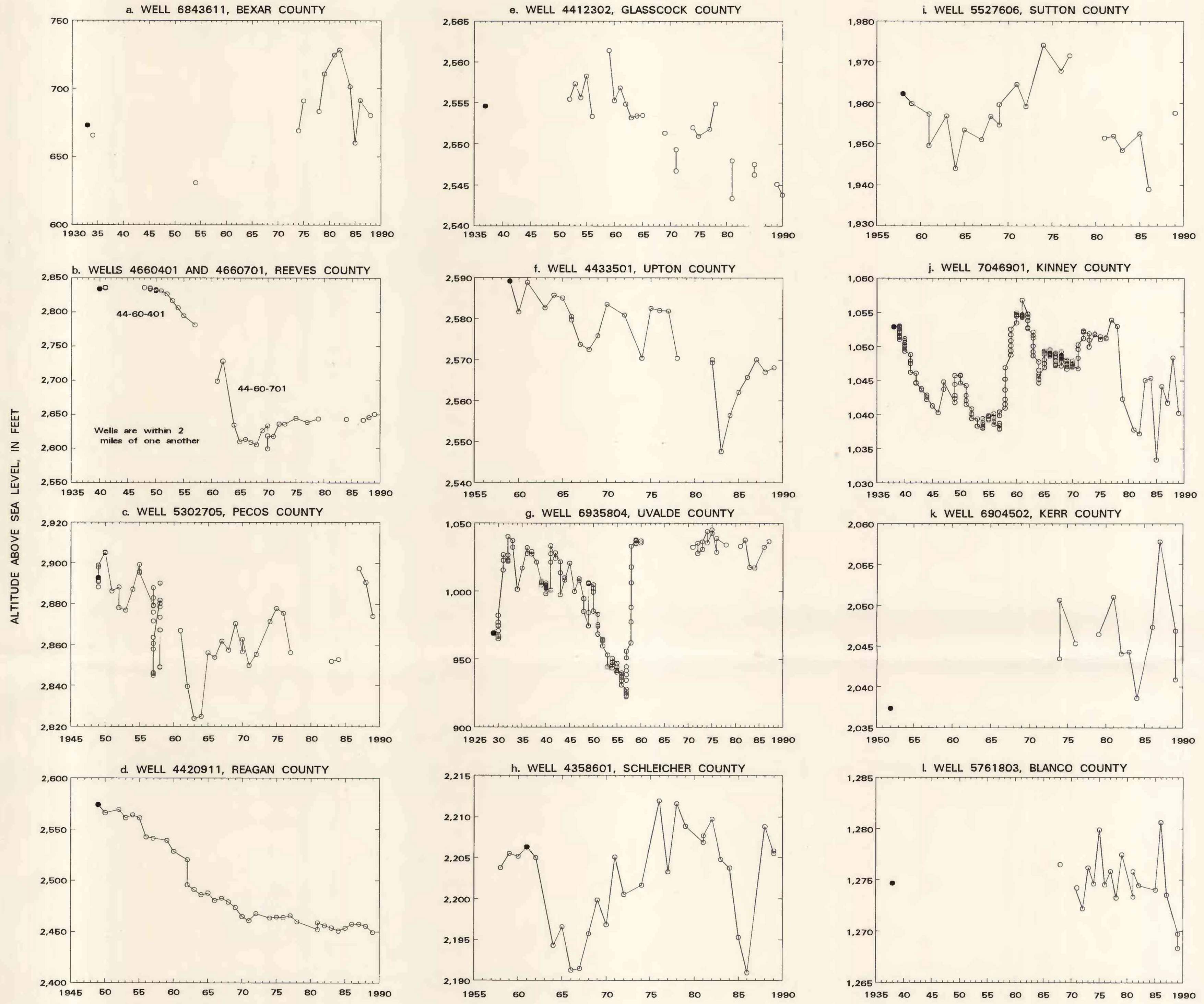
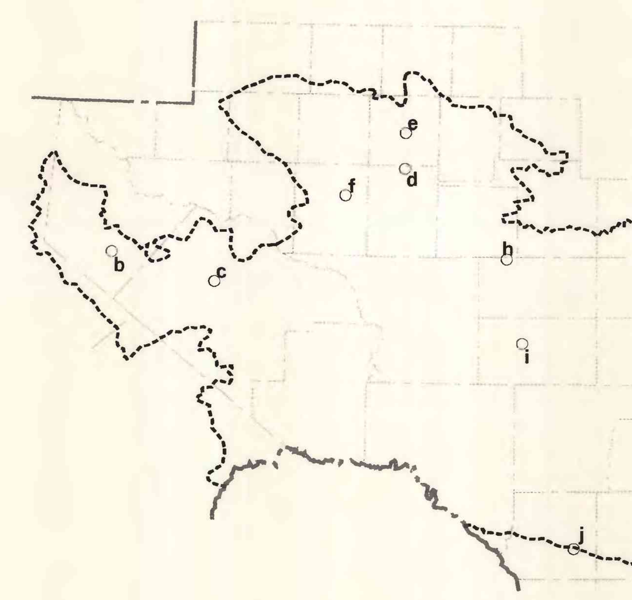


Figure 6. Water-level measurements of selected wells which were used to construct the historical potentiometric-surface map.

EXPLANATION

• WATER-LEVEL MEASUREMENT USED FOR THE HISTORICAL POTENTIOMETRIC-SURFACE MAP

○ WATER-LEVEL MEASUREMENT



LOCATION OF WELLS HAVING WATER-LEVEL HYDROGRAPHS

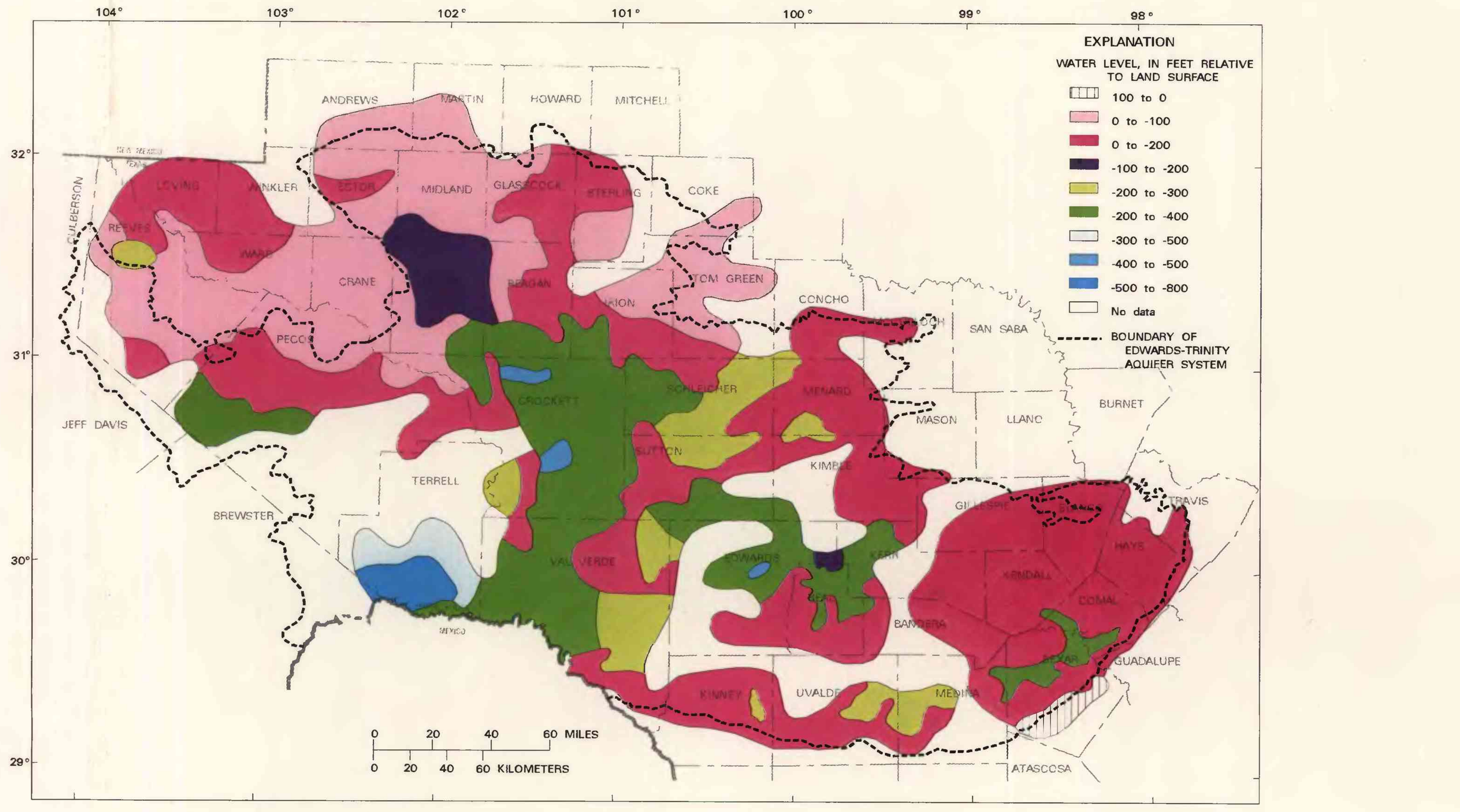


Figure 7. Water levels relative to land surface in wells used to construct the historical potentiometric-surface map.

Water levels in the aquifer system also fluctuate in response to variations in withdrawals. In the late 1980's, withdrawals from the Edwards-Trinity aquifer system and contiguous hydraulically connected units are estimated to have been about 1 billion acre-ft/yr (D.L. Lurry, U.S. Geological Survey, written commun., 1990). The largest areal concentration of withdrawals at the times of water-level measurements occurred near San Antonio, in Bexar County. In 1934, withdrawals from the Edwards aquifer in the San Antonio area totaled about 100,000 acre-ft (Livingston and others, 1936, p. 90; Nalley, 1989, table 3). By the mid-1980's, withdrawals, primarily for public supply in San Antonio, were three times larger; however, long-term hydrographs of water levels into the late 1980's indicate no net decline (R.W. Maclay, U.S. Geological Survey, written commun., 1990). Hydrographs for selected wells in the Edwards-Trinity aquifer system are shown in figure 6. The locations of the wells are designated by lowercase letters in figure 6 and on sheet 3. Figure 6a is an example of one such hydrograph from a well in the Edwards aquifer in southwest Bexar County.

Large transmissivity [200,000 to 2,000,000 ft^2/d (Maclay and Small, 1986, p. 61)], and the storage capacity to accept plentiful recharge during wet periods have thus far kept the Edwards aquifer from having a long-term loss of water in storage; but, according to R.W. Maclay (U.S. Geological Survey, written commun., 1990), withdrawals can affect the amplitudes of water-level fluctuations within a given year. Therefore, even though the 84 Bexar County water levels of October 1934 used for the map probably are representative of general predevelopment conditions, large withdrawals could have preceded the measurements and temporarily lowered water levels.

Away from the San Antonio area, most of the early withdrawals were for irrigation. Some of the earliest documented information on withdrawals and water levels pertains to the area around Pecos in Reeves County. By one account (Knowles and Lang, 1947, p. 15), in 1898 there were between 40 and 50 constantly flowing wells in the Cenozoic Pecos alluvium aquifer within a 2-mi radius of Pecos. A well in Pecos was reported to have had a head 28 ft above land surface when drilled in 1886. In 1940, the head was reported to be about 7 ft above land surface, indicating a decline of 21 ft (Knowles and Lang, 1947, p. 20). None of the measurements from 1927-41 in the vicinity of Pecos used for the map were above land surface, although some were very close.

Forty-four of the 64 measurements in Reeves County were made in 1940. Ogilbee and others (1962, p. 39) state that little or no change in water levels occurred from 1930 to 1940. In 1940, withdrawals for irrigation in Reeves County were estimated to be 11,000 acre-ft (Knowles and Lang, 1947, p. 19). Withdrawals were small compared to those in Bexar County, but transmissivity of the Edwards-Trinity aquifer and the Cenozoic Pecos alluvium aquifer is considerably smaller [about 5,000 ft^2/d (Ogilbee and others, 1962, p. 37-39)]. The historical potentiometric surface in Reeves County is probably slightly lower than it would have been with no ground-water development, but the difference, if known, probably would be negligible at the scale of the potentiometric-surface contours on sheet 3.

Figure 6b shows the long-term trend of water levels in the Edwards-Trinity aquifer at two sites 2 mi apart in Reeves County, beginning with a measurement in 1940 used for the historical potentiometric-surface map. Most of these water levels are affected by irrigation withdrawals. Annual irrigation withdrawals in Reeves County increased sharply in the late 1940's, peaked at about 525,000 acre-ft in 1953, and gradually decreased in most succeeding years for which estimates are available (Ogilbee and others, 1962, table 3; Texas Water Development Board, 1986, table 1; and Rees, 1987, table 1). Withdrawals in the county were estimated to be 68,000 acre-ft in 1989 (D.L. Lurry, U.S. Geological Survey, written commun., 1990).

In adjacent Pecos County, where aquifer characteristics are similar to those in Reeves County, irrigation development increased rapidly soon after World War II (Armstrong and McMillion, 1961, p. 44). One-half of the 154 measurements in Pecos County for the map were made during 1940-46, and the other one-half during 1947-50. After 1946, the annual flow of Comanche Springs (31,000 acre-ft/yr prior to 1946) began to decline steadily (Armstrong and McMillion, 1961, p. 43-44), an indication that withdrawals had begun to affect water levels at about that time. The historical potentiometric surface in Pecos County thus portrays water levels as they were at the threshold of development, and may reflect slightly the effect of irrigation withdrawals.

Figure 6c shows water levels in an irrigation area just northeast of Fort Stockton in Pecos County since the 1949 measurement used for the historical potentiometric-surface map. This hydrograph shows the effect of irrigation withdrawals estimated to be about 362,000 acre-ft in Pecos County in 1964 (Rees, 1987, table 1). Withdrawals for irrigation in 1989 were about 66,000 acre-ft (D.L. Lurry, U.S. Geological Survey, written commun., 1990).

A third area of early irrigation development was in northern Reagan and southern Glasscock Counties. Transmissivity of the aquifer in those counties probably averages considerably less than 5,000 ft^2/d. Withdrawals for irrigation in the two counties began about 1946 (Walker, 1979, p. 73-75). In Reagan County, 40 of the 52 measurements used for the map were made during 1958-61, and the remaining 12 measurements were made during or before 1950. Estimated withdrawals for irrigation from the Edwards-Trinity aquifer in Reagan County during 1958-61 ranged from 2,000 acre-ft in 1958 to 4,700 acre-ft in 1961 (Walker, 1979, table 3). Figure 6d shows that at one site in northern Reagan County water levels declined more than 50 ft from 1949 to 1962. For this site, the 1949 measurement was used for the historical potentiometric-surface map. For the northernmost part of the county, only pre-1951 measurements were used. These water levels probably were not affected substantially by withdrawals. However, 1958-61 measurements used for the north-central part of the county probably were affected by withdrawals. All of the measurements for the map in Glasscock County were from 1937, which predates any appreciable ground-water development.

Irrigation withdrawals in Reagan County continue to increase and water levels continue to decrease, as indicated by the hydrograph in figure 6d. The largest estimated annual total withdrawal was 34,000 acre-ft in 1989. Withdrawals for irrigation in Glasscock County peaked during 1974 at 55,000 acre-ft, and were estimated to be 31,000 acre-ft in 1989 (Texas Water Development Board, 1986, table 1; D.L. Lurry, U.S. Geological Survey, written commun., 1990). The hydrograph of an Edwards-Trinity aquifer well in Glasscock County (fig. 6e) indicates a long-term downward trend, beginning in the early 1960's, from the level of the measurement used for the historical potentiometric-surface map.

In adjacent Upton County, water-level declines prior to the 1959-63 measurements used for the map have been documented. White (1968, p. 32) reported that withdrawals for gasoline plants had caused declines of as much as 25 ft between 1949 and the time of his study (1965-67) in the central part of the county along the Upton-Reagan County line; irrigation withdrawals caused nearly 23 ft of decline in the northeastern part of the county between 1952 and the time of his study. Thus, the historical potentiometric surface shown in this report is probably somewhat lower in Upton County than it would have been if earlier water-level measurements had been available.

By 1989, industrial withdrawals in Upton County were negligible, but irrigation withdrawals were an estimated 14,000 acre-ft, the second largest documented annual total for the county (Texas Water Development Board, 1986, table 1; D.L. Lurry, U.S. Geological Survey, written commun., 1990). Transmissivity in Upton County is at least as low as in Reagan County and may average no more than 1,000 ft^2/d (White, 1968, table 2), so relatively small but areally concentrated withdrawals continue to affect water levels in the county. Figure 6f shows a gradual, generally downward water-level trend since 1959 in a well completed in the Edwards-Trinity aquifer but located outside the main irrigation area. The 1959 measurement was used for the historical potentiometric-surface map.

In the late 1980's, the largest irrigation withdrawals in the mapped area occurred in the Edwards aquifer in Uvalde County. An estimated 152,000 acre-ft were withdrawn in 1989 (D.L. Lurry, U.S. Geological Survey, written commun., 1990). Aquifer and recharge characteristics similar to those of the San Antonio area have resulted in wide-ranging water-level changes but no long-term decline in the Edwards aquifer in Uvalde County (fig. 6g).

Areas other than those discussed probably have been affected by withdrawals, but the drawdowns are assumed to be small in magnitude or area or both, and less than natural fluctuations resulting from variations in rainfall. The remaining hydrographs of figure 6 show long-term trends in selected wells from which measurements for the historical potentiometric-surface map were obtained. Most of the hydrographs show a wide range of water-level altitudes, which is primarily attributed to the variability in rainfall.

Topography and stream or spring drainage are two major factors affecting the configuration of the historical potentiometric surface. The potentiometric-surface contours and topographic contours are closely related throughout the mapped area. The potentiometric-surface and land-surface altitudes decrease about 2,500 ft from the northwest to the southeast, with the potentiometric surface typically an attenuated reflection of the land surface. The three largest streams, the Colorado River, the Pecos River, and the Rio Grande, affect the regional potentiometric gradients near those watercourses in the Trans-Pecos and the Edwards Plateau. Potentiometric contours curve upstream along the headwaters of streams along the eastern and southern edges of the Plateau, where numerous springs occur.

The water levels in wells used to construct the potentiometric-surface map ranged from almost 100 ft above land surface in Bexar County to almost 800 ft below land surface in Terrell County (fig. 7). The data show that, historically, water levels have been within 200 ft of land surface in much of the mapped area. In the central part of the aquifer system, however, water levels have ranged from 200 to 400 ft below land surface. Even in the southwestern part of the aquifer system where the zone of saturation is deep, topography influences the configuration of the potentiometric surface because the Rio Grande and smaller intermittent streams are deeply incised into the rocks that form the aquifer.

The general horizontal direction of ground-water flow is perpendicular to the potentiometric contours. The pattern of the potentiometric contours in most parts of the aquifer system indicates flow toward and discharge to perennial streams and springs.

In the Balcones fault zone, the potentiometric surface of the Edwards aquifer is a much less effective indicator of the direction of ground-water flow than in the other areas. The historical potentiometric surface indicates flow in the Edwards aquifer toward the freshwater/saline-water transition zone; however, the series of southwest-to-northeast trending faults that give the area its name function as barriers that divert flow to the northeast approximately parallel to the strike of the faults (Abbott, 1977, p. 13; Maclay and Small, 1986, p. 39, 49). Over geologic time, dissolution of carbonate rock along fractures associated with the barrier faults has greatly enhanced permeability, and thus the flow of water, in a direction subparallel to the faults. This anisotropic permeability allows a small potentiometric gradient to the northeast, one that is not discernible on a regional-scale map, to move large quantities of water from recharge areas in the southwestern part of the Balcones fault zone to major springs in the northeastern part.

SELECTED REFERENCES

1. Abbott, P.L., 1977, Effect of Balcones faults on ground-water movement, south-central Texas: Texas Journal of Science, v. 29, nos. 1 and 2, p. 5-14.
2. Alexander, W.H., Jr., and Patman, J.H., 1969, Ground-water resources of Kimble County, Texas: Texas Water Development Board Report 95, 106 p.
3. Armstrong, C.A., and McMillion, L.G., 1961, Geology and ground-water resources of Pecos County, Texas: Texas Board of Water Engineers Bulletin 6106, v. I, 241 p.
4. Ashworth, J.B., 1983, Ground-water availability of the Lower Cretaceous formations in the Hill Country of south-central Texas: Texas Department of Water Resources Report 273, 174 p.
5. Baker, R.C., Dale, O.C., and Baum, G.H., 1965, Ground-water conditions in Menard County, Texas: Texas Water Commission Bulletin 6519, 94 p.
6. Bennett, R.R., and Sayre, A.N., 1962, Geology and ground-water resources of Kinney County, Texas: Texas Water Commission Bulletin 6216, 176 p.
7. Brand, J.P., and Deford, R.K., 1958, Comanchean stratigraphy of Kent quadrangle, Trans-Pecos Texas: American Association of Petroleum Geologists Bulletin, v. 42, no. 2, p. 371-386.
8. Brune, Gunnar, 1981, Springs of Texas, volume I: Arlington, Texas, Gunnar Brune, 566 p.
9. Couch, H.E., and Muller, D.A., 1972, Water well and ground-water chemical analysis data, Glasscock County, Texas: Texas Water Development Board Report 143, 69 p.
10. DeCook, K.J., 1960, Geology and ground-water resources of Hays County, Texas: Texas Board of Water Engineers Bulletin 6004, 170 p.
11. DeCook, K.J., and Doyel, W.W., 1955, Records of wells in Hays County, Texas: Texas Board of Water Engineers Bulletin 5501, 63 p.
12. Follett, C.R., 1956a, Records of water-level measurements in Kinney, Uvalde, and Val Verde Counties, Texas, 1929 to March 1956: Texas Board of Water Engineers Bulletin 5611, 72 p.
13. ____1956b, Records of water-level measurements in Bexar County, Texas: Texas Board of Water Engineers Bulletin 5606, 61 p.
14. ____1956c, Records of water-level measurements in Hays, Travis, and Williamson Counties, Texas, 1937 to May 1956: Texas Board of Water Engineers Bulletin 5612, 74 p.
15. ____1973, Ground-water resources of Blanco County, Texas: Texas Water Development Board Report 174, 95 p.
16. George, W.O., Breeding, S.D., and Hastings, W.W., 1952, Geology and ground-water resources of Comal County, Texas: U.S. Geological Survey Water-Supply Paper 1138, 126 p.
17. George, W.O., Hastings, W.W., and Breeding, S.D., 1947, Geology and ground-water resources of Comal County, Texas: Texas Board of Water Engineers Miscellaneous Publication 59, 147 p.
18. Holt, C.L.R., Jr., 1956, Geology and ground-water resources of Medina County, Texas: Texas Board of Water Engineers Bulletin 5601, 289 p.
19. Inglehart, H.H., 1967, Occurrence and quality of ground water in Crockett County, Texas: Texas Water Development Board Report 47, 150 p.
20. Karl, T.R., and Knight, R.W., 1985a, Atlas of monthly and seasonal precipitation departure from normal (1895-1985) for the contiguous United States, winter: National Oceanic and Atmospheric Administration Historical Climatology Series 3-12, 181 figs.
21. ____1985b, Atlas of monthly and seasonal precipitation departure from normal (1895-1985) for the contiguous United States, spring: National Oceanic and Atmospheric Administration Historical Climatology Series 3-13, 183 figs.
22. ____1985c, Atlas of monthly and seasonal precipitation departure from normal (1895-1985) for the contiguous United States, summer: National Oceanic and Atmospheric Administration Historical Climatology Series 3-14, 183 figs.
23. ____1985d, Atlas of monthly and seasonal precipitation departure from normal (1895-1985) for the contiguous United States, fall: National Oceanic and Atmospheric Administration Historical Climatology Series 3-15, 181 figs.
24. Knowles, D.B., and Lang, J.W., 1947, Preliminary report on the geology and ground-water resources of Reeves County, Texas: Texas Board of Water Engineers Miscellaneous Publication 226, 88 p.
25. Kuniansky, E.L., 1990, Potentiometric surface of the Edwards-Trinity aquifer system and contiguous hydraulically connected units, west-central Texas, winter 1974-75: U.S. Geological Survey Water-Resources Investigations Report 89-4208, 2 sheets.
26. Livingston, Penn, 1947, Ground-water resources of Bexar County, Texas: Texas Board of Water Engineers Miscellaneous Publication 240 p.
27. Livingston, Penn, Sayre, A.N., and White, W.N., 1936, Water resources of the Edwards Limestone in the San Antonio area, Texas, in Contributions to the hydrology of the United States, 1936: U.S. Geological Survey Water-Supply Paper 773-B, p. 59-113.
28. Long, A.T., 1958, Ground-water geology of Real County, Texas: Texas Board of Water Engineers Bulletin 5803, 50 p.
29. ____1962, Ground-water geology of Edwards County, Texas: Texas Water Commission Bulletin 6208, 128 p.
30. Loucks, R.G., 1977, Porosity development and distribution in shoal-water carbonate complexes--subsurface Pearsall Formation (Lower Cretaceous) south Texas, in Bebout, D.G., and Loucks, R.G., eds., Cretaceous carbonates of Texas and Mexico, applications to subsurface exploration: Austin, University of Texas, Bureau of Economic Geology Report of Investigations 89, p. 97-126.
31. Maclay, R.W., and Small, T.A., 1986, Carbonate geology and hydrology of the Edwards aquifer in the San Antonio area, Texas: Texas Water Development Board Report 296, 90 p.
32. Mason, C.C., 1961, Ground-water geology of the Hickory Sandstone Member of the Riley Formation, McCulloch County, Texas: Texas Board of Water Engineers Bulletin 6017, 89 p.
33. Mount, J.R., 1963, Investigation of ground-water resources near Fredericksburg, Texas: Texas Water Commission Memorandum Report 63-03, 115 p.
34. Muller, D.A., and Couch, H.E., 1971, Water well and ground-water chemical analysis data, Schleicher County, Texas: Texas Water Development Board Report 132, 77 p.
35. ____1972, Water well and ground-water chemical analysis data, Reagan County, Texas: Texas Water Development Board Report 145, 59 p.
36. Muller, D.A., and Pool, J.R., 1972, Water well and ground-water chemical analysis data, Sutton County, Texas: Texas Water Development Board Report 147, 38 p.
37. Nalley, G.M., 1989, Compilation of hydrologic data for the Edwards aquifer, San Antonio area, Texas, 1988, with 1934-88 summary: Edwards Underground Water District Bulletin 48, 157 p.
38. Ogilbee, William, Wesselman, J.B., and Irelan, Burdge, 1962, Geology and ground-water resources of Reeves County, Texas, includes records of wells: Texas Water Commission Bulletin 6214, v. 1, 213 p.
39. Petitt, B.M., Jr., and George, W.O., 1956, Ground-water resources of the San Antonio area, Texas, records of wells and springs: Texas Board of Water Engineers Bulletin 5608, v. 2, pt. 1, 255 p.
40. Pool, J.R., 1972a, Water well and ground-water chemical analysis data, Irion County, Texas: Texas Water Development Board Report 146, 39 p.
41. ____1972b, Water well and ground-water chemical analysis data, Sterling County, Texas: Texas Water Development Board Report 148, 40 p.
42. Rayner, F.A., 1959, Records of water-level measurements in Crane and Midland Counties, Texas, 1937 through 1957: Texas Board of Water Engineers Bulletin 5906, 14 p.
43. Rees, R.W., 1987, Records of wells, water levels, pumpage, and chemical analyses from selected wells in parts of the Trans-Pecos region, Texas, 1968-1980: Texas Water Development Board Report 301, 256 p.
44. Rees, Rhys, and Buckner, A.W., 1980, Occurrence and quality of ground water in the Edwards-Trinity (Plateau) aquifer in the Trans-Pecos region of Texas: Texas Department of Water Resources Report 255, 41 p.
45. Reeves, R.D., 1967, Ground-water resources of Kendall County, Texas: Texas Water Development Board Report 60, 108 p.
46. ____1969, Ground-water resources of Kerr County, Texas: Texas Water Development Board Report 102, 71 p.
47. Reeves, R.D., and Lee, F.C., 1962, Ground-water geology of Bandera County, Texas: Texas Water Commission Bulletin 6210, 78 p.
48. Reeves, R.D., and Small, T.A., 1973, Ground-water resources of Val Verde County, Texas: Texas Water Development Board Report 172, 145 p.
49. Riggio, R.F., Bomar, G.W., and Larkin, T.J., 1987, Texas drought: Its recent history: Texas Water Commission LP 84-04, 74 p.
50. Rose, P.R., 1972, Edwards Group, surface and subsurface, central Texas: Austin, University of Texas, Bureau of Economic Geology Report of Investigations 74, 198 p.
51. Sayre, A.N., 1936, Geology and ground-water resources of Uvalde and Medina Counties, Texas: U.S. Geological Survey Water-Supply Paper 678, 146 p.
52. Shafer, G.H., 1956, Ground-water resources of the Crane Sandhills, Crane County, Texas: Texas Board of Water Engineers Bulletin 5604, 108 p.
53. Smith, C.I., and Brown, J.B., 1983, Introduction to road log Cretaceous stratigraphy, in Kettenbrink, E.C., Jr., ed., Structure and stratigraphy of the Val Verde Basin--Devils River uplift, Texas: West Texas Geological Society Publication no. 83-77, p. 1-47.
54. Stricklin, F.L., Jr., Smith, C.I., and Lozo, F.E., 1971, Stratigraphy of Lower Cretaceous Trinity deposits of central Texas: Austin, University of Texas, Bureau of Economic Geology Report of Investigations 71, 63 p.
55. Texas Board of Water Engineers, 1937a, Andrews County, Texas (records of wells, south half): Texas Board of Water Engineers Miscellaneous Publication 3, 34 p.
56. ____1937b, Gillespie County, Texas (records of wells): Texas Board of Water Engineers Miscellaneous Publication 93, 51 p.
57. ____1938, Midland County, Texas (records of wells): Texas Board of Water Engineers Miscellaneous Publication 187, 42 p.
58. ____1939, Edwards County, Texas (records of wells): Texas Board of Water Engineers Miscellaneous Publication 78, 30 p.
59. ____1940a, Kendall County, Texas (records of wells): Texas Board of Water Engineers Miscellaneous Publication 152, 50 p.
60. ____1940b, Kinney County, Texas (records of wells): Texas Board of Water Engineers Miscellaneous Publication 154, 38 p.
61. ____1940c, Val Verde County, Texas (records of wells): Texas Board of Water Engineers Miscellaneous Publication 285, 51 p.
62. ____1941, Irion County, Texas (records of wells): Texas Board of Water Engineers Miscellaneous Publication 142, 41 p.
63. Texas Water Development Board, 1986, Surveys of irrigation in Texas, 1958, 1964, 1969, 1974, 1979, and 1984: Texas Water Development Board Report 294, 242 p.
64. Walker, L.E., 1979, Occurrence, availability, and chemical quality of ground water in the Edwards Plateau region of Texas: Texas Department of Water Resources Report 235, 337 p.
65. White, D.E., 1968, Ground-water resources of Upton County, Texas: Texas Water Development Board Report 78, 137 p.
66. ____1971, Water resources of Ward County, Texas: Texas Water Development Board Report 125, 235 p.
67. Wilson, C.A., 1973, Ground-water resources of Coke County, Texas: Texas Water Development Board Report 166, 89 p.

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter
foot (ft)	0.3048	meter
foot squared per day (ft^2/d)	0.0929	meter squared per day
inch per year (in/yr)	25.4	millimeter per year
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

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.

HISTORICAL POTENTIOMETRIC SURFACE OF THE EDWARDS-TRINITY AQUIFER SYSTEM AND CONTIGUOUS HYDRAULICALLY CONNECTED UNITS, WEST-CENTRAL TEXAS

By

PETER W. BUSH, ANN F. ARDIS, AND KIRBY H. WYNN

1993