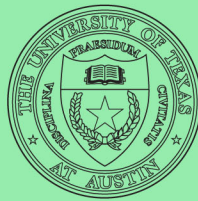


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HYDROLOGY OF THE CORPUS CHRISTI AREA, TEXAS

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CONTENTS

	Page
Introduction	1
Geology	6
Ground-Water Hydrology	6
Source and Replenishment of Ground Water	6
Climate	8
Surface Material	12
Land Surface Morphology	15
Movement of Ground Water	15
Occurrence of Ground Water	17
Water-Table Aquifers	18
Artesian Aquifers	25
Summary and Conclusions	39
Acknowledgments	40
References	41
Appendix A: Texas Well-Numbering Systems	43
Appendix B: Index to Subsurface Electric Log Control	45
Appendix C: Summary of Aquifer Pump Tests	54

ILLUSTRATIONS

Figures

1. Index map to Corpus Christi area, Nueces, San Patricio, Aransas, and Refugio Counties.
2. Average annual gross lake-surface evaporation and precipitation (in inches), Corpus Christi area. One inch equals 2.54 centimeters.
3. Hydrographs of shallow wells (less than 250 feet deep) compared to precipitation.
4. Hydrographs of deep wells compared to precipitation.
5. Relative permeabilities of surface materials, Corpus Christi area.
6. Flow net of water-table aquifer, 1971-1972 water levels.
7. Distribution and depositional origin of permeable sands containing shallow ground water in the Corpus Christi area.
8. Approximate altitude (elevation) of the base (deepest occurrence) of fresh to slightly saline artesian ground water in the Corpus Christi area.
9. Net thickness of sand containing fresh to slightly saline artesian ground water.
10. Cross sections showing zone and net thickness of sand containing fresh to slightly saline artesian ground water.
11. Approximate decline of water levels in wells tapping artesian aquifers in southwestern Nueces County and adjacent counties. Modified after Shafer and Baker, 1973.
12. Hydrographs of wells near Kingsville (Kleberg County) showing water-level declines in artesian aquifers.
13. TDS content of ground water from wells tapping artesian aquifers.
14. Relative favorability for future development of artesian ground water in the Corpus Christi area.
- A-1. Well-numbering system.
- B-1. Locations of wells from which electric logs used in this study were taken.
- C-1. Locations of wells in which aquifer pump tests were performed.

ILLUSTRATIONS

Tables

1. Surface water demand, Corpus Christi area.
2. Ground-water use, Corpus Christi area.
3. Yield ratings used for describing aquifers in the Coastal Bend region.
4. Classification of ground-water quality (after Robinove and others, 1958).
5. Hydrologic character of geologic units in the Corpus Christi area.
6. Monthly precipitation in Corpus Christi: 1932-1973 (in inches).
7. Slopes of stream channels near the Corpus Christi area (from Benson, 1964).
8. Ground-water flow, percent permeable area, and average precipitation in Refugio, San Patricio, and Nueces Counties, Texas.
9. Total dissolved solids content in ground water from wells tapping water-table aquifers, Corpus Christi area. Data obtained from the TWDB.
10. Geometry, age, and hydrologic characteristics of major surface-sand deposits in the Corpus Christi area. Data and interpretation after various sources.
11. Average rise in water levels in wells tapping water-table aquifers between 1966-1967 and 1972-1973, Corpus Christi area. Data obtained from the TWDB.
12. Total dissolved solids in ground water from wells tapping artesian aquifers, Corpus Christi area. Data obtained from the TWDB.
13. Recharge estimates and 1969-1971 ground-water pumpage in the Corpus Christi area. Data after various sources.
14. Amount of fresh to slightly saline ground water in storage, Corpus Christi area. Data from various sources.

INTRODUCTION

Ground-water resources in the Corpus Christi area--Nueces, San Patricio, Refugio, and Aransas Counties (fig. 1)--were investigated as part of a broader study of land and water resources of the four-county area (Kier and others, 1974a and 1974b; Kier and White, in preparation). Although surface water, primarily from Lake Corpus Christi on the Nueces River near Mathis, is the principal fresh water supply for the City of Corpus Christi and numerous other communities in the region (table 1), ground water is also a significant resource in the area. More than 24 million gallons a day (mgd), or approximately one-third of the demand for fresh water in the early 1970's, was met by ground-water supplies (table 2). About 58 percent of the ground-water pumpage was for rural/domestic and livestock purposes; about 25 percent was for irrigation in Nueces and San Patricio Counties.

This report delineates the occurrence and availability of fresh to slightly saline ground water (dissolved solids less than 3,000 milligrams per liter) in the four-county area (fig. 1). Specifically included are (1) the distribution of sands containing fresh to slightly saline water; (2) the direction and rate of ground-water flow; (3) the content of total dissolved solids (TDS) in ground water, and the relation of the TDS to the direction and rate of ground-water flow; (4) the effects of ground-water withdrawal on water levels, quality of water, and flow direction; (5) estimates of the quantities of ground water available for future development, and delineation of the areas favorable

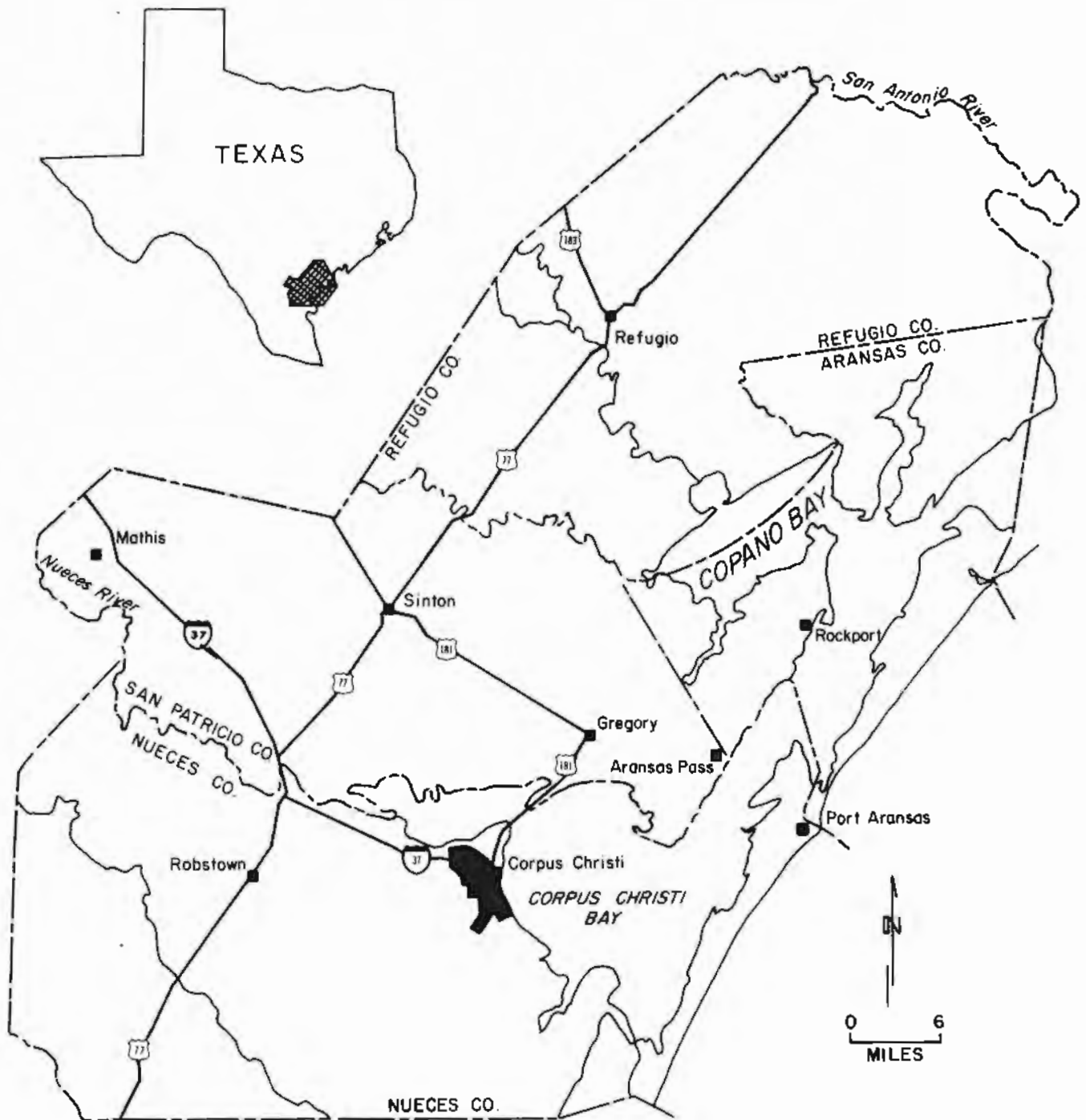


Figure 1. Index map to Corpus Christi area--Nueces, San Patricio, Aransas, and Refugio Counties, Texas.

for such development; and (6) potential problems limiting the availability and use of ground water in the Corpus Christi area.

Table 1. Surface-water demand, Corpus Christi area.¹

County	MGD ²
Nueces	59.6
San Patricio	1.6
Refugio	0.0
Aransas	0.0
Total	61.2

¹Modified after Sherman and Malina, 1974, table III-2, p. III-6.

²1 MGD = 3.785×10^3 cubic meters/day
or
= 3.785×10^6 liters/day

Data were derived from electric logs of oil and gas wells, records of water wells (through 1972), surficial geologic maps, and previous ground-water investigations. All water-well data were compiled and stored using System 2000 data management techniques. These data are available on open file at the Texas Water Development Board, Austin, Texas, and in the library of the Department of Geological Sciences, The University of Texas at Austin. A description of the well-numbering system is contained in Appendix A. An index to electric logs used to

Table 2. Ground-water use, Corpus Christi area.

County	No. of Irrigated Acres	Agricultural	Industrial	Municipal	Domestic- Livestock	Total
		Inventory Year 1969	Inventory Year 1971	Inventory Year 1971	(Estimated from various sources)	
		Water Use AcFt/Yr ¹ MGD ²	Water Use AcFt/Yr ¹ MGD ²	Water Use AcFt/Yr ¹ MGD ²	Water Use ² AcFt/Yr ¹ MGD ²	Water Use AcFt/Yr ¹ MGD ²
Aransas	0	0 0	2 0.1	198 0.2	600 0.5	800 0.7
Nueces	1,101	802 0.7	883 0.8	663 0.6	2,000 1.8	4,320 3.9
Refugio	0	0 0	485 0.4	860 0.7	900 0.8	2,240 1.9
San Patricio	13,634	6,097 5.4	175 0.2	1,422 1.3	12,400 11.0	20,100 18.0
Total	14,735	6,900 6.1	1,540 1.5	3,110 2.8	15,900 14.1	27,500 24.5

Totals are approximate because some of the pumpage, particularly for domestic and livestock purposes, is estimated. Pumpage figures are shown to the nearest 0.1 million gallons per day and to the nearest acre-foot. Acre-feet per year totals are rounded to three significant figures. Data from various sources, primarily Texas Water Development Board inventory files.

¹ 1 acre-foot = 1.234×10^3 cubic meters

² 1 MGD = 3.785×10^3 cubic meters/day
or
= 3.785×10^6 liters/day

determine the elevation of the deepest occurrence of fresh to slightly saline water and the net thickness of sand containing fresh to slightly saline water is shown in Appendix B. Aquifer pump-test data for the Corpus Christi area are shown in Appendix C. Terminology used in this study for rating the yield of wells and for describing the quality of water is explained in tables 3 and 4, respectively.

Table 3. Yield ratings used for describing aquifers in the Coastal Bend region.

Rating of Yield	Yield (Gallons per minute) ¹
Small	Less than 50
Moderate	50 to 500
Large	More than 500

¹ 1 Gallon/minute = 6.308×10^{-2} liters/second

Table 4. Classification of ground-water quality (after Robinove and others, 1958).

Description	Dissolved Solids (milligrams per liter)
Fresh	0 - 1,000
Slightly saline	1,000 - 3,000
Moderately saline	3,000 - 10,000
Very saline	10,000 - 35,000
Briny	35,000

GEOLOGY

In the Corpus Christi area exposed geologic units which are known to contain fresh to slightly saline water are, in order of decreasing age, Goliad Sand, Lissie and Beaumont formations (including ancient barrier-island/strandplain deposits), modern barrier-island deposits, and alluvium (table 5). The original depositional environments in which sediments accumulated affect the occurrence and availability of ground water. A typical grain size, geometry, and spatial orientation of sand characterize each depositional system. For example, fluvial sand bodies commonly trend parallel to regional dip, and barrier-island/strandplain sand bodies trend normal to regional dip. Fluvial sands are generally coarser grained than deltaic sands. Within most geological units of the Gulf Coast there is a general transition from coarse-grained fluvial sand landward, to fine-grained deltaic sand Gulfward.

In the Corpus Christi area, fluvial sand bodies 5- to 15-miles wide are characteristically associated with small amounts of mud. Deltaic and barrier-island/strandplain sand bodies 1- to 6-miles wide are typically associated with large amounts of mud deposited in intertributary, bay, or lagoonal environments.

GROUND-WATER HYDROLOGY

Source and Replenishment of Ground Water

Nearly all ground water is derived from the fraction of rainwater which infiltrates the soil and accumulates as a zone of saturation beneath the ground surface. Leakage from surface streams and artificial

Table 5. Hydrologic character of geologic units in the Corpus Christi area
(geologic classification modified after Schafer, 1968 and 1970).

Era	Period	Epoch	Geologic Unit	Ground Water Occurrence	Significant Location In Corpus Christi Area
Cenozoic	Quaternary	Modern and Holocene	Alluvium	Water Table	Nueces River
			Barrier island deposits	Water Table	Padre, Mustang, and St. Joseph Islands
		Pleistocene	Barrier island and/or strandplain deposits	Water Table	Eastern Aransas, San Patricio, and Nueces Counties
			Beaumont clay and Lissie Formation	Water Table and Artesian	Aransas, Refugio, San Patricio, and Nueces Counties
	Tertiary	Pliocene	Goliad Sand	Artesian	Refugio, San Patricio, and Nueces Counties

water impoundments lying above the zone of saturation (the water table) also contributes to recharge of ground water. Several factors--climate, surface permeability, and land-surface morphology--influence the amount of water which eventually reaches the aquifers.

Climate

Amounts of rainfall, evaporation, and persistence of extremes in these rates (that is, dry and wet periods) are some of the aspects of the general climatologic regime which determine the amount of moisture available for aquifer recharge. Average annual precipitation is 36 inches (91.4 cm) in the northeastern part of the area, and 28 inches (71.1 cm) in the southwestern part of the area. Average annual gross lake-surface evaporation is 58 inches (147.3 cm) in the northeastern part of the area, and more than 60 inches (152.4 cm) in the southwestern part of the area (fig. 2).

Annual precipitation data taken in Corpus Christi (table 6) indicate that during the past 24 years there have two major dry-wet cycles. During the 20 years previous to that period, dry and wet cycles were not as marked as they later became, and the cycles were not as long. Hydrographs of shallow wells in the Corpus Christi area illustrate the effect on water levels of short-term fluctuations of precipitation (fig. 3). Water levels are lowest during drought periods and highest during wet periods. Water-level changes may be accentuated because of increased use of ground water during dry periods and decreased use during wet periods.

Short-term fluctuations in precipitation do not as readily affect the water levels in deep wells. Thomas (1963) noted no direct effect of

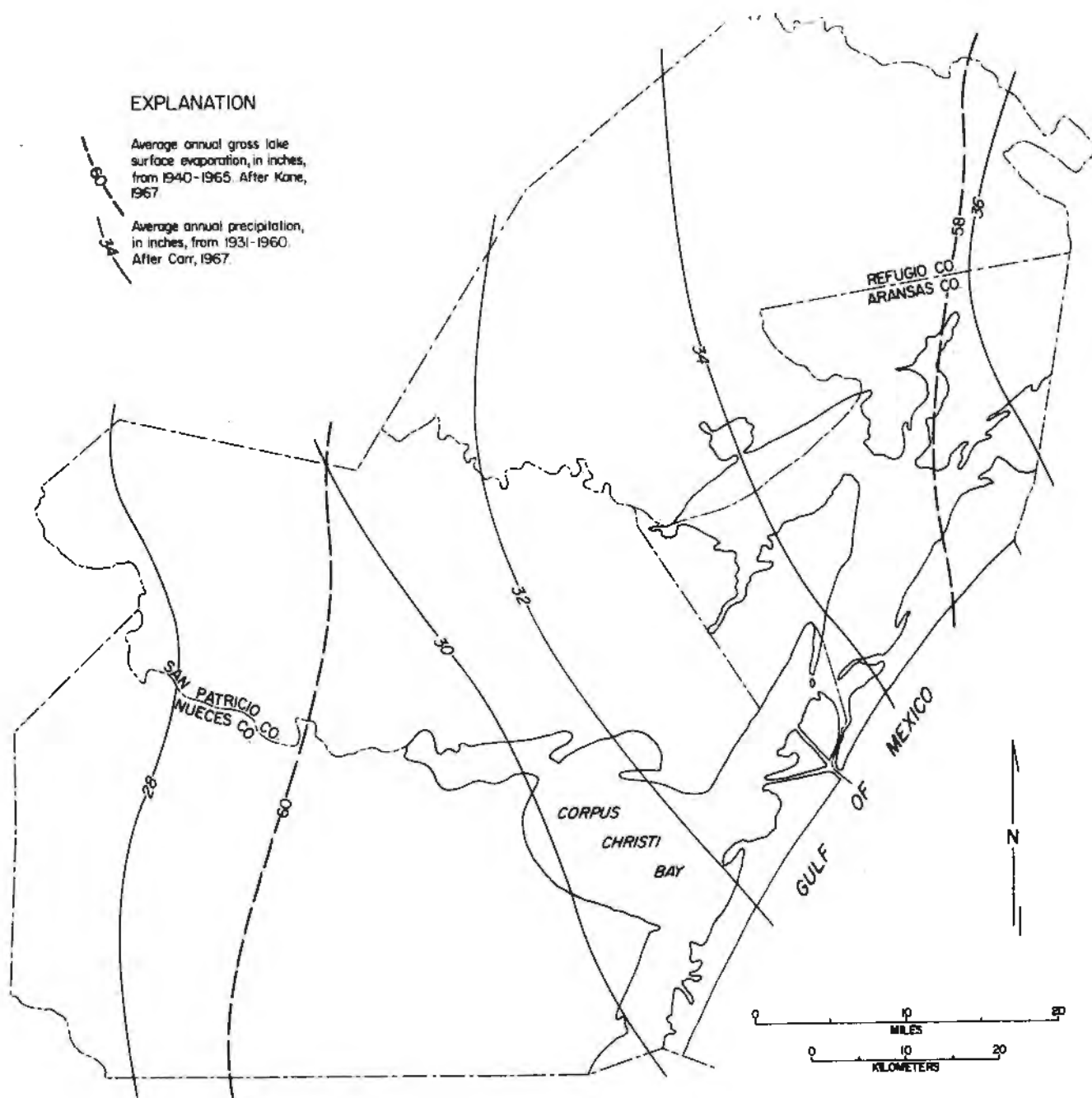


Figure 2. Average annual gross lake-surface evaporation and precipitation (in inches), Corpus Christi area. One inch equals 2.54 centimeters.

Table 6. Monthly precipitation in Corpus Christi: 1932-1973
(in inches)⁺.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1932	1.13	1.87	1.50	2.42	1.65	1.78	0.32	1.83	7.53	0.66	6.90	1.08	22.67
1933	0.70	1.89	0.47	0.44	3.69	2.72	2.54	2.27	4.71	1.99	1.33	0.31	23.06
1934	4.78	1.38	1.67	3.74	1.24	0.34	5.46	0.15	6.36	1.04	4.11	0.70	30.97
1935	1.87	0.86	2.06	1.16	4.97	1.56	1.37	0.43	12.45	5.76	0.81	5.69	38.99
1936	0.61	0.34	3.29	1.92	5.27	3.05	2.17	3.23	3.93	0.95	0.47	1.05	26.28
1937	0.42	0.58	2.05	0.43	1.19	0.82	2.07	1.66	0.57	2.04	4.09	8.13	24.05
1938	1.39	1.74	0.48	1.81	1.20	0.66	0.12	4.51	1.44	0.20	1.55	6.44	21.54
*1939	1.78	0.14	0.86	1.53	2.22	5.19	0.75	1.36	2.65	1.14	0.06	2.06	19.74
1940	0.76	1.10	1.57	0.05	4.17	2.84	4.02	0.66	3.14	3.49	1.23	2.12	25.15
1941	1.06	4.80	1.99	7.40	10.44	4.54	2.25	0.51	0.90	4.56	0.79	2.89	42.13
*1942	0.14	4.67	0.97	0.21	1.93	3.30	10.23	5.48	3.97	1.59	1.09	0.09	33.67
1943	4.07	1.74	1.76	0.36	4.95	0.36	0.48	0.35	4.26	0.81	4.01	3.72	26.87
1944	2.27	0.15	1.69	0.95	5.90	0.17	T	7.52	3.99	0.23	1.55	2.03	26.45
1945	0.98	2.37	4.01	3.65	0.61	2.58	2.52	5.96	1.82	3.48	0.43	1.73	30.14
1946	3.66	1.60	0.67	3.97	4.88	4.84	1.61	3.09	4.53	3.52	0.99	0.73	34.09
1947	1.77	0.18	1.36	1.48	5.29	1.83	3.50	5.05	1.06	1.04	8.53	2.17	33.26
1948	0.86	1.71	2.51	1.11	1.77	0.52	1.03	4.14	6.64	1.44	0.64	0.06	22.43
1949	1.03	2.25	1.62	4.83	0.19	1.11	4.56	1.40	5.16	6.36	T	1.77	30.28
1950	0.34	2.51	0.59	2.70	1.62	1.58	1.39	0.42	4.22	T	0.10	0.01	15.48
1951	0.55	1.08	2.36	0.63	0.95	4.02	0.22	0.14	14.54	0.90	1.43	0.09	26.91
1952	0.22	0.32	0.78	3.17	3.22	0.46	3.88	0.10	5.52	0.00	2.97	0.67	21.31
1953	0.17	1.33	0.30	0.30	0.88	0.25	0.14	12.64	0.78	5.24	0.69	1.42	24.14
1954	0.35	0.01	0.41	2.98	0.92	2.42	0.14	0.45	3.56	4.44	0.10	0.24	16.02
1955	0.91	1.32	0.07	0.04	2.11	0.28	0.95	0.83	11.70	1.55	1.69	0.42	21.87
1956	0.43	0.85	0.09	8.04	3.60	0.62	0.98	1.33	1.00	2.76	1.13	0.90	21.73
1957	0.14	1.48	2.74	2.53	4.82	5.34	0.00	2.12	2.42	0.40	5.24	0.77	28.00
1958	10.78	5.24	0.64	0.37	0.81	0.75	1.13	1.33	8.42	8.43	0.84	3.88	42.62
1959	1.74	4.53	0.31	1.39	4.49	5.69	2.29	5.58	2.41	7.73	0.76	1.52	38.44
*1960	1.56	1.07	1.97	3.26	1.93	3.77	1.42	7.06	1.61	10.66	2.24	7.80	44.35
1961	2.38	2.08	0.08	3.78	T	5.64	4.37	3.30	3.14	0.05	1.09	0.53	26.44
1962	0.22	0.06	0.41	1.18	0.24	2.93	T	0.90	5.37	0.39	1.13	2.66	15.49
1963	0.19	1.36	0.09	0.31	0.85	2.35	0.49	2.99	0.92	2.61	1.64	0.86	14.66
1964	1.61	1.53	1.14	0.08	4.39	0.38	2.25	0.50	6.98	0.19	0.21	2.45	21.71
1965	0.86	4.41	0.78	0.80	4.01	1.99	1.25	2.64	2.09	1.36	1.96	3.14	25.29
1966	2.12	1.15	0.69	5.03	7.23	4.35	1.23	4.15	2.84	0.85	0.07	0.18	29.89
1967	2.63	2.38	0.08	0.23	1.83	0.35	1.05	5.36	20.33	2.86	0.28	0.84	38.22
1968	2.11	2.42	0.90	0.82	9.38	8.36	5.43	0.62	6.34	3.68	1.34	0.13	41.53
1969	0.35	2.92	0.49	2.89	2.07	0.13	0.03	2.83	2.05	2.85	5.09	1.87	23.57
1970	1.79	1.01	1.55	0.15	3.92	9.16	1.72	7.32	8.51	3.13	0.81	0.40	39.47
1971	0.03	0.22	T	2.29	4.55	1.24	0.31	8.32	12.17	3.96	0.44	3.42	36.95
1972	1.23	3.41	1.44	1.53	5.99	3.65	2.82	3.74	9.49	0.46	2.48	0.17	36.41
1973	2.18	1.42	0.16	1.73	0.58	13.35	0.52	5.63	7.58	9.95	0.31	0.12	43.53
Record													
Mean	1.54	2.12	1.15	1.98	3.18	2.83	1.92	3.12	5.16	2.73	1.60	1.86	28.86
1932--													
1973													

*Indicates a break in the data sequence during the year, or season, due to a station move or relocation of instruments.

⁺1 inch = 2.54 centimeters.

Data source: National Oceanic and Atmospheric Administration, 1973.

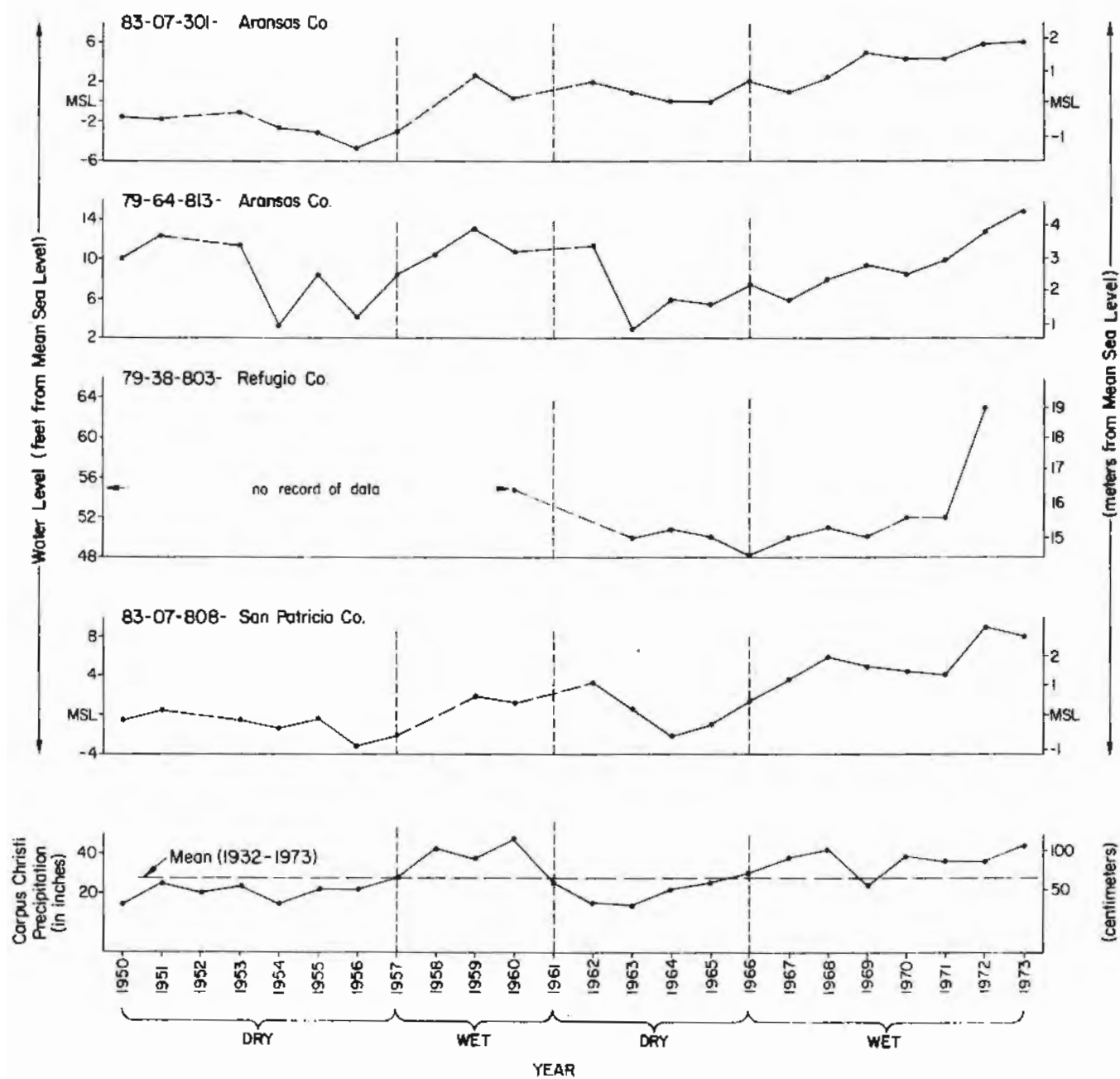


Figure 3. Hydrographs of shallow wells (less than 250 feet deep) compared to precipitation.

the drought period, 1950 to 1956, on water levels in deep wells tapping the Goliad Sand in the southwestern part of the area. Hydrographs of artesian wells, particularly those with a history of flowing onto the surface, do not reflect simultaneous water-level and precipitation changes (fig. 4).

Surface Material

The occurrence of permeable material at the ground surface affects the amount and rate of aquifer recharge. The more permeable the sediments, the more rapidly can precipitation infiltrate the ground. Impermeable materials allow almost no recharge to the aquifer.

Relative permeabilities of surficial material in the Corpus Christi area (fig. 5) were derived from the map of "Land and Water Resources of the Corpus Christi Area" (Kier and White, in preparation). Permeabilities were estimated according to the classification of Davis and DeWiest (1966, p. 164); permeability values range from 10^6 gpd/ft² to 10^{-3} gpd/ft² (4.8×10^1 cm/sec to 4.8×10^{-8} cm/sec).

Extensive outcrops of permeable sand cover most of Refugio County. Permeable deposits also occur in roughly one-half and one-third of the surface of San Patricio and Nueces Counties, respectively (statistical data derived from Kier and White, in preparation). Highly permeable sand occurs along the mainland shore in Aransas, San Patricio, and Nueces Counties.

Low-permeable clay deposits occur in much of San Patricio and Nueces Counties. Moderately permeable deposits composed of varying amounts of sand, silt, and clay occur in much of Refugio County and along the Nueces River.

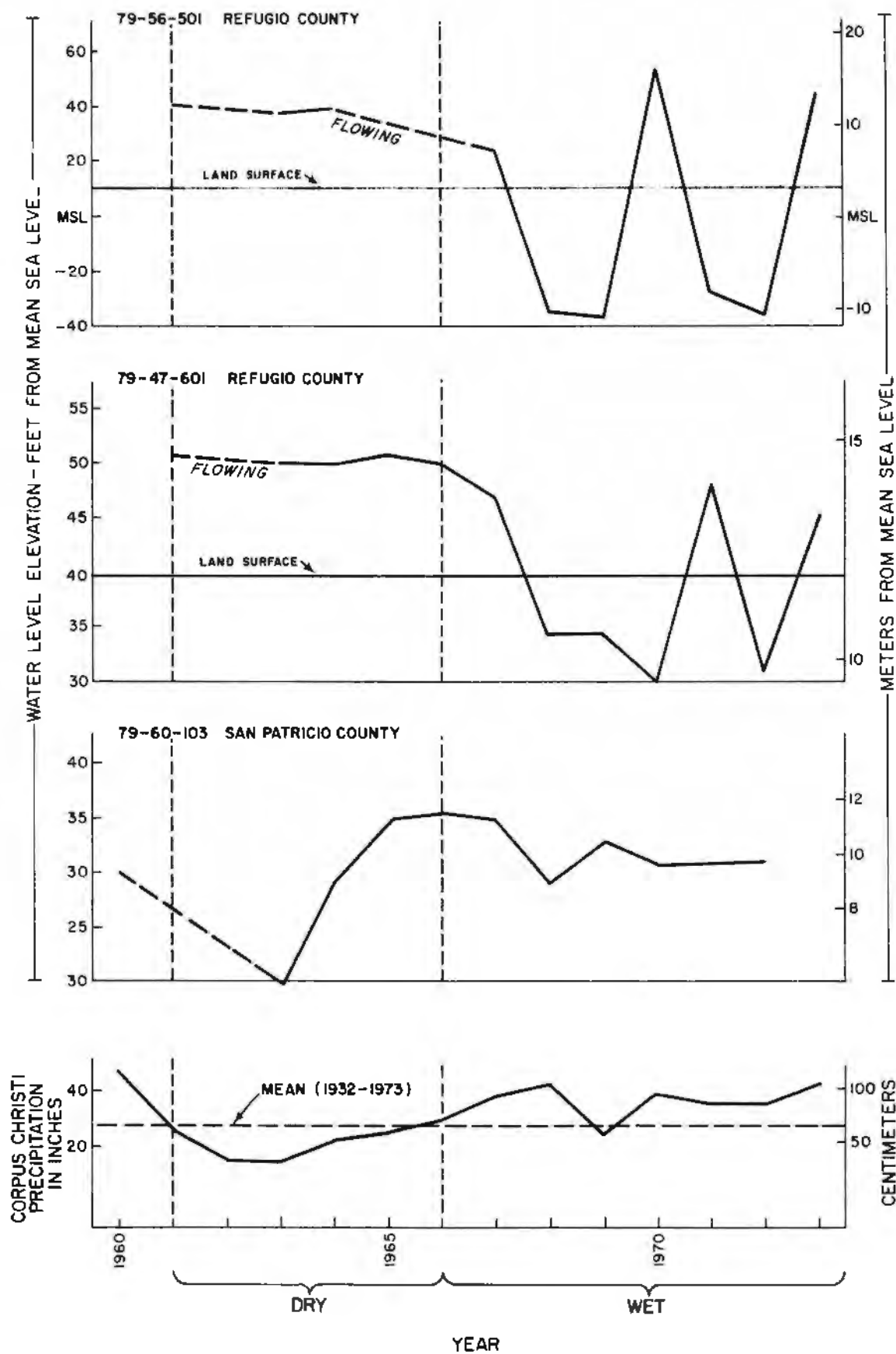


Figure 4. Hydrographs of deep wells compared to precipitation.

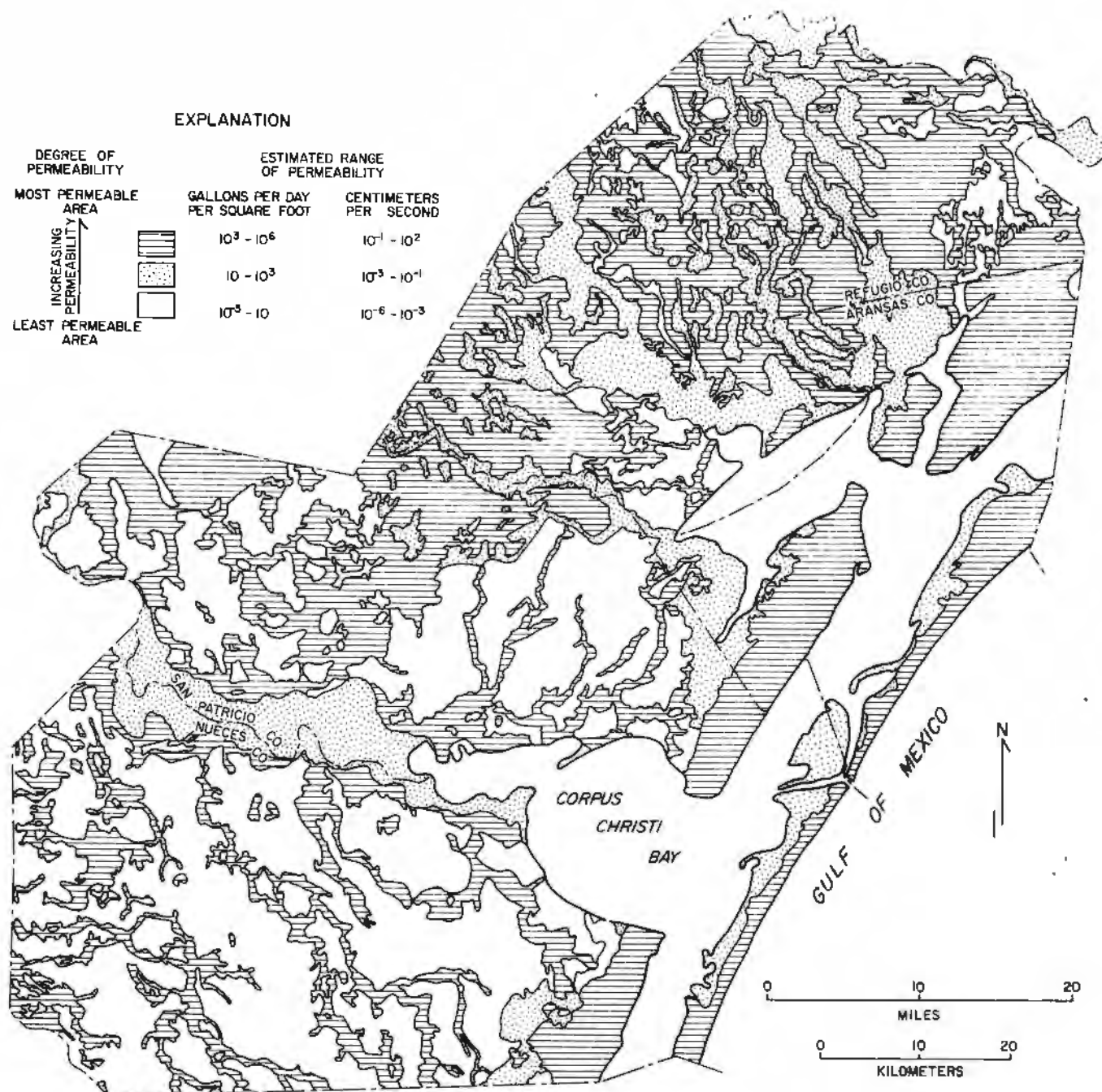


Figure 5. Relative permeabilities of surface materials, Corpus Christi area.

Land-Surface Morphology

The shape and slope of the land surface influences the amount of ground-water recharge by affecting the rate of surface runoff. Runoff from flat land is much slower than from rugged, high-relief terrain. The slower the runoff, the longer the time available for water to infiltrate the ground.

The Corpus Christi area is a gently sloping surface broken only by entrenched streams. Highest elevations are approximately 200 feet (61 m) in western San Patricio County, and the slope to the east-south-east is less than 5 feet per mile (0.9 m/km). Maximum relief between downcutting streams and the Coastal Plain surface is 80 feet (24.4 m) at the western margin of the area.

Low stream slopes in the Corpus Christi area favor low runoff rates and allow ample time for recharge. Slopes measured at gauging stations in and near the Corpus Christi area average between 5 and 6 feet per mile (0.95 m/km to 1.1 m/km) (table 7).

Movement of Ground Water

In the zone of saturation, ground water, like surface streams, moves under the influence of gravity. The altitude and slope of the upper surface of the zone of saturation can be shown by contour lines representing equal water-level elevations (fig. 6). Ground-water movement, or the potential for movement, is from high to low elevations in a direction perpendicular to the equipotential lines. In the Corpus Christi area, ground-water movement is from areas of recharge in the northwest toward the east or southeast.

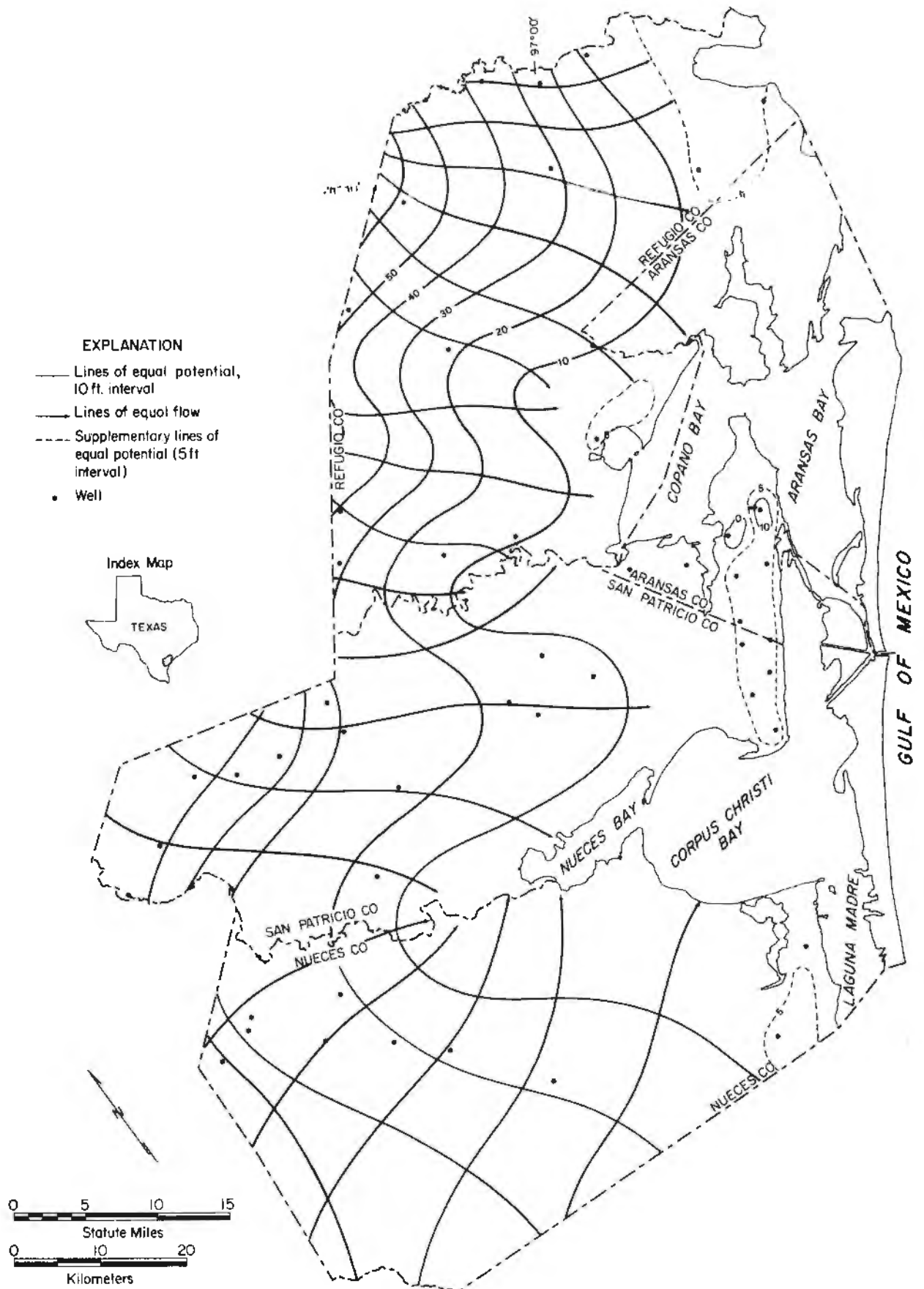


Figure 6. Flow net of water-table aquifer, 1971-1972 water levels.

Table 7. Slopes of stream channels near the Corpus Christi area
(from Benson, 1964).

Station	Slope	
	(ft/mi)	(m/km)
San Antonio River at Goliad, Texas	5.86	1.12
Mission River at Refugio, Texas	5.36	1.02
Nueces River near Three Rivers, Texas	5.45	1.04

Occurrence of Ground Water

Ground water in the Corpus Christi area occurs under water-table (unconfined) and artesian (confined) conditions. The distinction between water-table aquifers and artesian aquifers is important in the Corpus Christi area for two reasons: the uses of ground water from the two types of aquifers differ, and the relationship of these types of aquifers to surface activities differs. Water-table aquifers are important sources for small, economical supplies of ground water suitable for rural/domestic and livestock purposes. Wells which tap water-table aquifers generally have windmills or low-cost gasoline or electric pumps which can pump no more than a few gallons per minute. Furthermore, shallow aquifers are usually recharged locally. This bears directly on such problems of man's use of land areas as the disposal of solid, liquid, and household wastes, and water storage.

Ground water from deep artesian aquifers is more often used for large-volume, municipal and industrial water supplies because of the potentially greater yield of good quality water. Some large municipal and industrial wells in the Corpus Christi area pump more than 1,000 gallons per minute (63 liters/sec). Use of artesian ground water and the associated declines of artesian pressure, however, have been linked to subsidence of the land surface in the Houston area (Winslow and Doyel, 1954; Winslow and Wood, 1959; Turner and others, 1966; Gabrysch, 1969; Gabrysch and Bonnet, 1974).

In the Corpus Christi area, water wells less than 250 feet deep (76 meters) generally tap water-table aquifers; wells greater than 250 feet deep (76 meters) tap artesian aquifers. The distinction between water-table, aquifers and artesian aquifers is not exact, however. Locally, there may be shallow, confined aquifers where flow is diverted under and around near-surface layers of impermeable clay. No single depth below land surface can be projected as the dividing plane between water-table and artesian aquifers.

Water-Table Aquifers

Permeable sands containing shallow ground water occur throughout much of the Corpus Christi area (fig. 7). Fine- to medium-grained sand deposited in former barrier-island or shoreline environments occurs as elongate lenses along the mainland shore in the eastern part of the area. Fine- to coarse-grained sand deposited by ancient rivers occurs in the northwestern part of the area including most of Refugio and northern San Patricio Counties. Fine-grained sand and silt deposited in Pleistocene delta distributary environments and reworked locally by

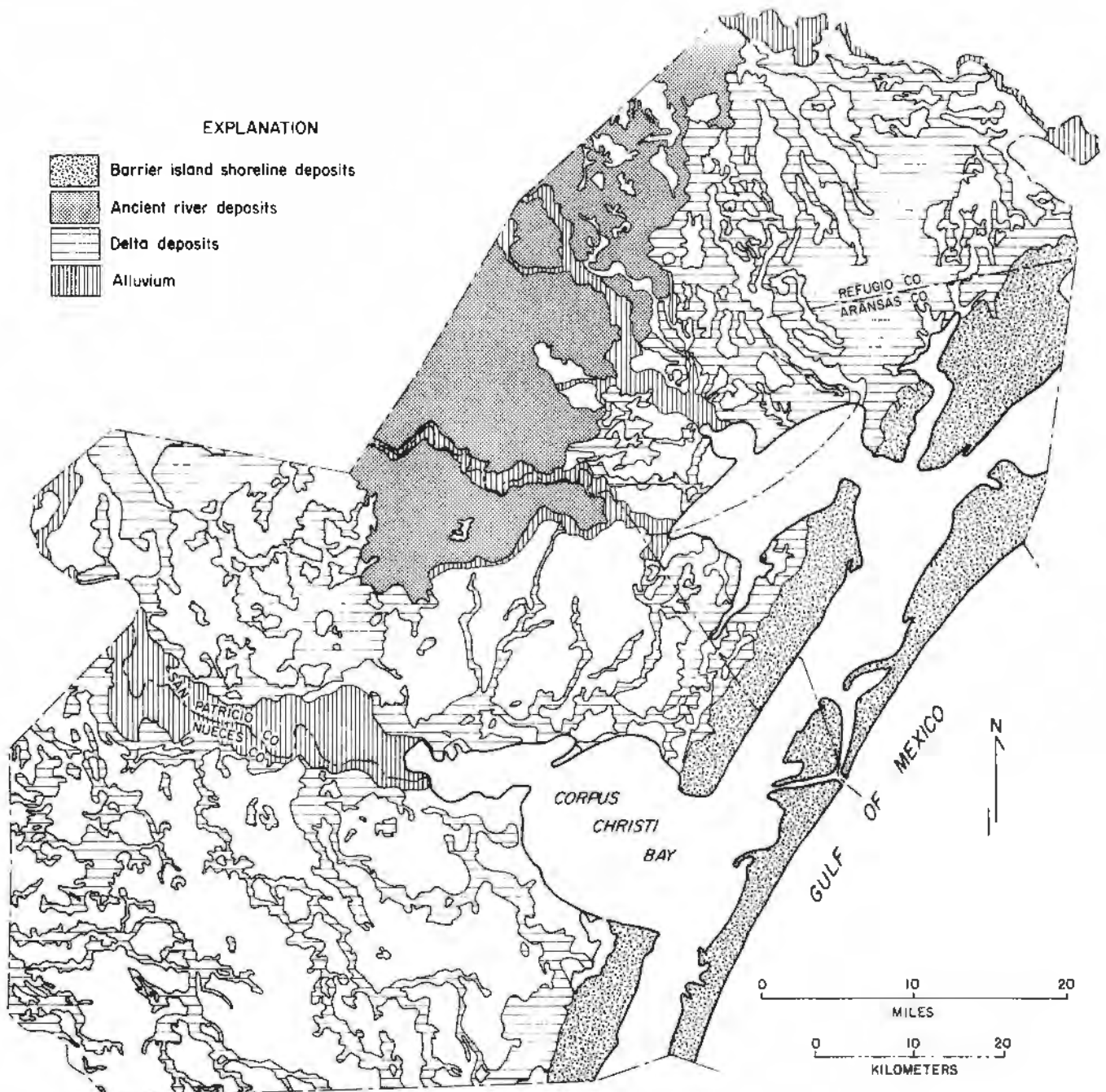


Figure 7. Distribution and depositional origin of permeable sands containing shallow ground water in the Corpus Christi area.

marine processes occur in southeastern San Patricio, Nueces, and northeastern Refugio Counties. Because the delta distributaries are widely dispersed within broad areas of mud in San Patricio and Nueces Counties, and because amounts of rainfall are relatively low in this part of the Corpus Christi area, the distributaries contain little potable ground water.

The amount of water moving through shallow aquifers was determined with a flow net (fig. 6) and Darcy's equation (Davis and DeWiest, 1966, p. 156). Ground water is more available in Refugio than in San Patricio and Nueces Counties because high permeability, large recharge area (sand outcrop; fig. 5), and higher annual precipitation permit greater ground-water flow. Table 8 shows the relationship between ground-water flow, extent of recharge area, and annual precipitation in Refugio, San Patricio, and Nueces Counties.

Table 8. Ground-water flow, percent permeable area and average precipitation in Refugio, San Patricio, and Nueces Counties, Texas.

County	Probable Rate of Flow (M gals/day) ¹	Permeable Area (approx. percent)	Average Annual Precipitation (inches) ²
Refugio	0.9 - 2.8	60	34
San Patricio	0.2 - 0.7	38	30
Nueces	0.2 - 0.5	21	28

¹ 1 M gals/day = 3.785×10^3 cubic meters/day
or
= 3.786×10^6 liters/day

² 1 inch = 2.54 centimeters

Shallow ground water in the Corpus Christi area ranges from fresh (144 mg/l TDS) to moderately saline (7,520 mg/l TDS). The range of TDS of ground water measured in wells for each county in the area is shown in table 9. The TDS content of ground water in coarser grained sands in Refugio County is lower (144 to 3,757 mg/l TDS) than in finer grained sands in San Patricio and Nueces Counties (337 to 4,556 mg/l TDS).

Table 9. Total dissolved solids content in ground water from wells tapping water table aquifers, Corpus Christi area (from the Texas Water Development Board).

County	Range of TDS milligrams per liter
Aransas	259 to 7,520
Nueces	1,097 to 2,550
Refugio	144 to 3,757
San Patricio	377 to 4,556

The TDS content of ground water is controlled primarily by the distribution and solubility of the minerals in the aquifer through which the ground water is moving, by the porosity and permeability of deposits, and by the flow path of water (Back, 1966). Ground water moving through an aquifer tends, with time, to become more mineralized (higher TDS content). Water moving through an aquifer composed of small-sized

grains, such as in San Patricio and Nueces Counties, will tend to have a higher TDS content than water moving through an aquifer composed of large-sized grains, such as in Refugio County, because smaller grain size generally correlates with decreased permeability and longer residence time of ground water.

Areas favorable for future development of water-table aquifers were delineated on the basis of (1) distribution of permeable material at the surface, (2) amount of rainfall, (3) known and estimated rates of ground-water flow, and (4) known and estimated water quality. Table 10 summarizes the geometry, age, and potential ground-water yields of surface sand deposits in the Corpus Christi area.

Water-table aquifers in ancient barrier-island/strandplain deposits in Aransas, eastern San Patricio, and Nueces Counties, and in fluvial deposits in Refugio and northern San Patricio Counties, are most suitable for additional shallow ground-water development. In these counties extensive surficial sands receive the largest amounts of rainfall in the Corpus Christi area--32 to 34 inches annually. Several shallow wells tapping water-table aquifers yield small to moderate quantities of fresh to slightly saline water.

Sands of deltaic origin in Nueces and southern San Patricio Counties are less extensive and receive less rainfall (28 to 32 inches annually) than barrier-island/strandplain and fluvial deposits to the north and east. These sand deposits are moderately favorable for additional development; a few shallow wells yield small quantities of slightly saline water.

Table 10. Geometry, age, and hydrologic characteristics of major surface sand deposits in the Corpus Christi area (data and interpretation after various sources).

Type of Surface Sand Deposit	Typical Geometry	Geologic Age	Significance as a Water-Table Aquifer
Barrier-island/ strandplain	Lens shape, elongate parallel to present shoreline, 2 to 6 miles wide, 30 to 60 feet thick	Holocene	Yields small quantities of fresh to slightly saline water
		Pleistocene	Yields small to moderate quantities of fresh to slightly saline water
Fluvial	Perpendicular to present shoreline, 5 to 15 miles wide, 10 to 100 feet thick	Pleistocene	Yields small to moderate quantities of fresh to slightly saline water
Deltaic	Perpendicular to present shoreline, distributary pattern, 1 to 5 miles wide, 20 to 100 feet thick	Pleistocene	Yields small quantities of slightly saline water

Small amounts of shallow ground water are also available in Modern alluvial deposits. Water in alluvium consisting of 5 to 40 feet of sand, silt, and clay is tapped by a few wells along the Nueces River and its tributaries.

Changes in water levels limit the availability of shallow ground water in the Corpus Christi area. Drawdown of the water table during periods of drought and water-level rises during rainy periods are important in terms of continued use of water from wells dug only to minimum depths. In the four counties under consideration, the average water levels rose from 2 to 12 feet (.61 to 3.66 meters) (table 11) from 1966-1967 (following a period of drought) to 1972-1973 (following a period of high rainfall). If a drought as severe as that of the early 1960's

Table 11. Average rise in water levels in wells tapping water-table aquifers between 1966-1967 and 1972-1973, Corpus Christi area (from the Texas Water Development Board).

County	Average rise ¹	
	in feet	in meters
Aransas	9	2.7
Nueces	12	3.7
Refugio	2	0.6
San Patricio	8	2.4

¹ Average was calculated from the water levels of all shallow wells in the county.

recurred, the water table would probably drop by about the same amount it rose in 1966 and 1967. Wells which are barely deep enough during wet periods may dry up when the need for water becomes most critical.

Artesian Aquifers

The depositional origin of the artesian aquifers and their orientation with respect to the coast are factors controlling the quantity and quality of artesian ground water. The availability of good quality ground water from artesian aquifers was estimated from (1) the elevation of the deepest occurrence of fresh to slightly saline water, (2) the distribution and net thickness of sand containing fresh to slightly saline water, (3) the amount of water-level decline attributable to withdrawal of ground water, and (4) the amount of total dissolved solids in the ground water.

The elevation of the deepest occurrence of fresh to slightly saline water is the maximum depth at which good quality water can be found. In the Corpus Christi area, the deepest occurrence of most fresh to slightly saline water is from a few feet above sea level to 1,400 feet (426.7 meters) below sea level (fig. 8). The base of fresh to slightly saline water is deepest in the northern and western parts of the area, averaging 800 to 1,400 feet (243.8 to 426.7 meters) below sea level. The elevation of the base rises (usually abruptly) to sea level and above in the east and southeast.

The distribution of net-sand thickness containing fresh to slightly saline water delineates the locations of the largest amounts of artesian ground water (fig. 9). Maximum thickness, up to 600 feet (182.9 meters), occurs in the northwestern part of the Corpus Christi area and decreases

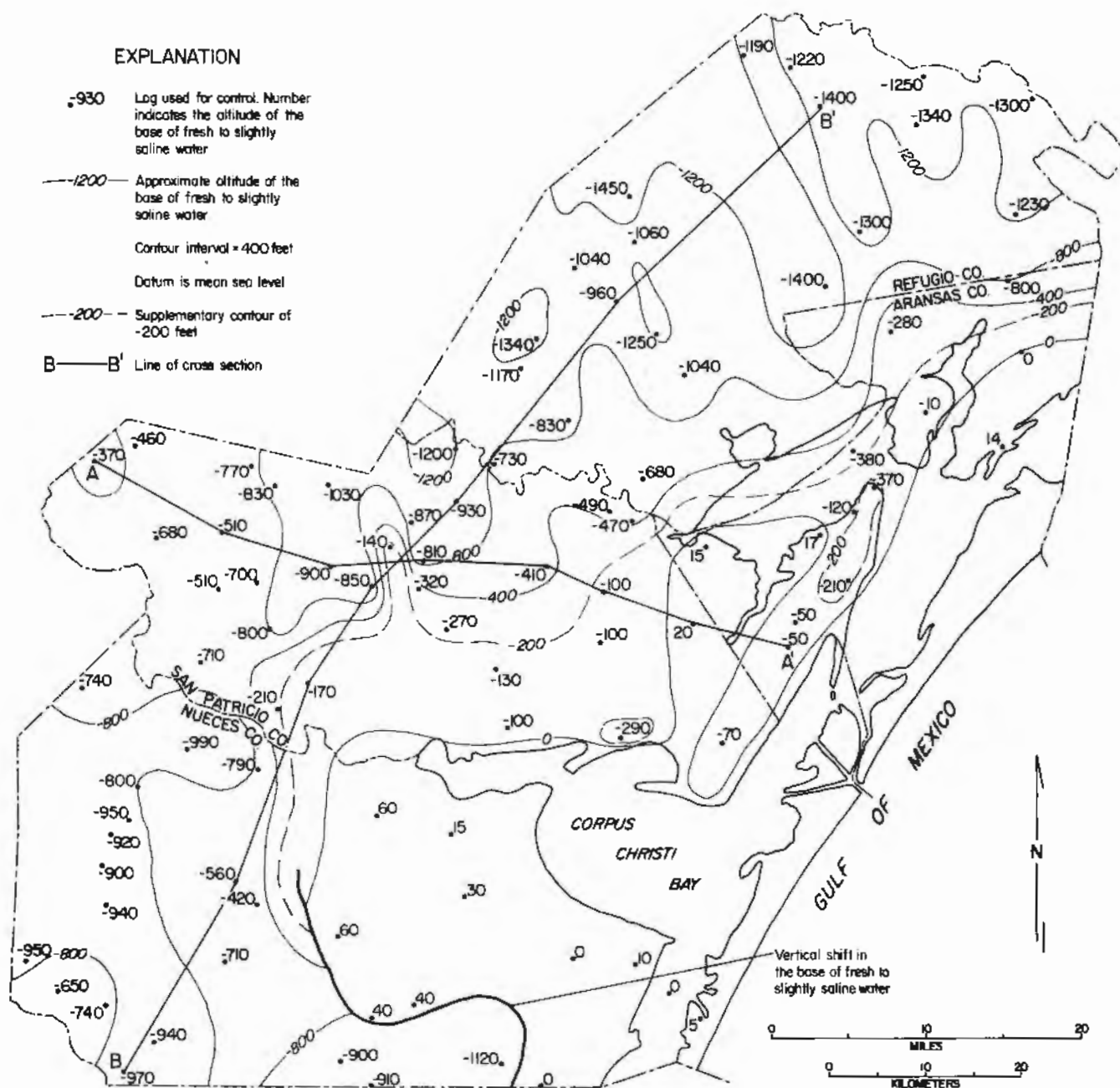


Figure 8. Approximate altitude (elevation) of the base (deepest occurrence) of fresh to slightly saline artesian ground water in the Corpus Christi area.

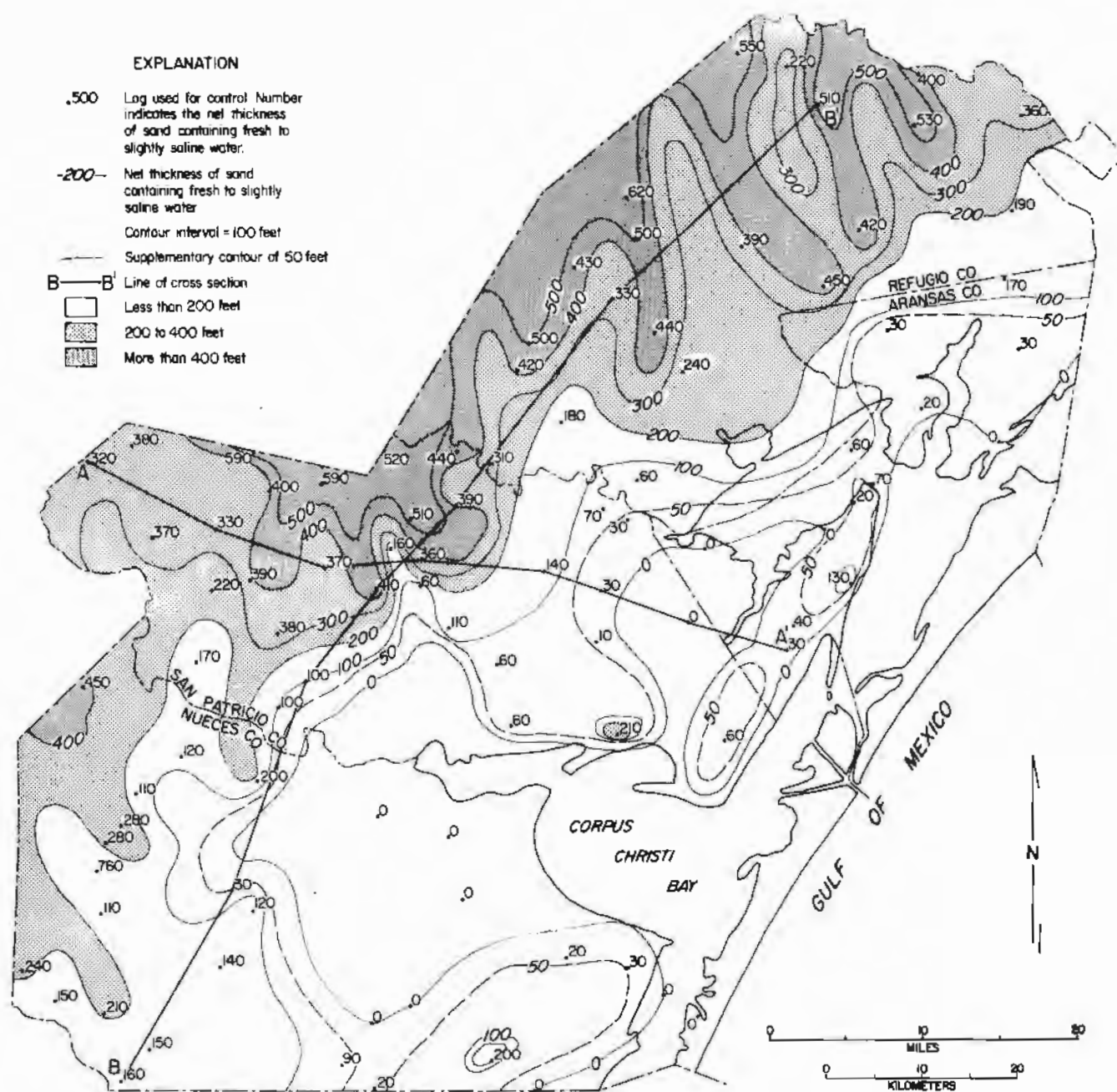


Figure 9. Net thickness of sand containing fresh to slightly saline artesian ground water.

to zero to the east and southeast. The relationship between net thickness of sand containing fresh to slightly saline water and the zone (total thickness of sediment between the top and the base) of fresh to slightly saline artesian ground water is shown in figure 10. The cross sections indicate the following: (1) fresh to slightly saline water in artesian aquifers may be overlain locally by as much as 600 feet (182.9 meters) of sediment containing moderate to very saline water; (2) muds or sands with moderate to very saline water occur between sands containing fresh to slightly saline water, as shown by the difference in thickness between the zone containing fresh to slightly saline water and the net thickness of sand containing fresh to slightly saline water; and (3) the thickness of the zone and the net amount of sand containing fresh to slightly saline water both decrease Gulfward.

The amounts of water-level decline, determined from historical water-level records, suggest where maintenance of ground-water supplies may be expensive, or where certain hazards due to ground-water withdrawal may develop. Declines of from 50 to 200 feet (15.2 to 60.6 meters) were recorded between 1932-1935 and 1968-1973 in southwestern Nueces County and adjacent counties to the south and west (fig. 11). Hydrographs of wells near Kingsville show progressive water-level declines of from 80 to 200 feet (24.4 to 60.6 meters) since the early 1930's (fig. 12). In a well in southwestern Refugio County, for example, the water level has declined over 50 feet (15.2 meters) since the early 1960's.

Significant declines in water levels may necessitate using large, efficient pumps to lift the ground water to the surface. The cost of

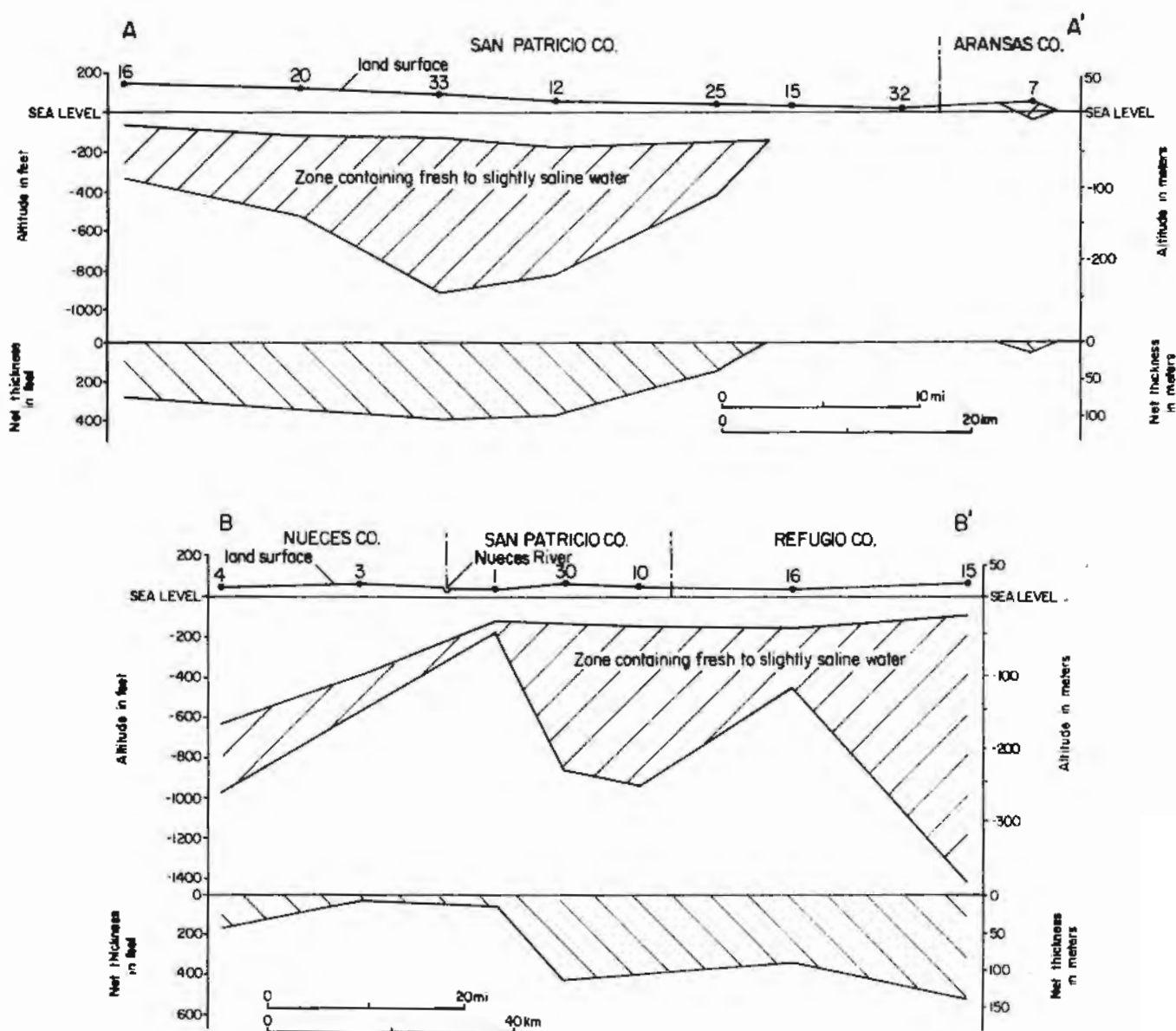


Figure 10. Cross sections showing zone and net thickness of sand containing fresh to slightly saline artesian ground water.

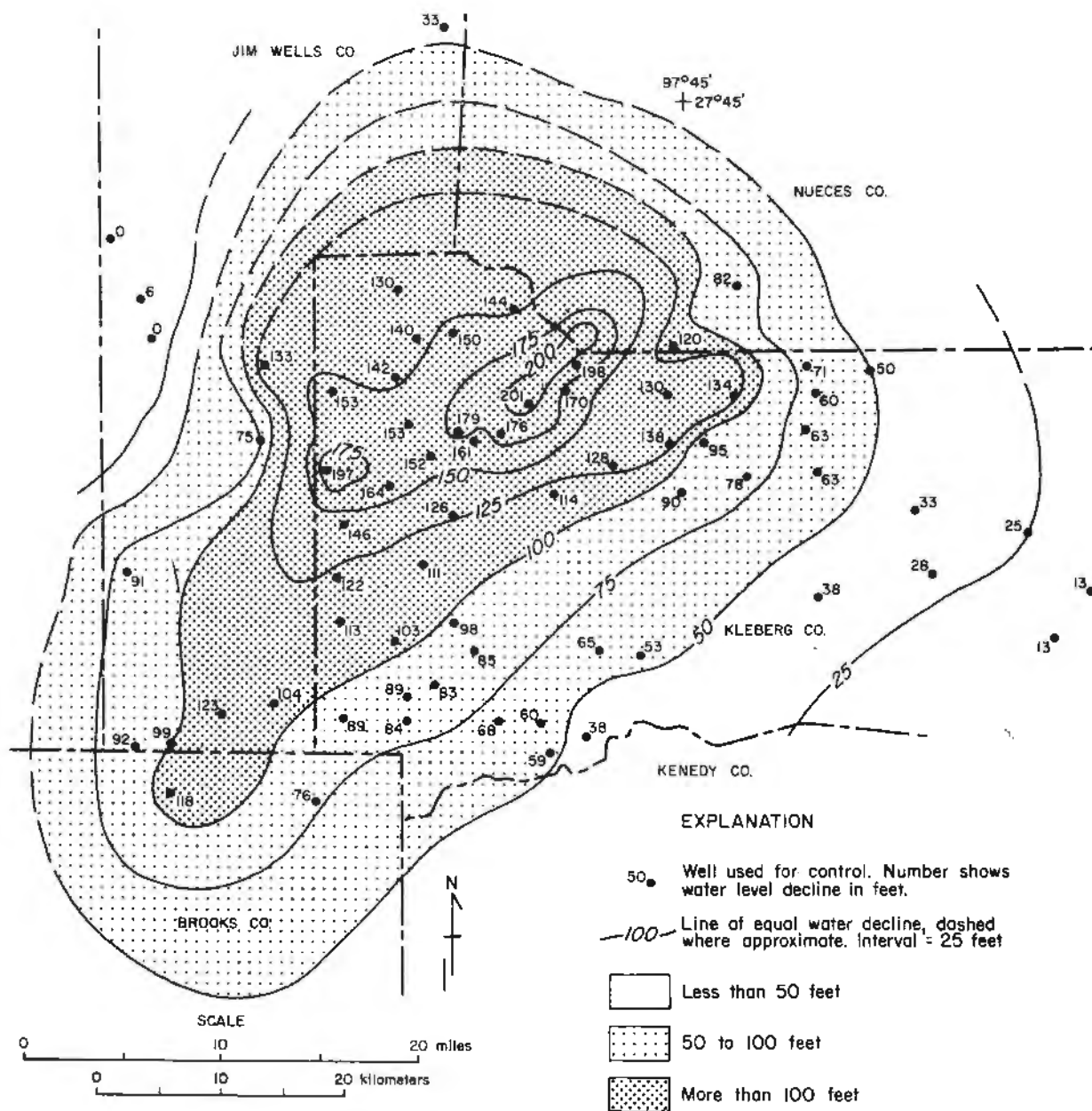


Figure 11. Approximate decline of water levels in wells tapping artesian aquifers in southwestern Nueces County and adjacent counties. Modified after Shafer and Baker, 1973.

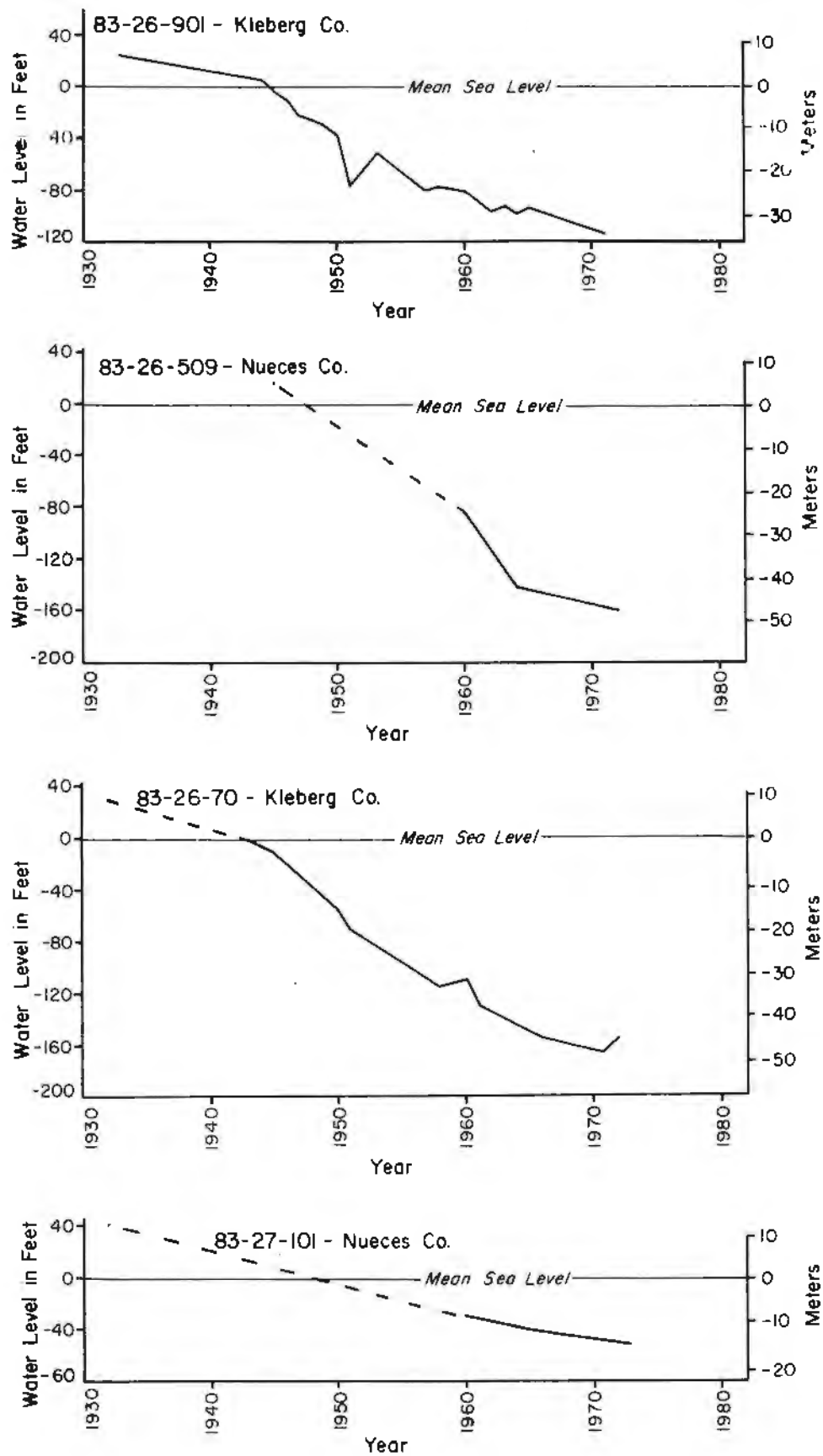


Figure 12. Hydrographs of wells near Kingsville (Kleberg County) showing water-level declines in artesian aquifers.

such pumps, which tend to become less efficient as declines continue, is an important consideration in planning for use of water resources.

Potential hazards due to the effects of large water-level declines include land-surface subsidence, faulting, and salt-water encroachment. Piezometric decline from large ground-water withdrawal could cause salt water to move both vertically and laterally toward areas of heavy pumpage (Winslow and others, 1957). However, recent chemical analyses of water from selected wells near Kingsville do not indicate significant increases in mineralization (Shafer and Baker, 1973, p. 39). Apparently there has been little, if any, lateral or vertical movement of salt water due to excessive pumping.

Based on work by Gustavson and Krietler (1976), Kier and White (in preparation) discussed faulting and subsidence in the Corpus Christi area. The only faulting and subsidence known to occur is associated with gas production in the Saxet oil field near Clarkwood in Nueces County. Recent releveing immediately south and west of the Corpus Christi area does not show any demonstrable subsidence (Bob Bluntzer, personal communication, 1977). Thus, in the Corpus Christi area, declines in artesian water level do not appear to have caused any natural hazards.

The distribution and amount of total dissolved solids in ground water indicates where water of the best quality occurs. TDS content in ground water from wells tapping artesian aquifers (table 12) ranges from fresh (486 mg/l) to moderately saline (5,143 mg/l) (fig. 13). Ground water of the best quality (TDS less than 1,000 mg/l) occurs in fluvial and deltaic sands in northwestern Refugio and San Patricio Counties (see

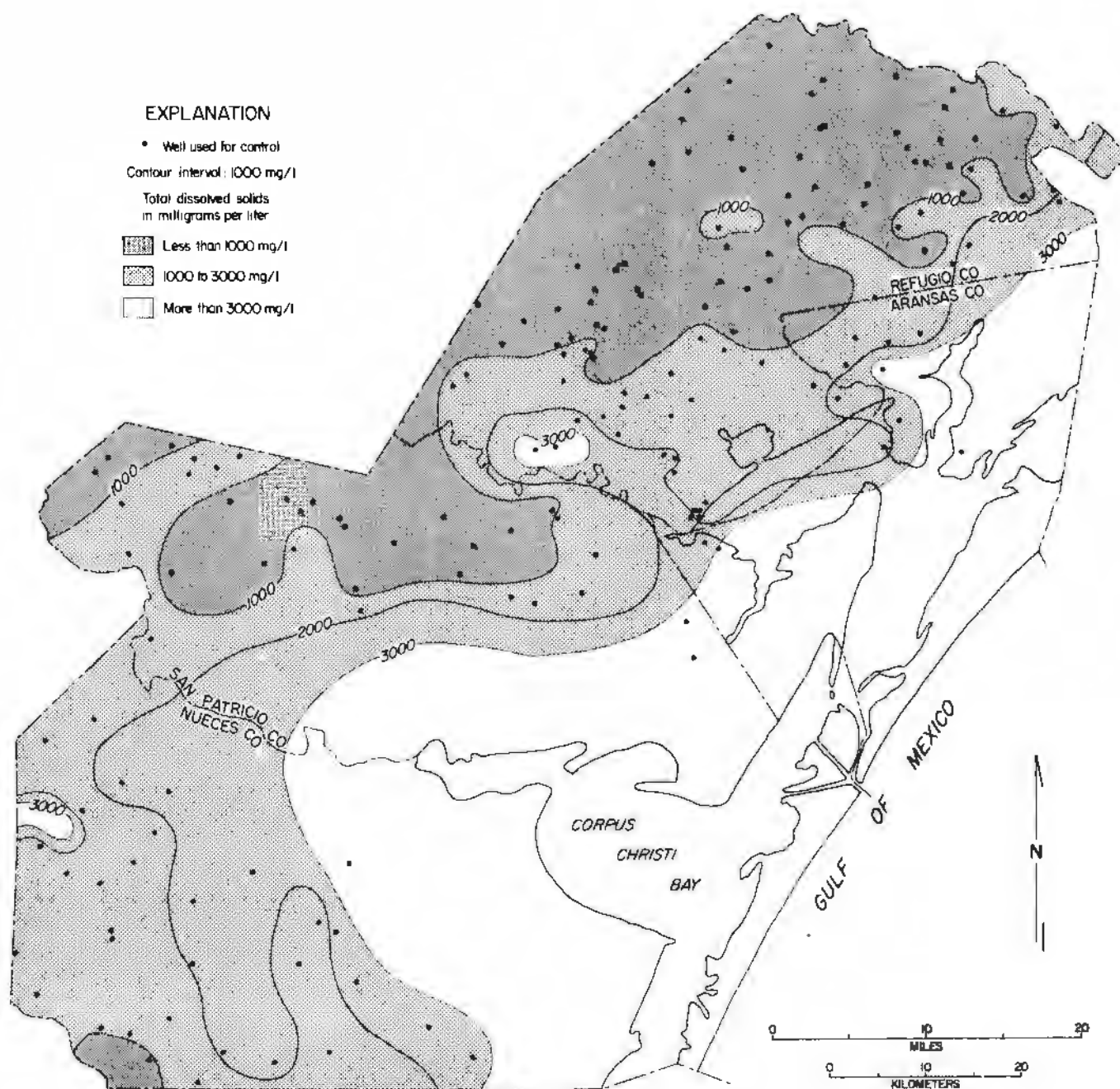


Figure 13. TDS content of ground water from wells tapping artesian aquifers.

Table 12. Total dissolved solids in ground water from wells tapping artesian aquifers, Corpus Christi area (from the Texas Water Development Board).

County	Range of TDS (milligrams per liter)
Aransas	1,258 to 4,620
Nueces	977 to 4,331
Refugio	486 to 5,143
San Patricio	689 to 3,986

Kier and others, 1974b, for facies interpretations); dissolved solids increase to more than 3,000 mg/l to the east. Sand bodies, 400 to 600 feet thick (121.9 to 182.9 meters), extend Gulfward in these counties (fig. 9). Continuity in the direction of regional ground-water flow probably permits large flows to move at relatively high rates.

In the eastern and southern parts of the Corpus Christi area, ground water containing more than 1,000 mg/l TDS occurs in ancient barrier-island/strandplain sands. These sand bodies, oriented parallel to the Gulf, are interbedded with less permeable muds and silts of lagoonal, deltaic, and shelf facies. The change in orientation of the aquifer from perpendicular to the coast to a more parallel-to-the-coast direction decreases the rate of ground-water flow, which in turn increases the residence time of the water in the aquifer, allowing TDS to build up.

The additional quantity of water which can be withdrawn on a long-term basis without depleting the artesian aquifer (that is, removing ground water from storage) was determined by subtracting present ground-water pumpage from estimated rates of recharge. Estimates of recharge were taken from data published by the Texas Water Development Board (table 13).

Table 13. Recharge estimates and 1969-1971 ground-water pumpage in the Corpus Christi area (after various sources).

County	Recharge MGD ¹	Pumpage MGD ¹	Data Source
Aransas	2.0	0.7	Shafer, 1970
Nueces	2.5	3.9	Shafer, 1968
Refugio	38.0	1.9	Mason, 1963
San Patricio	2.5	18.0	Shafer, 1968
Total	45.0	24.5	

¹ 1 MGD = 3.785×10^3 meters/day
or
= 3.785×10^6 liters/day

Within the Corpus Christi area, pumpage from artesian aquifers can increase over 50 percent before ground water will be removed from storage (table 13). This development, however, cannot occur equally throughout all parts of the region. Refugio County has the largest available

supply in the area, with 36 mgd ($1.363 \times 10^5 \text{ m}^3/\text{day}$), and nearly all the increased pumpage of ground water would therefore have to be in Refugio County.

In San Patricio and Nueces Counties, ground-water withdrawal already exceeds recharge by 15 mgd and 1 mgd, respectively. Therefore, considering these counties as a whole, ground water is being taken from storage. Locally, in northwestern San Patricio County, good quality artesian ground water is plentiful and would probably support increased pumpage.

Estimates of the amount of ground water in storage were also derived from published data (table 14). These estimates were based on the volume of sand containing fresh to slightly saline water, and on the

Table 14. Amount of fresh to slightly saline ground water in storage, Corpus Christi area (from various sources).

County	Storage (10^5 million gallons) ¹	Data source
Aransas	3	Shafer, 1970
Nueces	29	Shafer, 1968
Refugio	32	Mason, 1963
San Patricio	29	Shafer, 1968

¹ 1 million gallons = $3.785 \times 10^3 \text{ meters}^3$

or

$$= 3.785 \times 10^6 \text{ liters}$$

porosity of the sand, estimated at 30 percent. Sands in Refugio County contain the largest amount of ground water in storage-- 3.2×10^6 million gallons (M gals; $1.21 \times 10^4 \text{ m}^3$). Sands in Aransas County contain the lowest amount of ground water in storage-- 3.0×10^5 M gals ($1.14 \times 10^3 \text{ m}^3$).

Figure 14 shows areas most favorable for the future development of artesian ground water. The map was constructed considering the net thickness of sand with fresh to slightly saline water and the dissolved-solids content of ground water. Relative degrees of favorability are based on combinations of arbitrary values assigned to increments of 200 feet (61 meters) of sand thickness and 1,000 to 2,000 mg/l TDS. Factors used to determine the relative degrees of favorability are shown in the explanation in figure 14.

The northern and western parts of the Corpus Christi area are most favorable for the development of artesian ground water. These areas are characterized by thick accumulations of sand containing abundant water with low TDS contents. Areas least favorable for development are in the eastern and southern parts of the Corpus Christi area. Additional ground water probably should not be developed in these areas because the sands are thin and the water is highly mineralized. Further ground-water development should also probably be avoided in two areas in the southwestern part of Refugio and Nueces Counties, respectively, where large withdrawals have already lead to declines in artesian pressure.

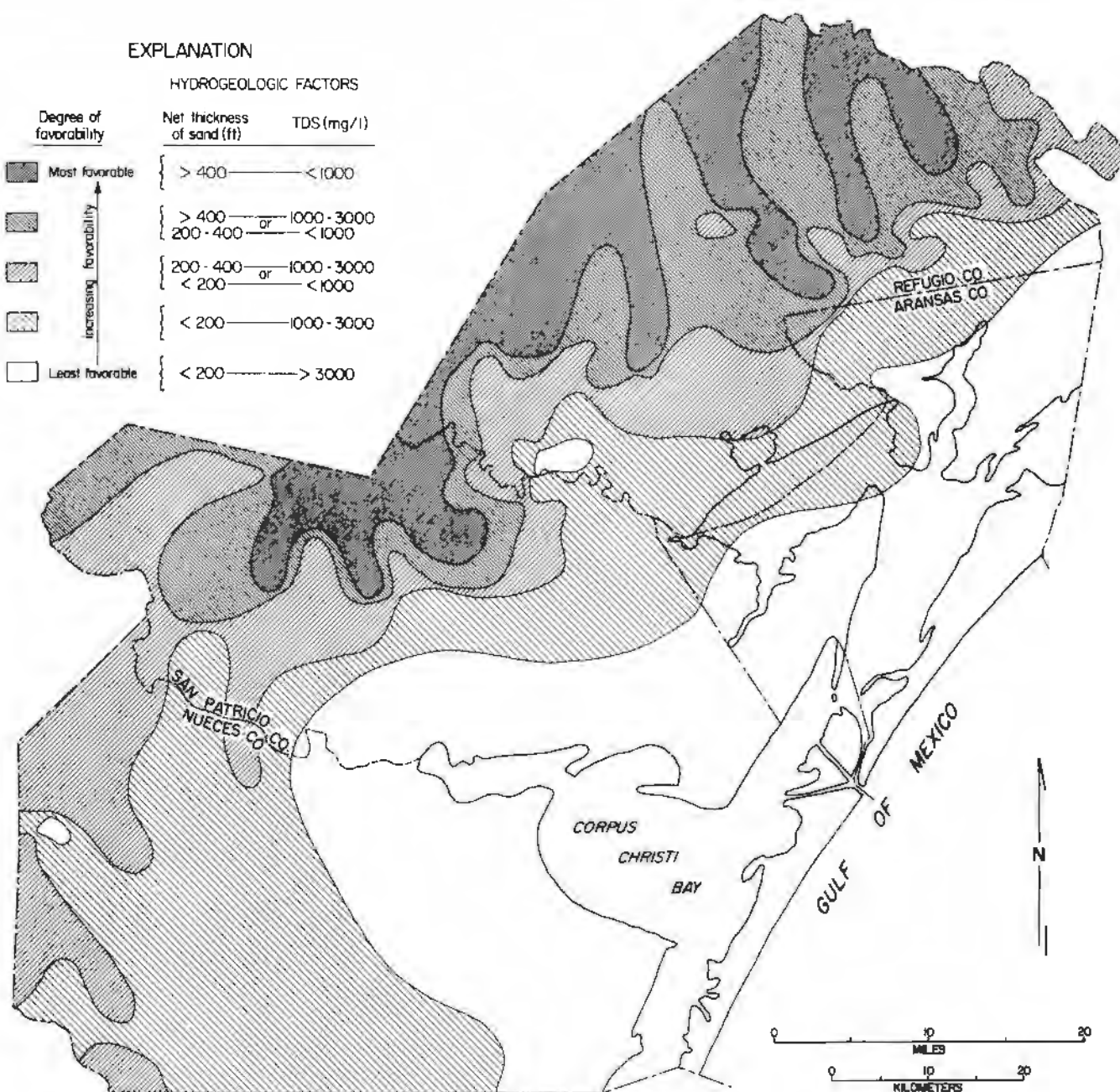


Figure 14. Relative favorability for future development of artesian ground water in the Corpus Christi area.

SUMMARY AND CONCLUSIONS

Additional quantities of fresh to slightly saline water from water-table and artesian aquifers are available for development in the Corpus Christi area. At least 20 mgd ($75.7 \times 10^3 \text{ m}^3/\text{day}$) of ground water, or over 50 percent more than the amount used annually during the 1969-1971 period, can be withdrawn on a sustained basis without exceeding average recharge of the aquifers. In addition, several billions of gallons of fresh to slightly saline water are available from storage in shallow and deep aquifers.

Abundant quantities of good quality ground water are not uniformly distributed throughout the Corpus Christi area. Development of water-table aquifers is most favorable in the northern and eastern parts of the Corpus Christi area, where permeable sands receive sufficient rainfall to recharge and supply water of good quality. In the eastern part of the area, where artesian aquifers contain only highly mineralized water, the shallow water-table aquifer is particularly important for providing small, economic supplies of fresh to slightly saline ground water.

Development of artesian aquifers is most favorable in the northern and western parts of the Corpus Christi area. Thick accumulations of permeable sands, oriented normal to the coast, contain water of good quality. Areas in southwestern Refugio and Nueces Counties probably should be avoided because of water-level declines of from 50 to 200 feet (15.2 to 61.0 meters).

ACKNOWLEDGMENTS

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The senior author, J. T. Woodman, prepared the first draft of this report based on his work for the Bureau of Economic Geology on the larger Coastal Bend region, and for his Master of Science thesis. R. S. Kier was responsible for the Bureau's contribution to the overall multidisciplinary investigation and prepared the final draft of the report. D. L. Bell designed the data management system used in part for the Bureau of Economic Geology's participation in the multidisciplinary study, and in part for his master's thesis. All authors have reviewed the final manuscript. Research aid was provided at various times by Ann E. St. Clair and Ann Bell.

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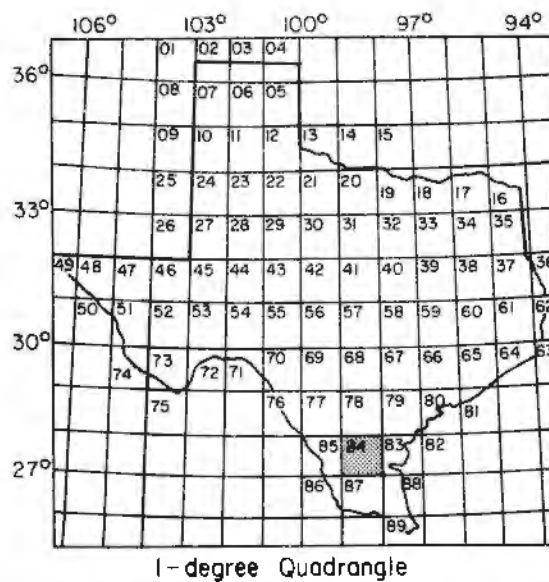
APPENDIX A

Texas Well-Numbering Systems

The well-numbering system adopted for this study conforms to a system used by the Texas Water Development Board. Each 1-degree quadrangle in the State is assigned a two-digit number from 01 to 89 (fig. A-1). These numbers are the first two digits in the well number. The 1-degree quadrangles are subdivided into 7-1/2-minute quadrangles which are assigned a two-digit number from 01 to 64. These numbers are the third and fourth digits of the well number. Each 7-1/2-minute quadrangle is then subdivided into 2-1/2-minute quadrangles which are assigned a single-digit number from 1 to 9. This is the fifth digit of the well number. Each selected well within the 2-1/2-minute quadrangle is then assigned a two-digit number in the order in which it was surveyed.

Oil, gas, and water wells with electric log data are given a Q number and are not included in the above system. Each well in a county is numbered in the order in which it was logged.

For the reader's convenience in locating the wells in the Corpus Christi area, wells with aquifer pump-test and electric-log data used for this study are given a map number (Appendix B, fig. B-1, Appendix C, fig. C-1, respectively). Wells are numbered sequentially by county.



Location of Well 84-21-601

- 84 1-degree quadrangle
- 21 7 1/2 minute quadrangle
- 6 2 1/2 minute quadrangle
- 01 Well number within 2 1/2 minute quadrangle

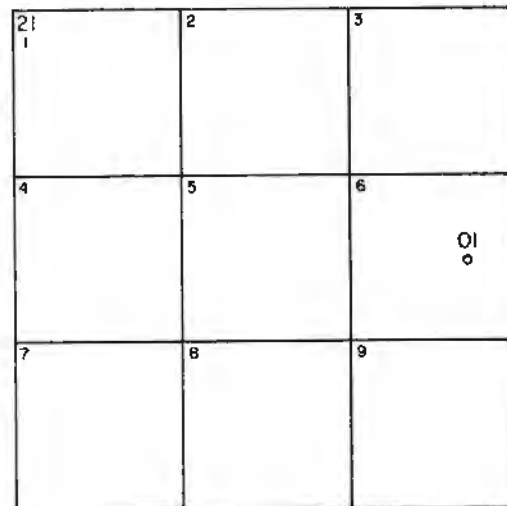
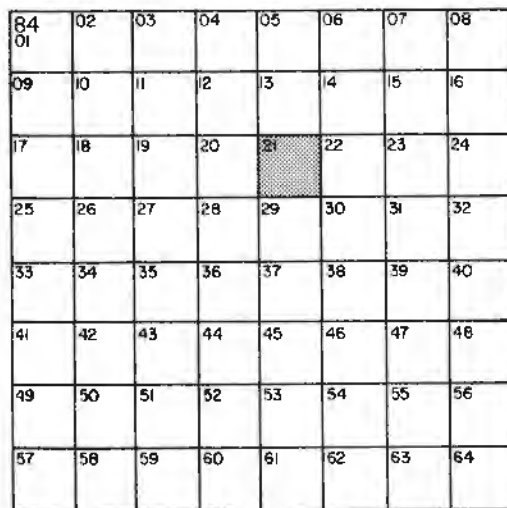


Figure A-1. Well-numbering system.

APPENDIX B

Index to Subsurface Electric Log Control for Aransas County (See figure B-1 for locations of wells).

Map Index Number	T.W.D.B. Q Number	Altitude of land surface (ft) ***	Altitude of base of fresh to slightly saline water (ft) ***	Net thickness of sand containing fresh to slightly saline water		
				Calculated from electric logs (ft) *** (A)	Estimated above ** shallowest electric log (ft) *** (B)	(A+B)
1.	2	15	-380	20	40	60
2.	46	0	-370	30	40	70
3.	47	15	*	0	0	0
4.	50	15	- 5	0	20	20
5.	51	0	0	0	0	0
6.	309	30	0	0	30	30
7.	323	15	- 50	30	0	30
8.	329	10	-120	20	0	20
9.	334	15	-280	10	20	30
10.	348	15	*	0	0	0
11.	349	10	-210	130	0	130
12.	352	15	- 50	40	0	40
13.	408	20	-800	40	130	170

Index to Subsurface Electric Log Control for Nueces County
(See figure B-1 for locations of wells).

46

				Net thickness of sand containing fresh to slightly saline water		
Map Index Number	T.W.D.B. Q Number	Altitude of land surface (ft) ***	Altitude of base of fresh to slightly saline water (ft) ***	Calculated from electric logs (ft) *** (A)	Estimated above ** shallowest electric log (ft) *** (B)	(A+B)
1.	1	100	-940	70	40	110
2.	7	90	-920	230	50	280
3.	9	70	-560	20	10	30
4.	21	50	-980	160	0	160
5.	24	60	*	0	0	0
6.	34	60	*	0	0	0
7.	79	120	-740	420	30	450
8.	134	45	-900	70	20	90
9.	156	78	*	0	0	0
10.	183	80	-740	200	10	210
11.	204	20	10	0	30	30
12.	304	110	-900	140	20	160
13.	308	65	-670	80	0	80
14.	340	65	-710	110	30	140
15.	358	30	10	0	20	20

Nueces County Continued.

				Net thickness of sand containing fresh to slightly saline water		
Map Index Number	T.W.D.B. Q Number	Altitude of land surface (ft) ***	Altitude of base of fresh to slightly saline water (ft) ***	Calculated from electric logs (ft) *** (A)	Estimated above ** shallowest electric log (ft) *** (B)	(A+B)
16.	362	65	-420	120	0	120
17.	363	60	-940	110	40	150
18.	391	90	-990	80	40	120
19.	488	120	-1,020	210	30	240
20.	493	80	-650	110	40	150
21.	508	80	-950	150	130	280
22.	701	40	-100	0	120	120
23.	798	55	*	0	0	0
24.	892	80	-790	140	60	200
25.	955	30	*	0	0	0
26.	1,035	105	-790	110	0	110
27.	1,070	70	-1,120	180	20	200
28.	1,117	40	*	0	0	0
29.	1,123	60	-830	250	0	250

Index to Subsurface Electric Log Control for Refugio County
(See figure B-1 for locations of wells).

48

				Net thickness of sand containing fresh to slightly saline water		
Map Index Number	T.W.D.B. Q Number	Altitude of land surface (ft) ***	Altitude of base of fresh to slightly saline water (ft) ***	Calculated from electric logs (ft) *** (A)	Estimated above ** shallowest electric log (ft) *** (B)	(A+B)
1.	2	25	-1,250	440	0	440
2.	26	43	-1,040	230	10	240
3.	39	50	-1,340	470	30	500
4.	62	25	-1,230	190	0	190
5.	64	25	-1,300	390	30	420
6.	88	50	-1,450	610	10	620
7.	106	42	-680	60	0	60
8.	124	20	-1,400	420	30	450
9.	128	34	-1,250	350	50	400
10.	132	70	-1,150	360	30	390
11.	147	90	-1,220	220	0	220
12.	197	64	-1,340	530	0	530
13.	198	90	-1,190	530	20	550
14.	210	10	-1,350	330	30	360
15.	231	80	-1,400	430	80	510

Refugio County Continued.

				Net thickness of sand containing fresh to slightly saline water		
Map Index Number	T.W.D.B. Q Number	Altitude of land surface (ft) ***	Altitude of base of fresh to slightly saline water (ft) ***	Calculated from electric logs (ft) *** (A)	Estimated above ** shallowest electric log (ft) *** (B)	(A+B)
16.	324	53	-930	300	30	330
17.	477	57	-1,040	370	70	440
18.	514	62	-830	170	10	180
19.	533	53	-1,060	460	40	500
20.	541	65	1,170	400	20	420

Index to Subsurface Electric Log Control for San Patricio County
(See figure B-1 for locations of wells).

50

				Net thickness of sand containing fresh to slightly saline water		
Map Index Number	T.W.D.B. Q Number	Altitude of land surface (ft) ***	Altitude of base of fresh to slightly saline water (ft) ***	Calculated from electric logs (ft) *** (A)	Estimated above ** shallowest electric log (ft) *** (B)	(A+B)
1.	13	50	-170	100	0	100
2.	18	110	-700	310	80	390
3.	23	100	-830	380	20	400
4.	31	0	-940	430	80	510
5.	32	110	-1,030	560	30	590
6.	34	63	-320	50	10	60
7.	119	120	-510	190	30	220
8.	131	35	-730	280	30	310
9.	135	68	-130	20	40	60
10.	139	55	-930	360	30	390
11.	145	40	-470	30	0	30
12.	155	53	-810	360	0	360
13.	177	63	-140	80	80	160
14.	190	86	-960	510	10	520
15.	203	36	*	0	0	0

San Patricio County Continued.

				Net thickness of sand containing fresh to slightly saline water		
Map Index Number	T.W.D.B. Q Number	Altitude of land surface (ft) ***	Altitude of base of fresh to slightly saline water (ft) ***	Calculated from electric logs (ft) *** (A)	Estimated above ** shallowest electric log (ft) *** (B)	(A+B)
16.	205	140	-370	270	50	370
17.	207	40	-210	100	0	100
18.	214	70	-800	350	30	380
19.	217	40	-290	170	40	210
20.	231	120	-510	290	40	330
21.	237	65	-274	40	110	150
22.	250	150	-460	300	30	330
23.	257	50	-100	10	0	10
24.	264	38	-680	350	20	370
25.	341	25	-410	100	40	140
26.	470	38	-710	170	0	170
27.	585	23	70	60	0	60
28.	587	50	*	0	0	0
29.	633	50	-100	60	0	60
30.	697	70	-850	400	10	410
31.	714	70	-1,200	400	40	440

San Patricio County Continued.

				Net thickness of sand containing fresh to slightly saline water		
Map Index Number	T.W.D.B. Q Number	Altitude of land surface (ft) ***	Altitude of base of fresh to slightly saline water (ft) ***	Calculated from electric logs (ft) *** (A)	Estimated above ** shallowest electric log (ft) *** (B)	(A+B)
32.	726	20	*	0	0	0
33.	740	84	-900	290	80	370
34.	742	100	-770	500	90	590
35.	760	10	-490	70	0	70
36.	861	60	*	0	0	0

* No fresh to slightly saline water

** Estimate made from near-by drillers logs

*** 1 ft = .3048 m

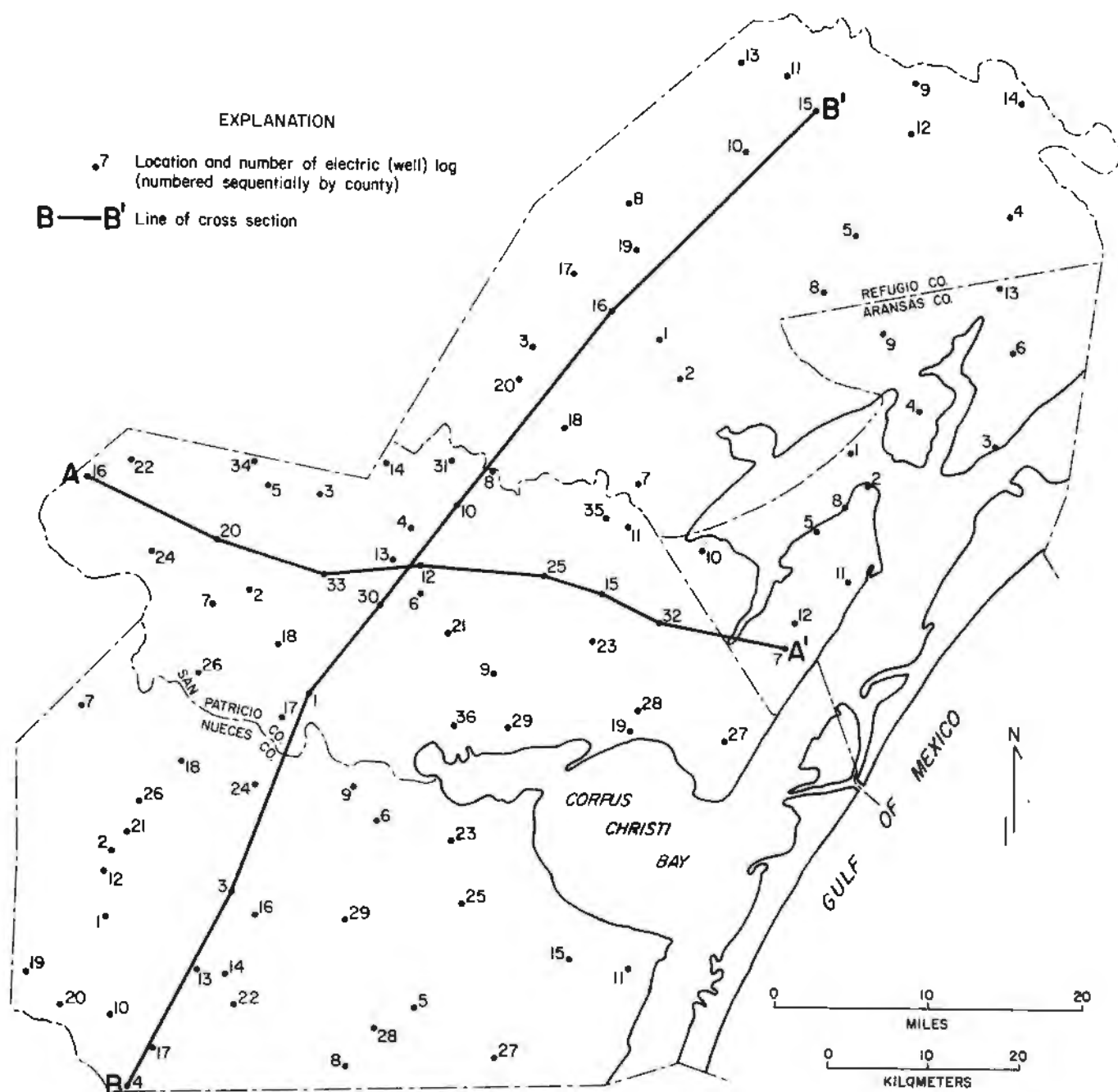


Figure B-1. Locations of wells from which electric logs used in this study were taken.

APPENDIX C
Summary of Aquifer Pump Tests
(See figure C-1 for locations of wells).

Map Well Number	State Well Number	Depth (ft)°	Screened Interval (ft)°	Screen Footage°	Transmissivity (gpd/ft)*	Transmissivity (cm ² /sec)*	Permeability (gpd/ft ²)*	Permeability (10 ⁴ cm/sec)*	Coefficient of Storage (10 ⁻⁵)
NUECES COUNTY									
1	83-26-503	720	600-720	100	6,000	9	60	28	14
2	83-26-507	952	655-876	130	4,050	6	31	15	8
3	83-26-508	895	855-895	40	4,600	7	115	54	8
4	83-26-509	950	817-950	103	4,305	6	42	20	8
5	83-26-511				5,000	7			12
REFUGIO COUNTY									
1	79-31-901	946	160-946	786	77,000	112	980	463	
2	79-46-604	875	578-864	99	14,400	21	145	68	
3	79-46-608	879	800-875	58	12,850	19	222	105	20
4	79-54-203	501	180-270		2,500	4			
5	79-54-802	331	282-300	18	32,300	47	1,800	850	100
6	79-54-803	331			8,740	13			

Summary of Aquifer Pump Tests Continued.

Map Well Number	State Well Number	Depth (ft) [°]	Screened Interval (ft) [°]	Screen Footage [°]	Transmissivity (gpd/ft)*	Transmissivity (cm ² /sec)*	Permeability (gpd/ft ²)*	Permeability (10 ⁴ cm/sec)*	Coefficient of Storage (10 ⁻⁵)
SAN PATRICIO COUNTY									
1	79-51-705	767	280-751	388	20,600	30	53	25	
2	79-58-201	522	224-509	169	11,000	16	65	31	
3	79-58-502	288	168-288	120	12,100	18	101	48	
4	79-58-903	375	185-375	155	24,200	35	156	74	
5	79-60-602	685	342-683	232	23,000	34	99	47	30
6	79-60-603	675	344-676	260	3,740	5	14	7	
7	83-07-829	182	50-182	132	3,015	4	23	11	220
8	83-07-835				2,600	4			630
9	83-07-836				3,665	5			450

[°] 1 ft = .3048 meter

* Data rounded to nearest whole integer

gpd/ft = gallons per day per foot = 4.72×10^{-5} centimeters² per second

cm²/sec = (centimeters)² per second

gpd/ft² = gallons per day per (foot)² = 4.72×10^{-5} centimeters per second

cm/sec = centimeters per second

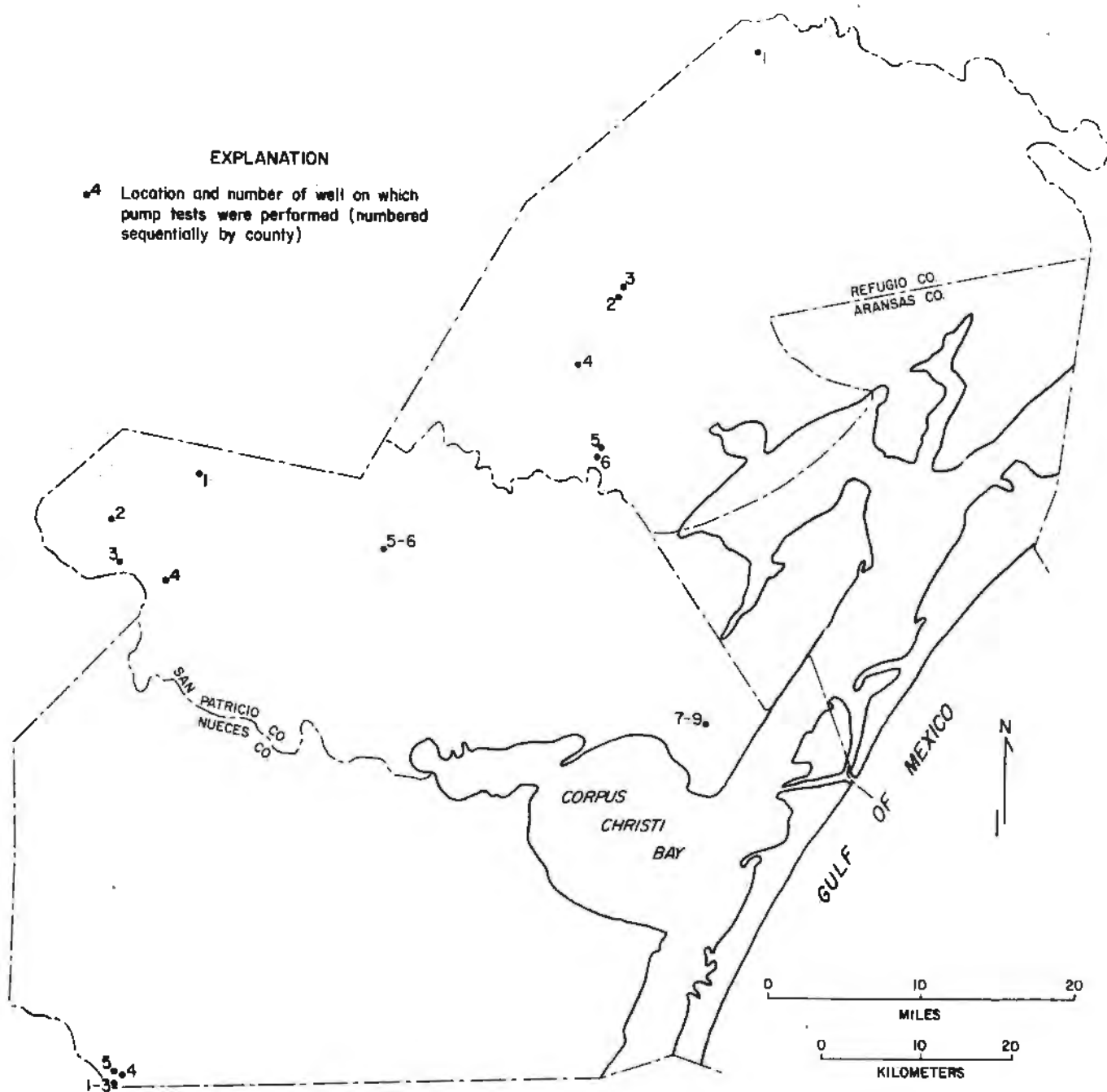


Figure C-1. Locations of wells in which aquifer pump tests were performed.