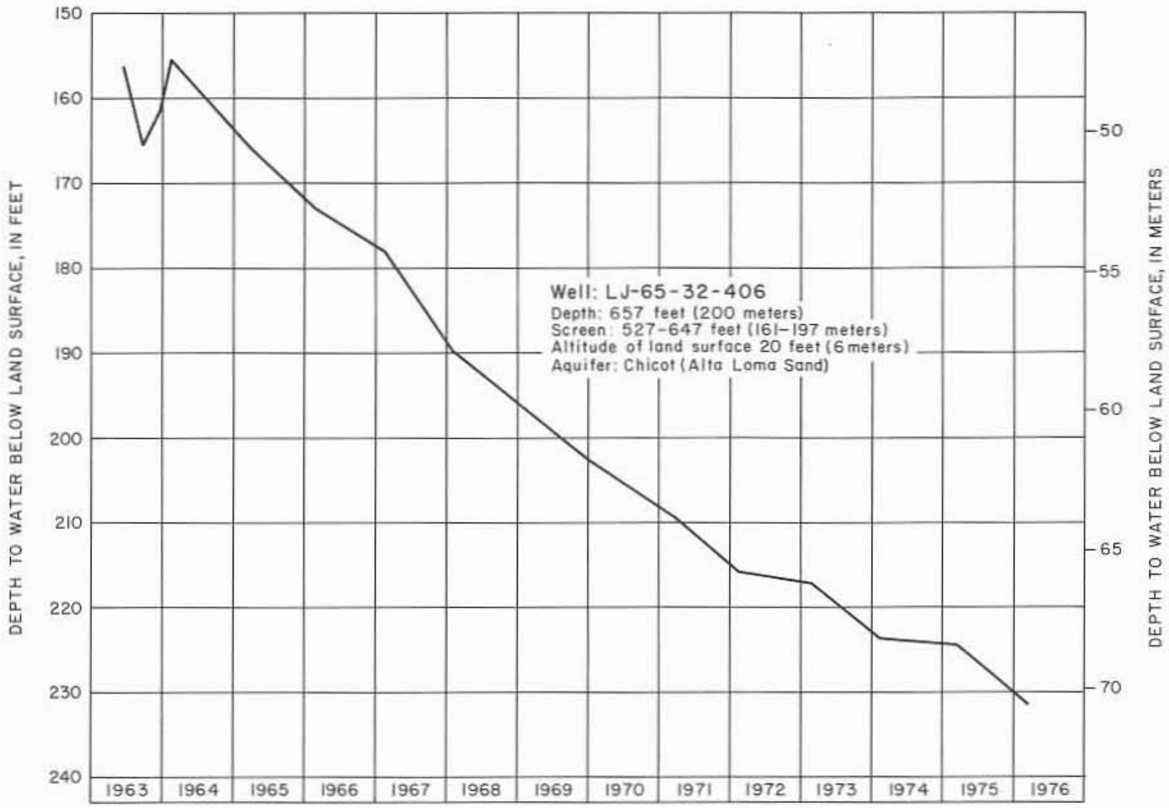

Figure 15.—Hydrograph Showing Changes in Water Levels in a Well Completed in the Alta Loma Sand in the NASA Area

of 61 feet (18.6 m) between February 1964 and February 1972, which indicates a rate of 7.6 feet (2.3 m) per year. Between February 1972 and March 1976, the water level declined about 15.5 feet (4.7 m), or at a rate of about 4 feet (1.2 m) per year. Although pumping has increased in the NASA area, the decrease in the rate of water-level decline probably reflects the regional pumping pattern.

Texas City Area

The Texas City area, which is in the southeastern part of Galveston County (Figure 5), includes the Cities of Texas City and La Marque and the adjoining areas. The economy of the area is industrial.

Pumpage

Pumping of ground water in the Texas City area is mostly from sands in the middle part of the Chicot aquifer. In this area, the Alta Loma Sand contains water that is more highly mineralized than in adjacent areas, which restricts its use for most purposes. Pumping for public supply remained almost constant for 1970-74 (Table 3) at about 7 million gal/d (0.31 m^3/s). Pumping for industrial use fluctuated between a low of 6.2 million gal/d (0.27 m^3/s) in 1974 to a high of 8.3 million gal/d (0.36 m^3/s) in 1971.

The total rate of pumping in the area in 1974 was 13.2 million gal/d (0.58 m^3/s); however, this represents a decrease of about 45 percent from the 1948 pumping rate of 24 million gal/d (1.05 m^3/s). In 1948, surface water was imported into the area to help meet industrial demands. In 1952, 10 million gal/d (0.44 m^3/s) of ground water was pumped in the area.

Decline of Water Levels

Water levels in wells completed in the Alta Loma Sand have declined as much as 20 feet (6.1 m) between 1965 and 1975 (Figure 8). Much of the decline has been caused by regional pumping outside the Texas City area, and possibly by leakage into the overlying sands within the Chicot aquifer. The potentiometric surface in the Evangeline aquifer has also declined, principally due to pumping in other areas. The estimated potentiometric surface in the Evangeline in the Texas City area is about 90 feet (27 m) below sea level (Figure 7).

Figure 16 shows hydrographs of water levels in two wells completed in the Chicot aquifer. Well KH-64-33-903 is completed in sands in the middle part of the Chicot aquifer, and well KH-64-33-805 is completed in the Alta Loma Sand. Water levels in wells completed in the middle sands are significantly lower than water levels in wells completed in the Alta Loma Sand because most of the ground water pumped in the area is pumped from the middle sands.

The decline in water levels in the Texas City area shows the same pattern as elsewhere in the Houston district. A much greater rate of decline occurred prior to 1970 than has occurred since 1970. The average rate of decline in well KH-64-33-805 was about 2.6 feet (0.8 m) per year from 1961 to 1970 and about 0.6 foot (0.2 m) per year from 1970 to 1976. In well KH-64-33-903, the average rate of decline was about 8 feet (2.4 m) per year from 1964 to 1971. From 1970 to November 1972, the water level rose about 19 feet (5.8 m) and then declined about 8 feet (2.4 m) from November 1972 to April 1975.

Alta Loma Area

The Alta Loma area, which contains the well fields for the town of Alta Loma and the City of Galveston, is in the west-central part of Galveston County (Figure 5).

Pumpage

All pumping in the Alta Loma area is for public supply, mostly for use by the City of Galveston, and nearly all the ground water is obtained from the Alta Loma Sand. Data from Gabrysch (1972) show that pumping remained almost constant from 1960 through 1970. Pumping increased from 11.9 million gal/d (0.52 m^3/s) in 1970 to 13.0 million gal/d (0.57 m^3/s) in 1972, then decreased to 10.2 million gal/d (0.45 m^3/s) in 1973 and 6.8 million gal/d (0.30 m^3/s) in 1974.

The decrease in ground-water pumping was due to use of surface water made available in late 1973. At that time, the City of Galveston began purchasing 6 million gal/d (0.26 m^3/s) of treated water from Lake Houston (Figure 5). In January 1976, the City of Galveston increased its use of surface water to 8 million gal/d (0.35 m^3/s).

Decline of Water Levels

The decrease in ground-water pumping in the Alta Loma area caused a local rise in water levels (well KH-65-40-707) as shown by the hydrograph on Figure 17. The 6 million gal/d (0.26 m^3/s) decrease in ground-water pumping in late 1973 caused the water level to rise. By March 1974, the water level had risen about 13 feet (4.0 m) above the level of March 1973. A net decline in the water level of 15 feet (4.6 m) occurred during 1965-75. Figure 8 also shows that the water-level decline in the area ranged from less than 10 feet to about 20 feet (3.0 to 6.1 m) during that 10-year period.

CHANGES IN CHEMICAL QUALITY OF GROUND WATER

In general, ground water of good chemical quality can be obtained in most areas of the Houston district. However, deterioration in water quality has been noted in samples from a few wells near the freshwater-saltwater interface in both Harris and Galveston Counties. The increase in the concentrations of chemical constituents is probably a result of updip migration of the saltwater. Water that was more highly mineralized than was expected was pumped from shallow wells, less than 100 feet (30 m) deep, in the vicinity of the Houston Ship Channel. Jorgensen (1976) concluded that the source of the highly mineralized water was the ship channel.

Wells in southern Harris County from which samples were obtained periodically to monitor changes in chloride content of the ground water have been destroyed, but prior to their destruction, increases in chloride were detected. Wells in Galveston County from which samples have been collected for many years are still available for water-quality observation. Changes in chloride concentrations are being monitored in the City of Galveston's "old" well field at Alta Loma.

Figure 18 shows that the chloride content in water from wells KH-65-48-204 and 211 has remained fairly constant since 1965. The chloride concentration in water from well KH-65-48-214 was at a high of 820 mg/l (milligrams per liter) in 1952, decreased to a low of 560 mg/l in 1965, increased to 820 mg/l in 1972, and decreased to 750 mg/l in 1974. The fluctuations in the chloride concentrations are probably due to pumping patterns in the well field.

Figure 19 shows the chloride content in water from wells in the "new" well field north of Alta Loma

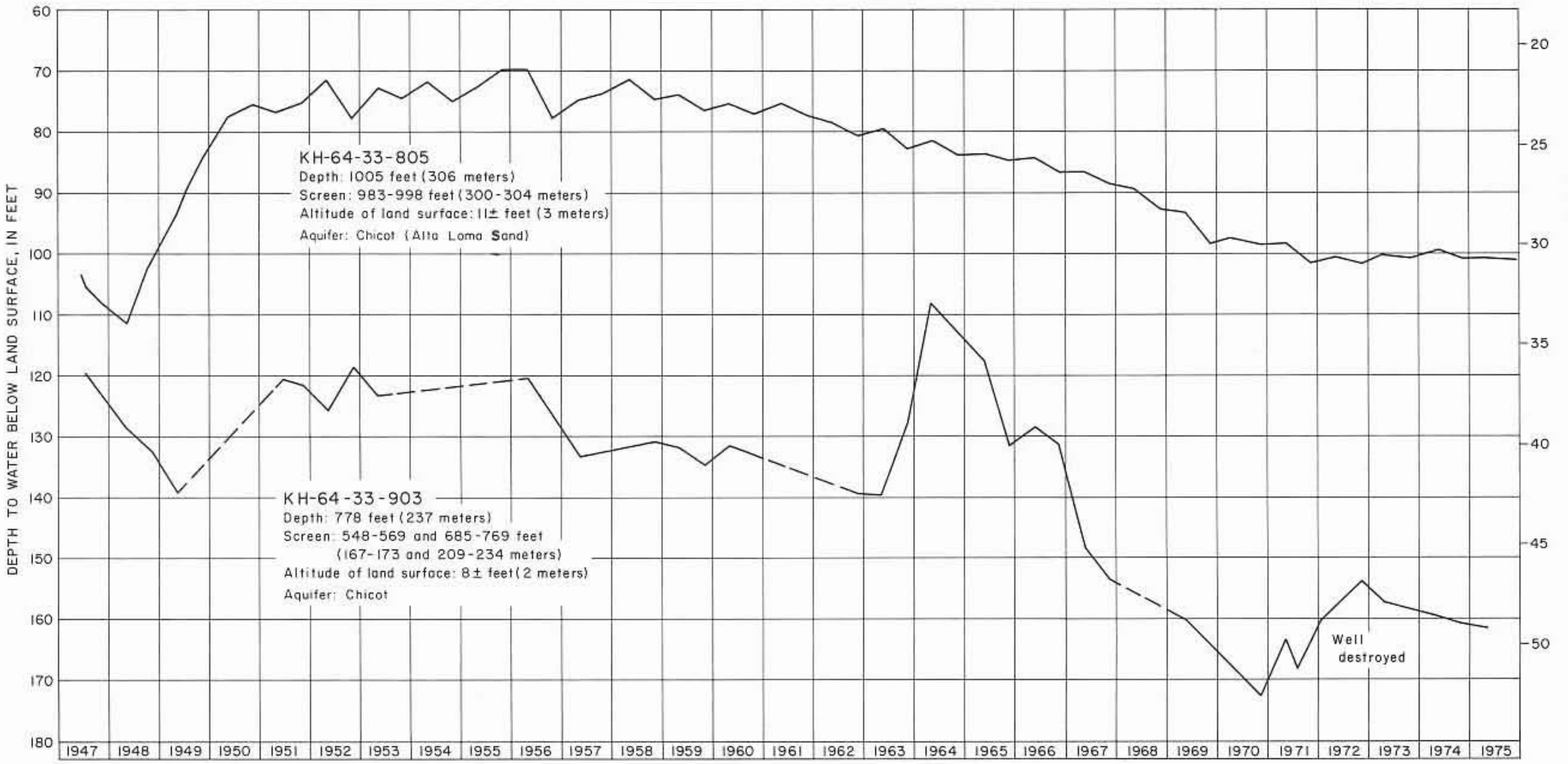

Figure 16

Hydrographs Showing Changes in Water Levels in the Texas City Area

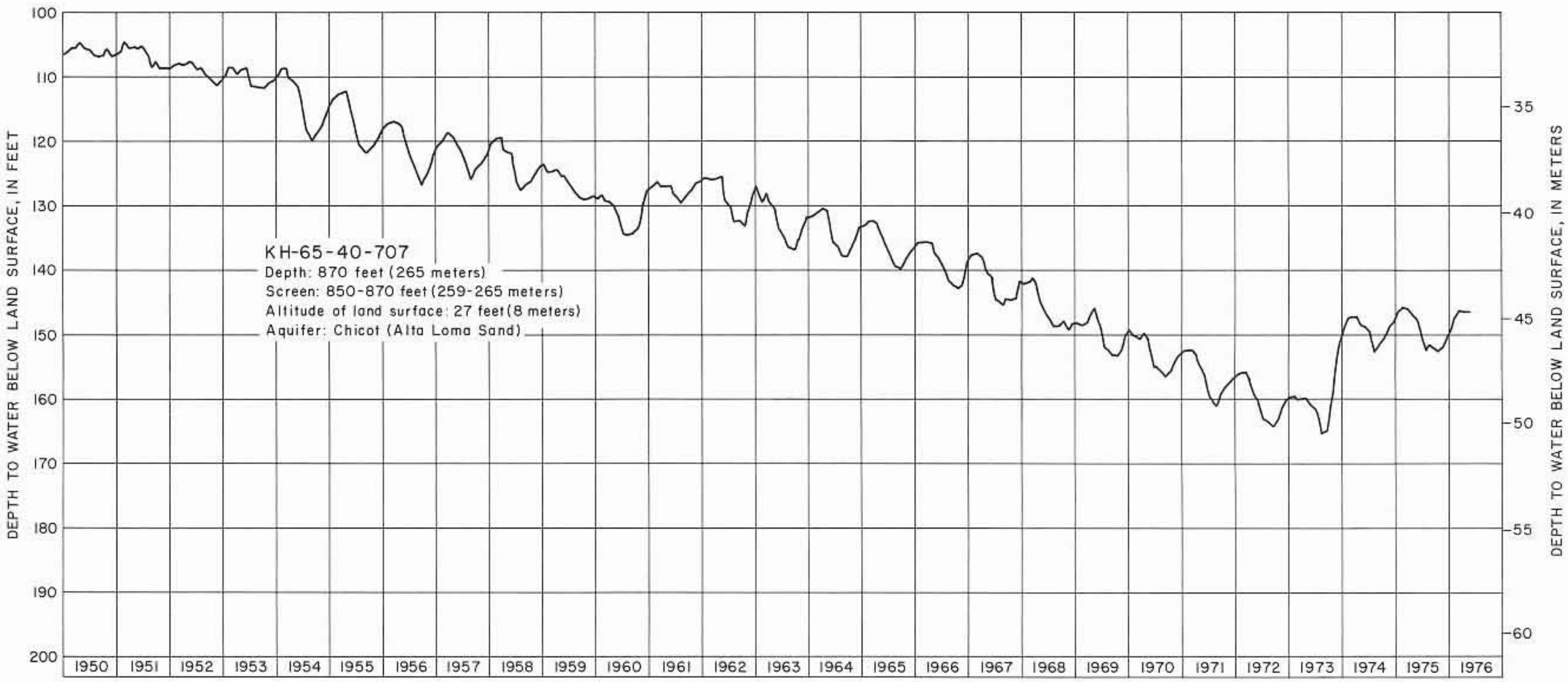

Figure 17

Hydrograph Showing Changes in Water Levels in Well KH-65-40-707 in the Alta Loma Area

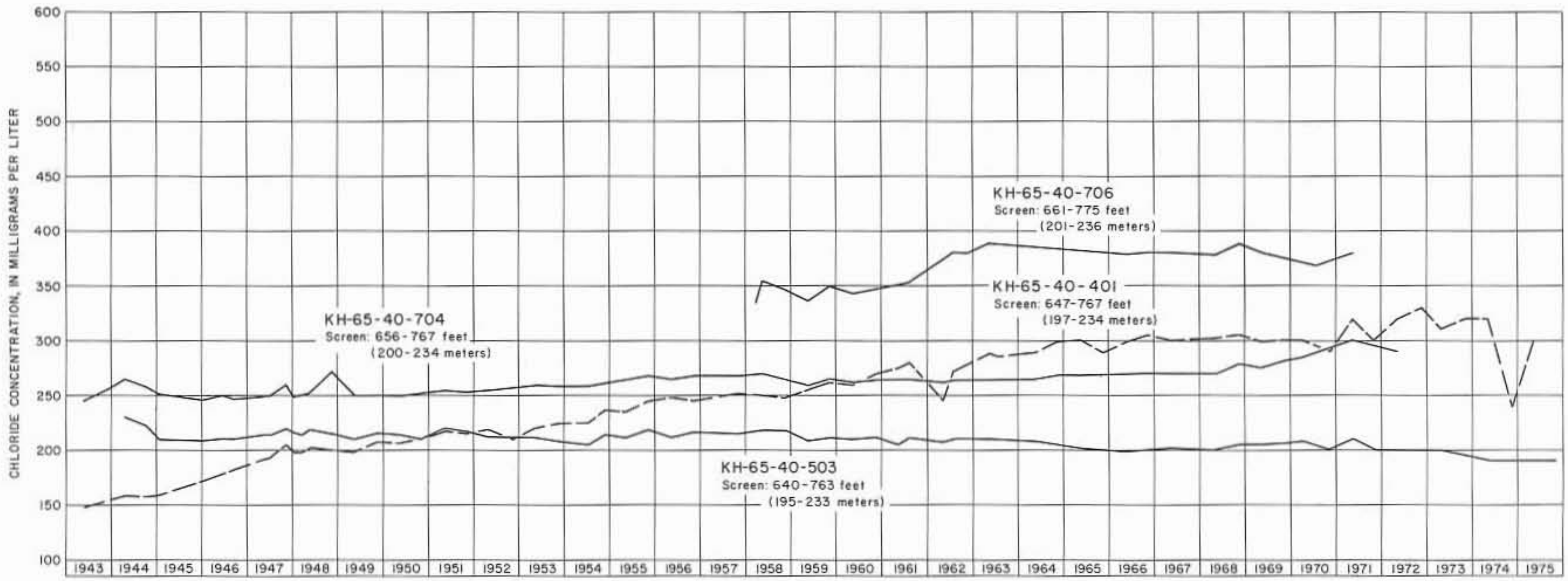

Figure 19

Changes in Chloride Content of Water from Wells in the City of Galveston's "New" Well Field North of Alta Loma has increased gradually since 1945, with the exception of water from well KH-65-40-503. The increases in chloride content suggest some encroachment of the more saline water from the direction of the "old" well field.

Figure 20 shows the changes in chloride content in water from a well in the Alta Loma Sand (KH-64-41-309) and from a well in the sand beds above the Alta Loma Sand (KH-64-41-308) in the middle part of the Chicot aquifer in the Texas City area. The chloride concentration in water from well KH-64-41-308 has fluctuated within narrow limits (205 mg/l to 230 mg/l), while the chloride concentration in water from well KH-64-41-309 has fluctuated widely. The maximum chloride concentration of 1,180 mg/l in water from this well occurred in 1952 (not shown on graph); the lowest concentration, 910 mg/l, occurred in 1955. The well yielded water with a chloride concentration of 980 mg/l in 1975.

SUBSIDENCE OF THE LAND SURFACE

The land surface is continuing to subside in the Houston district because water levels, except in the Alta Loma area, are continuing to decline. However, in much of the district, the rate of decline since about 1970 is less than before 1970. It is likely that the rate of subsidence has decreased in the areas in which declines have decreased, but the periods of releveling do not coincide with the records of changes in water-level declines.

The last two determinations of bench-mark elevations were made in 1964 and 1973. The rates of regional subsidence since 1973 cannot be ascertained until the elevations of the bench marks can be redetermined. The rates of subsidence at particular locations may be estimated from records of the borehole extensometers (compaction monitors) constructed for subsidence studies in the district. The monitors are designed to measure compaction of the subsurface material from the land surface to the total depth of a well.

Three of the ten monitoring wells constructed at eight sites (Figure 5) were drilled to the base of the Evangeline aquifer. No wells are pumping water from the aquifer below the Evangeline aquifer, and the Burkeville confining layer, which separates the Evangeline aquifer from the deeper aquifer, is assumed to be an effective barrier to ground-water flow. Well drillers have reported water levels in test wells in the deeper aquifer to be above land surface in central Harris County and in the Texas City area. The stress that causes compaction is the decline in water levels (decline in artesian pressure); therefore, it is concluded that the decline in artesian pressure is restricted to the Evangeline and Chicot aquifers and that little or no compaction occurs below the base of the Evangeline aquifer. If these conclusions are correct, the three monitoring wells drilled to the base of the Evangeline aquifer are total-subsidence monitors. Data being collected from all monitors, however, will be valuable in understanding the cause-and-effect relationship in water-level changes and changes in land-surface elevations.

Records from eight monitors are shown on Figures 21 and 22. Table 6 shows the average annual rate of subsidence for 1964-73 at eight monitoring sites and the average rate of compaction measured during the period of record. Except for well LJ-65-32-401, installed in 1962, all monitors were constructed in 1973-76. Two of the ten monitors were installed in May 1976, so the record is too short to establish reliable trends.

SUMMARY AND CONCLUSIONS

Pumping of ground water in the Houston district in 1974 was about 532 million gal/d (23.3 m^3/s) as compared to 488 million gal/d (21.4 m^3/s) in 1970. Although pumping increased during the 5-year period, the increase was only about 9 percent or an average of less than 2 percent per year. During 1960-69, ground-water pumping increased from about 311 to about 507 million gal/d (13.6 to 22.2 m^3/s), or about an average annual rate of increase of about 6.3 percent. Water levels continued to decline throughout the district but generally at lower rates than in previous years.

The decrease in the rates of water-level declines suggests that the aquifers in the Houston district could support almost as much production as in 1970-74 (about 500 million gal/d or 21.9 m^3/s) with little, if any, further decline in water levels.

Water levels declined as much as 80 feet (24 m) in the Chicot aquifer during 1965-75, with the maximum decline occurring in the northern part of the NASA area. The greatest depth to water was 290 feet (88 m) below sea level in the Baytown-La Porte area.

Water levels declined as much as 130 feet (40 m) in the Evangeline aquifer during 1965-75, and the maximum decline occurred in a well field in the Houston area. The greatest depth to water, however, was 400 feet (122 m) below sea level in the Pasadena area.

Although salt-water encroachment has probably occurred in the district, particularly in Galveston County, the data from monitoring wells at Texas City and Alta Loma do not indicate a significant increase in chloride concentrations in the past 5 years.

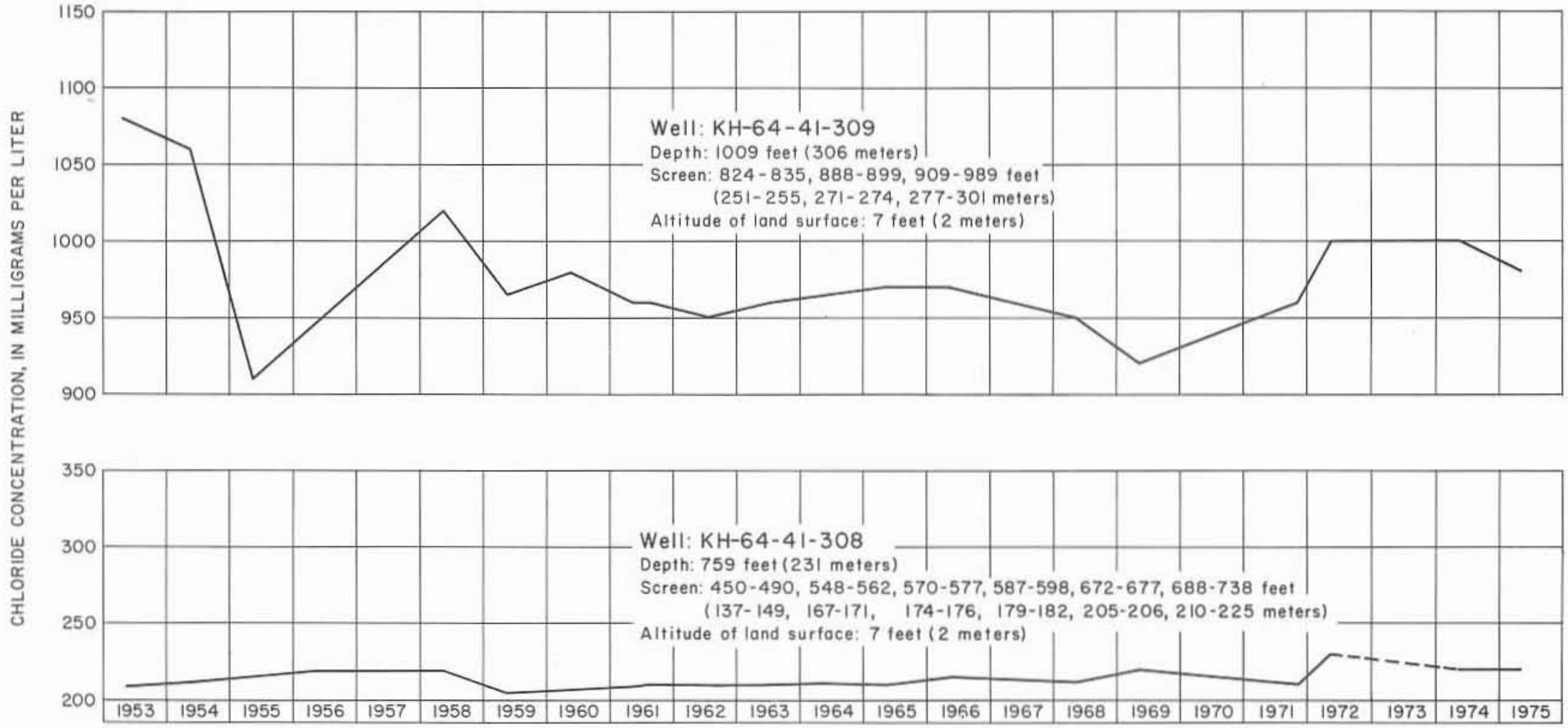

Figure 20

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

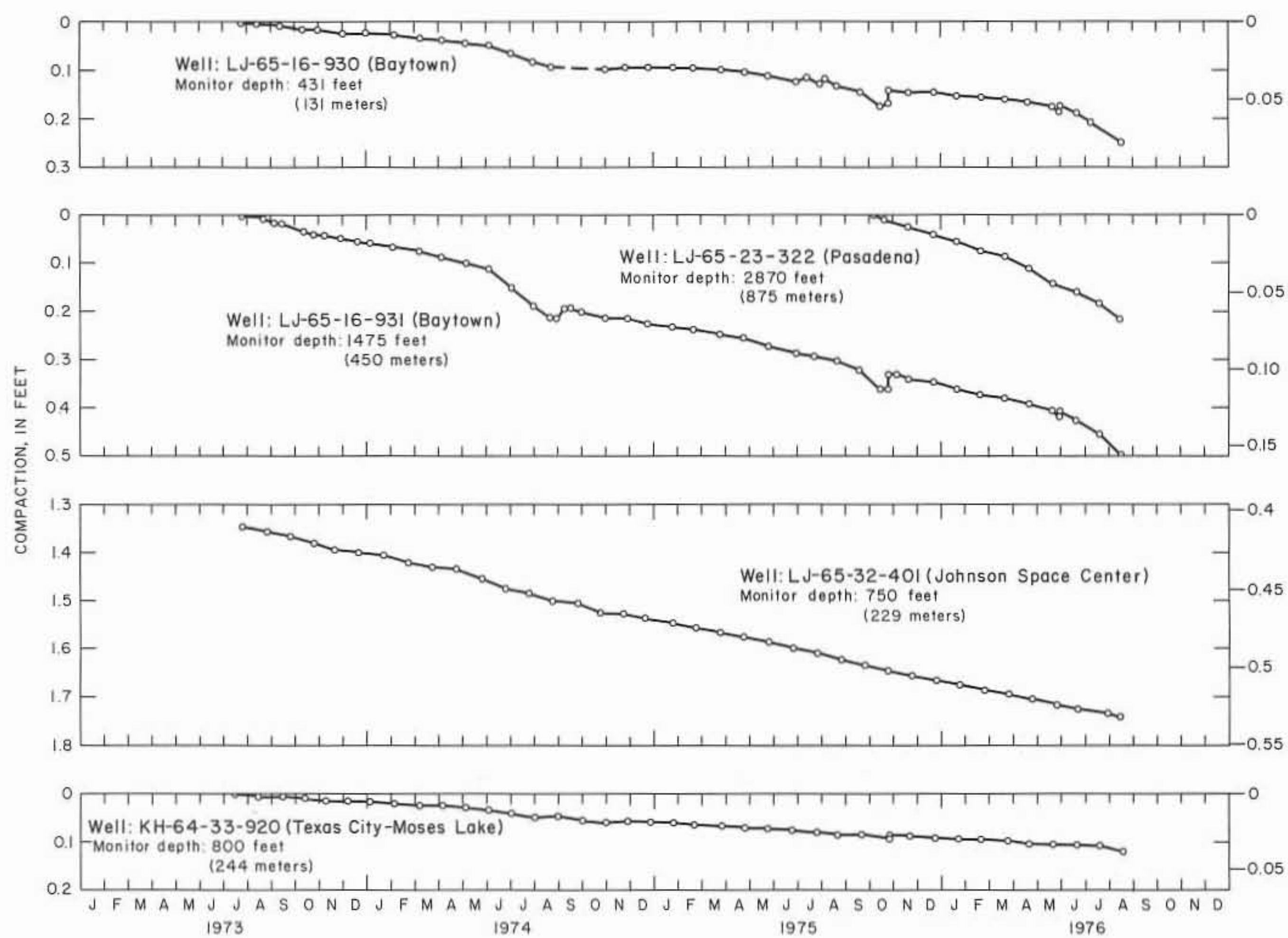

Figure 21

Measured Compaction at Baytown, Pasadena, Johnson Space Center and Near Texas City

Table 6.—Compaction and Subsidence Rates in the Houston District

Site location	Monitor number	Monitor depth (feet)	Period of record	Compaction (feet/year)	Average subsidence 1964-73 (feet/year)
Baytown	LJ-65-16-930	431	May 8, 1973—June 21, 1976	0.062	0.28
Baytown	LJ-65-16-931	1,475	July 24, 1973—June 21, 1976	.145	.28
Houston (East End)	LJ-65-22-622	995	July 20, 1973—June 21, 1976	.149	.22
Houston (Addicks)[1]	LJ-65-12-726	1,813	July 11, 1974—June 21, 1976	.068	.11
Texas City (Moses Lake)	KH-64-33-920	800	July 13, 1973—June 21, 1976	.037	.08
Johnson Space Center	LJ-65-32-401	770	Oct. 24, 1962—June 21, 1976	.126	.22
Seabrook	LJ-65-32-625	1,381	July 20, 1974—June 21, 1976	.229	.19
Pasadena[1]	LJ-65-23-322	2,870	Oct. 8, 1975—June 21, 1976	.228	.36
Clear Lake City	LJ-65-32-424	1,853	May 26, 1976—June 21, 1976	—	.22
Clear Lake City[1]	LJ-65-32-428	3,305	May 26, 1976—June 21, 1976	—	.22

[1] Designed to monitor total subsidence.

With the continued decline in water levels, subsidence of the land surface has also continued. Maps of land-surface subsidence have been based on changes in elevations of bench marks, but these elevations have not been redetermined since 1973. Equipment to continuously monitor the compaction of subsurface materials and subsidence has been installed at eight sites. All monitors but one have been installed since 1972, and all monitors show continued land-surface subsidence with no changes in the rates of subsidence.

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