

GROUND-WATER WITHDRAWALS, WATER LEVELS, AND GROUND-WATER QUALITY IN THE HOUSTON DISTRICT, TEXAS, WITH EMPHASIS ON 1985-89

By Dana L. Barbie and Glenn L. Locke

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CONVERSION FACTORS, VERTICAL DATUM, AND
ABBREVIATED WATER-QUALITY UNIT

Multiply	By	To obtain
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per year	0.0008928	million gallons per day
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
million gallons per day (Mgal/d)	0.04381	cubic meter per second

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Milligrams per liter (mg/L): A unit expressing the concentration of a chemical constituent in solution as weight (milligrams) of solute per unit volume (liter) of water. One mg/L equals 1,000 micrograms per liter.

GROUND-WATER WITHDRAWALS, WATER LEVELS, AND GROUND-WATER QUALITY IN THE HOUSTON DISTRICT, TEXAS, WITH EMPHASIS ON 1985-89

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ABSTRACT

This report is one in a series of reports prepared by the U.S. Geological Survey, beginning in 1937, on the ground-water resources in the Houston district. The Houston district includes Harris and Galveston Counties, and parts of Brazoria, Fort Bend, Waller, Montgomery, Liberty, and Chambers Counties. The primary emphasis of this report includes ground-water resources information for the district from 1985-89. Some data collected before 1985 and in early 1990 are included to present long-term trends and relations.

Ground-water withdrawal in the Houston district decreased from 451 to 419 Mgal/d (million gallons per day) between 1985 and 1989. Public supply used 77 percent of the ground water withdrawn in the district in 1985. From 1985 through 1989, withdrawals for public supply decreased from 349 to 338 Mgal/d, withdrawals for industrial use decreased from 37 to 32 Mgal/d, and withdrawals for irrigation use decreased from 65 to 49 Mgal/d.

From 1985 through 1989, ground-water withdrawals decreased from about 197.9 Mgal/d to about 166.9 Mgal/d in the Houston area and increased from about 179.5 Mgal/d to about 180.8 Mgal/d in the Katy area, and remained constant at about 67 Mgal/d in the rest of Harris County. Galveston County ground-water withdrawal decreased from about 6.1 to 4.0 Mgal/d during 1985-89.

During 1977-90, water levels in wells completed in the Chicot aquifer in the eastern part of the Houston district rose as much as 160 ft (feet) and declined as much as 80 ft in the western part. During 1985-90, water levels in wells completed in the Chicot aquifer in the western part of the Houston district rose as much as 140 ft, and declined as much as 40 ft in the western part.

During 1977-90, water levels in wells completed in the Evangeline aquifer in the southeastern part of the Houston district rose as much as 140 ft and declined as much as 200 ft in the northwestern part. During 1985-90, water levels in wells completed in the Evangeline aquifer in the eastern part of the Houston district rose as much as 40 ft, and declined as much as 140 ft in the northern part.

Dissolved-chloride concentrations in water from wells in the Houston district have not changed more than 100 mg/L during 1985-89, except for a decrease at one well in the eastern part of Galveston County. Well KH-65-48-316 yielded water with dissolved-chloride concentration decreasing from 720 mg/L in 1986 to 590 mg/L in 1989.

INTRODUCTION

Hydrologic data collection in the Houston district was begun by the U.S. Geological Survey about 1929. The Houston district, as described in this report, includes all of Harris and Galveston Counties and parts of Brazoria, Fort Bend, Waller, Montgomery, Liberty, and Chambers Counties (pl. 1). Numerous reports on ground-water hydrology, land subsidence, and saltwater encroachment in the district have been published since 1929. Two analog models (Wood and Gabrysch, 1965; and Jorgensen, 1975) and a finite difference model (Carr and others, 1985) describe the ground-water hydrology underlying the district. This report is one of a series of reports prepared by the Geological Survey, beginning in 1937, on the ground-water resources within the Houston district.

The purpose of this report is to update published information on the ground-water resources in the Houston district. Although the primary emphasis of this report is on general trends in ground-water withdrawal, water levels, and water-quality data collected during 1985-89, some data collected before 1985 and in early 1990 are included to present long-term trends and relations.

This report was prepared in cooperation with the City of Houston and the Harris-Galveston Coastal Subsidence District. Many home owners, well drillers, industrial-plant managers, and State and municipal officials provided valuable information for this report.

GEOHYDROLOGY

The geologic formations of the Houston district (table 1) are from oldest to youngest: (1) The Fleming Formation of Miocene age, which includes the Jasper aquifer, the Burkeville confining layer, and the lower part of the Evangeline aquifer; (2) the Goliad Sand of Pliocene age, which is the principal member of the Evangeline aquifer; and (3) the Willis Sand, the Bentley, Montgomery, and Beaumont Formations of Pleistocene age, and the alluvium of Holocene age, which compose the Chicot aquifer. The Evangeline aquifer is the major source of ground water in the Houston district. The Chicot aquifer is the major source of ground water in Galveston County, southern Harris County, and parts of adjacent counties. The Alta Loma Sand of Rose (1943), hereafter referred to as the Alta Loma Sand, is the basal sand of the Chicot aquifer in the southeastern part of the district. The Alta Loma Sand is the primary source of water from the Chicot aquifer except in the Texas City area, where localized lenses of sand and gravel in the middle part of the Chicot aquifer are the principal source of water (Gabrysch, 1980). The Jasper aquifer underlies the Houston district, but contains slightly saline water, except in the northern part of the district. Only two wells yield water from the Jasper aquifer in Harris County. A generalized geohydrologic section showing hydrologic units of the Chicot, Evangeline, and Jasper aquifers through Montgomery, Harris, Brazoria, and Galveston Counties is shown in plate 2. Data from some electric logs were confirmed by samples.

The Chicot aquifer and the underlying Evangeline aquifer are composed of discontinuous sedimentary deposits of gravel, sand, silt, and clay, which thicken to the southeast (Meyer and Carr, 1979). In most of the district, the water in the aquifers is fresh (less than 1,000 mg/L dissolved-solids concentration). The primary basis for separating the Chicot aquifer from the

Table 1. Correlation between geohydrologic units and geologic formations in the Houston district (Modified from Williams and Ranzau, 1987)

Geologic classification			Geohydrologic unit				
S Y S T E M	Series	Stratigraphic unit	Houston district (Jorgensen, 1975)		This report		
Q u a t e r n a r y	H o l o c e n e P l e i s t o c e n e	Alluvium	C A Q U I C O F T E R	U p p e r u n i t	C A Q U I C O F T E R	U p p e r u n i t	
		Beaumont Formation					
		Montgomery Formation	L o w e r u n i t	L o w e r u n i t	L o w e r u n i t	L o w e r u n i t	
		Bentley Formation					
		Willis Sand					Alta Loma Sand
T e r t i a r y	P l i o c e n e	Goliad Sand	E V A N G E L I N E	A Q U I F E R	E V A N G E L I N E	A Q U I F E R	
		Fleming Formation					Burkeville confining layer
	Jasper aquifer						Jasper aquifer

underlying Evangeline aquifer is a difference in hydraulic conductivity. The hydraulic conductivity is greater in the Chicot aquifer, and in part, causes the difference in the altitude of the water levels in wells in the two aquifers (Meyer and Carr, 1979). The water levels in wells completed in the Chicot aquifer are higher than the water levels in wells completed in the Evangeline aquifer. In the western and northern parts of the district, geologic units of the aquifer crop out and are under water-table conditions. In the southern and eastern parts of the district, the aquifers are under artesian conditions. Because there is a slight hydraulic connection between the aquifers and between the Chicot aquifer and the land surface, the system is termed "leaky" (Carr and others, 1985). The Chicot and Evangeline aquifers are confined underneath Galveston Bay and Lake Houston. The potentiometric surfaces of the aquifers in the Houston district, in effect, are the result of a system of intersecting cones of depression caused by water withdrawn from numerous wells throughout the area.

GROUND-WATER WITHDRAWAL

The major areas of ground-water withdrawal discussed in this report are in the Houston, Katy, Pasadena, Baytown-La Porte, Johnson Space Center, Texas City, and Alta Loma areas (pl. 1). Before 1977, ground water was the major source of freshwater available in the Houston district. Surface water has been available from Sheldon Reservoir, the Brazos River, and Lake Houston on the San Jacinto River (pl. 1) to parts of the district since 1942, 1948, and 1954, respectively. The use of surface water from Lake Houston was begun by the city of Galveston (pl. 1) in 1973. In late 1976, surface water diverted from the Trinity River (pl. 1) became available to parts of the Houston district. By the end of 1979, ground-water production for industrial and municipal use in the Pasadena, Baytown-La Porte, Johnson Space Center, and Texas City areas, was replaced in large part by surface water.

The average daily ground-water withdrawal for part of the Houston district during 1980-89 is listed in tables 2 and 3 by area and use. A total of average daily ground-water withdrawal in the Houston district during 1980-89 is listed in table 4. The Houston district's ground-water withdrawal was 451 Mgal/d in 1985 and decreased to 419 Mgal/d during 1989 (table 4). Public supply withdrawal decreased by 11 Mgal/d. Industrial withdrawal decreased by 5 Mgal/d. Irrigation withdrawal decreased by 16 Mgal/d in the Houston district, but in the Katy area withdrawals for rice irrigation decreased by 17 Mgal/d (table 5).

The city of Houston, the largest user of ground water in the district (pl. 1), has been supplementing and replacing ground-water production with surface water since 1954. In 1970, about 73 percent of the water supply for the city of Houston was from ground water (Gabrysch, 1980). During 1975-84, about 48 to 58 percent of the water supply for the city of Houston was from ground water (Williams and Ranzau, 1987, p. 25). During 1985-89, an average of about 55 percent (City of Houston Public Works Dept., oral comm., 1990) of the water supply for the city of Houston was from ground water. The city of Houston's ground-water withdrawal decreased from 194.0 Mgal/d in 1985, to 175.4 Mgal/d in 1989 (table 6).

Table 2. Average daily withdrawal of ground water in Harris County and parts of Fort Bend and Waller Counties, 1980-89

Area	Use	Ground-water withdrawal (million gallons per day)									
		1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Houston	Public supply:										
	City of Houston ¹	205.3	202.7	203.3	158.8	161.1	162.9	162.7	137.5	138.9	138.4
	Suburban	27.4	25.3	29.5	27.6	28.9	29.0	27.2	27.0	26.3	25.3
	Industrial	6.7	6.2	5.2	4.1	3.0	4.7	3.3	2.5	2.1	2.0
	Irrigation	1.0	.7	.9	.5	.8	1.3	1.1	1.1	1.3	1.2
	Subtotal	240.4	234.9	238.9	191.0	193.8	197.9	194.3	168.1	168.6	166.9
Katy	Public supply:										
	City of Houston ¹	13.1	13.5	16.8	20.2	23.6	29.3	31.0	36.4	35.5	35.1
	Suburban	43.9	49.6	64.0	62.2	74.1	78.3	76.2	83.7	92.0	91.3
	Industrial	14.4	11.9	9.2	10.4	11.3	10.1	6.5	5.1	10.0	9.0
	Irrigation:										
	Rice	97.8	98.4	94.7	40.0	62.5	60.7	37.9	48.0	41.7	43.7
	Other ²	2.1	1.7	2.0	1.8	2.1	1.1	1.3	1.6	2.0	1.7
	Subtotal	171.3	175.1	186.7	134.6	173.6	179.5	152.9	174.8	181.2	180.8
Pasadena	Public supply	17.6	16.6	13.8	15.8	16.2	15.9	14.9	18.1	15.7	15.2
	Industrial	30.6	28.1	25.0	25.8	23.7	21.1	18.4	19.1	17.9	19.2
	Subtotal	48.2	44.7	38.8	41.6	39.9	37.0	33.3	37.2	33.6	34.4
Baytown-	Public supply	11.1	6.8	4.8	4.3	4.4	4.0	3.9	3.6	4.2	4.2
LaPorte	Industrial	1.8	.9	.8	1.0	.8	1.1	.8	.8	.8	1.0
	Subtotal	12.9	7.7	5.6	5.3	5.2	5.1	4.7	4.4	5.0	5.2
Johnson	Public supply:										
Space	City of Houston ¹	.0	.0	.0	.0	.0	.2	.2	.3	.4	.2
Center	Suburban	5.6	4.8	5.7	5.1	5.1	4.7	4.6	4.9	4.9	4.1
	Industrial	.3	.2	.3	.2	.6	.2	.2	.2	.2	.2
	Irrigation	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
	Subtotal	6.0	5.1	6.1	5.4	5.8	5.2	5.1	5.5	5.6	4.6
Other	Public supply:										
areas	City of Houston ¹	1.3	1.3	1.3	1.3	1.8	1.6	1.7	1.7	1.7	1.7
Harris	Suburban	11.4	11.3	13.4	11.7	15.9	16.4	15.8	18.9	19.8	19.4
County	Industrial	.1	.1	.1	.1	.1	.1	.1	.1	.2	.2
	Irrigation ³	1.4	2.1	1.1	1.4	2.1	1.9	1.5	1.7	2.7	2.1
	Subtotal	14.2	14.8	15.9	14.5	19.9	20.0	19.1	22.4	24.4	23.4
Total		493.0	482.3	492.0	392.4	438.2	444.7	409.4	412.4	418.4	415.3

¹ City of Houston pumpage previously was included only in the Houston area (Williams and Ranzau, 1987).

² In the Katy area, "other irrigation" previously was included as "industrial" (Williams and Ranzau, 1987).

³ In other areas in Harris County, "irrigation" previously had included only rice irrigation. All other irrigation had been included as "public supply" (Williams and Ranzau, 1987).

Table 3. Average daily withdrawal of ground water in Galveston County, 1980-89

Area	Use	Ground-water withdrawal (million gallons per day)									
		1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Texas	Public supply	7.6	2.8	1.3	1.1	0.6	0.7	0.3	0.2	0.2	0.3
City	Industrial	1.4	.4	.3	.3	.4	.3	.2	.5	.2	.3
Subtotal		9.0	3.2	1.6	1.4	1.0	1.0	.5	.7	.4	.6
Alta	Public supply	1.8	2.0	2.0	1.2	2.4	2.0	1.1	.7	.7	.9
Loma											
Other	Public supply	7.2	5.9	4.8	4.5	3.9	3.1	3.0	2.6	2.5	^a 2.5
areas in	and industrial										
Galveston											
County											
Total		18.0	11.1	8.4	7.1	7.3	6.1	4.6	4.0	3.6	4.0

^a Three wells in the Wedgewood area of Friendswood, previously included under "public supply" for other areas in Galveston County, are now included under "public supply" for the Johnson Space Center (Williams and Ranzau, 1987).

Table 4. Average daily withdrawal of ground water in the Houston district, 1980-89

Use	Ground-water withdrawal (million gallons per day)									
	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Public supply	350	339	357	311	335	349	343	336	343	338
Industrial	59	51	44	44	41	37	29	27	31	32
Irrigation	102	104	99	44	68	65	42	53	48	49
Total	511	494	500	399	444	451	414	416	422	419

Table 5. Rice acreage and rate of ground-water withdrawal for rice irrigation in the Katy area, 1980-89

Year	Acreage	Withdrawal (acre-feet per acre per year)	Average withdrawal	
			(acre-feet per year)	(million gallons per day)
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
1985	23,041	2.95	67,970	60.7
1986	19,931	2.13	42,450	37.9
1987	18,887	2.85	53,830	48.0
1988	22,905	2.04	46,726	41.7
1989	18,839	2.60	48,982	43.7

Table 6. City of Houston ground-water withdrawal by area (million gallons per day)

Year	Area				Total
	Houston	Katy	Johnson Space Center	Other areas in Harris County	
1980	205.3	13.1	0	1.3	219.7
1981	202.7	13.5	0	1.3	217.5
1982	203.3	16.8	0	1.3	221.4
1983	158.8	20.2	0	1.3	180.3
1984	161.1	23.6	0	1.8	186.5
1985	162.9	29.3	0.2	1.6	194.0
1986	162.7	31.0	.2	1.7	195.6
1987	137.5	36.4	.3	1.7	175.9
1988	138.9	35.5	.4	1.7	176.5
1989	138.4	35.1	.2	1.7	175.4

Houston Area

The Houston area is located in the central and south-central parts of the Houston district and includes most of the city of Houston and the closely adjoining urbanized areas (pl. 1). Ground-water withdrawal is principally for public supply and primarily from the Evangeline aquifer. Ground-water withdrawal peaked in 1982. From 1985 through 1989, ground-water withdrawal decreased from 197.9 to 166.9 Mgal/d (table 2). Suburban public supply withdrawal decreased from 29.0 Mgal/d during 1985 to 25.3 Mgal/d during 1989 and industrial withdrawal decreased from 4.7 to 2.0 Mgal/d. Withdrawal of ground water for irrigation remained essentially unchanged from 1985 through 1989.

Katy Area

The Katy area is located in the western part of the Houston district and includes parts of Harris, Fort Bend, and Waller Counties (pl. 1). Before 1980, the Katy area was mostly agricultural with isolated housing developments; rice irrigation accounted for more than 90 percent of the ground-water withdrawal (Gabrysch, 1972, p. 15). In the 1980's, residential development expanded and demand for public supply increased by more than 40 Mgal/d the first 5 years. In 1984, as a result of the high cost of producing rice, the encroachment of residential development, and the U.S. Department of Agriculture's program to reduce rice production, rice acreage declined to about 31,800 acres (Williams and Ranzau, 1987, p. 31) from about 67,400 acres in 1968 (Gabrysch, 1980, p. 27).

Withdrawal of ground water for public supply in the Katy area increased from 107.6 to 126.4 Mgal/d between 1985 and 1989 (table 2). Industrial use of ground water has ranged from 5.1 to 10.1 Mgal/d between 1985 and 1989.

The average amount of water applied per acre for rice irrigation was calculated for several representative farms by dividing the amount of water pumped by the number of acres irrigated. This average was then multiplied by the total rice acreage in the Katy area to estimate total pumpage for rice irrigation. Rice acreage (table 5) was obtained from the U.S. Department of Agriculture in Harris, Fort Bend, and Waller Counties (oral comm., 1990). Water pumped for rice irrigation was 60.7 Mgal/d in 1985; and decreased to 43.7 Mgal/d in 1989. Other irrigation includes irrigation for lawns, golf courses, and nurseries. Ground-water pumpage for other than rice irrigation decreased during 1985 and 1986, but increased to previous levels of about 1.6 to 2.0 Mgal/d for 1987-89 (table 2).

Pasadena Area

The Pasadena area, located east of the Houston area and mostly west of the San Jacinto River, includes a large industrialized zone along the Houston Ship Channel (pl. 1). Large ground-water withdrawal in the Pasadena area began with the construction of large industrial plants starting in 1937 (Gabrysch, 1972, p. 13). Surface-water supplies became available in

1942 and 1954 to supplement ground-water withdrawal. In 1960, 74 Mgal/d of ground water and 53 Mgal/d of surface water were used in this area (Wood and Gabrysch, 1965). The maximum ground-water withdrawal in this area was 125.7 Mgal/d in 1968 (Gabrysch, 1972, p. 9). Lake Livingston on the Trinity River became the primary water source for the area in late 1976. Ground-water pumpage in the Pasadena area decreased to 39.9 Mgal/d in 1984 (table 2).

During 1985-89, ground-water withdrawal for industrial use ranged from 17.9 Mgal/d to 21.1 Mgal/d; in 1989, it was 19.2 Mgal/d (table 2). Ground-water withdrawal for public supply ranged from 14.9 Mgal/d to 18.1 Mgal/d during 1985-89. Use for public supply in 1989 was 15.2 Mgal/d.

Baytown-La Porte Area

The Baytown-La Porte area is located in the northeastern part of the Houston district, adjacent to the Pasadena area on the west and to Chambers County on the east (pl. 1). This area is comprised of industrial complexes and municipal developments.

Ground-water withdrawal in the Baytown-La Porte area is principally from the Alta Loma Sand of the Chicot aquifer, and was primarily for industrial use until 1978 when total pumpage was 21.6 Mgal/d, of which 10.2 Mgal/d was for industrial use and 11.4 Mgal/d was for public supply (Gabrysch, 1982, p. 14). Maximum ground-water withdrawal of 31.8 Mgal/d occurred during 1972 (Gabrysch, 1980, p. 21). Because of conversion to surface water by industry, ground-water withdrawal decreased between 1972 and 1983. Withdrawal of ground water has been stable at about 5 Mgal/d since 1982 (table 2).

Ground water used for public supply averaged 4.0 Mgal/d and was more than 80 percent of the total withdrawal during 1985-89 (table 2). During the same period, pumpage of ground water for industrial use averaged 0.9 Mgal/d.

Johnson Space Center Area

The Johnson Space Center area is located in the southeastern part of the Houston district; it is bounded on the north by the Baytown-La Porte area, on the west by the Houston and Pasadena areas, and on the east by Galveston Bay (pl. 1). Surface water replaced ground water as the principal water source for industry in 1977. Ground-water withdrawal for industry was reduced from 15.6 Mgal/d in 1976 (Gabrysch, 1982, p. 14) to 0.3 Mgal/d in 1980 (table 2).

Ground-water withdrawal for public supply ranged from 4.3 to 5.3 Mgal/d and averaged 4.9 Mgal/d during 1985-89. The use for public supply was about 93 percent of total use in the area (table 2) for the same period. Combined use of ground water for industry and irrigation was constant at 0.3 Mgal/d for the 5 years.

Texas City Area

The Texas City area is located in Galveston County (pl. 1) and includes parts of Texas City, La Marque, and the adjoining area. The economy of this area is industrial, principally

petrochemical. The upper and middle parts of the Chicot aquifer provide most of the ground water. In this area, the Alta Loma Sand contains water that is mineralized, which restricts its use for most purposes (Gabrysch, 1982, p. 25). Ground-water withdrawal decreased from 14.0 Mgal/d in 1976 (Gabrysch, 1982, p. 15) to 1.0 Mgal/d in 1984 (table 3) as a result of increased use of surface water. Total ground-water withdrawal ranged from 0.4 Mgal/d to 1.0 Mgal/d and averaged 0.6 Mgal/d during 1985-89.

Alta Loma Area

Well fields in the Alta Loma area, located in the west-central part of Galveston County (pl. 1) provide water for the town of Alta Loma and the city of Galveston. Ground-water withdrawals in the Alta Loma area are obtained almost exclusively from the Alta Loma Sand of the Chicot aquifer (Gabrysch, 1972, p. 19). The withdrawal is entirely for public supply. The largest amount of ground-water was withdrawn during 1972 when average pumpage was 13.0 Mgal/d (Gabrysch, 1980, p. 25). In late 1973, surface water began replacing ground water as the principal water source. By 1980, ground-water withdrawal had decreased to 1.8 Mgal/d (table 3). Withdrawal during 1980-84 averaged about 1.9 Mgal/d. Ground-water withdrawn in this area in 1985 was 2.0 Mgal/d. Pumpage decreased by more than one half to an average of 0.8 Mgal/d for 1986 through 1989.

CHANGES IN WATER LEVELS

The potentiometric surfaces of the Chicot and Evangeline aquifers in the Houston district declined in local cone-shaped depressions after wells were drilled and pumped. As the number of wells and amounts of withdrawal increased, the cones of depression expanded and some intersected. As a result, major regional cones of depression formed in the Houston and Pasadena areas, with smaller cones of depression in the vicinity of major water-well fields (Gabrysch and Coplin, 1990). Until late 1976, water levels in wells in the Houston district were declining. With the availability of large amounts of surface water, the Houston district, with the exception of the Katy area, has been converting from a primarily ground-water supply to a ground-water and surface-water supply. With the increasing use of surface water and the associated decrease in ground-water withdrawal, water levels in wells completed in the Chicot and Evangeline aquifers in the eastern part of the Houston district have risen since late 1976. Water-level changes in wells completed in the Chicot and Evangeline aquifers in the Houston district for 1977-90 and 1985-90 are presented in plates 3-6. The altitude of water levels in wells completed in the Chicot and Evangeline aquifers in the Houston district for 1990 are presented in plates 7 and 8. Graphs of water levels in selected wells completed in the Chicot and Evangeline aquifers in the Houston district are presented in figures 1-8.

Chicot Aquifer

In wells completed in the Chicot aquifer, the approximate altitude of water levels measured in January-February 1990 (pl. 7), ranges from 100 ft above sea level in the northwestern part of the Houston district to 300 ft below sea level in the central part of the district.

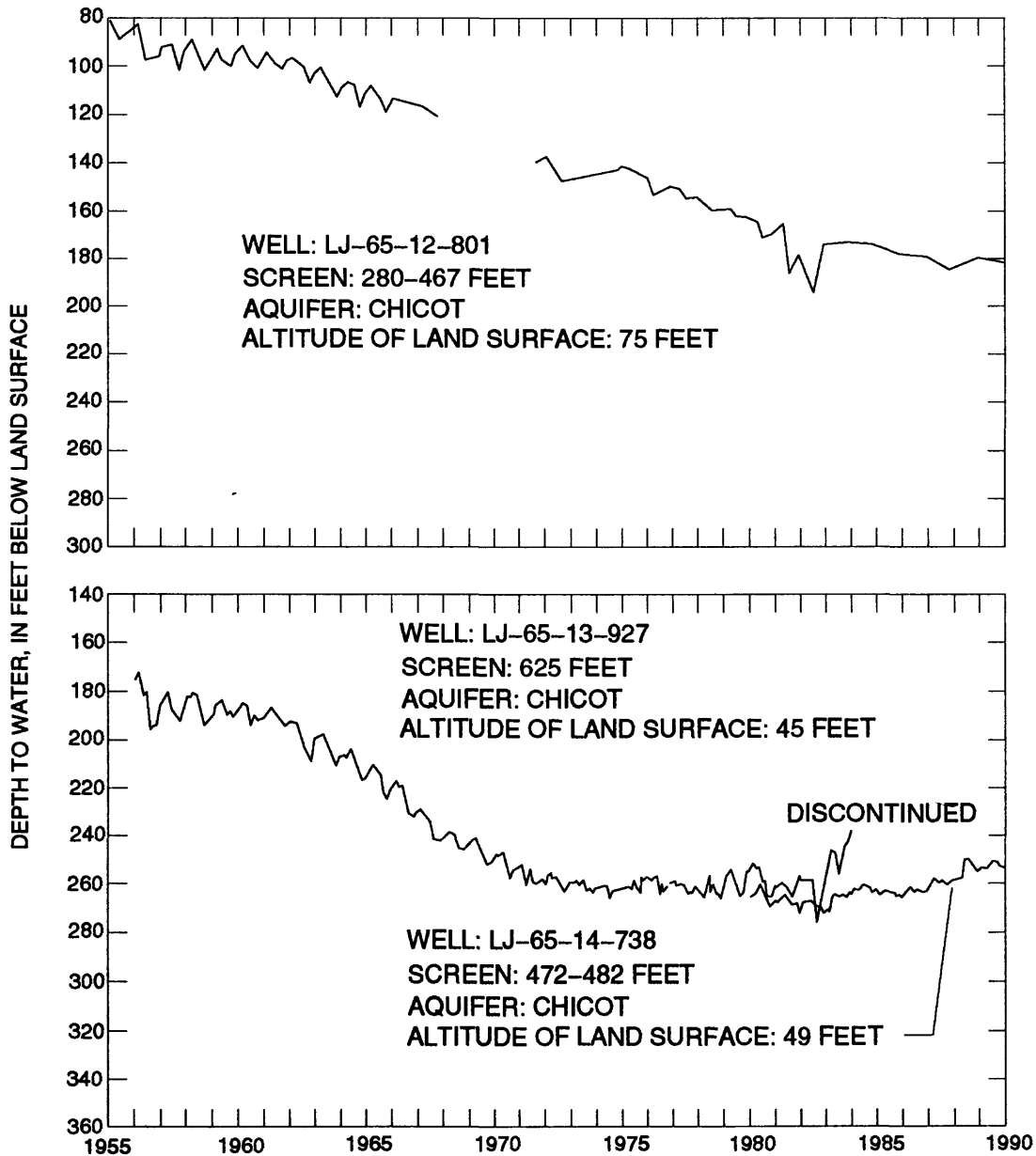


Figure 1. Water levels in selected wells completed in the Chicot aquifer in the Houston area. (Gap in curve indicates missing data.)

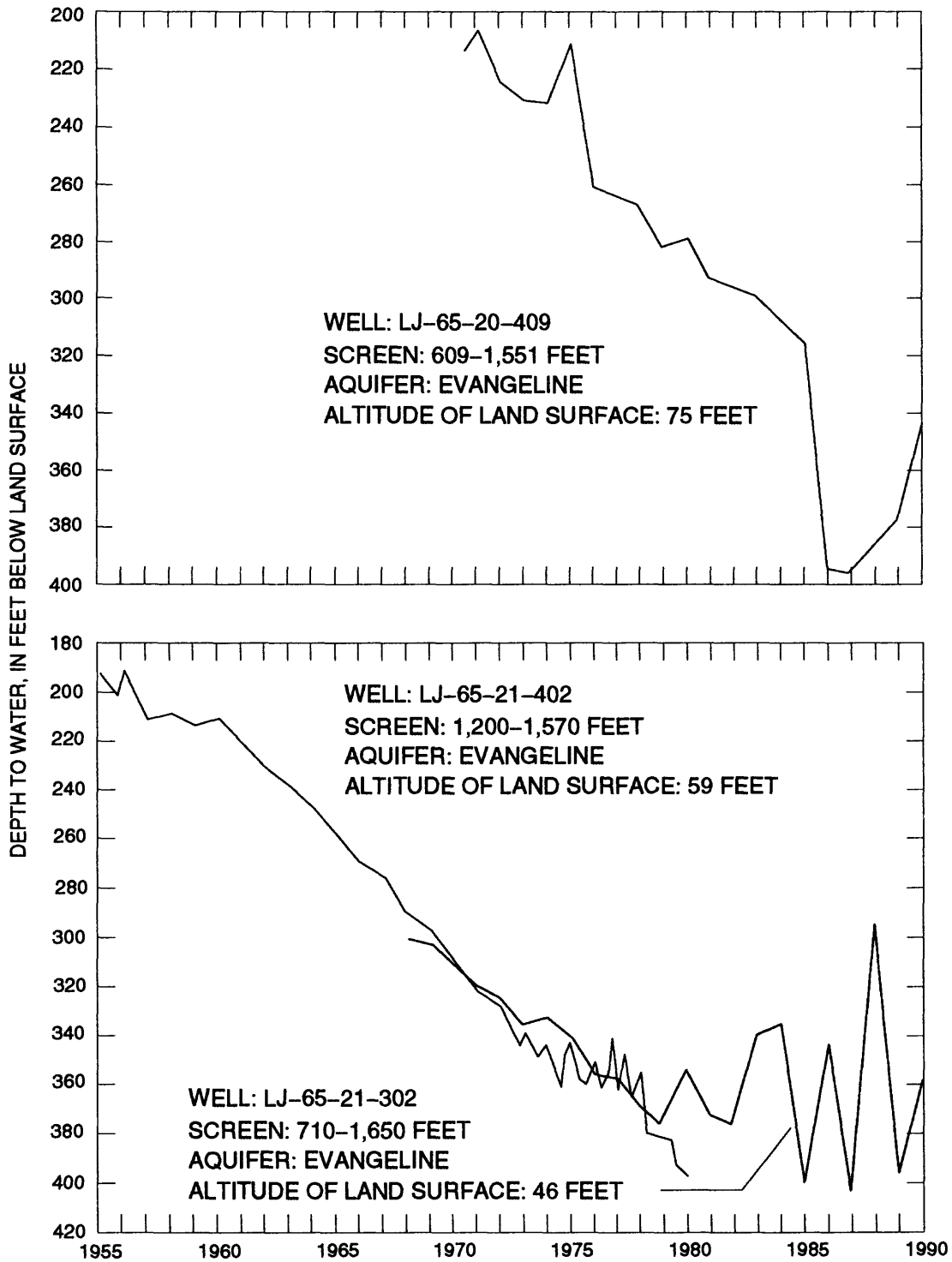


Figure 2. Water levels in selected wells completed in the Evangeline aquifer in the Houston area.

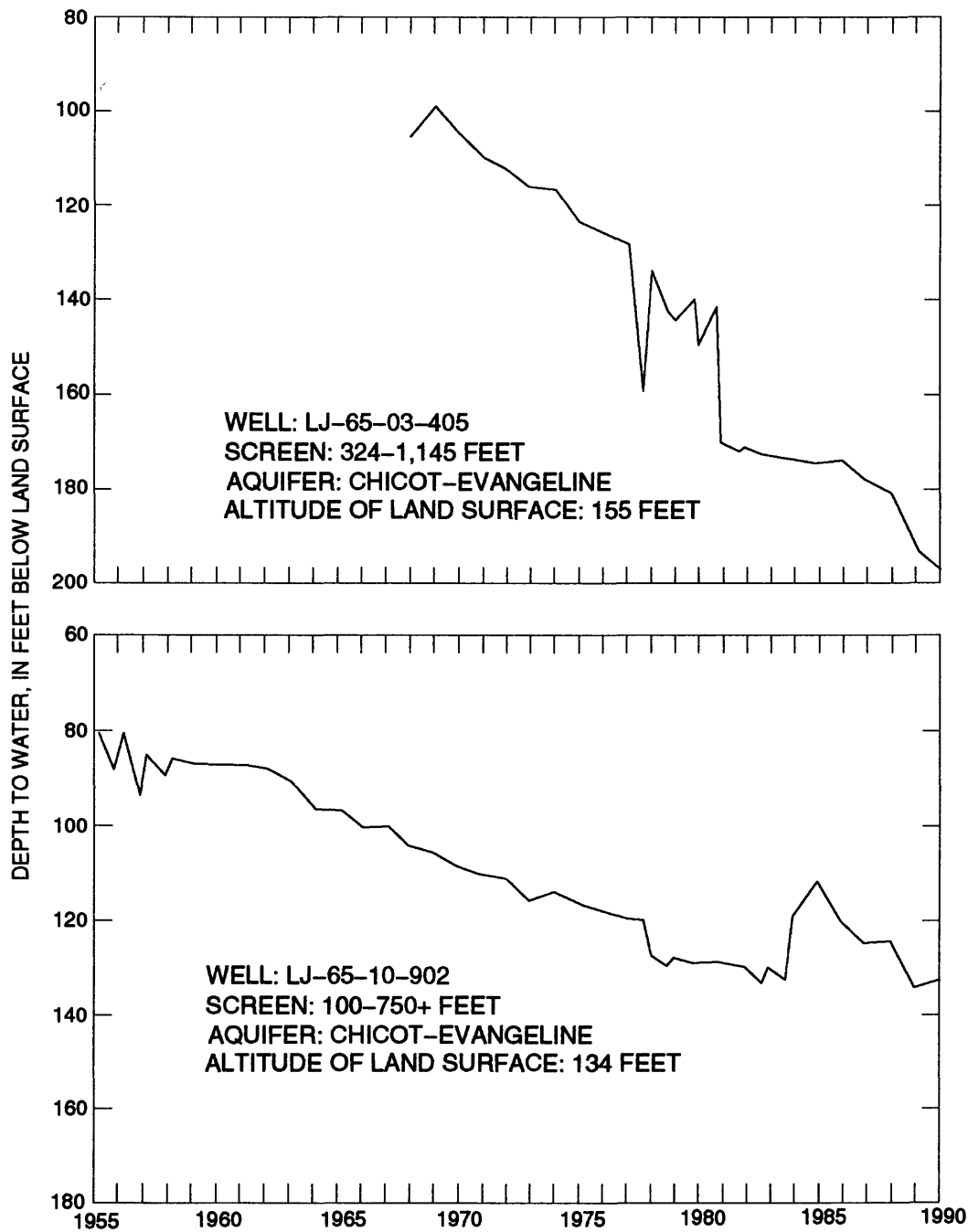


Figure 3. Water levels in selected wells in the Katy area.

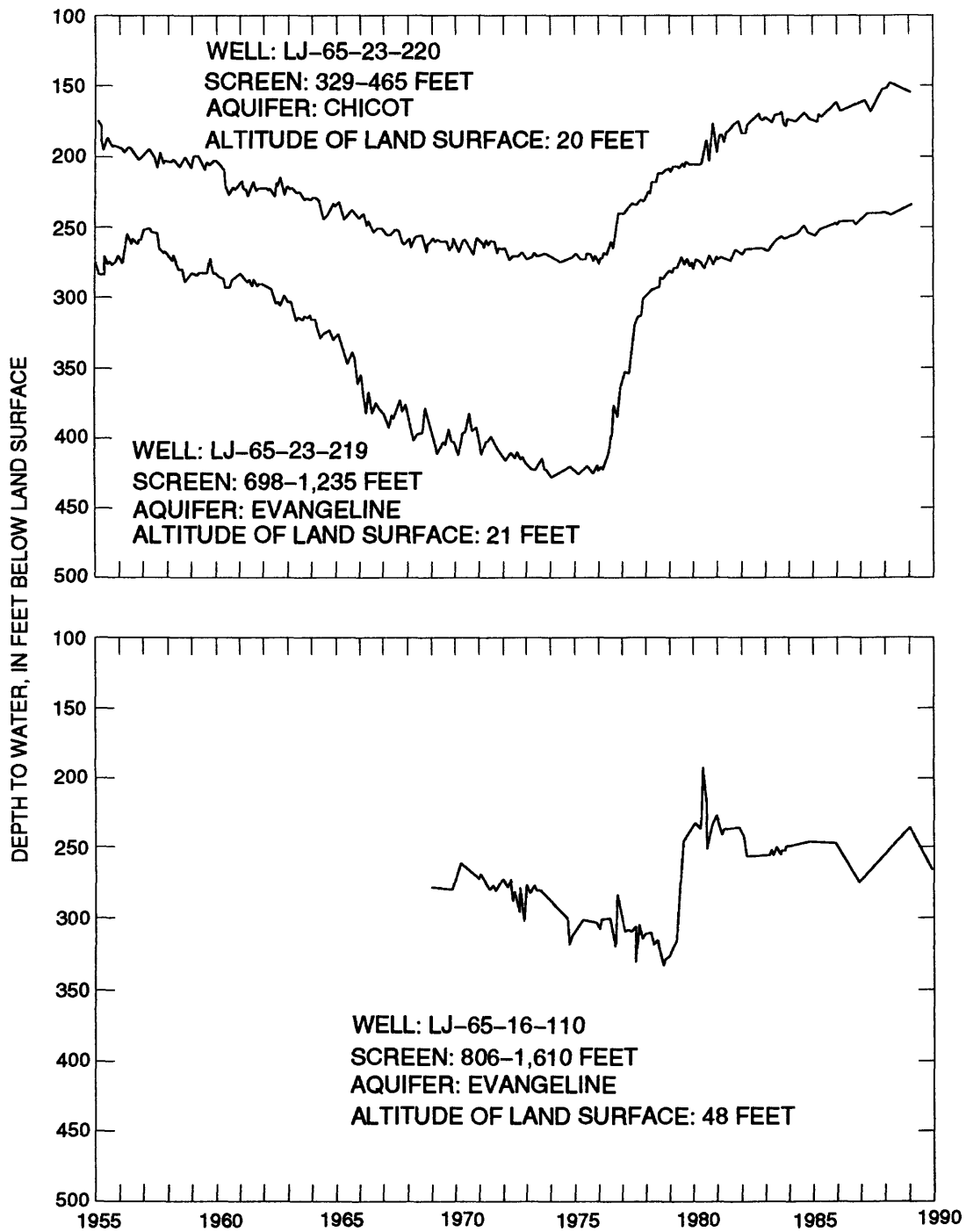


Figure 4. Water levels in selected wells in the Pasadena area.

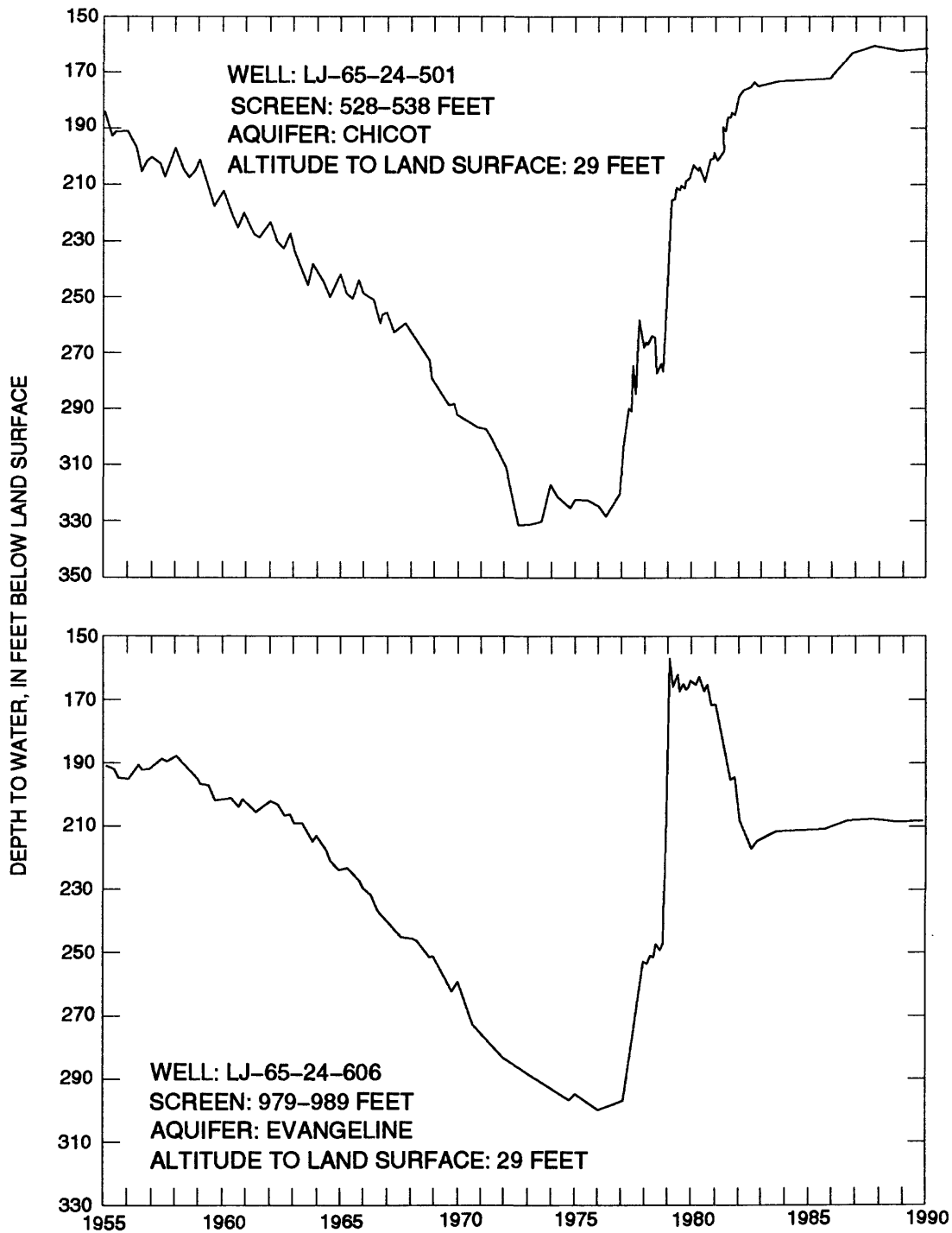


Figure 5. Water levels in selected wells in the Baytown–La Porte area.

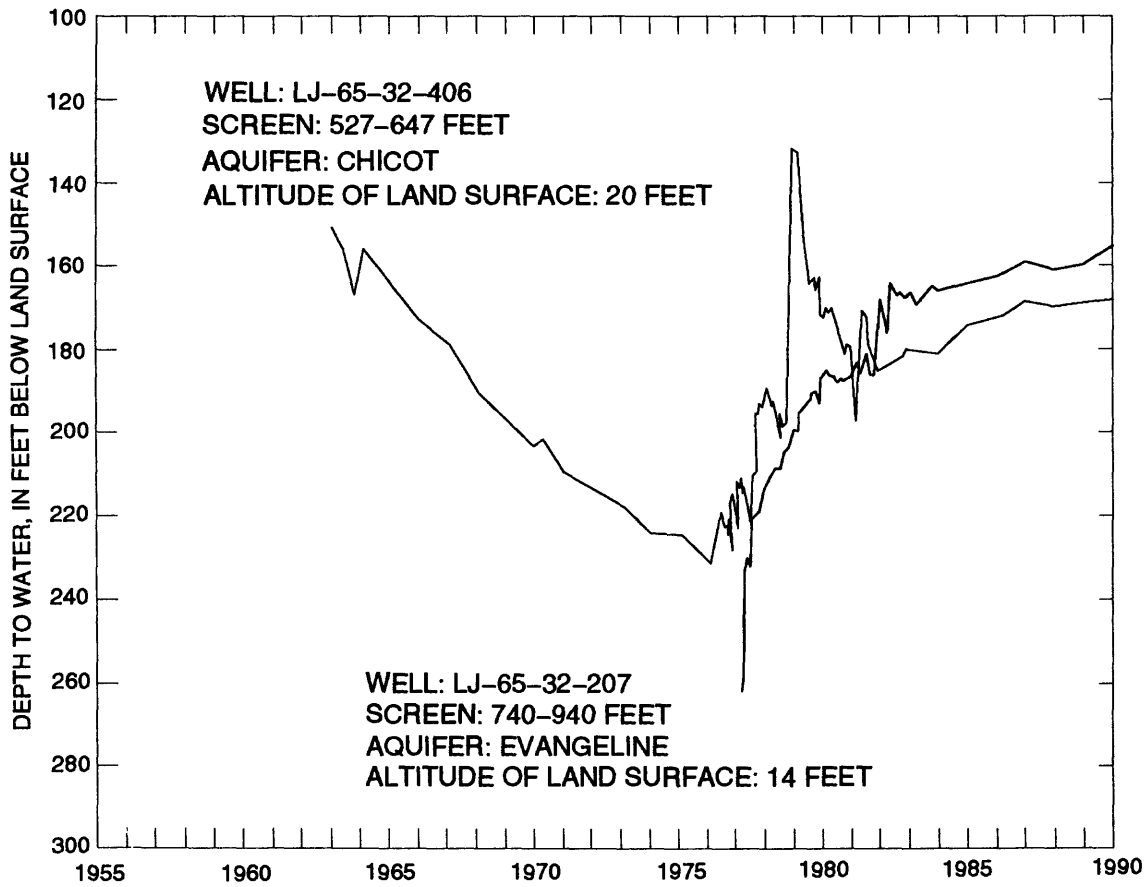


Figure 6. Water levels in selected wells in the Johnson Space Center area.

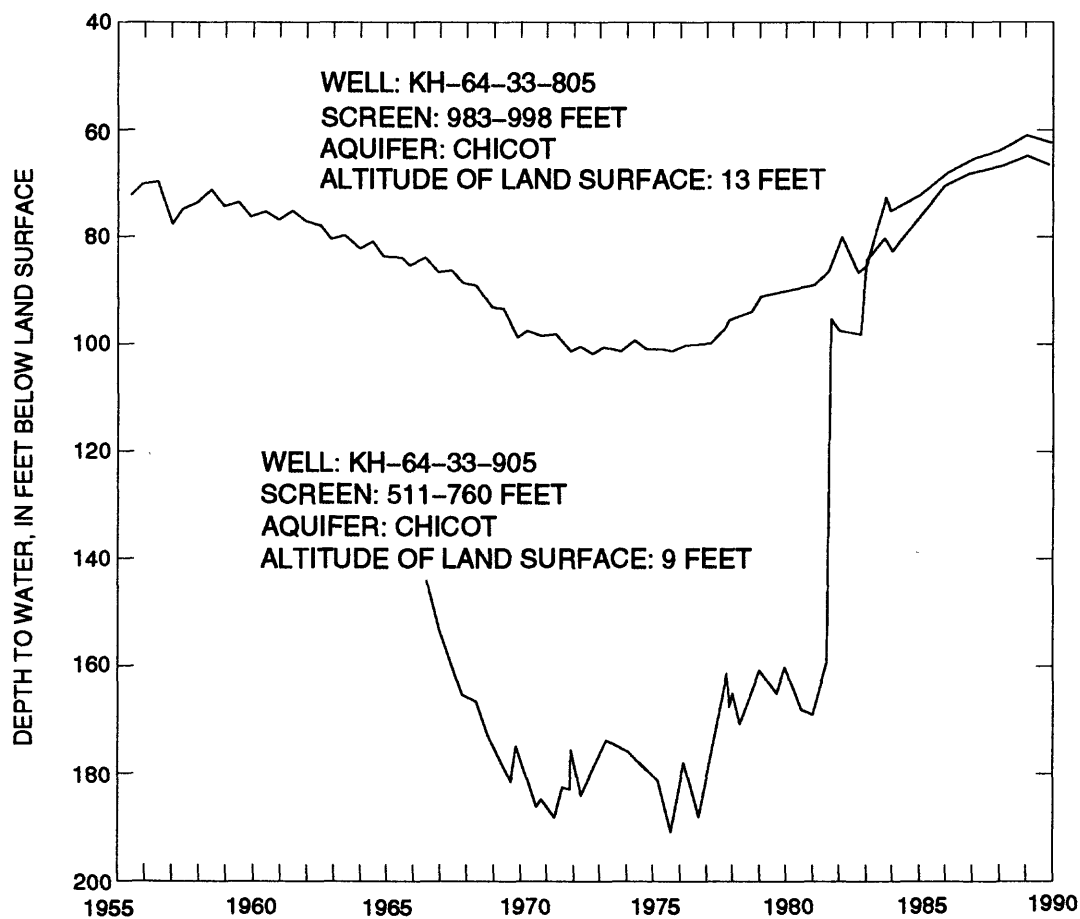


Figure 7. Water levels in selected wells in the Texas City area.

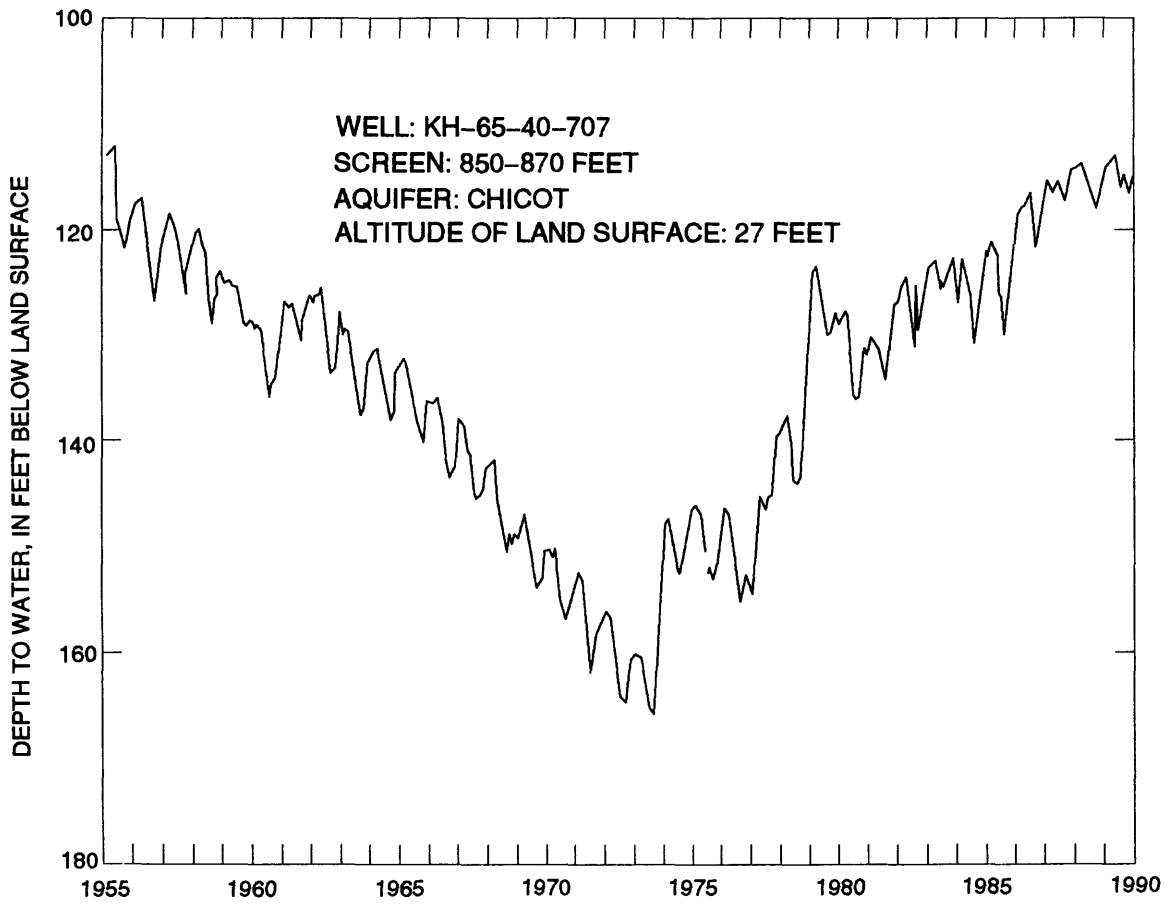


Figure 8. Water level in well KH-65-40-707, in the Alta Loma area.

Water levels in wells completed in the Chicot aquifer in the eastern part of the Houston district have risen as much as 160 ft during 1977-90 (pl. 3). Water levels in wells in the Alta Loma Sand, the basal sand of the Chicot aquifer in Galveston County, have risen as much as 60 ft. Water levels in wells completed in the middle part of the Chicot aquifer, which geohydrologically is found only in Galveston County, have risen as much as 110 ft. Water-level rises in the middle part of the Chicot aquifer are not included in plate 3 because they are not representative of the Chicot aquifer in the Houston district. In the western part of the Houston district, water levels in some wells completed in the Chicot aquifer have declined more than 80 ft; while in others, water levels have risen as much as 20 ft.

Water levels in wells completed in the Chicot aquifer rose throughout most of the Houston area during 1985-90 (pl. 5). The water levels rose as much as 140 ft in the west-central part. Hydrographs of the wells in figure 1 show the water level in well LJ-65-12-801 (pl. 1) declined about 7 ft, and the water level in well LJ-65-14-738 (pl. 1) rose about 9 ft during 1985-90.

Water levels in wells completed in the Chicot aquifer rose throughout most of the Katy area during 1985-90 (pl. 5). The water levels rose more than 40 ft in the northern part. However, some parts of the area experienced declines. The maximum decline was about 40 ft in the southeastern part of the area during 1985-90. The hydrograph of the well LJ-65-10-902 (pl. 1), screened mostly in the Chicot, shows that the water level declined about 21 ft during the 5 years (fig. 3).

Water levels in wells completed in the Chicot aquifer rose throughout the Pasadena area. The maximum rise was about 40 ft in the northern part during 1985-90. The hydrograph of well LJ-65-23-220 (pl. 1) shows a rise of the water level of about 22 ft during the 5 years (fig. 4).

Water levels in the Baytown-La Porte area also rose during 1985-90. The maximum rise was about 40 ft. The hydrograph of well LJ-65-24-501 (pl. 1) shows a rise of about 9 ft (fig. 5).

Water levels in wells rose as much as 20 ft in the central part of the Johnson Space Center area during 1985-90. The water-level rises were generally less than 20 ft throughout the area. The hydrograph of well LJ-65-32-406 (pl. 1) shows that the water level rose about 11 ft (fig. 6).

Water levels in wells in the Texas City area rose less than 20 ft in most of the area during 1985-90. A small decline occurred in the eastern part of the Texas City area. The hydrographs of wells KH-64-33-805 and 905 (pl. 1) show that the water levels rose about 10 ft during 1985-90 (fig. 7).

Water levels in wells in the Alta Loma area rose less than 20 ft during 1985-90. The hydrograph of well KH-65-40-707 (pl. 1) shows that the water level rose about 5 ft during 1985-90 (fig. 8).

Evangeline Aquifer

The approximate altitude of water levels in 1990 (pl. 8) in wells completed in the Evangeline aquifer ranged from 100 ft above sea level in the northwestern part of the Houston

district to 350 ft below sea level in the central part. However, the lowering of the potentiometric surface to as much as 350 ft below sea level is associated with well fields in the central and eastern parts of the district.

Water-level changes during 1977-90 in wells completed in the Evangeline aquifer are shown in plate 4. In the southeastern part of the Houston district, water levels have risen as much as 140 ft after surface water from the Trinity River was introduced to the area in late 1976. In the northwestern part of the Houston district, water levels have declined as much as 200 ft during 1977-90.

Water levels in wells and in well fields in the Houston area rose as much as 40 ft during 1985-90 (pl. 6). However, the Houston area also had a decline in water levels in wells and well fields of as much as 40 ft for the same 5 years. The hydrographs of the wells in figure 2 show the water level in well LJ-65-20-409 (pl. 1) declined about 34 ft, and the water level in well LJ-65-21-302 (pl. 1) rose about 43 ft during 1985-90.

Water levels in wells in the Katy area rose as much as 20 ft in the east-central part and declined as much as 140 ft in the far northeastern part during 1985-90 (pl. 6). The hydrograph of well LJ-65-03-405 (pl. 1) shows that the water level declined about 23 ft during 1985-90 (fig. 3).

Water levels in wells in the Pasadena area rose as much as 20 ft during 1985-90 (pl. 6). In the northeastern part of the Pasadena area, water levels declined as much as 20 ft during the same 5 years. In the remainder of the Pasadena area, water levels rose less than 20 ft. In figure 4, the hydrograph of well LJ-65-23-219 (pl. 1) shows that the water level rose about 23 ft during 1985-90 and the hydrograph of well LJ-65-16-110 shows that the water level declined about 22 ft during the same 5 years.

Water levels in wells in most of the Baytown-La Porte area rose less than 20 ft during 1985-90 (pl. 6). However, in a well field in the northern part, water levels declined as much as 20 ft during the same 5 years. The hydrograph of well LJ-65-24-606 (pl. 1) shows that the water level rose about 3 ft during 1985-90 (fig. 5).

Water levels in wells in the Johnson Space Center area rose less than 20 ft during 1985-90 (pl. 6). The hydrograph of well LJ-65-32-207 (pl. 1) shows that the water level rose about 7 ft during 1985-90 (fig. 6).

CHANGES IN WATER QUALITY

In most areas of the Houston district, the ground water has a chemical quality suitable for public supply, industry, or irrigation. In the Evangeline aquifer, in the southeastern part of Harris County and Galveston County, the ground water is slightly saline (1,000 mg/L to 3,000 mg/L dissolved-solids concentration) (Wood and others, 1963, p. 64). Increases in dissolved-chloride concentration of more than 145 mg/L in the Chicot aquifer near the freshwater-saltwater interface in Harris and Galveston Counties have been documented. The downward trend in

ground-water quality is probably a result of updip migration of saltwater toward the cones of depression caused by ground-water withdrawal (Gabrysch, 1982).

Samples of water have been collected from wells in Galveston County in the southeastern part of the district since 1966 to monitor changes in dissolved-chloride concentrations. Changes in dissolved-chloride concentrations are being monitored in the city of Galveston's "old" and "new" well fields in the Alta Loma area (pl. 1), and from other wells along Texas Highway 6 in Galveston County (pl. 1).

Dissolved-chloride concentrations in water from wells in the city of Galveston's "old" and "new" well fields have shown little change during 1985-89. Dissolved-chloride concentration in water from well KH-65-48-214 (pl. 1) in the city of Galveston's "old" well field, as shown in figure 9, ranged from 560 mg/L in 1965 to 820 mg/L in 1972. Dissolved-chloride concentrations during 1985-89 have been about 700 mg/L with one exception during 1987 when the concentration was 570 mg/L. Dissolved-chloride concentrations in water from well KH-65-40-401 (pl. 1) in the city of Galveston's "new" well field have been between 240 mg/L in 1974 and 330 mg/L in 1973 (fig. 10). From 1981 through 1983, dissolved-chloride concentrations decreased from 290 to 180 mg/L. From 1983-85, dissolved-chloride concentrations were about 180 mg/L. Dissolved-chloride concentrations in water from well KH-65-40-704 (pl. 1) in the "new" well field, as shown in figure 10, have ranged from 258 mg/L in 1959 to 320 mg/L in December, 1981. From 1985 through 1989, dissolved-chloride concentrations have been about 300 mg/L.

Dissolved-chloride concentrations in water from well KH-65-48-316 (pl. 1) in the Texas City area, as shown in figure 11, increased from 280 mg/L in 1969 to 720 mg/L in 1970. From 1970 through 1984, dissolved-chloride concentrations remained between 700 and 800 mg/L with one exception in 1976, when the concentration was 590 mg/L. During 1985-89, dissolved-chloride concentrations decreased from 720 mg/L in 1986, to 590 mg/L in 1989.

Dissolved-chloride concentrations in water from well KH-65-48-502 (pl. 1) in Galveston County as shown in figure 12, were between 245 mg/L in 1968 to 400 mg/L in 1976. From 1976 through 1984, dissolved-chloride concentrations decreased from 400 mg/L to 270 mg/L, and decreased from 270 mg/L to 240 mg/L during 1985-89. These dissolved-chloride concentration decreases are evidence of a possible reversal of the updip migration of saltwater in the eastern part of Galveston County.

SUMMARY AND CONCLUSIONS

Ground-water withdrawal in the Houston district decreased from 451 to 419 Mgal/d during 1985-89. Public supply, industrial, and irrigation withdrawals decreased by 11, 5, and 16 Mgal/d. In the Houston area, withdrawal decreased from 197.9 Mgal/d in 1985 to about 166.9 Mgal/d in 1989, principally as a result of the decreases of about 28 Mgal/d in public supply withdrawal. Withdrawal of ground water in the Katy area increased from about 179.5 Mgal/d during 1985 to about 180.8 Mgal/d during 1989 even though withdrawal for public supply increased from about 107.6 to about 126.4 Mgal/d. Withdrawal for irrigation during this same

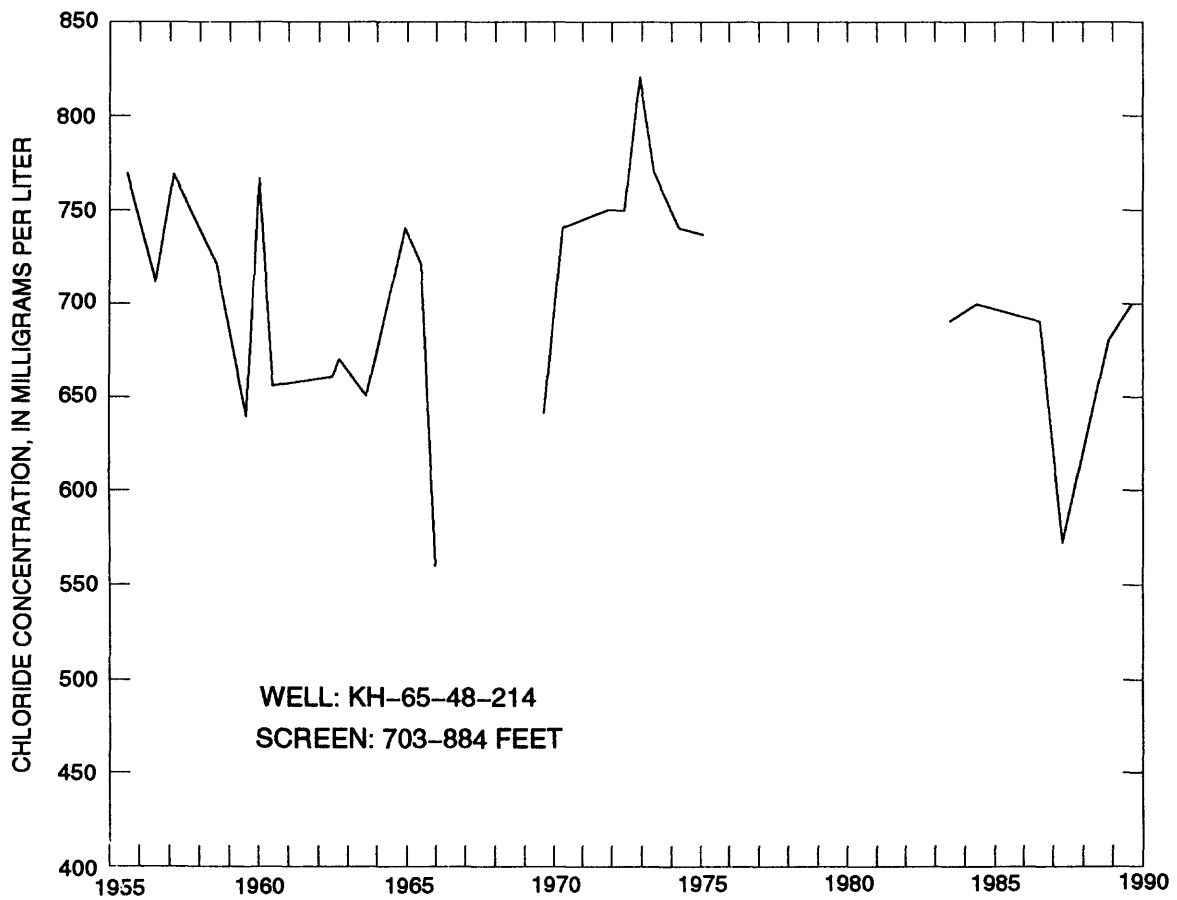


Figure 9. Changes in dissolved-chloride concentration in water from well KH-65-48-214, completed in the Chicot aquifer in the city of Galveston's "old" well field at Alta Loma. (Gaps in curve indicate missing data.)

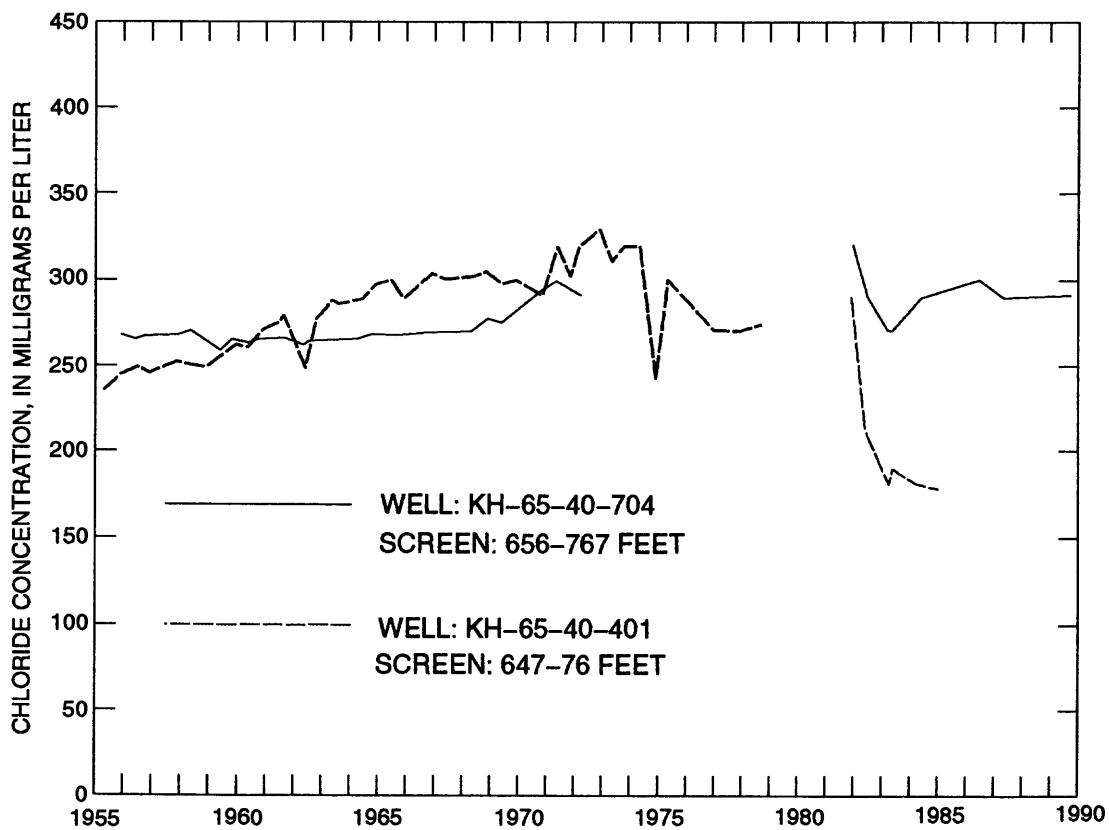


Figure 10. Changes in dissolved-chloride concentration in water from two wells completed in the Chicot aquifer in the city of Galveston's "new" well field north of Alta Loma. (Gaps in curve indicate missing data.)

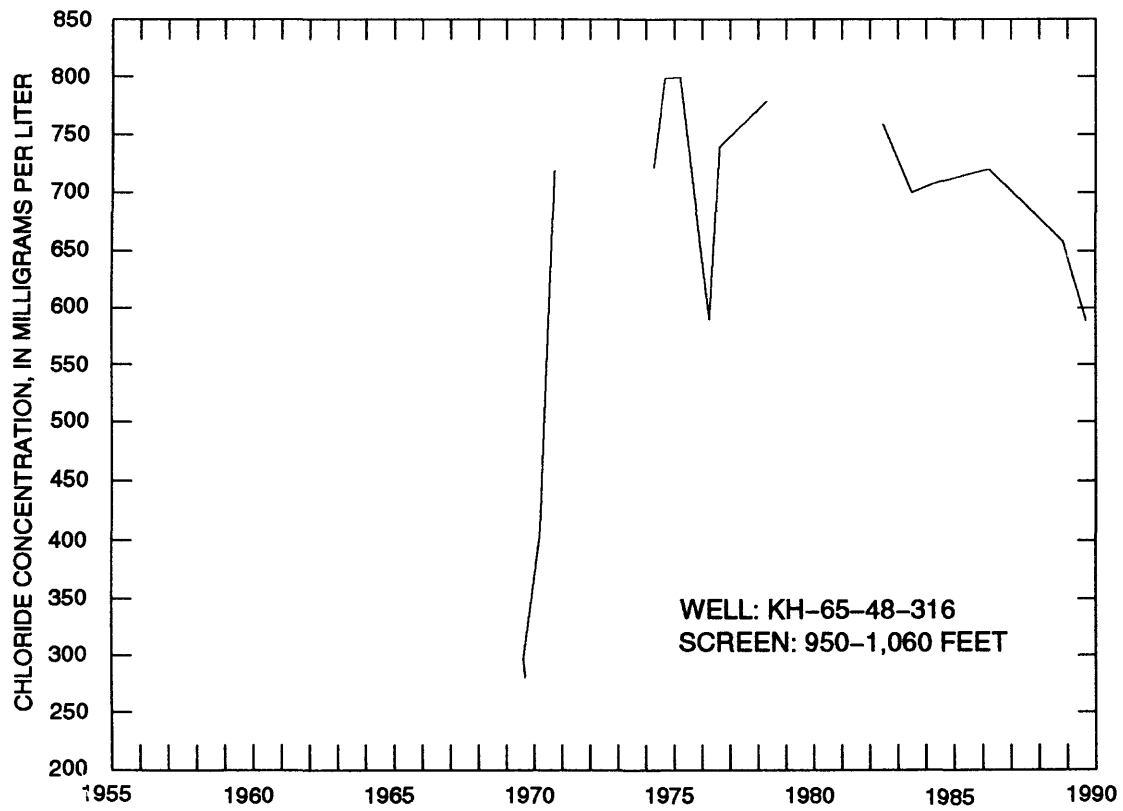


Figure 11. Changes in dissolved-chloride concentration in water from well KH-65-48-316, completed in the Chicot aquifer in the Texas City area. (Gaps in curve indicate missing data.)

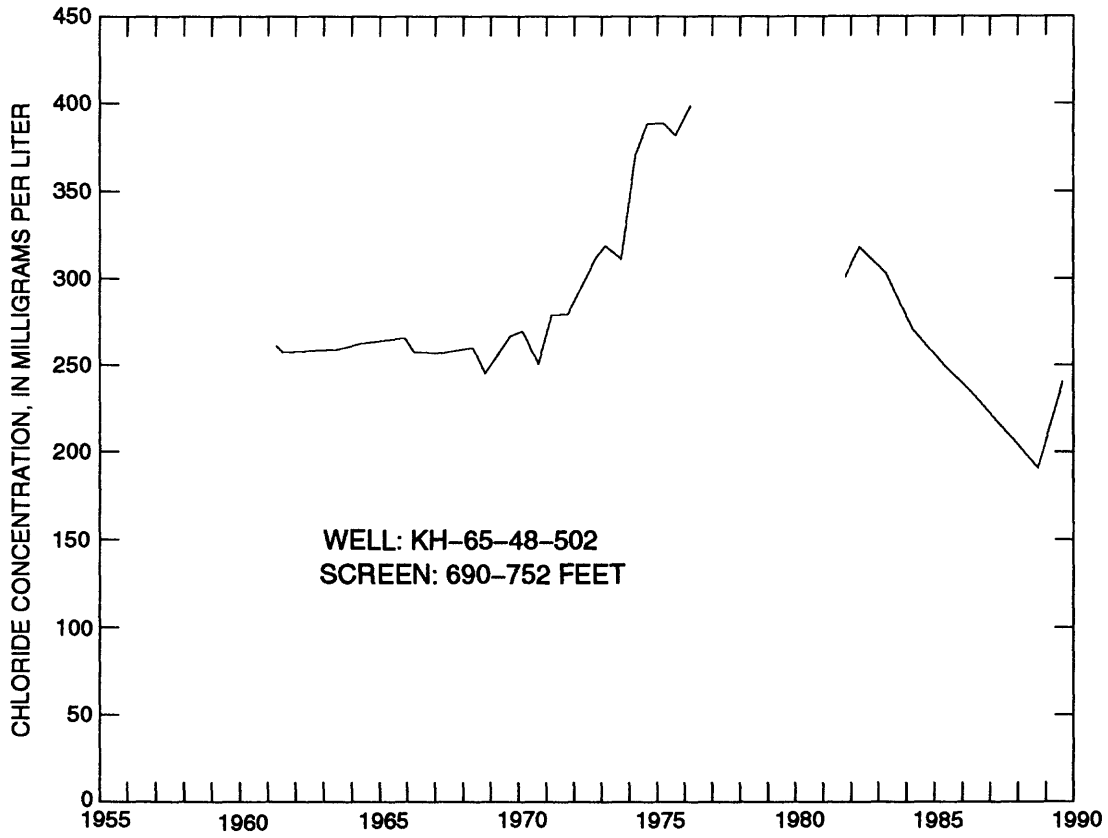


Figure 12. Changes in dissolved-chloride concentration in water from well KH-65-48-502, completed in the Chicot aquifer in Galveston County. (Gaps in curve indicate missing data.)

period decreased from about 61.8 to about 45.4 Mgal/d. Ground-water withdrawal from the rest of Harris County remained stable during 1985-89 at about 67 Mgal/d. Ground-water withdrawal in Galveston County decreased from 6.1 to 4.0 Mgal/d during 1985-89.

Water levels in wells throughout the Houston district declined until late 1976 when large amounts of surface water became available to the eastern parts of the Houston district. Between 1977-90, water levels in wells in the Chicot aquifer in the eastern part of the Houston district rose as much as 160 ft; while water levels in the western part of the Houston district declined as much as 80 ft. During 1985-90, water levels in wells in the Chicot aquifer in the western part of the Houston district rose as much as 140 ft. In the western part of the Houston district, water levels in wells in the Chicot aquifer declined as much as 40 ft.

Water levels in wells in the Evangeline aquifer in the southeastern part of the Houston district rose as much as 140 ft during 1977-90. Water levels in wells in the Evangeline aquifer in the northwestern part of the Houston district declined as much as 200 ft during the same period. From 1985 through 1989, water levels in wells in the Evangeline aquifer rose as much as 40 ft in the eastern part of the Houston district and declined as much as 140 ft in the northern part of the Houston district.

Water quality as indicated by the concentrations of chloride in water from wells in the Houston district have not changed more than 100 mg/L during 1985-89 except at one well in the eastern part of Galveston County. Well KH-65-48-316 yielded water with a decrease in dissolved-chloride concentration from 720 mg/L in 1986 to 590 mg/L in 1989. This dissolved-chloride concentration decrease is possible evidence of a reversal of the updip migration of saltwater in the eastern part of Galveston County.

SELECTED REFERENCES

- Baker, E.T., Jr., 1983, Hydrology of the Jasper aquifer in the southeast Texas Coastal Plain: U.S. Geological Survey Open-File Report 83-677, 68 p.
- Barbie, D.L., Coplin, L.S., Locke, G.L., 1990, Approximate water-level changes in wells completed in the Chicot and Evangeline aquifers, 1977-90 and 1989-90, and measured compaction, 1973-December 1989, in the Houston-Galveston region, Texas: U.S. Geological Survey Open-File Report 90-132, 7 sheets.
- _____, 1991, Approximate altitude of water levels in wells in the Chicot and Evangeline aquifers in the Houston area, Texas, January-February, 1990: U.S. Geological Survey Open-File Report 91-240, 2 sheets.
- Carr, J.E., Meyer, W.R., Sandeen, W.M., and McClane, I.R., 1985, Digital models for simulation of ground-water hydrology of the Chicot and Evangeline aquifers along the Gulf Coast of Texas: Texas Department of Water Resources Report 289, 101 p.
- Coplin, L.S., and Campodonico, Al, 1991, Records of wells, drillers' logs, water-level measurements, and chemical analyses of ground water in Harris and Galveston Counties, Texas, 1985-89: U.S. Geological Survey Open-File Report 90-598, 168 p.
- Gabrysch, R.K., 1967, Development of ground water in the Houston district, Texas, 1961-65: Texas Water Development Board Report 63, 35 p.
- _____, 1972, Development of ground water in the Houston district, Texas, 1966-69: Texas Water Development Board Report 152, 24 p.
- _____, 1977, Approximate areas of recharge to the Chicot and Evangeline aquifer systems in the Houston-Galveston area, Texas: U.S. Geological Survey Open-File Report 77-754, 1 sheet.
- _____, 1980, Development of ground water in the Houston district, Texas, 1970-74: Texas Department of Water Resources Report 241, 49 p.
- _____, 1982, Ground-water withdrawals and land-surface subsidence in the Houston- Galveston region, Texas, 1906-80: Texas Department of Water Resources Report 287, 64 p.
- _____, 1984, Ground-water withdrawals and changes in water levels in the Houston district, Texas, 1975-79: Texas Department of Water Resources Report 286, 42 p.
- Gabrysch, R.K. and Coplin, L.S., 1990, Land-surface subsidence resulting from ground-water withdrawals in the Houston-Galveston region, Texas, through 1987: Harris-Galveston Coastal Subsidence District, Report of Investigations 90-01, 53 p.
- Jorgensen, D.G., 1975, Analog-model studies of ground-water hydrology in the Houston district, Texas: Texas Water Development Board Report 190, 84 p.
- Lang, J.W., Winslow, A.G., and White, W.N., 1950, Geology and ground-water resources of the Houston district, Texas: Texas State Board of Water Engineers Bulletin 5001, 55 p.
- Locke, G.L., 1990, Ground-water withdrawals, water-level changes, land-surface subsidence, and ground-water quality in Fort Bend County, Texas, 1969-87: U.S. Geological Survey Water-Resources Investigations Report 90-4012, 155 p.
- _____, 1991, Records of wells, drillers' logs, water-level measurements, and chemical analyses of ground water in Brazoria, Fort Bend, and Waller Counties, Texas, 1985-89: U.S. Geological Survey Open-File Report 90-588, 40 p.
- _____, 1991. Records of wells, drillers' logs, water-level measurements, and chemical analyses of ground water in Chambers, Liberty, and Montgomery Counties, Texas, 1985-89: U.S. Geological Survey Open-File Report 90-594, 45 p.

- Meyer, W.R., and Carr, J.E., 1979, A digital model for simulation of ground-water hydrology in the Houston area, Texas: Texas Department of Water Resources LP-103, 27 p.
- Rose, N.A., 1943, Progress report on the ground-water resources of the Texas City area, Texas: U.S. Geological Survey Open-File Report, 45 p.
- Williams, J.F., III, and Ranzau, C.E., Jr., 1987, 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, 56 p.
- Wood, L.A., and Gabrysch, R.K., 1965, Analog model study of ground water in the Houston district, Texas: Texas Water Commission Bulletin 6508, 103 p.
- Wood, L.A., Gabrysch, R.K., and Marvin, R.F., 1963, Reconnaissance investigation of the ground-water resources of the Gulf Coast region, Texas: Texas Water Commission Bulletin 6305, 123 p.