GROUND-WATER WITHDRAWALS AND CHANGES IN GROUND-WATER LEVELS, GROUND-WATER QUALITY, AND LAND-SURFACE SUBSIDENCE IN THE HOUSTON DISTRICT, TEXAS, 1980-84

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 87-4153

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

Prepared in cooperation with the
CITY OF HOUSTON and the
HARRIS-GALVESTON COASTAL SUBSIDENCE DISTRICT

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Austin, Texas

1987

DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY

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METRIC CONVERSIONS

Factors for converting inch-pound units to metric (International System) units are given in the following table:

Multiply inch-pound unit	By	To obtain metric units
acre	0.4047	hectare
acre-foot	0.001233	cubic hectometer
acre-foot per acre	0.003048	cubic hectometer per hectare
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot per year (ft/yr)	0.3048	meter per year
gallon per minute (gal/min)	0.06308	liter per second
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer
million gallons per day (Mgal/d)	0.04381	cubic meter per second

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "mean sea level."

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ABSTRACT

During 1980-84, ground-water withdrawals from the Chicot and Evangeline aquifers in the Houston district decreased from 511 million gallons per day to 444 million gallons per day. This 13-percent decrease was due to the increased availability of surface water and a decreased demand for water. The largest decreases in ground-water withdrawals occurred in the Houston area. Ground-water pumpage was 219.2 million gallons per day during 1984 compared to 254.8 million gallons per day during 1980. Decreases in ground-water withdrawals from 1980 through 1984 occurred in most of the other areas in the Houston district (Pasadena, Katy, Baytown-LaPorte, and Texas City). Large decreases in ground-water withdrawals for rice irrigation in the Katy area were offset by increases in ground-water withdrawals for public supply. Hence, in the Katy area, the quantity of ground water withdrawn during 1984, 148.9 million gallons per day, was only slightly less than the 157.5 million gallons per day withdrawn during 1980.

Water levels generally rose in the eastern part of the Houston district and declined in the western part from spring 1980 to spring 1985. The rise of water levels in wells in the Chicot and Evangeline aquifers was as much as 80 feet and 60 feet, respectively. The decline of water levels in wells in the Chicot and Evangeline aquifers was as much as 40 feet and 80 feet, respectively.

Slight decreases in chloride concentrations in water from the Chicot aquifer occurred in the Alta Loma area between 1980 and 1984. In 1980, chloride concentrations in water from the Chicot aquifer ranged from 250 to 790 milligrams per liter, whereas in 1984, chloride concentrations ranged from 180 to 710 milligrams per liter. Water from one well in the Texas City area had an increase in chloride concentrations from 265 milligrams per liter in 1980 to 300 milligrams per liter in 1984. In water from another well in the Texas City area, chloride concentrations decreased from 760 milligrams per liter in 1980 to 710 milligrams per liter in 1984. The concentrations of chloride and dissolved solids in water from the Evangeline aquifer remained less than 100 milligrams per liter and 500 milligrams per liter during 1980-84.

Land-surface subsidence is still evident in the Houston district. Subsidence rates between 1980 and early 1985 in the eastern and southeastern parts of the Houston district were less than during 1975-79. At the Seabrook site, where a monitor measures most of the subsidence, the average compaction rate during 1980 to early 1985 was 0.04 foot per year while during 1975-79, the rate was 0.14 foot per year. However, subsidence rates in the western, southwestern, and northern parts of the Houston district during 1980 to early 1985 increased

from the 1975-79 rates. At the Addicks site, the land surface has subsided at a rate of about 0.17 foot per year from 1980 to early 1985. The subsidence rate from 1975 through 1979 at the site was 0.11 foot per year.

INTRODUCTION

The purpose of this report is to provide information about ground-water withdrawals, changes in ground-water levels, ground-water quality, and trends in land-surface subsidence in the Houston district during 1980-84. Some data collected prior to 1980 and during the early spring of 1985 are presented to establish long-term trends and relations.

The Houston district, as described in this report, includes all of Galveston County and parts of Brazoria, Chambers, Fort Bend, Harris, Liberty, and Waller Counties (fig. 1). Many homeowners, well drillers, industrial-plant managers, and State and municipal officials provided information for this report. Financial support was provided by the city of Houston and the Harris-Galveston Coastal Subsidence District in a cooperative agreement with the U.S. Geological Survey.

GEOHYDROLOGY OF THE STUDY AREA

The geohydrologic units discussed in this report primarily are the Chicot and Evangeline aquifers. The Jasper aquifer also underlies the Houston district, but contains water of poor quality except in the northern part of the district. Only two wells presently are known to yield water from the Jasper aquifer in Harris County. These aquifers are composed of sedimentary deposits in the Coastal Plain physiographic province. The province is a broad plain underlain by a southeasterly thickening wedge of layered beds of clay, silt, sand, and gravel. The geologic formations in the study area are, from oldest to youngest: The Oakville Sandstone and Fleming Formation of Miocene age; the Goliad Sand of Pliocene age; the Willis Sand, Bentley Formation, Montgomery Formation, and Beaumont Formation of Pleistocene age; and alluvium of Quarternary age. The relation among the geohydrologic units and the geologic formations is given in table 1. A generalized geohydrologic section of the Chicot, Evangeline, and Jasper aquifers through Montgomery, Harris, Brazoria, and Galveston Counties is shown in figure 2.

Chicot Aquifer

The Chicot aquifer includes all deposits from the land surface to the top of the Evangeline aquifer. The Chicot aquifer is composed of the Willis Sand, Bentley Formation, Montgomery Formation, Beaumont Formation, and Quaternary alluvium. The altitude of the base of the Chicot aquifer is shown in figure 3. The discontinuous sand and clay layers of the Chicot aquifer in some parts of the study area are separated into an upper and lower unit (Jorgensen, 1975, p. 10). When the upper unit of the Chicot aquifer cannot be defined, the aquifer is undifferentiated. The Chicot aquifer is under confined conditions except in the northern part of the district. Generally, in southeastern Harris County and most of Galveston County, the Chicot aquifer contains a thick sand section that has a relatively large (as much as 75 ft/d) hydraulic conductivity (Jorgensen, 1975, p. 15). This sand unit has been intensely pumped and is known locally as the Alta Loma Sand (Alta Loma Sand of Rose, 1943). In this area, there also is another sand unit within the Chicot aquifer referred to as the middle Chicot aquifer. The Chicot aquifer is the main source of ground water in Galveston and southern Harris Counties.

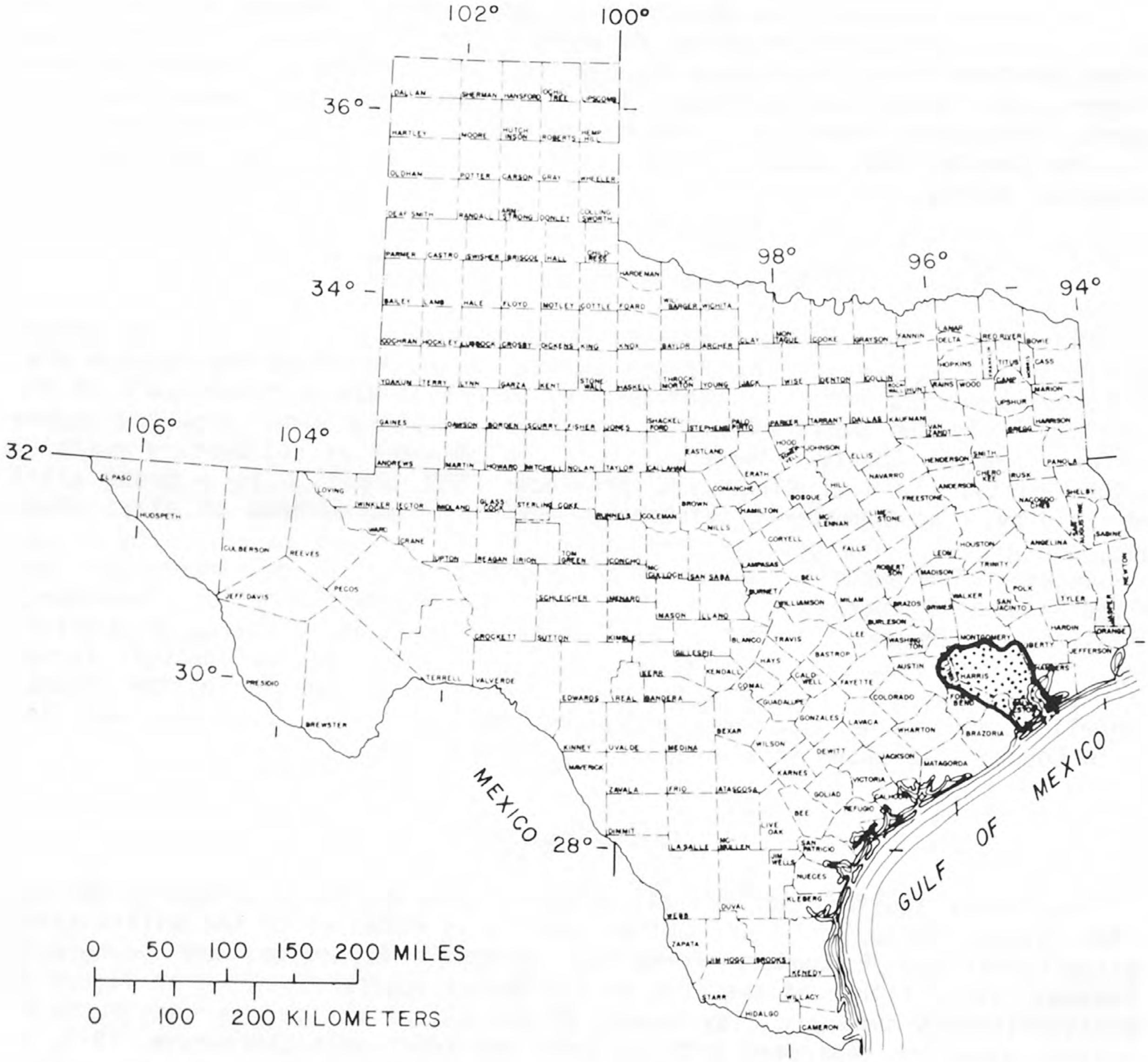


Figure 1.--Location of study area.

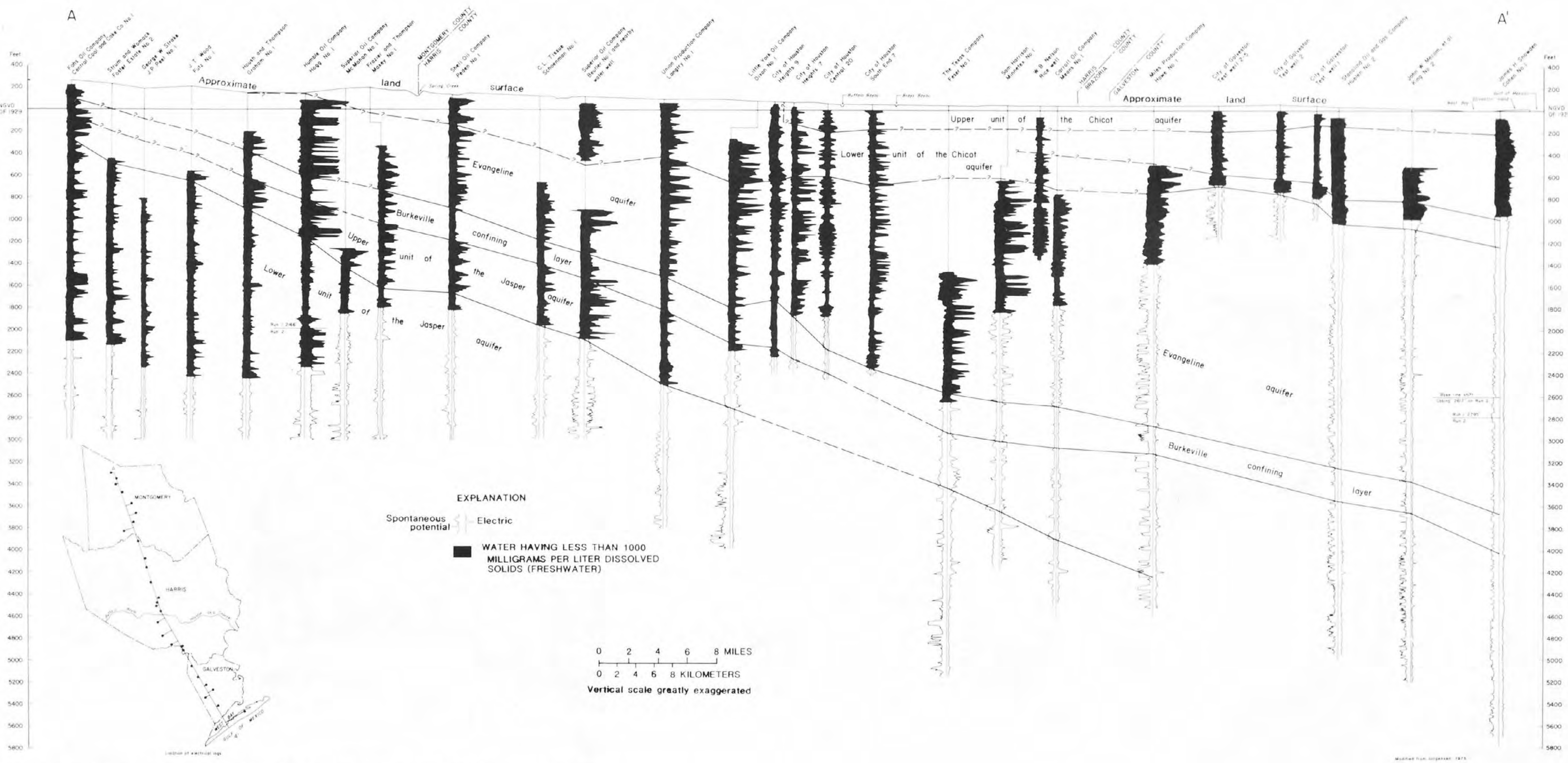
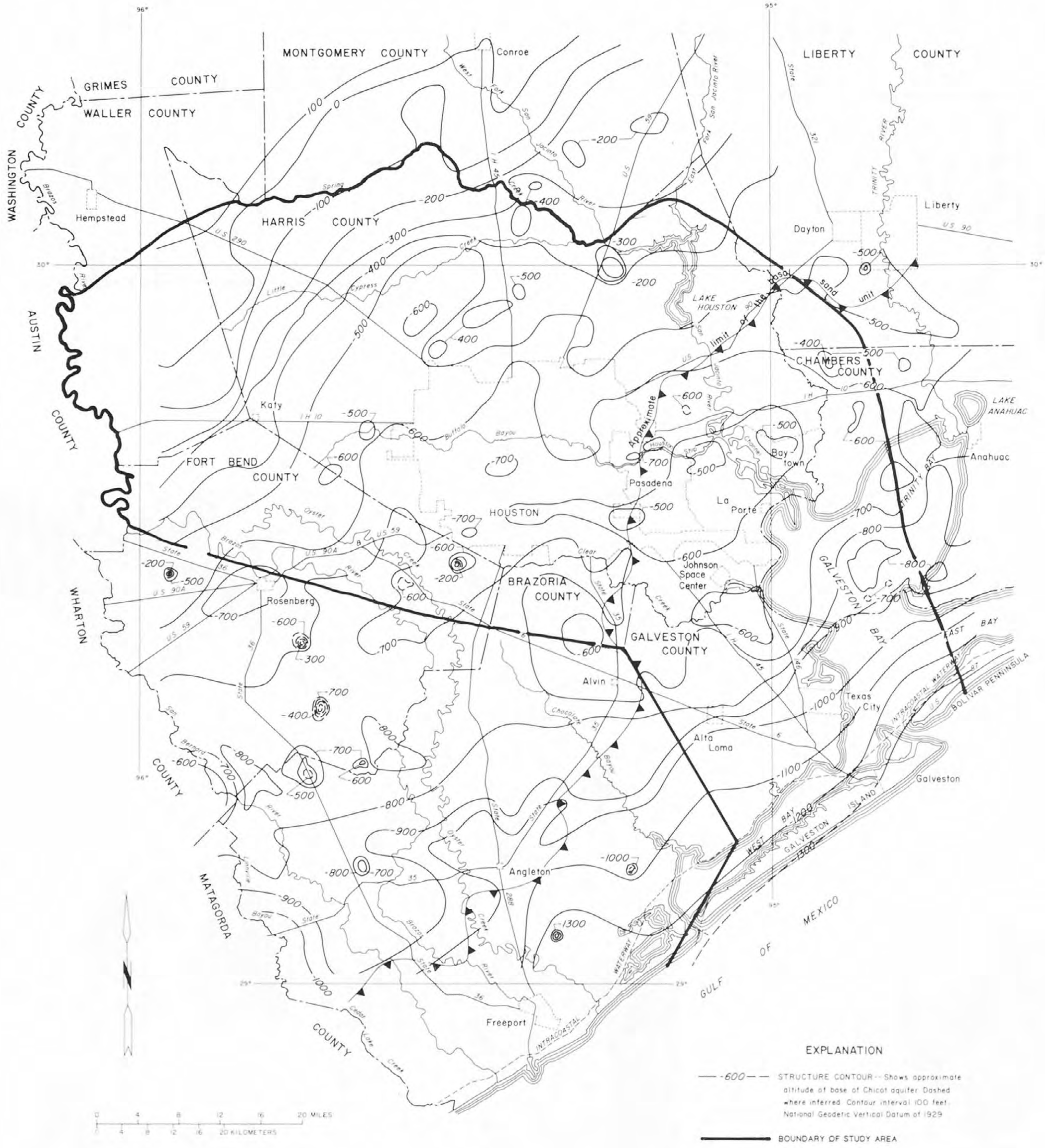


Figure 2.--Correlation of hydrologic units from northern Montgomery County to the Gulf of Mexico.



Geology from Jorgenson, 1975

Figure 3.--Approximate altitude of the base of the Chicot aquifer in the Houston district and vicinity.

Table 1.--Relations among geohydrologic units and geologic formations

Geologic classification: System	Geologic classification: Series	Geologic classification: Stratigraphic unit	Geohydrologic unit: Houston district (Lang, Winslow, and White, 1950)	Geohydrologic unit: Houston district (Jorgensen, 1975)	Geohydrologic unit: This report
Quaternary	Holocene	Quaternary alluvium	Alluvial deposits	Chicot aquifer: Upper unit	Chicot aquifer: Upper unit
Quaternary	Pleistocene	Beaumont Formation	Beaumont Clay	Chicot aquifer: Upper unit	Chicot aquifer: Upper unit
Quaternary	Pleistocene	Montgomery Formation	Beaumont Clay	Chicot aquifer: Upper unit / Lower unit	Chicot aquifer: Upper unit / Lower unit
Quaternary	Pleistocene	Bentley Formation	Beaumont Clay; "Alta Loma Sand"	Chicot aquifer: Lower unit	Chicot aquifer: Lower unit
Quaternary	Pleistocene	Willis Sand	"Alta Loma Sand"; Zone 7; Zone 6	Chicot aquifer: Lower unit	Chicot aquifer: Lower unit; "Alta Loma Sand"
Tertiary	Pliocene	Goliad Sand	Zone 5; Zone 4; Zone 3	Evangeline aquifer	Evangeline aquifer
Tertiary	Miocene	Fleming Formation	Zone 3 (part); Zone 2	Evangeline aquifer (part); Burkeville confining layer	Evangeline aquifer (part); Burkeville confining layer
Tertiary	Miocene	Oakville Sandstone	Zone 1	Jasper aquifer	Jasper aquifer

Evangeline Aquifer

The Evangeline aquifer, composed of the Goliad Sand and the upper part of the Fleming Formation, is similar in lithology to the Chicot aquifer. One difference between the two aquifers is that the Evangeline aquifer generally has a smaller hydraulic conductivity than does the Chicot aquifer. The contrast in hydraulic conductivity and a difference in water levels are the bases for separating the Evangeline aquifer from the Chicot aquifer. The altitude of the base of the Evangeline aquifer is shown in figure 4. The Evangeline aquifer is the major source of ground water in the Houston district. In Galveston and southern Harris Counties, water in the Evangeline aquifer is saline and is not used.

Jasper Aquifer

The Jasper aquifer is composed of interbedded sand and clay layers consisting almost entirely of terrigenous clastic sediments. The approximate altitude of the top of the Jasper aquifer is shown in figure 5. Because the Jasper aquifer underlies shallower aquifers, withdrawals from the Jasper aquifer in terms of total withdrawals in Harris County are not significant. However, hydraulically it is capable of yields of as much as 3,000 gal/min to wells in adjacent Montgomery County (Baker, 1983). Only the upper part of the Jasper aquifer is utilized in Harris County.

DEVELOPMENT OF GROUND WATER

Several publications document the historical development of ground-water withdrawals in the Houston district (Wood and Gabrysch, 1965; Gabrysch, 1972, 1980, 1982; Jorgensen, 1975; Carr and others, 1985). The areas discussed in this report are Houston, Katy, Pasadena, Baytown-LaPorte, Johnson Space Center, Texas City, and Alta Loma (fig. 6).

Prior to 1977, ground water was the major source of freshwater available in the Houston district. Small quantities of surface water obtained from Lake Houston on the San Jacinto River had been available in parts of the Houston district since 1954. The city of Galveston began using surface water from Lake Houston in 1973. In late 1976, surface water from Lake Livingston on the Trinity River became available. The availability of the increased surface water caused ground-water production to decrease substantially in all areas of the Houston district except the Katy area.

In areas to the north, west, and southwest of the Houston area (fig. 6), ground-water withdrawals for public supply have steadily increased due to urban expansion and the lack of surface water. The average daily ground-water withdrawals for public supply, industrial use, and irrigation in the Houston district during 1975-84 are listed in tables 2-4.

In general, until 1977, water levels in wells in the Houston district were declining. However, during the last several years, Houston and several adjacent areas have been converting from ground water to surface water as the main water supply. With the increasing conversion from ground-water use to surface-water use, water levels in wells in the Chicot and Evangeline aquifers began to rise

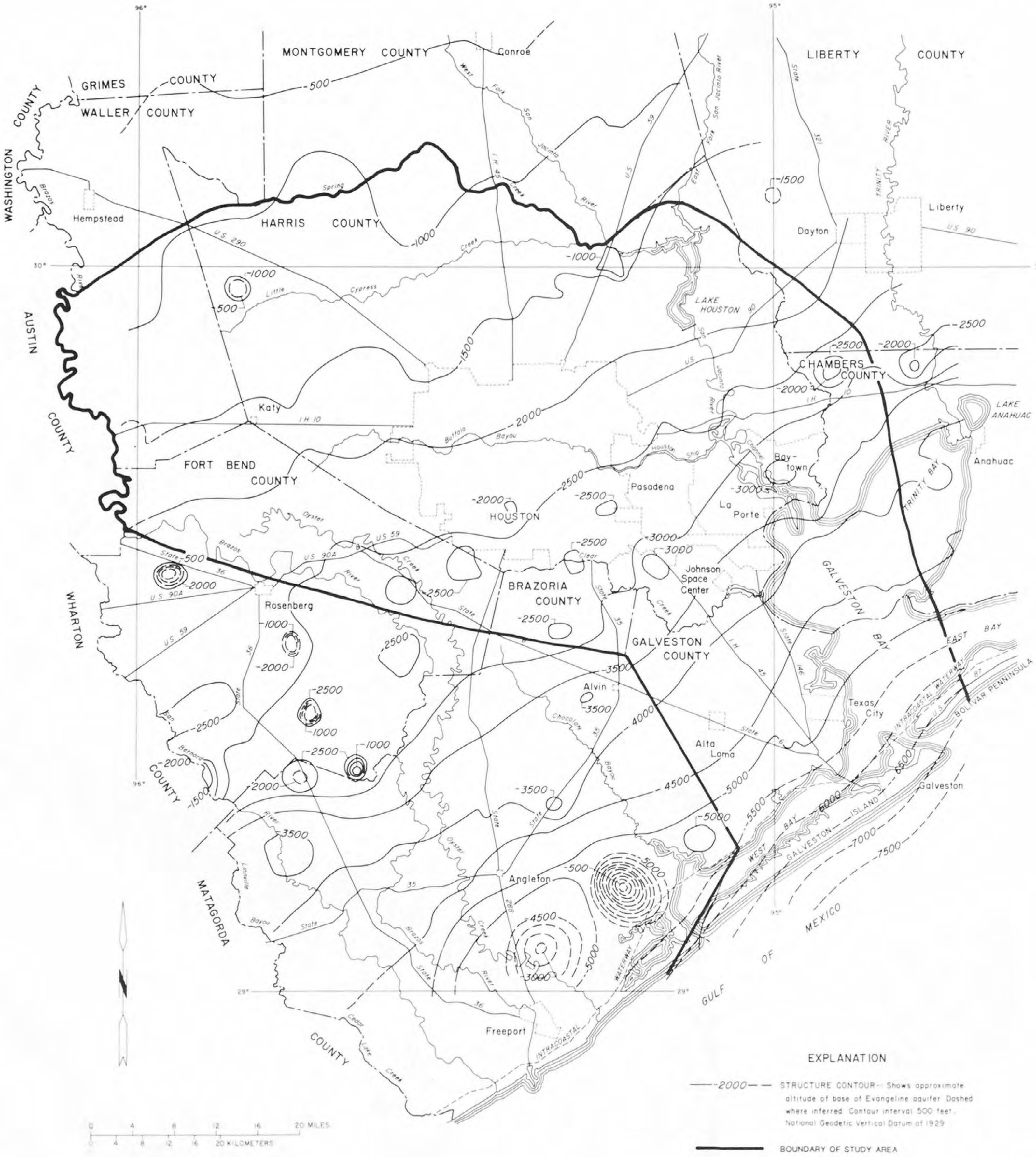


Figure 4.--Approximate altitude of the base of the Evangeline aquifer in the Houston district and vicinity.

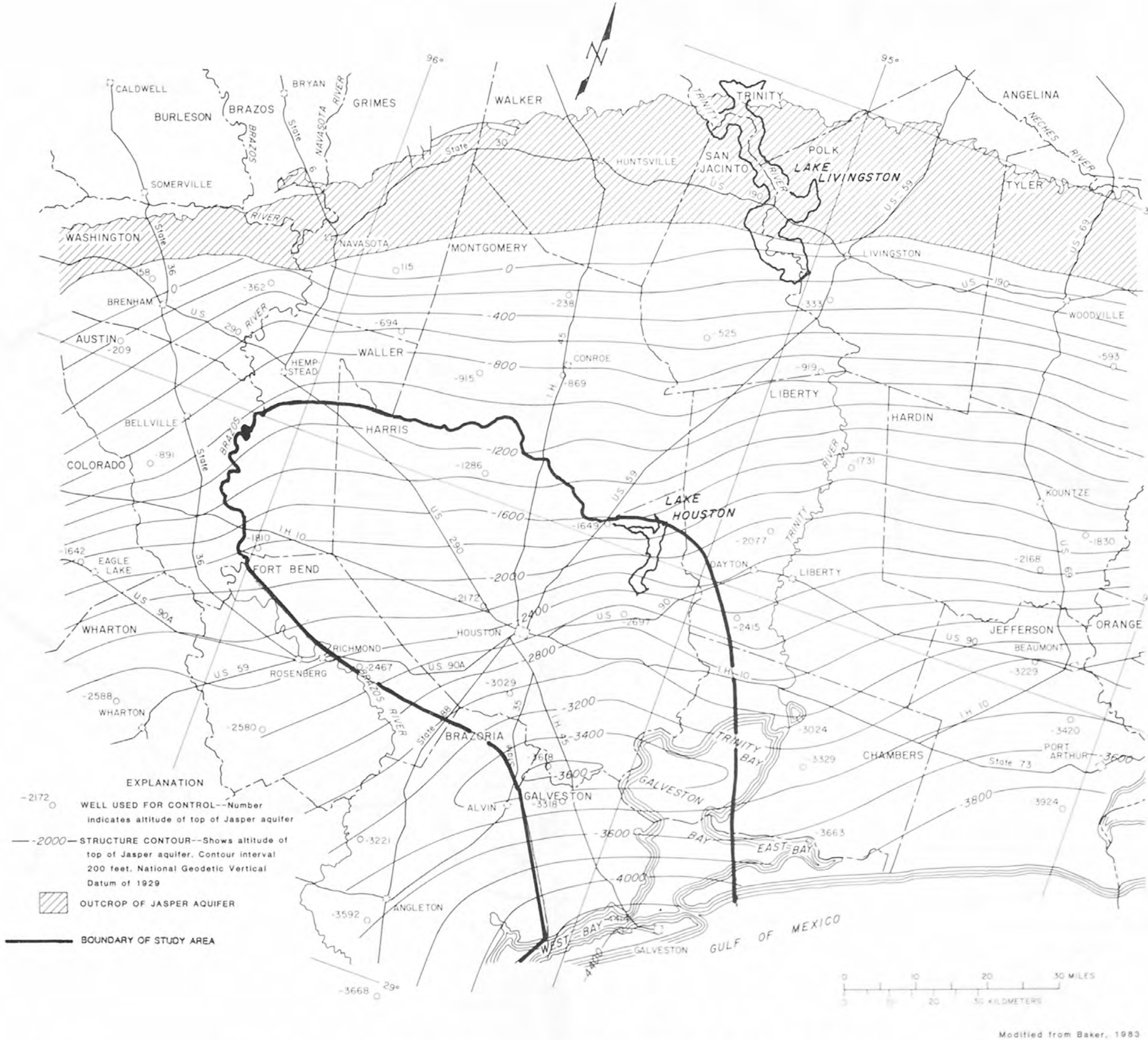


Figure 5.--Approximate altitude of the top of the Jasper aquifer in the Houston district and vicinity.

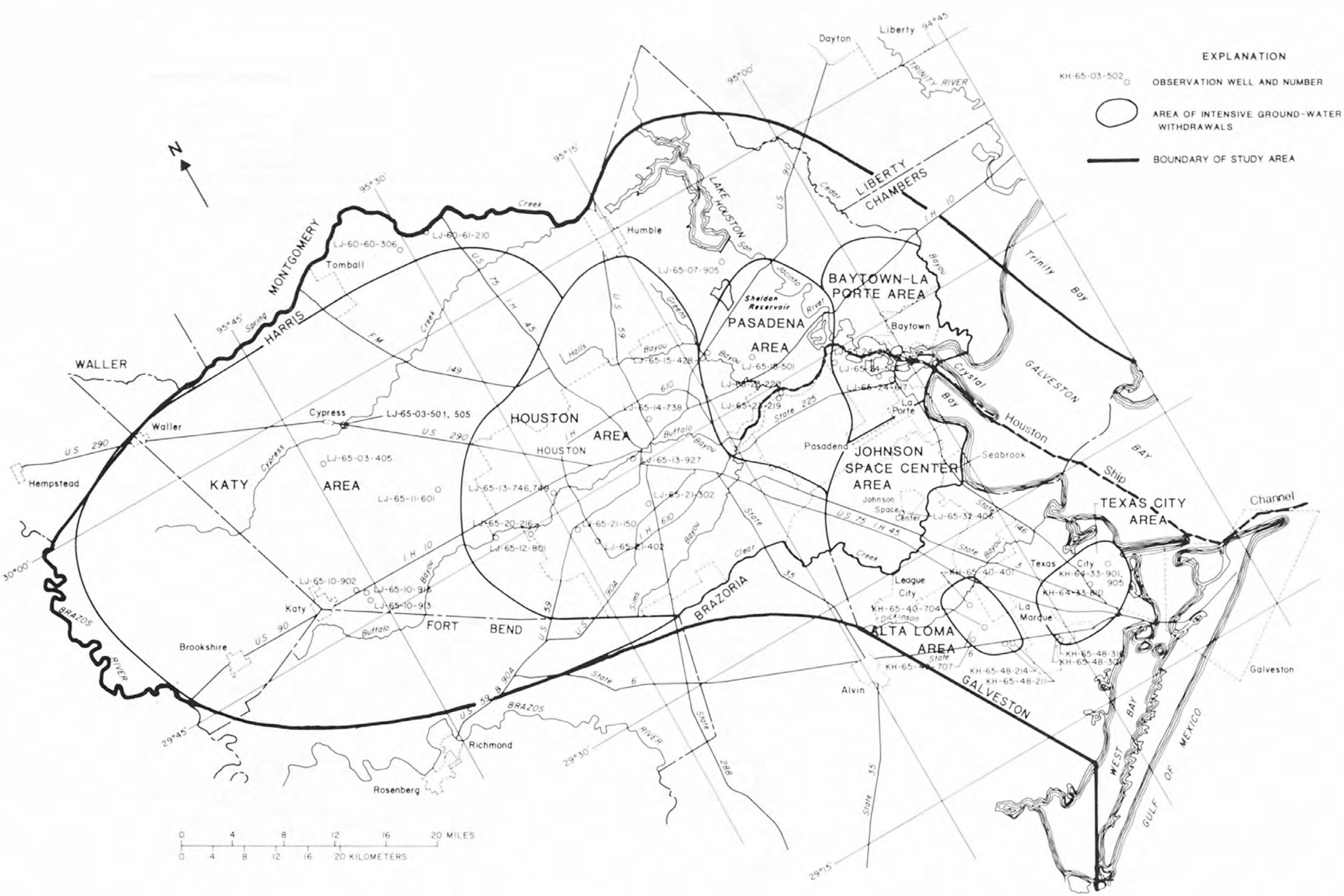


Figure 6.--Location of observation wells and areas of intensive ground-water withdrawals.

Table 2.--Average daily withdrawals of ground water in Harris County and parts of Fort Bend and Waller Counties, 1975-84

Area	Use	Ground-water withdrawals (million gallons per day)									
		1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Houston	Public supply:										
	City of Houston	150.7	163.4	185.2	188.9	203.0	219.7	217.5	221.4	180.3	186.5
	Surburban	23.5	24.8	28.5	29.4	22.9	27.4	25.3	29.5	27.6	28.9
	Industry	8.1	9.0	8.0	8.1	6.9	6.7	6.2	5.2	4.1	3.0
	Irrigation	.8	.8	.8	.9	.7	1.0	.7	.9	.5	.8
	Subtotal	183.1	198.0	222.5	227.3	233.5	254.8	249.7	257.0	212.5	219.2
Katy	Public supply	11.4	15.3	24.2	29.9	31.5	43.9	49.6	64.0	62.2	74.1
	Industry	11.6	10.8	12.9	14.2	13.1	16.5	13.6	11.2	12.2	13.4
	Irrigation	110.1	104.5	84.4	109.9	82.0	97.8	98.4	94.7	40.0	62.5
	Subtotal	133.1	130.6	121.5	154.0	126.6	158.2	161.6	169.9	114.4	150.0
Pasadena	Public supply	16.3	16.7	16.9	16.6	15.1	17.6	16.6	13.8	15.8	16.2
	Industry	93.9	89.1	66.4	46.3	33.0	30.6	28.1	25.0	25.8	23.7
	Subtotal	110.2	105.8	83.3	62.9	48.1	48.2	44.7	38.8	41.6	39.9
Baytown-LaPorte	Public supply	8.5	9.3	9.8	11.4	10.6	11.1	6.8	4.8	4.3	4.4
	Industry	17.6	17.2	12.3	10.2	3.8	1.8	.9	.8	1.0	.8
	Subtotal	26.1	26.5	22.1	21.6	14.4	12.9	7.7	5.6	5.3	5.2
Johnson Space Center	Public supply	6.5	4.9	3.4	4.0	3.4	4.5	3.9	4.6	4.1	4.1
	Industry	13.6	15.6	4.0	1.0	.5	.3	.2	.3	.2	.6
	Irrigation	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
	Subtotal	20.2	20.6	7.5	5.1	4.0	4.9	4.2	5.0	4.4	4.8
Other areas in Harris County	Public supply	5.6	5.3	6.6	7.2	8.7	11.9	11.9	14.1	12.5	16.8
	Industry	--	--	--	--	.3	.1	.1	.1	.1	.1
	Irrigation	.3	.7	.8	2.3	1.3	.9	1.5	.4	.6	1.2
	Subtotal	5.9	6.0	7.4	9.6	10.3	12.9	13.5	14.6	13.2	18.1
Total		478.6	487.5	464.3	480.5	436.9	491.9	481.4	490.9	391.4	437.2

Table 3.--Average daily withdrawals of ground water in Galveston County, 1975-84

Area	Use	Ground-water withdrawals (million gallons per day)									
		1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Texas City	Public supply	6.9	7.3	7.7	7.3	7.3	7.6	2.8	1.3	1.1	0.6
	Industry	7.4	6.7	3.3	2.4	1.6	1.4	.4	.3	.3	.4
	Subtotal	14.3	14.0	11.0	9.7	8.9	9.0	3.2	1.6	1.4	1.0
Alta Loma	Public supply	7.1	6.1	4.1	2.7	1.6	1.8	2.0	2.0	1.2	2.4
Other areas in Galveston County	Public supply and industry	5.7	6.5	6.8	7.7	7.8	8.3	6.8	5.9	5.5	4.9
Total		27.1	26.6	21.0	20.1	18.3	19.1	12.0	9.5	8.1	8.3

Table 4.--Total average daily withdrawals of ground water, 1975-84

Use	Ground-water withdrawals (million gallons per day)									
	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Public supply	239	256	290	301	308	350	340	358	312	336
Industry	155	152	110	86	63	61	53	46	46	43
Irrigation	111	106	86	113	84	100	101	96	41	65
Total (rounded)	505	514	486	500	455	511	494	500	399	444

in the eastern parts of Harris County. Although this report focuses on water-level changes during 1980-84, for long-term perspective, water-level changes from 1977 to 1985 in wells in the Chicot and Evangeline aquifers are shown in figures 7 and 8; 1977 was used as the base year for determining water-level changes because most conversions from ground water to surface water were made that year. During 1977-85, the water-level changes in wells in the Chicot aquifer in the Houston district ranged from rises of as much as about 140 ft to declines of as much as about 80 ft (fig. 7). Water levels in wells in the Evangeline aquifer from 1977 to 1985 ranged from rises of as much as about 120 ft to declines of as much as about 140 ft (fig. 8).

The water-level changes in wells in the Chicot and Evangeline aquifers during 5 years, spring 1980 to spring 1985, are shown in figures 9 and 10. The altitude of water levels in wells in the Chicot and Evangeline aquifers during spring 1985 are depicted in figures 11 and 12.

Only a few wells have been completed in the Jasper aquifer in Harris County. Three of these (LJ-60-60-306, LJ-60-61-210, and LJ-65-07-905) are located in the northern part of the county and two in the western part of the county (fig. 6). The two wells (LJ-65-03-501 and LJ-65-03-505) drilled in the western part of the county were once used as a water source for a health resort. Of the three wells drilled in northern Harris County, one (LJ-60-60-306) is used for public water supply. From 1980 through 1984, this well produced about 0.26 Mgal/d of water. Water from the second well (LJ-60-61-210) in northern Harris County is used to repressure oil-producing zones. No recent water-level information is available for this well, but in 1968, the well was flowing. The U.S. Geological Survey, in cooperation with the Harris-Galveston Coastal Subsidence District, drilled the third well (LJ-65-07-905), an exploratory well, to the Jasper aquifer near the Lake Houston dam in 1979. The water level of this well was 80 ft above land surface on December 3, 1979, compared to 68 ft above land surface on December 5, 1984.

Houston Area

The Houston area, located in central and south-central Harris County, includes most of the city of Houston and several densely urbanized areas adjacent to the city. The Evangeline aquifer supplies most of the ground water used in the Houston area. Some wells in the Houston area are screened in both the Chicot and Evangeline aquifers.

Ground-Water Withdrawals

The quantity of ground water used by the city of Houston increased from 1975 through 1982 (table 5). However, since 1982, the quantity of ground water used has rapidly decreased. Ground-water contribution to the total water supply for the city of Houston during 1984 was 50.5 percent, the smallest percentage since 1978. The quantities and percentages of ground water and surface water used by the city of Houston between 1975 and 1984 are listed in table 5. For most years since 1975, ground water has supplied slightly more than 50 percent of the total water supply with a mean of 53 percent for the 10 years. During 1984, ground-water withdrawals were 186.5 Mgal/d or 50.5 percent of the total water supply. Ground-water withdrawals during 1982 were 221.4 Mgal/d, a historical high. During 1982-84, ground-water withdrawals decreased by 34.9

Figure 7.--Approximate water-level changes in wells in the Chicot aquifer, spring 1977 to spring 1985.

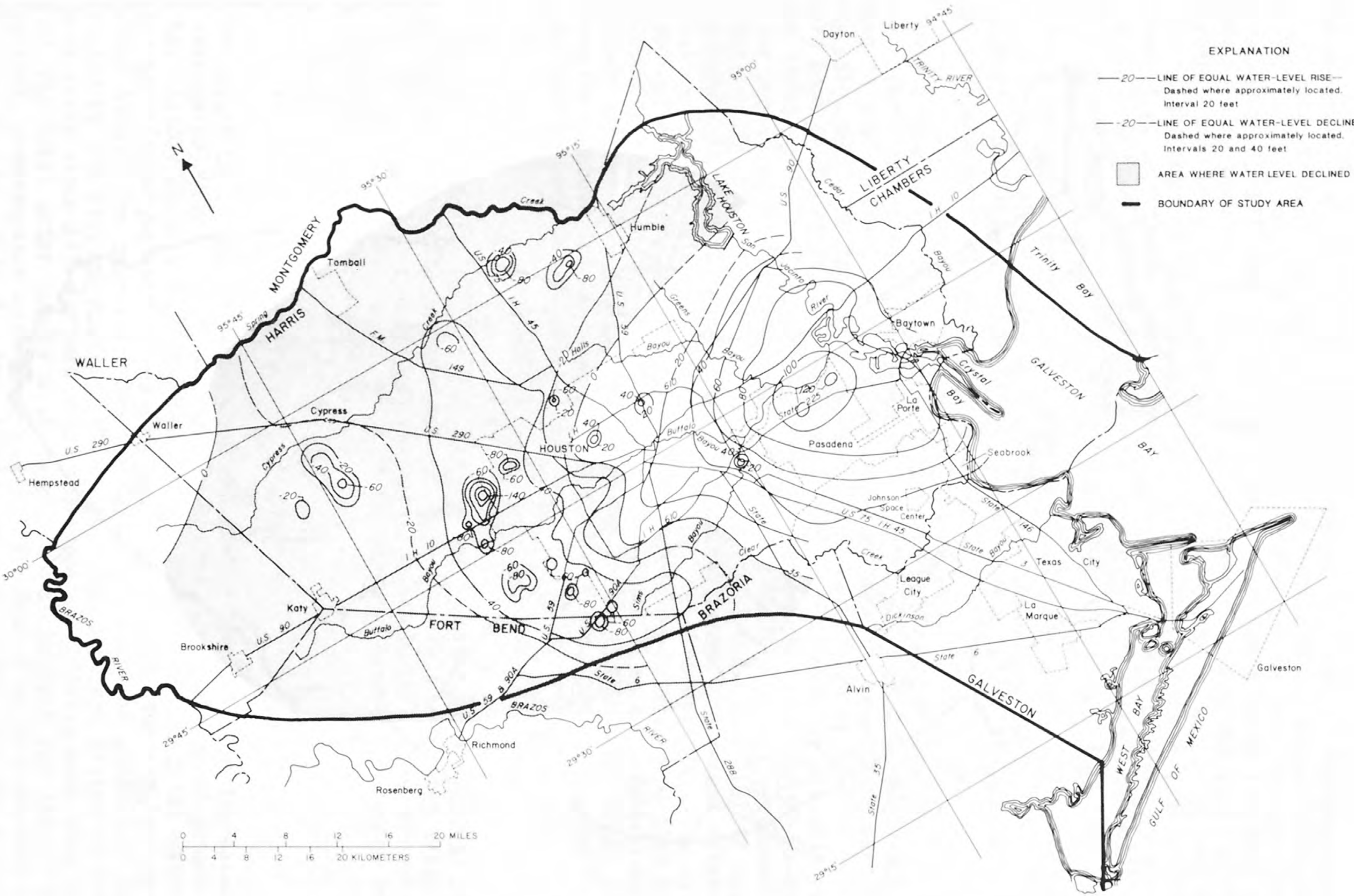


Figure 8.--Approximate water-level changes in wells in the Evangeline aquifer, spring 1977 to spring 1985.

Figure 9.--Approximate water-level changes in wells in the Chicot aquifer, spring 1980 to spring 1985.

Figure 10.--Approximate water-level changes in wells in the Evangeline aquifer, spring 1980 to spring 1985.

Figure 11.--Approximate altitude of water levels in wells in the Chicot aquifer, spring 1985.

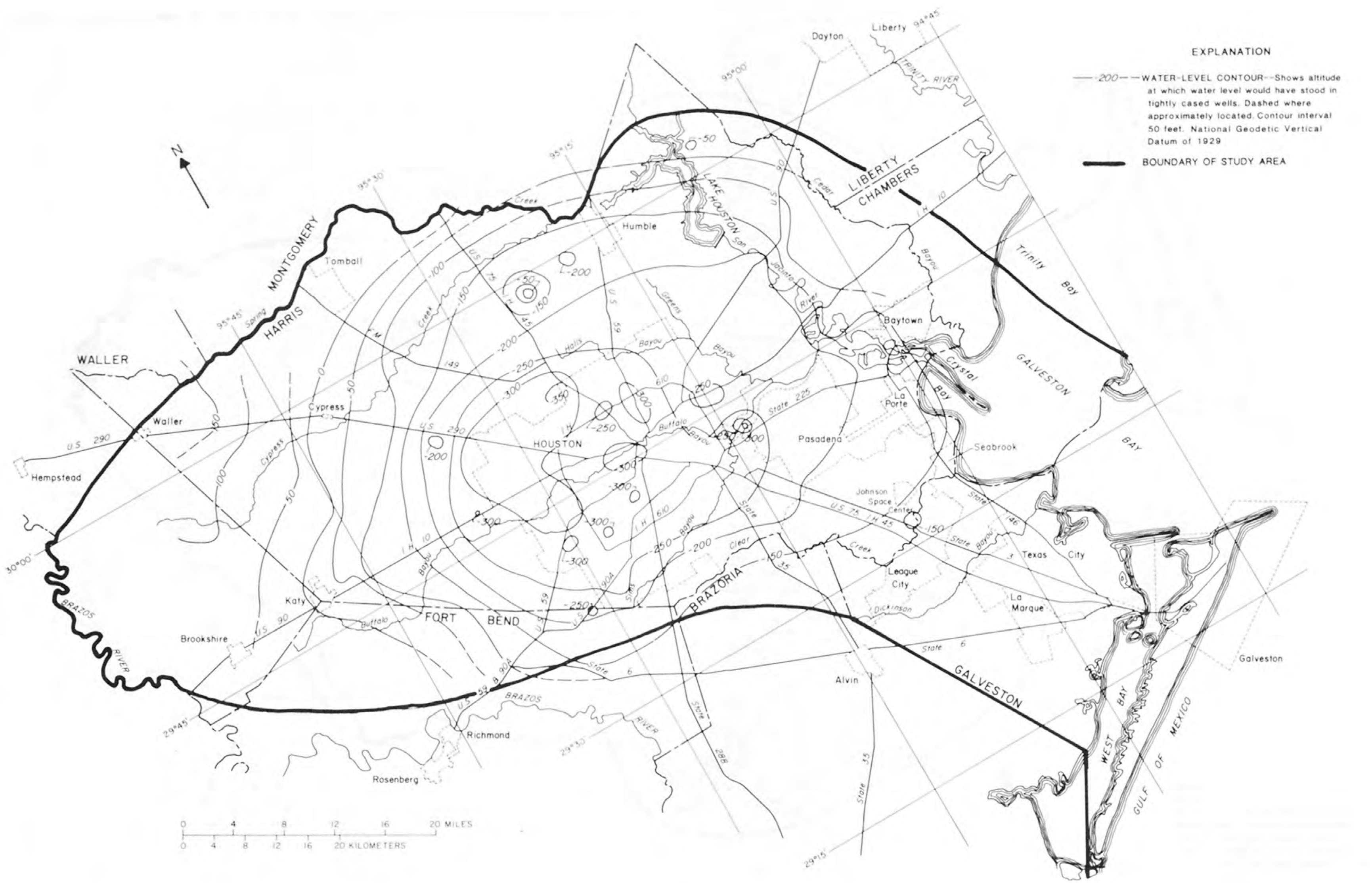


Figure 12.--Approximate altitude of water levels in wells in the Evangeline aquifer, spring 1985.

Table 5.--Average daily use of ground water and surface water by the city of Houston, 1975-84

Year	Use (million gallons per day)			Percentage of ground water to total
	Ground water	Surface water (treated plus untreated)	Total	
1975	150.7	148.8	299.5	50.3
1976	163.4	175.5	338.9	48.2
1977	185.2	184.6	369.8	50.1
1978	188.9	196.1	385.0	49.1
1979	203.0	171.1	374.1	54.3
1980	219.7	174.3	394.0	55.8
1981	217.5	167.1	384.6	56.6
1982	221.4	163.7	385.1	57.5
1983	180.3	157.2	337.5	53.4
1984	186.5	183.0	369.5	50.5

Mgal/d. The total water used by Houston also has decreased from the peak of 394.0 Mgal/d during 1980 to 369.5 Mgal/d during 1984. The reduction in total water use may be related to the depressed economic conditions existing in the Houston area during the past several years (1982-84). Precipitation records indicate the decrease in water use is not due entirely to climatic conditions. The average precipitation deviation during the summer months (June, July, and August), when water use is greatest, is shown for 1976-84 in figure 13. During 1981, summer precipitation was 10 in. greater than average and the total water used by the city of Houston was 384.6 Mgal/d. During 1982, summer precipitation was 3.7 in. less than normal, but, compared to 1981, total water use only increased by 0.5 Mgal/d to 385.1 Mgal/d (table 5). During 1983, summer precipitation was 9 in. greater than average and total water use decreased to 337.5 Mgal/d (table 5). Although some decrease would be expected because of increased summer precipitation, the total water use was the smallest since 1975 (table 5). During 1984, summer precipitation was 2.1 in. less than average and total water use increased to 369.5 Mgal/d (table 5). Although this increase was substantial compared to 1983, total water use was the second smallest since 1976 (table 5).

Changes in Water Levels

Water-level changes in wells in the Chicot aquifer from spring 1980 to spring 1985 ranged from rises of as much as about 60 ft in the eastern part of the Houston area to declines of as much as about 40 ft in the southwestern part of the area. In the eastern part of the Houston area, the water level rose about 7 ft in well LJ-65-14-738 (fig. 14) from January 1980 to January 1985. The hydrograph of well LJ-65-12-801 (fig. 14), completed in the Chicot aquifer and located in the western part of the Houston area, shows a water-level decline of about 12 ft during the same time.

Water levels in wells in the Evangeline aquifer rose as much as about 60 ft in the eastern part of the Houston area from 1980 to spring 1985 due to decreased ground-water withdrawals in the Houston and Pasadena areas (fig. 10). However, water levels in wells in the Evangeline aquifer declined as much as about 60 ft (fig. 10) in the western part of the Houston area due to continued ground-water withdrawals there and increased withdrawals in the adjacent Katy area. The hydrograph of well LJ-65-21-302 (fig. 14), located just south of the center of Houston, shows a water-level rise of 33 ft from January 1980 to January 1985. However, the water level in well LJ-65-20-216 (fig. 14), in the western part of the city of Houston, declined 23 ft from January 1980 to January 1985.

During spring 1985, the altitudes of water levels in wells in the Chicot aquifer were as much as 300 ft below sea level and in wells in the Evangeline aquifer they were as much as 350 ft below sea level.

Katy Area

Parts of Harris, Fort Bend, and Waller Counties comprise the Katy area (fig. 6). The area is predominantly rural, although housing subdivisions, commercial establishments, and light industries are commonplace in the northeastern one-half of the area. In terms of economic expansion, the Katy area was the fastest growing sector of the Houston district from 1980 through 1984.

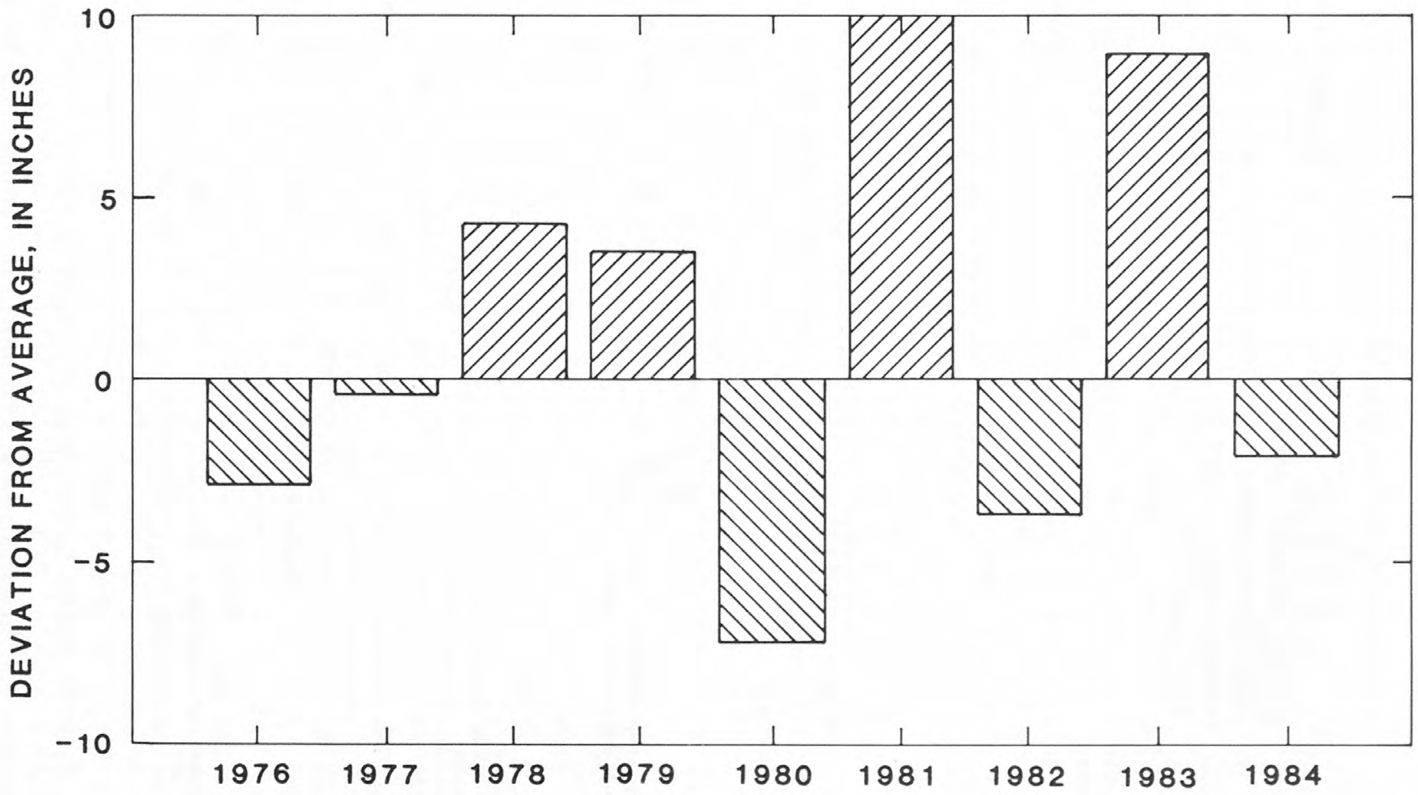


Figure 13.--Difference between average and actual summer (June, July, and August) precipitation, 1976-84.

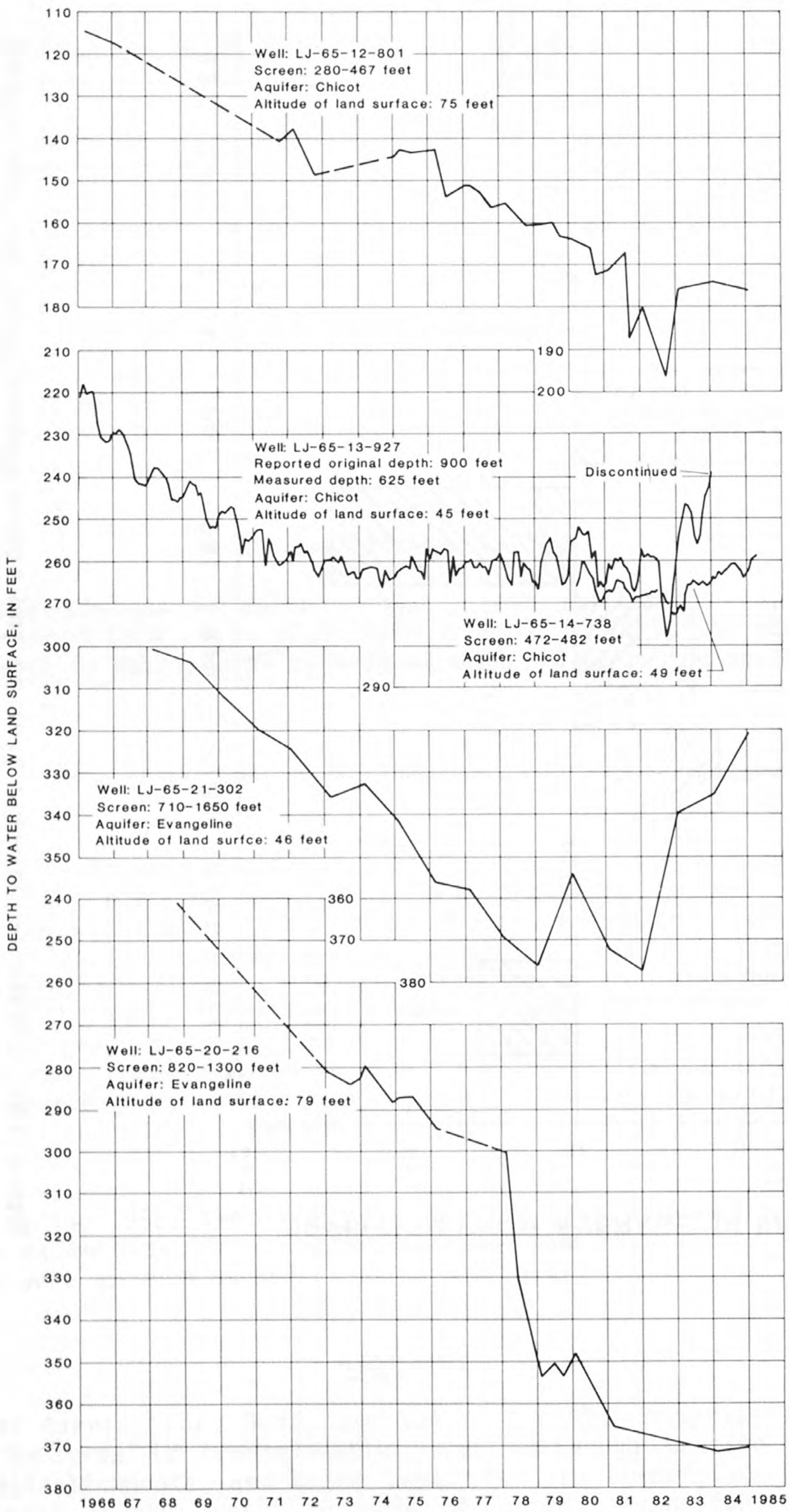


Figure 14.--Hydrographs of wells in the Houston area.

Ground-Water Withdrawals

Total ground-water withdrawals in the Katy area during 1984 were 150.0 Mgal/d; the total withdrawals during 1980 were 158.2 Mgal/d (table 2). The rates of ground-water withdrawals in the Katy area, by user, for 1980-84 are presented in table 6. There has been a substantial increase in ground water withdrawn for public supply between 1980 and 1984, whereas withdrawals for irrigation have decreased substantially. The irrigation withdrawals in Harris County for 1984, 23.0 Mgal/d, were 54 percent of the 1980 irrigation withdrawals of 42.5 Mgal/d. However, the total Harris County ground-water withdrawals were nearly the same for those years, 87.3 Mgal/d during 1984 and 84.9 Mgal/d during 1980. The Evangeline aquifer is the principal aquifer used for water supply in the area, although water pumped for irrigation comes from wells screened in both the Chicot and Evangeline aquifers.

In the Fort Bend County part of the Katy area, ground-water withdrawals during 1984 were 37.1 Mgal/d compared to 37.5 Mgal/d during 1980. Ground-water withdrawals for public supply increased from 13.2 Mgal/d during 1980 to 17.5 Mgal/d during 1984. Total ground-water withdrawals for irrigation were 16.1 Mgal/d during 1984 and 21.0 Mgal/d during 1980.

In the Waller County part of the Katy area, ground-water withdrawals decreased from 35.8 Mgal/d during 1980 to 25.6 Mgal/d during 1984. The decrease was due mainly to decreased pumpage for rice irrigation.

Rice Irrigation

Estimates of rice acreage planted and the quantity of ground water used for the irrigation of rice in the Katy area during 1977-84 are presented in table 7. The acreage measurement was obtained from the U.S. Department of Agriculture (oral commun., 1985) offices in Fort Bend, Harris, and Waller Counties. The quantity of ground water used at selected test farms, which are typical of rice farms in the area, was calculated from measurements of pumpage rates of the wells per unit power consumption and total power used by the wells during the growing season. Total pumpage for each selected farm was divided by the area of the farm to determine water applied per acre. The average of the quantity of water applied per acre at all test farms was multiplied by total acreage irrigated to estimate the quantity of ground water withdrawn for irrigation. Rice acreage planted during 1977-82 exceeded 40,000 acres. In 1983, rice acreage was less because the Department of Agriculture implemented the Payment-In-Kind (PIK) program to decrease planted acreage. The number of acres planted was decreased to 22,717 in 1983, but increased to 31,807 acres in 1984. The cost of producing rice and the encroachment of residential and commercial developments associated with the expansion of the Houston metropolitan area probably will limit the production of rice in future years.

Changes in Water Levels

Water levels in wells in the Chicot aquifer rose as much as about 20 ft in part of the Katy area and declined as much as about 40 ft (fig. 9) in other parts between spring 1980 and spring 1985. Most of the water-level rises occurred where withdrawals for irrigation had decreased. The hydrograph of

Table 6.--Average daily withdrawals of ground water in the Katy area by county, 1980-84

Use	Ground-water withdrawals (million gallons per day)		
	Harris County	Fort Bend County	Waller County
1980			
Public supply	30.0	13.2	0.7
Industry	12.4	3.3	.1
Irrigation	42.5	21.0	34.3
Total	84.9	37.5	35.1
1981			
Public supply	34.0	14.8	.8
Industry	10.3	2.7	.1
Irrigation	43.5	20.1	34.8
Total	87.8	37.6	35.7
1982			
Public supply	45.3	17.8	.9
Industry	8.1	2.7	.1
Irrigation	39.1	19.2	36.4
Total	92.5	39.7	37.4
1983			
Public supply	46.0	15.3	.9
Industry	8.0	2.8	.1
Irrigation	17.8	8.5	13.7
Total	71.8	26.6	14.7
1984			
Public supply	55.6	17.5	1.0
Industry	8.7	3.5	.1
Irrigation	23.0	16.1	23.4
Total	87.3	37.1	24.5

Table 7.--Rice acreage and quantity of ground water withdrawn for rice irrigation in the Katy area, 1977-84

Year	Acreage	Withdrawals (acre-feet per acre)	Total withdrawals (acre-feet)	Total withdrawals (million gallons per day)
1977	41,631	2.27	94,500	84.4
1978	48,107	2.56	123,150	109.9
1979	46,175	1.99	91,890	82.0
1980	45,086	2.43	109,560	97.8
1981	44,452	2.48	110,240	98.4
1982	41,149	2.58	106,160	94.7
1983	22,717	1.97	44,750	40.0
1984	31,807	2.20	69,980	62.5

water levels in well LJ-65-10-902 (fig. 15), screened mainly in the Chicot aquifer, coincides with the change in ground-water withdrawals for irrigation. In general, a constant rate of withdrawals caused a steady decline in water levels until 1979. Withdrawals for irrigation were fairly constant but at a decreased rate during 1979-82, and water levels stabilized during that period. During 1983 and 1984, the rate of ground-water withdrawals for irrigation decreased substantially, and, consequently, water levels rose as much as 20 ft.

Between spring 1980 and spring 1985, water levels in wells in the Evangeline aquifer in the Katy area ranged from rises of as much as about 10 ft to declines of as much as about 40 ft (fig. 10). Water levels in wells in the Evangeline aquifer (fig. 10) rose slightly in the western and southern parts of the Katy area and declined in the central, northern, and eastern parts of the area. A hydrograph of well LJ-65-03-405 (fig. 15), screened in the Evangeline aquifer and located in an expanding suburban section of the area, indicates that the water level declined 25 ft between January 1980 and January 1985. The water-level rises generally were located in rice-growing areas, and the declines were located in and near recently developed subdivisions and commercial establishments.

Pasadena Area

The Pasadena area, which is east of the Houston area and mostly west of the San Jacinto River (fig. 6), includes a large industrialized zone along the Houston Ship Channel. Large ground-water withdrawals began in the Pasadena area after 1937. Surface-water supplies from Sheldon Reservoir supplemented ground-water withdrawals beginning in 1942. Additional surface-water supplies from Lake Houston became available in the Pasadena area during 1954. Lake Livingston on the Trinity River became the primary water source for the area in 1977.

Ground-Water Withdrawals

Of the 39.9 Mgal/d of ground water withdrawn during 1984, 23.7 Mgal/d (60 percent), was for industrial use (table 2). The remaining 16.2 Mgal/d (40 percent) of ground water withdrawn was for public supply. Ground-water withdrawals have decreased substantially during the last 25 years. The maximum ground-water withdrawal was 125.7 Mgal/d during 1968 (Gabrysch, 1982, p. 4); after 1968, ground-water withdrawals decreased until 1982 and there has not been a substantial change since.

Changes in Water Levels

From spring 1980 to spring 1985, water levels rose in most of the Pasadena area. The water levels rose as much as about 60 ft in wells in the Chicot and Evangeline aquifers (figs. 9 and 10). Water levels declined in a small part of the area. The decline was as much as about 80 ft in one well in the Evangeline aquifer in the northern part of the area (fig. 10).

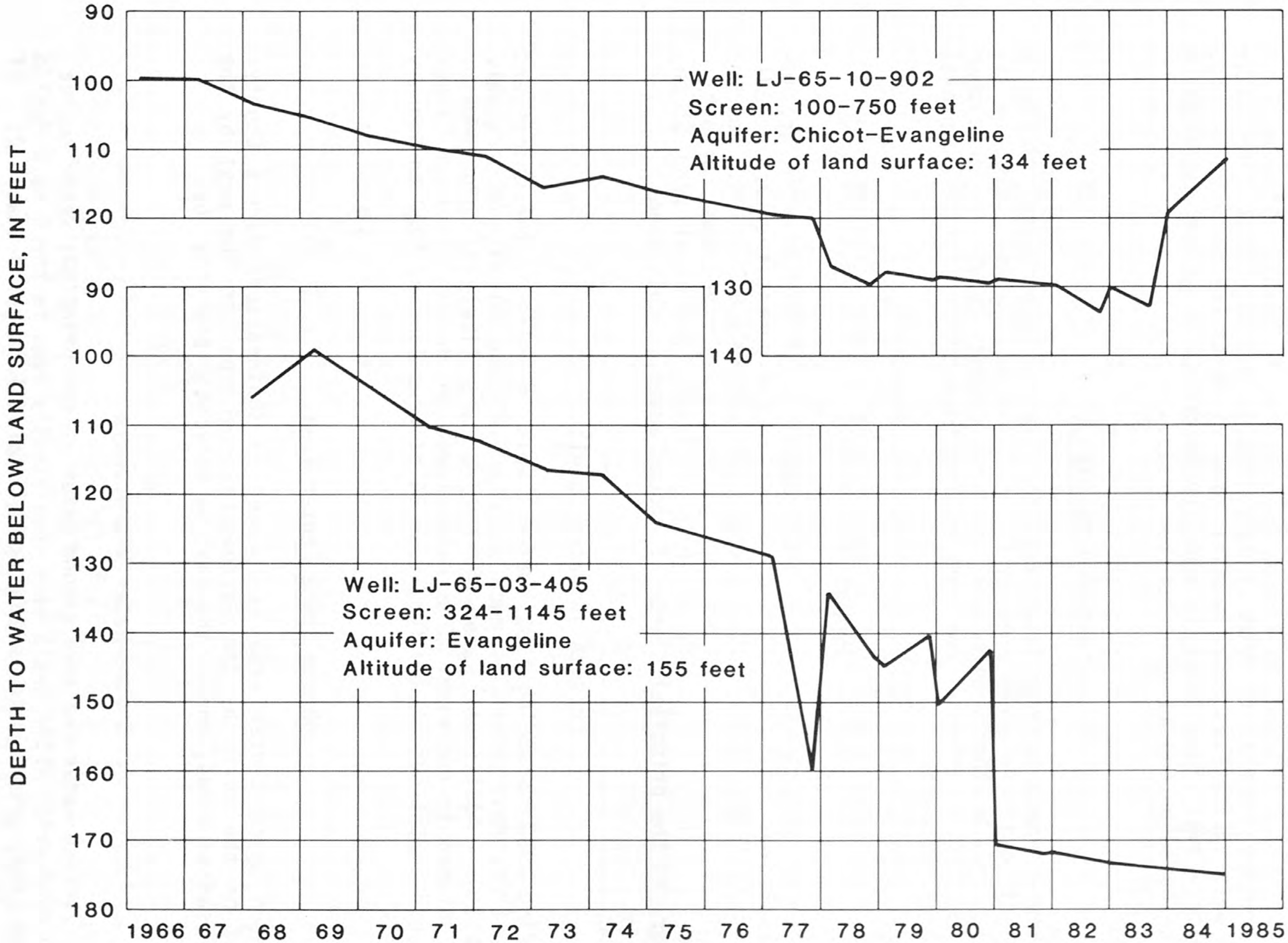


Figure 15.--Hydrographs of wells in the Katy area.

The hydrographs of wells LJ-65-23-220 (Chicot aquifer) and LJ-65-23-219 (Evangeline aquifer) are shown in figure 16. The water level in the well in the Chicot aquifer rose 32 ft from January 1980 to January 1985. The water level in the well in the Evangeline aquifer rose 20 ft during the same period. Additional water-level rises likely are due to decreases in ground-water withdrawals in the Pasadena and adjacent Houston areas.

Baytown-LaPorte Area

The Baytown-LaPorte area is located in the extreme eastern part of Harris County, adjacent to the Pasadena area on the west and to Chambers County on the east (fig. 6). In a northerly direction, the area extends about 8 mi on either side of the San Jacinto River. The area is comprised of industrial complexes and municipal developments.

Ground-Water Withdrawals

The availability of surface water has prompted large decreases in ground-water withdrawals for public supply and industrial use during the last decade. From 1976 through 1984, ground-water withdrawals decreased from 26.5 to 5.2 Mgal/d. Of the 5.2 Mgal/d withdrawn during 1984, 85 percent was for public supply (table 2). The Alta Loma Sand of Rose (1943), the basal sand of the Chicot aquifer, is the principal source of ground water in this area.

Changes in Water Levels

From spring 1980 to spring 1985, water levels in wells in the Chicot and Evangeline aquifers have risen as much as about 60 and 40 ft, respectively (figs. 9 and 10). Additional water-level rises are likely if ground-water withdrawals continue to decrease. The water level in observation well LJ-65-24-501, screened in the Chicot aquifer, rose 34 ft from January 1980 to January 1985 (fig. 17).

Johnson Space Center Area

The Johnson Space Center area is located in southeastern Harris County. It is bounded on the north by the Baytown-LaPorte area, on the west by the Houston and Pasadena areas, and on the east by Galveston Bay (fig. 6).

Ground-Water Withdrawals

In 1977, surface water replaced ground water as the principal water source. Since 1978, ground-water withdrawals have consistently been in the 4 to 5 Mgal/d range. During 1984, ground-water withdrawals totaled 4.8 Mgal/d (table 2). Of this quantity, 85 percent was for public supply. Most ground water used in this area is from the Chicot aquifer.

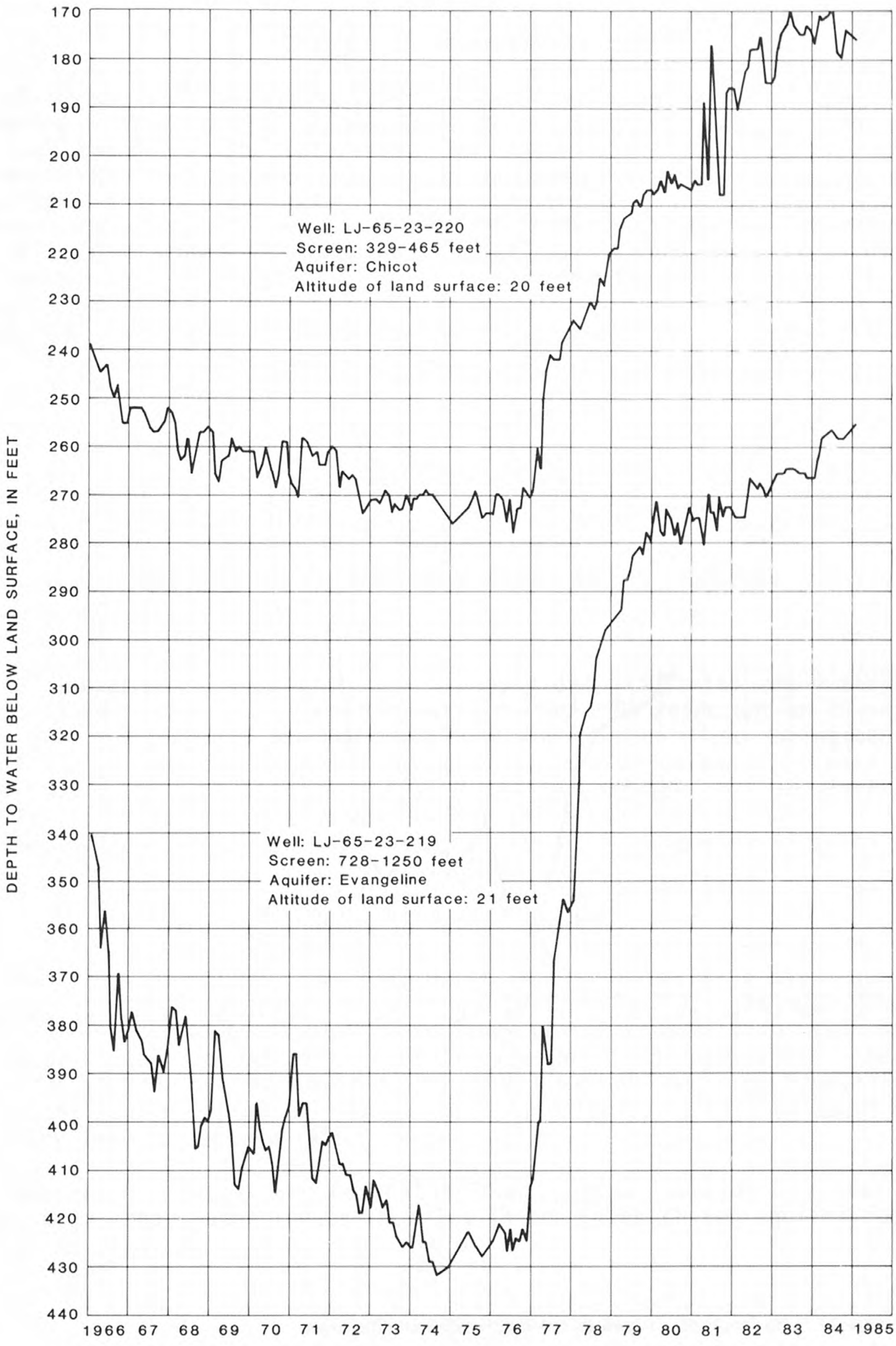


Figure 16.--Hydrographs of wells in the Pasadena area.

Figure 17.--Hydrograph of well in the Baytown-LaPorte area.

Changes in Water Levels

From spring 1980 to spring 1985, water levels in wells in the Chicot aquifer rose in most of the Johnson Space Center area. As much as about 20 ft of rise was measured. The water level in one well declined less than 10 ft. Water levels in wells in the Evangeline aquifer rose as much as about 10 ft from spring 1980 to spring 1985 (fig. 10). Water levels did not decline in any wells in the Evangeline aquifer. A hydrograph of water levels in well LJ-65-32-406 in the Chicot aquifer (fig. 18) shows a generally steady rise in water levels since 1976, interrupted by a very rapid rise in late 1978. The steady rise beginning in 1976 resulted from decreases in ground-water withdrawals. The rapid rise in 1978 is attributed to a gas-well rupture and a subsequent pressure increase in the aquifer (Gabrysch, 1982, p. 27).

Texas City Area

Texas City and the city of LaMarque and the adjoining area comprise the Texas City area (fig. 6). The economy of this area, which is located in Galveston County, is based on the petrochemical industry.

Ground-Water Withdrawals

Ground-water withdrawals for public supply and industrial use during 1984 were 1.0 Mgal/d (table 3). The withdrawals during 1984 represent an 89-percent decrease from the 9 Mgal/d used during 1980. Public-supply use during 1984 was 0.6 Mgal/d or 60 percent of the total ground water withdrawn. In this area, the upper and middle parts of the Chicot aquifer provide most of the ground water. The lower part of the Chicot aquifer (Alta Loma Sand of Rose, 1943) and the Evangeline aquifer contain water that is slightly to moderately saline.

Changes in Water Levels

From spring 1980 to spring 1985, water levels in wells in the lower part of the Chicot aquifer rose as much as about 10 ft (fig. 9). The hydrograph of water levels in well KH-64-33-810 in the lower Chicot aquifer (fig. 19) shows a gradual water-level rise of 18 ft from January 1980 to January 1985. The combined hydrographs of wells KH-64-33-901 and KH-64-33-905, completed in the middle Chicot aquifer (fig. 19), show a general water-level rise of about 80 ft from January 1980 to January 1985.

Elsewhere in northeastern Galveston County, in a location 8 mi north of the Texas City area, water levels in wells in the lower Chicot aquifer rose as much as 80 ft (fig. 9).

Alta Loma Area

The Alta Loma area is located in west-central Galveston County (fig. 6) and contains the well fields for the city of Galveston and the town of Alta Loma.

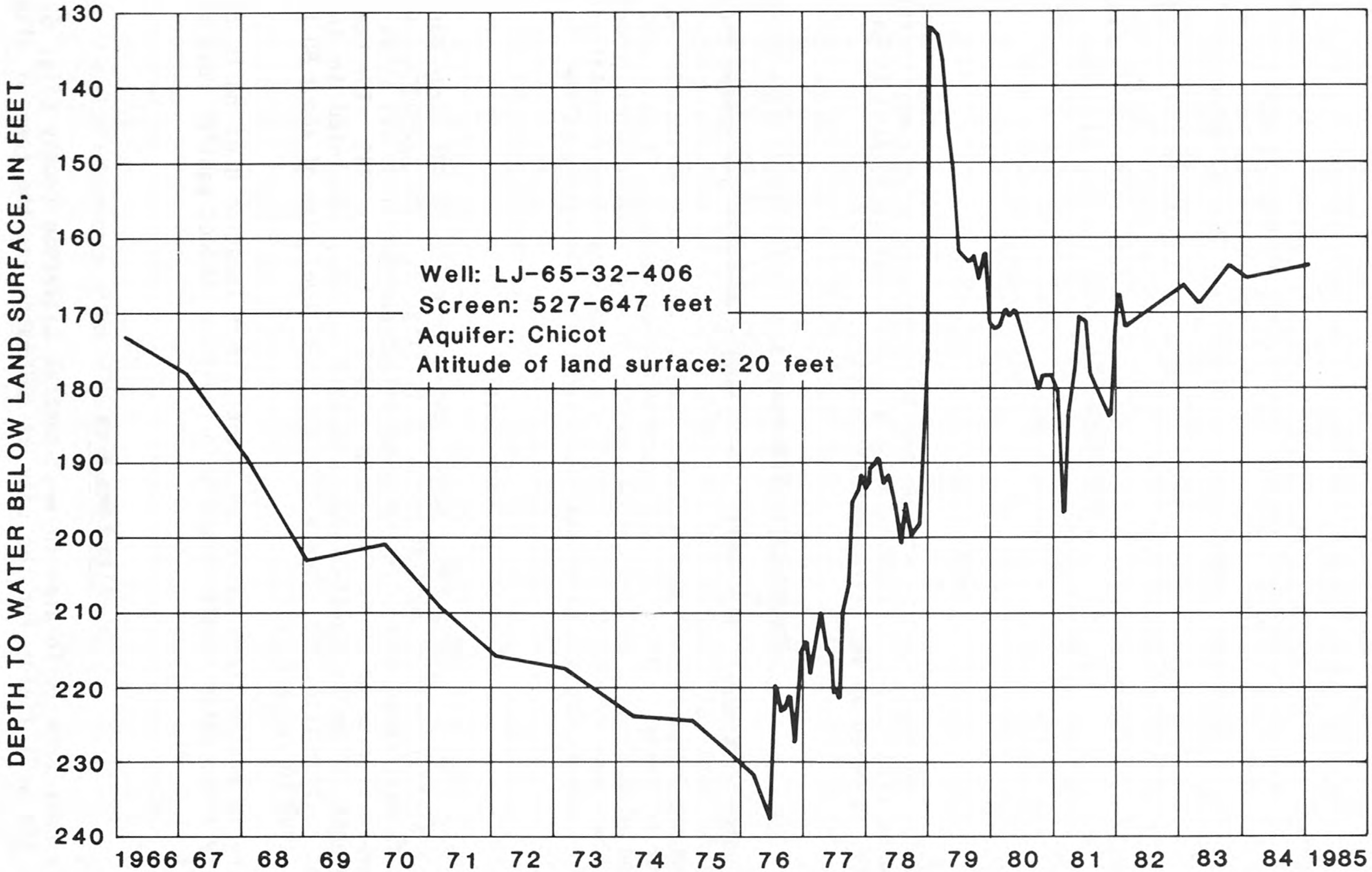


Figure 18.--Hydrograph of well in the Johnson Space Center area.

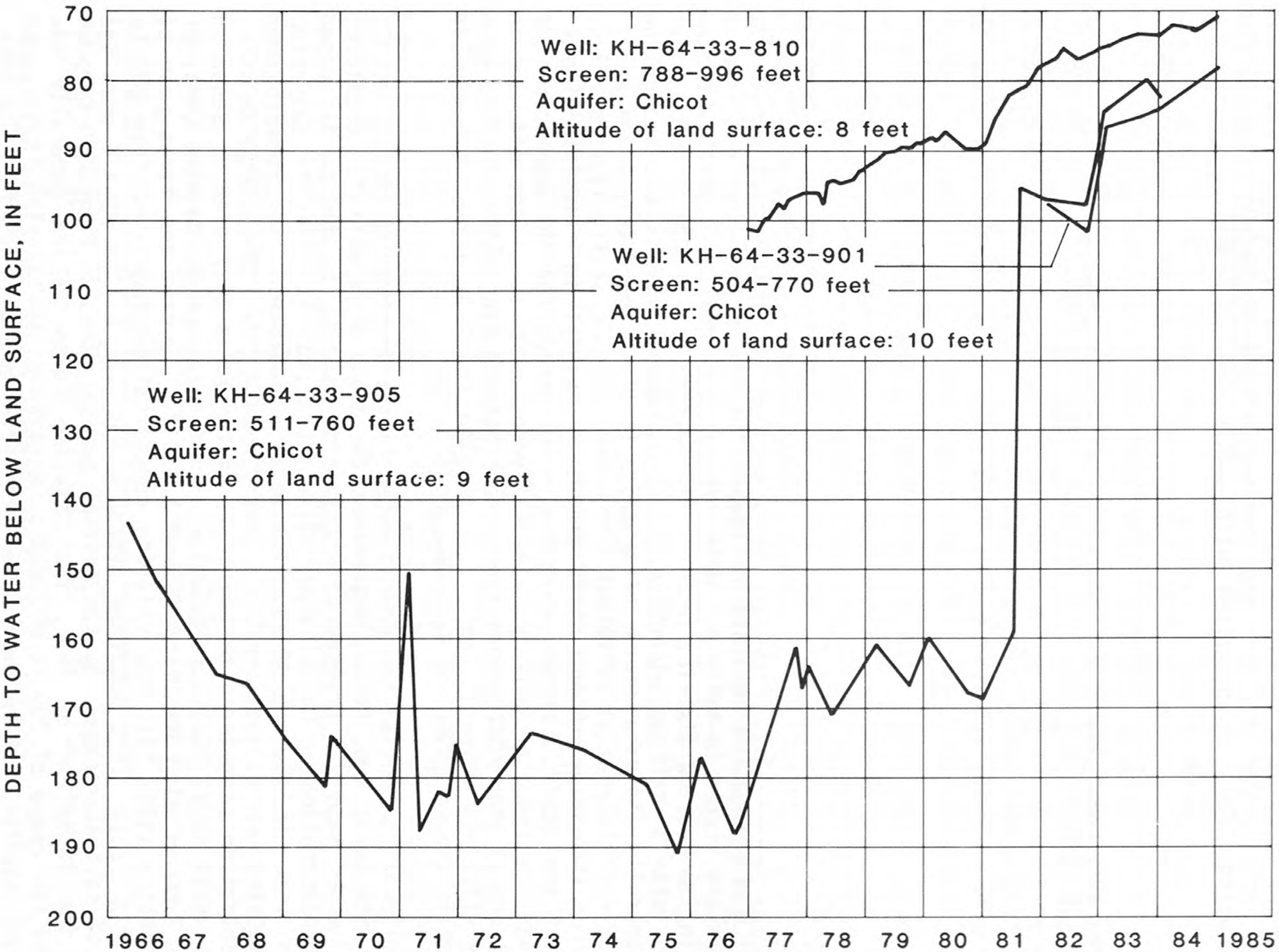


Figure 19.--Hydrographs of wells in the Texas City area.

Ground-Water Withdrawals

In the Alta Loma area, as in the Texas City area, surface water has replaced ground water as the principal water source. The conversion to surface water began in 1972. Ground-water withdrawals during 1972 were 13.0 Mgal/d (Gabrysch, 1982, p. 9). By 1980, ground-water withdrawals had decreased to 1.8 Mgal/d. During 1984, ground-water withdrawals were 2.4 Mgal/d (table 3).

Changes in Water Levels

In the Alta Loma area, water levels in wells in the Chicot aquifer rose as much as about 20 ft from spring 1980 to spring 1985 (fig. 9). The rise in water levels in well KH-65-40-707, which is in the Chicot aquifer (Alta Loma Sand of Rose, 1943), is shown in figure 20. Water levels in this well rose only about 6 ft from 1980 to 1985, but rose nearly 40 ft since surface water was introduced in 1973.

CHANGES IN CHEMICAL QUALITY OF GROUND WATER

The chemical and biological characteristics of water determine its usefulness for industry, agriculture, or homes. Water dissolves mineral matter present in soils, sediments, and rocks. Selected chemical analyses of water from the Chicot and Evangeline aquifers in several of the major areas outlined in this report are listed in table 8. Water of suitable quality generally can be obtained in the Houston district from relatively deep wells. The Chicot aquifer generally yields a calcium bicarbonate (hard) water, whereas the Evangeline aquifer generally yields a sodium bicarbonate (soft to moderately hard) water. Analyses of constituents at different times are shown in Stiff diagrams (figs. 21 and 22). The shape of the Stiff diagram is useful in classification of water. Also the Stiff diagrams provide a rapid method for the comparison of large changes in chemical quality. The different patterns of the diagrams in figures 21 and 22 show that waters from the Chicot and Evangeline aquifers have distinctly different compositions in the Houston and Katy areas, but similar composition in the Pasadena and Baytown-LaPorte areas.

The mineral content of the ground water in the Houston district generally increases with depth and, hence, determines the depth of a well for obtaining a potable water supply. Greater mineralization usually is due to increased chloride concentrations. Chloride-concentration trends at sites in Galveston County are shown in figures 23-25. Saltwater encroachment is probable when aquifers located near coastal areas are pumped excessively. The change in chloride concentration in water from two wells in the Texas City area is shown in figure 23. Well KH-65-48-316 is screened in the basal sand, the Alta Loma, of the Chicot aquifer at a depth of 950 to 1,060 ft. During the first year of water production (1969-70), the chloride concentration increased from 280 to 720 mg/L (fig. 23). This increase probably was due to the upward vertical migration of saltwater caused by the initial pumping stress. From 1970 through 1984 with the exception of 1976, the chloride concentration generally has remained in the range of 700 to 800 mg/L. Well KH-65-48-301 also is screened in the Chicot aquifer, but in the middle part, between 656 to 780 ft. The chloride concentration increased an average of 10 mg/L (milligrams per liter) per

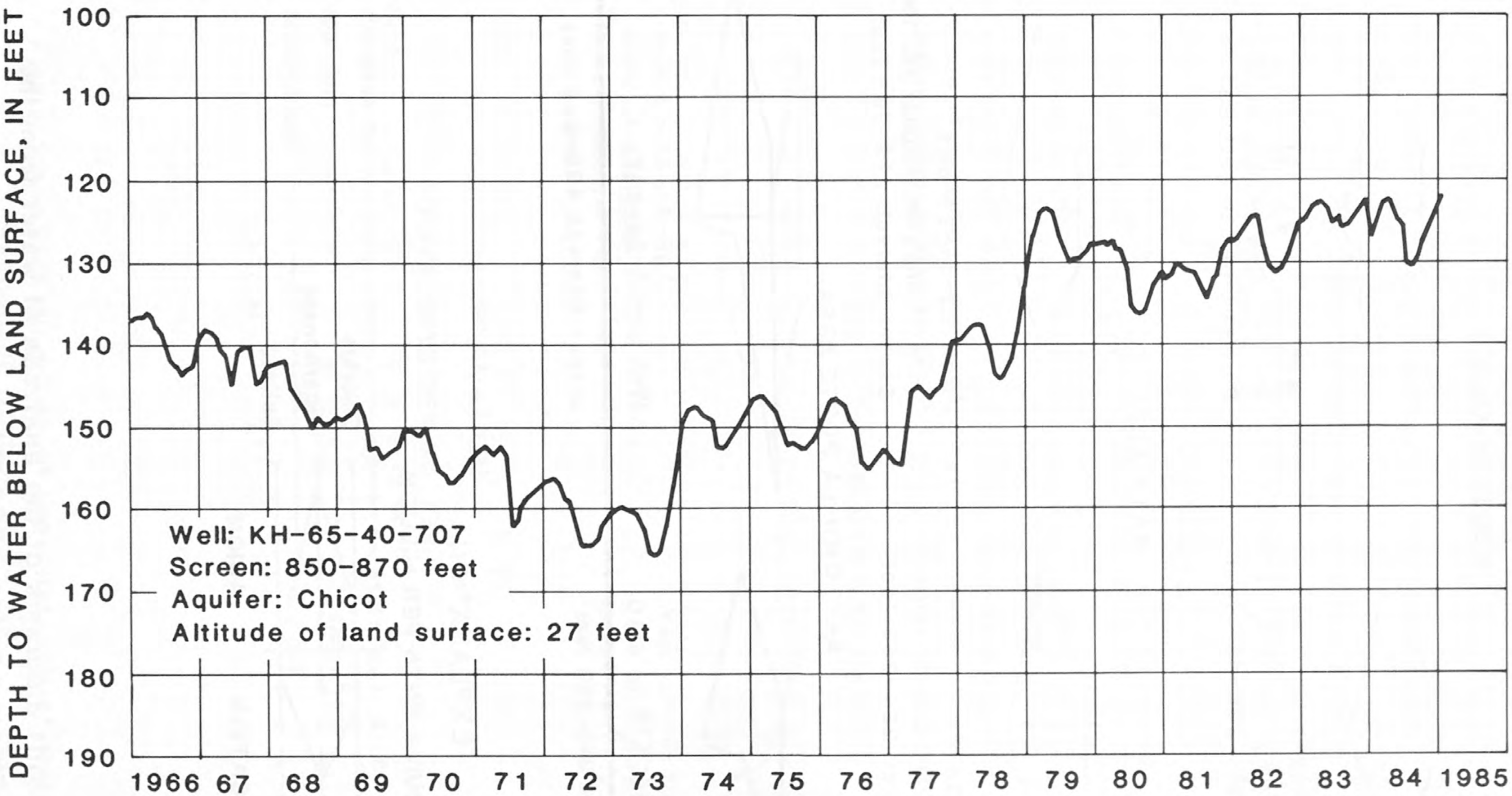


Figure 20.--Hydrograph of well in the Alta Loma area.

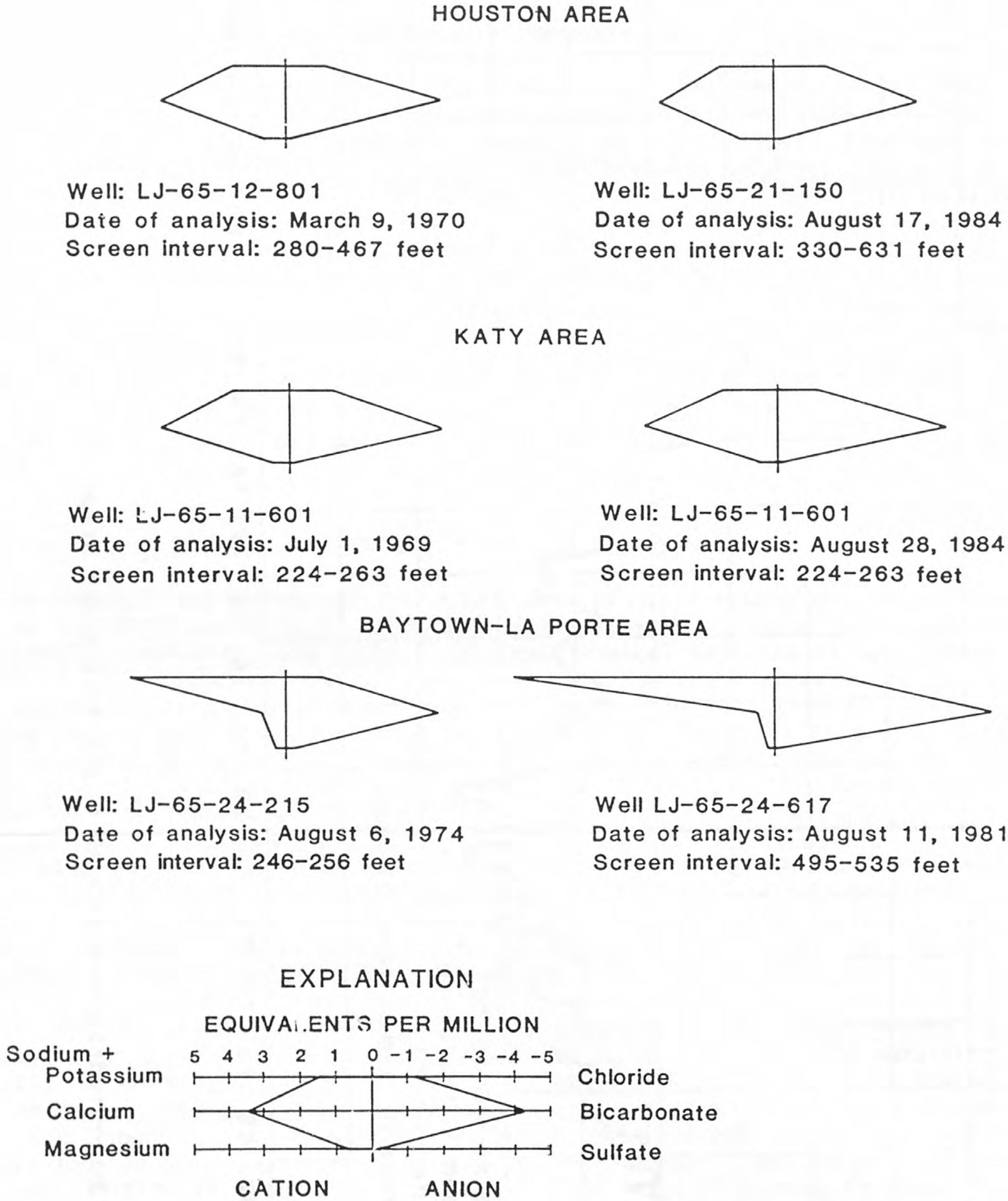
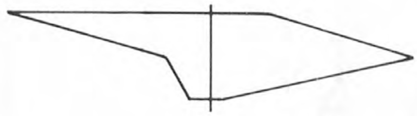
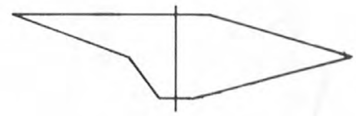


Figure 21.--Stiff diagrams of the analyses of water from the Chicot aquifer, 1969-84.

HOUSTON AREA

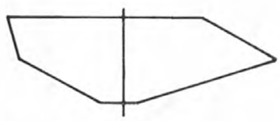


Well: LJ-65-13-746
Date of analysis: September 23, 1970
Screen interval: 964-1478 feet

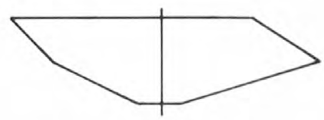


Well: LJ-65-13-749
Date of analysis: February 10, 1984
Screen interval: 786-1506 feet

KATY AREA

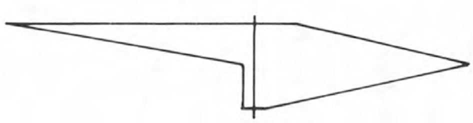


Well: LJ-65-10-913
Date of analysis: January 26, 1971
Screen interval: 610-1055 feet

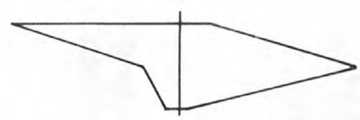


Well: LJ-65-10-916
Date of analysis: June 26, 1979
Screen interval: 540-856 feet

PASADENA AREA



Well: LJ-65-15-501
Date of analysis: June 21, 1961
Screen interval: 800-1188 feet



Well: LJ-65-15-428
Date of analysis: April 9, 1982
Screen interval: 742-1530 feet

EXPLANATION

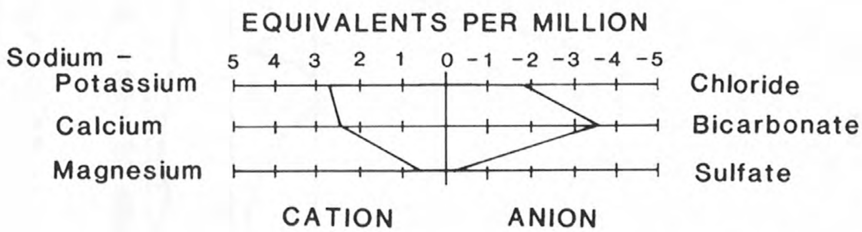


Figure 22.--Stiff diagrams of the analyses of water from the Evangeline aquifer, 1961-84.

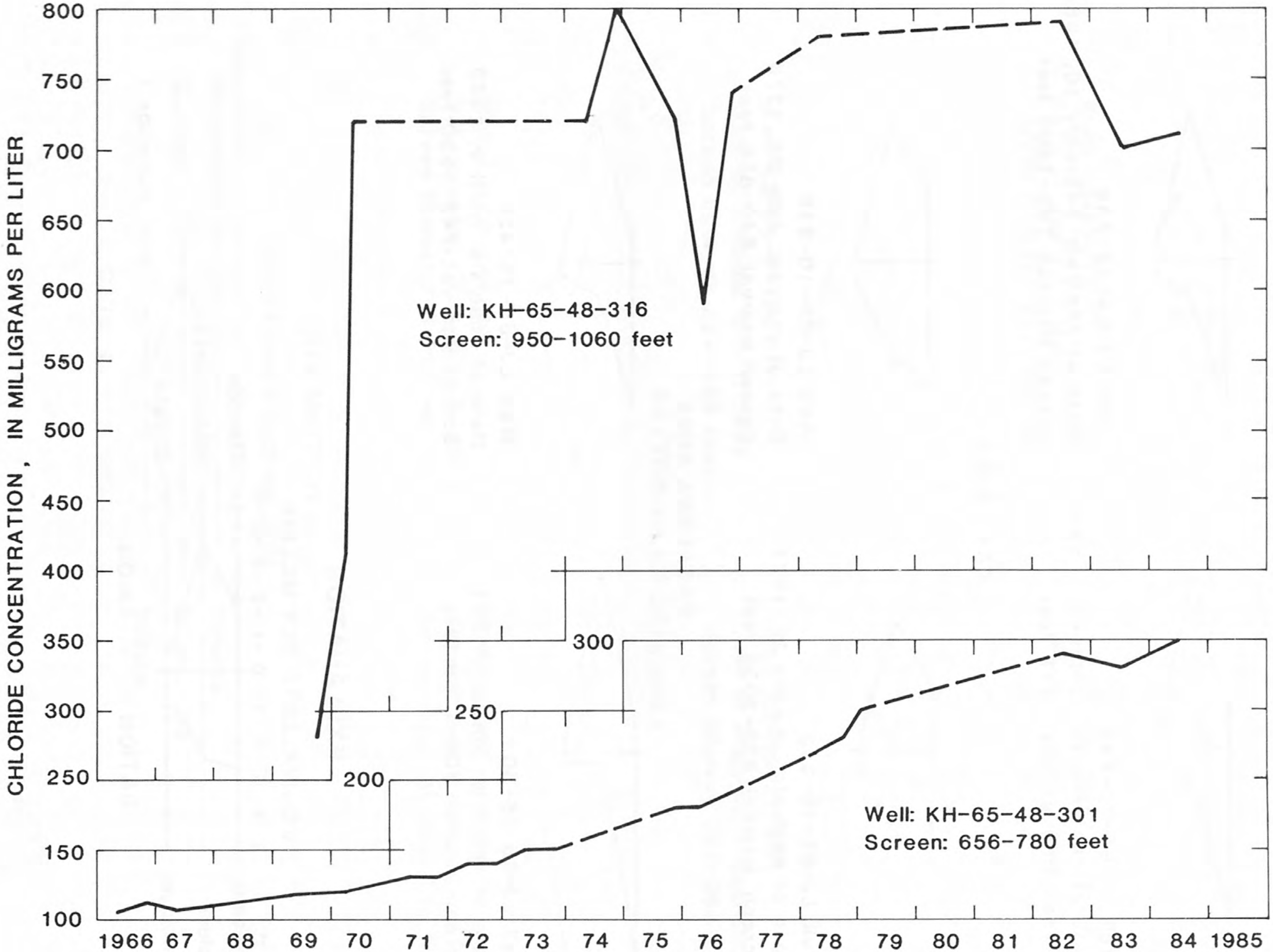


Figure 23.--Changes in chloride concentrations in water from two wells completed in the Chicot aquifer in the Texas City area.

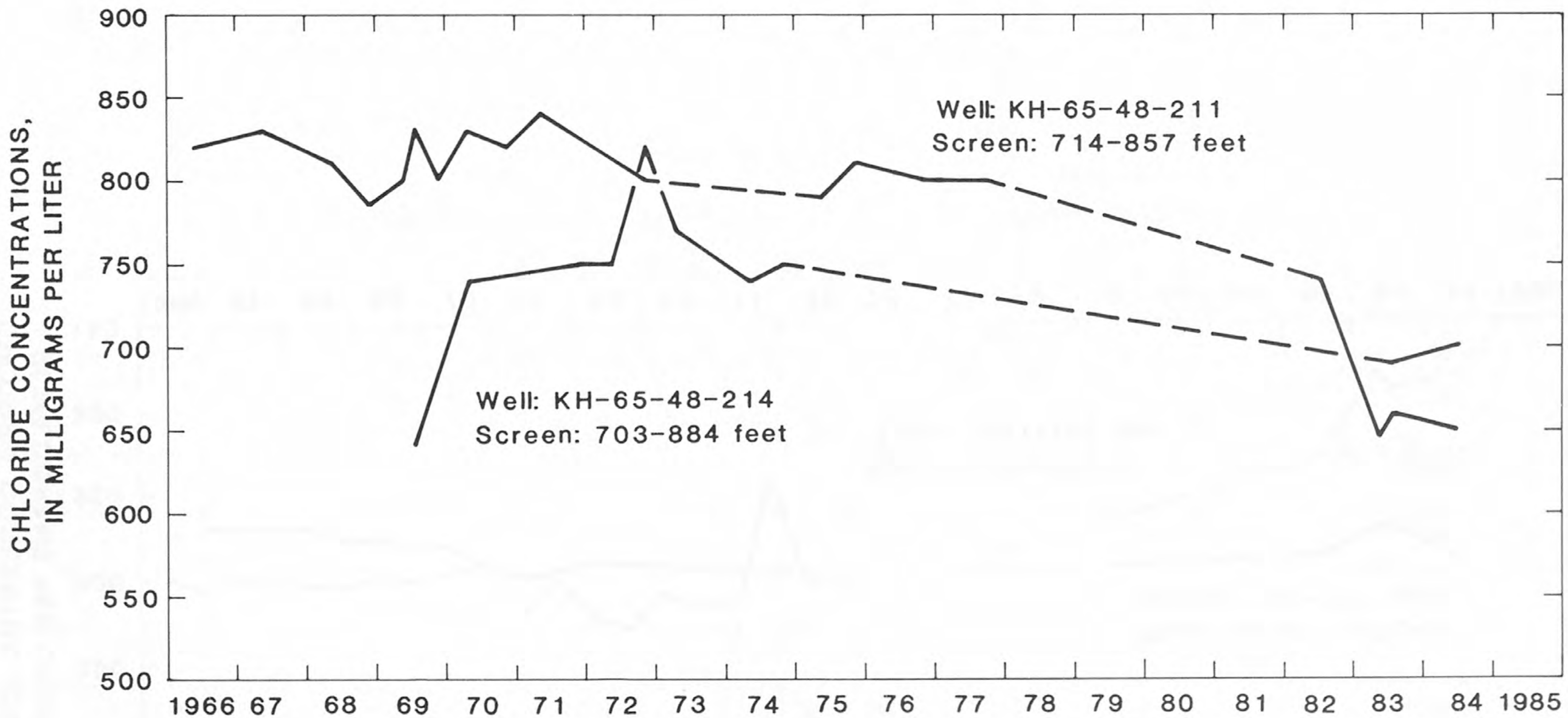


Figure 24.--Changes in chloride concentrations in water from two wells completed in the Chicot aquifer in the city of Galveston's "old" well field at Alta Loma.

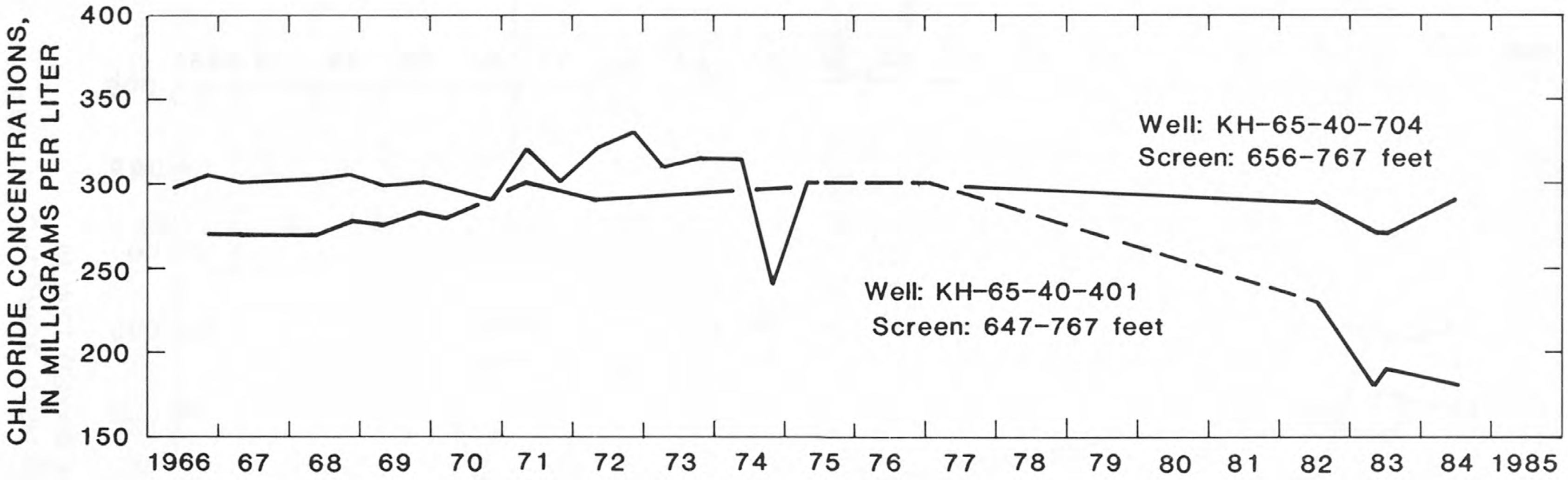


Figure 25.--Changes in chloride concentrations in water from two wells completed in the Chicot aquifer in the city of Galveston's "new" well field north of Alta Loma.

Table 8.--Selected chemical analyses of water from the Chicot and Evangeline aquifers, 1979-84

[Analyses given in milligrams per liter except pH, which is in standard units, and specific conductance, which is in microsiemens per centimeter at 25 °Celsius. Location of wells shown in figure 6.]

Well number	Area	Aquifer	Date	Producing interval	Specific conductance	pH	Hardness as $CaCO_3$	Calcium	Magnesium	Sodium	Bicarbonate	Sulfate	Chloride	Fluoride	Silica	Dissolved solids, sum of constituents	Iron	Manganese	Source of analysis
LJ-65-21-150	Houston	Chicot	05-03-82	330-631	514	7.4	220	69	11	32	260	9.0	47	0.20	22	400	<0.050	<0.050	Edna Woods Laboratories
LJ-65-13-749	Houston	Evangeline	02-10-84	786-1,506	486	7.6	70	22	4.0	88	250	15	28	.50	18	380	.100	.010	Edna Woods Laboratories
LJ-65-11-601	Katy	Chicot	08-28-84	224-263	542	7.6	210	75	5.9	35	290	5.4	41	.20	29	430	--	.002	U.S. Geological Survey
LJ-65-10-916	Katy	Evangeline	06-26-79	540-856	549	7.2	150	50	6.0	75	230	17	76	1.0	10	420	.050	.050	Curtis Laboratories
LJ-65-15-428	Pasadena	Evangeline	04-09-82	742-1,530	478	8.0	56	16	4.0	90	250	7.0	24	.60	14	360	.070	.050	Edna Woods Laboratories
LJ-65-24-617	Baytown-LaPorte	Chicot	08-11-81	495-535	777	8.0	33	10	2.0	170	370	--	66	1.3	21	570	--	.050	Edna Woods Laboratories

year from 1966 to 1984. In mid-1980, the chloride concentration was about 265 mg/L; in mid-1984, the chloride concentration had increased slightly to 300 mg/L.

The changes in chloride concentration in water from two wells in the Chicot aquifer in the city of Galveston's "old" well field at Alta Loma are shown in figure 24. The chloride concentration in water from these wells decreased from a range of 700 to 800 mg/L in 1977 to a range of 600 to 700 mg/L in 1984, due to decreases in withdrawals. Trends in chloride concentrations in water from two wells in the Chicot aquifer in the city of Galveston's "new" well field, located north of Alta Loma, are shown in figure 25. The chloride concentration between 1966 and 1977 remained relatively constant at 270 to 320 mg/L. From 1977 to 1984, the chloride concentration in water from well KH-65-40-401 (fig. 24) decreased from 300 to 180 mg/L due to decreases in withdrawals.

Chemical analyses of water from the Jasper aquifer in the northern part of Harris County indicate that concentrations of some constituents are about at the allowable limits for potable water. In 1981 for example, water from well LJ-60-61-210 contained 515 mg/L dissolved solids and 425 mg/L bicarbonate as determined by the Texas Department of Health (1983, p. 61).

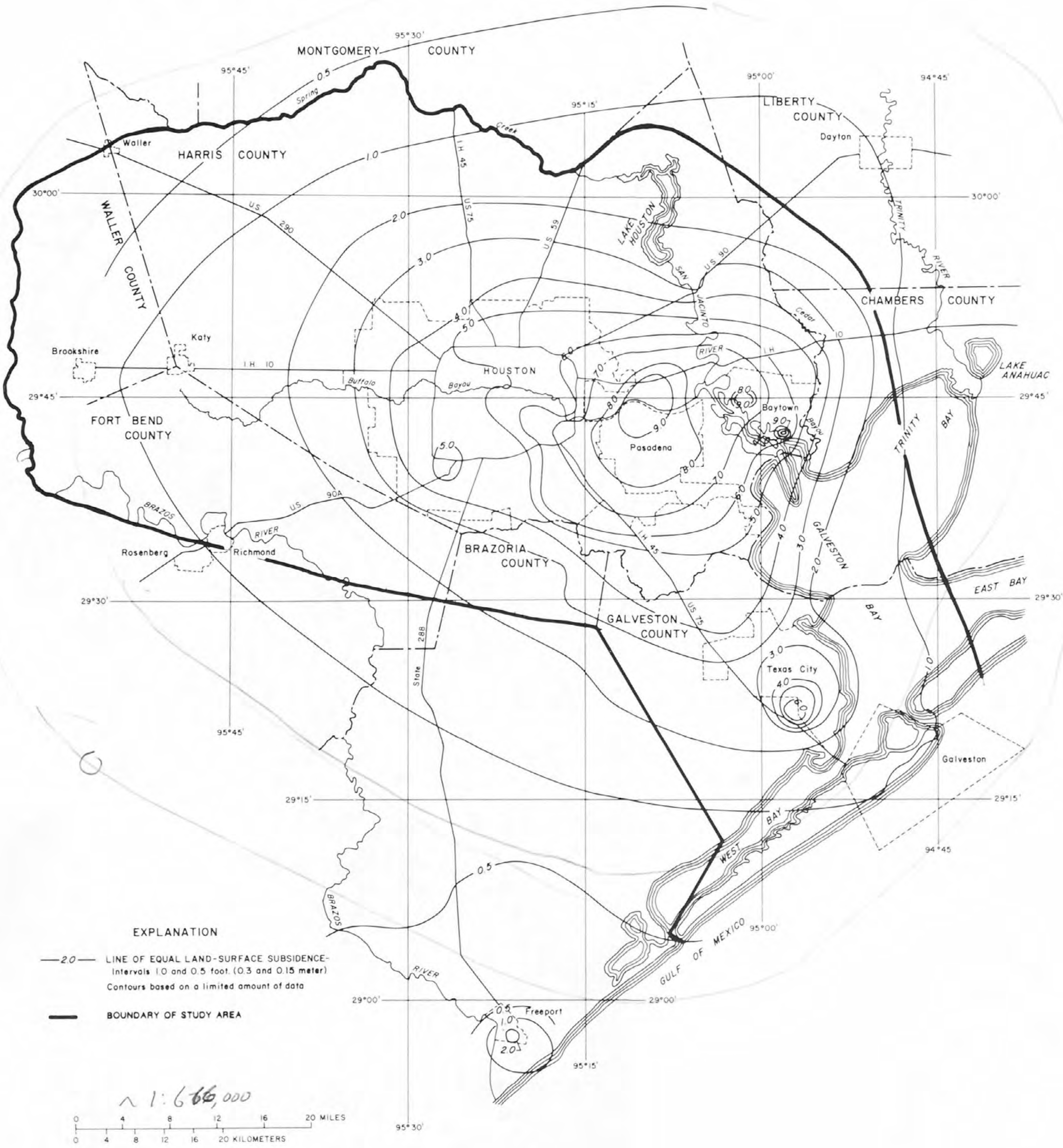
CHANGES IN LAND-SURFACE SUBSIDENCE

Land-surface subsidence, or the gradual sinking of the land surface due to the compaction of unconsolidated sediments, can result from the depressuring of ground-water aquifers or oil and gas reservoirs by fluid withdrawal.

The land surface in the Houston district has subsided for many years. The approximate subsidence in the Houston district and vicinity from 1906 to 1978 is shown in figure 26. Ground-water withdrawals are the main contributor to subsidence (Gabrysch, 1982, p. 1). The location of borehole extensometers in the Houston district is shown in figure 27. The extensometers measure compaction between land surface and a specific depth interval. The compaction that has taken place at the extensometer sites between 1973 and early 1985 is shown in figure 28. In areas where water-level declines have stopped because ground-water withdrawals have decreased (Pasadena, Baytown-LaPorte, Johnson Space Center, and Texas City), the rate of compaction has slowed or stopped. At the Seabrook site (fig. 28), the compaction rate during 1975-79 was 0.14 ft/yr. The rate had slowed to 0.04 ft/yr from 1980 to early 1985. In areas where ground-water levels are still declining (parts of the Houston and Katy areas), the rate of compaction has increased. At the Addicks site (fig. 28), the land surface has subsided at a rate of about 0.11 ft/yr from 1975 through 1979; the rate from 1980 to early 1985 was 0.17 ft/yr.

SUMMARY AND CONCLUSIONS

In terms of ground-water use in the Houston district, 1980-84 represented a transition interval. During this period, total ground-water use decreased substantially, and total surface-water use increased. Ground-water withdrawals during 1984 were 444 Mgal/d in comparison to 511 Mgal/d during 1980. From 1980 through 1984, the use of ground water for public supply decreased substantially.



~1:666,000

1 cm² = 10,965 acres

Modified from Gabrysch, 1982

Figure 26.--Approximate land-surface subsidence, 1906-78, Houston district and vicinity.

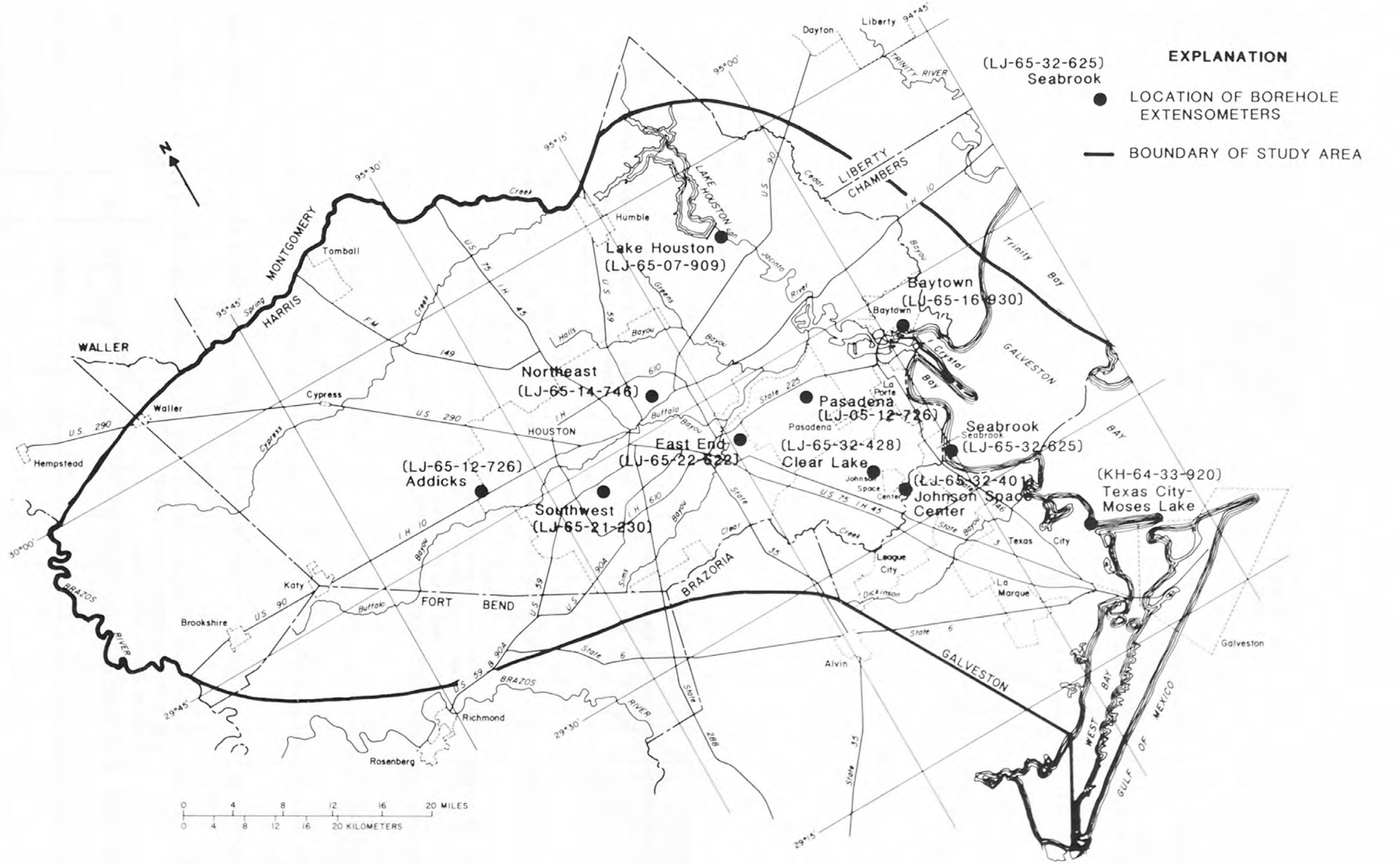


Figure 27.--Location of borehole extensometers.

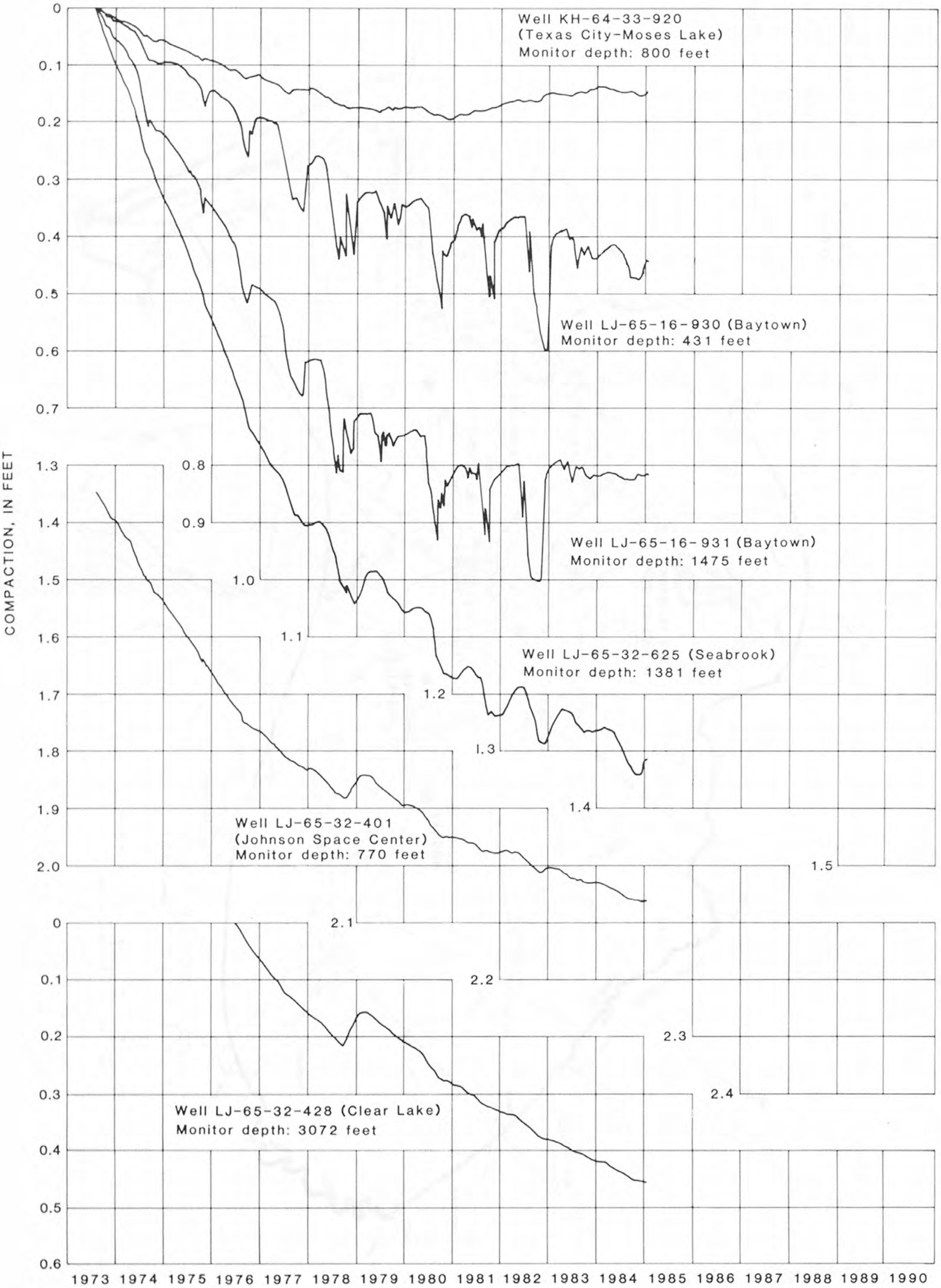


Figure 28.--Measured compaction, 1973-85.

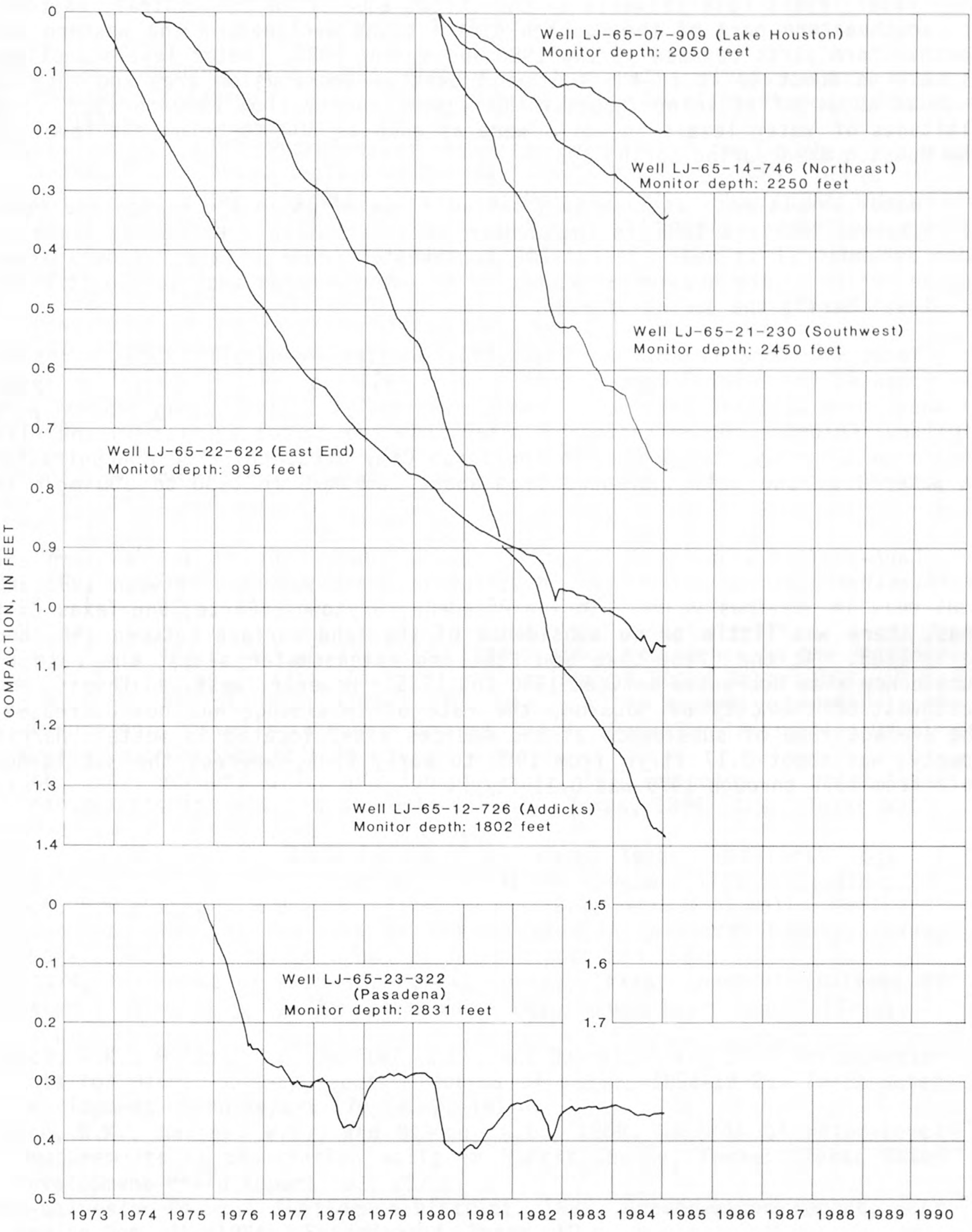


Figure 28.--Measured compaction, 1973-85--Continued.

Water levels rose in wells in the Chicot aquifer in the central, eastern, and southeastern part of the Houston district and declined in the western and southwestern parts between spring 1980 and spring 1985. Water levels declined as much as about 40 ft in the southwest part of the Houston area and rose as much as about 80 ft in northeastern Galveston County from 1980 to 1985. The altitudes of water levels in wells were as much as 300 ft below sea level in the Houston area during spring 1985.

Water levels rose as much as about 60 ft in wells in the Evangeline aquifer between 1980 and 1985 in the center of the Houston area and declined as much as about 80 ft near the extreme southwestern edge of the Pasadena area. In the center of the Houston area, depths to water were as much as 350 ft below sea level during the spring of 1985.

Water from the Chicot and Evangeline aquifers generally appears not to have changed in chemical composition between 1980 and 1984. Chemical analyses of water from wells in the 1960's compared to analyses made during 1980-84 were similar. Chloride concentration in water from the Chicot aquifer in the Alta Loma area slightly decreased. In the Texas City area, chloride concentration in water from one well increased from about 265 mg/L in 1980 to 300 mg/L in 1984.

Land-surface subsidence is still very evident, but in the eastern and southeastern parts of the Houston district the rate was less between 1980 and 1985 than in previous years. In the Pasadena, Baytown-LaPorte, and Texas City aras, there was little or no subsidence of the land surface between 1983 and early 1985. At the Clear Lake and East End extensometer sites, the rate of subsidence also decreased between 1980 and 1985. However, west, southwest, and northwest of the city of Houston, the rate of subsidence has not decreased. The average rate of subsidence at the Addicks site, located in western Harris County, was about 0.17 ft/yr from 1980 to early 1985, whereas the subsidence rate from 1975 through 1979 was 0.11 ft/yr.

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