BULLETIN 5601

GEOLOGY AND GROUND-WATER RESOURCES OF MEDINA COUNTY, TEXAS

Prepared in cooperation with the Geological Survey,
United States Department of the Interior

August 1956

Second Printing March 1976
by
Texas Water Development Board

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ABSTRACT

The Edwards limestone of Cretaceous age is the principal water-bearing formation in Medina County and makes up the major part of a ground-water reservoir, or aquifer, which in places includes thinner limestone formations both above and below the Edwards. The Glen Rose limestone, also of Cretaceous age, yields moderate amounts of water to wells and springs in the northern part of the county. Other Cretaceous formations, including the Austin chalk, Anacacho limestone, and Escondido formation, yield only small amounts of water, and that of the Austin and Escondido is of generally inferior quality.

The Carrizo sand and the Indio formation, both of Tertiary age, supply most of the water used in the southern part of the county. The Leona formation of Quaternary age supplies water for irrigation and other farm use in areas adjacent to the main streams.

Although the regional southeastward dip of the rocks is at a low angle, the Edwards limestone, which caps the hills in the northern part of the county, is found at a depth of about 2,000 feet below the sea level in the southern part of the county. The formations have been lowered by a series of faults. The faults, which are a part of the Balcones fault system, are mostly normal or tension faults and trend more or less parallel in a northeasterly direction. Thus belts of rock, successively younger toward the southeast, are found at the surface. Individual faults of the Balcones system are as much as 35 miles long and have a maximum displacement of 700 feet. The Culebra anticline in eastern Medina County and western Bexar County is related to the Balcones fault system.

In all the ground-water reservoirs, water occurs under both water-table and artesian conditions. In the Edwards limestone, recharge occurs mainly where the streams cross the outcrop. The low flow of the streams is supplied by a large number of small springs that issue from the base of the Edwards limestone in the northern part of Medina County, and the area to the north, and from porous beds in the Glen Rose limestone. Most of this flow is absorbed by the Edwards limestone farther south as the streams cross the outcrop of the Edwards near the Balcones fault zone.

The movement of water in the Edwards limestone is generally southward and eastward but is locally controlled by faults. Much more water is believed to enter and leave the county underground through channels in the Edwards limestone than is withdrawn by wells in the county. The total withdrawal from the Edwards through wells is estimated to be about 1,600,000 gallons a day. The Edwards limestone supplies water for public use in Castroville and Hondo, and for an Air Force base at Hondo.

The sands of the Indio formation of Tertiary age supply a cannery near Natalia and numerous domestic and stock wells. Values for coefficient of transmissibility, in places where the sand is more than 60 feet thick, range from 10,000 to 20,000 gallons per day per foot.

The Carrizo sand, which overlies the Indio formation, serves the communities of Natalia and Devine. A coefficient of transmissibility of 134,000 gallons per day per foot was determined for the Carrizo at Devine. Water from the Carrizo sand and from the Leona formation is used for irrigation and for domestic and stock use.

The water in the Travis Peak formation probably is highly mineralized; the water from the Glen Rose formation generally is very hard, and in most places the water is high in sulfate and dissolved solids. Water from the Edwards limestone is generally hard, but of good quality in other respects except in the southern part of the county. Two analyses of water from the Austin chalk showed moderately high concentrations of sulfate; three samples from the Anacacho are of generally satisfactory quality; waters from the Escondido and Indio formations contain moderate to large amounts of dissolved solids, and are locally high in chloride content; the water from the Carrizo sand and the Leona formation is hard but of good quality in other respects. The Leona yields high-nitrate water locally.

The report contains records of 1,099 wells and 23 springs, logs of 127 wells, periodic measurements of 3 streams, and chemical analyses of 129 water samples obtained from wells and springs. The records show that 895 wells are used for domestic and stock purposes, 14 are used for public supply, 35 are used for irrigation, and 4 are used for industrial purposes; about 150 wells, including about 100 oil tests, are not used for water supply.

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

The investigation whose results are given in this report was planned to obtain data on the occurrence of ground water in Medina County. Special consideration was given to the sources, availability, potential development, and chemical character of the ground water; to is direction of movement; to the fluctuations of water levels in wells; and to the thickness and extent of the water-bearing formations.

The investigation was a part of an extensive program of ground-water studies of the western part of the Balcones fault zone (fig. 1), which is being carried on cooperatively by the United States Geological Survey, the Texas State Board of Water Engineers, and the city of San Antonio. The field work was done between June 1950 and October 1952.

L. W. Stephenson of the U. S. Geological Survey visited the area in the spring of 1951, contributing valuable assistance in the study of the paleontology and stratigraphy of the Upper Cretaceous formations. W. L. Knighten, Gene M. Austin, and George E. Welder of the Texas State Board of Water Engineers ran a series of level lines to establish the altitudes of wells within the county.

LOCATION AND GENERAL FEATURES OF THE AREA

Medina County is in south-central Texas between latitudes 29°05' and 29°41', and longitudes 98°48' and 99°25'. It is bounded on the north by Bandera County, on the east by Bexar and Atascosa Counties, on the south by Frio County, and on the west by Uvalde County (see fig. 1). Hondo, which had a population of 4,220 in 1950, is the county seat and is near the geographic center of the county.

The county is rectangular, comprising 1,353 square miles. According to the 1950 census, it had a population of 17,013. The most highly populated areas are in the central and southeastern parts of the county.

Transportation facilities include a number of paved Federal and State highways and an extensive network of paved and graded county highways. The Southern Pacific Railway lines serve Lacoste, Hondo, and D'Hanis, and the International and Great Northern Railway system serves Natalia and Devine.

PREVIOUS INVESTIGATIONS

Information on the geology, geography, and ground-water resources in Medina County is given in several published reports. One of the first publications (Liddle, 1918) includes a general discussion of the geology and geography and a summary of the mineral resources of the county. A. N. Sayre (1936) gave a more detailed account of the ground-water geology and presented records of wells,

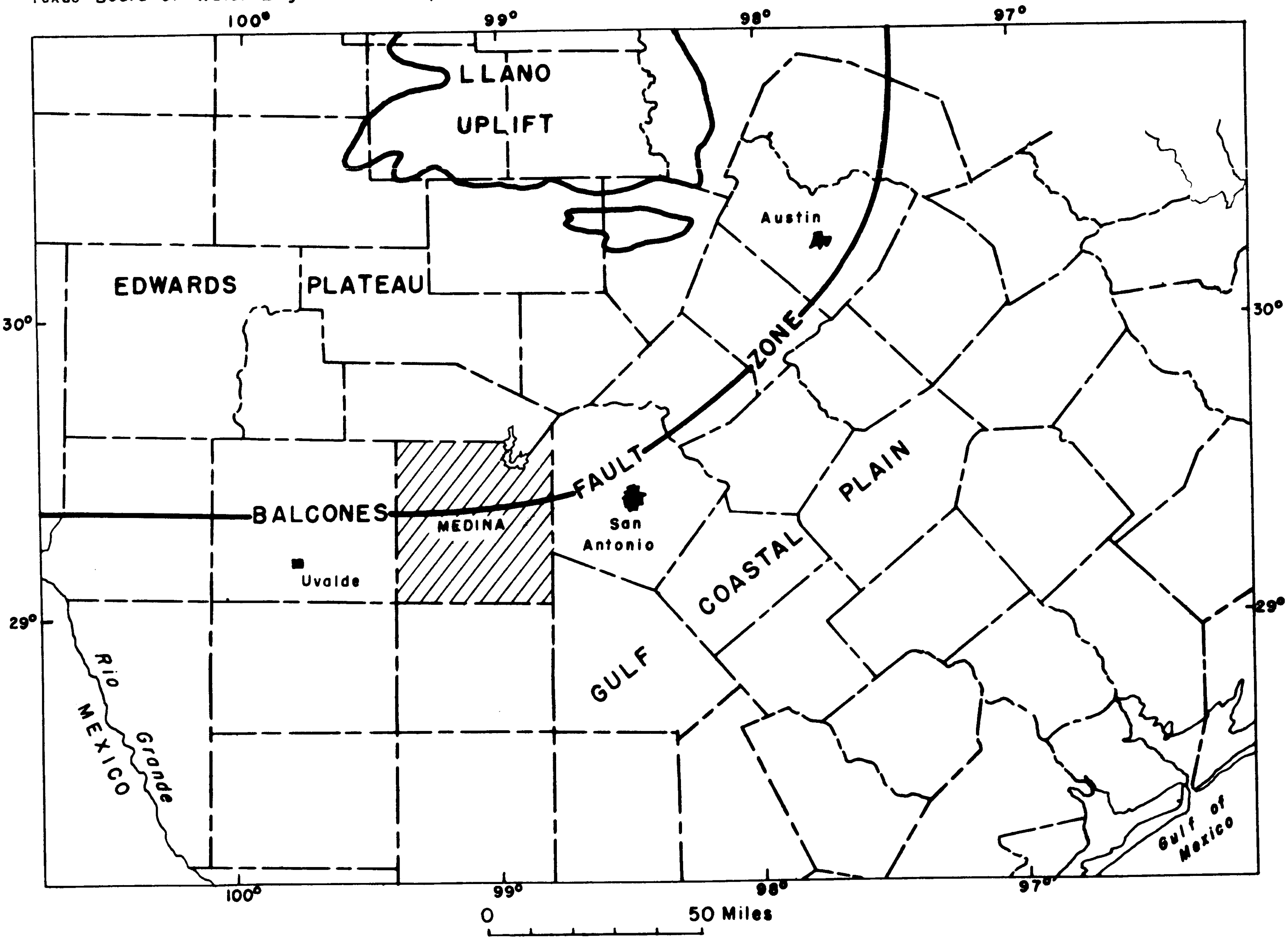


FIGURE 1.- Index map of central Texas showing physiographic provinces and location of Medina County.

water levels, and chemical analyses of ground waters. The data presented in Water-Supply Paper 678 were used in the preparation of this report. These reports and other references are listed at the end of this report.

ACKNOWLEDGMENTS

The writer is indebted to numerous farmers, ranchers, well drillers, and city and county officials who willingly supplied information and aided in the collection of field data.

GEOGRAPHY

SURFACE FEATURES

The area under discussion occupies parts of two major physical divisions or provinces, separated by the northeast-trending Balcones fault zone (fig. 1). A division of the Great Plains, called the Edwards Plateau by Hill and Vaughn (1898, p. 204), forms the northern part of Medina County. The remaining two-thirds of the county is referred to as the Gulf Coastal Plain or, more specifically, as the Rio Grande Plain.

The land surface ranges in altitude from about 560 feet, where Bear Creek leaves the southeast corner of the county, to about 2,030 feet on Hackberry Hill in the northwest corner of the area. The total relief in Medina County is, therefore, about 1,470 feet, although locally the relief does not exceed 500 feet.

The Balcones escarpment, which marks the boundary between the two geomorphic provinces, was formed by movement along the fault zone, dropping the area south of the fault in relation to the area north of it by several hundred feet. Numerous streams, eroding headward from the Balcones escarpment, have cut deep valleys into the Edwards Plateau, until only the highest buttes and narrow ridges represent the original plateau. This area, north of the major faults, is rough or rolling and is locally known as the "hill country." Beds of massive limestone alternating with softer marls and shales form steplike terraces which circle the hills.

In contrast to the major relief of the Edwards Plateau is the minor relief of the low plains south of the Balcones escarpment. With local exceptions, the alternating, more or less indurated strata of the different formations dip more rapidly to the south than does the land surface. Erosion of the alternating hard and soft layers has formed cuestas with northward-facing escarpments.

An exception to the cuesta topography is found in the areas occupied by the chert and caliche of the Uvalde gravel. The Uvalde gravel protects the underlying less resistant formations from erosion.

DRAINAGE

The surface drainage of Medina County is, in general, to the south and southeast, coincident with the regional dip of the strata and slope of the area. Local structural features have modified the drainage.

Squirrel, Seco, Hondo, Verde, and Quihi Creeks are the principal tributaries that drain the northern and western parts of Medina County. These intermittent streams drain into the Frio River, a tributary of the Nueces, in Frio County. The northern and eastern parts of the area are drained by the Medina River, which empties into the San Antonio River. These streams are fed by springs in the Edwards Plateau and lose most of their waters to the outcrops of the Edwards limestone near the Balcones fault system. The Medina River is the only perennial stream in the county. Hondo Creek resumes a perennial flow south of U. S. Highway 90 and continues flowing for 8 or 10 miles. The southeastern part of the county is drained by Black, Francisco Perez, and Chacon Creeks, which join the Frio River in McMullen County.

The entire area is subject to torrential rains and floods. In times of flood, those channels that are generally dry are filled and sometimes overflow upon the bordering terraces.

CLIMATE

The average annual precipitation at Hondo during the 67-year period 1885-1952 was 27.99 inches, and the average at Rio Medina during the 24-year period 1923-1946 was 26.76 inches. Records of the United States Weather Bureau show that at Hondo the maximum yearly total, 61.57 inches, was in 1919, and the minimum yearly total, 21.25 inches, was in 1901. The same weather station recorded a maximum monthly rainfall of 21.70 inches for May 1935 (fig. 2).

The precipitation varies considerably from year to year, and occasional droughts cause much damage to the forage crops and reduce the supply of water available for irrigation. Conversely, unusually heavy rains have caused floods which have damaged parts of the towns of D'Hanis and Hondo. Two local floods occurred during the spring of 1951. A flood on May 6, 1951, was caused by excessive rainfall in the Quihi area, where as much as 18 inches of rain was reported to have fallen in 4 hours. During a 3-hour storm on May 4, 1951, 10 to 16 inches of rain fell over the southwestern part of the county.

Most of the precipitation occurs during the growing season of 258 days. The average annual rate of evaporation from a free-water surface, as determined at the Texas Experimental Station at Dilley (fig. 3B), is approximately 62 inches. Thus, the potential annual evaporation is more than twice as great as the annual precipitation of Medina County.

The average annual temperature at Hondo is 69°F. The temperature is very changeable in winter; daily maximums are rarely below 32°F., and frequent warm periods occur. The average date of the first killing frost is November 23; the average date of the last killing frost is March 10.

Precipitation and temperature records at Hondo and Rio Medina, collected by the United States Weather Bureau, are given in tables 1 and 2 and are shown graphically in figures 2, 3A, 4, and 5.

Table 1.- Precipitation, in inches, at Hondo, Tex.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1880	3.50	4.00	2.25	4.00	3.00	2.25	6.25	8.50	3.00	2.25	2.25	0.50	41.75
1881	.50	1.25	1.13	3.25	4.75	.00	1.25	1.13	5.75	4.25	2.00	1.59	26.75
1882	2.00	2.13	4.25	.87	6.75	.13	3.00	3.75	9.00	2.75	1.13	.50	36.25
1885	3.75	.75	3.75	5.50	8.00	.75	6.50	1.00	1.50	.75	.75	1.50	34.25
1886	.75	1.13	2.38	2.25	2.50	3.50	1.50	2.75	2.13	.63	.38	.25	20.13
1887	.25	.75	.50	.50	2.50	1.25	.75	3.63	1.75	2.13	2.50	2.50	19.00
1888	1.50	2.50	2.25	7.50	4.50	4.00	.75	4.75	2.00	1.00	3.75	2.50	37.00
1889	3.50	1.50	2.50	1.25	.00	4.75	11.63	3.50	6.13	.75	2.25	.00	37.75
1890	.00	2.25	.25	5.38	1.50	5.25	1.50	1.50	4.25	2.00	1.00	1.50	26.63
1891	5.50	1.25	1.13	4.50	2.38	2.13	.75	1.00	3.50	1.50	1.00	4.00	28.63
1892	1.50	.75	1.50	.13	.75	2.75	.00	6.13	1.00	1.50	1.13	4.00	21.87
1893	.13	1.13	2.50	2.00	3.38	1.87	.87	.75	.13	.00	2.50	.75	15.63
1894	1.50	.50	.75	2.63	1.75	3.00	.63	8.50	1.50	.75	.00	.00	21.50
1895	1.25	3.87	2.50	.25	5.50	2.00	1.00	2.00	1.25	1.50	.00	.13	21.00
1896	2.00	1.87	.13	1.50	1.50	2.00	2.00	1.00	3.50	3.63	.00	.75	19.87
1897	1.25	.00	1.25	1.00	2.75	2.00	.00	1.50	1.13	3.25	.00	.00	14.13
1898	.25	.25	.87	2.00	.50	8.25	.75	4.75	1.50	.00	1.75	1.00	21.87
1899	.00	.00	.00	1.38	3.75	12.87	1.63	.00	2.00	1.50	.87	1.75	25.75
1900	3.50	.00	2.50	6.38	3.38	.00	3.75	1.87	.00	2.13	1.13	.25	24.87
1901	.25	.00	.75	.13	3.00	2.50	4.00	.00	1.13	.00	.50	.00	12.25
1902	.50	.25	.75	1.13	3.75	.00	.25	.00	3.25	1.25	6.63	2.63	20.38
1903	2.25	6.50	1.25	2.00	1.63	3.87	7.63	1.63	4.25	.13	.00	.00	31.13
1904	.00	.75	.00	2.50	3.63	1.63	3.13	1.50	11.75	2.25	.63	.50	28.25
1905	2.13	1.00	3.25	10.00	2.75	7.50	3.38	.25	3.87	2.38	2.63	1.00	40.13
1906	.00	.87	.13	1.87	6.50	.75	4.50	3.00	8.38	1.75	2.50	1.38	31.63
1907	.00	.00	1.38	2.25	5.63	1.38	3.13	.25	.38	6.63	6.25	.13	27.38
1908	.25	.75	1.25	4.50	9.25	.00	2.50	7.38	.75	1.75	2.00	.00	30.38
1909	.00	.16	.75	1.44	4.11	1.06	1.61	2.53	.00	.16	2.43	1.29	15.54
1910	.00	.33	1.64	4.37	1.42	.92	1.04	.41	.73	5.14	.80	1.86	18.66
1911	.32	2.15	2.46	4.36	2.20	.20	.71	.44	.67	3.17	2.37	1.52	20.57
1912	.00	1.73	2.23	2.86	1.41	7.66	.36	.14	3.70	3.82	3.36	1.60	28.87
1913	.77	1.04	.38	.64	3.57	4.99	.75	3.97	3.66	7.46	5.76	6.17	39.16
1914	.00	1.34	.55	3.15	6.49	2.25	.30	7.00	2.48	1.75	3.76	1.14	30.21
1915	1.57	2.44	.85	3.96	1.25	.00	.10	6.54	1.56	1.93	.00	.60	20.80
1916	1.53	.00	4.03	8.07	6.08	.00	8.02	4.96	.40	2.34	.97	.06	36.46
1917	1.02	.54	.07	.49	3.64	4.28	2.61	.00	1.70	1.25	1.03	.10	16.73
1918	.07	.30	.40	3.32	1.65	.34	1.31	.75	2.61	3.25	2.69	5.28	21.97
1919	3.23	1.59	1.85	2.32	3.20	8.81	11.78	9.90	9.36	7.20	.71	1.62	61.57
1920	3.12	.33	2.70	.12	5.69	2.35	5.54	3.25	.78	2.59	2.82	.10	29.39
1921	.88	.30	3.09	3.19	4.48	6.23	1.03	.00	7.36	.92	1.62	.00	29.10
1922	1.08	.74	2.56	8.80	3.35	3.25	.45	.00	.30	1.68	1.33	.00	23.54
1923	.38	5.34	2.32	4.73	.32	2.64	3.15	2.55	5.33	4.38	4.25	3.48	38.87
1924	1.69	3.05	2.57	5.18	5.86	3.89	.00	.00	3.35	.20	.04	1.75	27.58
1925	.48	.07	.35	1.08	6.31	1.40	1.10	7.33	2.09	2.41	1.42	1.20	25.24
1926	2.65	.00	4.88	11.76	1.88	4.05	2.96	1.15	.97	3.69	2.22	2.80	39.01
1927	.83	2.59	2.19	3.14	2.44	9.39	5.97	1.25	2.92	1.51	.00	3.00	35.25
1928	.82	2.64	.76	.95	6.70	1.79	1.49	3.07	4.37	.15	1.26	1.32	25.32
1929	.83	.40	2.52	2.64	8.68	2.00	4.50	.30	2.12	2.28	1.81	3.73	31.81
1930	.65	.20	2.01	4.73	2.63	4.59	.20	.98	2.14	7.21	2.73	.96	29.04
1931	4.71	3.17	1.80	5.01	3.71	2.36	5.80	4.11	.77	1.40	1.67	2.94	36.89
1932	1.24	3.31	.98	2.41	2.96	1.17	18.61	3.52	8.08	.04	.79	1.77	44.88
1933	3.27	1.81	.10	.80	3.08	1.53	.20	1.80	1.84	1.51	.49	.26	16.69
1934	3.17	.34	1.10	4.50	.97	.00	3.17	.23	1.45	.00	2.07	4.04	21.04
1935	.39	2.00	2.14	1.29	21.70	5.83	9.78	.70	9.81	1.09	.72	3.55	59.00
1936	.41	.46	1.26	.96	6.19	6.98	4.12	1.13	6.63	3.24	2.11	.63	34.12
1937	1.05	.00	2.81	.30	2.03	2.81	.59	.20	2.73	2.23	2.03	5.33	22.11
1938	2.87	.50	1.59	3.60	4.57	1.33	1.53	.47	.69	.89	.42	1.40	19.83
1939	2.33	.46	.33	.94	1.80	.20	4.46	2.01	1.98	2.76	2.27	1.03	20.57
1940	.37	2.46	1.30	2.72	6.80	2.91	1.04	1.88	.58	2.72	2.02	3.06	27.86
1941	5.25	3.15	5.20	4.39	2.39	1.76	1.08	.73	7.30	2.89	.78	.52	35.44
1942	.02	1.39	.55	4.84	4.58	1.57	2.11	4.27	4.00	4.77	.16	1.05	29.31
1943	.38	.24	.86	1.45	4.35	6.91	4.78	.02	7.62	.94	1.40	2.15	31.10
1944	2.46	1.43	3.06	.98	7.39	2.58	.00	7.82	.35	1.77	3.10	2.69	33.63
1945	3.07	2.33	1.93	4.16	2.22	4.14	.46	.45	7.06	1.37	.55	.80	28.54
1946	2.74	1.55	.91	3.55	1.78	1.78	.92	4.64	4.18	4.04	1.12	4.45	30.66
1947	2.24	.35	1.28	.47	2.34	3.20	.25	4.68	.55	.68	.98	1.10	18.12
1948	.17	1.72	.49	.60	.00	8.59	6.33	.43	2.26	2.06	.80	.52	23.97
1949	1.90	3.61	3.84	7.20	.70	4.95	1.08	4.15	2.13	6.38	.00	2.03	37.97
1950	2.61	1.19	.29	.29	5.97	3.97	2.86	4.17	4.09	.23	.16	.04	25.87
1951	.30	1.49	2.51	.54	10.57	2.61	.12	1.10	4.41	.53	1.01	.20	25.39
1952	.09	2.16	2.04	1.45	3.02	3.89	1.46	.01	4.65	.00	3.47	2.32	24.56
Average	1.44	1.37	1.67	2.99	3.92	3.08	2.77	2.54	3.17	2.21	1.62	1.55	28.34

Table 2.- Precipitation, in inches, at Rio Medina, Tex.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1922	-	-	-	-	-	-	-	-	1.40	3.80	0.07	0.00	5.27
1923	0.00	5.84	2.91	2.46	0.35	0.23	3.60	2.16	4.38	2.24	3.19	3.85	31.21
1924	.87	2.60	2.67	6.09	4.10	4.43	.04	1.80	.25	.31	.00	1.27	24.43
1925	.05	.00	.00	.90	2.05	.00	.97	2.58	2.86	2.37	3.14	1.36	16.28
1926	2.68	.00	2.94	8.40	.00	2.68	1.52	.00	.00	1.37	1.84	2.12	23.55
1927	1.77	2.94	2.10	1.04	3.20	6.98	1.20	.00	1.83	1.08	.00	2.52	24.66
1928	.34	2.49	2.04	1.23	4.49	1.87	1.63	1.32	3.12	1.41	.48	1.23	21.65
1929	.48	.43	2.16	.94	8.47	1.94	4.77	.23	.70	1.60	1.59	1.20	24.51
1930	.43	.00	2.53	2.35	4.17	3.20	2.38	.00	.00	8.88	.74	.50	25.18
1931	3.31	3.41	5.95	3.95	1.54	2.20	3.12	1.30	.00	1.22	.72	3.76	30.48
1932	2.46	2.43	.00	2.72	2.64	.57	6.77	6.05	7.84	.00	.00	1.05	32.53
1933	1.65	2.87	.00	.74	2.40	4.00	1.75	3.71	1.10	.02	.00	.70	18.94
1934	5.20	.83	1.39	3.21	1.40	1.70	4.17	.00	.82	.00	1.27	3.57	23.56
1935	.50	2.30	2.18	1.41	12.91	7.86	2.61	.00	11.41	1.52	.00	2.58	45.27
1936	.44	.44	1.72	.95	4.93	11.59	2.56	1.32	2.56	2.33	1.99	1.14	31.54
1937	1.12	.00	2.74	.45	1.66	4.40	2.66	.61	1.64	2.91	.73	4.19	23.11
1938	3.30	1.20	2.38	4.37	2.82	1.93	.72	.20	2.25	.47	.38	1.28	21.30
1939	1.81	.56	.35	.85	1.01	.59	3.71	1.81	1.53	.50	2.27	1.06	16.05
1940	.51	1.94	.85	1.30	4.17	7.35	1.53	.40	1.22	5.12	1.72	3.89	30.00
1941	.92	7.72	4.79	4.63	2.85	3.39	2.07	.32	4.56	1.03	.42	.47	33.17
1942	.00	.91	.00	7.88	2.30	1.13	7.51	3.15	6.07	3.18	.34	.73	33.18
1943	.25	.00	1.11	2.18	4.75	4.04	1.65	.50	1.28	.39	2.05	1.02	19.22
1944	3.12	1.60	1.80	.76	4.66	1.54	2.20	8.14	.98	1.29	3.34	3.55	32.98
1945	3.16	1.56	1.34	1.90	1.81	1.75	1.50	.60	5.11	1.78	.00	1.34	21.85
1946	2.67	1.51	.66	2.75	2.82	3.38	1.37	8.87	6.83	2.58	1.64	2.03	37.11
1947	1.79	.32	1.30	.20	2.57	.55	.62	1.85	-	.34	.62	-	10.16
1948	.22	-	-	2.10	2.85	4.22	2.25	-	2.75	2.41	.88	-	17.68
1949	2.38	-	2.43	7.36	1.10	7.32	1.39	2.69	1.41	-	-	-	26.08
1950	1.31	1.77	.21	2.48	3.71	-	-	3.11	1.85	-	.21	.00	14.65
1951	.57	2.11	2.16	.43	9.67	.97	.72	.45	2.63	.33	1.06	.19	21.29
1952	.23	1.77	2.51	1.96	2.62	1.77	2.51	.00	8.99	.00	4.54	2.76	29.66
Average	1.54	1.82	1.86	2.64	3.40	3.28	2.58	1.88	2.85	1.82	1.16	1.93	26.76

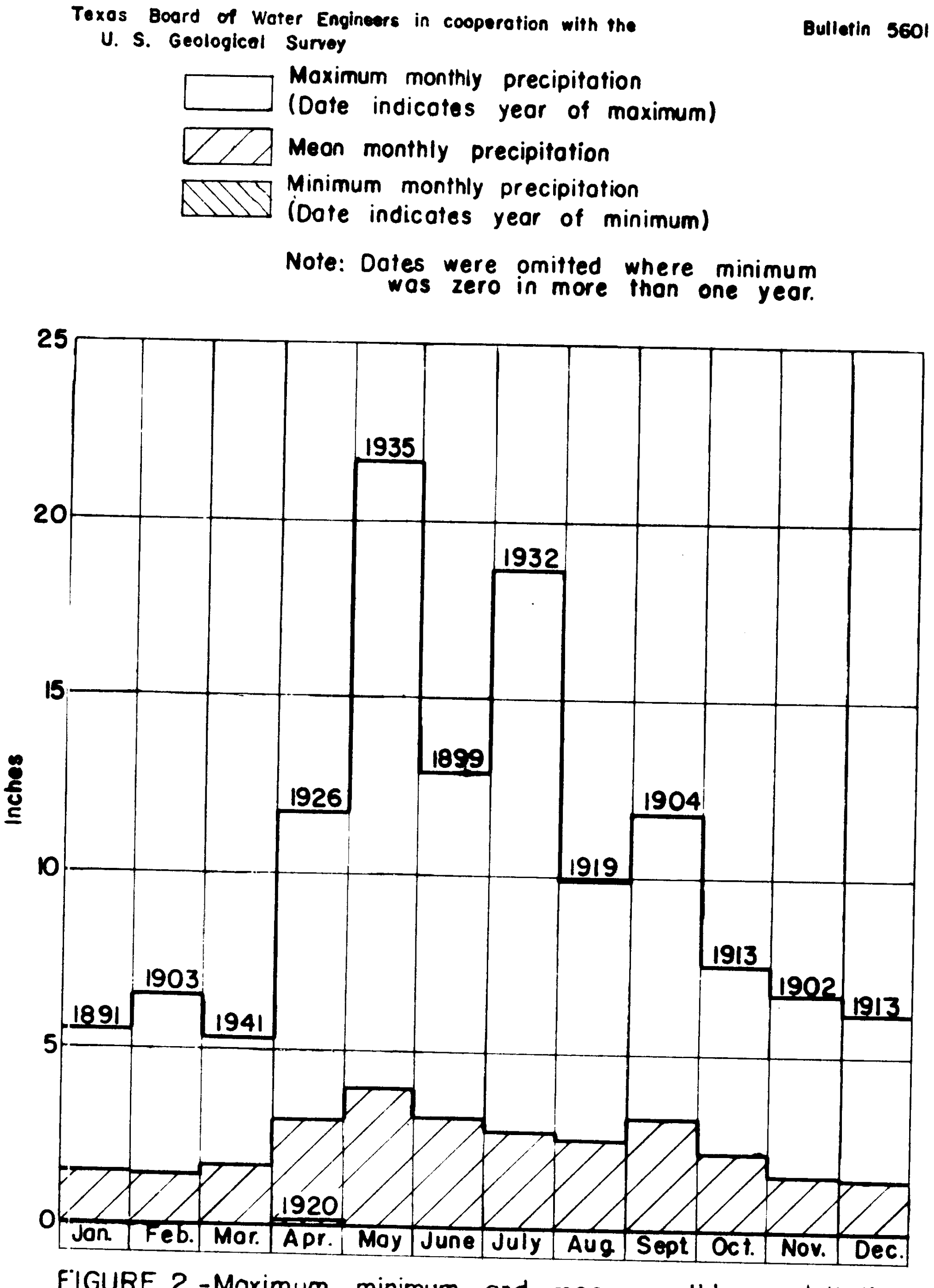


FIGURE 2.-Maximum, minimum, and mean monthly precipitation at Hondo, Tex., 1885-1952.

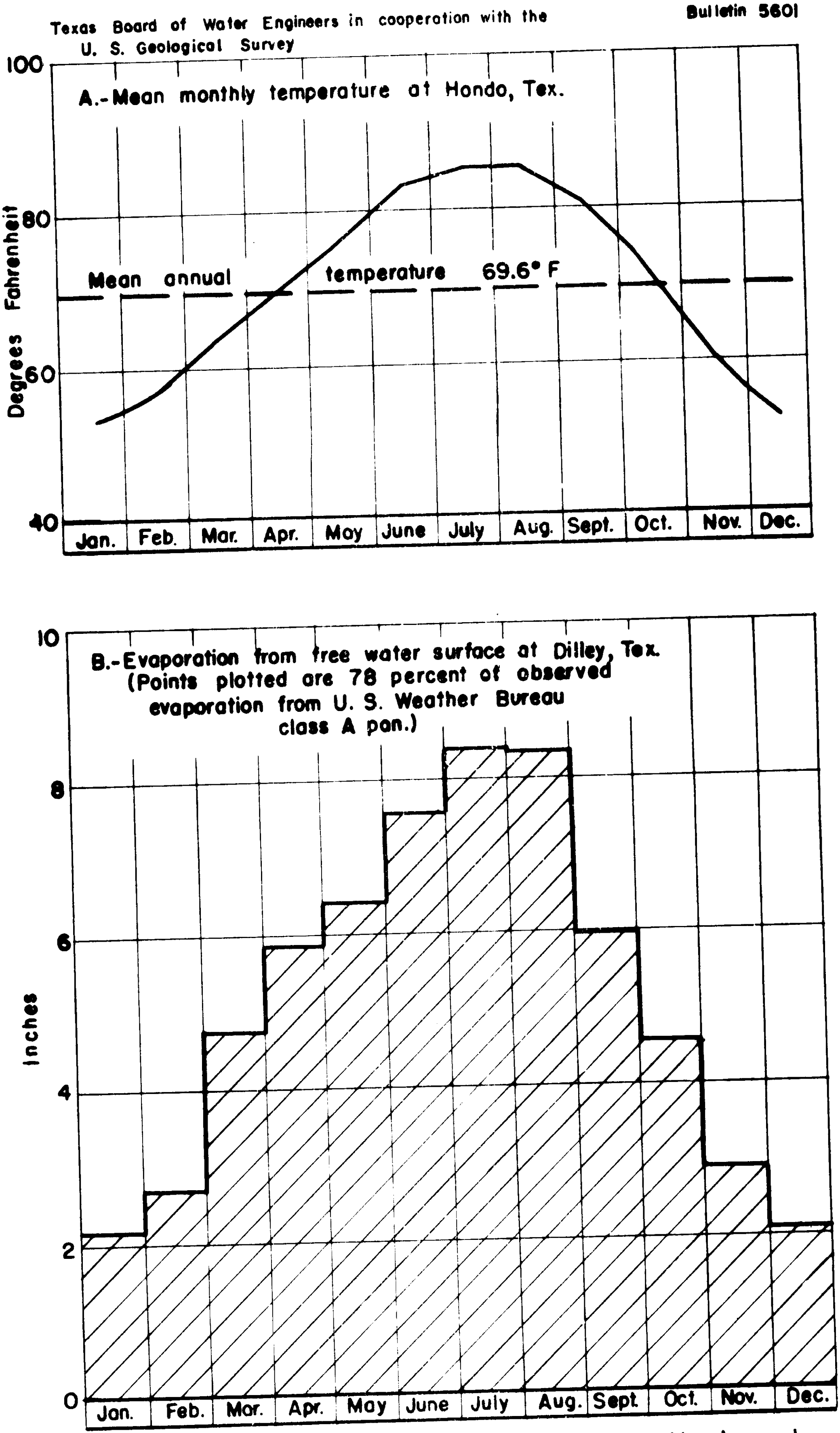


FIGURE 3.-Graphs showing temperature at Hondo and evaporation at Dilley, Tex.

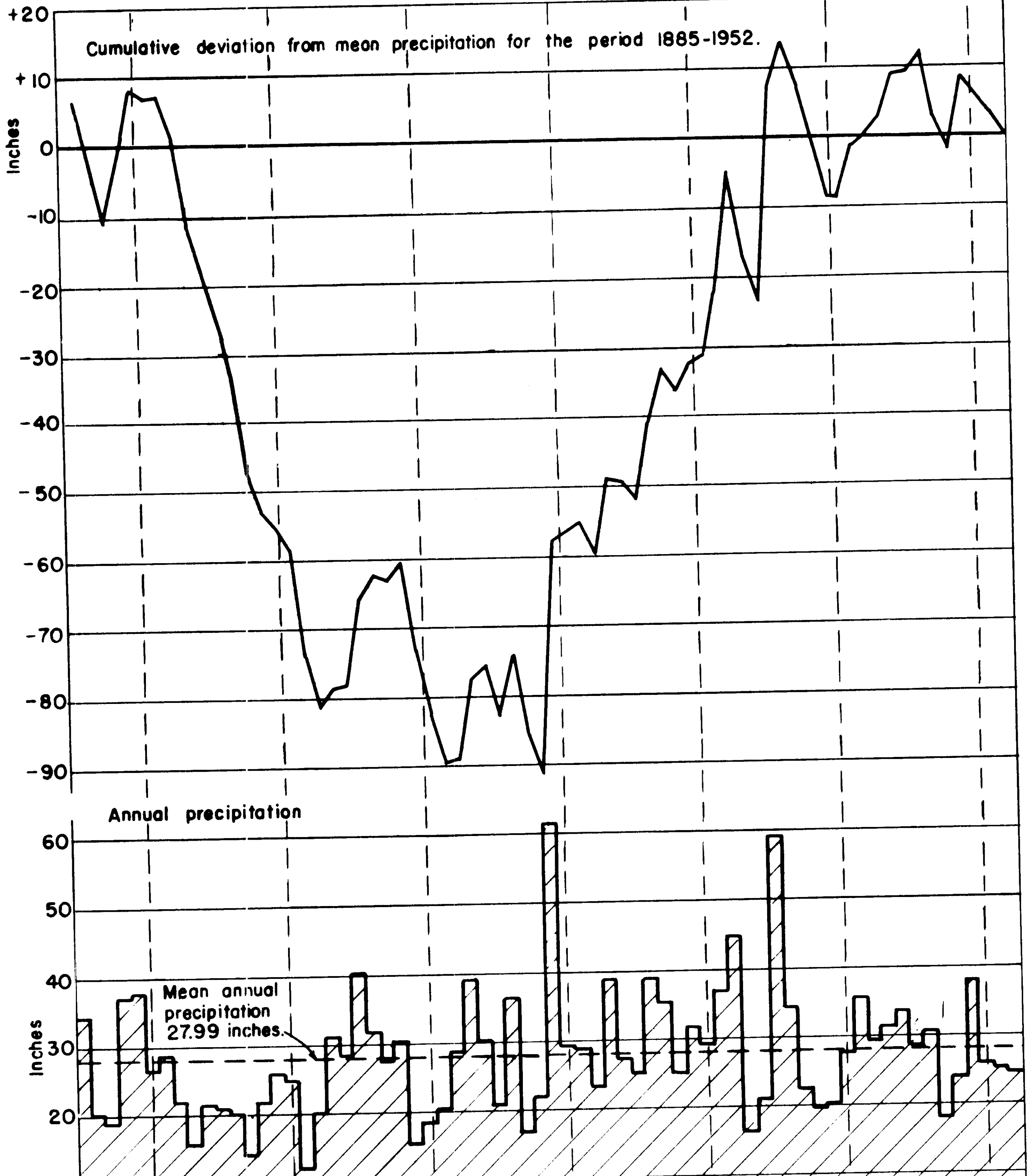


FIGURE 4.-Precipitation at Hondo, Tex., 1885-1952.

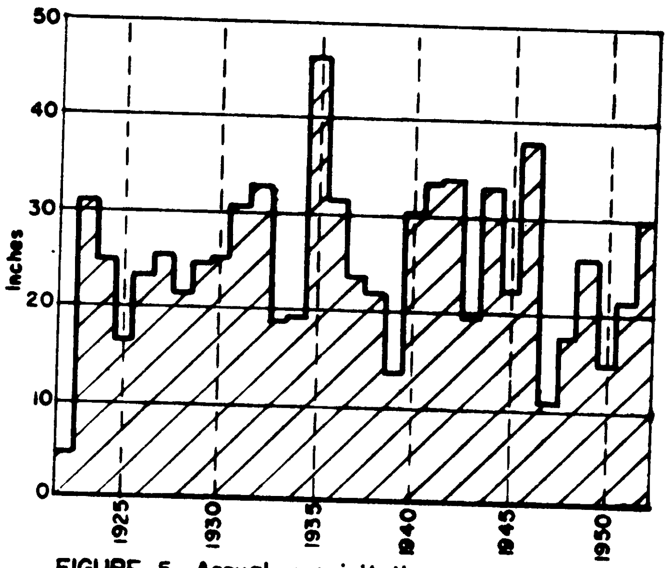


FIGURE 5.-Annual precipitation at Rio Medina, Tex., 1922-52.

DEVELOPMENT

Farming and stockraising are the principal occupations. The rugged upland area in northern Medina County is limited to the raising of cattle, sheep, and goats, except along stream valleys where feed crops can be raised. The character of the soil and the amount of rainfall has restricted the use of a large part of southwestern Medina County to grazing.

The relatively level country in the central, eastern, and southeastern portions of the county is used for diversified farming. The principal dry-land crops are broom corn, oats, maize, sorghum, corn, peanuts, and cotton. Surface water has been used since 1925 to irrigate truck crops in southeastern Medina County. In recent years, a number of irrigation wells have been developed for supplemental irrigation of grain crops.

Oil and gas have been produced from the Taylor, Ina, Adams, Chacon, and Bear Creek fields in the southern part of Medina County. Only the Chacon and Ina fields are still active. Industrial plants include pottery and broom-corn processing. Tile and brick are manufactured at D'Hanis, and vegetables from the irrigation district are processed and canned at Natalia. The U. S. Air Force has a base at Hondo, the county seat.

GEOLOGY

The rocks exposed in Medina County are of sedimentary origin, with the exception of several igneous intrusions north and west of Hondo. Serpentine has been reported in logs of oil tests in the southern part of the county. The sedimentry rocks range in age from Cretaceous to Recent and consist of limestone, chalk, caliche, conglomerate, gravel, sand, silt, shale, and clay.

The geologic formations from which Medina County obtains its water supply are, from oldest to youngest; the Glen Rose limestone, Edwards limestone and associated limestones, Austin chalk, Anacacho limestone, silts and sands of the Escondido formation, sands of the Indio formation, Carrizo sand, and sands and gravels of the Leona formation (see table 3). The formations crop out in east-west belts extending across Medina County as shown on plate 1. The normal continuity of the belts has been disrupted by faulting. The dip of the beds is generally toward the south and southeast at an angle steeper than the slope of the land surface, so that the land surface bevels the outcrops of the formations. The average normal dip is estimated at 15 - 20 feet to the mile, but deformation along fault lines has caused the strata in some fault blocks to be inclined from the normal position. Toward the south, the multiple faulting of the Balcones zone has increased the depths at which the formations are normally encountered.

Toward the north, successively older strata crop out and the formation lowest in the geologic column has the highest topographic exposure. Such an arrangement of the rocks, whereby permeable limestone and sandstones are interbedded with relatively impermeable clays and shales, causes the ground water downdip from the outcrop to be under artesian pressure. Rain falling on the outcrops percolates into the porous beds and is then transmitted down the dip to greater depths below the surface.

Table 3 shows the subdivisions of the geologic formations with their approximate thicknesses, lithologic character, and water-bearing properties. The areas of outcrop of the different geologic units are shown on plate 1.

Plate 2, A-A', is a cross section down the dip of the formations from Bandera County south along the Hondo Creek to Frio County, in which the surface outcrops of the formations are correlated with the structure and subsurface geology. The formations of Cretaceous age maintain a generally uniform thickness, whereas the Tertiary formations thicken rapidly downdip to the south. The section illustrates the complicated, multiple faulting of the Balcones zone.

Plate 2, B-B', is a cross section, approximately parallel to section A-A'. It extends from Medina Lake and Bandera County through Rio Medina and Lacoste to Bexar County. The total vertical displacement of the six faults in this section is approximately equal to the total displacement of the 25 faults along section A-A'. The Culebra anticline, bounded by the Cliff fault on the northwest and the Castroville fault on the southeast, is a southwestward-plunging anticline.

Table 3.- Geologic formations of Medina County, Tex.

System	Series	Group	Formation	Approximate thickness (feet)	Lithologic character	Water-bearing properties
Quaternary	Recent		Alluvium	0-30	Silt, sand, clay, and gravel. Confined to stream valleys.	Not known to yield large supplies of water.
	Pleistocene		Leona formation	0-65	Silt, sand, and fine gravel, occurring beneath terraces along larger streams.	Yields moderate to large supplies of potable water.
Tertiary	Pliocene(?)		Uvalde gravel	0-30	Coarse flint gravel and caliche on hilltops and divides.	Not known to yield water in Medina County.
	Eocene	Claiborne	Mount Selman formation	0-100	Sandstone and shale with limonite and calcite concretions.	Furnishes large supplies of good water in Frio County. Only the lowest portion crops out in Medina County.
			Carrizo sand	240-300	Coarse- to medium-grained nonmicaceous reddish sandstone. Locally crossbedded.	Yields moderate to large supplies of potable water.
		Wilcox	Indio formation	440-710	Thin-bedded sandstone, siltstone, and shale. Contains lignite and calcareous nodules.	Yields moderate supplies of moderately mineralized water.
	Paleocene	Midway	Kincaid formation	80-155	Marine limestone, sandstone, and shale. Lower part contains glauconite.	Not a fresh-water aquifer in Medina County.
Cretaceous	Gulf	Navarro	Escondido formation	550-740	Shale, sandstone, and some limestone. Increasingly arenaceous to west.	Yields moderate supplies of moderately mineralized water.

Table 3.- Geologic formations of Medina County--continued

System	Series	Group	Formation	Approximate thickness (feet)	Lithologic character	Water-bearing properties
Cretaceous	Gulf	Navarro	Corsicana marl	30-55	Limestone and shale; thickens to east.	Not a fresh-water aquifer in Medina County.
			Taylor marl	0-150	Clay and marl; thickens to east.	Not a fresh-water aquifer in Medina County.
			Anacacho limestone	350-530	Fossiliferous limestone, marl, and clay. Increasingly calcareous to west.	Yields small supplies of water locally.
			Austin chalk	210-290	White to buff chalk, marl, and limestone.	Yields small supplies of water.
			Eagle Ford shale	20-65	Black shale and gray arenaceous limestone; weathers to yellow clay and brown flagstones.	Not known to yield water in Medina County.
	Comanche	Washita	Buda limestone	35-110	Dense, massive limestone, light yellow to buff. Veined calcite.	Generally not water-bearing.
			Grayson shale (formerly Del Rio clay)	35-95	Blue clay; weathers to yellow. Contains thin beds of limestone.	Yields no water to wells in Medina County.
			Georgetown limestone	20-75	Hard white limestone. Thin-bedded limestone and marl near top.	May be water-bearing but does not furnish entire supply to any known well in Medina County. If and where water-bearing, it forms a part of the principal limestone reservoir.

Table 3.- Geologic formations of Medina County--continued

System	Series	Group	Formation	Approximate thickness (feet)	Lithologic character	Water-bearing properties
Cretaceous	Comanche	Fredericksburg	Edwards limestone	400-620	Hard, massive white limestone with flint nodules. Cavernous in places.	Yields large supplies of potable water.
			Comanche Peak limestone	25-45	Sandy marl and limestone. Contains no flint.	Not a fresh-water aquifer in Medina County.
			Walnut clay	12-42	Fossiliferous sandy marl and limestone.	Not known to yield water in Medina County.
		Trinity	Glen Rose limestone	800-1,175	Alternating beds of hard limestone and softer marl.	Yields moderate supplies of potable but rather hard water.
			Travis Peak formation	220-650	Shale, silt, sandstone, and limestone.	Probably contains moderate supplies of water of undetermined quality.
	Coahuila (Mexico)	Nuevo Leon and Durango (Mexico)	Sligo formation	0-208	Gray limestone, black shale, and sandstone.	Not known to yield water in Medina County.
			Hosston formation	0-440	Red sandstone and shale. Some limestone.	Not known to yield water in Medina County.
Pre-Cretaceous				190+	Hard, black, lignitic shale. Some anhydrite.	Not known to yield water in Medina County.

ROCK FORMATIONS AND THEIR WATER-BEARING PROPERTIES

Pre-Cretaceous rocks

The Paleozoic era was long and complex, as shown by the rocks that crop out in Llano County and adjacent counties in central Texas. After the deposition of the Paleozoic rocks, the sea retreated from central Texas and some of the county probably remained as land during the Triassic and Jurassic periods. As yet, not enough deep wells have been drilled to ascertain the age of the pre-Cretaceous rocks. The black shale reported at a depth of 5,395 feet in the driller's log of well I-6-105 is probably of Pennsylvanian age. Sellards (1931, p. 819-827) identified schists of probable Paleozoic age along the Balcones fault zone. No rocks older than those of Cretaceous age crop out in Medina County. No water has been reported from pre-Cretaceous rocks in Medina County.

Cretaceous system

The Cretaceous rocks of Texas have been divided into the Coahuila (in Mexico), Comanche, and Gulf series. In Early Cretaceous time the sea advanced over this area, depositing sediments upon an eroded surface of Paleozoic rocks. During this period, minor fluctuations in the depth of the sea were accompanied by the deposition of limestones, shales, and sandstones. At the close of the Comanche epoch, the sea withdrew completely from this region, as indicated by the presence of a disconformity and the absence of the oldest formation of the Gulf series.

Coahuila series (Mexico)

The oldest basinward strata of Cretaceous age, extending from Arkansas to Mexico, have been classified by Imlay (1945, p. 1416-1469) as the Hosston, Sligo, and Pearsall formations, in ascending order. The Pearsall is the subsurface equivalent of the Travis Peak formation of the Comanche series. The Hosston and Sligo formations are correlative with the Nuevo Leon and Durango groups, respectively, of the Coahuila series of Mexico. These lowermost Cretaceous formations have been tentatively identified from 4,723 to 5,395 feet in the core log of well I-6-105. The red sandstone of the Hosston formation rests disconformably upon a black shale of probable Pennsylvanian age. An insufficient number of deep wells have been drilled in Medina County to determine the water-bearing properties of the rocks of the Coahuila series. No potable water has been reported from the two wells that penetrate these formations.

Comanche series

The Comanche series in Medina County includes rocks of the Trinity, Fredericksburg, and Washita groups. These rocks consist of limestone, marl, clay, shale, silt, and sandstone and have an aggregate thickness of more than 2,300 feet. They crop out in the northern part of the county.

Trinity group

Travis Peak formation.- The Travis Peak formation, the lowest formation of the Trinity group, does not crop out in Medina County. The nearest reported exposures are along the Guadalupe River in the northwestern part of Comal County (George, 1947, p. 16).

The Travis Peak has been encountered in only three wells in the county, all of which have been abandoned and completely or partially plugged. Wells I-1-15, I-2-67, and J-2-15 entered the Travis Peak formation below 2,500 feet. The logs of these wells (table 10) show a series of fine-grained sandstones, limestones, and varicolored shales. Wells I-1-15 and I-2-67 reported water, of undetermined quality, in the formation.

In the past, the cost of drilling to the depth necessary to obtain water from the Travis Peak was prohibitive for ordinary use. An increased demand for water may encourage further exploration of this formation as an aquifer.

Glen Rose limestone.- The oldest formation exposed in Medina County is the Glen Rose limestone, which crops out in the northern part of the county. The base of the formation is not exposed, but well logs and exposures in adjacent counties show that the Glen Rose grades downward into the Travis Peak formation.

A thickness of 1,175 feet of the Glen Rose limestone was penetrated in well I-1-15 in western Medina County. Near the Bandera County line in central Medina County, a thickness of 900 feet has been estimated from surface measurements and the log of well C-9-63. The driller's log of well I-6-105 indicates the Glen Rose to be approximately 1,100 feet thick in the south-central part of the county.

The Glen Rose limestone consists of alternating beds of hard gray limestone and bluish-gray to yellow marl. The limestone is generally dense to finely crystalline, but some beds are granular or composed of reef material. A terrace type of topography has developed on the more easily eroded marl beds in the outcrop area. The marl beds range from a few inches to 15 feet in thickness, whereas the limestone beds range from a foot to 50 feet. The limestone becomes thicker and more massive in the lower portion of the formation.

The lowest exposure of the Glen Rose is near Bandera County in the bed of Hondo Creek. The total exposed thickness, estimated from the bed of Hondo Creek to the base of the Walnut clay, is approximately 650 feet. The formation is composed of alternating beds of limestone and marl. A well-known fossil zone, called the *Salenia texana*, occurs approximately 100 feet above the bed of the creek. This zone was used by George (1952, p. 17-21) as marking an arbitrary dividing line between the upper and lower members of the Glen Rose limestone. The following section was measured from the bed of Hondo Creek, 0.1 mile south of Bandera County, to the Salenia texana zone, 0.4 mile south of the Bandera County line.

	Thickness (feet)
Glen Rose limestone:	
Limestone, dense, gray, contains Corbula texana Whitney on upper surface of bed ----------------------------	0.7
Limestone, light-gray, nodular, chalky, with alternating thin beds of shale; contains Porocystis globularis (Giebel), Orbitolina texana (Roemer), Nerinea sp., and casts of large mollusks --	6.5
Limestone, nodular; contains Salenia texana, Hemiaster sp., and large mollusks --	3.7
Shale, yellowish-gray; contains Orbitolina texana (Roemer) --	4.8
Shale, light-gray; forms flat bench -------------------------	3.0
Limestone, yellowish-white, thick-bedded, dense, with calcite veins --	4.1
Limestone, yellowish-white, thick-bedded, massive with calcite veins ---	4.8
Shale, light-yellow, fossiliferous --------------------------	1.0
Shale, gray; forms bench ------------------------------------	5.8
Limestone, light-gray, soft ---------------------------------	3.0
Shale, light-gray, arenaceous -------------------------------	5.8
Marl, yellowish-gray, soft ----------------------------------	17.8
Shale, light- to dark-gray, calcareous, thin-bedded to laminar-bedded; no fossils. Weathered blue-gray ----------	3.6
Limestone, gray, fine-grained, sandy; argillaceous in bottom 3 inches --	0.8
Limestone, yellowish-white, fine-grained, sandy, massive ----	4.1
Limestone, yellowish-gray, nodular; irregular iron nodules on exposed weathered surface. Contains reef-type fossils -	3.5
Limestone, light-gray, dense, bedded ------------------------	0.9
Shale, light-gray, platy; contains Orbitolina ---------------	0.2
Limestone, light-gray to white, dense, massive; contains a few pelecypods --	2.7

Glen Rose limestone--continued	Thickness (feet)
Limestone, light-gray, arenaceous, dense, massive	1.5
Limestone, grayish-brown, massive, dense, crystalline, slightly arenacous. Top of bed contains tracks of three-toed *Tyrannosaurus* and five-toed *Brontosaurus*	2.8
Limestone, white, very fossiliferous, partially coquinal; contains *Crassatella*, *Turritella*, and small pelecypods and gastropods	7.8
Limestone, light-gray, thin-bedded, and coquina; contains oyster shells	18.2
Total thickness of section measured	107.1

The Glen Rose limestone contains large numbers of echinoids, rudistids, gastropods, and pelecypods, and a large foraminiferal fauna (Stead, 1951, p. 577), in which the genus *Orbitolina* is especially abundant. Few fossils have original shell material, most of them being found as casts or moulds of the original shells. The following species were collected from a quarry 0.7 mile south of Bandera County on the Hondo-Tarpley highway and have been identified by members of the U. S. Geological Survey: *Salenia texana* Credner, *Porocystis globularis* (Giebel), *Porocystis* sp., *Orbitolina texana* (Roemer), *Idonearca* sp., *Enallaster texanus* (Roemer), *Nerinea* sp., *Tylostoma* sp., *Pecten stantoni* Hill, *Nuculana* ?, *Hemiaster* sp..

In the outcrop area of the Glen Rose limestone, nearly all the normal or base flow of the streams is supplied by contact springs and seeps which issue from the basal portion of the outcropping marl. Some springs issue from solutional openings, but even these are found at definite bedding contacts at the base of a more porous bed. No springs are known to issue along faults in the Glen Rose limestone.

Some water appears to pass from surface streams into the Glen Rose limestone in Medina County, although the volume is probably small compared to losses to the Edwards limestone in the lower reaches of the streams. Surface water has been reported to enter the lower portion of the formation in outcrop areas in Bandera, Kendall, and Comal Counties.

Supplies of water sufficient for stock and domestic use are obtainable from wells over most of the outcrop area of the Glen Rose limestone, and, in several places, rather large supplies have been developed. Most of the water is found in sandy marl, thin-bedded arenaceous limestone, and calcareous sandstone. Several wells have encountered water in cavernous limestone.

Only one water well taps the lower part of the Glen Rose limestone. Well C-9-63, completed in the lower part of the Glen Rose at 823 feet, is reported to have been pumped at 737 gallons a minute with a specific capacity of 3.7 gallons a minute per foot of drawdown. A sample of water collected from the well (table 12) had 622 parts per million of sulfate. The water is being used for supplemental irrigation of feed crops.

The quality of the water varies widely, but it is generally found that the deeper wells yield water that is more highly mineralized than that from shallow wells (table 12). The water that issues as springs from the Glen Rose limestone is similar in quality to the water from shallow wells.

Fredericksburg group

Overlying the Glen Rose limestone in Medina County are sandy marls and limestones of the Fredericksburg group (pl. 6). The group includes the Walnut clay, the Comanche Peak limestone, and the Edwards limestone. The Comanche Peak limestone and Edwards limestone are shown as a single unit on the geologic map. Both formations are similar in lithology and water-bearing properties, and they constitute a single aquifer, which, for convenience, is designated in this report the "principal aquifer."

Walnut clay.- The Walnut clay, the lowest formation in the Fredericksburg group, is a sandy marl 4 to 12 feet thick. It lies conformably upon the Glen Rose limestone. The Walnut clay is difficult to identify and map in many areas because of its thinness and its similarity to the underlying Glen Rose limestone. The thinness and persistence of the formation, however, warrant its use as a stratigraphic marker. The presence of specimens of *Exogyra texana* Roemer and *Gryphaea marcoui* Hill and Vaughan and irregular nodules of limestone aid in identifying the formation. In some areas the marl is honeycombed, but the solutional cavities are probably restricted to beds near the surface. No wells in Medina County obtain water from the Walnut clay.

Comanche Peak limestone.- The Comanche Peak limestone overlies the Walnut clay conformably and ranges in thickness from 25 to 45 feet. It is a sandy to argillaceous marl grading upward into a light-gray massive limestone. The marl section contains *Exogyra texana* Roemer, whereas the limestone contains caprinids. The nodular appearance of the formation is its most distinctive characteristic. It is probable that some water, believed to come from the Edwards limestone, actually comes from the Comanche Peak limestone, but, because the wells are uncased, there is no positive evidence regarding the source of the water.

The electrical properties of the Comanche Peak limestone are illustrated in the partial electric log of well J-4-71 (fig. 6).

Edwards limestone.- The Edwards limestone lies conformably upon the Comanche Peak limestone and is overlain disconformably by the Washita group. The Comanche Peak limestone and the lower part of the Edwards limestone are very similar in lithology, but may be distinguished by their faunas and distinctive weathering.

The Edwards consists of massive beds of light-buff to light-gray hard, dense, fine-grained, brittle limestone, interbedded with occasional layers of marl or thin-bedded limestone. Flint occurs in thin beds, lenticular masses, and nodules at a number of horizons. Siliceous casts and molds of fossils are commonly found in the flint or chert nodules. The flint or chert ranges in color from light-gray to black and has a white spongy, weathered surface, and it is not known to occur in any other formation in the area. A cream- to gray-colored earthy, porous limestone containing *Ostrea* fragments is commonly found at the top of the

North view of Edwards and Comanche Peak limestones (Kecp), undifferentiated, capping the Walnut clay (Kw), and Glen Rose limestone (Kgr). Well C-7-11 is in the foreground.

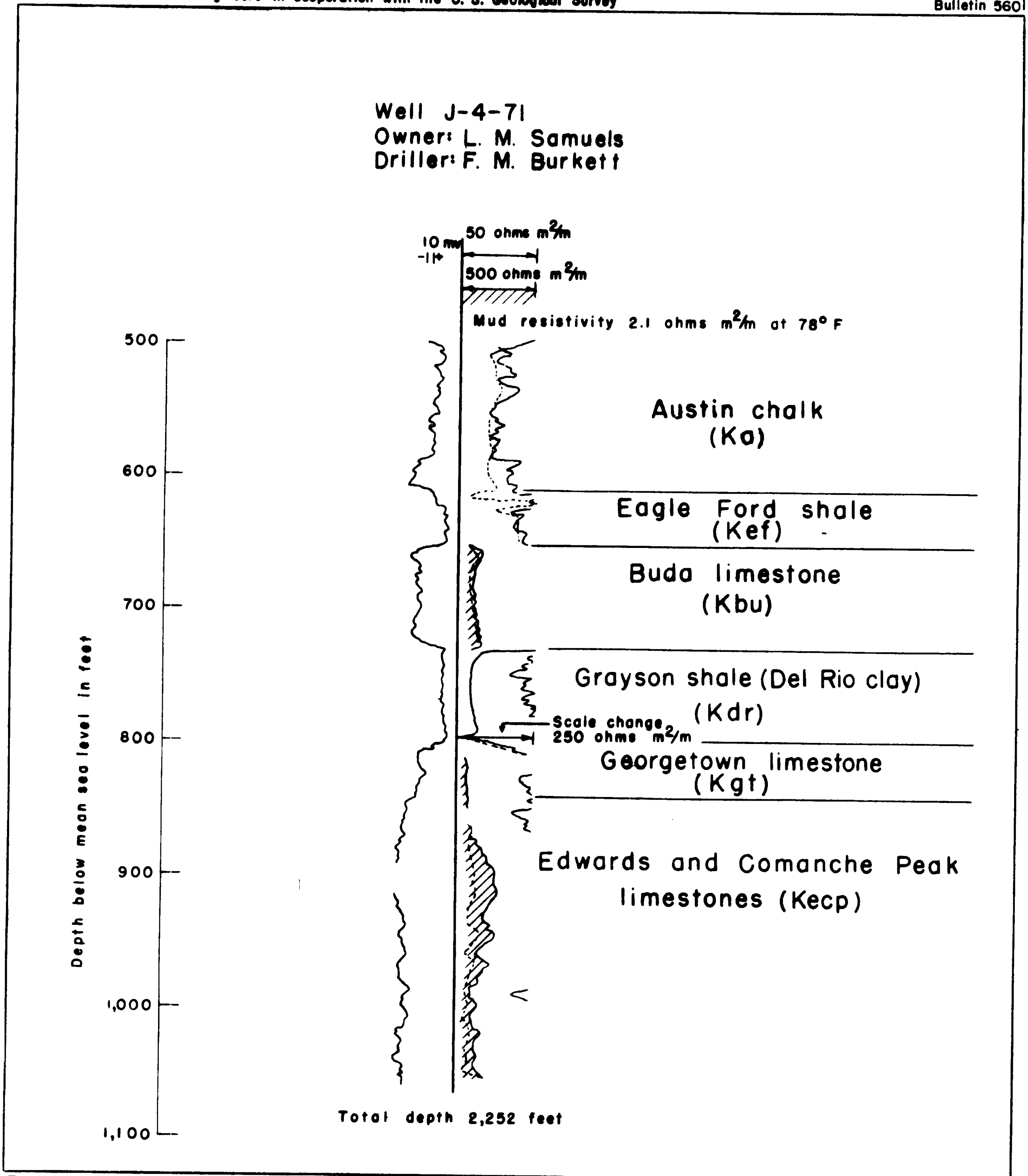


FIGURE 6.-Partial electric log of well J-4-71 illustrating the electrical properties of the Eagle Ford shale; Buda limestone; Grayson shale (Del Rio clay); Georgetown limestone; and Edwards and Comanche Peak limestones, undifferentiated.

formation. Drillers refer to this stratum as the "Dobie" zone and report that it contains traces of "dead oil" or asphalt.

The electrical properties of the Edwards limestone are illustrated in the partial electric log of well J-4-71 (fig. 6). The water in the Edwards limestone in this well was reported to be highly mineralized. The electric log, therefore, may not be characteristic of the Edwards limestone elsewhere.

Numerous caves have been found in the outcrop area of the Edwards limestone, especially along the southern margin of the plateau. A striking example is Bat Cave, located on a bluff overlooking the west branch of Verde Creek. The cave has four or more levels, the entrance room being approximately 30 by 180 feet in size and 90 feet high. Woodard Cave, west of Seco Creek, has a vertical entrance or sinkhole about 30 feet long and 18 feet wide and extends downward a distance of approximately 190 feet. The entrance and the underlying chambers are elongated in the direction of the jointing, which is about N. 60° E. The water in the principal reservoir is believed to be contained in caverns and solutional channels similar to those near the surface. Wells I-1-2, I-1-7, and I-2-23, which are 4 to 6 miles downdip from Woodard Cave, suck and blow air, indicating a cavernous condition.

The Edwards limestone is generally too hard to yield whole specimens of fossils that can be identified, although several distinctive types occur in the less indurated thin-bedded limestone and shale members. The most common fossils found are rudistids of the genera *Toucasia*, *Monopleura*, and *Requienia*, and other reef-dwelling fossils such as *Caprina*, *Phacoides*, and *Pecten*. Siliceous sponges (pl. 7) were found in massive Edwards limestone near well J-1-20.

The Edwards limestone constitutes the principal part of the most important ground-water reservoir in Medina County, designated in this report the "principal aquifer." It supplies water for public supply, industry, irrigation, and domestic and stock use in more than half the county. The recharge, discharge, and movement of the water in the reserovir and the extent to which it is developed are discussed in more detail under the heading Occurrence and movement of ground water.

Washita group

Georgetown limestone.- The Georgetown limestone disconformably overlies the Edwards limestone. It is similar to the Edwards in lithology and topographic expression, but can be distinguished by its many fossils. The Georgetown limestone generally contains more detrital material than the Edwards limestone. It is easily separated from the overlying Grayson shale (Del Rio clay) by the difference in lithology and fossil content.

In Medina County, the Georgetown consists of a dense yellowish-white massive to thick-bedded limestone, 20 to 50 feet thick. The upper section has thin beds of argillaceous limestone and marl containing a characteristic fauna. The following species were collected from a yellowish-gray marl 3 feet below the base of the Grayson shale (Del Rio clay) at a locality 16 miles north-northwest of D'Hanis in the bed of Seco Creek, 1.2 miles north of the Hondo-Utopia road: *Kingena wacoensis* (Roemer), *Turrilites brazoensis* Roemer, *Stoliczkaia uddeni* Bose, and *Hemiaster* sp..

PLATE 7

Fossil sponges in Edwards limestone
5.1 miles northwest of Rio Medina.

Outcrops of the Georgetown limestone are scattered throughout northwestern and north-central Medina County. In other areas, the Georgetown limestone has been faulted out of sight, as shown on plate 2.

No wells in Medina County obtain their principal water supply from the Georgetown limestone. Drillers have reported small amounts of sulfur water, but no wells have been completed in the formation. The Georgetown may, however, form a part of the principal aquifer in some areas.

Grayson shale.- The Grayson shale, formerly known as the Del Rio clay, conformably overlies the Georgetown limestone and occurs in the same outcrop areas in the county. It consists of 35 to 95 feet of bluish-green clay which weathers yellow brown. Exogyra arietina Roemer, a fossil shell shaped like a ram's horn, is characteristic of the formation and is found in well cuttings and on the surface. Aggregates of these shells form limestone beds, 3 to 4 inches thick, interspersed in the lower clayey section. The upper clay has fewer fossils and is sandier than the lower section. Thin beds of sandy limestone containing pyrite nodules are common in the upper part of the clay.

The electrical properties of the Grayson shale are illustrated in the partial electric log of well J-4-71 (fig. 6). The Grayson is a relatively tight shale containing several thin beds of sandstone and limestone.

The Grayson shale forms a characteristic slope which is arcuate in cross section below the protecting Buda limestone. The brownish-yellow clay weathers to a dark-brown or black soil. Local ranchers and farmers take advantage of the comparative impermeability of the clay be constructing surface reservoirs in its outcrop area. The Grayson shale is not water bearing in Medina County. Instead, it serves as an upper confining bed in the artesian area of the principal aquifer.

Buda limestone.- The Buda limestone, uppermost formation of the Comanche series, lies conformably on the Grayson shale. It is a very fine-grained dense, massive light-gray to pink limestone (table 3). The limestone breaks with angular or conchoidal fracture when struck with a hammer; fracture surfaces display a porcelaneous texture, red and black specks, and numerous small veinlets of crystalline calcite. In some areas, the Buda limestone may be confused with some brittle, porcelaneous buff-colored beds in the Georgetown limestone. The presence of Kingena wacoensis (Roemer) in the Georgetown limestone aids in distinguishing these beds of similar texture.

The electrical properties of the Buda limestone are illustrated in the partial electric log of well J-4-71 (fig. 6).

The Buda limestone is relatively resistant to erosion and crops out in fault scarps, bluffs, and low hills. A few outcrops are honeycombed, but the majority are massive, having nodular surfaces. Several specimens of Budaiceras and Pecten roemeri Hill were identified in the limestone. Although the formation is fossiliferous, most of the fossils are in the form of casts or are replaced by crystalline calcite.

The thickness of the Buda limestone is between 35 and 55 feet in its outcrop area. Well logs indicate that the formation increases in thickness to the south.

Although well drillers have reported that the Buda limestone produces small quantities of water in local fractured zones near the major faults, no wells are known to obtain water from the formation in Medina County.

Gulf series

The Gulf series in Medina County is represented by the Eagle Ford shale, the Austin chalk, the Anacacho limestone, the Corsicana marl, and the Escondido formation.

Eagle Ford shale

The Eagle Ford shale lies upon the Buda limestone unconformably and underlies the Austin chalk. In Medina County, there is no appreciable discordance in dip between the Buda limestone and Eagle Ford shale, but there is marked evidence of an unconformity. In the west bank of Hondo Creek on Jim Anderson's ranch, 6 miles north of Hondo, the basal bed of the Eagle Ford consists of a sandy yellow shale containing rounded pebbles and granules of the Buda limestone, resting on an uneven, nodular surface of the Buda.

The lower portion of the Eagle Ford shale consists of a light-yellow to gray laminated siltstone and sandstone and thin beds of brownish limestone. The overlying beds are increasingly calcareous; the upper portion of the formation consisting of a light-buff flaggy limestone. The total thickness of the Eagle Ford shale in the outcrop is between 15 and 30 feet, but logs of wells in the southern part of the county show a thickness of as much as 160 feet.

The limestone portion of the formation is very fossiliferous, containing *Acanthoceras stephensoni* Adkins, *Inoceramus labiatus* Schlotheim, *Ostrea*, *Pecten*, shark's teeth, and fish scales.

The electrical properties of the Eagle Ford shale are illustrated in the partial electric log of well J-4-71 (fig. 6). The Eagle Ford is a dense, sandy shale. It is not known to be water bearing in Medina County.

Austin chalk

In Medina County, the Austin chalk consists of 225 to 350 feet of limestone, chalk, marl, and thin beds of clay. The chalk lies unconformably on the Eagle Ford shale. Stephenson (1929, p. 1323-1334) shows that the unconformity is widespread in Texas. There are many good exposures of the formation, but none show the complete section (pl. 8).

The lowermost beds of the Austin chalk consist of light-gray to buff dense thin-bedded limestone, very similar in lithology to the upper beds of the Eagle

PLATE 8

View of quarry in Austin chalk, looking east, near Verde Creek. The rock was used as building stone in the construction of the Medina County Courthouse.

Ford shale, although the Austin chalk contains less sand. Inoceramus subquadratus Schluter is commonly found in the lower beds of the Austin. Scattered grains of glauconite are found in the limestone.

Approximately 75 feet above the base of the Austin chalk, the dense limestone grades into a massive soft chalky impure light-gray to yellowish-white limestone. There are several beds of marl and clay in this medial section, which is 150 to 200 feet thick and is very fossiliferous. Some of the fossils found in the section are Mortoniceras minutum (Lasswitz), Hemiaster texanus Roemer, Pecten bensoni Kniker, Inoceramus sp., and Gryphaea aucella Roemer. An indurated conglomerate of Gryphaea aucella shells, 3 to 4 feet thick, forms a prominent horizon in the upper part of the Austin chalk. Nodular and dumbbell-shaped concretions of pyrite and marcasite are commonly found in the chalky limestone.

The uppermost portion of the Austin chalk consists of massive white chalky limestone and alternating layers of marl and chalk. In most places, this part of the formation contains the fossils Exogyra tigrina Stephenson, Parapachydiscus sp., Baculites, Ostrea centerensis Stephenson, and Inoceramus undulato-plicatus Roemer.

The electrical properties of the Austin chalk are illustrated in the partial electric log of well J-4-49 (fig. 7).

In Medina County, 9 wells are known to obtain water from the Austin chalk. Only 1 of the wells, I-3-79, produces more than 3 gallons a minute. It is near a zone of faulting and is believed to obtain most of its water through local recharge from gravel of the overlying Leona formation. Other wells have very small yields of water containing large amounts of hydrogen sulfide. The sulfur is believed to be derived from the pyrite and marcasite in the formation. There is a large solutional cavity or cave east of Hondo Creek, 8 miles north of Hondo, but it is the only known evidence of subsurface solution in this formation in Medina County.

Anacacho limestone

The Anacacho limestone overlies the Austin chalk unconformably and is equivalent in age to the Taylor marl of Bexar County. Stephenson (1927, p. 9) states, "In eastern Medina County and in western Bexar County, the westward-thinning body of Taylor marl overlaps the eastward-thinning tongue-like extension of the Anacacho limestone." To simplify mapping, the small amount of the Taylor marl in the eastern part of the county was included in the Anacacho limestone.

The Anacacho limestone varies in thickness from 240 feet in eastern Medina County to 450 or 500 feet in the western part of the county. The formation consists of argillaceous light-yellow, blue-gray, or buff thick-bedded limestone; light-gray chalk; light-yellow to blue marl; and sandy yellow clay. The formation is very fossiliferous, the lowermost part consisting of fragments of fossil shells and many whole shells. This stratum is coarse grained and indurated and suggests near-shore deposition. Several massive beds of the coarse-grained detrital limestone are impregnated with asphalt, the most noteworthy exposure being in the bed of Seco Creek, 2 miles north of D'Hanis. The fossils Pycnodonta vesicularis (Lamarck), Hoplitoplacenticeras aff. H. vari, and Nucleolites wilderae Ikens are common in the lower strata.

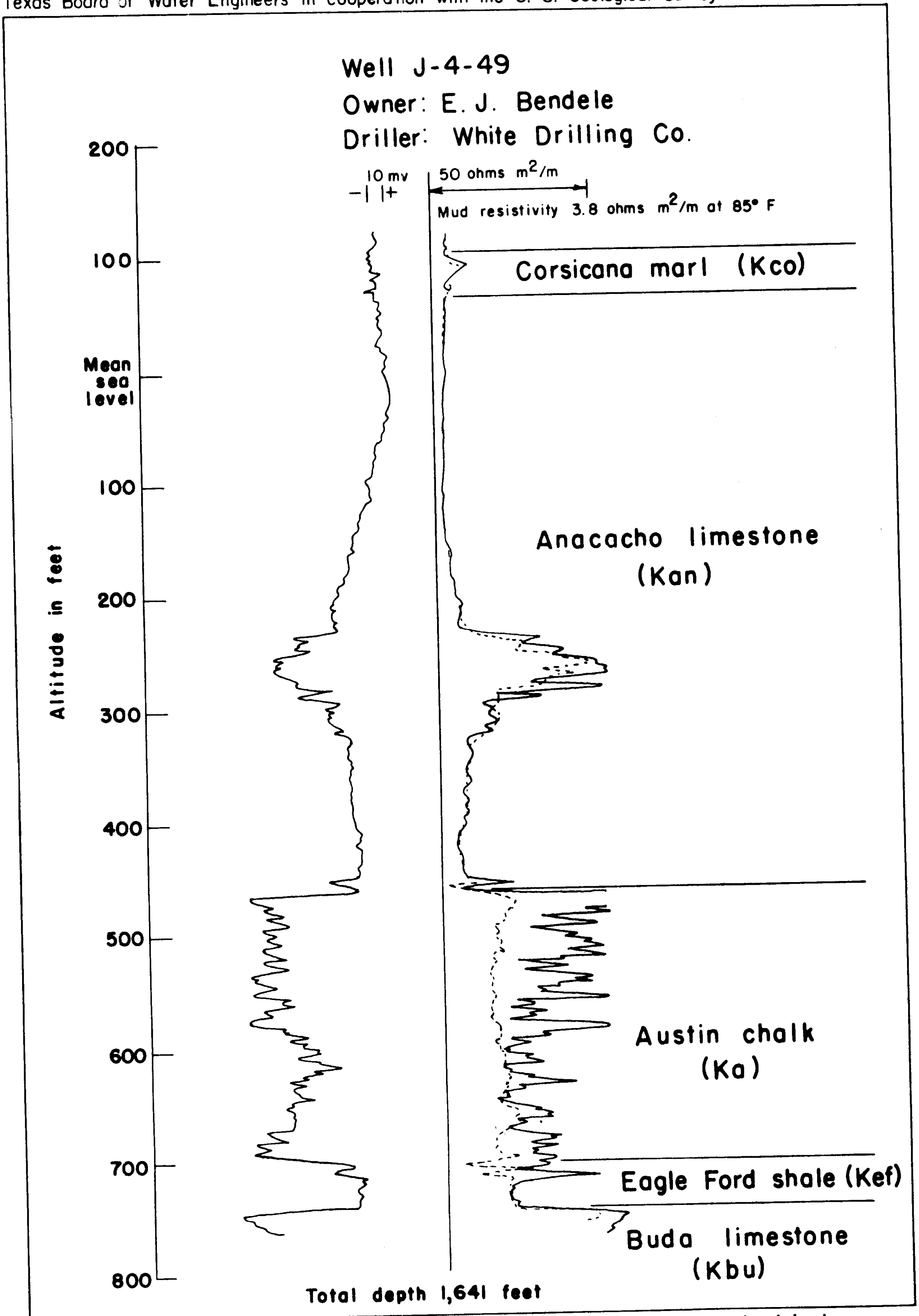


FIGURE 7.-Partial electric log of well J-4-49 illustrating the electrical properties of the Anacacho limestone and the Austin chalk.

The following section was measured along Seco Creek from Haby Crossing fault northward to Fort Lincoln, 1.8 to 2.0 miles north of D'Hanis.

	Thickness (feet)
Anacacho limestone	
Marl, light yellow, thin-bedded, glauconitic, contains Plicatula sp. --	9.6
Marl, light gray, thin-bedded, glauconitic, contains Salenia whitneyi Ikins and numerous bryozoa------------	2.3
Limestone, light yellow, marly, contains large numbers of Pycnodonta vesicularis (Lamarck)------------------	3.0
Limestone, chalky, light yellow, glauconitic, massive, contains Pycnodonta vesicularis (Lamarck), Venericardia, and bryozoa---	4.7
Chalk, massive, white, indurated, sparsely fossiliferous-	5.1
Marl, yellow to gray, glauconitic------------------------	0.6
Limestone, light gray, thin-bedded, dense, contains Pycnodonta vesicularis (Lamarck) and Exogyra spinifera Stephenson.--	2.4
Limestone, light yellow to light gray, massive, large-grained, composed of indurated fragments of fossils, predominantly echinoids------------------------------	4.5
Limestone, gray, massive, weathers light yellow, indurated, contains traces of asphalt-----------------	4.8
Limestone, white, thin-bedded, hard, contains Nucleolites wilderae Ikins and a few small vaculites--------------	2.0
Limestone, light to dark gray, massive, indurated, composed of fossil fragments cemented with asphalt-----	15.5
Total --	54.5

The middle strata of the Anacacho limestone consists of chalky, fine-grained soft white to light-gray limestone and thinner beds of gray marl. The proportion of marl increases from west to east. Fossils in the middle portion of the Anacacho include Parapachydiscus streckeri Adkins, Exogyra ponderosa Roemer, Baculites sp., Inoceramus sp., Bostrychoceras aff. B. polyplocum (Roemer), Sphenodiscus lenticularis Owen, Scaphites, and Gardium (Pachycardium) sp.

In eastern Medina County, near Rio Medina, the upper strata of the Anacacho limestone consist of massive- to thin-bedded fine-grained light-gray to buff fossiliferous limestone. The marl beds prevalent in other parts of the county, have merged into limestone. The limestone is well exposed along San Geronimo Creek near

Rio Medina (see pl. 9). The most common fossils are: Pycnodonta vesicularis (Lamarck), Baculites taylorensis Adkins, Scaphites aricki Adkins, Pseudocompsoceras sp. Inoceramus sp., Anomia sp., Exogyra ponderosa Roemer, Eutrophoceras planoventer Stephenson, and Exogyra costata spinosa Stephenson.

A dark- to yellowish-gray massively bedded bentonitic clay overlies the Anacacho limestone in the easternmost part of Medina County. The clay is believed to be a westward extension of the Taylor marl. The fossils Exogyra ponderosa Roemer and Dentalina alternata (Jones) are common. In the western part of the county, the uppermost beds of the Anacacho consist of fine-grained white to pinkish-gray fossiliferous chalky limestone and several beds of light-gray marl and darker gray shale.

The following section was measured from the bed of Seco Creek to the north-facing bluff at the James Amberson ranch, 2.7 miles north of D'Hanis.

	Thickness (feet)
Corsicana marl	
Marl, silty, irregularly bedded, calcareous, yellow to light brown, indurated	13.4
Marl, thin-bedded, soft, silty, light brown, stained with iron	2.7
Marl, irregularly bedded, calcareous, dense, silty, yellowish gray	3.5
Marl, nodular-bedded, calcareous, light gray to brown, silty, with iron stains	2.8
Shale, thin bedded, variegated gray, yellow, and bluish gray, with thin, ferruginous layers	5.4
Total	27.7
Disconformity	
Anacacho limestone	
Limestone, arenaceous, thin bedded, light yellow, indurated, with Diploschizia cretacea minor Stephenson, Terebratulina filosa Conrad, Scaphites porchi Adkins, also Turitella, Ostrea, and Lima	0.8
Limestone, dense, arenaceous, thin bedded, light yellow to gray, with Echinocorys texanus (Cragin), Pycnodonta vesicularis (Lamarck) and Inoceramus sp.	6.7

(continued on next page)

PLATE 9

Anacacho limestone in west bank of San Geronimo Creek,
1.2 miles south of Rio Medina.

Anacacho limestone	Thickness (feet)
Limestone, dense, 5 inches to 2 feet, thick beds, arenaceous, slightly glauconitic, light yellow, with Bostrychoceras polyplocum Roemer and Inoceramus ------------	11.2
Marl, chalky, yellowish white, irregularly bedded, arenaceous, slightly glauconitic ------------------------------------	1.0
Limestone, dense, light yellow, thin bedded, glauconitic, silty --	2.1
Marl, soft, light brown, massive, slightly glauconitic -------	3.6
Total ---	25.4

The electrical properties of the Anacacho limestone in well J-4-49 are shown in figure 7. The electric log shows a section of clay near the top, grading downward into limestone.

Few wells are known that draw water from the Anacacho limestone. Sayre (1936, p. 56) found several wells north of Castroville producing water from the formation, but all these wells have since been deepened or abandoned. The circulation of water in the limestone portion of the formation is restricted to the area of surface drainage.

Navarro group

Corsicana marl.- The Corsicana marl is a relatively thin and well defined unit cropping out in a narrow belt along the western edge of the southwest-plunging Culebra anticline. It overlies the Anacacho limestone unconformably. The formation has been concealed by the overlapping Escondido formation and, in the central part of Medina County, by faulting. A silty marl, west of Seco Creek, is believed to be the equivalent of the Corsicana marl.

Stephenson (1941, p. 23) mapped the Corsicana marl in eastern Medina County and described the fauna at several localities. The fauna can be distinguished from those of the superjacent Escondido by its larger number of species and individuals. The following species were identified by Stephenson in 1951 in the Corsicana marl cropping out along the Medina canal, 2.5 miles northwest of Rio Medina: Lima acutilineata texana Stephenson, Exogyra costata Say, Gryphaea mutalibis Morton, Plicatula mullicaensis Weller, Trigonia castrovillensis Stephenson, Crenella serica Conrad, Lima ? sayrei Stephenson, Hemiaster bexari Clark, Cardium (Granocardium) tippanum (Conrad), Pecten (Neithea) bexarensis Stephenson, Baculites sp., Indonearca sp., Crassatella sp.

The strata of the Corsicana that crop out north of D'Hanis suggest a deposition nearer to shore than the Corsicana marl near Castroville. A section measured from the bed of Seco Creek to the adjacent north-facing bluff shows calcareous, silty marl and thin-bedded shale unconformably overlying the Anacacho limestone. The following species, which are found in the Corsicana marl near Castroville, have been observed in the outcrops of the Corsicana in the Seco Creek section: Crenella serica Conrad, Trigonia castrovillensis Stephenson, Bellifusus sp., Pecten sp.

Brown (1952, p. 14) found a large foraminiferal fauna of Corsicana age in the lower strata of the Navarro group of the Seco Creek area.

Beds of shale are intercalated in the Corsicana marl near D'Hanis. The shale is a brackish-water deposit suggestive of the Olmos formation of the Eagle Pass area. It is possible that the Corsicana passes laterally into the coal-bearing Olmos formation, as both formations occur in the same stratigraphic position - that is, they are underlain by equivalents of the Taylor marl and overlain by the Escondido formation.

The electrical properties of the Corsicana marl in well I-6-94 are shown in figure 8. The Corsicana is a relatively dense arenaceous clay and marl which is not water bearing. No wells are known to produce water from the Corsicana marl in Medina County.

Escondido formation.- The highest formation of the Navarro group in Medina County, the Escondido, is exposed at the surface in a broad east-west belt in the central part of the county. The thickness of the formation ranges from about 550 feet in the southwestern part of the county to 900 feet in the southeastern part.

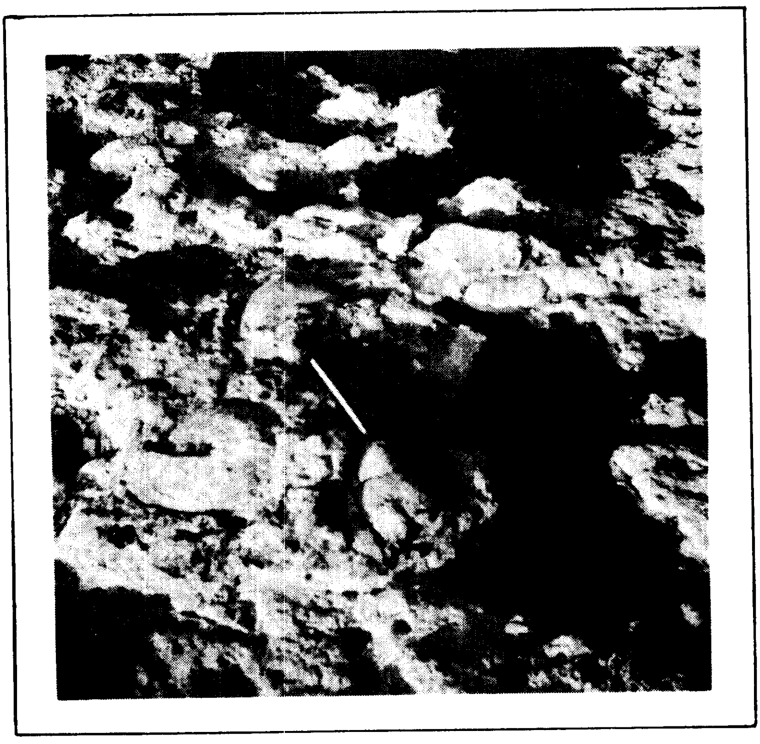
According to Stephenson (1941, p. 23), an unconformity separates the Corsicana marl from the overlying Escondido formation. Although the two formations are separated by a sharp change in lithology, the only evidence of an unconformity observed is the presence of a phosphatic bed, one-third of an inch thick. This contact is 2 feet above a bed of Gryphaea mutabilis Morton in the Corsicana marl and is 0.4 mile west of Medina River and 5.6 miles north of Castroville.

A major unconformity separates the Escondido from the overlying Kincaid formation (Stephenson, 1915, p. 159). There are no notable irregularities in the upper surface of the Escondido formation, but erosion is indicated by the absence of several beds. A thin layer of sandstone-pebble conglomerate marks the contact of the formations.

A conspicuous fossil zone in the upper part of the Escondido formation occurs approximately 12 feet below the base of the Kincaid formation. At one locality, Rock Crossing on Hondo Creek, this zone consists of 15 feet of very fossiliferous siltstone and hard arenaceous limestone (pl. 10-A). The limestone bed contains numerous fossils of Sphenodiscus pleurisepta (Conrad), Ostrea sp., and gastropods. The upper surface of the Sphenodiscus bed is shown in plate 10-B.

In the western part of Medina County, the Escondido consists of flaggy gray calcareous to argillaceous fine-grained sandstone, thin-bedded buff siltstone, gray to bluish-gray shale, and layers or lenses of sandy marl and limestone. The limestone beds consist of conglomerates of fossil shells cemented with arenaceous limestone.

A. Limestone bed in upper part of the Escondido formation at Rock Crossing of Hondo Creek. The brush-covered bluff above the limestone bed is formed by the Kincaid formation.



B. *Sphenodiscus pleurisepta* (Conrad) horizon at upper surface of limestone bed shown in plate 10A.

The following section was measured on the west side of the D'Hanis Brick and Tile Co.'s clay pit, 1.1 miles northwest of D'Hanis.

Escondido formation	Thickness (feet)
Siltstone, yellow, ferruginous, soft, thin bedded -----------	1.1
Limestone, silty, yellowish-brown, dense, thin- to irregularly bedded, contains sharks teeth, *Sphenodiscus* sp., and pelecypod casts ----------------------------------	0.5
Shale, silty, light gray, thin bedded ----------------------	0.9
Sandstone, hard, fine-grained, thin bedded, reddish-yellow, ferruginous --	1.6
Siltstone, yellowish-brown, slightly ferruginous, soft ------	5.0
Shale, silty, yellowish-brown, ferruginous, with selenite ---	6.7
Siltstone, massive bedded, slightly ferruginous, with fossil ripple marks and burrows ---------------------------------	1.2
Shale, silty, yellowish-brown, ferruginous, contains sharks teeth and *Donax* ---	2.8
Shale, silty, bluish-gray, thin bedded, slightly indurated --	9.0
Shale, silty, massive-bedded, yellowish-brown with selenite -	11.2
Siltstone, light gray, ferruginous, thin bedded -------------	1.6
Shale, bluish-gray, massive bedded, silty, indurated --------	15.0
Total --	56.6

A lithologic and paleontologic change takes place in the Escondido between the eastern and western parts of Medina County. The formation becomes increasingly arenaceous to the west, whereas the shale and limestone increase in thickness to the east.

The Escondido is equivalent to the Kemp clay in northeastern Bexar County. A gradual lithologic change toward the west merges the two formations. Stephenson (1941, p. 27) has arbitrarily separated the formations in western Bexar County. Compared with the Kemp, the Escondido is a more strongly lithified shaly clay, increasingly arenaceous to the west, and contains prominent interbedded strata of dense calcareous sandstone. The lateral change of facies is reflected also in the fauna. The Escondido contains fossils not known to the Kemp and lacks some of the fossils common in the Kemp.

The electrical properties of the Escondido formation as illustrated by the partial electric log of well I-6-94 are shown in figure 8. The formation in this area consists of thin beds of fine-grained sandstone and thickly to massively bedded clay and shale.

The water-bearing sands and shales of the Escondido formation generally are not continuous or very thick. The thickest and most persistent sands are in the western part of the county, the thinnest in the east. The most important supplies of water in the formation are found in the western part of the county. The sandstones are interbedded with clay and shale and the water is under artesian pressure except at the outcrop.

The waters in the Escondido formation have a considerable range in chemical composition. The water obtained from wells in the outcrops of the lower sandy beds is generally of good quality and suitable for domestic use. Water from the upper beds is generally of poorer quality, containing excessive amounts of chloride and sulfate, and some wells produce small amounts of asphalt.

Tertiary system

The close of the Cretaceous period was marked by elevation of the land and retreat of the sea throughout central Texas. Early Tertiary time began with a new transgression of the sea. A prominent unconformity and break in the megafuanal succession marks the hiatus between the two periods of deposition.

Paleocene series

Midway group

The Midway group includes the Kincaid and Wills Point formations. Gardner (1933, p. 77) stated that there were no recognizable outcrops of the Wills Point in Medina County.

Kincaid formation.- The Kincaid formation overlies the Escondido formation unconformably. The base of the Kincaid is marked by phosphate nodules, casts of shells, shark's teeth, and reworked sands and pebbles of the Escondido formation. In Medina County, the exposed thickness of the Kincaid ranges from 30 to 75 feet. Logs of wells in the southern part of the county indicate that the formation thickens in the direction of dip.

Outcrops in eastern Medina County are of a glauconitic, sandy greenish-gray shale overlain by an impure glauconitic, sandy yellowish-gray limestone containing pyrite nodules. *Venericardia bulla* Dall, *Venericardia crenaea* Gardner, *Cucullaea macrodonta* Whitfield, and *Membranipora* are the most characteristic fossils of the facies.

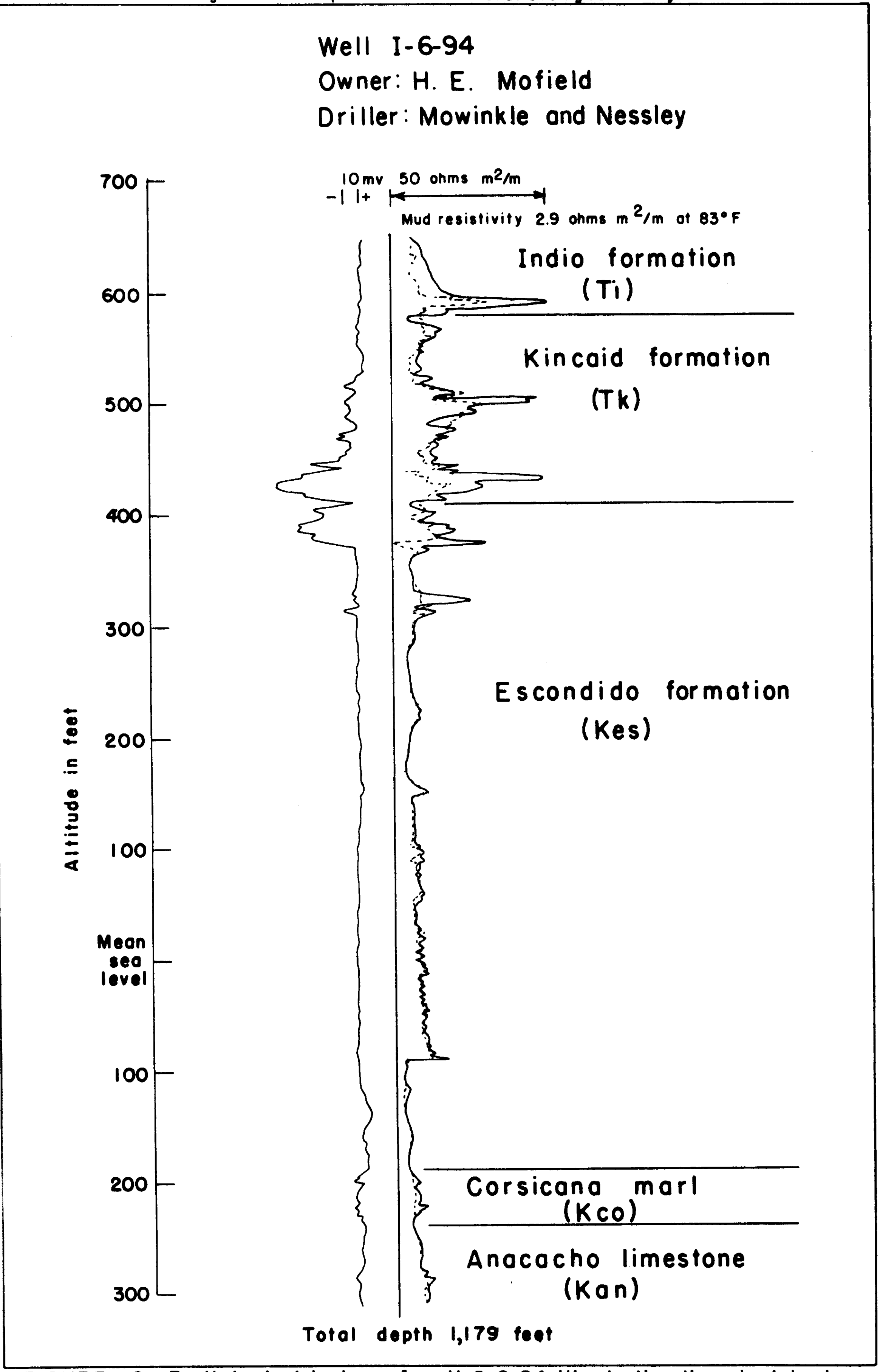


FIGURE 8.- Partial electric log of well I-6-94 illustrating the electrical properties of the Escondido formation and the Corsicana marl.

A slightly different facies is exposed in the western part of the county. Here it is an impure gray arenaceous limestone, locally containing small balls of clay, and a yellowish-gray glauconitic, calcareous, sandy clay. Concretions consisting of dense sandy limestone and brown crystalline calcite are common. Fossil shells are often found in the concretions. The most common fossils found in the area are Hercoglossa vaughani Gardner, Venericardia crenaea Gardner, and Cucullaea texana Gardner. On the basis of the facies change, Liddle (1918, p. 74-75) divided the Midway group into the Elstone and Squirrel Creek formations. Gardner (1933, p. 76) stated that both facies belong in the Kincaid formation.

The electrical properties of the Kincaid formation are illustrated in the partial electric log of well I-9-27 shown in figure 9.

No wells are known that produce water from the Kincaid formation in Medina County.

Eocene series

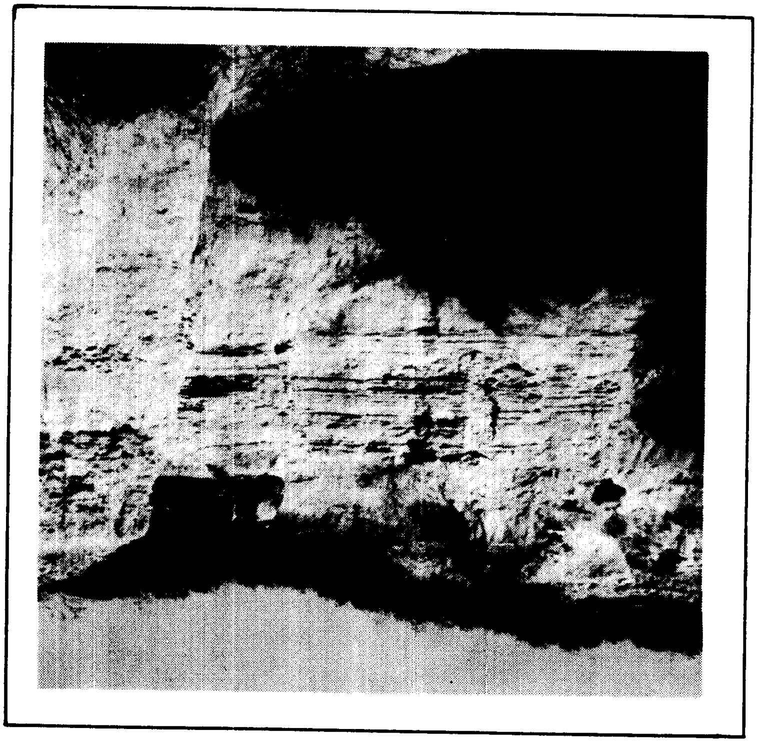
Wilcox group

The Wilcox group overlies the Midway group and is overlain disconformably by the Claiborne group. Inasmuch as the Wills Point formation is missing from the outcrop of the Midway group, the basal Wilcox rests disconformably on the Kincaid formation. The Wilcox group is represented by the Indio formation in Medina County.

Indio formation.- At the present state of knowledge, the various divisions of the Wilcox group recognized elsewhere cannot be distinguished in this area (Stenzel, 1951, p. 2625). Trowbridge (1923, p. 90) named the sandstones and shales overlying the Midway in Maverick and Dimmit Counties, Tex., the Indio formation. This name was used by Liddle (1921, p. 75) and Sayre (1936, p. 60) as a formation of Wilcox age overlying the Midway group and underlying the Carrizo sand. The basal strata of the Indio consist of thin-bedded to laminar varicolored fine-grained sandstones, carbonaceous laminar shales, and thin-bedded to laminar siltstones. Thin to laminar beds of silt, sand, and clay are exposed in a quarry 10.8 miles south of D'Hanis near East Squirrel Creek and are shown in plate 11. The Indio formation ranges in thickness from 440 feet to 710 feet in Medina County.

The Indio formation consists chiefly of thin-bedded argillaceous sandstone and laminated arenaceous shale. Locally it contains thick beds of clay and sandstone and thinner beds of lignite and calcareous sandstone. Many of the shale and sandstone beds are lenticular and some of the sandstone is crossbedded.

Calcareous and arenaceous concretions are common in the middle part of the Indio formation (pl. 12). A gray silty laminated clay, approximately 90 feet above the top of the Kincaid formation, contains dense gray calcareous sandstone lenses 3 to 15 feet long and a few inches to 5 feet thick. The lenses contain pyrite replacements of whole and fragmental parts of leaves, and small clay inclusions. The following species were collected from a sandstone lens exposed in a road cut on the Dunlay-Biry highway, 1.5 miles north of Biry, and have been identified by R. W. Brown of the U. S. Geological Survey: Laurus wardiana Knowlton,



Thin- to laminar-bedded silt, sand, and clay of the Indio formation in quarry 10.8 miles south of D'Hanis.

PLATE 12

Lenses of sandstone in the lower part of the Indio formation, showing concretionary structure.

Dinnamomum postnewberryi Berry, Terminalia hilgardiana (Lesquereux) Berry, and fragments of other dicotyledonous leaves.

The following section of the lower part of the Indio formation was measured in a west-facing bluff east of East Squirrel Creek, about 10 miles south of D'Hanis.

Indio formation	Thickness (feet)
Siltstone, dark yellow, thin bedded, contains thin layers of limonite --	5.1
Siltsone, light gray, laminar bedded, contains limonite nodules --	2.1
Shale, light bluish-gray, laminar bedded, contains lenses of light gray sandstone 0.5 to 3.0 feet thick ---------------	5.6
Sandstone, light gray, irregular to massive bedded. Contains round limonite concretions 0.03 to 0.2 foot in diameter; lenses of dense blue gray, calcareous sandstone 5 to 7 feet in diameter, occur in the softer sandstone -----------	10.4
Shale, dark bluish-gray, laminar bedded --------------------	0.3
Sandstone, cross-bedded, yellow, white, and blue ------------	2.8
Unconformity, angular	
Siltstone, light gray, laminar bedded with alternating layers of yellow sandstone ------------------------------	4.3
Sandstone, yellow with alternating laminar bedded layers of light gray siltstone ------------------------------------	2.2
Sandstone, white --	0.7
Shale, silty, light gray and yellow, laminar bedded ---------	0.6
Shale, dark blue to dark gray, bentonitic, contains carbonaceous seams --	0.6
Siltstone, light gray, laminar bedded ----------------------	0.5
Sandstone, light orange, thick bedded ledge former ----------	1.4
Sandstone, light yellow, thin bedded -----------------------	0.5
Sandstone, light orange, laminar bedded --------------------	0.3
Sandstone, light orange, argillaceous ----------------------	0.15
Sandstone, light orange, laminar bedded, argillaceous -------	0.4

(Continued on next page)

Indio formation--continued	Thickness (feet)
Sandstone, yellowish-orange, thick bedded, medium grained, very dense, contains hollow iron nodules	1.5
Sandstone, yellowish-orange, bedding 1/2 to 2 inches thick, dense	0.8
Sandstone, fine grained, light gray, dense	0.7
Sandstone, thin bedded, alternating yellow and white	0.9
Sandstone, white, soft	0.6
Concealed to top of Kincaid formation exposed in East Squirrel Creek	24.5
Total	66.45

The upper part of the Indio formation consists of a heterogeneous series of thin-bedded sandstones, laminar-bedded silty clays, thin beds and lenses of lignite, and a few limonite concretions. The proportion of sand increases toward the top of the formation. Drillers identify this section by the presence of lignite and pyrite in the well cuttings and refer to it as the "salt and pepper" formation.

The electrical properties of the Indio formation are illustrated in the partial electric log of well I-9-27 shown in figure 9. Drillers' logs of wells in this area indicate that the Indio consists of fine-grained sandstone, siltstone, shale, and lignite. The water is highly mineralized.

Lignite was mined in 1900 from several surface exposures in the upper part of the Indio formation. These mines have been closed for many years and their workings filled with debris. The following section was measured by Dumble (1903, p. 925) in the Riley mine, $2\frac{1}{4}$ miles west of Lytle.

	Thickness (feet)
Clay, yellow, laminated	15
Sand, gray, micaceous, medium grained, laminated	20
Sand, yellow, micaceous, with ferruginous streaks	20
Sand, yellowish-gray, laminated, micaceous with streaks of black clay or lignite	30
Lignite	5 - 8
Clay, gray	10

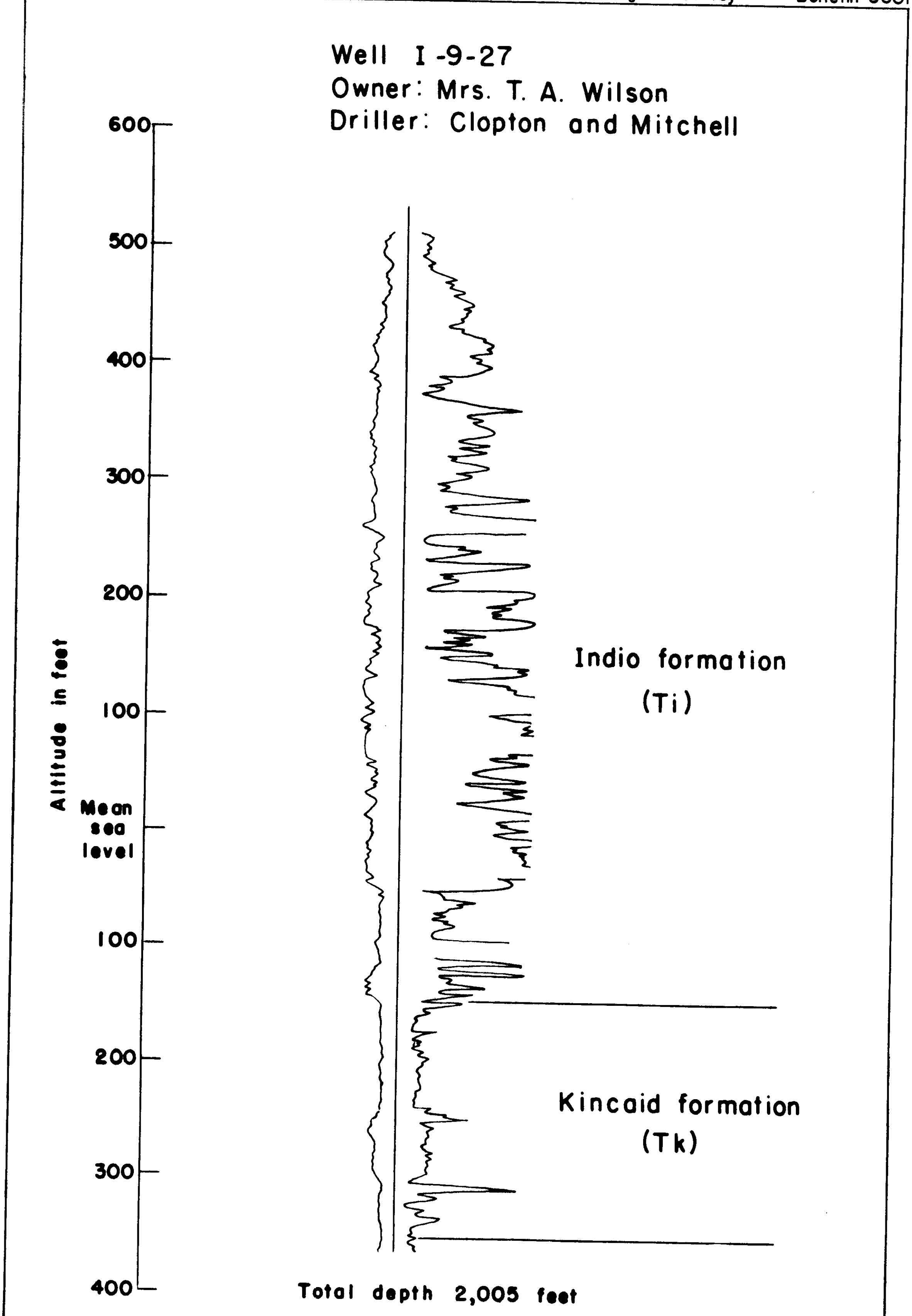


FIGURE 9.- Partial electric log of well I-9-27 illustrating the electrical properties of the Indio and Kincaid formations.

Ground water obtained from the Indio formation is variable in quality and quantity. Wells yield 2 to 500 gallons a minute (table 9) of water ranging in dissolved-solids content from 348 to 11,200 parts per million (table 12).

The varied lithology and lenticular shape of many of the sand beds make it difficult to determine the lateral extent of any given aquifer in the Indio formation. In general, however, wells penetrating the upper section of the formation yield more water than those lower in the section.

Claiborne group

Carrizo sand.- The Carrizo sand crops out in the southern part of Medina County in a belt extending from the Atascosa County line southwest to the Frio County line (pl. 1). The formation lies disconformably upon the underlying Indio formation and is 230 to 330 feet thick.

The Carrizo sand consists chiefly of friable ligh-gray to dark-red medium-grained quartz sandstone. Clay or shale occur near the middle of the formation as thin, lenticular beds or as lumps 2 to 3 inches in diameter. Locally the formation is limonitic and contains several thin beds of ferruginous sandstone. In many outcrops, the formation is massive, and crossbedding is highly developed in some areas. The basal beds of the formation are thin to thick bedded. All ferruginous colors of the Carrizo are due to weathering; the sand is light gray underground.

The sand is, in general, an aggregate of subangular grains of quartz with little or no mica, secondary gypsum, or calcite. Lonsdale (1935, p. 23) gives the petrographic analyses of 13 samples of the Carrizo sand in Atascosa and Frio Counties. The results of the analyses show that the greatest percentage of sand grains are between 0.295 and 0.147 millimeter in diameter. The grains ranged from angular to rounded, the greatest number being subangular to subrounded. The Carrizo sand is considered to be nonmarine, of estuarine, and deltaic origin, and to be remarkably uniform. The good sorting and small amount of cementation of the sand indicate a high porosity.

The electrical properties of the Carrizo sand, as illustrated in the partial electric log of well J-7-22, are shown in figure 10. The sand is porous and permeable and contains fresh water.

The Carrizo sand supplies water to shallow wells in its outcrop area and to deeper wells southeast of the outcrop. These wells yield abundant supplies of water for domestic and stock use. The water is essentially under water-table conditions in the outcrop area because the upper surface of the saturated part of the formation is in permeable sand. The formation dips south or southeast and the depth of wells increases with the distance from the outcrop. Southeast of the outcrop area the water is under artesian conditions.

Wells in the outcrop area of the Carrizo sand yield adequate supplies of water for municipal use and irrigation. Devine and Natalia obtain their public water supply from the lower section of the Carrizo sand. Ten wells have been

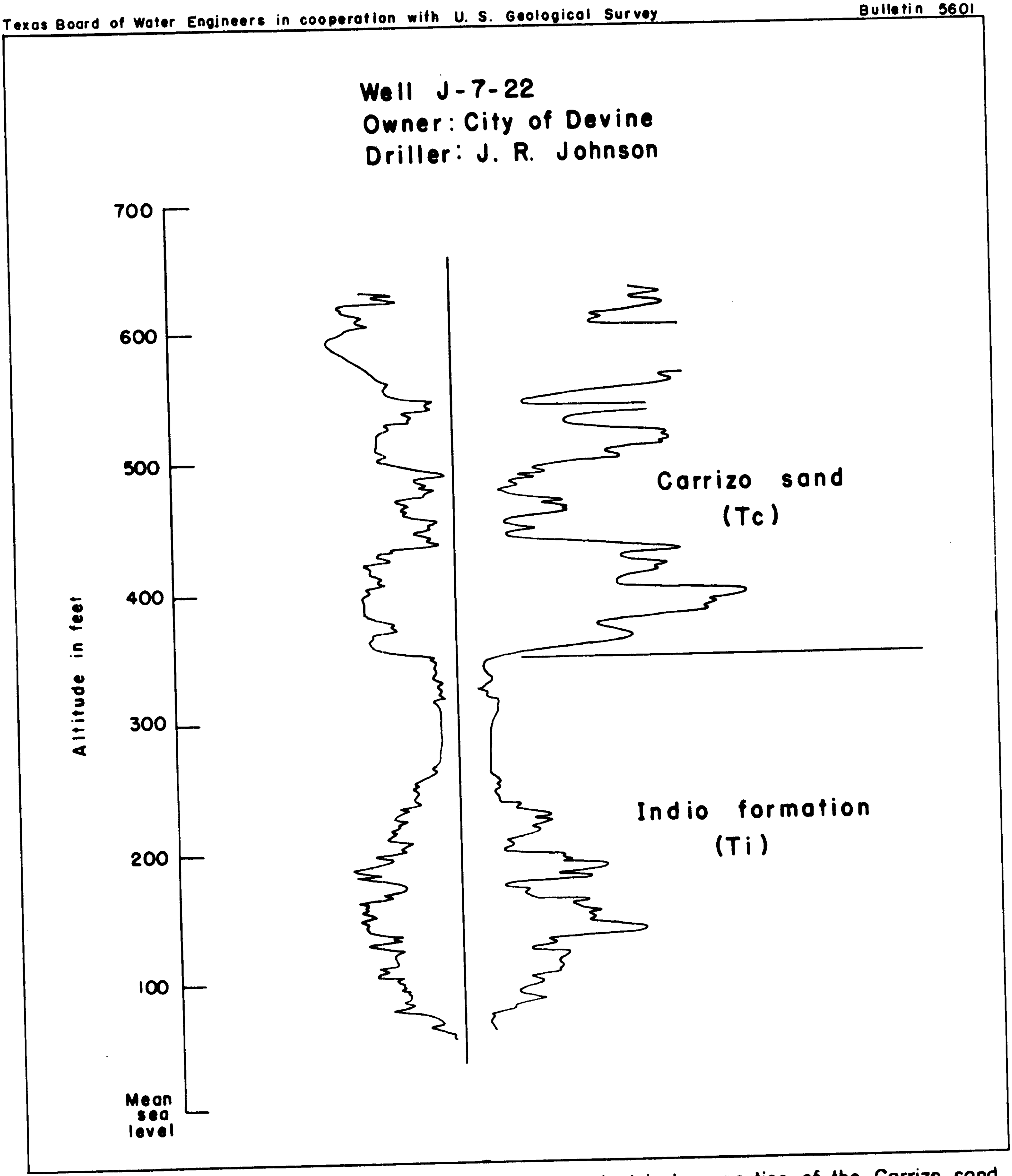


FIGURE 10.-Electric log of well J-7-22 illustrating the electrical properties of the Carrizo sand.

drilled and equipped with pumping plants for irrigation in the area of outcrop. Several of these wells obtain water from both the Indio and the Carrizo. The thinning of the Carrizo at the northern edge of the outcrop restricts the amount of storage and limits the use of the water there.

Water from wells in the outcrop of the Carrizo sand is comparatively uniform in its chemical character (table 12). The water is of very good quality, having less than 500 parts per million of dissolved solids.

Mount Selman formation.- The Mount Selman formation crops out in a small area in southeastern Medina County. The lower part of the formation was named the Bigford by Trowbridge (1923, p. 75) and treated as a formation of the Wilcox group. Plummer (1932, p. 619-620) regarded the Bigford as a part of the Mount Selman formation of the Claiborne group. The Bigford differs lithologically, but merges laterally into the Reklaw member of the Mount Selman formation northeast of Medina County.

The basal member of the Mount Selman consists of brown to buff clay, thin sandstone, and very thin limestone beds. Thin lenses of lignite and calcareous concretions also are found. An abundance of plant remains, leaves, and stems have been recovered along the escarpment formed by the Bigford member in northern Frio County (Lonsdale 1935, p. 29). The Mount Selman formation is about 100 feet thick in Medina County.

The Mount Selman formation occurs in too small an area in Medina County to store an appreciable amount of water. No wells are known to obtain water from the Mount Selman in this county.

Pliocene(?) series

Uvalde gravel

The Uvalde gravel is the oldest and highest terrace deposit in Medina County and is found in remnants capping hills and forming stream divides. The gravel consists of coarse, rounded flint pebbles and boulders and some limestone pebbles. Reworked fossils in the gravel indicate that it was derived from the Edwards limestone, probably from the Edwards Plateau. The gravel is cemented by caliche. The thickness of the Uvalde ranges from a thin film over the surface to a layer nearly 20 feet thick. The gravel and caliche in these deposits are mined for road-surfacing material. The formation is generally too thin to hold much water and its topographic position on hilltops permits most of the water to drain out readily.

Quaternary system

Pleistocene series

Leona formation

The Leona formation consists of deposits forming broad terraces in the valleys of the present streams. These terraces are topographically lower than those formed by the Uvalde gravel.

The Leona is composed of lenticular beds of sand, gravel, silt, and clay. The pebbles and cobbles of the gravel are predominantly limestone, and some flint. Coarser gravel is found near the base of the formation, the proportion of silt increasing toward the top.

The terraces extend to distances ranging from several hundred feet to 3 or 4 miles on one or both sides of the major strems. As a rule, the formation is thickest near the present stream channels or the older abandoned meander channels. The terrace deposits range in thickness from a mere film over the underlying formations to a layer 70 or 80 feet thick.

The outcrop area of the Leona forms broad plains in central and eastern Medina County, and most of the towns in the county are situated on the outcrop. Rio Medina, Quihi, and D'Hanis obtain their water supplies from the formation. Private water supplies in Hondo, Castroville, and Lacoste are obtained from the gravel, although the public supplies of those places are obtained from wells tapping the Edwards limestone.

A number of small springs occur in the principal stream valleys where the streams have cut below the water table in the Leona formation. Among the typical springs fed by ground water from the Leona are nos. I-5-28 in Seco Creek; I-3-82 and I-6-74 in Hondo Creek; I-3-103, I-3-104, and I-3-125 in Verde Creek; and J-1-36 in San Geronimo Creek.

Recharge of the Leona formation is derived from rainfall and storm-water runoff on the surface of the formation. The piezometric surfaces of the underlying formations are below the base of the Leona and those formations do not contribute to its recharge. Conversely, the Leona formation contributes to the recharge of the underlying permeable formations.

As a rule, the Leona formation contains little water where the underlying formations are permeable, but contains large supplies of water where it overlies less permeable strata, especially where it is thick. The thickest deposits of the Leona are found where the old stream channels have cut deep valleys in the least resistant of the underlying formations. Each stream-terrace deposit is a separate ground-water reservoir.

In most areas of outcrop in the county, the Leona formation furnishes an adequate supply of water for domestic and stock uses. In several areas, notably along Hondo Creek south of U. S. Highway 90, the Leona has the thickness and lateral extent necessary to store a large supply of water. Wells I-6-20, I-6-21, I-6-76, and I-6-77 have been withdrawing irrigation water from this reservoir.

Recent series

Alluvium

The stream valleys of Medina County contain Recent flood-plain deposits of silt and gravel. Several of the larger stream valleys have small terrace deposits which have been formed since Leona time. The deposits are restricted to narrow areas along the streams. A number of wells adjacent to the Medina River obtain their water from the Recent sediments. The water levels in the wells have been observed to fluctuate with the river level.

Igneous rocks

Several small exposures of igneous rocks have been found in Medina County. A larger number of similar igneous masses occur in Uvalde County and have been described by Vaughan (1900, p. 2-3), Lonsdale (1927, p. 15-23), and Sayre (1936, p. 27). The igneous rocks occur in isolated masses in rough alinement with the trend of faulting in the Balcones system.

The igneous rocks in Medina County are in the form of plugs and dikes that crosscut, and form steep contacts with, the adjacent sedimentary rocks. A small plug of olivinebasalt is on the Mumme ranch, 13.7 miles north of Hondo (pl. 1). This plug is about 300 feet in diameter at the surface and is surrounded by the Edwards limestone. The limestone near the contact has been altered to a varicolored marble containing veins of serpentine. Another small mass of olivinebasalt is found along Cow Creek, 1½ miles northeast of West Verde Creek. The exposure is in the form of an elongated plug or dike, striking N. 55° E. A narrow zone of serpentine-bearing marl marks the contact between the dike and the surrounding Glen Rose limestone. A plug of nephielitebasalt 3.4 miles south of D'Hanis, east of the D'Hanis-Yancey road, probably intrudes the Escondido formation, but the alluvial materials of the Leona formation obscure the contacts.

The youngest formation intruded by igneous rocks in this area is the Escondido. Lonsdale (1927, p. 44) believed that all the basalts of the Balcones fault region are related in origin and are probably of early Tertiary age. Sayre (1936, p. 27-32) indicates that some igneous masses came into existence in the early part of the Late Cretaceous epoch.

Metamorphic rocks

Serpentine has been recorded in the logs of several wells in Medina County. Leith and Mead (1915, p. 22) have stated that serpentine is an alteration product of basic igneous rocks. The serpentine found in Medina County may be an intermediate product in the hydration of basaltic intrusives. The bodies of serpentine are closely associated with the faulting. The serpentine is reported to range in composition from a relatively pure, very fine-grained dense dark-green massive rock to an impure, dense light-green fragmental rock, interbedded with limestone. In a number of wells near Chacon Lake, serpentine was encountered in the upper part of the Austin chalk and lower part of the Anacacho limestone (pl. 2). Serpentine was reported in wells J-4-65 and J-4-71 from 1,385 to 1,771 feet and from 1,441 to 1,580 feet below the surface, respectively. The serpentine mass near Chacon Lake is bounded on the north by the Pearson fault. Wells drilled north of the fault failed to penetrate any serpentine. Another large body of serpentine is found north of the Dunlay fault. Wells I-6-27 and I-6-30 (see pl. 2) encountered serpentine at 476 and 616 feet, respectively, in the Anacacho limestone and upper part of the Austin chalk.

No wells are known to produce water from metamorphic rocks in Medina County.

STRUCTURE

The structure of the rocks of Medina County affects the occurrence and movement of ground water. The principal structural features are the faults and folds forming the Balcones fault zone. The surface traces of the faults are shown on plate 1. The subsurface position of the faults and folds is indicated by contours drawn on the base of the Grayson shale (Del Rio clay) (pl. 3). Cross sections A-A' and B-B', drawn transverse to the general direction of faulting, are shown in plate 2.

FAULTING

Balcones fault zone

The Balcones fault zone separates the Gulf Coastal Plain from the Edwards Plateau (see fig. 1). This zone, as a structural feature, is traceable from Del Rio northeast to Waco. In many places, a prominent escarpment marks the location of the trace of the main fault. In some places, prominent folds are associated with the fault zone.

The displacement on individual faults in Medina County ranges from a few inches to more than 700 feet and the length, from a fraction of a mile to 35 miles. The displacement on most of the faults is greatest near the middle of their length, diminishing toward the ends. Some of the faults die out in monoclinal flexures and are intersected by cross faults or branch faults.

In general, the faults of Medina County have nearly straight traces. In areas of considerable relief, this indicates that the fault plane may be nearly vertical. Measurements on many of the faults show that the hade ranges from 12° to 28° from the vertical. Slickensides, fault breccia, and gouge are evident in several exposures of the fault surfaces (pl. 13).

Anacacho limestone at Haby Crossing fault, showing slickensides and a hade of 26° from vertical. In Verde Creek, 4.8 miles northeast of Hondo.

Photograph by J. W. Lang

Faulting in northern Medina County

The most extensive fault of the Balcones zone, the Haby Crossing fault, enters the eastern part of the county northeast of Cliff, passes through the Haby Crossing on the Medina River, and continues southwestward past Kings Waterhole on Hondo Creek to Seco Creek north of D'Hanis. The displacement along the fault is greatest east of Haby Crossing where the upper part of the Austin chalk is in contact with the lower part of the Edwards limestone, indicating a stratigraphic displacement of 600 to 800 feet. The more resistant Edwards limestone on the upthrown side of the fault forms a very prominent escarpment. The displacement of the fault decreases to the west. Several auxiliary faults branch from the major fault in the central part of the county.

The throw of the individual faults decreases west of the Medina River, and escarpments are no longer prominent in the topography. A system of parallel faults in central Medina County has a total displacement equal to the displacement of the larger faults to the east. The faulting in this area is complex and consists of cross faults, branch faults, hinge faults, and scissors faults. The numerous faults have formed wedges or blocks of rocks which are generally downthrown to the south in the form of stairsteps (see pl. 2). Horsts, upthrown blocks between downthrown blocks, are found north of the Vandenburg School, Seco Creek, and Ina Field faults, and south of the Fort Lincoln fault. Grabens, downthrown blocks between upthrown blocks, are found north of the Seco Creek and Fort Lincoln faults and south of the Medina Lake and Dunlay faults.

The complicated faulting of central Medina County is partly dissipated to the west, many of the faults dying out and passing into small monoclinal folds. A relatively narrow zone of highly complicated faulting is present in the northwestern part of the county. The Woodard Cave fault has a displacement of more than 200 feet, and a parallel fault, 2 miles south, has a displacement of 300 feet. A wedge or graben of the Austin chalk is present where the latter fault crosses Seco Creek.

Faulting in southern Medina County

The Pearson and Biry faults are the southernmost major faults in Medina County. They are probably contemporaneous and are closely related to each other. The Pearson fault crosses Francisco Perez Creek east of Biry and continues northeastward through Pearson to the Bexar County line. The displacement of the fault increases to the northeast. The maximum displacement is about 400 feet at the Bexar County line. The Biry fault, extending southwest of Biry, has an average displacement of less than 100 feet. This fault is probably an extension of the Pearson fault, which is possibly associated with the San Antonio structure described by Sellards (1919, p. 82 - 86). The Adams gas field, southwest of Biry, and the Chacon Lake oil field, south of Pearson, are both closely related to the faults (pl. 1).

The Pearson fault appears to act as a barrier to the movement of ground water in the Edwards limestone. North of the fault, an adequate supply of water of good chemical quality may be obtained from wells. Oil tests drilled into the Edwards limestone south of the fault failed to reveal water of good quality. Most wells south of the fault system obtain their principal water supply from the Indio formation.

Cause of faulting

The faults are more or less parallel and are normal tension faults resulting from gravitational settling. They are generally regarded as having been caused by the gradual sinking of the Coastal Plain with reference to the Llano uplift (see fig. 1). Stephenson (1928, p. 899) has pointed out, however, the uplift may have occurred as well as sinking. The age of the faulting has not been accurately determined, but it is believed that faulting may have occurred at intervals from Early Cretaceous to Recent geologic time. Bryan (1933, p. 439-442; 1936, p. 1357) states that there have been three periods of movement along the Balcones fault zone at Waco, Tex., the first relatively early in Early Cretaceous time, the second during Georgetown time, and the third during Recent time. The youthful appearance of the escarpments in eastern Medina County and the relations of the stream channels to the faults indicate a recent period of movement. Evidence of two directions of movement along a fault plane may be observed where the Seco Creek fault crosses Hondo Creek. Beds of the Eagle Ford shale on the downthrown side of a normal fault dip toward the fault, indicating a secondary movement or readjustment along the fault plane.

FOLDING

Culebra anticline

A pronounced structural feature, the Culebra anticline (Sellards 1919, p. 83-84), extends from north-central Bexar County southwestward into Medina County. It is bounded on the northwest by the Cliff fault and on the southeast by the Castroville fault. The principal structure is a broad anticlinal fold, 7 to 9 miles wide, plunging to the southwest. The fold is asymmetrical, the steeper flank being on the southeast side.

Topographically, the anticline consists of a central hill of Austin chalk surrounded successively by bands of the Anacacho limestone, Corsicana marl, and Escondido formation. The Medina River flows around the nose or plunging end of the anticline, and San Geronimo Creek flows along the northwest flank. Cross section B-B' (pl. 2), which crosses the Culebra anticline, was prepared from data selected from well logs and from surface geology.

Other folds

A large monoclinal fold near Devine in southeastern Medina County has an axis that trends northeast, parallel to the Balcones faulting. This monoclinal fold is possibly associated with the Alta Vista structure, named by Sellards (1919, p. 85-86) for a structural trend in southern Bexar County. The Bear Creek oil field in Medina County, south of the fold, is similar in structure to the Somerset field in Atascosa County and the Alta Vista field in Bexar County.

OCCURRENCE AND MOVEMENT OF GROUND WATER

The fundamental principles governing the occurrence and movement of ground water have been discussed in detail by Meinzer (1923a, p. 2-192; 1923b, p. 68; 1942, p. 385-497), Tolman (1937, p. 96-380), Wenzel (1942), and others. The section that follows is limited to the principles that are essential in understanding the hydrology of the ground water.

Ground water in Medina County is derived chiefly from water that falls as rain and snow. A part of the precipitation runs off in streams, a part is returned to the atmosphere by evaporation and by transpiration of trees and other plants, and a part enters the soil. Of the part that enters the soil, a small portion sinks into the zone of saturation, in which all the openings of the rocks are filled with water.

In most places, ground water is slowly but steadily moving under the influence of gravity from areas of intake to areas of discharge. In the more permeable rocks, such as coarse sand and gravel and cavernous limestone, the water moves with comparative freedom, although the movement generally is very slow compared to the flow of a stream. Such rocks are capable of yielding abundant supplies of water to wells. In less permeable rocks, such as fine sand, silt, and shale or clay, molecular attraction retards the movement of the water so that the water may not move toward a well as fast as it is withdrawn by even a small pump.

Ground water occurs under both water-table and artesian conditions in Medina County. Under water-table conditions, the water is unconfined and does not rise in wells above the level at which it is encountered. This level, which is known as the water table, is the upper surface of the zone of saturation. Water-table conditions usually are found to occur in the outcrop of permeable water-bearing beds. Under artesian conditions, the water is confined by an overlying relatively impermeable bed and the water will rise in wells above the level at which it is encountered.

The water table is not a level surface, but usually slopes from areas of ground-water intake or recharge toward areas of ground-water discharge. Where the land surface is lower than the water table in adjacent areas, some of the ground water will emerge as springs. This condition occurs in several places along Hondo Creek where the stream channel has cut below the level of the water table in the Leona formation, and ground water discharges into the creek.

Artesian conditions are established were beds of permeable rock dip below the ground between less permeable strata. Water in the outcrop area provides a hydraulic head for the water moving downdip. If there were no loss in head because of friction, a well drilled into the confined aquifer would find the head of the water equivalent to the height of a column of water having the same altitude as the water in the outcrop area. The artesian aquifer acts as a closed system, and any change in pressure eventually affects the aquifer as a whole. If there is insufficient recharge from rainfall or streamflow in the outcrop area, the water table will decline and the pressure in the artesian system will decline also. Correspondingly, any natural discharge such as springflow or artificial discharge such as pumping from wells will cause a decrease in pressure throughout the aquifer. For these reasons the pressure in an artesian aquifer may decrease and the water levels in wells may decline, but the aquifer will still be full of water.

The withdrawal of ground water from either a water-table or an artesian aquifer causes a decline in water level at the well, and a hydraulic gradient is developed toward the well from all directions. The quantity of water moving toward the well is proportional to this gradient. For example, if a pumped well in permeable material will yield 100 gallons a minute when the water level is lowered 10 feet, it will yield about 200 gallons a minute when the water level is lowered 20 feet. This ratio between the drawdown and the yield of the well is called the specific capacity and is generally expressed as yield in gallons a minute per foot of drawdown. Drillers generally observe the drawdown as they county the number of bailers of water withdrawn in a given length of time. This is a quick and convenient guide for the selection of a pump. The ratio holds within certain limits and is affected by factors other than permeability, such as the construction and development of the well.

A cone of depression gradually spreads out in all directions from a center of ground-water discharge or pumping. This cone deepens and widens at a rate decreasing with time. The ultimate limits of the cone of depression are the physical boundaries of the aquifer or areas of rejected recharge or discharge (Theis, 1938, p. 889-902). When the pump is shut off, the water rises again in the well at a rate decreasing with time, and the cone of depression becomes shallower until it nearly vanishes. However, if a large amount of water is taken out of the aquifer, a measurable persistent lowering of the water level may result. This usually is not very serious, and, in an extensive aquifer, any excessive local decline may be avoided by proper spacing of wells.

MOVEMENT OF WATER IN AQUIFERS

The amount of water moving through an aquifer depends upon the porosity, permeability, and dimensions of the aquifer and the amount of recharge and opportunity for discharge. The topography of the surface of the outcrop, the climate, the type of soil, and the amount and kind of vegetation are important factors in determining the amount of recharge to the aquifer.

The porosity and permeability of a rock formation largely determine its capacity to take in, store, and transmit water. Porosity is the ratio of total pore space to total volume of a material, and permeability is its capacity to transmit water. The properties are not directly related. Clay and shale may have a high porosity, but, because the individual pore spaces are very small, the permeability is low. Sand and gravel may have less porosity than clay and shale, but the individual pores are large and interconnected, permitting a more rapid movement of water.

The permeability of most limestones depends upon the processes that take place after deposition. Although small openings may remain in the rocks after deposition. and consolidation, many limestones are essentially impermeable until solution along fractures enlarges them, in places to the size of channels and caverns. A part of the fracturing may take place during the compaction of the limestone, but the major disruption and fracturing occur as a result of faulting and folding. Much faulting has taken place in Medina County, and joints, faults, and other openings have provided the passages that were later enlarged and extended by solution.

A minor amount of solution may occur during and immediately after deposition, but the most important solution occurs after the limestone is elevated and exposed to solution by meteoric waters. It is generally recognized that carbon dioxide in solution in meteoric waters greatly increases their solvent action on limestones. Water acquires carbon dioxide while passing through the air and through soils containing decaying vegetable matter.

The solvent action of ground water on limestone is a continuing process of enlarging the existing solution channels. The average flow of Comal Springs in New Braunfels, over a period of about 20 years, has been 320 cubic feet per second (cfs). The dissolved solids in the water averaged about 285 parts per million. On this basis, George (1952, p. 37) estimated that an average of more than 200 tons of dissolved rock material is carried away daily by the water that issues from these springs.

Time is an important factor when considering solution of limestone. Pressure and temperature also affect the quantity of calcium carbonate that is dissolved by ground water. A change in these factors controlling solution may result in a redeposition of calcium carbonate in the same system of solution channels. Crystals of secondary calcite were recovered from the cuttings of well J-1-44 after the drill penetrated several void spaces at a depth of about 960 feet below the present water level. Travertine, a form of secondary calcite, accumulates along the edges of a subsurface stream in the Woodard Cave or sinkhole.

The solubility of limestone in water is an important factor when studying the hydrology of the limestone aquifers in Medina County. In the study of the silt, sand, and gravel aquifers of the county, the permeabilities are regarded as essentially stable, whereas the limestone aquifers, because of their solubility, are continually changing in porosity and permeability. The changing characteristics of the limestone reservoir may change the amount of recharge, discharge, and movement of water, and may affect the quality of water and its availability. In terms of historic time, however, changes in permeability and porosity caused by solution of the limestone probably would be insignificant.

NATURAL RECHARGE

The recharge or intake area of an aquifer is the outcrop of the aquifer itself, or of a hydraulically connected formation, capable of absorbing water and adding a part of it to the zone of saturation. An area of recharge may be only a narrow belt on the surface, but it may be supplied in part by streams which drain a much larger area. Several of the aquifers used in Medina County crop out in the county itself, and a large part of the county, therefore, is a recharge area that receives water by direct penetration of rainfall. The outcrops extend east and west beyond the borders of the county. The catchment area for the streams that cross the aquifers includes the drainage areas of Seco, Hondo, and Verde Creeks and the Medina River, which extend north of Medina County.

Travis Peak formation

The water of the Travis Peak formation is derived from precipitation over a large area north of Medina County. Water enters the sands of the formation in the outcrop area and travels downdip to Medina County. Water in the Travis Peak was encountered in wells I-1-15, I-2-67, and J-2-15.

Glen Rose limestone

Limestones and sandy marls of the Glen Rose crop out in northern Medina County and the surrounding counties of Uvalde, Real, Bandera, Kerr, and Kendall. Inasmuch as the outcrop covers only 84 square miles in northern Medina County, the principal recharge to the aquifer must be from rainfall in adjacent counties having larger surface exposures of permeable strata.

In Medina County, the limestone beds in the exposed upper part of the Glen Rose are overlain and underlain by marl and shale which retard vertical movement of water. The most permeable zones are found at the base of limestone beds where they are in contact with underlying beds of shale. The solutional openings in the limestone range from minute to cavernous and receive varying amounts of water. Beds of sandy marl and fossiliferous zones in the limestone are locally permeable. Numerous caves and springs are found in limestone in the outcrop area of the Glen Rose.

Edwards limestone

The surface exposure of the Edwards limestone forms a broad belt across northern Medina County. The approximately 200 square miles of outcrop in Medina County is an area of recharge. A large amount of water enters the limestone by direct penetration of rainfall on this area, and an even larger amount is derived from streams crossing the outcrop carrying runoff from the catchment area on the Edwards Plateau. The streams receive flood flow from the entire drainage area, but their normal or base flow is sustained largely by water from springs in the Glen Rose limestone.

The recharge area of the limestone differs from that of a sandstone in that water must encounter an opening in the limestone caused by solution, jointing, or fracturing before it can move rapidly downward. The openings in the limestone may be large and lead into an extensive network of cavernous solution channels. The large openings are in the form of sinkholes, joints or faults enlarged by solution, or zones of smaller interconnected channels. Large quantities of water may enter the openings within a comparatively small area.

A series of discharge measurements were made in June 1952 of the streams crossing the Edwards limestone in Medina County. The discharge of each stream was measured on the upstream and downstream sides of the outcrop. Additional measurements were made along the streams as they cross the outcrop, to determine the sections of greatest recharge. The miscellaneous discharge measurements are shown in table 4. The entire discharge of Hondo, Seco, and Verde Creeks entered the Edwards limestone in the recharge area.

A discharge of 34.7 cfs was measured where Hondo Creek crosses the Glen Rose limestone. After flowing 2 miles, the stream crosses the south branch of the Woodard Cave fault and passes onto the Edwards limestone. Several large fractures cross the creek bed just south of the fault. In this locality, 9.2 cfs of water entered the limestone. The stream lost an additional 19.1 cfs of water while flowing over 6.9 miles of the Edwards limestone, including losses into four faults and innumerable solution holes in the bed of the creek. The greatest seepage losses were found in this section of the creek. The remaining 6.4 cfs entered the Edwards limestone before the stream crossed the Medina Lake fault and left the Edwards. There was no flow in the creek a mile south of the fault. Only during and immediately after exceptionally heavy rains do Hondo, Seco, and Verde Creeks flow south of the outcrop area of the Edwards limestone.

Similar stream losses to the Edwards limestone are shown by measurements of Seco and Verde Creeks (table 4). These streams flowed only part of the way across the Edwards outcrop, and it seems likely that if the discharge were sufficient for the streams to flow across the entire outcrop, much additional water would enter the limestone through cracks and solutional channels. The stream losses are undoubtedly higher during floods when the greater depth of water and larger water surface would increase the rate of recharge.

The average annual infiltration to the Edwards limestone from Seco, Hondo, and Verde Creeks is estimated to be of the magnitude of 35,000 acre-feet. This estimate is based on the available discharge measurements, rainfall records, and average number of days a year that these streams have been reported to flow along their entire length.

Stream gages on Seco and Hondo Creeks were erected in 1952 above and below the outcrop of the Edwards limestone. The locations of these gages are shown on plate 1. A more accurate estimate of the recharge to the Edwards limestone may be made from the discharge measurements of these gages after a record of sufficient length has been established.

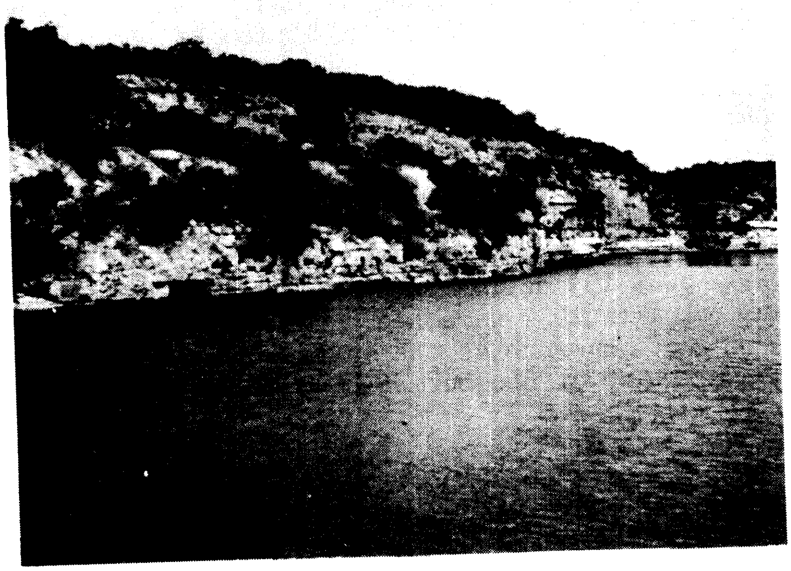
Two dams were built across the Medina River in 1912 to impound water for irrigation. The main dam, used for storage, is 16 miles north of Castroville, and a smaller dam, diverting water to the canal system, is 4 miles below the main dam. The diversion dam is on the outcrop of the Edwards limestone, and, except for a small area to the Glen Rose limestone exposed in the bed of the stream, the reservoir also is on the outcrop of the Edwards limestone. The diversion dam is a concrete structure 440 feet long and 50 feet above the stream bed. The capacity of the reservoir behind it is about 4,000 acre-feet.

The storage dam upstream from the diversion dam is a concrete structure 1,500 feet long, and the spillway is 152 feet above the stream bed. The original capacity of the storage reservoir was 254,000 acre-feet at the spillway crest. District officials state that the present capacity is about 213,000 acre-feet.

Numerous fractures and solutional holes are visible in the walls of the canyon above and below the dams (pl. 14, A and B). The fractures have the same general northeast trend as the Balcones faulting. Grouting of the solution channels and fractures at the diversion dam in 1948 failed to reduce the leakage from the diversion reservoir. Increasing the stage of the lake increases the hydraulic gradient

Table 4.- Miscellaneous discharge measurements to determine seepage from streams in Medina County, Tex., in June 1952. (Measurements by Surface Water Branch, U. S. Geological Survey, Austin, Tex.)

Date	Stream	Location	Approximate distance (miles from initial point)	Length of section (mi.)	Discharge (cfs)	Loss in section (cfs)
June 12, 1952	Hondo Creek	0.3 mile north of Bob Dupuy Ranch, 2.5 miles south of Bandera County	0	0	34.7	0
June 12, 1952	Hondo Creek	0.2 mile south of M. Garrison Ranch at low-water bridge	4.4	4.4	25.5	9.2
June 12, 1952	Hondo Creek	Concrete low-water bridge, 9.4 miles north of Hondo	11.3	6.9	6.4	19.1
June 12, 1952	Hondo Creek	Concrete slab at Schlentz crossing, 7.8 miles north of Hondo	14.1	2.8	0	6.4
June 12, 1952	Seco Creek	Ford at Patton Ranch, 17.2 miles north of D'Hanis	0	0	15.2	0
June 12, 1952	Seco Creek	0.1 mile south of concrete dam at Woodard Ranch, 13.1 miles north of D'Hanis	5.8	5.8	0.01	15.2
June 12, 1952	Seco Creek	Concrete slab, 7.4 miles north of D'Hanis	14.8	9.0	0	0
June 13, 1952	West Verde Creek	Crossing 1.0 mile south of J. Short Ranch headquarters, 16.4 miles north of Hondo	0	0	1.53	0
June 13, 1952	Verde Creek	Concrete slab at Grodt crossing 12.2 miles northwest of Hondo	3.3	3.3	0	1.53



A. West bluff of Medina Diversion Lake north of dam, showing large solution holes at water line.

B. Discharge of water from solution hole in east bluff of Medina River, 300 feet south of dam.

of the ground water moving from the lake, which, in turn, increases the rate of movement of the water and accelerates the solution of the limestone. Most of the reservoir area of Medina Lake is in the outcrop of the Glen Rose limestone. Movement of water from the Glen Rose limestone to the Edwards limestone is believed to occur along faults.

The U. S. Geological Survey made discharge measurements along the Medina River from 1922 to 1934. The results of these measurements are shown in table.5.

Burleigh (1949, p. 9-15) estimated that the seepage losses from the storage and diversion reservoirs in 1930 were nearly 72,000 acre-feet. The average annual loss may be even larger, inasmuch as the water surface in the storage reservoir probably dropped below many of the outlet conduits along the stream bed in September 1930.

Livingston, Sayre, and White (1936, p. 76) estimated that the seepage losses in the $3\frac{1}{2}$-mile stretch of the river below the reservoir between the Mico gaging station, about 2,000 feet below the main reservoir, and the diversion dam was about 16,000 acre-feet in 1930. In addition, an average loss of 38,500 acre-feet a year was estimated for the stretch between Pipe Creek and the Mico station, according to 11 years of record from 1923 to 1933. This includes evapotranspiration losses, but these are probably balanced by tributary inflow, so that the figures represent essentially recharge to ground water.

The diversion reservoir was dry and the storage reservoir was at a low stage during 1951 and 1952, preventing the measurement of seepage losses at that time.

Livingston, Sayre, and White (1936, p. 73-83) estimated that the combined annual average recharge of the Edwards limestone from the Nueces, Frio, Dry Frio, Medina, and Sabinal Rivers and Hondo Creek may amount to 150,000 acre-feet. The combined recharge from all streams crossing the outcrop of the Edwards limestone in Medina County only may average 90,000 acre-feet a year. In addition, a considerable quantity of water must enter the formation directly from precipitation.

Table 5.- Annual discharge of Medina River, 1922-34

Calendar year	Medina River near Pipe Creek (acre-feet)	Flow over Diversion Dam at Habys Crossing (acre-feet)	Seepage past Diversion Dam (acre-feet)	Medina Canal near Rio Medina (acre-feet)
1922	--	300	15,500	18,100
1923	78,900	500	17,800	22,500
1924	84,100	5,700	19,200	16,000
1925	26,500	0	16,900	32,600
1926	64,200	5,300	17,500	11,700
1927	66,200	0	17,700	17,500
1928	20,500	0	17,600	15,700
1929	45,200	0	16,500	20,000
1930	62,900	0	15,400	21,000
1931	147,000	0	17,400	21,600
1932	197,000	200	18,600	21,600
1933	49,300	0	21,100	32,300
1934	12,700	0	16,800	4,900

Indio formation

The Indio formation crops out over an area of 245 square miles in southern Medina County. A large part of the outcrop consists of clays and shales that have a low permeability. The effective recharge area is only a small part of the total area of outcrop.

Water may enter the Indio formation directly from rainfall on the outcrop, from streams that cross the outcrop, or by downward percolation of water from overlying formations. In all areas in Medina County for which information was obtained, the water table in the Indio formation was below the level of the streams. Squirrel, Seco, Tehuacana, Hondo, Black, San Francisco, and Chacon Creeks lose a part of their flow as they cross the outcrop of the Indio formation. In many places, the Indio formation is covered by as much as 60 feet of the Leona formation, through which there may be some downward percolation of ground water. The Leona formation is more permeable than the Indio and may take in the streamflow rapidly and allow it to percolate slowly into the underlying Indio formation. The overlying Carrizo sand is not known to contribute water to the Indio formation. Electric logs and drillers' logs show there is 50 to 100 feet of clay in the upper part of the Indio. A pumping test of the water-bearing sands of the Indio formation and the Carrizo sand was made in September 1952 at the Devine well field. Well J-7-21, penetrating 115 feet of saturated Carrizo sand, was pumped at a uniform rate and the rate of drawdown was observed in two observation wells. One of the observation wells, J-7-23, penetrates approximately the same thickness of saturated Carrizo sand as well J-7-21. A rapid drawdown was observed in well J-7-23. Another observation well, J-7-22, penetrated approximately 85 feet of saturated sand in the Indio formation. Although wells J-7-22 and J-7-23 were an equal distance from the pumped well, there was no measurable drawdown of the water in the well tapping the Indio. This indicates that there is little or no movement of water between the two formations in this locality.

Carrizo sand

The outcrop of the Carrizo sand in Medina County is a part of the intake area for the water being pumped in the Winter Garden area. A pumping test made of well J-7-21, in the outcrop of the Carrizo sand in Medina County, shows that the sand has a coefficient of transmissibility of more than 100,000 gallons per day per foot (gpd/ft.). This rather high transmissibility, which is favorable to recharge, is explained by the high degree of sorting of the sand grains and the lack of cementing material in the outcrop.

Water enters the Carrizo sand directly from rainfall on the outcrop, from streams that cross the outcrop, by downward percolation of water from overlying formations, and in some places by upward movement of water from lower formations.

Chacon, Francisco Perez, Black, Hondo, and Tehuacana Creeks cross the outcrop of the Carrizo sand. The water levels in wells in the Carrizo are below the beds of all these streams. The water levels in wells J-7-24 and J-7-47 rose rapidly after Chacon and Francisco Perez Creeks overflowed their banks in May 1951. Livingston, Sayre, and White (1936, p. 85) noted an apparent loss of 10 second-feet of water from the Leona River in the outcrop of the Carrizo sand in Zavala County in June 1931; measurements in February 1930, however, showed no apparent loss.

The Carrizo is covered by the Leona formation in a large area near Devine, and, during high water, there is apparently some stream loss into the permeable gravel of the Leona. Water may percolate through the gravel into the Carrizo sand and thus increase the amount of recharge to the formation at some distance from the streams.

Leona formation

The Leona formation consists of terraced deposits of silt, sand, and gravel paralleling the principal streams in Medina County. Each stream terrace represents a separate aquifer confined to a stream valley. As a rule, the greatest thickness of saturated material is found near the present or previous drainage channels. The formation generally thins transverse to the stream channel, although there may be a sufficient thickness of saturated material in the interstream area for partial connection of parallel aquifers. The aquifers are connected at the junctions of the stream valleys.

Ground water occurs in the Leona formation in partially separated areas of Medina County. The total area of the surface exposures of the formation is approximately 218 square miles. Of this area, the Leona along Seco Creek covers 23 square miles; along Hondo and Verde Creeks, more than 109 square miles; along the Medina River, 41 square miles; along Chacon Creek, 40 square miles; and along a small stretch on the Frio River, 5 square miles.

Recharge to the Leona formation in Medina County is from precipitation on the outcrops, from discharge of springs, from underlying aquifers, and from streamflow. The principal source of recharge is the floods that intermittently fill the channels and valleys of Seco, Hondo, Verde, and Chacon Creeks and the perennial flow of the Medina and Frio Rivers. Periodic measurements of water levels in wells in each of the aquifers indicate that the water table fluctuates with the amount of precipitation and the rate of streamflow.

Ground water in the Leona formation generally occurs under water-table conditions. However, locally, the water is confined by nearly impermeable lenses of silt or clay. Small bodies of water not connected to the main reservoir may be encountered along the thin flanks of the stream-terrace deposits. The water in these isolated reservoirs may be exhausted rapidly by pumping.

ARTIFICIAL RECHARGE

Artificial recharge is one method by which the yield of an aquifer may be increased. Artificial recharge is being practiced in several places in the United States and Europe (Meinzer, 1946; Sayre and Stringfield, 1948), but has not been tried in Medina County. It has been considered, however, for several years.

Artificial recharge may be accomplished by one of two methods: Recharge by "water spreading" on the land surface or through ditches or basins, and injection of water through wells. All the important aquifers in Medina County could be recharged to some extent by surface spreading, allowing water to move downward to the zone of saturation. Under the economic conditions current during this investigation, the introduction of water through wells would not be practical.

The principal aquifer, as indicated by the data given in table 5 for the Medina River, takes in a large portion of the flow of the creeks and rivers crossing the outcrop. After periods of heavy rainfall, the floodwaters in the streams would be available for artificial recharge. Sinkholes, solutionally enlarged joints and faults, and solutional caves are found throughout the outcrop of the limestone. Leakage from the Medina storage and diversion lakes shows the effects of impounding water on permeable limestone. (See pl. 14-A) Excess floodwaters could be impounded on other streams in the outcrop of the Edwards limestone to increase recharge. Other possible methods of recharge would be to divert the excess streamflow into large sinkholes such as the Woodard Cave, or to spread the water over a fractured area, an example being the area near well C-9-49. A sinkhole in the bed of the Leona River in Uvalde County was covered by a steel grid to keep out logs and boulders. The County plans to construct a small dam downstream from this opening to increase the head of water and prevent the water from bypassing the sinkhole.

The sandstones of the Indio formation and the relatively unconsolidated Carrizo sand are exposed in the outcrop areas. Excess floodwater could be spread over areas where the more permeable sands crop out. This method of recharge has many limiting factors. The mud and slime carried by the streams would tend to settle on the surface and restrict the infiltration of water. However, intermittent flooding, followed by drying and scarification or other treatment of the soil, might maintain the infiltration rate satisfactorily.

At the present time, artificial recharge is expensive and, therefore, impractical except in areas where water is in high demand.

DISCHARGE

Ground water is discharged from the underground reservoirs in Medina County through springs and seeps, through wells, and by evaporation and transpiration. Before any water was pumped from wells in Medina County, the average annual losses of ground water by natural processes was approximately equal to the average annual gains. The gains and losses include underground movement of water from and to adjacent counties. This state of approximate equilibrium between average annual recharge and discharge was unbalanced by pumping water from the reservoir. As discharge from wells increases, there is a gradual lowering of the water levels in wells and a corresponding decrease in natural discharge. However, the amount of water withdrawn annually from the ground-water reservoirs in Medina County by pumping from wells is small, so far, compared with the volume of water that moves in and out of the county through underground channels.

Discharge from springs

Springs in Medina County are of three types: (1) Contact springs in which water issues at the surface from permeable material overlying less permeable strata; (2) springs discharging water from solutional conduits formed along fractures in limestones; and (3) depression springs developed on the banks of streams which have cut channels below the water table. All the springs issue as flowing water, which locally maintains the low flow of streams. Springs of small, diffused flow are called seeps.

The flow of the springs in Medina County varies with the precipitation and, consequently, with the volume of water in storage in the reservoir. Measurements and estimates of the flow of most of the springs and seeps in the county were made in January 1952. The approximate total discharge was 890,000 gallons a day or about 1,000 acre-feet a year. This figure probably represents a below-average discharge, as the estimate was made during a period of low rainfall.

Springs in Glen Rose limestone

Ground water from the Glen Rose limestone is discharged by springs and seeps into streams that cross its outcrop. The perennial flow of many of the streams is maintained by this spring flow.

The perennial flow of West Verde Creek is fed by water discharging from contact springs C-9-3 and C-9-64, and from a spring issuing from a large solutional opening in limestone, C-9-5. Contact springs D-7-44 and D-8-4 discharge into San Geronimo Creek. Both streams receive their largest flow from springs north of Medina County.

The Medina River, the largest perennial stream in Medina County, obtains a large part of its normal flow from springs in Bandera County. Older settlers have reported the existence of many large springs now covered by Medina Lake. Indian and Moccasin Springs, C-9-8 and C-9-10, perennially discharge 120 to 450 gallons a minute of water from openings in the Glen Rose limestone west of Medina Lake. East of Medina Lake, contact springs D-7-4, D-7-7, and D-7-9 intermittently discharge 35 to 100 gallons a minute into streams draining into the surface reservoir.

The flow of Seco Creek is augmented by contact springs C-7-1, C-7-7, C-7-8, C-7-9, and C-8-34. The water from these springs flows by gravity from openings near bedding planes in sandy marl and limestone. A number of unrecorded small springs and seeps occur along the same contacts.

The low flow of Hondo Creek is maintained by springs from the Glen Rose limestone in Bandera and Medina Counties, but the largest part of its flow is gained before it enters Medina County. The springs and seeps along Hondo Creek in Medina County discharge less than 700 gallons a minute. A contact spring, C-8-32, discharges into Hondo Creek from a sandy layer in the Glen Rose limestone.

Springs in Edwards limestone

The hydrostatic level of the water in the Edwards limestone is below the land surface in all but a small area in the southern part of Medina County. The altitude of the water table in the area of outcrop is insufficient to maintain the piezometric surface above the land surface in the downdip part of the aquifer, consequently there is no discharge by springs from the Edwards limestone in Medina County except in the Medina Lake area.

Medina Lake and the diversion lake have increased the recharge to the limestone aquifer in their vicinity. Increasing the head of the surface water in the reservoirs has increased the volume of water that may flow to the water table. Numerous fractures and solutional caverns are visible in the walls of the canyons above and below both the dams. (See pl. 14-A.) The solutional caverns and channels are interconnected both horizontally and vertically, extending down to the underlying Walnut clay, which is essentially impermeable.

During the periods when the water is at a high stage in the reservoirs, a large volume of water may be seen discharging from joints, openings along bedding planes, and other solutional holes in the canyon walls below the dams. (See pl. 14-B.) A spring, D-7-24, near the bed of Medina River 600 feet south of the Medina Lake dam, was flowing approximately 450 gallons a minute in May 1953. The water issues approximately 20 feet above the Walnut clay, from a fracture in the Comanche Peak and Edwards limestones. Spring D-7-39 was flowing approximately 1,300 gallons a minute in May 1953 from a large solutional hole in the east wall of the Medina River Canyon, 300 feet south of the diversion dam. (See pl. 14-B.) At that time, the diversion lake's surface was approximately 40 feet above the stream bed. The water discharging into the canyon below the dam probably moves laterally from the diversion reservoir and around the dam through interconnecting solution channels. Spring D-7-39 was dry from September 1952 to March 1953, while the diversion lake was empty.

Springs in the Anacacho limestone

Several small springs and seeps are found along the outcrop of the Anacacho limestone. Spring I-3-82, 4 miles north of Hondo in the bed of Hondo Creek, issues from the intersection of cross joints with a bedding plane. A series of small seeps along San Geronimo Creek intermittently discharge water from a solution-widened bedding-plane fissure.

Springs in Leona formation

Water is discharged from the sand and gravel of the Leona formation where stream channels have cut below the water table. Most of the ground water does not flow from any individual or definite point of discharge, but seeps from large areas of permeable material and from a few small springs.

Springs I-3-103, I-3-104, and I-3-125 discharge into Quihi Creek near its juncture with Hondo Creek. The total perennial flow of the three springs ranges at different times from 120 gallons a minute to 400 gallons a minute. Another spring, I-6-74, discharges 25 to 600 gallons a minute into Hondo Creek, 8 miles south of U. S. Highway 90. The altitude of the water at this spring is approximately equal to the altitude of the water level in well I-6-76, half a mile west of the river channel.

Depression springs are evident also in the bed of San Geronimo Creek near Rio Medina and in the bed of Seco Creek south of D'Hanis. The flow of spring J-1-36 in San Geronimo Creek was approximately 160 gallons a minute in January 1951. Spring I-5-28 in Seco Creek was flowing approximately 25 gallons a minute in August 1951.

Discharge from wells

Water is discharged artifically from pumped wells and from wells that penetrate artesian formations containing water under sufficient hydrostatic head to rise above the surface. Only four flowing wells were found in the county in 1952. Pumped wells supply water for nearly all domestic, stock, public-supply, and industrial usage in Medina County. Approximately one-fourth of the irrigation water is supplied by wells.

The estimated average withdrawal of water from wells in the principal aquifer in 1951 was 1,480,000 gallons a day; in 1952 it was 1,600,000 gallons a day.

For all formations, the estimated average discharge from wells in 1952 was 4,800,000 gallons a day for the following uses: Domestic and stock, 1,200,000 gallons a day; public-supply, 1,030,000 gallons a day; industrial, 70,000 gallons a day; and irrigation, 2,500,000 gallons a day.

Evaporation and transpiration

Evaporation and plant transpiration discharge considerable ground water in Medina County, particularly where the water table is shallow in outcrops of the aquifers. Figure 3 shows that the monthly evaporation at Dilley, as determined by the U. S. Department of Agriculture, Soil Conservation Service, is highest during the summer months. Transpiration from plants also reaches a maximum during the same period. In most areas, evaporation reduces the downward percolation of water from the surface and soil to the water table. The amount of water lost from the water table directly by evaporation is relatively small because the depth to water is generally more than 50 feet below the surface.

The shallow water table in the Leona formation is accessible to many plants that are capable of sending their roots to the capillary fringe or the zone of saturation. Along the low land bordering the streams in the county, a heavy growth of brush and trees derives most of its supplemental water from the ground-water reservoir. The water table in the outcrops of the other aquifers is generally below the depth normally penetrated by plant roots.

MOVEMENT OF GROUND WATER

In a homogeneous medium, ground water moves in the general direction of the hydraulic gradient - that is, from points at which the artesian head or water table is high to points at which it is low. The Edwards and associated limestones do not form a homogeneous aquifer. The water seems to flow in solutional channels along fractures more or less parallel to the fault pattern. The contours on the piezometric map indicate only the general direction of flow. The water moves from the outcrop areas where the water table is at a relatively high altitude down the dip to the south, where, because of loss of head from friction, the hydrostatic head is progressively lower. The amount of water that can be withdrawn perennially from a ground-water reservoir depends upon the amount of recharge; the capacity of the aquifers to serve as conduits from the areas of recharge to the points of discharge; and the amount of water available from storage.

The coefficient of permeability of a water-bearing material is the rate of flow, in gallons a day, through a crosssection of 1 square foot under a hydraulic gradient of 1 foot per foot (or through a section 1 foot thick and 1 mile wide under a gradient of 1 foot per mile) at a temperature of 60° F. The field coefficient of permeability is the same except that it is measured at the prevailing temperature of the water rather than at 60° F. The coefficient of transmissibility of an aquifer is the product of the thickness of the aquifer, in feet, multiplied by the average field coefficient of permeability.

The amount of water that is released from storage when the head in an aquifer declines is called the coefficient of storage. It has been defined as the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. For water table conditions, the coefficient of storage is essentially the same as the specific yield, which is defined as volume of water a sample will yield by gravity, after being saturated to its own volume.

Capacity of formations to transmit and yield water

Several pumping tests have been made of the Edwards limestone and of water-bearing sands of the Indio formation and the Carrizo sand. These tests consisted of pumping a well at a uniform rate and either observing the rate of drawdown in other observation wells, or stopping the pump and observing the rate of recovery in the wells. These results were analyzed by means of the nonequilibrium formula developed by Theis (1935) to determine the coefficients of transmissibility and storage of the water-bearing beds. A discussion of this formula, the assumptions upon which it is based, and the applications are given by Theis (1938, p. 889-902) and Wenzel (1942).

The nonequilibrium formula assumes that the water-bearing formation is infinite in areal extent, that it is homogeneous and isotropic, that its transmissibility is the same at all places, and that it is bounded by impermeable beds above and below. It assumes also that the coefficient of storage is constant and that water is released from storage instantaneously with a decline in head. Although these conditions rarely, if ever, occur in nature, they are reasonably approximated, especially in extensive sand aquifers, and the nonequilibrium formula may be applied with some confidence.

The coefficients of transmissibility and storage determined from pumping tests made in wells tapping the Indio formation and Carrizo sand are given in table 6.

Table 6 indicates that the coefficients of transmissibility of the sands of the Indio formation range from 10,000 to 20,000 gpd/ft. This wide range was to be expected because the Indio formation consists of many lenticular bodies of sand, clay, and silt. The saturated material has a wide variation in grain size and percentage of clay. Well J-4-19 penetrated 64 feet of saturated material. Well I-6-126 penetrated 270 feet of silt, clay, and sand, and has 80 feet of screen. Well I-6-127 penetrated 340 feet of the Indio formation and has 72 feet of screen. Study of the available data indicates that the coefficients of transmissibility obtained from the pumping tests may possibly express the range to be expected in the Indio formation where it has a thickness of 60 feet or more.

Table 6.- Results of pumping tests in southern Medina County

Well observed	Well causing interference	Aquifer penetrated	Coefficient of transmissibility (gpd/ft)	Coefficient of storage
J-4-19	J-4-141	Lower part of Indio formation	11,000	------
I-6-126	I-6-123	Upper part of Indio formation	20,000	0.0016
I-6-126	I-6-123	Upper part of Indio formation	12,000	------
J-7-23	J-7-21	Carrizo sand	134,000	.028

Guyton (1942, p. 6-17) made a series of pumping tests on wells supplying Camp Swift in Bastrop County. The wells obtained water from an interbedded sand and clay zone, approximately 250 feet thick, in the Wilcox group. The coefficients of transmissibility ranged from 37,000 to 87,000 gpd/ft and the storage coefficients ranged from 0.0003 to 0.0007. These coefficients are in the same order of magnitude as those for the Indio formation in Medina County, if the difference in the saturated thicknesses of the sands is taken into consideration.

The coefficient of transmissibility of the Carrizo sand, as determined by a pumping test on well J-7-21, is approximately 134,000 gpd/ft (fig. 11). This was determined during a test made on wells in the Devine well field that penetrate approximately 115 feet of saturated sand. The wells are on the outcrop of the Carrizo sand. Pumping tests of the Carrizo sand were conducted in 1948 by D. E. Outlaw (manuscript in preparation) in the Winter Garden district where coefficients of transmissibility ranged between 35,000 and 39,000 gpd/ft.

As stated, the nonequilibrium formula assumes that the water-bearing formation is homogeneous and isotropic; that its transmissibility is the same at all places; and that it is infinite in areal extent. These assumptions are even less applicable to the limestone strata of Medina County than they are to the sands. The solutional channels in the limestone are neither homogeneous nor isotropic, and they vary in areal extent. Faults, other fractures, and outcrops constitute hydrologic boundaries within the aquifer, and affect the rate of decline caused by pumping from wells.

The Edwards limestone has a wide variation in porosity and permeability. Water moves in fractures and solutional channels of varying size. Drillers have reported caverns as much as 20 feet in depth in wells in the limestone, whereas adjacent wells may be tight - that is, they may penetrate only small openings that are not connected. These irregularities in the character of the openings in the limestone restrict the application of the quantitative formulas.

A pumping test was made in October 1952 of the cavernous limestone in the upper part of the Edwards limestone. The test consisted of pumping municipal well J-1-83 at Castroville at the approximate rate of 510 gallons a minute and observing the rate of drawdown in adjoining well J-1-82. Well J-1-82 is 65 feet south of well J-1-83 and penetrates essentially the same thickness of the Edwards limestone. Both wells are open in the limestone. After pumping 9 hours, the water level in well J-1-83 had dropped 6.1 feet and the water level in well J-1-82 had dropped 0.08 foot. The water level in well J-1-84, 160 feet south of well J-1-82, was not measurably affected by the discharge of well J-1-83. The test indicates a rapid movement of water or a large volume of storage in the immediate vicinity of the pumped well. The results could not be used for computing coefficients of transmissibility and storage.

Direction of ground-water movement

The direction in which water is moving in an underground reservoir can be determined if the shape of the water table or the direction of the artesian-pressure gradient is known. In a ground-water reservoir of fairly homogeneous sand, sandstone, or gravel, the direction and amount of slope of the piezometric surface

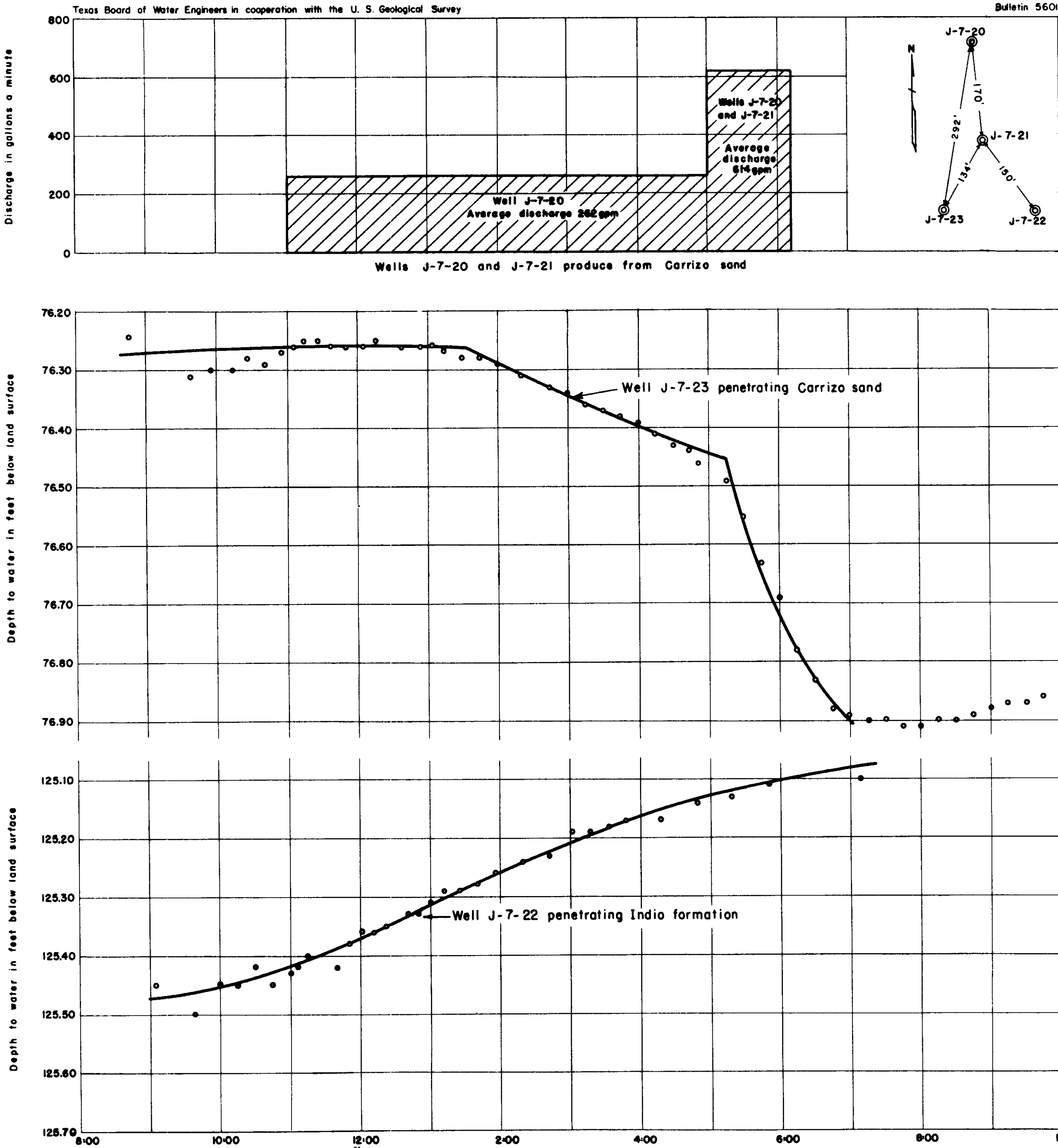


FIGURE 11.-Pumping test on wells J-7-20 and J-7-21, Medina County, Tex.

usually can be mapped using data for a moderate number of observation wells. In a formation such as the Edwards limestone, the lack of uniformity of porosity and permeability decreases the accuracy of such a piezometric map.

In January 1951 and September 1952, the altitudes of the static levels of water in wells in the Edwards limestone were determined by measurements made below reference points of known altitude. From these data, lines of equal altitude of water have been drawn and are shown on plates 4 and 5. The general directions of the movement of water varied but little from January 1951 to September 1952.

The configuration of the piezometric surface of the principal aquifer in Medina County is controlled chiefly by the hydrologic characteristics of the aquifer and its confining beds, the topography and drainage of the outcrop area, and the amount of throw of the faults. In general, the piezometric surface of the aquifer slopes from 30 to 60 feet per mile to the south in the area of outcrop. South of the outcrop also, the piezometric surface slopes to the south, but at a rate of 15 to 30 feet per mile. In the south-central part of the county, the slope is in an easterly direction and ranges from 2 to 15 feet per mile. The gradient of the piezometric surface cannot be correlated directly with the amount of movement of the water because of the varying permeability of the limestone in the area.

The altitude of the water table in the outcrop of the Edwards limestone was about 940 feet in September 1952. In the vicinity of D'Hanis, the altitude of the piezometric surface was about 685 feet; in the vicinity of Hondo, about 660 feet; and near Castroville, about 650 feet. The altitude of the surface in the San Antonio area was approximately 630 feet and at Comal Springs at New Braunfels, 623 feet. These differences in altitude of the piezometric surface are sufficient for water to move to the east from Medina County to the San Antonio area.

The Edwards limestone underlies all Medina County from the outcrop south, but in the southern third of the county the water in the formation is highly mineralized (see pls. 4 and 5) and also the formation lies too deep to be reached economically by water wells. Drillers' logs and core logs of oil tests drilled in this area show that the limestone lacks the high porosity common in the formation to the north. (See table 10.) The mineralization of the water encountered in many of these wells, for example, I-8-3, indicates that very little water moves down the dip. The approximate location of the boundary between the normal and more highly mineralized water in the Edwards is shown on plates 4 and 5. The location of the boundary suggests that the Pearson fault and several of the faults southwest of Dunlay retard the circulation of the water from the north to the south side of the faults.

Relation of structure to movement of water

The movement of water to the south and east in Medina County has been complicated by the Balcones system of faults, which are transverse to the general hydraulic gradient (see pls. 4 and 5). The faults having large displacements may form barriers, diverting the ground water from its normal course.

Water entering the Edwards limestone from the Medina Lake area moves downdip to the south. The movement of water down the dip is retarded by the Haby Crossing fault, which, in the area from Medina River to Cliff, has sufficient throw to bring a relatively impermeable formation opposite the Edwards limestone. Most of the water moves to the southwest, along the fault, to the area north of Quihi where the throw is less than the thickness of the Edwards. Thence the water passes across the fault into the downthrown part of the Edwards. (See pls. 4 and 5.)

In the vicinity of Hondo and Verde Creeks, the throw of the faults is not sufficient to offset the Edwards limestone completely. The Medina Lake fault and the fault to its north locally divert the ground water moving in the outcrop area of the limestone. Fault gouge and a relatively impermeable limestone on the downthrown sides of the faults may prevent the movement of much water across the faults. The faulting between the Medina Lake fault and Hondo does not affect the southward movement of the ground water appreciably.

In the area near Woodard Cave where the Edwards limestone crops out, the faulting is sufficient to affect the movement of the water, but does not completely prevent movement across the major fault. Drillers have reported that wells I-1-1 and C-7-28, south of the fault, did not encounter any porous zones or caverns such as were penetrated by wells drilled north of the fault and several miles to the south. The contours on plate 5 indicate an increase in the hydraulic gradient, probably due to a reduction in the permeability of the limestone. The displacement along the fault south of this area is too small to affect appreciably the movement of the ground water.

As suggested before, the Pearson fault and several of the faults southwest of Dunlay may serve as effective barriers to the downdip movement of the Edwards water. The highly mineralized water obtained from wells in the area south of the faults is indicative of poor artesian circulation.

The movement of water in the Escondido and Indio formations is locally affected by faulting, as shown by the difference in the chemical character of the waters on two sides of a fault (table 12). The movement of water through the Carrizo sand and the Leona formation is not appreciably affected by faulting.

FLUCTUATIONS OF WATER LEVELS

The quantity of water stored in an artesian reservoir varies from day to day, season to season, and year to year, in response to changes in the rates at which water is taken into or discharged from the reservoir. The static or nonpumping level, which is the level to which water will rise in a well under its full pressure head, fluctuates in response to these changing conditions in a reservoir. Fluctuations of the water levels in wells are caused also by changes in atmospheric pressure, interference from nearby wells, earthquakes, and other disturbances. Determination of the fluctuations of the static levels and of the causes of fluctuations are essential to an understanding of the ground-water conditions in the reservoir.

Fluctuations of ground-water levels in Medina County were observed in 54 wells during the course of this investigation. Periodic measurements of the depth to water in the wells were made by observers using a steel tape chalked to show the water mark. Measurements of many of the same wells were made in 1930 (Sayre, 1936). The records of measurements of the water levels in the observation wells in Medina County are in table 11. The locations of these wells are shown on figure 12. Hydrographs of the water levels of 7 wells in the Edwards limestone and 1 well in the Escondido formation may be compared in figures 13 and 14. These 8 wells, selected as permanent observation wells, have been measured periodically since 1930, except for well J-1-82, which was first measured, and was equipped with a water-level recorder, in 1950.

Some of the fluctuations of the static levels in wells penetrating the Edwards limestone are attributed to changes of storage affecting the artesian reservoir, but other changes in pressure upon the confined water do not involve changes in storage.

Ground water not discharged by springs and wells or by evaporation and transpiration must be discharged by seepage through the confining beds into other ground-water reservoirs or by subsurface movement in the aquifers into adjacent counties. The county lines do not represent the boundaries of the aquifers. Inasmuch as the discharge from the springs and wells in Medina County is considerably less than the recharge, a large part of the remaining water must seek a point of discharge in other areas. The general direction of ground-water movement is to the south and thence to the east, as shown in plates 4 and 5, into Bexar and Comal Counties.

Effects of changes in storage

The amount of water in storage in the principal aquifer is increased by infiltration of rainfall on the outcrop, of ephemeral runoff from nearby hills, and of flow in the streams crossing the outcrop. The storage volume is reduced by discharge from wells in Medina County and by subsurface movement of the water from Medina County toward the areas of natural and artificial discharge in Bexar and Comal Counties. The fluctuations of the water levels show the net effect of the additions to and subtractions from the artesian reservoir.

The relation between recharge by precipitation and change in water level in well J-1-82 is shown in figure 13. Comparison of the highest daily water levels with the precipitation graph shows a rapid rise in the static level immediately after a rainfall that exceeds 3 inches. Infiltration from precipitation may occur in any month of abundant rainfall, but it is most likely to occur in the spring and fall.

Distinction between recharge from precipitation and that from stream flow can be made only on the basis of time of occurrence. The only time when precipitation may be the predominant means of recharge is when the intermittent streams are dry and the perennial stream, the Medina River, is at a low stage. The first inch of rainfall under these conditions does not tend to raise the water level appreciably in well J-1-82. Thus an inch may be a measure of the precipitation required to replenish the typical soil-moisture deficiency.

Texas Board of Water Engineers in cooperation with the U. S. Geological Survey

Bulletin 5601

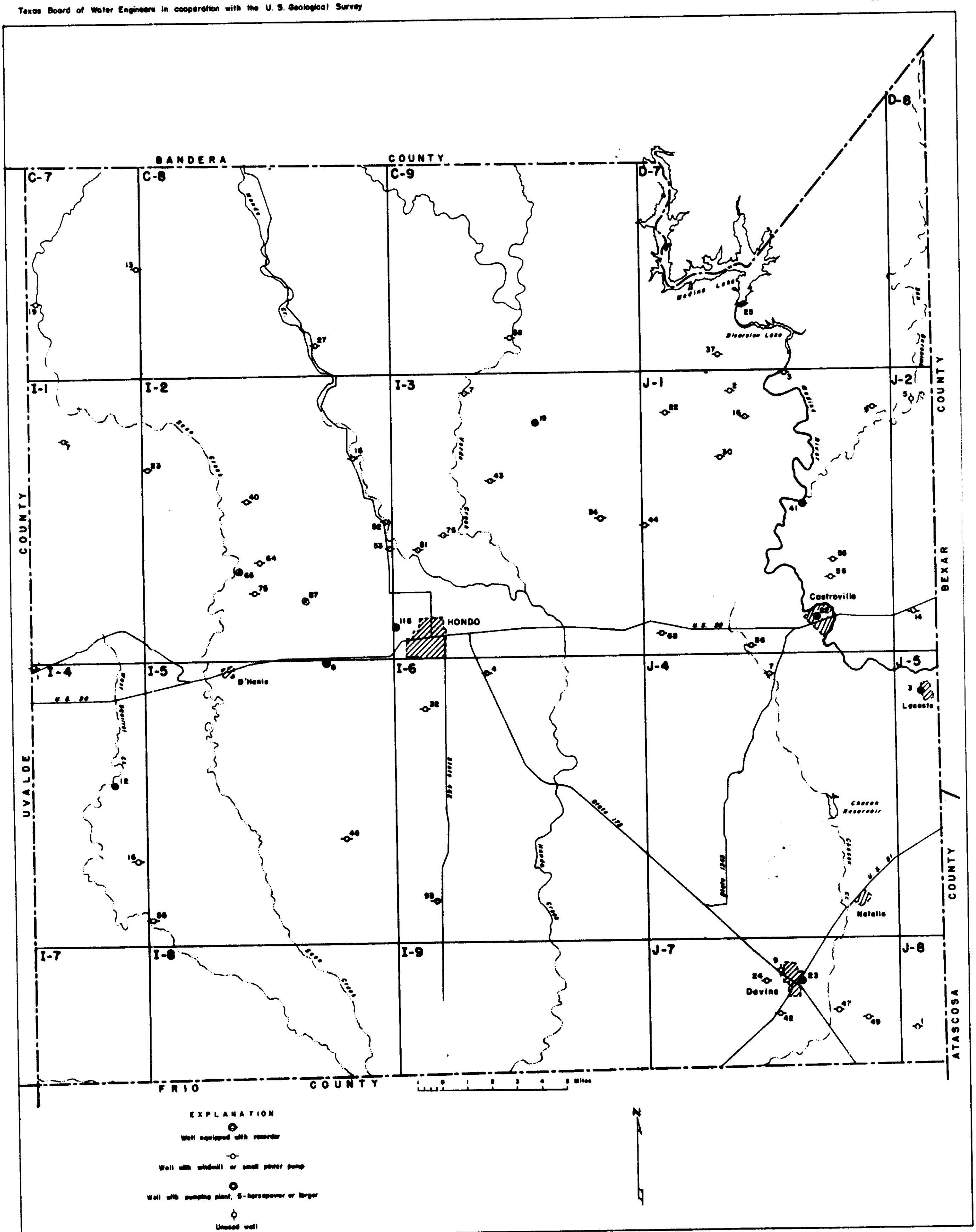


FIGURE 12.-Location of observation wells in Medina County, Tex.

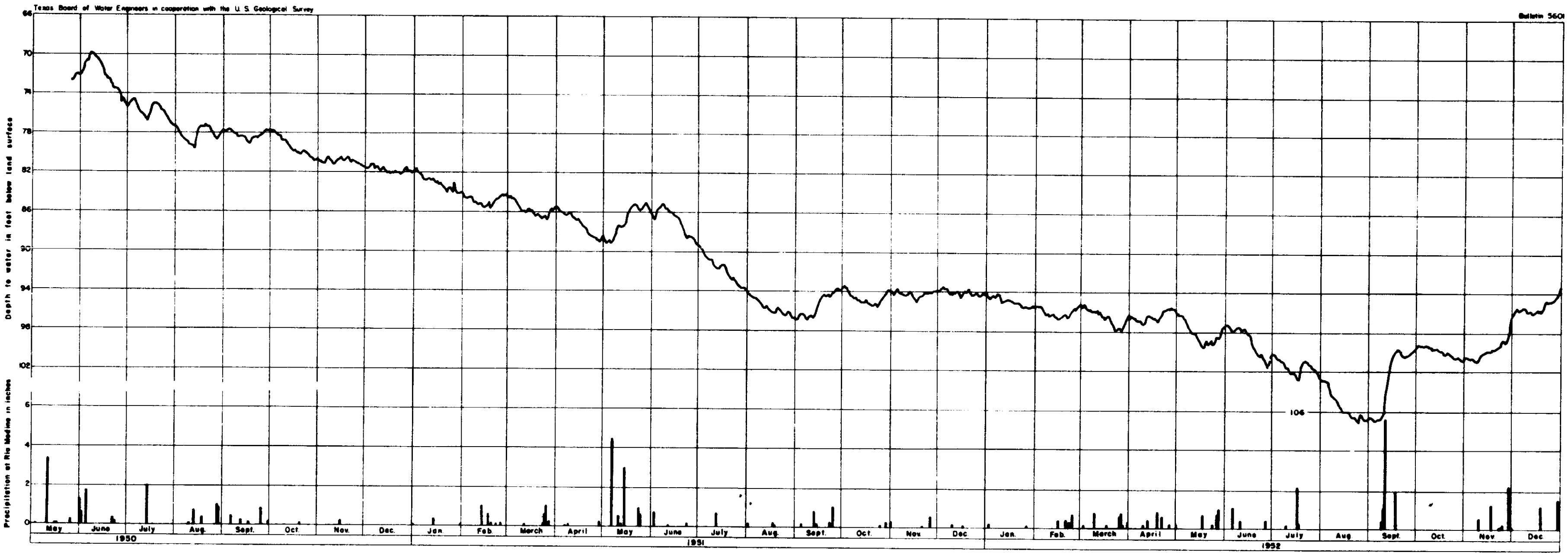


FIGURE 13.- Fluctuation of water level in well J-1-82 in the Edwards limestone, Castroville, Tex., May 1950 - December 1952.

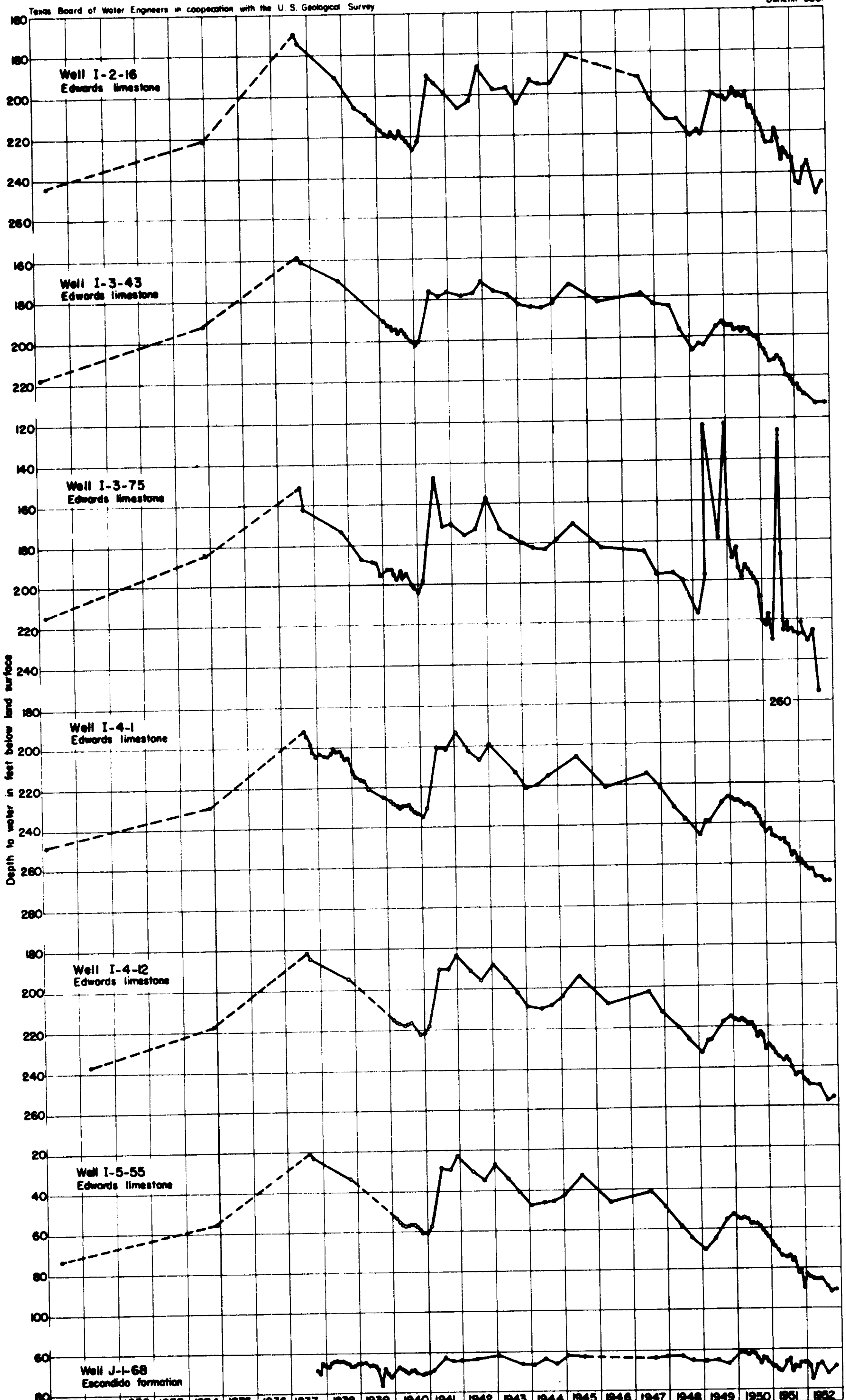


FIGURE 14.-Fluctuation of water levels in wells in the Edwards limestone and the Escondido formation.

Seepage from streams is a major source of recharge to the principal aquifer. The periods of greatest rise in the static level of well J-1-82 correspond to the periods of greatest rainfall and the maximum flow of the streams crossing the outcrop. Although the well is more than 10 miles south of the recharge area, the effects of recharge from precipitation and streamflow are transmitted to it almost immediately. The prompt response is an artesian phenomenon that reflects an increase in head at the outcrop as well as an addition of water to storage in the reservoir.

The effects of discharge of ground water from the reservoir are not immediately evident in the fluctuation of the static level of well J-1-82. The local pumping from the reservoir does not affect appreciably the static level of the well. The area of greatest discharge from the principal aquifer is 30 to 60 miles east and northeast of well J-1-82. If the annual discharge from this area is greater than the annual recharge to the outcrop, the static level in the well will decline. This situation existed in 1951 and 1952, when the recharge from the below-average rainfall was insufficient to balance the discharge from the reservoir. The static level in well J-1-82 declined approximately 1.5 feet a month during this period.

The maximum difference between highest and lowest level recorded in any of the wells in the Glen Rose limestone is 18.4 feet, the minimum is 12.2 feet, and the average is 15.3 feet. This moderate range in fluctuations of the water level is more or less typical of wells in the outcrop of the Glen Rose. The water levels in these wells did not decline appreciably during the below-average precipitation of 1951 and 1952.

The difference between the highest and lowest water levels of well J-1-68 in the Escondido formation is 12.23 feet. During the 1951 and 1952 period of below-normal rainfall, the water level declined approximately 8 feet. The fluctuation of the water level in this well is typical of wells in the outcrop area of the Escondido formation.

In observation well I-6-93, penetrating sediments of Wilcox age, the static water level was 51.9 feet below the land surface in January 1951 and 54.4 feet below the land surface in March 1952. In November 1952, the water level had risen to 32.1 feet below the land surface. The rise in water level reflects the recharge to the outcrop by local precipitation in May and June.

The maximum difference between the highest and lowest water levels recorded in any of the wells in the Carrizo sand is 13.3 feet, the minimum is 4.3 feet, and the average is 9.8 feet. The average decline in water level during 1951 and 1952 was 2.9 feet. All the observation wells in the Carrizo sand are in the outcrop area. The water levels in all but two of the wells in the Carrizo were higher in 1952 than the levels recorded for 1930.

Other changes in water level

Artesian wells generally function like barometers--the water level in them fluctuates with the atmospheric pressure. When the atmospheric pressure increases, the additional weight of the air column depresses the water level in the well; when the pressure decreases and the air column is lighter, the water level rises. The fluctuations caused by changes in atmospheric pressure on the water in well J-1-82, as interpreted from the record of a barograph, ranged from 0.2 to 1.7 feet during the period from May 1950 to December 1952.

Fluctuations in atmospheric pressure do not affect water levels in wells tapping unconfined water because the atmospheric-pressure change is divided between the water and the material forming the aquifer. However, true water-table wells are rare in this area, and most of them will show some fluctuation due to changes in atmospheric pressure, indicating that the water occurs under slight confinement.

Fluctuations in water levels caused by earthquakes have been observed in well J-1-82. Each time, after the initial shock, the water in the well fluctuates above and below the static water level and then gradually returns to the static level.

QUALITY OF GROUND WATER

CHEMICAL CHARACTER OF THE GROUND WATER

The differences in chemical character of ground waters in Medina County in a general way reflect differences in the geologic formations. As water moves underground to wells or natural outlets of the water-bearing formations, it comes into contact with soluble minerals in the rocks. As a result of this contact, two general processes occur. Most important at first is simple solution of the rock minerals. It is limited by the relative solubility of the rocks, time of contact, pressure, and temperature. The other process that alters water quality is ion exchange between the ions dissolved in the water and the rock minerals. For example, water may pass through a calcareous zone taking calcium carbonate into solution in the form of calcium bicarbonate; and then pass through a clay zone, in which calcium in the water is exchanged for sodium adsorbed in the clay particles. Thus the resulting water may contain considerable dissolved sodium bicarbonate, even though neither the limestone nor the clay contained sodium bicarbonate as such.

Samples of water were collected from 125 wells penetrating 9 aquifers, 7 springs, 2 lakes, and a cave. The results of the analyses are given in table 12, and representative analyses are shown graphically in figure 15. The points where the water samples were collected are indicated by bars over the location numbers shown on plate 1. Most of the water samples were collected in 1952-53 and the analyses were made in the laboratory of the Geological Survey at Austin, Texas. Those made in 1930 were made in Washington, D. C., and were taken from Water-Supply Paper 678 (Sayre, 1936, p. 36-37).

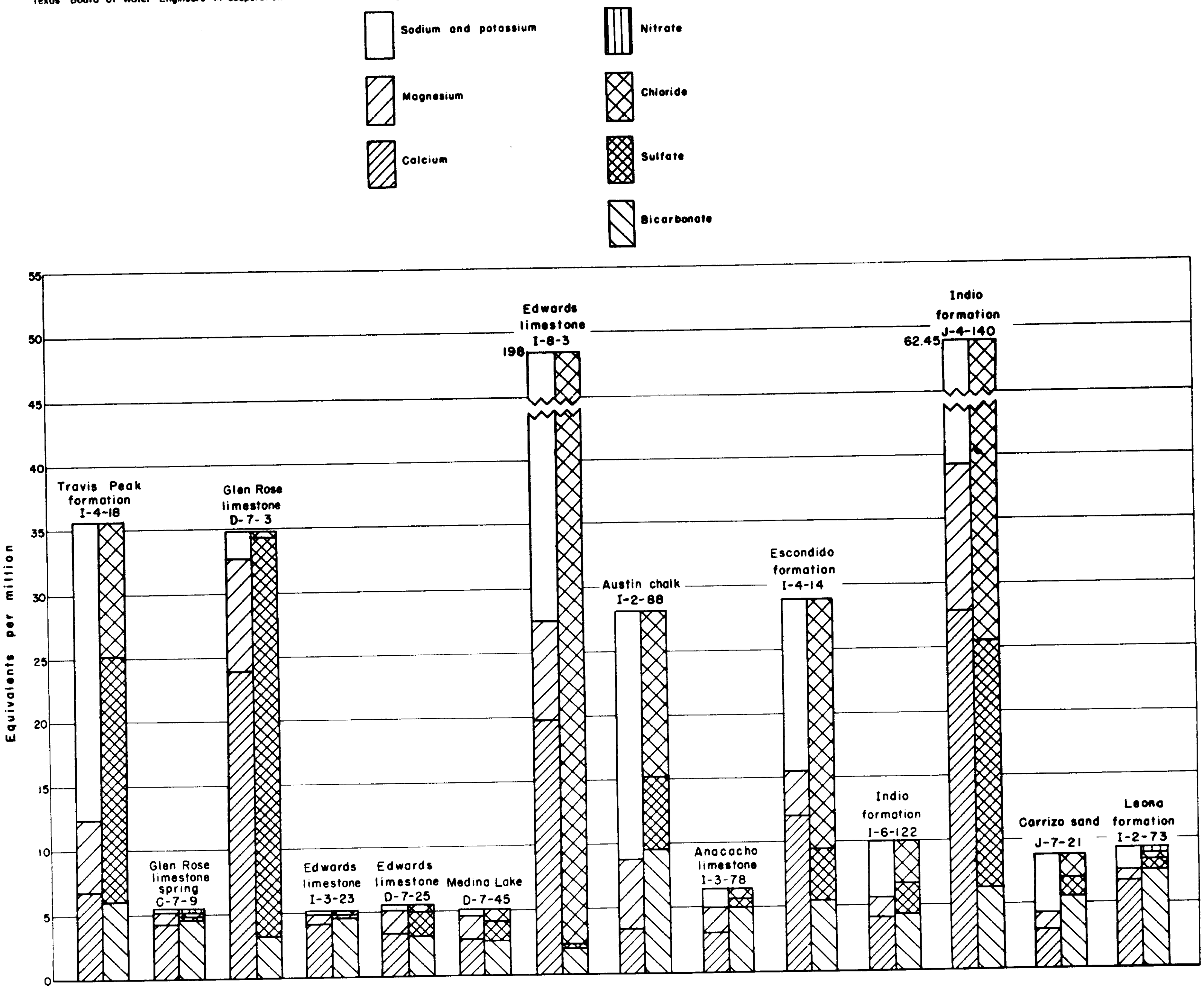


FIGURE 15.-Graphical representation of analyses of ground water in Medina County, Tex.

The chemical composition of typical ground waters from the principal aquifers in Medina County is shown graphically in figure 15. The heights of the sections in a block correspond to the quantities, in equivalents per million, of the cations magnesium, calcium, sodium, and potassium, and the anions bicarbonate, chloride, sulfate, and nitrate.

Travis Peak formation

The Travis Peak formation yields water to well I-4-18, a drilled well near the Uvalde-Medina County line south of D'Hanis. This water contained 2,220 parts per million (ppm) of dissolved solids and excessive amounts of sulfate, chloride, and fluoride. Inasmuch as this is the only analysis of water from the Travis Peak formation in Medina County, it may not be representative of water contained in the formation in the remainder of the county.

Glen Rose limestone

The Glen Rose limestone yields water containing moderate to large amounts of dissolved solids, the observed range in concentration being from 223 to 4,110 ppm. The more highly mineralized waters are high in sulfate content and are very hard. Water from springs and shallow wells in the Glen Rose is lower, generally, in dissolved solids than the water from the deeper wells, which is high in dissolved solids. The average content of dissolved solids in analyzed samples from springs and wells was about 1,870 ppm. The deeper wells that are relatively low in sulfate may penetrate interconnected solutional channels that permit free movement of water.

Edwards limestone

Ground water produced from the Edwards limestone generally is uniform in quality, containing less than 30 ppm of dissolved solids. The observed range in hardness (as $CaCO_3$) was from 168 to 4,390 ppm. The municipal supplies of Hondo and Castroville are obtained from the principal aquifer. The dissolved solids in the water from the four wells owned by the city of Hondo and the Hondo Air Force Base range from 255 to 275 ppm. The water in the Castroville well, J-1-83, has 240 ppm of dissolved solids.

A few wells penetrating the Edwards limestone yield water containing more than 500 ppm of dissolved solids. The water in well J-1-38 had 110 ppm of sulfate; that from wells J-1-41, J-1-86, and J-2-1 had 298, 345, and 196 ppm of chloride, respectively; and that from well I-3-81 had 106 ppm of nitrate. The water from the Edwards in all these wells is believed to have been mixed with water from overlying formations entering the wells through leaky casing.

Plates 4 and 5 show an area in southern Medina County where there is probably little circulation of water in the Edwards limestone. The drillers of oil tests that have penetrated the Edwards limestone in this area report that water, if present at all, is highly mineralized. Oil test I-8-3 yielded water containing 6,960 ppm of chloride and dissolved solids of 11,400 ppm.

The water northwest of the Haby Crossing fault is of better quality than the water south of the fault. The fault has been shown to retard the downdip movement of water (see pls. 4 and 5), resulting in a decrease in the amount of circulation in the reservoir south of the fault. Where solution has developed a reservoir with a system of connecting passages permitting the free movement of water, the amount of dissolved solids generally is comparatively uniform.

Austin chalk

In general, water in the Austin chalk is highly mineralized, although several wells yield water of good quality. Water from wells I-2-61 and I-2-88 was moderately high in sulfate and chloride, and contained 813 and 1,610 ppm of dissolved solids, respectively.

Anacacho limestone

The Anacacho limestone locally yields water acceptable for domestic purposes, although it may be very hard. The analyses for well I-3-78 and spring I-3-82 show the water to be of acceptable quality.

Escondido formation

The Escondido formation yields water containing moderate to large amounts of dissolved solids, the observed range in concentration being from 484 to 3,330 ppm. The more highly mineralized waters are found near old oil and gas fields, which probably contaminate the water locally. In both dilute and concentrated waters, chloride and sulfate are usually found in significant amounts. The available analyses show no significant relation between the chemical character of the water and the depth of the wells.

Indio formation

Ground water in the Indio formation is generally of poor quality in Medina County. The range in concentration of sulfate, chloride, and dissolved solids is wide. The water in the lower part of the formation is higher generally in dissolved solids than water from wells in the upper part. The water from I-8-9 is of good quality. The more highly mineralized waters in the Indio formation may be the result of contamination by oil-field waters. The wide variation in the composition of the water may be due in part also to the wide variation in type of sediments and the condition of their deposition.

Carrizo sand

The analyses of water from wells show that the water in the Carrizo sand is generally of good quality, although hard. Dissolved solids are generally less than 500 ppm. The wells that supply the city of Devine yield water that has from 350 to 500 ppm of dissolved solids and less than 100 ppm each of sulfate and chloride.

Leona formation

In chemical quality, the water from the Leona formation is satisfactory for most purposes. The nitrate content of the water is high in many places, the observed range being from 1.5 to 387 ppm. The water generally is very hard; the hardness ranges from a high of 516 ppm in well I-3-131 to 116 ppm in well J-4-18. Water from the Leona formation is the principal supply for the villages of D'Hanis, Quihi, and Lacoste.

RELATION OF CHEMICAL CHARACTER TO USE

Various standards have been proposed from time to time to evaluate a water for drinking. The United States Public Health Service (1946) in standards for drinking water used on common carriers in interstate commerce, stated that certain chemical substances in natural or treated waters should not be present in excess of the concentrations listed below. The standards have been widely adopted by State and municipal authorities.

Constituent	Concentration (parts per million)
Iron and manganese together	0.3
Magnesium	125
Sulfate	250
Fluoride	1.5
Chloride	250

Total solids should not exceed 500 ppm; however, if water of such concentration is not available, a total solids content of 1,000 ppm may be permitted.

Use of waters that do not meet these suggested standards is common. Consumers accustomed to drinking water containing 1,500 ppm or more of dissolved solids may find an urban supply unpalatable that contains only 200 ppm, at least until they become used to it. Although most of the waters sampled are considered by the users to be satisfactory for drinking and cooking purposes, water from a number of wells in Medina County contains objectionable amounts of sulfate and chloride; water from about half the wells sampled contains more than 500 ppm of dissolved solids.

Hardness, depending principally on the amount of calcium and magnesium in solution, is an important factor in public and industrial supplies. Water having a hardness of less than 60 ppm is considered very hard and should be softened for most purposes, but such waters are widely used without treatment.

The percentage of sodium among the principal cations, or percent sodium as it is commonly termed, is a value obtained by dividing the equivalents per million of sodium by the equivalents per million of calcium, magnesium, sodium, and potassium and multiplying by 100. It has a bearing on the suitability of a water for irrigation and lawn and garden sprinkling. Water in which the percent sodium is more than 60 may be injurious to certain types of soils, particularly if adequate drainage is not provided.

CONTAMINATION OF GROUND WATER

A few of the water wells in Medina County show evidence of contamination and have been abandoned because water from them has become too highly mineralized to use. Wells I-5-2, J-1-37, and J-1-82 were abandoned when water from the Austin chalk containing hydrogen sulfide entered the wells through imperfect or corroded casing and contaminated the water from lower aquifers.

Some water wells that have been abandoned because they yield highly mineralized water may be restored to use by casing the wells, cementing the space outside the casing, and perforating the casing in the zones known to have fresh water.

During the period from 1925 to 1930, many shallow oil tests were drilled in the southern part of the county. A number of wells in the Indio formation near the old oil tests yield water too highly mineralized for human use. Wells I-8-1, I-8-2, and I-8-7 produce water having 2,840, 4,090, and 3,970 ppm of dissolved solids, respectively. These wells are within a mile of oil test I-8-3, which produces water having 11,400 ppm of dissolved solids. The water in well J-4-50, near oil tests J-4-47 and J-4-48 which flow salt water, has 1,290 ppm of chloride. In many oil fields, the salt water is under sufficient pressure to raise it into contact with the shallow fresh-water aquifers, if an opening is provided. If the oil tests are not properly sealed or cased, contamination may occur. Other wells that yield mineralized water, however, such as I-4-14, I-5-31, and J-4-75, are too far from oil tests to have been contaminated from such sources. Analyses of water from these wells are not available, and no opinion can be expressed as to the reason for the high degree of mineralization.

UTILIZATION OF GROUND WATER

Records for 1,003 water wells and 26 springs were obtained in Medina County and are listed in table 9. Of the 1,003 wells, 895 are being used for domestic or stock purposes, 14 are used for public supplies, 35 are used for irrigation, and 4 are used by industry. Records were obtained from 103 oil tests and 55 domestic and stock, public-supply, and irrigation wells that are not being used. The geologic source of the ground water is shown in table 7.

Table 7.- Source and use of ground water from observed wells and springs in Medina County.

Geologic formation	Domestic and stock	Public supply	Irrigation	Industry	Not used	Spring	Total
Leona formation	178	1	7	--	4	6	196
Leona and Indio formations	--	--	2	--	--	--	2
Carrizo sand	55	3	5	1	8	--	72
Indio formation	166	3	13	1	8	--	191
Escondido formation	107	--	--	--	7	--	114
Anacacho limestone	11	--	--	--	2	1	14
Austin chalk	11	--	1	--	1	--	13
Edwards and associated limestones	256	7	6	2	13	2	286
Edwards and Glen Rose limestones	3	--	--	--	1	--	4
Glen Rose limestone	107	--	--	--	11	17	135
Glen Rose and Travis Peak formations	--	--	1	--	--	--	1
Travis Peak formation	1	--	--	--	--	--	1
TOTAL	895	14	35	4	55	26	1,029

DOMESTIC AND STOCK

Most of the water used for domestic and stock purposes is obtained from wells and springs. In the northern part of the county, where there are large cattle ranches, springs and seepage areas are important sources of stock water. In the southern part of the county, wells equipped with windmills or small-capacity electric or gas-driven pumps supply the comparatively small requirements of domestic and stock users.

PUBLIC SUPPLY

The water supply for Hondo is supplied by 4 drilled wells that penetrate the Edwards limestone. Two wells near the center of town were drilled in 1906 and 1909. The wells, I-3-133 and I-3-134, are 1,500 and 1,600 feet deep, respectively, and are equipped with turbine pumps. Wells I-3-117 and I-3-118 were drilled into the Edwards limestone at depths of 1,400 and 1,500 feet, respectively, in 1942 to supply the Hondo Air Force Base with water. These two wells also supplement the water supply of the city of Hondo. The daily average water use at Hondo including that at the air base, was about 475,000 gallons in 1952; maximum withdrawals were about 900,000 gallons per day.

Well J-1-82, drilled in 1923, supplied the city of Castroville with water from the Edwards limestone until 1948 when "sulfur" water entered the well through defective casing. Well J-1-83, presently supplying the city, was drilled in 1948. It is 715 feet deep and is equipped with a turbine pump operated by an electric motor. The following pumpage records were furnished by the city of Castroville.

Table 8.- Daily averages of water pumped at Castroville, Tex.

1951		1952	
Month	Gallons	Month	Gallons
January	49,000	January	71,000
February	55,000	February	63,000
March	54,000	March	63,000
April	61,000	April	57,000
May	71,000	May	61,000
June	69,000	June	102,000
July	122,000	July	79,000
August	134,000	August	134,000
September	105,000	September	168,000
October	81,000	October	140,000
November	56,000	November	97,000
December	71,000	December	86,000

A number of the residents of Lacoste use water pumped from the Southern Pacific Railway well, J-5-3. During times of drought, local farmers haul water from this well for domestic and stock use. The water is of good quality and is not treated.

Devine obtains its water supply from three wells in the Carrizo sand and a fourth well in the Indio formation. Wells J-7-20, J-7-21, in the Carrizo sand and J-7-22, in the Indio formation are in the well field under the elevated steel tank in the east part of town. Well J-7-41, in the Indio formation drilled in 1952, is in the west part of town. All the wells are equipped with electrically operated turbine pumps. The total pumpage from the four wells during 1952 was 50.29 million gallons. The monthly pumpage in 1952 was as follows:

Month	Gallons	Month	Gallons
January	3,267,500	July	4,560,000
February	3,447,500	August	5,500,000
March	3,017,500	September	4,400,000
April	3,517,000	October	4,147,500
May	3,960,000	November	3,975,000
June	4,255,000	December (est.)	3,850,000
TOTAL ---------------------------------- 50,291,000			

The water supply for Natalia comes from two drilled wells in the Carrizo sand. The wells are equipped with turbine pumps operated by electric motors. The total pumpage in 1951 was 16.98 million gallons and in 1952 was 19.60 million gallons. The total pumpage, by months, in 1952 was as follows:

Month	Gallons	Month	Gallons
January	1,462,000	July	2,323,000
February	1,440,000	August	2,752,000
March	1,333,000	September	1,837,000
April	1,518,000	October	1,649,000
May	1,756,000	November	1,547,000
June	1,979,000	December (est.)	1,480,000
TOTAL ------------------------ 21,076,000 gallons			

Public water supplies are not provided in D'Hanis, Quihi, Rio Medina, Dunlay, and Yancey. Water is obtained from privately owned shallow wells in the Leona formation, except at Yancey where water is obtained from sands in the Indio formation.

INDUSTRY

The principal industrial use of ground water in Medina County is for cooling and air conditioning. Many private homes and business establishments have shallow wells that supply water for evaporative air conditioners.

The Atlantic Pipeline Co. well (I-3-66), drilled to 1,341 feet taps the Edwards limestone. It is equipped with a turbine pump powered with an electric motor. The water is used for cooling at the Quihi pumping station. The Humble Refining Co. uses well J-5-18, drilled to a depth of 94 feet in the Carrizo sand, for cooling at the Natalia pumping station. The Natalia Cannery Co. obtains water from well J-4-131, drilled to a depth of 441 feet in the Indio formation. The water is used in canning vegetables grown in the Medina Irrigation District.

The Southern Pacific and the International and Great Northern Railroad lines used ground water from the Edwards limestone for filling locomotive boilers and for depot facilities until the advent of diesel engines. The water from the railroad wells is now used principally for public supply.

The Medina Valley State Fish Hatchery drilled a well, J-4-135, 69 feet deep in the Carrizo sand in 1951 to supplement the surface water supplying the fish ponds.

IRRIGATION

In 1952, there were 35 irrigation wells in Medina County, descriptions of which are given in table 9. The larger irrigation wells pump water from the Glen Rose limestone, the Edwards limestone, the Indio formation, the Carrizo sand, and the Leona formation. All the wells are equipped with turbine pumps powered by electric, gas, gasoline, or diesel motors. The irrigation of crops with ground water in Medina County is comparatively new, although crops have been irrigated with surface water since 1918. The earliest large development of ground water for irrigation began in 1934 when well I-6-20 was drilled 90 feet into the Leona formation. The well was equipped with a turbine pump and is reported to have yielded 650 gallons a minute. The major irrigation development has occurred since 1947, the largest number of irrigation wells having been completed in 1952.

FUTURE DEVELOPMENT

In most parts of Medina County, the water level in the principal limestone aquifer is more than 100 feet below the surface, thus retarding its use for irrigation. The contour map (pl. 3), showing the depth to the Georgetown limestone, indicates that it would be necessary to drill to a depth of more than 1,200 feet in most of the areas where the water might rise to less than 100 feet from the land surface. Analyses show that the Edwards in a large area in southern Medina County contains highly mineralized water (pl. 4 and 5). The area in the vicinity of Castroville is the most favorable for the development of large supplies of ground water of good quality.

The Indio formation yields moderate amounts of water having a wide variation in composition. The more permeable sands of this formation may be developed for supplemental irrigation, provided that the more highly mineralized zones of water are cased off and cemented. The variation in thickness of the water-bearing sands and their comparatively low permeability preclude any large development of ground water. Extensive test drilling will be necessary to determine the best localities.

Irrigation in Medina County from the Carrizo sand is limited by the sandy nature of the soil on the outcrop. It is probable that considerable additional land could be irrigated by using proper conservation practices and water sprinklers. The lowering of the water table accompanying an increase in pumping from the area would allow additional amounts of floodwater to enter the formation from streams crossing the outcrop. Water levels in wells in the outcrop area have shown an immediate rise after flow in the local streams.

The Leona formation consists of local terrace deposits of silt, sand, and gravel whose principal source of recharge is floodwater. Large supplies of water may be developed from this formation in areas having saturated sands and gravels of sufficient thickness and areal extent. The terraced deposits along Hondo Creek south of U. S. Highway 90 have the thickness and lateral extent necessary to store a large supply of ground water. Wells I-6-20 and I-6-76 in the Leona are used for irrigation.

SUMMARY OF CONCLUSIONS

The principal aquifers in Medina County are the Glen Rose limestone, the Edwards and associated limestones, the Escondido formation, the Indio formation, the Carrizo sand, and the Leona formation. Minor amounts of ground water are obtained from the Travis Peak formation, the Austin chalk, and the Anacacho limestone. The Anacacho limestone merges with the Taylor marl to the east. The Corsicana marl and Escondido formation become increasingly sandy to the west.

The rocks dip gently toward the coast and the movement of water is downdip except as controlled by faults of the Balcones system. Faults having large displacements form local barriers diverting the ground water from its normal course.

The hydraulic gradient of the water in the principal aquifer, shown by the altitudes of the water levels in wells, is southward from the recharge area, thence eastward. The absence of potable water in this aquifer in the southern part of the county indicates that little water moves southward out of the county. The altitude of the piezometric surface near Castroville is sufficiently high, as compared to the altitude of the water level in wells in San Antonio and at Comal Springs in New Braunfels, to indicate that water is able to move to these lower points of discharge.

The combined withdrawal of water from the principal aquifer by all wells in 1952 was approximately 1,810 acre-feet. Inasmuch as the estimated recharge to the Edwards limestone in the county is thought to average 90,000 acre-feet a year, the total discharge of water by all wells was only about 2 percent of the total recharge.

The observed range of coefficients of transmissibility of the lenticular sands of the Indio formation is from 10,000 to 20,000 gallons per day per foot. The wide variation in chemical composition of the water (the amount of dissolved solids ranges from 348 to 11,200 parts per million) is due to the variation in type of sediments and the conditions under which they were deposited, and the rate of movement of ground water in them and possibly to contamination by oil field wastes. The wide variation of factors affecting the storage and movement of ground water in the Indio formation suggests that extensive test drilling should precede the development of any large supplies of ground water. Supplies of water adequate for domestic and stock use and for supplemental irrigation may be obtained where there is more than 60 feet of saturated sand.

The coefficient of transmissibility of the Carrizo sand in the Devine well field is approximately 134,000 gallons per day per foot. The water is of uniformly good quality. Additional large quantities of water could be developed from the Carrizo without drastically lowering the water table, providing the wells were adequately spaced.

Water in sufficient quantities for public supply and irrigation can be obtained from wells in the principal aquifer in most parts of Medina County. In the southern part of the county, the water is too highly mineralized for most uses, and the aquifer probably has a relatively low permeability also. In the area near Castroville, the artesian water will rise to within a hundred feet of the surface.

Large supplies of ground water may be pumped for short periods of time from the Leona formation, but the small areal extent of the terraces and the comparative thinness of saturated sands and gravels limit the amount of ground water held in storage in the reservoirs and exclude nearly all the Leona formation in this county from further large-scale development.

REFERENCES

ADKINS, W. S., 1928, Handbook of Texas Cretaceous fossils: Texas Univ. Bull. 2838.

BROWN, N. K., JR., 1952, Upper Cretaceous Foraminifera from Seco Creek, Medina County, Tex.: Univ. Texas, M. A. thesis.

BRYAN, FRANK, 1933, Recent movement along the fault of the Balcones system, McLennan County, Tex.: Am. Assoc. Pet. Geol. Bull., vol. 17, p. 439-442.

BURLEIGH, HARRY L., 1949, Extract from report of geologic reconnaissance, Medina Project: U. S. Bureau of Reclamation, typed report, p. 9-15.

________ 1936, Evidence of recent movements along faults of the Balcones system in central Texas: Am. Assoc. Pet. Geol. Bull., vol. 20, no. 10, p. 1537-1571.

DUMBLE, E. T., 1903, Geology of southwestern Texas: Am. Inst. Min. Eng. Trans., vol. 33.

GARDNER, JULIA, 1933, The Midway group of Texas: Texas Univ. Bull. 3301, p. 75-77.

GEORGE, W. O., 1952, Geology and ground-water resources of Comal County, Tex.: U. S. Geol. Survey Water-Supply Paper 1138.

GUYTON, W. F., 1942, Results of pumping tests on wells at Camp Swift, Tex.: U. S. Geol. Survey typed open-file report, p. 6-17.

HILL, R. T. and VAUGHAN, T. W., 1898, Geology of the Edwards Plateau and Rio Grande Plain adjacent to Austin and San Antonio, Tex.: U. S. Geol. Survey 18th Ann. Rept., pt. 2.

IMLAY, R. W., 1945, Subsurface Lower Cretaceous formations of south Texas: Am. Assoc. Pet. Geol. Bull., vol. 29, p. 1416-1469.

LEITH, C. K. and MEAD, W. J., 1915, Metamorphic geology: Holt Publishing Co., New York.

LIDDLE, R. A., 1918, The geology and mineral resources of Medina County: Texas Univ. Bull. 1860.

LIVINGSTON, PENN, 1947, Relationship of ground water to the discharge of the Leona River in Uvalde and Zavala Counties, Tex.: Texas Board of Water Engineers.

LIVINGSTON, PENN, SAYRE, A. N., and WHITE, W. N., 1936, Water resources of the Edwards limestone in the San Antonio area, Texas: U. S. Geol. Survey Water-Supply Paper 773.

LONSDALE, J. T., 1927, Igneous rocks of the Balcones fault region of Texas: Texas Univ. Bull. 2744.

____________ 1935, Geology and ground-water resources of Atascosa and Frio Counties, Tex.: U. S. Geol. Survey Water-Supply Paper 678.

MEINZER, O. E., 1923, The occurrence of ground water in the United States, with a discussion of principles: U. S. Geol. Survey Water-Supply Paper 489.

____________ 1923, Outline of ground-water hydrology, with definitions: U. S. Geol. Survey Water-Supply Paper 494.

____________ 1942, Physics of the earth, part 9, Hydrology, New York: McGraw-Hill Book Co., Inc.

____________ 1946, General principles of artificial ground-water recharge: Econ. Geol., vol. 41, p. 191-201.

SAYRE, A. N., 1936, Geology and ground-water resources of Uvalde and Medina Counties, Tex.: U. S. Geol. Survey Water-Supply Paper 678.

SAYRE, A. N., and STRINGFIELD, V. T., 1948, Artificial recharge of ground-water reservoirs: Am. Water Works Assoc. Journal, vol. 40, p. 1152-1158.

SELLARDS, E. H., 1919, The geology and mineral resources of Bexar County: Texas Univ. Bull. 1932.

____________ 1931, Rocks underlying Cretaceous in Balcones fault zone of central Texas: Am. Assoc. Pet. Geol. Bull., vol. 15, p. 819-827.

SELLARDS, E. H., ADKINS, W. S., and PLUMMER, F. B., 1932, The geology of Texas: Texas Univ. Bull. 3232.

STEAD, F. L., 1951, Foraminifera of the Glen Rose formation (Lower Cretaceous) of central Texas: Texas Journal of Sci., vol. 3, no. 4, p. 577-605.

STENZEL, H. B., 1951, New observations on the Wilcox group: Am. Assoc. Pet. Geol. Bull., vol. 35, no. 12, abstract, p. 2625.

STEPHENSON, L. W., 1915, The Cretaceous-Eocene contact in the Atlantic and Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 90, p. 155-182.

____________ 1927, Notes on the stratigraphy of the Upper Cretaceous formations of Texas and Arkansas: Am. Assoc. Pet. Geol. Bull., vol. 11, p. 1-17.

____________ 1929, Unconformities in the Upper Cretaceous series of Texas: Am. Assoc. Pet. Geol. Bull., vol. 13, p. 1323-1334.

____________ 1941, The larger invertebrate fossils of the Navarro group of Texas: Texas Univ. Bull. 4101.

STEPHENSON, L.W., 1953, Probable Reklaw age of a ferruginous conglomerate in eastern Texas: U. S. Geol. Survey Prof. Paper 243-C, p. 31-43.

THEIS, C. V., 1938, The significance and nature of the cone of depression in ground-water bodies: Econ. Geol., vol. 33, no. 8, p. 889-902.

TOLMAN, C. F., 1937, Ground water, New York: McGraw-Hill Book Co., Inc., p. 96-380.

TROWBRIDGE, A. C., 1923, Tertiary stratigraphy in the lower Rio Grande region: Geol. Soc. of Am. Bull. 34.

U. S. GEOLOGICAL SURVEY, 1933, Surface-water supply of the United States, 1930, part 8, Western Gulf of Mexico basins: U. S. Geol. Survey Water-Supply Paper 748.

U. S. PUBLIC HEALTH SERVICE, 1946, Public Health Service drinking water standards: Reprint 2697, p. 13.

VAUGHAN, T. W., 1900, Description of the Uvalde quadrangle: U. S. Geol. Survey, Geol. Atlas, Uvalde folio, p. 2-3.

WENZEL, L. K., 1942, Methods of determining permeability of water-bearing materials, with special reference to discharging-well methods: U. S. Geol. Survey Water-Supply Paper 887.