TEXAS WATER DEVELOPMENT BOARD

Report 174

GROUND-WATER RESOURCES OF BLANCO COUNTY, TEXAS

August 1973

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GROUND-WATER RESOURCES OF BLANCO COUNTY, TEXAS

By

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United States Geological Survey

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GROUND-WATER RESOURCES OF BLANCO COUNTY, TEXAS

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ABSTRACT

The geologic and hydrologic units in Blanco County that yield water to wells, or are capable of yielding water, range in age from Precambrian to Quaternary. The units that yield at least moderate or large quantities of fresh to moderately saline water to wells are, in order of decreasing yields, the Ellenburger-San Saba aquifer, Pearsall Formation, lower member of the Glen Rose Limestone, and Hickory Sandstone Member of the Riley Formation. The upper member of the Glen Rose Limestone; the Pennsylvanian, Mississippian, and Devonian rocks; the rocks between the Ellenburger-San Saba aquifer and the Hickory Sandstone Member of the Riley Formation; and the Precambrian rocks yield only very small to small quantities of fresh to moderately saline water to wells. The Sligo and Hosston Formations, Walnut Clay, Edwards and associated limestones, and Quaternary deposits are not known to yield water to wells, although the Quaternary alluvium probably would yield very small to small quantities of fresh water.

Ground water in Blanco County is used primarily for rural-domestic and stock needs, and to a lesser extent for municipal supply and irrigation. Use of ground water for all purposes in 1968 was about 1,400 acre-feet or 1.2 mgd (million gallons per day). Of this amount, about 1,300 acre-feet was used for rural-domestic and stock needs. Only 15 acre-feet of ground water was used for public supply.

About 26,000 acre-feet per year of fresh to slightly saline water is available for ground-water development from all of the aquifers on a long-term basis. This quantity is 19 times the ground-water usage for all purposes in the county in 1968.

The present yields of wells range from less than 1 to about 600 gpm (gallons per minute). Yields of 200 to 600 gpm from wells are unusual because the potential yield of wells drilled in most places in the county is from 10 to 25 gpm.

Ground water of good to fair quality for public and domestic supplies is available in most of the county, and much of the water meets the standards recommended by the U.S. Public Health Service. Hardness probably is the most objectionable property.

Ground water in Blanco County is suitable for many industrial applications or can be made suitable. The corrosive potential of the water is low, but the very hard water will require softening for some industrial applications.

Because irrigation in Blanco County is practiced only during periods of deficient rainfall, use of the ground water for irrigation is considered safe. The sodium hazard is mostly low, but the salinity hazard ranges from medium to very high.

GROUND-WATER RESOURCES OF BLANCO COUNTY, TEXAS

INTRODUCTION

Purpose and Scope of the Investigation

The purpose of the investigation, which was made by the U.S. Geological Survey in cooperation with the Texas Water Development Board, was to determine the occurrence, quality, availability, and dependability of the water resources of Blanco County and to make the results of the study available in a report to the public. The report is based on the records of 585 wells, 48 springs, three electrical logs of wells, 49 drillers' logs, 526 chemical analyses of water from wells and springs, and climatological data.

During the investigation, which started in 1968, an inventory was made of all municipal wells, oil tests, and irrigation wells, and a sufficient number of stock wells, domestic wells, and springs to provide basic ground-water data throughout the county (Table 9 and Figure 13). Drillers' logs of water wells and oil tests (Table 10) and electrical logs of oil tests were used in conjunction with other data in studying the subsurface geology.

The municipal and irrigation pumpage was inventoried, and pumpage for rural-domestic and stock use was estimated. Water samples were taken to provide representative information on the quality of the water (Table 11).

The investigation was facilitated by assistance and information furnished by city officials, farmers, ranchers, and personnel of the U.S. Department of Agriculture.

Location and Extent of the Area

Blanco County, an area of 719 square miles in central Texas, is near the southeast edge of the Edwards Plateau, and includes part of the Llano Uplift (Figure 1). The county is bounded on the north by Llano and Burnet Counties, on the east and southeast by Travis, Hays, and Comal Counties, on the southwest by Kendall County, and on the west by Gillespie County. Johnson City, the county seat, is on the Pedernales River at the junction of U.S. Highways 281 and 290 about 45 miles west of Austin.

Previous Investigations

No previous detailed study had been made of the ground-water resources of Blanco County, but a few basic-data and reconnaissance reports include all or parts of the county. A well-inventory report (Barnes and Cumley, 1942) contained records of 389 wells and 45 springs, logs of seven oil tests, and the results of chemical analyses of water from 382 wells and springs. Some of these data are included in this report. Table 1 lists the well numbers used in this report and the corresponding numbers used in the report by Barnes and Cumley (1942).

The public water supply of the town of Blanco was described by Sundstrom, Broadhurst, and Dwyer (1949). Alexander, Myers, and Dale (1964) included data for the southern part of Blanco County in a ground-water reconnaissance report. Mount and others (1967) included data for the northern part of Blanco County in a similar reconnaissance report.

History and Economic Development

As fear of Indian raids diminished in the early 1850's, the first permanent settlements of English-speaking colonists were attracted to Blanco County by the many springs and flowing streams, and the favorable land for sheep and cattle ranching. Some of these springs still furnish water used in nearby rock houses, many of which were constructed in the 1850's. The Walnut Creek Methodist Church, 8 miles northwest of Round Mountain, has been in use since 1855 and for many years depended upon the shallow ground-water supply for domestic purposes; a nearby spring-fed pool probably was used for baptizing.

Blanco County was organized in 1858, and by 1860 the U.S. Bureau of Census listed the county population as 1,281. The population increased to a maximum of 4,703 in 1900, and by 1960 had decreased to 3,657. Johnson City and Blanco, the principal towns, had populations of 767 and 1,022 respectively in 1970.

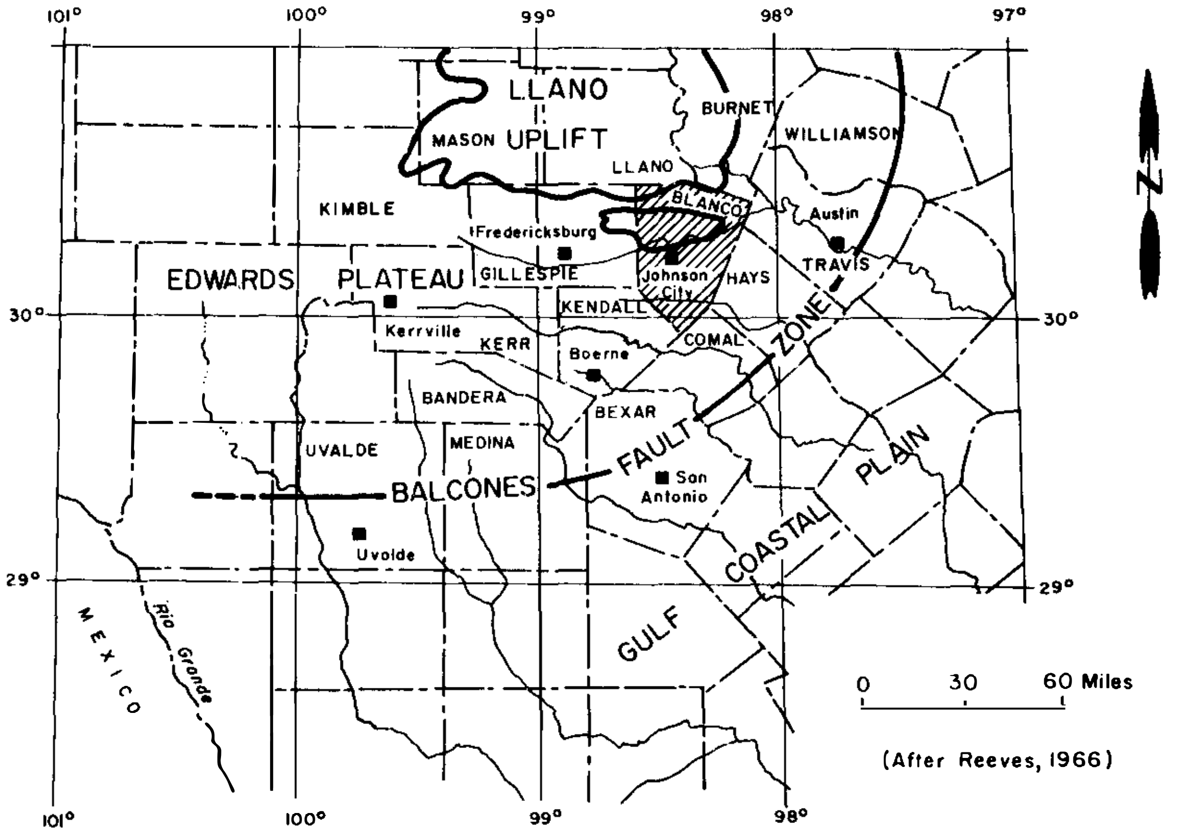

Figure 1.–Physiographic Features of Central Texas and Location of Blanco County

The picturesque landscape of Blanco County has long been popular with hunters. During the 1960's, people from San Antonio, Austin, and elsewhere bought many small ranches for recreational purposes and some larger ranches for investments. Tourist business has been increasing because of the proximity of the county to the boyhood home and ranch of ex-President Lyndon B. Johnson.

The economy of Blanco County is based principally on cattle, sheep and goats, and turkeys, estimated by the Texas Crop and Livestock Reporting Service as 20,000, 100,000, and 100,000 head, respectively, in 1964. Deer hunting also is important to the county's economy.

The cultivated acreage is small, less than 4 percent of the total area according to the U.S. Census of Agriculture in 1964. The amount is decreasing because some of the cultivated land is being converted to improved pastures. Farming consists principally of the production of feed for stock use. The value derived from manufacturing or industry, mostly trailer construction and feed grinding, is only a small part of the total economy. No oil or gas has been produced in the county.

Topography and Drainage

The land surface of Blanco County is predominantly hilly. The minimum altitude is about 730 feet above mean sea level in the bed of the Pedernales River where it leaves Blanco County. The maximum altitude is 1,901 feet at Circle triangulation station, 6½ miles northwest of Blanco. This maximum altitude is on the watershed divide between the Blanco and Pedernales Rivers. Regionally, the land surface slopes southeastward, although the Blanco and Pedernales Rivers flow generally east.

The county is well drained by streams within the Colorado and Guadalupe River Basins. The watershed divide between the two basins is roughly along an east-west line about 3 miles north of Blanco. The Pedernales River, which is north of the divide, is in the Colorado River Basin. The Blanco and Little Blanco Rivers, which are south of the divide, are in the Guadalupe River Basin. A small area in the northern part of the county is drained by small creeks into the Colorado River.

The Geological Survey has maintained a gaging station on the Pedernales River near Johnson City since May 1939. During most of this period, a recording gage

Table 1.--Well Numbers Used in This Report and Corresponding Numbers Used by Barnes and Cumley (1942)

NEW NUMBER	OLD NUMBER	NEW NUMBER	OLD NUMBER	NEW NUMBER	OLD NUMBER
AZ-57-36-201	3	AZ-57-37-603	53	AZ-57-38-804	74
202	1	604	60	901	91
203	2	702	17	902	85
301	9	703	16	904	86
302	8	704	18	908	92
601	10	705	33	39-401	90
801	4	706	15	601	96
803	5	801	35	703	93
805	6	802	38	705	94
806	7	804	36	801	95
901	11	805	37	802	112
902	12	901	51	803	113
904	13	902	52	901	98
37-101	25	903	49	902	97
102	24	904	50	904	111
103	22	905	62	44-201	269
104	23	38-101	57	301	243
106	21	102	56	502	270
202	42	104	68	503	271
203	41	201	79	601	266
205	28	202	80	602	265
206	29	406	67	603	267
207	27	407	66	604	268
208	26	408	58	801	260
209	30	410	59	802	272
301	44	411	69	803	273
302	43	412	71	804	274
303	47	501	78	901	261
305	46	502	70	903	262
307	45	503	82	904	263
401	20	504	81	905	258
404	19	506	76	907	259
501	32	507	77	908	246
502	31	601	87	45-102	216
503	40	701	64	103	217
504	48	702	65	107	240
506	39	703	63	109	241
601	55	802	83	110	242
602	54	803	75	112	214

Table 1.—Well Numbers Used in This Report and Corresponding Numbers Used by Barnes and Cumley (1942)—Continued

NEW NUMBER	OLD NUMBER	NEW NUMBER	OLD NUMBER	NEW NUMBER	OLD NUMBER
AZ-57-45-113	215	AZ-57-45-905	166	AZ-57-52-207	279
201	211	909	168	209	276
202	219	912	191	210	275
203	210	46-101	156	301	256
204	209	102	157	303	277
205	212	201	73	304	257
206	213	204	155	306	252
207	218	205	72	308	250
303	159	302	137	309	249
306	186	304	84	311	248
308	158	305	134	314	251
401	239	306	135	401	291
403	220	307	136	502	281
501	208	308	140	504	293
502	221	309	139	506	280
601	161	310	133	601	307
602	190	311	138	602	304
603	160	403	162	604	255
604	189	601	129	606	306
605	188	602	128	607	305
607	187	604	127	801	297
701	236	701	154	802	296
702	237	702	164	803	295
705	235	703	153	804	294
707	222	704	167	806	298
708	245	706	165	903	313
709	244	801	143	904	303
710	238	802	144	905	302
711	234	901	126	906	308
802	192	906	142	907	309
803	203	47-101	132	53-103	247
804	224	102	115	104	232
805	223	104	130	106	231
806	207	105	131	108	233
807	205	201	114	202	198
808	204	401	116	205	228
809	206	702	117	206	202
903	163	52-203	278	209	225

Table 1.—Well Numbers Used in This Report and Corresponding Numbers Used by Barnes and Cumley (1942)—Continued

NEW NUMBER	OLD NUMBER	NEW NUMBER	OLD NUMBER	NEW NUMBER	OLD NUMBER
AZ-57-53-211	226	AZ-57-54-201	152	AZ-57-61-205	342
212	227	304	125	206	344
213	199	401	147	207	340
214	200	402	150	208	333
216	201	404	148	304	368
301	194	405	455	305	404
306	169	406	454	306	408
307	170	408	149	307	406
309	171	409	172	309	405
312	193	502	458	402	324
401	230	503	456	403	323
402	254	504	457	405	325
403	317	505	146	503	331
501	352	602	124	504	330
502	353	603	123	505	371
503	196	604	145	506	372
504	197	605	459	601	416
506	229	606	121	602	370
510	351	607	122	603	415
511	350	702	452	604	419
512	349	801	453	605	420
602	173	804	451	606	418
603	174	805	450	607	417
604	195	55-102	119	608	414
605	401	103	120	610	409
702	320	106	118	611	410
703	315	60-202	299	612	369
706	319	203	300	614	413
708	318	302	311	615	412
709	316	303	312	701	326
801	348	306	314	702	327
802	347	308	310	803	380
803	345	61-103	321	804	382
805	346	104	322	805	381
902	403	201	334	808	328
903	402	202	337	809	329
904	354	203	338	901	373
54-101	151	204	343	902	374

Table 1.—Well Numbers Used in This Report and Corresponding Numbers Used by Barnes and Cumley (1942)—Continued

NEW NUMBER	OLD NUMBER	NEW NUMBER	OLD NUMBER	NEW NUMBER	OLD NUMBER
AZ-57-61-903	375	AZ-57-62-403	441	AZ-57-05-202	390
906	376	404	440	207	388
907	377	408	439	301	387
909	378	501	473	302	428
910	379	503	471	303	426
62-102	445	504	472	304	427
104	446	505	470	307	385
105	444	701	432	308	383
106	448	702	431	310	384
107	449	703	435	311	421
202	466	704	433	312	386
203	465	705	436	313	422
204	463	706	438	314	425
205	468	708	434	315	423
206	467	801	437	316	424
207	464	802	475	601	391
208	447	803	476	06-101	429
401	442	804	474	103	430
402	443	05-201	389		

located at the bridge on U.S. Highway 281 has supplied a continuous record of the streamflow. The drainage area upstream from the station is 947 square miles, about 160 square miles of which is in Blanco County. The average discharge for 30 years of record (water years 1940-69) was 153 cfs (cubic feet per second) or 110,800 acre-feet per year. During this period, the maximum discharge was 441,000 cfs on September 11, 1952; there was no flow at various times in 1951-52, 1954, 1956-57, 1963-64, and 1967-68. The flood stage of 42.5 feet on September 11, 1952, was the maximum since at least 1859. A flood in July 1869 reached a stage of 33 feet.

Climate

Blanco County has a dry subhumid climate in which the annual potential evapotranspiration exceeds the annual precipitation. Mild winters and hot summers are common. The average growing season is 234 days.

The annual precipitation at Blanco averaged 31.76 inches for the period 1897-1968 and ranged from 12.98 inches in 1901 to 55.06 inches in 1919 (Figure 2). Average monthly precipitation for the 72-year period ranged from 1.91 inches in January to 3.73 inches in May and averaged 2.65 inches (Figure 3). Actual monthly precipitation during the period ranged from 0 or a trace in 22 separate months to 22.66 inches in September 1952; 12 months had more than 10 inches of rainfall.

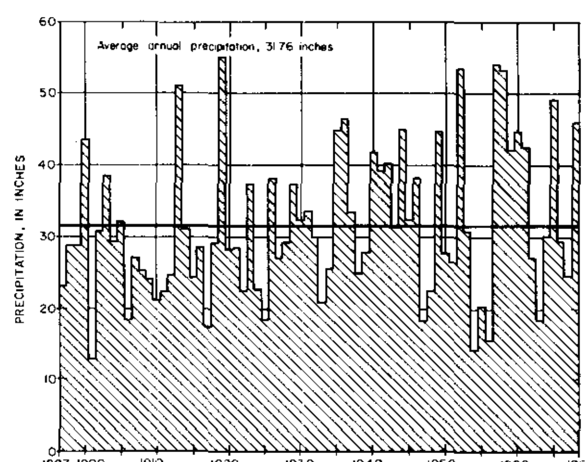

Figure 2.—Annual Precipitation at Blanco, 1897-1968

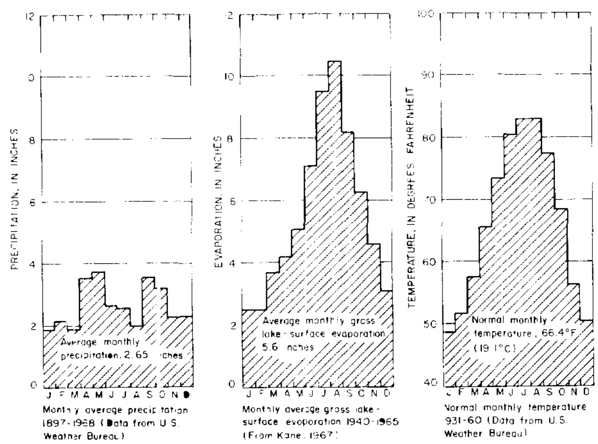

Figure 3.—Average Monthly Precipitation and Normal Monthly Temperature at Blanco, and Average Monthly Gross Lake-Surface Evaporation in Blanco County

The average gross lake-surface evaporation in Blanco County was 5.6 inches monthly, or 67.3 inches annually, for the period 1940-65 (Kane, 1967, p. 85). Thus the average annual gross lake-surface evaporation is about twice the average annual precipitation.

The normal monthly temperature at Blanco during the period 1931-60 was 66.4°F (19.1°C). July and August are the hottest months; January is the coldest month. Generally, as the monthly temperature increases or decreases, there is a corresponding increase or decrease in monthly gross lake-surface evaporation (Figure 3), although humidity and wind velocity are other factors affecting evaporation.

Well-Numbering System

The well-numbering system used in this report is one adopted by the Texas Water Development Board for use throughout the State and is based on latitude and longitude. Under this system, each 1-degree quadrangle in the State is given a number consisting of two digits from 01 to 89. These are the first two digits appearing in the well number. Each 1-degree quadrangle is divided into 7½-minute quadrangles which are given 2-digit numbers from 01 to 64. These are the third and fourth digits of the well number. Each 7½-minute quadrangle is subdivided into 2½-minute quadrangles and given a single digit number from 1 to 9. This is the fifth digit of the well number. Finally, each well within a 2½-minute quadrangle is given a 2-digit number in the order in which it is inventoried, starting with 01. These are the last two digits of the well number. In addition to the 7-digit well number, a 2-letter prefix is used to identify the county. The prefix for Blanco County is AZ. Thus, well AZ-57-46-601 (domestic and stock well, owned by Mrs. C. A. Wheatley) is in Blanco County (AZ), in the 1-degree quadrangle 57 (the numbers of all the wells in Blanco County begin with either AZ-57 or AZ-68), in the 7½-minute quadrangle 46, in the 2½-minute quadrangle 6, and was the first well (01) inventoried in the 2½-minute quadrangle (Figure 4).

On the well- and spring-location map in this report (Figure 13), the 1-degree quadrangles are numbered in large bold numerals. The 7½-minute quadrangles are numbered in their northwest corners where possible. The 3-digit number shown with the well symbol contains the number of the 2½-minute quadrangle in which the well is located and the number of the well within that quadrangle. For example, the W. D. Stevenson well (AZ-57-45-801) is shown in Figure 13 with the number 801 in quadrangle 45.

Definitions of Terms

In the following sections of the report, certain technical terms subject to different interpretations are used. For convenience and clarification, these terms are defined as follows:

Aquifer—A geologic formation, group of formations, or part of a formation that is water bearing.

Artesian water—Ground water that is under sufficient pressure to rise above the level at which it is encountered in a well; it does not necessarily rise to or above the surface of the ground.

Fault—A fracture in the earth's crust, with displacement of one side of the fracture with respect to the other.

Fresh water—Water containing less than 1,000 mg/l (milligrams per liter) dissolved solids (Winslow and Kister, 1956, p. 5).

Hydraulic conductivity—The rate of flow of water in gallons per day through a cross sectional area of 1 square foot under a unit hydraulic gradient.

Moderately saline water—Water containing 3,000 to 10,000 mg/l dissolved solids (Winslow and Kister, 1956, p. 5).

Potentiometric surface—The imaginary surface to which water will rise in artesian wells, or the surface formed by the water table in the outcrop areas. The terms "water table" and "potentiometric surface" are synonymous in the outcrop area, but potentiometric surface alone is applicable in artesian areas.

Slightly saline water—Water containing 1,000 to 3,000 mg/l dissolved solids (Winslow and Kister, 1956, p. 5).

Specific conductance (conductivity)—A measure of the ability of a solution to conduct electricity,

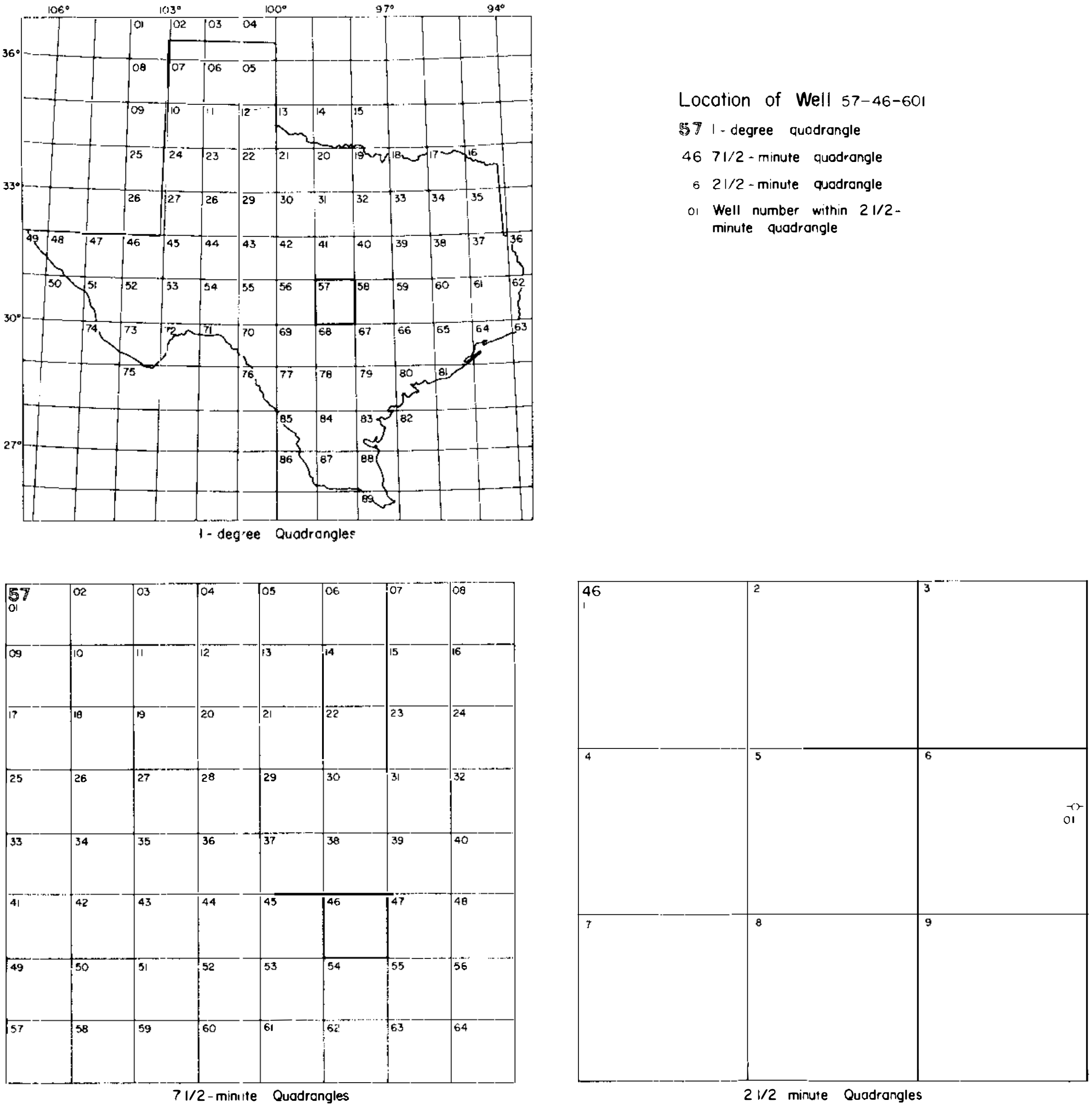

Figure 4
Well-Numbering System

expressed in micromhos at 25°C. It is approximately proportional to the content of dissolved solids.

Transmissivity—The number of gallons of water that will move in one day through a vertical strip of the aquifer one foot wide and having the height of the aquifer when the hydraulic gradient is unity. It is the product of the hydraulic conductivity and the saturated thickness of the aquifer.

Water level, static level, or hydrostatic level—In an unconfined aquifer, the distance from the land surface to the water table. In a confined (artesian) aquifer, the level to which the water will rise either above or below land surface.

Water table—The upper surface of a saturated zone under atmospheric pressure.

Yield—The following ratings apply for general discussion of yields of wells in Blanco County.

DESCRIPTION	YIELD (GALLONS PER MINUTE)
Very small	Less than 5
Small	5 to 20
Moderate	20 to 100
Large	More than 100

GEOLOGY AS RELATED TO THE OCCURRENCE OF GROUND WATER

Meinzer, (1934, p. 6) best describes in a few words the relationship of geology to ground water—"Geology affords the framework on which hydrology is built; more accurately, it describes the rock formations that make up the great and intricate system of natural waterworks, the functioning of which forms the essential part of the subject of ground-water hydrology."

The geologic and hydrologic units that are exposed at the land surface in Blanco County (Figure 5) range in age from Precambrian (more than 500 million years old) to Quaternary (less than 1 million years old). They mostly consist of limestone, dolomite, sandstone, shale, granite, schist, and gneiss. Not all of the rocks are water bearing, and those that are water bearing yield varying amounts of water to wells. Table 2 lists the geologic and hydrologic units in the county and gives their approximate thickness, lithologic character, and water-bearing properties. The position and correlation of most of these units in the subsurface is illustrated in a north-south section (Figure 6). Location of the section is shown on Figure 13.

The principal structural influence on ground water is the complex faulting associated with the Llano Uplift. Almost all of the faults are restricted to the Paleozoic and older rocks. In many areas, entire geologic and hydrologic units are in juxtaposition with units that are of a different age and which have different hydrologic properties. The Cretaceous rocks, which overlap the Paleozoic and older rocks, are relatively unfaulted. Only one fault is known to displace the Cretaceous rocks.

Precambrian Rocks

Precambrian rocks crop out in several areas in the northwestern part of the county. The outcrops are mostly from 7 to 18 miles northwest of Johnson City. With the exception of two small exposures near Gillespie County, the outcrops are restricted to the area north of the Pedernales River.

The Precambrian rocks, which are igneous and metamorphic, are mostly medium to coarse-grained granite, amphibole and mica schist, and quartz diorite gneiss. Exposures of granite are slightly more extensive than those of the schist and gneiss.

The Precambrian rocks yield very small to small quantities of fresh water to dug and drilled wells. The wells obtain much of their water from fractures and faults, although some water may be obtained from the shallow weathered zone of granite.

Hickory Sandstone Member of Riley Formation

The Hickory Sandstone Member of the Riley Formation of the Upper Cambrian Series overlies the Precambrian rocks and crops out in the northwestern part of the county. Exposures are highly irregular in shape, partly due to faulting and partly due to overlapping by Cretaceous rocks. The Hickory Sandstone Member dips predominantly southeastward from the outcrop area at angles up to about 10° in some areas (Barnes, 1963, p. 2). In well AZ-57-45-301, drilled as an oil test 4.5 miles north-northeast of Johnson City, the top of the Hickory is about 1,100 feet below land surface (Figure 6).

The Hickory consists mostly of noncalcareous, non-glauconitic, crossbedded sandstone. The lower part is massive, and conglomerate lenses occur near the base in some areas. The upper part is less massive and has considerable shale and silt near the top. Maximum thickness of the Hickory is not known because few wells penetrate it due to its deep occurrence in most of the county. However, well data indicate that it is at least 300 feet thick.

The Hickory Sandstone yields small to moderate quantities of fresh to slightly saline water to wells. Drillers have reported test-bailing as much as 30 gpm during short tests. All of the wells known to produce water from the Hickory are north of U.S. Highway 290

Table 2.—Geologic and Hydrologic Units and Their Water-Bearing Properties

SYSTEM	SERIES	GROUP	GEOLOGIC OR HYDROLOGIC UNIT	APPROXIMATE THICKNESS (FEET)	LITHOLOGY	WATER-BEARING PROPERTIES
Quaternary	Holocene and Pleistocene		Alluvium, fanglomerate, and high level gravel	0 - 20 ?	Gravel, sand, silt, and clay.	Not known to yield water to wells in Blanco County. Alluvium probably would yield very small to small quantities of fresh water in some places along the Pedernales and Blanco Rivers.
Cretaceous	Comanche	Fredericksburg	Edwards and associated limestones	0 - 160	Hard massive limestone, nodular marly limestone, dolomite, and flint.	Not known to yield water to wells in Blanco County but may contribute some water to uncased holes tapping the Glen Rose Limestone. Yields water to springs near the base of the unit.
			Walnut Clay	0 - 13	Silty marl, clay, and basal coquina.	Not known to yield water to wells.
		Trinity	Glen Rose Limestone: Upper member	0 - 330 ?	Shale and marl alternating with thin beds of impure limestone and dolomite; impure anhydrite beds at base and near middle.	Yields very small to small quantities of fresh to moderately saline water to wells in much of the county.
			Glen Rose Limestone: Lower member	0 - 250 ?	Massive fossiliferous limestone in basal part grading upward into thin beds of limestone, marl and shale; *Salenia texana* and *Corbula texana* Whitney beds at top.	Yields very small to moderate quantities of fresh to slightly saline water to wells in much of the county.
			Travis Peak (Pearsall) Formation	0 - 285 ?	Sandstone, massive fossiliferous limestone, sandy limestone, dolomite, conglomerate, sand, clay, and shale.	Yields small to large quantities of fresh to moderately saline water to wells in much of the county.
	Coahuila	Nuevo León and Durango of Mexico	Sligo and Hosston Formations	0 - 210 ?	Shale, limestone, dolomite, sand, sandstone, and conglomerate.	Not known to yield water to wells in Blanco County.
Carboniferous, Devonian, and Devonian(?)	Middle and Lower Pennsylvanian; Upper and Lower Mississippian; Upper, Middle, and Lower Devonian, and Devonian (?)		Pennsylvanian, Mississippian, and Devonian rocks	0 - 800 ?	Massive limestone, in part cherty, shale, calcareous spiculite, lenticular biohermal limestone, crinoidal limestone, and chert.	Yields very small to small quantities of fresh to slightly saline water to a few wells near the Pedernales River south of Cypress Mills and at Cypress Mills.
Ordovician and Cambrian	Lower Ordovician and Upper Cambrian		Ellenburger - San Saba aquifer	0 - 2,310 +	Thinly to thickly bedded cherty limestone and dolomite; rocks honeycombed and cavernous in places.	Yields small to large quantities of fresh to moderately saline water to wells north of an east-west line about midway between Johnson City and Blanco.
Cambrian	Upper Cambrian		Rocks between Ellenburger - San Saba aquifer and Hickory Sandstone Member of Riley Formation	0 - 755 +	Thinly to thickly bedded limestone, in part biohermal, glauconitic, and shaley; glauconitic to nonglauconitic sandstone; and shale.	Yields very small to small quantities of fresh water to wells north of U.S. Highway 290 and west of U.S. Highway 281.
			Hickory Sandstone Member of Riley Formation	0 - 300 +	Mostly noncalcareous, nonglauconitic, crossbedded sandstone; lower part massive with conglomerate lenses near base; upper part less massive with considerable shale and silt near top.	Yields small to moderate quantities of fresh to slightly saline water to wells north of U.S. Highway 290 and west of U.S. Highway 281.
Precambrian	Llano		Precambrian rocks	—	Mostly medium to coarse-grained granite, amphibole and mica schist, and quartz diorite gneiss.	Yields very small to small quantities of fresh water to wells.

and west of U.S. Highway 281. Insufficient well data prevent an accurate determination of the downdip limit of fresh to slightly saline water, but the limit probably is less than five miles south of the Pedernales River.

Rocks Between Hickory Sandstone Member of Riley Formation and Ellenburger-San Saba Aquifer

The rocks between the Hickory Sandstone Member of the Riley Formation and the Ellenburger-San Saba aquifer comprise, from oldest to youngest, the Cap Mountain Limestone and Lion Mountain Sandstone Members of the Riley Formation, and the Welge Sandstone, Morgan Creek Limestone and Point Peak Shale of the Wilberns Formation, all in the Upper Cambrian Series. These are treated as a unit because individually they are relatively insignificant in regard to the hydrology of the area.

The unit crops out almost entirely in the northwest quarter of the county and generally dips southeastward. In well AZ-57-45-301, about 3 miles east of the nearest outcrop of the unit, the top of the unit is at a depth of 380 feet below land surface (Figure 6).

The rocks between the Hickory and the Ellenburger-San Saba aquifer are mostly thinly to thickly bedded limestone that is partly biohermal, glauconitic, and shaley; and glauconitic to non-glauconitic sandstone; and shale. In well AZ-57-62-101, drilled as an oil test 4 miles east of Blanco, the rock unit was reported by Barnes (1967a, p. 4) to have a thickness of 755 feet. Maximum thickness is believed to be in excess of 755 feet.

The rocks between the Hickory Sandstone Member and the Ellenburger-San Saba aquifer yield very small to small quantities of fresh water to wells north of U.S. Highway 290 and west of U.S. Highway 281. Buffalo Springs (spring AZ-57-45-204, 4½ miles northwest of Johnson City), which issues from the basal part of the rock unit, flowed an estimated 500 gpm in July 1941.

Ellenburger-San Saba Aquifer

The Ellenburger-San Saba aquifer includes the San Saba Limestone Member of the Wilberns Formation of Cambrian age and Ellenburger Group of Ordovician and Cambrian age. The two formations are designated as a single aquifer because they are lithologically similar and function hydrologically as a unit.

The aquifer crops out mostly north of an east-west line through Johnson City. Extensive exposures extend for several miles along much of the Pedernales River and along Cypress Creek from U.S. Highway 281 to Cypress Mills. From the outcrop areas, the aquifer dips predominantly southeastward into the subsurface at angles up to 10° in some areas (Barnes, 1963, p. 2). In wells AZ-57-61-305, 2½ miles northeast of Blanco and about 10 miles from the nearest outcrop of the Ellenburger-San Saba aquifer, the top of the aquifer is estimated to be about 1,000 feet below land surface (Figure 6).

The Ellenburger-San Saba aquifer is composed of thinly to thickly bedded cherty limestone and dolomite. In places, the rocks are honeycombed and cavernous. Maximum thickness of the aquifer is not known, but is believed to be in excess of 2,310 feet. This thickness was reported by Barnes (1967a, p. 4) in well AZ-57-62-101, 4 miles east of Blanco.

The Ellenburger-San Saba aquifer yields small to large quantities of fresh to moderately saline water to wells. All of the wells known to produce from the aquifer are north of an east-west line about midway between Johnson City and Blanco.

The quantity of water yielded by a well tapping the aquifer depends on the size and number of solution openings in the rock penetrated by the well. Widely variable yields are common because the water is contained in honeycombed and cavernous zones in the aquifer, in fractures, and along fault planes where openings have been enlarged by solution. For example, only 3 and 45 gpm were reportedly obtained from two test wells that were drilled within 1 mile of two irrigation wells which yield 200 gpm each. The location of highly favorable well sites prior to drilling are, for the most part, unpredictable; therefore the more productive wells are largely the result of chance or of considerable test drilling. Six wells tapping the aquifer in the county yield from 150 to 610 gpm, and wells having a similar capacity probably could be developed by test drilling. In existing wells, where large yields are desired, the process of acidizing the formation, whereby solution openings are enlarged, may be effective in increasing the yields.

Many springs in the county flow from the Ellenburger-San Saba aquifer. Springs AZ-57-45-608 and AZ-57-45-601 flowed a measured 470 and 1,650 gpm, respectively, in May 1969. Although the flow from these springs is much less during periods of less than normal rainfall, they have not been known to fail. Cloud and Barnes (1948, p. 133) reported several springs flowing from 5 to 60 gpm.

The maximum depth and lateral extent of the fresh to slightly saline water in the Ellenburger-San Saba aquifer could not be determined because of the lack of deep-well data downdip from the outcrop. The mineralization of the water can be expected to increase downdip until it becomes unsuitable for most purposes.

Devonian, Mississippian, and Pennsylvanian Rocks

The Devonian, Mississippian, and Pennsylvanian rocks comprise, from oldest to youngest, the Pillar Bluff(?) Limestone of the Lower Devonian(?), Stribling Formation of the Lower and Middle Devonian, Ives Breccia Member of Houy Formation of the Middle and Upper Devonian, Chappel Limestone of the Lower Mississippian, Barnett Shale of the Lower and Upper Mississippian, and Marble Falls Limestone and Smithwick Shale of the Lower and Middle Pennsylvanian. These formations are treated as a unit because in Blanco County they contain a relatively small quantity of water.

The Devonian, Mississippian, and Pennsylvanian rocks crop out almost entirely in a narrow band along a 6- to 7-mile reach of the Pedernales River east of Johnson City. A small exposure, not shown on Figure 5, is at Cypress Mills. From the outcrop areas, the rocks dip southeastward into the subsurface, and in many places directly underlie the Cretaceous rocks.

The Devonian, Mississippian, and Pennsylvanian rocks consist of massive limestone that is in part cherty, shale, calcareous spiculate, lenticular biohermal limestone, crinoidal limestone, and chert. The rock unit ranges in thickness from 0 to possibly about 800 feet. All but about 50 feet of this total thickness is probably composed of Pennsylvanian rocks (Barnes, 1967a, p. 4).

The Devonian, Mississippian, and Pennsylvanian rocks yield very small to small quantities of fresh to slightly saline water to a few wells near the Pedernales River south of Cypress Mills and at Cypress Mills.

Hosston and Sligo Formations

The Hosston and Sligo Formations are the oldest Cretaceous rocks in the county. Imlay (1945, p. 1425) divided the Cretaceous rocks of south Texas into the Coahuila (in Mexico), Comanche, and Gulf Series. The pre-Comanche rocks were classified as the Hosston and Sligo Formations and correlated with the Nuevo León and Durango Groups of the Coahuila Series of Mexico.

The Hosston and Sligo Formations do not crop out in Blanco County but are believed to be present as a wedge mostly south of Little Blanco River in the southern tip of the county (Figure 6). Their presence very far north of Little Blanco River is doubted because they are reportedly absent in the vicinity of Blanco (W. O. George, written communication, 1948). These formations in Kendall County consist of shale, limestone, dolomite, sand, sandstone, and conglomerate (Reeves, 1967, p. 9). Thickness of the formations ranges from 0 to probably 210 feet. The Hosston and Sligo Formations are not known to yield water to wells in Blanco County.

Travis Peak (Pearsall) Formation

Imlay (1945, p. 1441) stated that the Pearsall Formation is the subsurface equivalent of the Travis Peak Formation. The Travis Peak (Pearsall) Formation, which is the oldest formation of the Trinity Group, crops out in an irregular pattern in the northern half of the county, where it overlaps an erosional surface composed of rocks ranging in age from Pennsylvanian to Precambrian.

The Travis Peak (Pearsall) Formation consists of sandstone, massive fossiliferous limestone, sandy limestone, dolomite, conglomerate, sand, clay, and shale. The pre-Cretaceous rocks from which much of the Travis Peak (Pearsall) Formation is derived influence its character and composition. The formation at and near the outcrop is characteristically conglomeratic at the base, but grades upward into finer clastic material, fossiliferous limestone and, in the upper part beneath the Glen Rose Limestone, more clastic material. Figure 7 is a photograph showing the upper part of the Travis Peak (Pearsall) Formation beneath the Glen Rose Limestone. The contact is shown in Figure 7A. The upper part of the Travis Peak shown in Figure 7B is a hard, well-cemented sandstone about 9 feet thick underlain by fossiliferous limestone. The thickness of the Travis Peak (Pearsall) Formation ranges from 0 to possibly 285 feet.

The Travis Peak (Pearsall) Formation yields small to large quantities of fresh to moderately saline water to wells in much of the county. Well AZ-57-45-902 in Johnson City, which draws most, if not all, of its water from the upper part of the Travis Peak (Pearsall), is reported to yield 90 gpm of water. The relatively high yield is due partly to the unusual type well construction. This well was dug with a clam-shell bucket to a diameter of 10 feet and gravel-packed around a 10-inch casing. Shortly after construction, the well was reportedly test-pumped at 150 gpm for 36 hours. Wells drilled into the Travis Peak (Pearsall) commonly yield much less water.

Water in the Travis Peak (Pearsall) Formation becomes increasingly mineralized downdip from the outcrop, with chlorides and sulfates showing the largest increases among the anions. The available data, however, do not permit the determination of the downdip limit of the fresh to slightly saline water.

Glen Rose Limestone

The Glen Rose Limestone, which is the youngest formation of the Trinity Group in Blanco County, is divided into upper and lower members as was done in Comal and Kendall Counties by George (1952, p. 17-18) and Reeves (1967, p. 15-17), respectively. A thin limestone bed at the top of a prominent fossiliferous zone (*Salenia texana* zone) has been arbitrarily

A. Contact of Glen Rose Limestone and upper part of Travis Peak (Pearsall) Formation.

B. Upper part of Travis Peak (Pearsall) Formation.

Figure 7.--Outcrops of Glen Rose Limestone and Travis Peak (Pearsall) Formation, 2.8 Miles East of Johnson City on Farm to Market Road 2766

established as the top of the lower member. The thin limestone bed is capped by a layer of the fossil *Corbula texana* Whitney, which is widespread in Blanco County.

Lower Member

The lower member of the Glen Rose Limestone crops out in a highly irregular pattern north and south of the Pedernales River. Because the river has completely eroded through the lower member, the member north of the river is a separate hydrologic unit from the main body south of the river. The lower member is not known to be present beneath the upper member of the Glen Rose northwest of a line from the town of Round Mountain to the entry of the Pedernales River into Blanco County. Lengthy exposures may be seen along Miller Creek and along the Blanco and Little Blanco Rivers. East of Blanco and Twin Sisters, the exposure of the lower member is broadened considerably by being upthrown along a prominent northeasterly-trending fault (Figure 5). According to Barnes (1967b), that part of the fault 8 miles northeast of Blanco has a throw of 57 feet. Figure 8 shows that the top of the lower member of the Glen Rose dips eastward at about 10 to 20 feet per mile except in areas affected by the fault.

The lower member of the Glen Rose Limestone consists of massive fossiliferous limestone in the basal part and grades upward into thin beds of limestone, marl, and shale containing the *Salenia texana* and *Corbula texana* Whitney beds at the top. The thickness of the member ranges from 0 to possibly 250 feet and diminishes toward the northwest.

The lower member of the Glen Rose Limestone yields very small to moderate quantities of fresh to slightly saline water to wells in much of the county. In general, the larger yields to wells are from the massive basal limestone which contains numerous solution channels carrying significant quantities of water. Figure 9 is a photograph showing a massive section of the lower member of the Glen Rose Limestone and a nearby spring. The top of the 50-foot bluff shown in Figure 9A is about 10 feet below the top of the lower member, Figure 9B shows spring AZ-57-55-107, about 50 feet northwest of the bluff, flowing about 5 inches above a northwest-trending fissure. Flow of the spring was estimated to be about 25 gpm on May 27, 1969. A former owner irrigated about 10 acres from a small lake formed by a dam and fed by this spring. The largest reported yield from the lower member was 65 gpm from well AZ-57-53-208 which was used for irrigation, but yields of 5 to 20 gpm are more common.

Upper Member

The upper member of the Glen Rose Limestone crops out in large areas north and south of the Pedernales River. Its outcrop is the most extensive of all the geologic and hydrologic units in the county (Figure 5). Although the upper member normally overlies the lower member, it overlaps other rocks as old as Precambrian in the northwestern part of the county.

The upper member of the Glen Rose consists of shale and marl, alternating with thin beds of impure limestone and dolomite. Impure beds of anhydrite or gypsum occur at the base and near the middle of the member. A stair-step or slope-and-terrace topography, which has been formed from the alternating beds of limestone and shale or marl, typifies the upper member and helps to distinguish it from the lower member. Thickness of the upper member ranges from 0 to possibly 330 feet.

The upper member of the Glen Rose Limestone yields very small to small quantities of fresh to moderately saline water to wells in much of the county. Generally, water of better quality is obtained from relatively shallow wells in the upper member. Wells that bottom at about the top of the *Corbula* bed yield water having a high content of sulfate. This is probably due to the poor-quality water associated with the gypsum deposits that rest on the *Corbula* bed. In other levels of the aquifer, the relatively slow circulation of water, which is mostly confined to thin beds of limestone and dolomite, has contributed to a generally high mineralization of the ground water.

Walnut Clay

The Walnut Clay, the basal formation of the Fredericksburg Group, overlies the upper member of the Glen Rose Limestone. It crops out on the higher ridges or hills north and south of the Pedernales River and consists of sandy marl, clay, or basal coquina. Because the thickness ranges from 0 to 13 feet, the Walnut Clay is not separated on the geologic map (Figure 5) but is included with the overlying Edwards and associated limestones. The Walnut is not known to yield water to wells.

Edwards and Associated Limestones

The Edwards and associated limestones as a hydrologic unit consist, from oldest to youngest, of the Comanche Peak and Edwards Limestones. The unit is exposed as outliers capping the high ridges and hills north and south of the Pedernales River. The largest exposure is in the west-central part of the county where the unit forms the topographic divide between the Pedernales and Blanco Rivers.

The Edwards and associated limestones consist of hard massive limestone, nodular marly limestone, and flint. The limestone is characteristically honeycombed and cavernous. Thickness of the unit ranges from 0 to 160 feet; the maximum occurs at Circle triangulation

A. Massive lower member of Glen Rose Limestone on Flat Creek.

B. Spring AZ-57-55-107 on Flat Creek near A.

Figure 9.—Outcrop of Lower Member of Glen Rose Limestone and Nearby Spring, 10 Miles East of Johnson City

station 6½ miles northwest of Blanco and 0.9 mile north of spring AZ-57-53-709.

The Edwards and associated limestones are not known to yield water to wells in Blanco County but may contribute some water to uncased holes tapping the members of the Glen Rose Limestone. Some springs, such as AZ-57-53-709, emerge at the base of the unit.

Alluvium, Fanglomerate, and High-Level Gravel

Alluvium, fanglomerate, and high-level gravel have resulted mostly from the action of streams during Holocene and Pleistocene time and consequently are exposed along or near many of the streams in the county. The deposits are not widespread and for that reason are not shown on the geologic map in Figure 5. They consist of gravel, sand, silt, and clay, having a thickness which ranges from 0 to possibly 20 feet. The alluvium occurs as narrow belts and disconnected patches that form the flood plains and terraces along the present streams. A deposit of fanglomerate, which is exposed on Precambrian rocks, is at the foot of a fault-line scarp in the northwest corner of the county. The fragmental material is cemented by calcium carbonate (Barnes, 1952). The high-level gravel occurs as very small patches within half a mile of the Pedernales River in the far western part of the county (Barnes, 1965, a, b).

The alluvium, fanglomerate, and high-level gravel are not known to yield water to wells in Blanco County. However, the alluvium probably would yield very small to small quantities of fresh water in some places along the Pedernales and Blanco Rivers.

GROUND-WATER HYDROLOGY

Source and Occurrence of Ground Water

The general principles of the occurrence and movement of ground water in all types of rocks have been described in detail by many writers including Meinzer (1923, p. 2-142; 1942, p. 385-478) and Tolman (1937).

The principal source of ground water in Blanco County is precipitation on the land surface of the county, but some ground water, which is moving downdip within the formations, enters Blanco County from the adjoining counties on the west. Surface runoff entering the county from adjoining counties also may become ground water. A large part of the precipitation runs off into adjoining counties, is consumed by evapotranspiration, or is stored in the soil to be evaporated or transpired later. A small part of the water infiltrates through the soil, subsoil, and bedrock, moving both laterally and downward to the water table. The factors affecting recharge include the intensity and amount of rainfall, slope of the land surface, type of soil and rocks, type of material between the land surface and the water table, type and amount of vegetation, quantity of water in the aquifer, and rate of evaporation.

In the sandy outcrop areas of the Travis Peak (Pearsall) Formation and the Hickory Sandstone Member of the Riley Formation in Blanco County, ground water is unconfined and occurs under water-table conditions. Downdip from the outcrop, where the sand is overlain by less permeable material, the water becomes confined and occurs under artesian conditons.

In much of Blanco County, where limestone is on or near the surface, water is unconfined in the shallow subsurface only briefly because it soon passes beneath a confining layer where it is then under artesian conditions. Thus, in Blanco County, most of the water in limestone beds occur under artesian conditions.

Water under artesian conditions, if not disturbed by heavy pumping, will rise in wells to an elevation equal to its elevation in the recharge area minus the loss in head or pressure due to friction. Where the elevation of the land surface at a well is considerably below the general level of the area of the outcrop, the pressure may be sufficient to cause the water to rise above the land surface. A few wells in Blanco County, such as wells AZ-57-45-105, -302, -304, and -402, flow all of the time; other wells, such as AZ-57-45-503 and -907, which are shallow dug wells, flow only during wet seasons. Well AZ-57-46-301, a 1,000-foot well, flows occasionally. The flows of these wells are small; the largest measured flow was 2.8 gpm from well AZ-57-45-302. Many more flowing wells could be drilled near the streams in the deeper valleys in Blanco County, but generally wells at such locations are not needed because of the accessibility of surface water.

Ground water in the saturated zones moves slowly under the force of gravity from areas of recharge to areas of discharge. Adequate data were not available to determine accurately the direction or rate of movement of the water in the aquifers. In general, however, water moves down the dip of the aquifers toward the east and southeast. In moving downdip, much of the water passes into adjoining counties. The quantity of water leaving Blanco County may equal the quantity entering the county from the west.

Ground water is discharged naturally through springs and seeps and by evapotranspiration. Ground water is discharged artificially by wells. The greatest factor affecting natural discharge through springs is the amount of pressure head forcing the discharge; the greater the pressure head, the greater the flow of the springs.

Ground-Water Development

Table 9 contains records of 585 wells and 48 springs; 16 of the wells were originally drilled as oil tests, seven of which were converted for use as water wells. The wells range in depth from 12 feet (well AZ-57-45-503) to 3,318 feet (oil test AZ-57-62-101). Nearly two-thirds of the wells range from 100 to 500 feet in depth. The locations of the wells and springs are shown on Figure 13.

Ground water in Blanco County is used primarily for rural-domestic and stock needs, and to a lesser extent for municipal supply and irrigation. In 1968, an estimated 1,400 acre-feet or 1.2 mgd (million gallons per day) of ground water was used for all purposes. Of this total quantity, about 1,300 acre-feet was used for rural-domestic and stock needs. Most of the rural domestic and livestock wells tap the upper and lower members of the Glen Rose Limestone. Ground water is not used for industrial purposes.

Table 3 shows municipal pumpage of ground water and surface water from 1955 through 1968 for Blanco and Johnson City, the only towns in Blanco County having a municipal supply. Each town has used ground water exclusively for part of the 14-year period—Johnson City from 1955 through 1966 and Blanco only during 1955. Johnson City used ground water and surface water in 1967 and surface water only during 1968. For the period 1956-68, Blanco used 29 percent ground water and 71 percent surface water. A total of 15 acre-feet or 0.013 mgd of ground water was used in the county in 1968 for public supply.

Blanco has had a public water supply since 1941 when it started using water from a 13-foot dug well on the bank of Blanco River. According to Sundstrom, Broadhurst, and Dwyer (1949), the town used an estimated 20,000 to 30,000 gpd in 1941. The present (1969) municipal well, which is 54 feet deep, taps the upper member of the Glen Rose Limestone.

Ground water has never been used extensively for irrigation in Blanco County. All crops known to be irrigated are used for feed in ranching and dairying operations. The 1968 pumpage of an estimated 130 acre-feet on 121 acres is a 23 percent increase over pumpage in 1958, but is a decrease from the pumpage in 1964 (Table 4). However, pumpage for irrigation varies with the amount and distribution of rainfall during the growing season; Figure 2 indicates that 1964 was a year of below-average precipitation, whereas 1958 and 1968 were years of above-average precipitation. Records indicate that only four or five wells were available for irrigation use in 1958, 1964, and 1968.

Aquifer Tests

The ability of aquifers to transmit and yield water is usually expressed as transmissivity. Transmissivity is applicable to aquifers where the water moves through detrital material such as sand, sandstone, gravel, or conglomerate; it is not very applicable to aquifers where the water moves through solution openings, fissures, and faults in carbonate rocks such as limestone and dolomite, because in these rocks hydrologic conditions are quite variable even in very short distances.

In Blanco County, transmissivity would apply to much of the Travis Peak (Pearsall) Formation and the Hickory Sandstone Member of the Riley Formation. None of these aquifers were tested in Blanco County because of a lack of suitable wells tapping them. Reeves (1967, p. 29) found the transmissivity of the upper part of the Travis Peak (Pearsall) Formation in Kendall County to be 1,130 gpd (gallons per day) per foot from an aquifer test at Comfort, about 30 miles southwest of Blanco. The transmissivity from this test should not be considered as representative of the full extent of the aquifer tested; an average transmissivity from several tests spread over a large area would be much more representative.

Determinations of transmissivity of the Hickory Sandstone Member of the Riley Formation were made in Mason County which adjoins Gillespie County on the north; tests show the transmissivities of the Hickory at two sites to be 13,300 and 44,000 gpm per foot (Myers, 1969, p. 369-370).

Changes in Water Levels

Water levels in wells respond continuously to the natural and artificial factors which act on the aquifers. Generally, the principal factors that affect water levels are the rate of recharge to and the rate of discharge from an aquifer. Variations in atmospheric pressure, rate of evapotranspiration, and load on an aquifer cause only small changes in water levels. Water-level declines of considerable magnitude usually are the result of large withdrawals of water by wells; whereas large rises in water levels, especially in limestone aquifers, usually are the result of heavy rains.

Water-level fluctuations in Blanco County usually are the result of variation in rainfall because the withdrawal of ground water by wells is small. The fluctuations are usually small and gradual, but large and rapid fluctuations occur, especially in wells tapping the upper and lower members of the Glen Rose Limestone. In these aquifers, rises in water levels of 50 feet or more may occur in wells within 2 or 3 days as the result of heavy rain; declines of water levels of a similar magnitude in these wells usually follow the rises but occur less rapidly.

Long-term records of annual (or more frequent) water-level measurements in wells in Blanco County are not available, but water-level measurements made in 1938 and 1941 are available for comparison with measurements made in 1968 (Table 5). The 1938 and

Table 3.—Municipal Pumpage, 1955-68

(Figures are approximate because some of the pumpage was estimated. Figures are shown to nearest 0.001 mgd and nearest acre-foot.)

	JOHNSON CITY				BLANCO				TOTAL			
	GROUND WATER		SURFACE WATER		GROUND WATER		SURFACE WATER		GROUND WATER		SURFACE WATER	
YEAR	MGD	AC-FT/YR	MGD	AC-FT/YR	MGD	AC-FT/YR	MGD	AC-FT/YR	MGD	AC-FT/YR	MGD	AC-FT/YR
1955	0.050	56	0	0	0.050	56	0	0	0.100	112	0	0
1956	.048	54	0	0	.018	20	.029	33	.066	74	.029	33
1957	.054	61	0	0	.012	13	.056	63	.066	74	.056	63
1958	.078	87	0	0	.020	22	.057	64	.097	109	.057	64
1959	.075	84	0	0	.027	30	.045	50	.102	114	.045	50
1960	.072	81	0	0	.029	32	.047	53	.101	113	.047	53
1961	.037	41	0	0	065	73	.050	56	.102	114	.050	56
1962	.037	42	0	0	.062	70	.062	70	.099	112	.062	70
1963	.041	46	0	0	.001	1	.118	132	.042	47	.118	132
1964	.069	77	0	0	.001	1	.128	143	.070	78	.128	143
1965	.034	38	0	0	.063	71	.059	66	.097	109	.059	66
1966	.030	34	0	0	.072	81	.089	100	.103	115	.089	100
1967	.043	48	.015	17	.020	22	.152	170	.062	70	.167	187
1968	0	0	.025	28	.013	15	.103	116	.013	15	.128	144

Table 4.—Acres Irrigated, Quantity of Ground Water Used for Irrigation, and Number of Irrigation Wells, 1958, 1964, and 1968

YEAR	NUMBER OF WELLS AVAILABLE FOR USE	APPROXIMATE ACRES IRRIGATED USING GROUND WATER	GROUND WATER USED	
			MGD	AC-FT
1958*	4	100	0.095	106
1964*	5	190	.168	188
1968	5	121	.116	130

* Acreage and water usage from Gillett and Janca (1965, p.13)

1941 measurements were a part of the well inventory by Barnes and Cumley (1942). Water levels were measured in many of the same wells during 1968 as part of the current study.

Of the 21 wells tapping the Glen Rose Limestone (upper and lower members and the undifferentiated unit), 10 wells had rises in water levels ranging from 0.13 to 24.38 feet and 11 wells had declines ranging from 0.54 to 40.11 feet; the average net change indicates that the water level was 1.51 feet higher in 1968.

Of the 11 wells tapping the Travis Peak (Pearsall) Formation, seven wells had rises in water levels ranging from 0.67 to 28.76 feet and four wells had declines ranging from 0.20 to 6.58 feet; the average net change indicates that the water level was 6.23 feet higher in 1968.

Of the nine wells tapping the Ellenburger-San Saba aquifer, six wells had rises in water levels ranging from 0.12 to 16.84 feet and three wells had declines ranging from 7.10 to 12.05 feet; the average net change indicates that the water level was 1.37 feet higher in 1968.

The water level in a well producing water principally from the rocks between the Ellenburger-San Saba aquifer and the Hickory Sandstone Member of the Riley Formation was 6.41 feet higher in 1968.

Of the four wells tapping the Hickory Sandstone Member, two wells showed rises in water levels of 1.51 and 6.24 feet while two wells showed declines of 3.00 and 5.90 feet; the average net change indicates that the water level was 0.29 foot lower in 1968.

Of the three wells tapping the Precambrian rocks, two showed rises of 0.47 and 3.44 feet and one showed a decline of 1.15 feet; the average net change indicates that the water level was 0.92 foot higher in 1968.

In summary, 28 wells showed rises in water levels while 21 wells showed declines. The average of the water levels in the 52 wells was 2.47 feet higher in 1968 than in 1938 or 1941.

The significance of the changes in the water levels is limited. The time interval of 27 to 30 years between only two sets of measurements does not permit the establishment of long-term trends in the water levels. However, the fact that the water levels were higher in 1968 in most of the aquifers indicates that at least at the time the measurements were made, more water was in storage in 1968 than in 1938 or 1941.

A map of Blanco County showing the configuration of the potentiometric surface or water table in 1968 was not constructed because of the wide variance in the elevation of water levels even in short distances. Such water-level behavior is characteristic of many limestone or dolomite aquifers, particularly the Glen Rose Limestone.

Well Construction

Figure 10 illustrates three types of construction of farm and ranch wells in Blanco County. The most common type in use (on the left in the illustration) is the one in which only short surface casing is used to prevent or retard entrance of surface water that may be contaminated. This type, however, freely permits the entrance of water below the surface casing. Until recently, this type of construction was used in most of the wells.

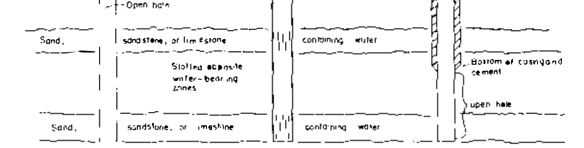

Figure 10.—Typical Construction of Farm and Ranch Wells

The type of construction shown in the center illustrates a well cased to its full depth with the casing

Table 5.—Changes in Water Levels in Wells From 1938, 41 to 1968

(Water levels are in feet below land surface)

Principal water-bearing unit: Kgru, upper member of Glen Rose Limestone; Kgrl, lower member of Glen Rose Limestone; Kgr, Glen Rose Limestone, undifferentiated; Ktp, Travis Peak (Pearsall) Formation; OCes, Ellenburger-San Saba aquifer; Cpc, rocks between Ellenburger-San Saba aquifer and Hickory Sandstone Member of Riley Formation; Crh, Hickory Sandstone Member of Riley Formation; pCr, Precambrian rocks.

WELL	WATER LEVEL		CHANGE RISE (+) DECLINE (-)	PRINCIPAL WATER-BEARING UNIT
	IN 1938 OR 1941	IN 1968		
AZ-57-36-301	28.79	25.35	+ 3.44	pЄr
302	13.43	14.58	- 1.15	pЄr
801	12.64	4.99	+ 7.65	Ktp
803	28.43	31.43	- 3.00	Єrh
806	9.79	9.12	+ .67	Ktp
902	29.75	23.51	+ 6.24	Єrh
37-106	7.85	7.11	+ .74	OЄes
702	49.09	55.67	- 6.58	Ktp
802	177.20	174.42	+ 2.78	Ktp
902	105.60	106.76	- 1.16	Ktp
38-701	8.32	1.91	+ 6.41	Єpc
802	98.14	81.30	+16.84	OЄes
908	32.89	29.88	+ 3.01	OЄes
39-703	71.73	42.97	+28.76	Ktp
44-503	83.25	54.60	+28.65	Ktp
905	40.50	47.60	- 7.10	OЄes
45-110	11.22	10.75	+ .47	pЄr
113	6.62	5.11	+ 1.51	Єrh
202	12.00	17.90	- 5.90	Єrh
604	1.03	.91	+ .12	OЄes
711	145.23	141.96	+ 3.27	Ktp
804	88.75	74.50	+14.25	Kgr
806	32.58	41.62	- 9.04	OЄes
903	79.20	75.44	+ 3.76	OЄes
46-306	75.10	59.07	+16.03	OЄes
310	34.24	27.87	+ 6.37	Ktp
403	69.94	81.99	-12.05	OЄes
601	28.90	29.10	- .20	Ktp
704	9.21	10.89	- 1.68	Ktp
52-301	60.70	69.61	- 8.91	Kgr
304	67.85	70.38	- 2.53	Kgr
308	112.18	112.72	- .54	Kgr

Table 5.—Changes in Water Levels in Wells From1938, 41 to 1968—Continued

WELL	WATER LEVEL IN 1938 OR 1941	WATER LEVEL IN 1968	CHANGE RISE (+) DECLINE (-)	PRINCIPAL WATER-BEARING UNIT
AZ-57-52-804	50.88	42.47	+ 8.41	Kgr
906	181.60	181.06	+ .54	Kgru
53-205	114.14	119.32	5.18	Kgru
206	28.77	29.48	.71	Kgru
211	36.62	25.60	+11.02	Kgr
212	105.14	106.10	- .96	Kgru
301	157.25	132.87	+24.38	Kgru
506	121.80	124.90	- 3.10	Kgru
603	35.20	13.49	+21.71	Kgr
54-409	27.02	30.03	- 3.01	Kgrl
602	14.00	12.33	+ 1.67	Kgru
61-103	27.40	27.27	+ .13	Kgru
402	112.70	102.60	+10.10	Kgru
610	36.40	27.43	+ 8.97	Kgrl
701	20.32	21.36	- 1.04	Kgru
808	37.70	40.89	- 3.19	Kgrl
902	36.70	76.81	-40.11	Kgrl

slotted opposite the water-bearing zones. This type, which protects the well from any caving shale or clay zones, retards but may not prevent undesirable water from entering the well through the annulus between the borehole and the casing.

The type of construction shown on the right is rarely used but will become more popular as drillers and owners become more determined to keep undesirable water from entering the well. Cement is forced up and around the outside of the casing from the bottom of the casing to the surface. Although this will increase the total cost, the well will yield water of better chemical quality if the water-bearing zone is properly selected.

Cable-tool drilling rigs have been used to drill most of the wells in Blanco County, but recently rotary drilling rigs have been used more frequently. When a cable-tool rig is used, a bailer removes the drill cuttings; if a rotary rig is used, the cuttings are removed by circulating mud or they are blown out with air. Each method has advantages and disadvantages, but regardless of the method used, the skill and experience of the well driller still are most important items in well drilling.

AVAILABILITY OF GROUND WATER

The ground-water resources of Blanco County are only partly developed. About 26,000 acre-feet per year of fresh to slightly saline water is available for ground-water development from all of the aquifers on a long-term basis.

This quantity is related to the average annual base flow of the Pedernales River, which is sustained by natural discharge of ground water as spring flow and seepage. The average annual base flow of the Pedernales River at Johnson City, over a span of 29 years (using the averages of 5-month periods from November to March) is 34,000 acre-feet. This is about 36 acre-feet per year for each square mile of drainage area of the Pedernales River upstream from Johnson City.

Assuming that an equal amount of ground water is discharged per square mile throughout the rest of the county, the average base flow for the 719 square miles in Blanco County is 26,000 acre-feet per year. This volume is 19 times the ground-water usage for all purposes in 1968.

An attempt to pump as much as 26,000 acre-feet per year of ground water may not be practicable or desirable. Because of the relatively low water-yielding ability of the aquifers, a large number of wells would be required. Also, a large development of ground water on the order of 26,000 acre-feet per year probably would cause a significant reduction in the base flow of the Pedernales, Blanco, and Little Blanco Rivers, and of the many spring-fed tributaries.

The present yields of wells in Blanco County range from less than 1 gpm to about 600 gpm. Yields of 200 to 600 gpm from wells are rare, and should not be anticipated in future drilling because the potential yields of wells drilled in most places in the county probably would be from 10 to 25 gpm. However, large yields of more than 100 gpm could be expected from wells tapping the Ellenburger-San Saba aquifer in about a 5-mile-wide area extending from just south of the Pedernales River at the Gillespie County line northeastward through Johnson City and Cypress Mills. Even in this area, test drilling may be necessary to achieve such large yields.

QUALITY OF GROUND WATER

The chemical constituents in ground water are dissolved from the soil and rock through which the water has passed; consequently, the amount and kind of minerals in solution in ground water depend on the composition and solubility of the rocks. Other factors that influence the mineralization of the water are the length of time the water has been in contact with the rocks and the effects of temperature and pressure. Table 6 gives the source and significance of the dissolved-mineral constituents and properties of water. Table 11 gives the analyses of water samples collected in Blanco County.

Analyses of 526 samples of water from 469 wells and 48 springs in Blanco County are given in Table 11. The principal geologic or hydrologic source of the water samples is indicated in the table. Most of the samples were collected during investigations made in 1938, 1941, and 1968-69.

The suitability of a water supply depends upon the chemical quality of the water and the limitations imposed by the contemplated use of the water. Various criteria have been developed for most categories of water quality, including bacterial content, physical characteristics, and chemical constituents. Usually, water-quality problems of the first two categories can be alleviated economically, but the removal or neutralization of undesirable chemical constituents may be difficult and expensive.

For many purposes, the dissolved-solids content is a major limitation on the use of water. A general classification of water based on dissolved-solids content (Winslow and Kister, 1956, p. 5) is as follows:

DESCRIPTION	DISSOLVED-SOLIDS CONTENT (MILLIGRAMS PER LITER)1/
Fresh	Less than 1,000
Slightly saline	1,000 to 3,000
Moderately saline	3,000 to 10,000
Very saline	10,000 to 35,000
Brine	More than 35,000

1/ Milligrams per liter (mg/l) is considered equivalent to parts per million (ppm) for water containing less than 7,000 mg/l dissolved solids.

Suitability for Public and Domestic Supply

The U.S. Public Health Service has established, and periodically revises, standards to control the quality of the drinking water to be used on common carriers engaged in interstate commerce. The standards are designed to protect the traveling public and are commonly used to evaluate public supplies. According to these standards, the concentrations of chemical constituents should not exceed the listed concentrations except where other more suitable supplies are not available. Some of the standards adopted by the U.S. Public Health Service (1962, p. 7-8) are as follows:

SUBSTANCE	CONCENTRATION (MILLIGRAMS PER LITER)
Chloride (Cl)	250
Fluoride (F)	1.0*
Iron (Fe)	.3
Nitrate (NO_3)	45
Sulfate (SO_4)	250
Dissolved solids	500

* Upper limit for Blanco County based on a 60-year annual average of maximum daily air temperature of 78.8°F (26°C) at Blanco. The minimum desirable concentration is 0.7 mg/l.

Table 7 shows a comparison of the chemical quality of ground water in Blanco County with standards recommended by the U.S. Public Health Service. The table shows the principal water-bearing units, the number of water samples analyzed, and the number which exceeded the recommended limits.

The concentration of dissolved solids in 456 analyzed samples ranged from 125 to 3,530 mg/l. Dissolved solids exceeded 1,000 mg/l in 74 samples (16 percent), was between 500 and 1,000 mg/l in 110 samples (24 percent), and was less than 500 mg/l in 272 samples (60 percent).

Water having a chloride content exceeding 250 mg/l may have a salty taste, but if the concentration is not too excessive, individuals may become conditioned to the water in a short time. Of the 524 water samples analyzed for chloride, all but seven samples contained less than 250 mg/l, and more than 85 percent contained less than 100 mg/l. The chloride content ranged from 0 to 555 mg/l.

Table 6.—Source and Significance of Dissolved-Mineral Constituents and Properties of Water

CONSTITUENT OR PROPERTY	SOURCE OR CAUSE	SIGNIFICANCE
Silica (SiO_2)	Dissolved from practically all rocks and soils, commonly less than 30 mg/l. High concentrations, as much as 100 mg/l, generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam of high pressure boilers to form deposits on blades of turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps, and other equipment. More than 1 or 2 mg/l of iron in surface waters generally indicates acid wastes from mine drainage or other sources.	On exposure to air, iron in ground water oxidizes to reddish-brown precipitate. More than about 0.3 mg/l stains laundry and utensils reddish-brown. Objectionable for food processing, textile processing, beverages, ice manufacture, brewing, and other processes. U.S. Public Health Service (1962) drinking-water standards state that iron should not exceed 0.3 mg/l. Larger quantities cause unpleasant taste and favor growth of iron bacteria.
Calcium (Ca) and magnesium (Mg)	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Cause most of the hardness and scale-forming properties of water; soap consuming (see hardness). Waters low in calcium and magnesium desired in electroplating, tanning, dyeing, and in textile manufacturing.
Sodium (Na) and potassium (K)	Dissolved from practically all rocks and soils. Found also in ancient brines, sea water, industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers and a high sodium content may limit the use of water for irrigation.
Bicarbonate (HCO_3) and carbonate (CO_3)	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot water facilities to form scale and release corrosive carbon dioxide gas. In combination with calcium and magnesium, cause carbonate hardness.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Commonly present in mine waters and in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives bitter taste to water. Some calcium sulfate is considered beneficial in the brewing process. U.S. Public Health Service (1962) drinking-water standards recommend that the sulfate content should not exceed 250 mg/l.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in ancient brines, sea water, and industrial brines.	In large amounts in combination with sodium, gives salty taste to drinking water. In large quantities, increases the corrosiveness of water. U.S. Public Health Service (1962) drinking-water standards recommend that the chloride content should not exceed 250 mg/l.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils. Added to many waters by fluoridation of municipal supplies.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth, depending on the concentration of fluoride, the age of the child, amount of drinking water consumed, and susceptbility of the individual. (Maier, 1950)
Nitrate (NO_3)	Decaying organic matter, sewage, fertilizers, and nitrates in soil.	Concentration much greater than the local average may suggest pollution. U.S. Public Health Service (1962) drinking-water standards suggest a limit of 45 mg/l. Waters of high nitrate content have been reported to be the cause of methemoglobinemia (an often fatal disease in infants) and therefore should not be used in infant feeding. Nitrate has been shown to be helpful in reducing inter-crystalline cracking of boiler steel. It encourages growth of algae and other organisms which produce undesirable tastes and odors.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils. Includes some water of crystallization.	U.S. Public Health Service (1962) drinking-water standards recommend that waters containing more than 500 mg/l dissolved solids not be used if other less mineralized supplies are available. Waters containing more than 1000 mg/l dissolved solids are unsuitable for many purposes.
Hardness as $CaCO_3$	In most waters nearly all the hardness is due to calcium and magnesium. All the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called non-carbonate hardness. Waters of hardness as much as 60 ppm are considered soft; 61 to 120 mg/l, moderately hard, 121 to 180 mg/l, hard; more than 180 mg/l, very hard.
Specific conductance (micromhos at 25°C)	Mineral content of the water.	Indicates degree of mineralization. Specific conductance is a measure of the capacity of the water to conduct an electric current. Varies with concentration and degree of ionization of the constituents.
Hydrogen ion concentration (pH)	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, and phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline waters may also attack metals.

Where fluoride is present in drinking water, the concentration should not average more than 1.0 mg/l. The presence of fluoride in average concentrations greater than 1.6 mg/l (twice the optimum value of 0.8 mg/l) would constitute grounds for rejection of the supply (U.S. Public Health Service, 1962, p. 8). The fluoride content exceeded 1.0 mg/l in 75 of 218 samples (34 percent) and 1.6 mg/l in 52 samples (24 percent). The high fluoride content is found primarily in water from the upper member of the Glen Rose Limestone. A less than desirable fluoride content (under 0.7 mg/l) was found in 52 percent of the samples.

Excessive iron (greater than 0.3 mg/l) contributes a metallic taste to water in addition to staining plumbing fixtures and laundry. The total iron in 33 water samples ranged from 0.00 to 27 mg/l and exceeded 0.3 mg/l in 15 samples (45 percent). Excessive iron in much of the ground water in Blanco County is a problem of some concern.

Nitrate concentrations in excess of 45 mg/l in water used for infant feeding have been related to the incidence of infant cyanosis (methemoglobinemia or "blue baby" disease)—a reduction of oxygen content in the blood constituting a form of asphyxia (Maxcy, 1950, p. 271). The nitrate in 332 water samples ranged from 0 to 1,100 mg/l and exceeded 45 mg/l in 67 samples (20 percent).

High concentrations of nitrate in ground water may be an indication of pollution from organic matter, commonly sewage (Lohr and Love, 1954, p. 10); but in Blanco County, the source of the nitrate contamination is probably stock excrement.

Water containing sulfate in excess of 250 mg/l may produce a laxative effect, and large concentrations of sulfate in combination with other ions impart a bitter taste to water, commonly referred to as an alum taste. The sulfate content in 523 samples ranged from 2 to 2,900 mg/l; only 96 samples (18 percent) contained more than 250 mg/l. Most of the high sulfate water is in the Glen Rose Limestone, particularly the upper member.

The sulfate and dissolved-solids content of water from the wells and springs in various aquifers in Blanco County are shown on Figure 11. The map is useful in indicating areas of good or poor quality water; however, high sulfate or dissolved-solids content in water in some areas may be related to well construction. Good quality water may therefore be available in some of the areas where poor quality is indicated by the map.

Ground water in Blanco County is characteristically very hard. The hardness as determined in the 480 samples ranged from 81 to 2,540 mg/l. Of these 480 samples, none were soft; four were moderately hard; nine were hard; and 467 were very hard. Because natural soft ground water is absent or rare in Blanco County, commercial water softeners may be used if soft water is needed. Even if used, the softeners will have to be recharged frequently and probably will not be recommended where the hardness is more than 500 mg/l. High hardness generally is not considered detrimental to health except to the small percentage of people susceptible to kidney ailments.

To provide information on the presence and extent of pesticides in ground water, pesticide analyses were made on four samples of ground water. The water was analyzed for nine insecticides (aldrin; DDD; DDE; DDT; dieldrin; endrin; heptachlor; heptachlor epoxide; and lindane) and three herbicides (2,4-D; silvex; and 2,4-5-T) recommended for monitoring by the Federal Committee on Pest Control (Green and Love, 1967, p. 13-16). Samples of water were taken May 20, 1969, from spring AZ-57-53-215 and from wells AZ-57-45-111 and AZ-57-60-305, 399 and 200 feet in depth, respectively. Samples were taken on May 27, 1969, from spring AZ-57-45-608. The analyses indicated that no pesticides were present in the water sampled.

Suitability for Industrial Use

The quality of water for industry does not necessarily depend on its acceptibility for human consumption, but varies according to the individual requirements of each process. A few of the limits for chemical constituents in water to be used in industry are given in Table 8; for more detailed information on the requirements for specific industries, the reader is referred to Nordell (1961).

Corrosion is the most widespread and probably the most costly water-related difficulty with which industry must cope. Large concentrations of dissolved solids, chloride, and sulfate; and low or high pH; and small concentrations of calcium usually are conducive to corrosion. The concentrations of dissolved solids, chloride, and sulfate in ground water in Blanco County are not excessive; the pH usually is between 7 and 8; and calcium is usually very high. On the basis of these properties and constituents, the corrosive potential of ground water in Blanco County is low.

Although some calcium hardness is desirable for the prevention of corrosion, excessive hardness is objectionable for most industrial applications because it contributes to the formation of scale in boilers, pipes, water heaters, radiators, and various other equipment where water is heated or evaporated. The very hard water in Blanco County will therefore require softening for many industrial applications.

Boiler-feed water for the production of steam must meet rigid chemical-quality requirements because the problems of corrosion and scale are intensified. Treatment of boiler water generally is needed, and therefore its suitability for treatment must be considered

Table 7.—Comparison of Quality of Ground Water in Blanco County with Standards Recommended by U.S. Public Health Service

PRINCIPAL WATER-BEARING UNIT	IRON (Fe)		SULFATE (SO_4)		CHLORIDE (Cl)		FLUORIDE (F)		NITRATE (NO_3)		DISSOLVED SOLIDS				HARDNESS AS $CaCO_3$	
	Number of determinations (Total and the number exceeding the recommended limits)															
	TOTAL	OVER 0.3 MG/L	TOTAL	OVER 250 MG/L	TOTAL	OVER 250 MG/L	TOTAL	OVER 1.0 MG/L	TOTAL	OVER 45 MG/L	TOTAL	LESS THAN 500 MG/L	500 TO 1,000 MG/L	OVER 1,000 MG/L	TOTAL	OVER 60 MG/L[1]
Edwards and associated limestones	0	0	2	0	2	0	2	0	0	0	2	2	0	0	2	2
Glen Rose Limestone, upper member	6	5	87	39	87	1	43	29	46	8	80	27	19	34	81	81
Glen Rose Limestone, lower member	6	2	123	5	124	0	56	11	71	10	110	99	7	4	111	111
Glen Rose Limestone, undifferentiated	2	2	47	26	47	0	27	15	27	7	40	9	17	14	46	46
Travis Peak (Pearsall) Formation	2	0	105	17	105	1	32	9	73	27	91	44	36	11	97	97
Pennsylvanian, Mississippian, and Devonian rocks	0	0	5	0	5	0	1	0	3	2	4	1	1	2	4	4
Ellenburger-San Saba aquifer	10	5	88	7	88	0	35	5	57	5	71	56	10	5	80	80
Rocks between Ellenburger-San Saba aquifer and Hickory Sandstone Member of Riley Formation	3	1	32	0	32	1	8	3	29	3	31	19	12	0	27	27
Hickory Sandstone Member of Riley Formation	4	0	28	2	28	4	10	3	21	5	22	12	6	4	26	26
Precambrian rocks	0	0	6	0	6	0	2	0	5	0	5	3	2	0	6	6
TOTALS	33	15	523	96	524	7	216	75	332	67	456	272	110	74	480	480

[1] Upper limit of soft water.

Table 8.--Water Quality Tolerances for Industrial Applications [1]

Allowable limits in milligrams per liter except as indicated

INDUSTRY	TURBIDITY	COLOR	COLOR + O_2 CONSUMED	DO (ML/L)	ODOR	HARDNESS	ALKALINITY (AS $CaCO_3$)	pH	TOTAL SOLIDS	Ca	Fe	Mn	Fe + Mn	Al_2O_3	SiO_2	Cu	F	CO_3	HCO_3	OH	$CaSO_4$	Na_2SO_4 TO Na_2SO_3 RATIO	GENERAL [2]
Air Conditioning [3]	--	--	--	--	--	--	--	--	--	--	0.5	0.5	0.51	--	--	--	--	--	--	--	--	--	A, B
Baking	10	10	--	--	--	[4]	--	--	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	C
Boiler feed:																							
0-150 psi	20	80	100	2	--	75	--	8.0+	3,000-1,000	--	--	--	--	5	40	--	--	200	50	50	--	1 to 1	--
150-250 psi	10	40	50	.2	--	40	--	8.5+	2,500- 500	--	--	--	--	.5	20	--	--	100	30	40	--	2 to 1	--
250 psi and up	5	5	10	0	--	8	--	9.0+	1,500- 100	--	--	--	--	.05	5	--	--	40	5	30	--	3 to 1	--
Brewing: [5]																							
Light	10	--	--	--	Low	--	75	6.7-7.0	500	100-200	.1	.1	.1	--	--	--	1	--	--	--	100-200	--	C, D
Dark	10	--	--	--	Low	--	150	7.0	1,000	200-500	.1	.1	.1	--	--	--	1	--	--	--	200-500	--	C, D
Canning:																							
Legumes	10	--	--	--	Low	25- 75	--	--	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	C
General	10	--	--	--	Low	--	--	--	--	--	.2	.2	.2	--	--	--	1	--	--	--	--	--	C
Carbonated beverages [6]	2	10	10	--	0	250	50	--	850	--	.2	.2	.3	--	--	--	.2	--	--	--	--	--	C
Confectionary	--	--	--	--	Low	--	--	[7]	100	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	--
Cooling [8]	50	--	--	--	--	50	--	--	--	--	.5	.5	.5	--	--	--	--	--	--	--	--	--	A, B
Food, general	10	--	--	--	Low	--	--	--	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	C
Ice (raw water) [9]	1-5	5	--	--	--	--	30-50	--	300	--	.2	.2	.2	--	10	--	--	--	--	--	--	--	C
Laundering	--	--	--	--	--	50	--	--	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	--
Plastics, clear, undercolored	2	2	--	--	--	--	--	--	200	--	.02	.02	.02	--	--	--	--	--	--	--	--	--	--
Paper and pulp: [10]																							
Groundwood	50	20	--	--	--	180	--	--	--	--	1.0	.5	1.0	--	--	--	--	--	--	--	--	--	A
Kraft pulp	25	15	--	--	--	100	--	--	300	--	.2	1	.2	--	--	--	--	--	--	--	--	--	--
Soda and sulfite	15	10	--	--	--	100	--	--	200	--	.1	.05	.1	--	--	--	--	--	--	--	--	--	--
Light paper, HL-Grade	5	5	--	--	--	50	--	--	200	--	.1	.05	.1	--	--	--	--	--	--	--	--	--	B
Rayon (viscose) pulp:																							
Production	5	5	--	--	--	8	50	--	100	--	.05	.03	.05	< 8.0	< 25	< 5	--	--	--	--	--	--	--
Manufacture	.3	--	--	--	--	55	--	7.8-8.3	--	--	.0	.0	.0	--	--	--	--	--	--	--	--	--	--
Tanning [11]	20	10-100	--	--	--	50-135	135	8.0	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	--
Textiles:																							
General	5	20	--	--	--	20	--	--	--	--	.25	.25	--	--	--	--	--	--	--	--	--	--	--
Dyeing [12]	5	5- 20	--	--	--	20	--	--	--	--	.25	.25	.25	--	--	--	--	--	--	--	--	--	--
Wool scouring [13]	--	70	--	--	--	20	--	--	--	--	1.0	1.0	1.0	--	--	--	--	--	--	--	--	--	--
Cotton bandage [13]	5	5	--	--	Low	20	--	--	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	--

1/ American Water Works Association, 1950.
2/ A--No corrosiveness; B--No slime formation; C--Conformance to Federal drinking water standards necessary; D--NaCl, 275 mg/l.
3/ Waters with algae and hydrogen sulfide odors are most unsuitable for air condition.
4/ Some hardness desirable.
5/ Water for distilling must meet the same general requirements as for brewing (gin and spirits mashing water of light-beer quality; whiskey mashing water of dark-beer quality).
6/ Clear, odorless, steril water for syrup and carbonization. Water consistent in character. Most high quality filtered municipal water not satisfactory for beverages.
7/ Hard candy requires pH of 7.0 or greater, as low value favors inversion of sucrose, causing sticky product.
8/ Control of corrosiveness is necessary as is also control of organisms, such as sulfur and iron bacteria, which tend to form slimes.
9/ $Ca(HCO_3)_2$ particularly troublesome. $Mg(HCO_3)_2$ tends to greenish color. CO_2 assists to prevent cracking. Sulfates and chlorides of Ca, Mg, Na should each be less than 300 mg/l (white butts).
10/ Uniformity of composition and temperature desirable. Iron objectionable as cellulose adsorbs iron from dilute solutions. Manganese very objectionable, clogs pipelines and is oxidized to permangantes by chlorine, causing reddish color.
11/ Excessive iron, manganese or turbidity creates spots and discoloration in tanning of hides and leather goods.
12/ Constant composition; residual alumina 0.5 mg/l.
13/ Calcium, magnesium, iron, manganese, suspended matter, and soluble organic matter may be objectionable.

because in closed systems the boiler water is reused many times. Excessive silica in boiler water is undesirable because it forms a hard scale, the scale-forming tendency increasing with pressure in the boiler. The following table shows maximum suggested concentrations of silica for water used in boilers (Moore, 1940, p. 263).

CONCENTRATION OF SILICA MG/L	BOILER PRESSURE (POUNDS PER SQUARE INCH)
40	Less than 150
20	150 - 250
5	251 - 400
1	More than 400

The upper limit for silica in boiler-feed water is 20 mg/l if boiler pressures are as much as 250 psi (pounds per square inch). Of the 98 determinations of silica, the concentration of silica ranged from 1.1 to 26 mg/l. Only three samples exceeded 20 mg/l. Silica is not a problem in ground water in Blanco County where boiler pressure is less than 250 psi.

In summary, ground water in Blanco County is suitable or can be made suitable for many industrial applications. Although the corrosive potential of the water is low, the very hard water will require softening for some industrial applications. Silica is not a problem in boiler-feed water where boiler pressure is low to moderate.

Suitability of Water for Irrigation

The suitability of water for irrigation depends on the chemical quality of the water and other factors such as soil texture and composition, the subsoil texture, type of crop, irrigation practices, and amount of rainfall. Many classifications of irrigation water express suitability in terms of one or more variables and offer criteria for evaluating the relative overall suitability of irrigation water rather than placing rigid limits on certain chemical constituents. The more important characteristics pertinent to such evaluation of water for irrigation are the proportion of sodium to total ions, an index of the sodium hazard; total concentration of soluble salts, an index of the salinity hazard; amount of boron; and RSC (residual sodium carbonate).

A system of classification commonly used for judging the suitability of the quality of water for irrigation was proposed by the U.S. Salinity Laboratory Staff (1954, p. 69-82). It is based primarily on the salinity hazard as measured by the electrical conductivity of the water and on the sodium hazard as measured by the SAR (sodium adsorption ratio). Wilcox (1955, p. 15) stated that this system of classification. . . "is not directly applicable to supplemental waters used in areas of relatively high rainfall." Because the annual precipitation in Blanco County averages about 32 inches, most irrigation is supplemental; the classification is therefore not directly applicable but nevertheless is useful as a guide.

The salinity and sodium hazards of ground water from various aquifers and at a representative number of sites in Blanco County are shown on the diagram in Figure 12. Data on the diagram indicate that the sodium hazard of the ground water is mostly low. The salinity hazard is somewhat variable and ranges from medium to very high. The medium to very high salinity hazard, however, does not necessarily preclude the use of such water for irrigation as the water-quality requirements for supplemental irrigation are not stringent.

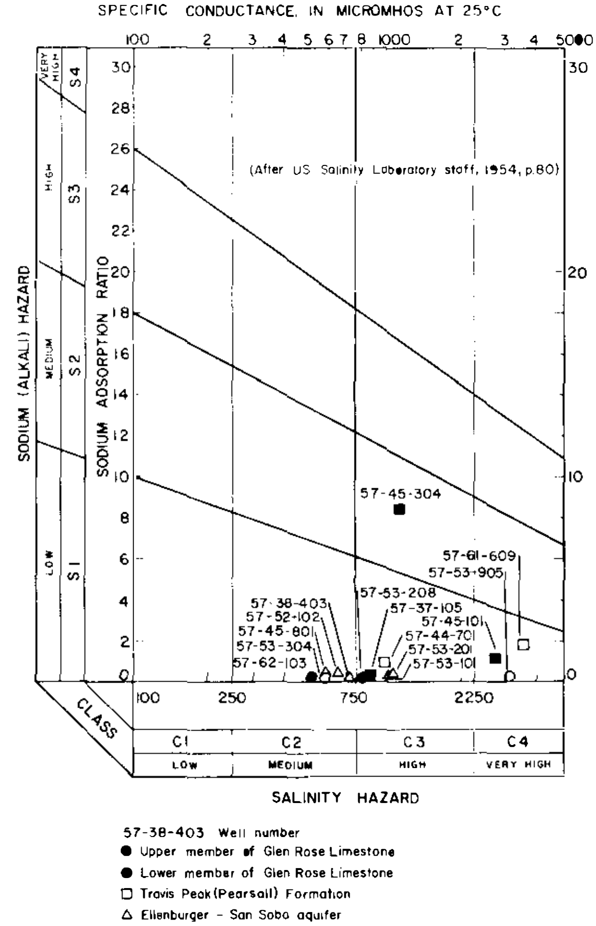

Figure 12.—Classification of Irrigation Water

Another factor used in assessing the suitability of water for irrigation is RSC (residual sodium carbonate). Excessive RSC will cause the water to be alkaline, and the organic content of the soil on which it is used may become grayish-black. The soil thus affected is referred to as "black alkali". Wilcox (1955, p. 11) states that laboratory and field studies have resulted in the conclusion that water containing more than 2.5 me/l (milliequivalents per liter) RSC is unsuitable for irrigation; water containing from 1.25 to 2.5 me/l is marginal, and water containing less than 1.25 me/l probably is safe.

The RSC as determined in 147 samples ranged from 0.00 to 3.96 me/l. Of the 147 samples, 141 had less than 1.25 me/l RSC, 139 of which had no RSC; three samples were in the 1.25 to 2.5 me/l; and three samples were above 2.5 me/l. All of the water samples containing RSC were from rocks older than the Ellenburger-San Saba aquifer.

Even though RSC is not a problem in ground water in most of Blanco County, good irrigation practices and proper use of amendments might make it possible to use the marginal water successfully for irrigation. Furthermore, the degree of leaching will modify the limit to some extent (Wilcox, Blair, and Bower, 1954, p. 265). Most of the soils in Blanco County, which are classed as calcareous clay loam, would not be conducive to a high degree of leaching, however.

An excessive concentration of boron renders water unsuitable for irrigation. Scofield (1936, p. 286) indicated that boron concentrations of as much as 1 mg/l are permissible for irrigating most boron-sensitive crops, and concentrations as much as 3 mg/l are permissible for the more boron-tolerant crops. Of 20 samples analyzed for boron, only two exceeded 1.0 mg/l, and they had boron concentrations of only 1.1 and 1.5 mg/l. Therefore, boron is not considered to be a problem in Blanco County.

Because irrigation in Blanco County is practiced only during periods of deficient rainfall, and because most of the ground water sampled meets the various irrigation standards, use of ground water for irrigation in Blanco County is considered safe. Also, stock feed is the principal crop irrigated and is relatively tolerant to sodium and salinity hazards. The sprinkler system of application is used by all irrigators in the county and this method may permit the use of poor quality water because small, uniform applications are possible.

NEEDS FOR FUTURE STUDIES

The collection of basic data such as an inventory of pumpage, observation of water levels, and collection of water samples for chemical and pesticides analysis should be continued periodically in Blanco County. This information should be collected separately for each of the major aquifers. The interpretation of these basic data will aid in monitoring future changes in ground-water conditions.

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	THICKNESS (FEET)	DEPTH (FEET)
Well AZ-57-36-303		
Owner: Lyla Sowders Driller: Virdell Bros.		
Boulders and clay streaks	12	12
Clay, yellow, and some rock	15	27
Sandrock, blue-gray	13	40
Granite, gray, red, and blue	61	101
Well AZ-57-38-909		
Owner: G.G. Lechow Driller: Virdell Bros.		
Topsoil	2	2
Caliche	6	8
Clay, red	15	23
Lime, broken	12	35
Lime and caves	97	132
Lime, solid	28	160
Well AZ-57-44-505		
Owner: Herman Deike Driller: Lonnie Itz		
Lime, porous, yellow	40	40
Clay, blue	2	42
Limerock, yellow	3	45
Limestone, porous, white	15	60
Limerock, hard, brown	13	73
Rock, porous	2	75
Layers of blue clay and limerock	10	85
Lime, porous, and white clay and sand	85	170
Cave	2	172
Limerock, yellow	16	188
Well AZ-57-44-506		
Owner: Willie Rech Driller: Virdell Bros.		
Topsoil	1	1
Boulders	4	5
Caliche	19	24
Clay	16	40
Lime, white	38	78
Well AZ-57-44-506—Continued		
Lime, gray	142	220
Sandrock	18	238
Lime, dark gray	202	440
Lime, light and dark gray	155	595
Sandrock	25	620
Lime, gray	5	625
Well AZ-57-46-902		
Owner: M. M. Davis Driller: E. R. Owen		
Topsoil	3	3
Shale, light yellow	4	7
Limestone, gray, and shale	46	53
Limestone, medium gray	39	92
Limestone, soft, light gray	26	118
Limestone, soft, dark brownish-gray	32	150
Sandrock, medium gray	20	170
Rock, white, and soft limestone	40	210
Limestone, white	10	220
Rock, water	5	225
Limestone, gray	25	250
Well AZ-57-52-201		
Owner: Allen Keller Driller: Virdell Bros.		
Topsoil	1	1
Caliche	13	14
Lime, white	1	15
Clay, yellow	3	18
Lime, chalk, yellow	6	24
Clay, yellow	3	27
Shale, gray	53	80
Sandstone, gray	47	127
Shale, gray	17	144
Dolomite, dark gray	190	334
Dolomite, light gray	146	480
Dolomite, dark gray	20	500

	THICKNESS (FEET)	DEPTH (FEET)
Well AZ-57-52-204		
Owner: C. G. Lange Driller: E. R. Owen		
Lime, yellow, and shale	31	31
Shale, gray, and lime	129	160
Lime and shale, medium dark	93	253
Lime, light	20	273
Lime, medium dark gray, and flint	13	286
Shale and lime mix, light yellow	14	300
Shale, red, and little lime	25	325
Shale, orange-red	9	334
Lime, white	4	338
Shale, reddish orange	5	343
Flintrock, very hard	13	356
Sand, brown, and silt	5	361
Flint, white, very hard	38	399
Well AZ-57-52-205		
Owner: Martin Meier Driller: Lonnie Itz		
Lime, white	30	30
Lime, white and yellow	20	50
Clay layers, blue	20	70
Limerock, porous, white	20	90
Clay layers, yellow	30	120
Limerock, hard, white	48	168
Well AZ-57-52-206		
Owner: Martin Meier Driller: Lonnie Itz		
Lime, white	40	40
Limerock, white, and layers of blue clay	35	75
Lime, porous	15	90
Lime, hard, white	85	175
Limerock, hard, blue	30	205
Well AZ-57-52-208		
Owner: Lorenz A. Lange Driller: -- Markle		
Not available	220	220
Well AZ-57-52-208—Continued		
Clay, blue and brown	80	300
Clay, brown and white	55	355
Rock, brown	10	365
Clay, blue, brown, and white	10	375
Clay, blue and white	5	380
Rock, brown	20	400
Sand, gray	10	410
Rock, blue	20	430
Clay, blue, gray, white	5	435
Rock, hard, blue	20	455
Rock, blue and green	30	485
Limestone, dark blue	5	490
Not available	50	540
Limestone, light blue	5	545
Clay, blue and white	10	555
Limestone, blue	5	560
Breaks, no water	5	565
Limestone, white with quartz	5	570
Clay, blue and white	15	585
Clay, blue and gray	40	625
Well AZ-57-53-208		
Owner: Mrs. Vivian Bryan Driller: —		
Topsoil	1	1
Limestone	25	26
Caliche	4	30
Limestone, blue	25	55
Caliche	3	58
Limestone	10	68
Limestone, blue	22	90
Limestone	20	110
Limestone, blue	30	140
Well AZ-57-53-311		
Owner: J. D. McLemore Driller: E. R. Owen		
Limestone, yellow	16	16

	THICKNESS (FEET)	DEPTH (FEET)
Well AZ-57-53-311—Continued		
Limestone, gray	104	120
Limestone, medium dark	35	155
Limestone, yellow and shale	28	183
Shale, soft, brown	15	198
Flint, hard	1	199
Shale, brown, and rock	3	202
Well AZ-57-53-501		
Owner: C. C. Capps Driller: D. N. Johnson		
Shale	70	70
Sand, water	40	110
Sand, white	20	130
Shale, blue	10	140
Limestone, white	80	220
Sand, water	15	235
Rock, red	100	335
Shale, blue	25	360
Gumbo, red	11	371
Limestone, gray	91	462
Limestone, brown	15	477
Limestone, gray	106	583
Limestone, sandy brown	14	597
Limestone, sandy gray, and water	37	634
Limestone, sandy gray	351	985
Limestone, soft, brown	10	995
Limestone, hard, gray	10	1,005
Well AZ-57-53-502		
Owner: C. C. Capps Driller: Robert Rodson		
Topsoil	2	2
Gravel	6	8
Limestone, gray	33	41
Sand, water	8	49
Limestone, gray	26	75
Sand, water	15	90
Limestone, white, and hard shells	10	100
Well AZ-57-53-502—Continued		
Rock	10	110
Sand, water	2	112
Rock, blue	8	120
Shale, blue	10	130
Limestone, white	90	220
Sand, water	4	224
Rock, hard, red	96	320
Shale, blue	6	326
Limestone, hard, white	2	328
Gumbo, red	7	335
Rock, hard, blue	17	352
Shale, blue	7	359
Limestone, hard, blue	40	399
Limestone, sandy, gray	6	405
Limestone, gritty, brown	25	430
Limestone, sandy, white	8	438
Limestone, hard, gray	7	445
Limestone, brown	25	470
Limestone, gray	10	480
Limestone, brown	20	500
Limestone, white	28	528
Limestone, brown	7	535
Limestone, gray	25	560
Limestone, sandy, brown	3	563
Limestone, sandy, gray	2	565
Limestone, sandy, brown	5	570
Limestone, sandy, gray	152	722
Limestone, broken, white	13	735
Limestone, gritty, gray	20	755
Limestone, broken, white	35	790
Limestone, sandy, gray	158	948
Sand, oil, and water	12	960
Well AZ-57-53-508		
Owner: M. C. Winters Driller: — Merkel		
Boulders and dirt	20	20
Shale, jet blue	20	40

	THICKNESS (FEET)	DEPTH (FEET)
Well AZ-57-53-508--Continued		
Shale, gray	120	160
Shale, gray, and hard limerock at 171 ft. into gray shale at 190 ft.	20	180
Shale	10	190
Shale, gray	60	250
Shale, gray, and hard lime at 285ft., 2 gpm bail test at 305ft.	60	310
Lime, gray	10	320
Limerock, blue	20	340
Lime, hard, mixed gray and white	10	350
Lime, gray, with brown mixed at 355 ft.	10	360
Lime, gray, with brown and green rock	10	370
Lime, dark gray, with mixed quartz, no water	10	380
Limerock, white and gray mixed	10	390
Lime, white, with gray mixed	10	400
Lime, gray, white, and green mixed	10	410
Small break at 410 ft., bail test, no water	10	420
Lime, blue, gray, and white mixed at 420 ft.	10	430
Lime, gray and white mixed with brown at 435 ft.	10	440
2 ft. break at 447-449 ft., bail test, no water	10	450
Well AZ-57-53-606		
Owner: M. C. Winter Driller: Virdell Bros.		
Topsoil	1	1
Caliche	25	26
Clay, blue	24	50
Chalk, gray	12	62
Shale, gray	28	90
Lime, gray, and shale	25	115
Shale, gray	55	170
Shale, tan	10	180
Shale, gray	100	280
Lime, sand	68	348
Well AZ-57-53-606--Continued		
Lime rock ledges, and shale between	32	380
Sand rock, white, with water	20	400
Well AZ-57-53-607		
Owner: M. C. Winters Driller: Virdell Bros.		
Topsoil	1	1
Gravel and boulders	39	40
Shale, crystallized, gray	105	145
Lime, broken, blue-gray	75	220
Lime, light gray	240	460
Lime, gray with red specks	50	510
Lime, white with gray streaks	110	620
Lime, light gray	20	640
Well AZ-57-53-608		
Owner: M. C. Winters Driller: Virdell Bros.		
Surface dirt and clay	40	40
Gravel	10	50
Limerock, sandrock at 57-59 ft., bail test 10 gal. per minute	10	60
Lime, hard	20	80
Well AZ-57-53-609		
Owner: M. C. Winters Driller: Virdell Bros.		
Topsoil	1	1
Clay, yellow	5	6
Clay, red	10	16
Sand and gravel	3	19
Clay, red	11	30
Clay, yellow	9	39
Sand and gravel with water	1	40
Lime, soft chalk, with shale streaks	40	80
Well AZ-57-53-905		
Owner: Claude Bourland Driller: Crawford Well Drilling Co.		
Stone, yellow	6	6

	THICKNESS (FEET)	DEPTH (FEET)
Well AZ-57-53-905—Continued		
Caliche	6	12
Limestone, gray	85	97
Sandstone, water-bearing	31	128
Shale, blue	4	132
Well AZ-57-54-703		
Owner: Hubert Taylor, Jr. Driller: —		
Caliche	40	40
Limestone, gray	345	385
Limestone, white	20	405
Stone, hard, brown	5	410
Sandstone	30	440
Well AZ-57-54-903		
Owner: F. C. Gillespie Driller: Glass and Bible Drilling Co.		
Gravel	6	6
Lime, blue	34	40
Lime, gray	140	180
Lime, white	60	240
Lime, gray	50	290
Rock, water	30	320
Lime, gray	33	353
Well AZ-57-54-905		
Owner: Mrs. Hannah Jones Driller: Crawford Well Drilling Co.		
Caliche	40	40
Limestone, white	70	110
Limestone, gray	90	200
Shale, blue, caving from 300 to 380 ft.	180	380
Not given	20	400
Well AZ-57-60-607		
Owner: Max C. Kluge Driller: E. R. Owen		
Lime, soft, yellow	15	15
Lime, shale, soft, blue	60	75
Lime, light gray	20	95
Rock, water	15	110

	THICKNESS (FEET)	DEPTH (FEET)
Well AZ-57-61-101		
Owner: C. R. Whitworth Driller: E. R. Owen		
Limestone, yellow	60	60
Mud	30	90
Lime, gray	40	130
Lime cavities	70	200
Lime, soft, gray	30	230
Lime, gray and white	100	330
Lime, hard	40	370
Well AZ-57-61-305		
Owner: E. W. Walker—Oil Test Driller: Meeks and Smith		
Topsoil	10	10
Clay, yellow	8	18
Clay, blue	46	64
Clay, hard, blue	16	80
Sand, water	12	92
Shale, blue	86	178
Shells	57	235
Shale, hard	90	325
Limestone, gray	95	420
Limestone, brown	40	460
Limestone, pink	40	500
Shale, red, some shells and flint	135	635
Shale, brown, and shells	5	640
Limestone, shells, and black shale	249	889
Limestone, hard, and shells	11	900
Shale, black	178	1,078
Well AZ-57-61-401		
Owner: Gilmer Williams Driller: Crawford Well Drilling Co.		
Topsoil	10	10
Caliche	33	43
Limestone, white	42	85
Stones, soft gray—small amount water at 125 ft.	45	130
Shale, gray	65	195

Well AZ-57-61-401—Continued

	THICKNESS (FEET)	DEPTH (FEET)
Stone, porous, gray, water-bearing	20	215
Shale, blue	13	228

Well AZ-57-61-404

Owner: W. T. Yett
Driller: E. R. Owen

	THICKNESS (FEET)	DEPTH (FEET)
Caprock, hard	12	12
Lime, hard and soft layers, yellow	41	53
Shale, blue	5	58
Shale, yellow and gray	7	65
Lime shale, yellow	61	126
Lime shale, blue	44	170
Lime, light gray, and lime shale	80	250
Lime shale, light	15	265
Lime, light gray and shale	143	408
Shale, gray	2	410
Lime, light yellow, soft	18	428
Shale, blue, and lime	22	450
Lime, light	5	455
Lime, medium gray	20	475
Lime, light	5	480

Well AZ-57-61-406

Owner: Max C. Kluge
Driller: E. R. Owen

	THICKNESS (FEET)	DEPTH (FEET)
Gravel	2	2
Shale, yellow	23	25
Lime, soft gray	65	90
Lime, gray, and some shale	40	130
Shale, gray	10	140
Lime, dark gray	30	170

Well AZ-57-61-501

Owner: [illegible]ed Moffett
Driller: Crawford Well Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Caliche	60	60
Stone, loose	20	80
Limestone, yellow	40	120

Well AZ-57-61-501—Continued

	THICKNESS (FEET)	DEPTH (FEET)
Limestone, gray	220	340
Sandstone, porous, brown	35	375

Well AZ-57-61-502

Owner: W. T. Yett
Driller: E. R. Owen

	THICKNESS (FEET)	DEPTH (FEET)
Lime, yellow	34	34
Lime shale, blue	3	37
Lime, yellow	5	42
Lime, light	18	60
Lime, light yellow	60	120
Lime, light yellow, and shale	50	170
Lime, gray	65	235
Lime, light gray	70	305
Lime, gray	7	312
Lime, medium gray	93	405
Lime, dark gray, and shale	12	417
Lime, medium gray	20	437

Well AZ-57-61-601

Owner: C. E. Crist—Oil Test No. 3
Driller: E. L. Nixon

	THICKNESS (FEET)	DEPTH (FEET)
Topsoil	3	3
Gravel	12	15
Clay, yellow	3	18
Limestone, and shells	17	35
Shale, gray	13	48
Shale, calcareous	37	85
Shale, blue	4	89
Limestone, gray	11	100
Shale, gray	5	105
Shale, calcareous	63	168
Gumbo, blue	4	172
Limestone, water	12	184
Shale, blue	13	197
Limestone, and shells	23	220
Limestone, gray	20	240
Shale, blue	3	243
Limestone, gray	43	286

Table 10.—Drillers' Water Wells and Oil Tests—Continued

	THICKNESS (FEET)	DEPTH (FEET)
Well AZ-57-61-601—Continued		
Shale, blue	2	288
Limestone, gray	16	304
Gumbo, blue	22	326
Limestone, blue	8	334
Sand, dry	5	339
Shale, blue	6	345
Limestone, gray	9	354
Gumbo, blue	6	360
Limestone, gray, water	48	408
Limestone, pink	27	435
Limestone, gray	25	460
Limestone, pink	36	496
Limestone, gray	5	501
Shale, brown	21	522
Limestone, gray	3	525
Shale, brown	3	528
Limestone, gray	2	530
Shale, gray	22	552
Limestone, black	21	573
Limestone, sandy	22	595
Shale, gray	5	600
Limestone, sandy	4	604
Shale, blue	2	606
Shale, light blue	21	627
Shale, gray	10	637
Limestone, gray	11	648
Shale, blue	21	669
Limestone, blue	6	675
Shale, blue	99	774
Limestone, blue	4	778
Shale	24	802
Limestone, broken	209	1,011
Pyrite	2	1,013
Limestone, broken	46	1,059
Shale, gray	9	1,068
Limestone, blue	39	1,107
Shale, blue	62	1,169

	THICKNESS (FEET)	DEPTH (FEET)
Well AZ-57-61-601--Continued		
Shale, hard	2	1,171
Shale, blue	9	1,180
Limestone, blue	10	1,190
Shale, gray	12	1,202
Limestone, gray	96	1,298
Rock, hard	34	1,332
Well AZ-57-61-606		
Owner: C. E. Crist—Oil Test No. 1 Driller: E. L. Nixon		
Soil, black	2	2
Gravel	12	14
Clay, yellow	8	22
Limestone, gray	16	38
Limestone, blue	11	49
Limestone, porous, dark-colored	60	109
Limestone, gray	5	114
Gumbo, blue	25	139
Limestone, light blue	20	159
Gumbo, blue	22	181
Limestone, brown	5	186
Limestone, gray	12	198
Limestone, brown, water	14	212
Limestone, porous, brown	9	221
Limestone, dark gray	13	234
Limestone, dark brown	11	245
Limestone, brown	52	297
Limestone, gray, water	5	302
Limestone, dark-colored	15	317
Gumbo, blue	27	344
Limestone, dark gray	36	380
Limestone, sandy, brown	9	389
Limestone, dark gray	28	417
Limestone, brown	77	494
Limestone, pink	12	506
Rock, brown	10	516
Clay, red	17	533

Table 10.—Drillers' Water Wells and Oil Tests—Continued

Well AZ-57-61-606—Continued

	THICKNESS (FEET)	DEPTH (FEET)
Shale, brown	43	576
Limestone, blue	21	597
Shale, dark blue	128	725

Well AZ-57-61-607

Owner: C. E. Crist—Oil Test No. 2
Driller: E. L. Nixon

	THICKNESS (FEET)	DEPTH (FEET)
Soil, black	2	2
Gravel	3	5
Limestone, gray	26	31
Gumbo, blue	14	45
Limestone, gray	15	60
Limestone, light gray	48	108
Shale, gray	4	112
Limestone, broken	55	167
Limestone, blue	6	173
Gumbo, blue	7	180
Limestone, blue	6	186
Shale, blue	4	190
Limestone, gray	10	200
Limestone, blue	25	225
Limestone, sandy	60	285
Shale, blue	55	340
Limestone, gray	30	370
Shale, blue	22	392
Limestone, brown	30	422
Limestone, pink	18	440
Shale, brown	95	535
Limestone, pink	55	590
Limestone, dark blue	30	620
Shale, dark blue	250	870
Limestone, broken	50	920
Limestone, blue	56	976

Well AZ-57-61-611

Owner: Polk Morisey—Oil Test
Driller: H. T. Roe and E. L. Nixon

	THICKNESS (FEET)	DEPTH (FEET)
Sand, gravel, and shell	30	30
Limestone, brown, silicate and some sulphur	10	40

Well AZ-57-61-611—Continued

	THICKNESS (FEET)	DEPTH (FEET)
Limestone, light-colored	10	50
Limestone, firm, drab-colored	10	60
Limestone, brown	10	70
Limestone, dark-colored	40	110
Limestone, light yellow, and shell	10	120
Limestone, and shell	60	180
Limestone, dark-colored, highly siliceous	20	200
Rock, thin, dark-colored, slight show of gas and light-colored limestone	5	205
Limestone, hard, dark-colored and pink	33	238
Limestone, dark-colored and drab-colored highly siliceous particles	20	258
Rock, dark brown, highly siliceous	10	268
Rock, fine-grained, dark brown	10	278
Limestone, light-colored, siliceous	10	288
Limestone, calcitic and siliceous, show of gas	17	305
Gumbo, blue, show of gas	18	323
Sand, gritty, blue	7	330
Limestone, hard and siliceous gray, show of gas	24	354

Well AZ-57-61-801

Owner: Howard A. Doebbler
Driller: Pence Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface and boulders	1	1
Limestone, alternating with strips of lime and shale	23	24
Lime and shale	46	70
Limestone, hard	25	95
Limestone	30	125
Limestone, water	11	136
Shale and lime	3	139
Limestone, hard, between gray and white	13	152
Shale and lime	3	155

Table 10.—Drillers' Water Wells and Oil Tests—Continued

Well AZ-57-61-904

Owner: Oscar Jonas, Jr.
Driller: Crawford Well Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Caliche	20	20
Limestone	195	215
Caprock, hard	10	225
Sandstone, water-bearing	24	249

Well AZ-57-61-905

Owner: Oscar Jonas, Jr.
Driller: Crawford Well Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Caliche	20	20
Limestone, gray	70	90
Sandstone, very porous, yellow	60	150

Well AZ-57-62-103

Owner: Austin C. Webb
Driller: Crawford Well Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Gravel, river	30	30
Limestone, gray	50	80
Limestone, very hard, white	40	120
Limestone, very hard, yellow	30	150
Sandstone, porous	30	180

Well AZ-57-62-201

Owner: Roy Cogdill
Driller: Crawford Well Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Topsoil	10	10
Caliche	40	50
Stone, white	38	88
Stone, gray	32	120
Stone, white	30	150
Sandstone, hard, yellow, water-bearing	40	190
Stone, hard, gray	3	193

Well AZ-57-62-406

Owner: C. A. Rust, Jr.
Driller: E. R. Owen

	THICKNESS (FEET)	DEPTH (FEET)
Lime, soft, yellow	6	6
Lime, yellow and gray	9	15

Well AZ-57-62-406—Continued

	THICKNESS (FEET)	DEPTH (FEET)
Lime, gray, and little shale	27	42
Lime, medium gray, and little shale	45	87
Lime, light	33	120

Well AZ-57-62-407

Owner: C. A. Rust, Jr.
Driller: E. R. Owen

	THICKNESS (FEET)	DEPTH (FEET)
Lime, yellow, and shale	12	12
Lime, gray, and lime shale	48	60
Lime, medium gray	15	75
Lime, light yellow	60	135

Well AZ-57-62-409

Owner: C. A. Rust, Jr.
Driller: E. R. Owen

	THICKNESS (FEET)	DEPTH (FEET)
Topsoil	3	3
Lime, yellow, and shale	7	10
Lime, gray	52	62
Lime, light	13	75
Lime, medium yellow	50	125
Lime, gray	10	135
Lime, light yellow	30	165
Lime, gray	5	170

Well AZ-57-62-410

Owner: Frank K. Willis
Driller: Crawford Well Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Stone, surface, and soil	40	40
Stone, gray	60	100
Rock, white, medium hard	18	118
Limestone, gray	22	140
Sandstone, yellow (water)	15	155
Limestone, white	20	175

Well AZ-57-62-502

Owner: H. Wilcox
Driller: Crawford Well Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Caliche	40	40
Limestone, gray	140	180

Table 10.—Drillers' Water Wells and Oil Tests—Continued

	THICKNESS (FEET)	DEPTH (FEET)
Well AZ-57-62-502—Continued		
Stone, very hard, yellow	30	210
Well AZ-57-62-707		
Owner: Emery Nix Driller: Crawford Well Drilling Co.		
Stone, loose, and dirt	10	10
Stone, hard, yellow	60	70
Sandstone, porous, brown-good water	20	90
Limestone, dry, Austin white	45	135
Sandstone, porous, white, water	20	145
Shale, blue	5	150
Well AZ-68-05-206		
Owner: B. B. Beveridge Driller: Crawford Well Drilling Co.		
Limestone	230	230
Sandstone, water-bearing	28	258
Well AZ-68-05-601		
Owner: Albert Specht—Oil Test Driller: Theodore Hicks		
Topsoil	8	8
Limestone, gray	162	170
Limestone, light gray, and marl	50	220
Limestone, very sandy, gray	40	260
Limestone, sandy, white	40	300
Limestone, sandy, gray	30	330
Shale, gray, and some limestone	60	390
Well AZ-68-05-601—Continued		
Shale, calcareous, gray	40	430
Limestone, crystallized, white	60	490
Shale, blue and red	50	540
Limestone, white, with red and green shale	35	575
Limestone, with chert, and red and green shale	85	660
Limestone, sandy, shale and chert	30	690
Shale, noncalcareous	28	718
Shale, dark	62	780
Shale, dark, and sandy shale	70	850
Shale, sandy, dark	230	1,080
Shale, sandy, gray, with red shale	40	1,120
Shale, sandy, dark	120	1,240
Clay, blue and red, and sandy shale	30	1,270
Shale, mixed red and green	60	1,330
Shale, dark red	70	1,400
Shale, red and green	30	1,430
Well AZ-68-05-602		
Owner: R. Schaeferkoeter Driller: Crawford Well Drilling Co.		
Topsoil	2	2
Rock, white	8	10
Caliche	50	60
Rock, gray	90	150
Sandstone, porous, gray	30	180