TEXAS WATER DEVELOPMENT BOARD

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GROUND-WATER RESOURCES OF THE SAN ANTONIO AREA, TEXAS

A Progress Report on Studies, 1960-64

By

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Edwards Underground Water District
San Antonio City Water Board
San Antonio City Public Service Board
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ABSTRACT

Geologic and hydrologic investigations have been conducted in the San Antonio area since 1929. The purpose of this progress report is to summarize the results of the previous investigations and to present the results of the 1960-64 study. The San Antonio area, as discussed in this report, includes parts of Kinney, Uvalde, Medina, Bexar, Comal, and Hays Counties, Texas. The area boundaries coincide with the hydraulic boundaries of the Edwards and associated limestones, the ground-water reservoir (aquifer) that is the chief source of water to the city of San Antonio and vicinity. The San Antonio area lies within two physiographic sections: the Edwards Plateau of the Great Plains province on the north and northwest and the West Gulf Coastal Plain of the Coastal Plain province on the south and southeast, the two sections being separated by the Balcones fault zone.

The base flow of the streams that drain the Edwards Plateau is spring flow from a water-table aquifer in the plateau; this base flow and a part of the flood flow are lost by seepage into the outcrop of the Edwards and associated limestones at the Balcones fault zone. Recharge to the principal part of the aquifer is chiefly by this seepage from streams that cross the outcrop of the Edwards and associated limestones, but partly by direct infiltration of precipitation on the outcrop. During the period 1934-64, the average annual recharge was estimated to be nearly 500,000 acre-feet.

Most of the 1934-64 discharge from the aquifer has been from springs, except during the periods 1954-57 and 1963-64, when the discharge from wells exceeded the discharge from springs. In 1964, the discharge from springs was about 214,000 acre-feet, more than 95 percent of which was from Comal Springs (Comal County) and San Marcos Springs (Hays County). The discharge from wells in 1964 was more than 267,000 acre-feet, about 75 percent of which was in Bexar County. The average annual discharge from both wells and springs for the period 1934-64 was about 520,000 acre-feet.

Water levels in wells in the Edwards and associated limestones were the lowest of record in 1956 and early 1957, the end of the drought period of 1947-57. As a result of heavy precipitation during the period 1957-61, the water levels rose nearly to the levels of 1947. During 1962-64, rainfall was below average, and the water levels dropped lower than in 1961.

During the period 1947-61, the net change in ground-water storage in the Edwards and associated limestones was small. During the period 1962-64, the storage decreased by more than 750,000 acre-feet.

The water in the Edwards and associated limestones is almost uniformly a calcium bicarbonate water with a hardness generally above 200 parts per million. A zone of transition between water of good and poor quality exists downdip in the artesian part of the aquifer. An arbitrary line of so-called "bad water" (1,000 parts per million dissolved solids) delineates the approximate southern boundary of good water in the aquifer.

A study of the zone of transition in the aquifer indicates that if the aquifer head were to drop about 100 feet below the record low, the net increase in the mineralization of water in a well near the bad water line probably would be about 7 percent. Further observations in this zone are needed at low stage in aquifer head to verify the results of this study.

GROUND-WATER RESOURCES OF THE SAN ANTONIO AREA, TEXAS

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INTRODUCTION

Location and Extent of Investigated Area

The term "San Antonio area," as used in this report, was employed by early investigators to denote the area that has been the source of water for the city of San Antonio and vicinity. Petitt and George (1956) first used this term to include parts of Kinney, Uvalde, Medina, Bexar, Comal, and Hays Counties, Texas, an area about 180 miles long and about 5 to 40 miles wide within and adjacent to the Balcones fault zone (Figure 1). The principal ground-water reservoir (aquifer) in the area is the Edwards and associated limestones of Cretaceous age; its hydraulic boundaries coincide with the boundaries of the San Antonio area.

Purpose and Scope

This report supplements the previously published work concerning the geology and hydrology of the Edwards and associated limestones in the San Antonio area and brings the hydrologic data up to date through 1964. The report presents records of precipitation, streamflow, and water level; it gives estimates of recharge to and discharge from the aquifer. Estimates of changes in storage in the aquifer are made by using the recharge and discharge figures. The relation of aquifer head to the changes in storage and the movement of water in the aquifer is discussed. Also provided is a summary of the studies of the quality of water in the zone of transition between water of good quality and saline water in the aquifer.

Previous Work

Results of previous investigations of the Edwards and associated limestones in the San Antonio area have been published as progress reports summarizing the general geology and hydrology. (See "References.") The investigations in the San Antonio area were begun as early as 1929; they were cooperative projects of the then Texas Board of Water Engineers and the U.S. Geological Survey. Results of these early investigations were reported by Livingston and others (1936), by Sayre (1936), and by Sayre and Bennett (1942); other significant reports were those by Livingston (1947a and 1947b) and by Lang (1954). More comprehensive reports on the hydrology of the San Antonio area were presented by Petitt and George (1956) and by Garza (1962a). The results of other geologic and hydrologic investigations of the Edwards and associated limestones have been published as county reports, and a series of basic-data reports has been published by the Edwards Underground Water District for the 1962-64 period. Cooperators in the investigations have included the San Antonio City Water Board, the Edwards Underground Water District, the San Antonio City Public Service Board, the Bexar Metropolitan Water District, and individual county governments throughout the San Antonio area.

Acknowledgments

Appreciation is expressed to the many individuals who furnished information basic to the preparation of this report. These include farmers, ranchers, drillers, representatives of water supply agencies and industrial plants, and officials of the various cooperators of the project.

This report was prepared under the administrative direction of L. B. Leopold, chief hydrologist of the Water Resources Division of the U.S. Geological Survey, and under the immediate supervision of Trigg Twichell, chief of the Texas district.

Topography and Drainage

The San Antonio area lies within two physiographic sections, the Edwards Plateau of the Great Plains province on the north and northwest and the West Gulf Coastal Plain of the Coastal Plain province on the south and southeast. The Balcones escarpment, the remains of a fault scarp in the Balcones fault zone, separates the two physiographic sections (Figure 1). The Edwards Plateau has been eroded by streams into a steep and rugged topography; the West Gulf Coastal Plain is rolling or moderately hilly in the area close to the Balcones escarpment and has a gentler relief toward the coast.

The base flow of the streams that drain the Edwards Plateau in the San Antonio area is spring flow from a water-table aquifer. Most of the base flow and a part of the flood flows are lost by seepage into the outcrop of the Edwards and associated limestones at the Balcones fault zone. Below the outcrop of the Edwards and associated limestones, the streams are dry or flow intermittently. The Guadalupe River is the only stream that contributes little or no water to the aquifer.

Climate

The climate of the San Antonio area ranges from semiarid in the western part of the area to subhumid in the eastern part. Temperatures generally are above freezing during the winter, although killing frosts do occur between November and early March. Maximum temperatures during the summer usually are between 90°F and 100°F. The average growing season is more than 250 days in most of the San Antonio area.

Precipitation ranges from an annual average of about 20 inches in the western part of the San Antonio area to about 33 inches in the eastern part

(Table 1). Most of the rain falls as isolated thundershowers, but occasionally some winter rains are widespread. Although the heaviest rainfall occurs in May, June, and September, the rain distribution throughout a year is fairly uniform. The monthly precipitation at selected stations of the U.S. Weather Bureau in the San Antonio area is shown in Figure 2, and the locations of these and other stations are shown in Figure 1.

Table 1.--Average annual precipitation at selected stations

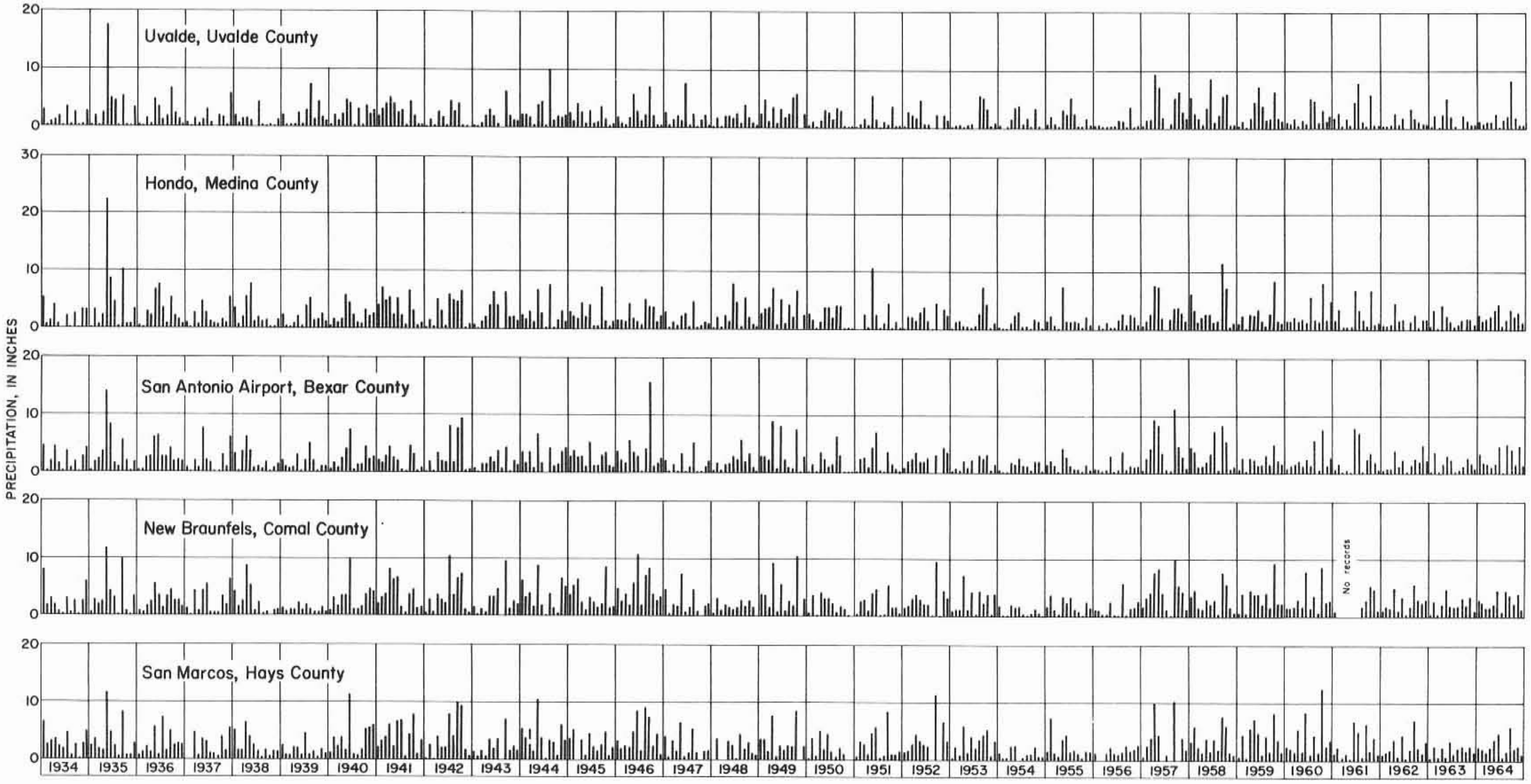
Station	Length of record (years)	Annual average * (inches)
San Marcos	67	33.01
New Braunfels	72	30.95
Fischer's Store	71	29.31
Boerne	73	31.93
San Antonio	91	27.53
Riomedina	42	26.26
Hondo	64	28.26
Sabinal	49	25.24
Uvalde	66	23.99
Brackettville	78	20.36

* Average of complete years only.

GENERAL GEOLOGY AND HYDROLOGY

Descriptions of the geology of the San Antonio area may be found in each county report and in other area-wide reports. (See "References.") Petitt and George (1956) summarized these previous works, and Garza (1962a) limited his geologic discussion of the area to a brief mention of the geologic units forming the major and minor aquifers and their general hydrologic properties. The following is from Garza (1962a, p. 7-9):

> "The geologic units, in order of their importance as aquifers, are the Edwards and associated limestones, the Glen Rose Limestone, the Leona Formation, the Travis Peak Formation, the Austin Chalk, rocks of the Taylor and Navarro Groups, the Carrizo Sand, and undifferentiated sands of the Wilcox Group.
>
> "The Edwards and associated limestones, which consists of the Georgetown, Edwards, and Comanche Peak Limestones of Cretaceous age, forms the main ground-water reservoir in the San Antonio area. It underlies or forms the surface of the Edwards Plateau north and northwest of San Antonio. In fresh exposures, most of the Edwards is a dense, hard limestone, but, on weathering, the rock is extensively



(From records of U.S. Weather Bureau)

Figure 2

Precipitation at Selected Stations

U. S. Geological Survey in cooperation with the Texas Water Development Board and Others

honeycombed and cavernous. Thus, where the Edwards and associated limestones is exposed, conditions are favorable for direct infiltration of rainwater. The exact thickness of the Edwards and associated limestones at all places is not known, but it probably averages at least 500 feet. Wells that penetrate fractures or cavernous zones obtain large yields, but other wells may yield little or no water.

"The Glen Rose Limestone of Early Cretaceous age crops out north of the Balcones fault zone, where the overlying Edwards and associated limestones has been removed by erosion. In general, the Glen Rose yields small to moderate amounts of water of fair to poor quality for domestic and stock use....

"The Leona Formation of Pleistocene age consists of alluvium and terrace deposits in the valleys of the major streams of the San Antonio area. The Leona Formation is important as an aquifer only in the Leona River valley southeast of the city of Uvalde, where some wells yield enough water for irrigation. In this area the Edwards and associated limestones and the gravels of the Leona Formation are hydraulically connected, and production from the Leona is limited by the recharge the Leona receives from the underlying Edwards and associated limestones.

"The yields of wells that draw from the other formations generally are small, and the quality of the water from some of the formations is unsatisfactory in most of the San Antonio area. In Comal and Kendall Counties, the Cow Creek Limestone Member of the Travis Peak Formation of Early Cretaceous age yields moderate quantities of water to wells; in the Cibolo Creek drainage area the Cow Creek may transmit a significant volume of water to the Edwards and associated limestones by underflow. In general, the Austin Chalk of Late Cretaceous age yields only small quantities of water to wells, and in most places the water contains hydrogen sulfide gas in objectionable quantities. Near Uvalde and other localized areas, the Austin Chalk yields moderate quantities of water similar in chemical quality to the water in the Edwards and associated limestones, suggesting a hydraulic connection between the formations. The Anacacho Limestone of Taylor age and the Escondido Formation of the Navarro Group yield small quantities of water for domestic and stock uses west of Bexar County.

"The Carrizo Sand of Eocene age supplies water to the city of Devine in Medina County and to a few irrigation wells in the extreme southern part of Bexar County. The undifferentiated sands of the Wilcox Group have not been fully tested, but in wells used for domestic supply the water is generally of fair to poor quality."

GROUND WATER

The Edwards and associated limestones is the most important aquifer in the San Antonio area. Early immigrants to the area settled in the vicinity of the springs which issue from the aquifer. As the population grew and the San Antonio area developed, wells were drilled to supply most of the water for municipal, military, industrial, irrigation, and domestic purposes.

Hydrologic observations of the Edwards and associated limestones were in progress intermittently from 1929 to about 1949. The current continuing program was begun in 1949, and the records since the early investigations cover climatic conditions ranging from minor dry and wet cycles to severe droughts and extremely wet periods.

Recharge

Recharge to the Edwards and associated limestones in the San Antonio area is chiefly by seepage from streams that cross the outcrop of the aquifer in the Balcones fault zone and, to a lesser extent, by direct infiltration of rainfall on the outcrop. Discharge measurements of the streams at gaging stations (Figure 1) are basic to the estimates of recharge to the aquifer. The streamflow records for the period 1960 through September 1964 have been published by the U.S. Geological Survey. (See "References.") The records for the October-December 1964 period are shown in Table 2.

Estimates of recharge for the period 1934-53 were made by Petitt and George (1956, p. 21-41) and later revised and extended through 1959 by Garza (1962a, p. 10-13). Fundamentally, the method employed by these investigators was the same as that used in this report to extend the recharge estimates through 1964 (Table 3). The method was based on the fact that recharge in each stream basin is the difference between total inflow above the infiltration area of the aquifer and the total outflow below the infiltration area. Hence seepage investigations made at different stages of the streams have helped in locating the infiltration areas, which generally coincide with the outcrop of the aquifer along the Balcones fault zone. That part of the inflow above the infiltration area in each stream basin is measured at a gaging station. The flood runoff determined at this gaging station is used to estimate the direct infiltration or runoff on the outcrop itself. Those stream losses due to evaporation and transpiration by vegetation are assumed to be proportionately the same in the area of the outcrop and above the outcrop. The total outflow for each stream basin is measured at another gaging station below the outcrop. Generally, this method has worked well over long periods of time, probably because errors tend to balance out over such periods.

Because not all the streams in the areas of recharge have been suitable for controlled gaging, assumptions concerning runoff in these and other areas have been made. Some areas having little or no runoff have been included either as part of the basins for which estimates of recharge have been made or as individual areas with assumed runoff characteristics similar to those in adjacent basins. The unit of runoff above the outcrop of a particular basin usually was applied to the outcrop area, except when rainfall records clearly indicated a wide variance of rainfall within the basin; in such a case, a correction based on rainfall distribution was applied to the unit of runoff.

Table 2.--Monthly mean discharge, in cubic feet per second, at selected stream-gaging stations, October-December 1964

(Figures rounded to nearest cubic foot per second)

Stream-gaging station	Discharge, in cfs		
	October	November	December
West Nueces River near Brackettville	90	6	1/
Nueces River at Laguna	327	135	111
Nueces River below Uvalde	185	41	23
Leona River spring flow near Uvalde	0	0	0
Dry Frio River near Reagan Wells	25	14	9
Frio River at Concan	104	65	58
Frio River below Dry Frio River near Uvalde	0	0	0
Sabinal River near Sabinal	43	25	19
Sabinal River at Sabinal	5	2	1
Seco Creek at Miller Ranch near Utopia	22	7	4
Seco Creek at Crook Ranch near D'Hanis	1/	1/	0
Hondo Creek near Tarpley	20	13	7
Hondo Creek at King Water Hole near Hondo	1/	1/	0
Medina River near Pipe Creek	163	109	71
Red Bluff Creek near Pipe Creek	3	5	0
Medina Canal near Riomedina	36	4	12
Medina River near Riomedina 2/	22	21	17
Medina River near San Antonio 3/	112	231	58
San Antonio River at San Antonio	23	43	17
Salado Creek (upper station) at San Antonio	2	6	1
Cibolo Creek near Boerne	5	5	3
Cibolo Creek at Selma	1/	0	0
Guadalupe River at Comfort	142	84	73
Guadalupe River near Spring Branch	198	161	108
Guadalupe River above Comal River at New Braunfels 4/	413	365	133
Comal River at New Braunfels	171	207	208
Blanco River at Wimberley	30	61	25
Blanco River near Kyle	19	47	10
San Marcos River spring flow at San Marcos	104	104	102

1/ Less than 0.5.
2/ Flow regulated by Medina Lake and diversion reservoir.
3/ Flow slightly regulated by Medina Lake and diversion reservoir.
4/ Flow largely regulated by Canyon Reservoir.

Table 3.--Estimated annual recharge, in thousands of acre-feet, to the Edwards and associated limestones, 1934-64

Year	Nueces and West Nueces River basins	Frio and Dry Frio River basins	Sabinal River basin	Medina River basin	Cibolo and Dry Comal Creek basins	Blanco River basin and adjacent area	Area between Sabinal and Medina River basins	Area between Cibolo Creek and Medina River basins	Total
1934	8.6	27.9	7.5	46.5	28.4	19.8	19.9	21.0	179.6
1935	411.3	192.3	56.6	71.1	182.7	39.8	166.2	138.2	1,258
1936	176.5	157.4	43.5	91.6	146.1	42.7	142.9	108.9	909.6
1937	28.8	75.7	21.5	80.5	63.9	21.2	61.3	47.8	400.7
1938	63.5	69.3	20.9	65.5	76.8	36.4	54.1	46.2	432.7
1939	227.0	49.5	17.0	42.4	9.6	1.1	33.1	9.3	399.0
1940	50.4	60.3	23.8	38.8	30.8	18.8	56.6	29.3	308.8
1941	89.9	151.8	50.6	54.1	191.2	57.8	139.0	116.3	850.7
1942	103.5	95.1	34.0	51.7	93.6	28.6	84.4	66.9	557.8
1943	36.5	42.3	11.1	41.5	58.3	20.1	33.8	29.5	273.1
1944	64.1	76.0	24.8	50.5	152.5	46.2	74.3	72.5	560.9
1945	47.3	71.1	30.8	54.8	129.9	35.7	78.6	79.6	527.8
1946	80.9	54.2	16.5	51.4	155.3	40.7	52.0	105.1	556.1
1947	72.4	77.7	16.7	44.0	79.5	31.6	45.2	55.5	422.6
1948	41.1	25.6	26.0	14.8	19.9	13.2	20.2	17.5	178.3
1949	166.0	86.1	31.5	33.0	55.9	23.5	70.3	41.8	508.1
1950	41.5	35.5	13.3	23.6	24.6	17.4	27.0	17.3	200.2
1951	18.3	28.4	7.3	21.1	12.5	10.6	26.4	15.3	139.9
1952	27.9	15.7	3.2	25.4	102.3	20.7	30.2	50.1	275.5
1953	21.4	15.1	3.2	36.2	42.3	24.9	4.4	20.1	167.6
1954	61.3	31.6	7.1	25.3	8.8	10.7	11.9	4.2	160.9
1955	128.0	22.1	.6	16.5	3.3	9.5	7.7	4.3	192.0
1956	15.6	4.2	1.6	6.3	2.2	8.2	3.6	2.0	43.7
1957	108.6	133.6	65.4	55.6	397.9	76.4	129.5	175.6	1,143
1958	266.7	300.0	223.8	95.5	268.7	70.7	294.9	190.9	1,711
1959	109.6	158.9	61.6	94.7	77.9	33.6	96.7	57.4	690.4
1960	88.7	128.1	64.9	104.0	160.0	62.4	127.0	89.7	824.8
1961	85.2	151.3	57.4	88.3	110.8	49.4	105.4	69.3	717.1
1962	47.4	46.6	4.3	57.3	24.7	28.9	23.5	16.7	249.4
1963	39.7	27.0	5.0	41.9	21.3	16.2	10.3	9.3	170.7
1964	126.1	55.1	16.3	43.3	51.1	22.2	61.3	35.8	411.2
Total	2,854	2,465	967.8	1,567	2,783	949.0	2,092	1,743	15,420
Average	92.1	79.5	31.2	50.6	89.8	30.6	67.5	56.2	497.4

The Medina Dam stores and regulates water on the Medina River near the infiltration areas of the aquifer. Recharge to the aquifer from the leakage in the Medina Lake area was based on the extensive investigations of that area made by Lowry (1955).

During the 1934-64 period, the annual recharge to the aquifer ranged between the minimum of approximately 44,000 acre-feet in 1956 and the maximum of more than 1,700,000 acre-feet in 1958 (Table 3). The annual average was almost 500,000 acre-feet. During 1960-64, the period with new data covered by this report, the average annual recharge was about 475,000 acre-feet.

Discharge

The discharge from the Edwards and associated limestones in the San Antonio area is through springs and wells. Most of the 1934-64 discharge was from springs, but the amount from wells increased considerably during the latter half of the period (Figure 3). Actually, the annual well discharge from 1954 to 1957 and from 1963 to 1964 exceeded the annual spring flow. The fact that these periods were deficient in general rainfall resulted in decreased spring flow and increased withdrawals from wells. The converse is true when precipitation is above normal, as shown in Figure 3 for the period 1958-61. The chief reason for the difference in the annual discharge from wells is the difference in precipitation from one year to the next; but new wells are drilled each year, and the accompanying increase in withdrawals becomes evident in the course of several years.

The discharge from the aquifer during 1934-64 is shown, by counties, in Table 4. Most of the discharge in Comal and Hays Counties is through Comal and San Marcos Springs, and in the other counties is from wells.

Discharge from Springs

The principal springs in the San Antonio area are Leona River Springs near Uvalde, San Antonio and San Pedro Springs at San Antonio, Comal Springs at New Braunfels, and San Marcos Springs at San Marcos (Figure 1). These springs issue along faults that have developed into open cracks and solution channels as water discharges naturally from the aquifer. Part of the discharge from Leona River Springs is by underflow through the Leona Formation.

Spring flow during the 1955-64 period is shown in Figure 4. Three of the principal springs--San Antonio, San Pedro, and Leona River--ceased flowing during the 1955-56 period, which was the peak of the long drought during 1948-57. Comal Springs ceased flowing during June-November 1956 for the first time on record. San Marcos Springs reached a record low of 46 cfs (cubic feet per second)[1/] on August 15, 16, 1956.

During the period 1957-61, recharge from heavy rainfall caused above-average flows from all springs (Figure 4). San Marcos Springs had a record

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[1/] One cfs is 448.8 gpm (gallons per minute) or 646,317 gpd (gallons per day).

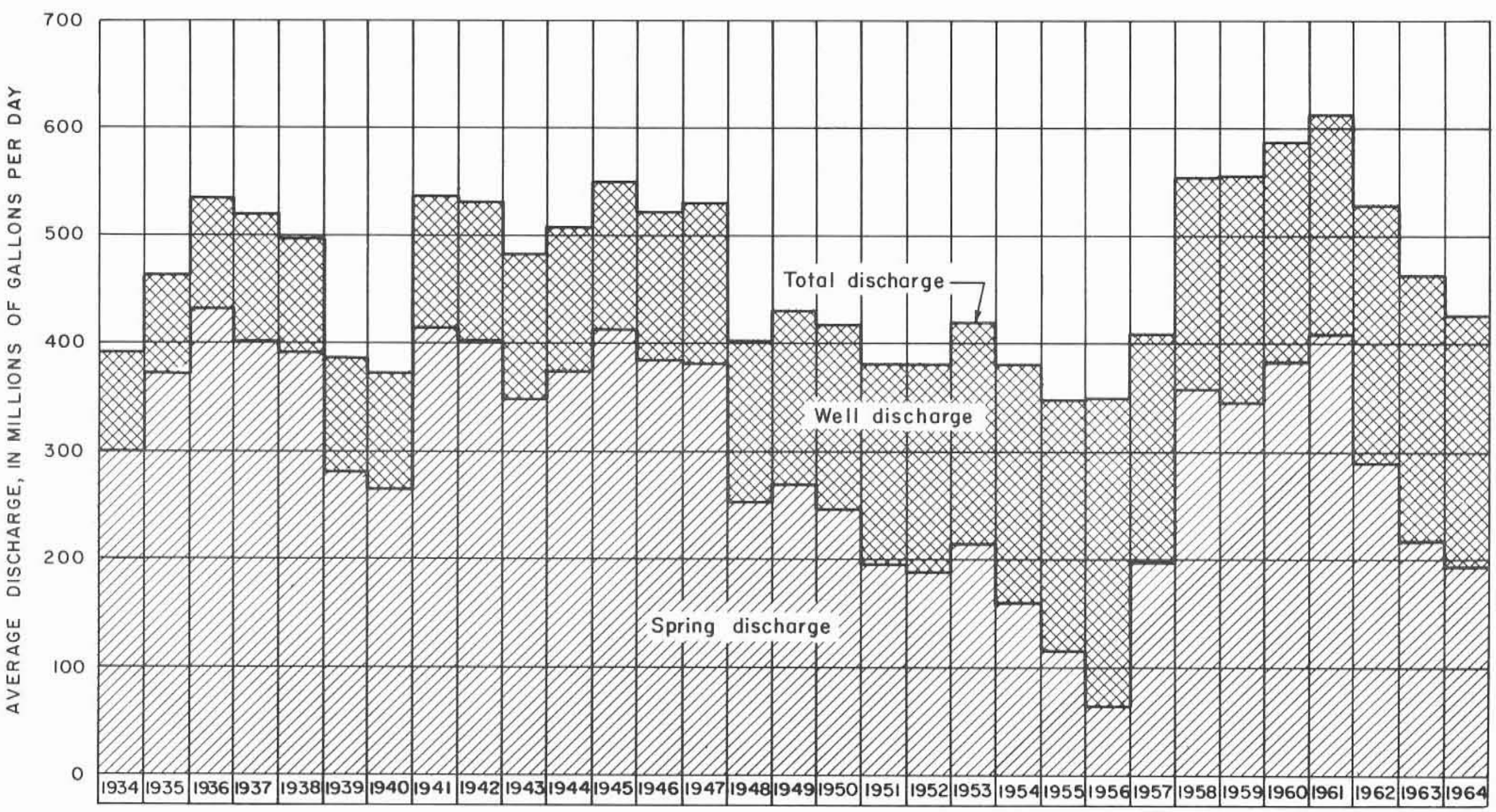

Figure 3

Discharge from Springs and Wells in the Edwards and Associated Limestones

U. S. Geological Survey in cooperation with the Texas Water Development Board and Others

Table 4.--Total discharge, by counties, from the Edwards and associated limestones, 1934-64, in millions of gallons per day

Year	Daily discharge, by counties					Total discharge	
	Uvalde and eastern Kinney	Medina	Bexar	Comal	Hays	Million gallons per day	Thousand acre-feet per year
1934	11.3	1.2	97.6	204.5	76.4	391.0	437.9
1935	10.9	1.3	153.4	211.8	86.5	463.9	519.6
1936	23.8	1.3	192.1	233.7	83.2	534.1	598.2
1937	25.3	1.3	180.2	225.4	77.8	510.0	571.2
1938	22.1	1.3	167.7	223.5	83.4	498.0	557.8
1939	16.3	1.4	109.4	195.8	63.5	386.4	432.8
1940	14.4	1.4	104.2	182.0	70.0	372.0	416.6
1941	16.0	1.4	176.3	223.2	119.9	536.8	601.2
1942	20.1	1.5	181.4	227.8	100.2	531.0	594.7
1943	17.2	1.5	153.6	222.4	86.8	481.5	539.3
1944	9.3	1.5	149.0	226.0	120.8	506.6	567.4
1945	11.1	1.5	178.4	234.9	123.0	548.9	614.8
1946	5.6	1.5	160.8	233.8	119.6	521.3	583.9
1947	12.3	1.8	172.6	229.3	113.9	529.9	593.5
1948	8.2	1.7	142.1	181.3	69.0	402.3	450.6
1949	11.8	1.8	147.6	187.0	80.2	428.4	479.8
1950	15.9	2.0	158.3	170.6	69.9	416.7	466.7
1951	15.1	2.0	166.8	134.4	61.7	380.0	425.6
1952	20.3	2.8	167.0	118.9	70.4	379.4	424.9
1953	24.6	3.6	172.9	126.5	90.5	418.1	468.3
1954	23.8	5.6	186.4	90.2	72.8	378.8	424.3
1955	25.3	9.9	192.1	62.6	57.2	347.1	388.8
1956	53.2	15.8	205.0	30.0	45.0	349.0	390.9
1957	25.9	10.6	169.1	101.1	100.9	407.6	456.5
1958	21.2	5.9	178.1	206.9	139.2	551.3	617.5
1959	38.4	7.4	194.2	206.9	105.8	552.7	619.0
1960	48.0	6.8	192.3	210.0	128.1	585.2	655.4
1961	50.5	5.7	205.6	222.8	125.7	610.3	683.5
1962	57.6	7.2	196.4	176.5	88.2	525.9	589.0
1963	45.6	8.7	194.3	139.0	73.1	460.7	516.0
1964	43.9	7.7	179.5	126.9	65.2	423.2	474.0

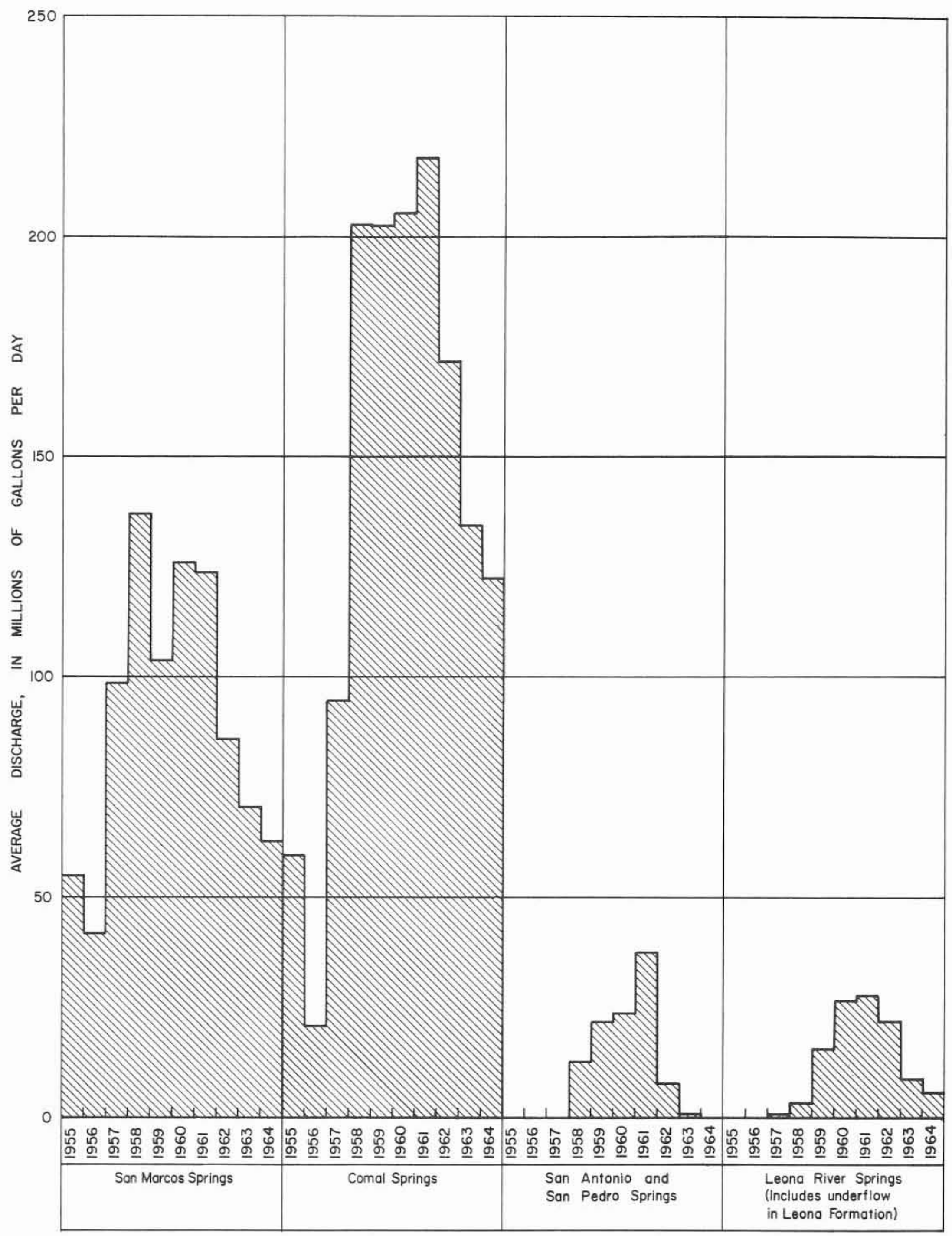

Figure 4

Discharge from the Major Springs

U. S. Geological Survey in cooperation with the Texas Water Development Board and Others

high of 292 cfs on May 9, 1958. The annual average discharge of Comal Springs during the period 1958-61 was about 320 cfs; the long-term average is 277 cfs. The discharge of San Antonio and San Pedro Springs in both 1960 and 1961 exceeded the estimated annual average of about 36 cfs. The annual discharge from Leona River Springs during 1961 was the highest on record.

Discharge from Wells

The discharge from wells tapping the Edwards and associated limestones in the San Antonio area is shown according to use in Figure 5 for the period 1955-64. During this interim, more than one-half of the average annual discharge from wells was used for minicipal and military purposes. The cities of San Antonio, Uvalde, Sabinal, Hondo, Castroville, New Braunfels, and San Marcos depend upon water from wells drawing from the aquifer. Other smaller communities and many independent water companies, as well as the military installations adjacent to the city of San Antonio, similarly depend on the aquifer. Over 90 percent of the discharge required for municipal and military purposes is used in Bexar County. Of this 90 percent, more than 70 percent is used by the city of San Antonio.

The withdrawal of water from the Edwards and associated limestones for irrigation is mainly in Uvalde, Medina, and Bexar Counties; during the period 1955-64, the amount of land under irrigation increased from nearly 30,000 acres to more than 40,000 acres, and most of the increase was in Uvalde County. In 1964, nearly 19,000 acres was irrigated with ground water from this aquifer in Uvalde County, approximately 16,000 in Bexar County, and more than 5,000 in Medina County. The amount of water used annually for irrigation varies, of course, according to the amount and distribution of rainfall. For example, the annual withdrawals for irrigation during 1955-56, the peak of a long drought, were greater than those of 1957-61, an extremely wet period (Figure 5).

Water for the larger industries, and for the domestic, stock, and minor purposes in the San Antonio area is withdrawn from wells tapping the aquifer. The amount of water withdrawn annually for these uses remained nearly constant during the 1955-64 period (Figure 5).

Fluctuation of Water Levels

To determine water-level fluctuations, 72 observation wells that tap the Edwards and associated limestones in the San Antonio area were measured periodically during 1964. Measurements were made monthly in 41 of these wells, and bimonthly in 10 of them. Instruments that recorded water levels continuously were in operation on 21 of the wells.

The water levels in most of the observation wells are lowered each summer, chiefly because of the increased withdrawals from wells at that season. The magnitude of the lowering depends on the proximity of the observation wells to the center of pumping. In the San Antonio area, the center of the largest withdrawals from wells is in the vicinity of San Antonio. The water levels recover rapidly when the rate of pumping decreases, but the recovery can be even faster when the aquifer is recharged by floodwaters during wet periods. The rates of

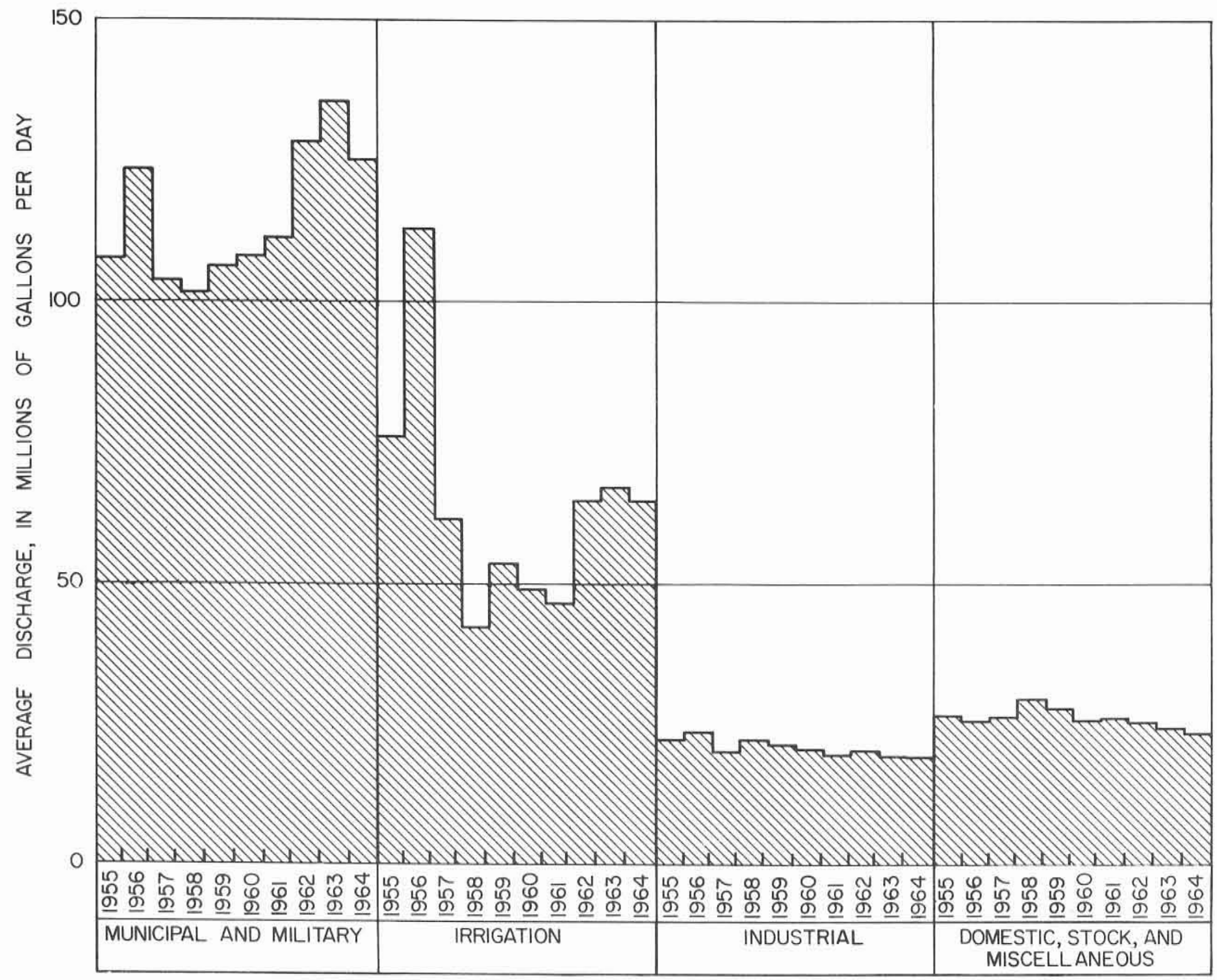

Figure 5

Use of Water from Wells in the Edwards and Associated Limestones

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recharge (Table 3, 1957-58) can be much greater than the largest rate of withdrawals (Figure 3, 1956), and the water-level fluctuations can be greater and more rapid during wet periods than during droughts or dry periods. The net annual change in water level reflects the difference between recharge to and discharge from the aquifer.

The fluctuations of water levels in representative wells tapping the Edwards and associated limestones in the San Antonio area are shown in Figure 6. The trend in water levels during the period 1947-56 reflects a drought and the general increase in withdrawals from wells throughout the San Antonio area. Recharge from heavy rainfall during the period 1957-61 caused the water levels to rise to approximately the same levels as they were before the drought. This large cycle of water-level fluctuation and other smaller ones are likewise shown in Figure 7, which indicates the close correlation between discharge from Comal Springs, water level in Bexar County well 26, and precipitation at Boerne. Also shown is the comparison of accumulated recharge and accumulated discharge.

The changes in water level in well V-6 in Kinney County (Figure 6) are closely related to those in the discharge of Las Moras Springs, which is west of the ground-water divide near Brackettville. (This divide, which separates the San Antonio area from areas west of it, is discussed in the subsequent section on "Movement of Water.") Two main factors--the increased irrigation development, west and southwest of Brackettville, and a relatively dry season--brought about abnormally low water levels in the summer of 1964. The water level in well V-6 dropped more than 20 feet and Las Moras Springs ceased to flow during this period. After the pumping decreased in the fall and winter, the levels and spring flow recovered. This situation can be expected to recur, and if the irrigation development continues to increase, the springs may cease flowing for longer periods.

Movement of Water

The Edwards and associated limestones is not homogeneous; the openings in the aquifer range from large cavities, where water moves freely, to small cracks in which losses in aquifer head are large. Because of these conditions and because sufficient control is not available to detect the changes in aquifer head in more detail, only a general direction of movement can be shown by the water table and piezometric map (Figure 8). On Figure 8 is shown the approximate altitude of the water table and piezometric surface of the Edwards and associated limestones in the San Antonio area during January 1961, when the water levels were at or near the high of the period 1960-64. The general movement of the water is in the direction of the hydraulic gradient--that is, in a direction normal to the contour lines representing equal hydrostatic pressure (Figure 8).

In the area of outcrop of the Edwards and associated limestones, the water moves under water-table conditions generally southward or southeastward under steep hydraulic gradients toward the artesian part of the aquifer (Figure 8). In the artesian part of the aquifer, the water moves at relatively low hydraulic gradients toward the east and northeast. Comal and San Marcos Springs are the two spillway points of greatest natural discharge from the aquifer. Ground-water divides in the vicinity of Brackettville in Kinney County and in the northeastern part of Hays County are shown on Figure 8. These divides are

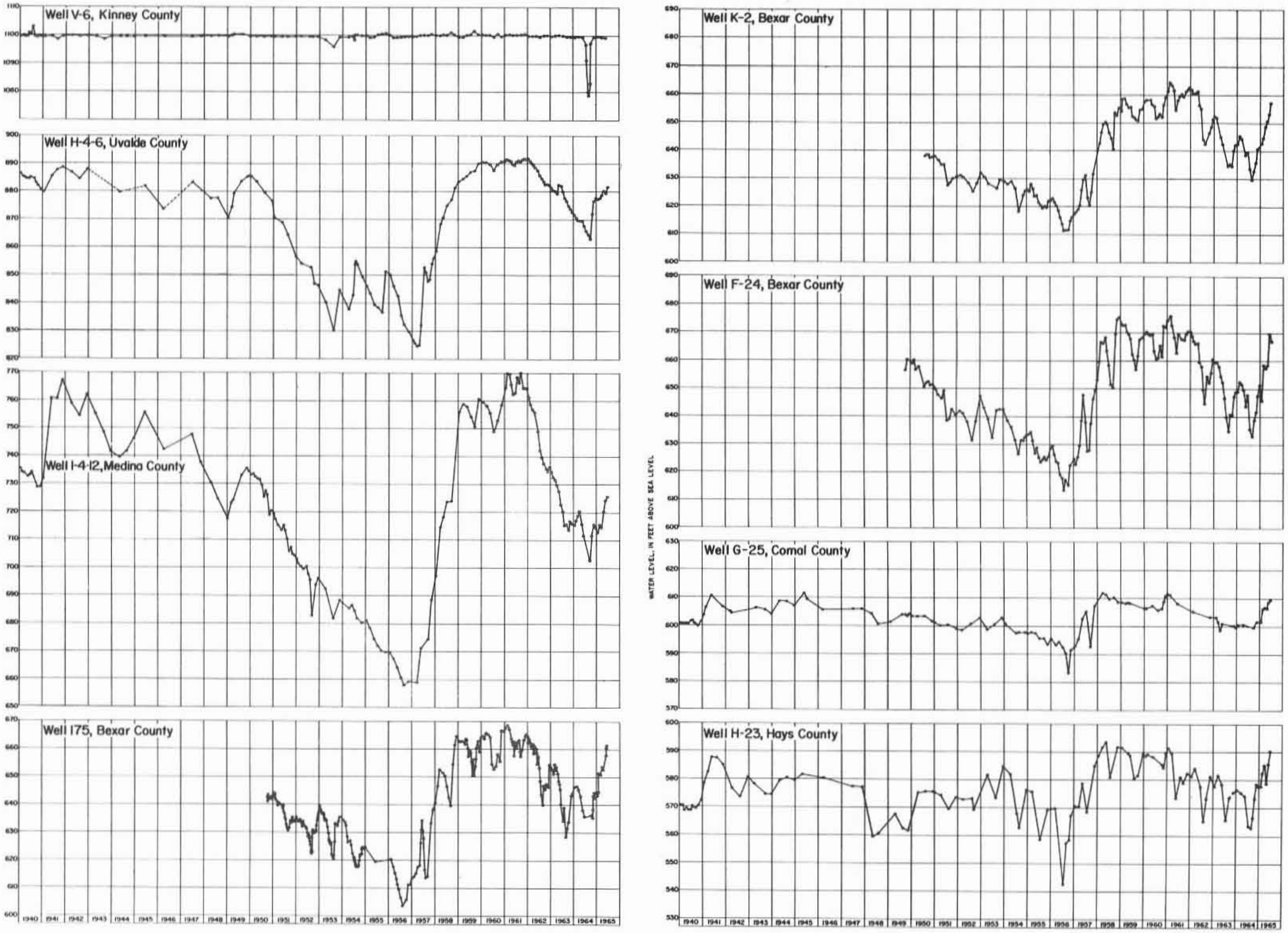

Figure 6

Hydrographs of Representative Wells in the Edwards and Associated Limestones (Sheet 1 of 2)

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Figure 6

Hydrographs of Representative Wells in the Edwards and Associated Limestones (Sheet 2 of 2)

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Figure 7

Discharge from Comal Springs, Water Level in Bexar County Well 26, Precipitation at Boerne, and Comparison of Accumulated Recharge and Discharge in the Edwards and Associated Limestones

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assumed to represent the western and eastern hydraulic boundaries of the Edwards and associated limestones in the San Antonio area.

The flow of ground water in the Edwards and associated limestones has been described as nonuniform and generally unsteady (Garza, 1962a, p. 9). The velocity of flow changes from place to place, as well as from time to time at any one place. This type of flow system is complex, particularly during periods of heavy recharge to or large withdrawals from the aquifer. Correlation of aquifer head and changes in storage is impossible during these extreme periods. However, the aquifer may reach conditions of equilibrium during winters when the recharge to and artificial discharge from the aquifer are small. The flow of ground water under approximate conditions of equilibrium is considered to be nearly steady (Garza, 1962a, p. 26), and correlation of aquifer head and changes in storage may then be possible.

Changes in Storage

Water-level fluctuations in Bexar County well 26 were used by Petitt and George (1956) to indicate the changes in storage in the Edwards and associated limestones in the San Antonio area. Well 26 was considered appropriate because of its central location in the area, because of its long and continuous records of water level, and because the water level in this well correlated with levels in other wells in the area. The one drawback in the use of this well is that, because of its proximity to the large center of pumping in the vicinity of San Antonio, the water-level records during the pumping season cannot be used. Nor can they be used during periods of heavy rainfall. However, over a long period of time and under different climatic conditions, suitable correlation points were found to define the curve representing the changes in storage in the aquifer (Figure 9). Records for the period 1946-64 were used in this correlation because recharge and discharge data for this period are the most recent available that cover a cycle of near maximum water-level fluctuation. Beginning with 1946, each point represents the accumulated difference between recharge and discharge plotted against the water level in well 26 at the end of each year. Points representing changes in storage for periods of nearly steady flow define the change-in-storage curve.

The estimated decrease in ground-water storage in the aquifer during the drought period of 1947-57 was more than 2 million acre-feet, but this loss was nearly matched by the accretion of ground water during the wet period of 1957-61 (Figure 7). However, a decrease of about 750,000 acre-feet of ground-water storage took place during 1962-64, a period of below average precipitation.

QUALITY OF WATER

The water in the Edwards and associated limestones in most of the San Antonio area is a calcium bicarbonate water having a hardness generally of more than 200 ppm (parts per million). The quality of the water may vary from place to place, but in general the dissolved-solids content increases downdip in the formation toward the south and southeast. Chemical analyses of the water from wells and springs in the Edwards and associated limestones and the other aquifers in the San Antonio area may be found in the report by Petitt and George (1956) and in each county report. (See "References.")

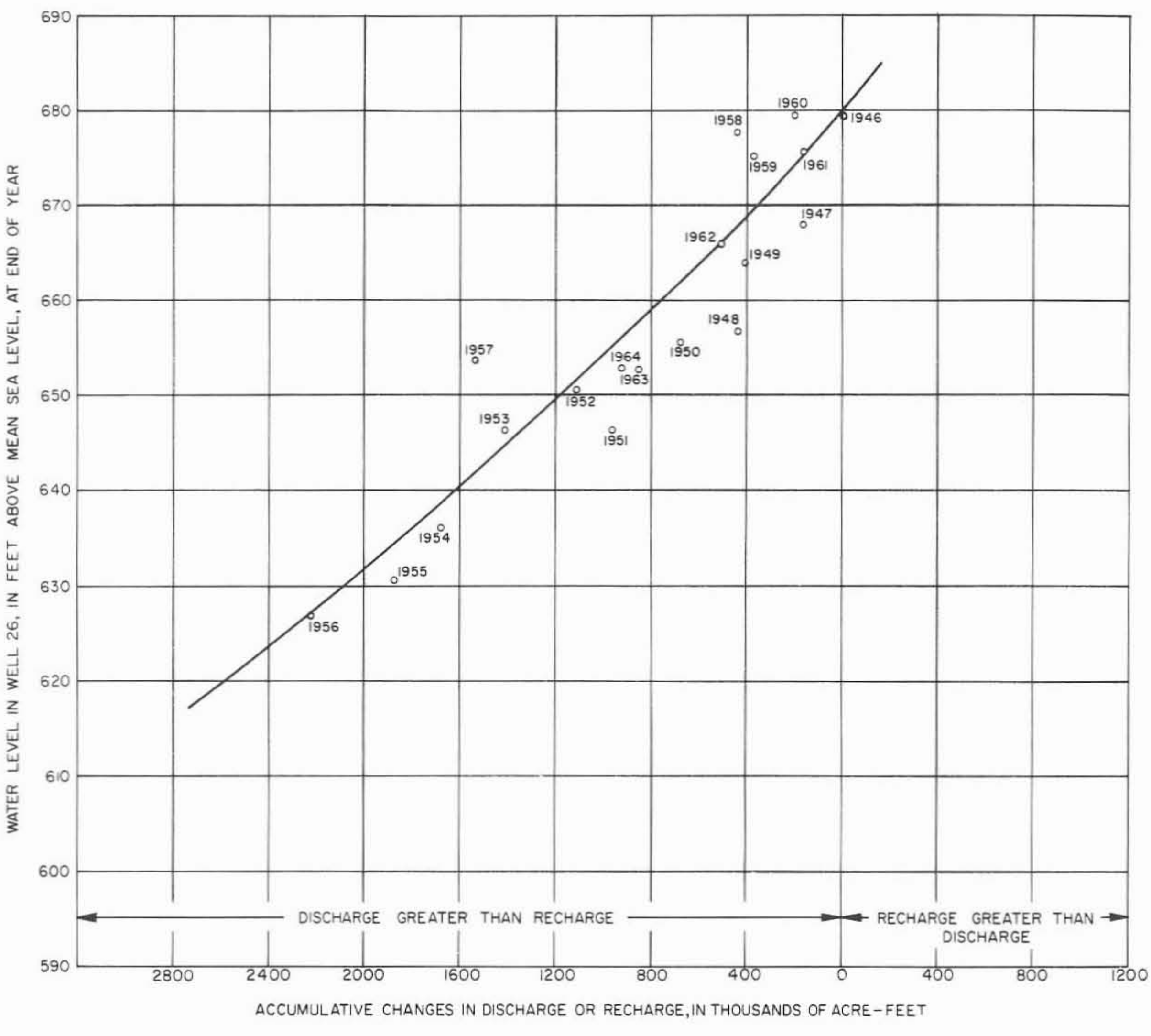

Figure 9

Relation of Changes in Water Level in Well 26, Bexar County, to Accumulated Changes in Storage in the Edwards and Associated Limestones, 1946-64

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The zone of transition between water of good quality and saline water exists in the downdip artesian region of the Edwards and associated limestones. An arbitrary line of so-called "bad water" (1,000 ppm dissolved solids) marks the approximate southern boundary of water of good chemical quality (Figure 10). The location of this line is based on the chemical analyses of water from wells tapping the aquifer in the zone of transition. The dissolved-solids content of water from many wells was estimated from the specific conductance of the water. Water from some wells north of the line and all wells south of the line contains hydrogen sulfide gas.

In Figure 11 is shown the relation between specific conductance of water from selected wells in and near the zone of transition and the altitude of water level in well 26 at the time the samples were collected. The respective locations of well 26 and of the other sampled wells (J-87, J-40, M-44, and J-90) are shown in Figure 1. The selected wells, which are in Bexar County where a periodic resampling program has been in progress since 1955, are strong wells that show few drawdown effects when pumped or allowed to flow. In Figure 11 is shown the relation between the regional changes in the chemical quality of the water along the zone of transition and the water level in a well that represents regional changes in aquifer head.

Well J-87, near the zone of transition, is in the good-water area (generally having about 300 ppm dissolved solids), and well J-40 is almost at the bad-water line (having 1,000 ppm dissolved solids). The quality of the water from well J-87 shows no significant changes throughout the period of record. The quality of the water from well J-40 generally becomes poorer during the pumping season (May to about September) but improves when the pumpage has decreased (September to about April), particularly following periods when the rate of recharge has been great. Apparently these changes in quality are the result of pressure surges, caused by the effects of pumpage and recharge, that disturb the hydraulic equilibrium in the zone of transition. The effects of these surges on the changes in the quality of water are more noticeable in the zone of transition than in the good-water area because of the greater changes in water quality in this zone over relatively short distances. The net change in the quality of water from well J-40 from 1956 to 1965 (shown by the dashed line in Figure 11) has been a decrease in mineralization of less than 4 percent. The maximum impairment of the quality of water during this period was less than 5 percent from the median; the maximum improvement was more than 8 percent.

Wells M-44 and J-90 tap more saline areas in the zone of transition (3,000 to 4,000 ppm dissolved solids) than does well J-40. The quality of the water from these wells apparently improves during the pumping season and becomes poorer during the winter--the reverse of the trend shown by well J-40 (Figure 11). The change in water quality in the more saline areas apparently lags the change near the bad-water line. This lag probably corresponds to a regional lag in the updip-downdip shift of the hydraulic equilibrium in this zone due to the pressure changes in the aquifer. The net change in the chemical quality of the water from wells M-44 and J-90 during the period of record was less than 5 percent.

Garza (1962a, p. 38), in relating quality and temperature of water to depth of wells, reported that the low temperature gradient of the water of good quality is due to relatively free circulation; the water of poor quality has a

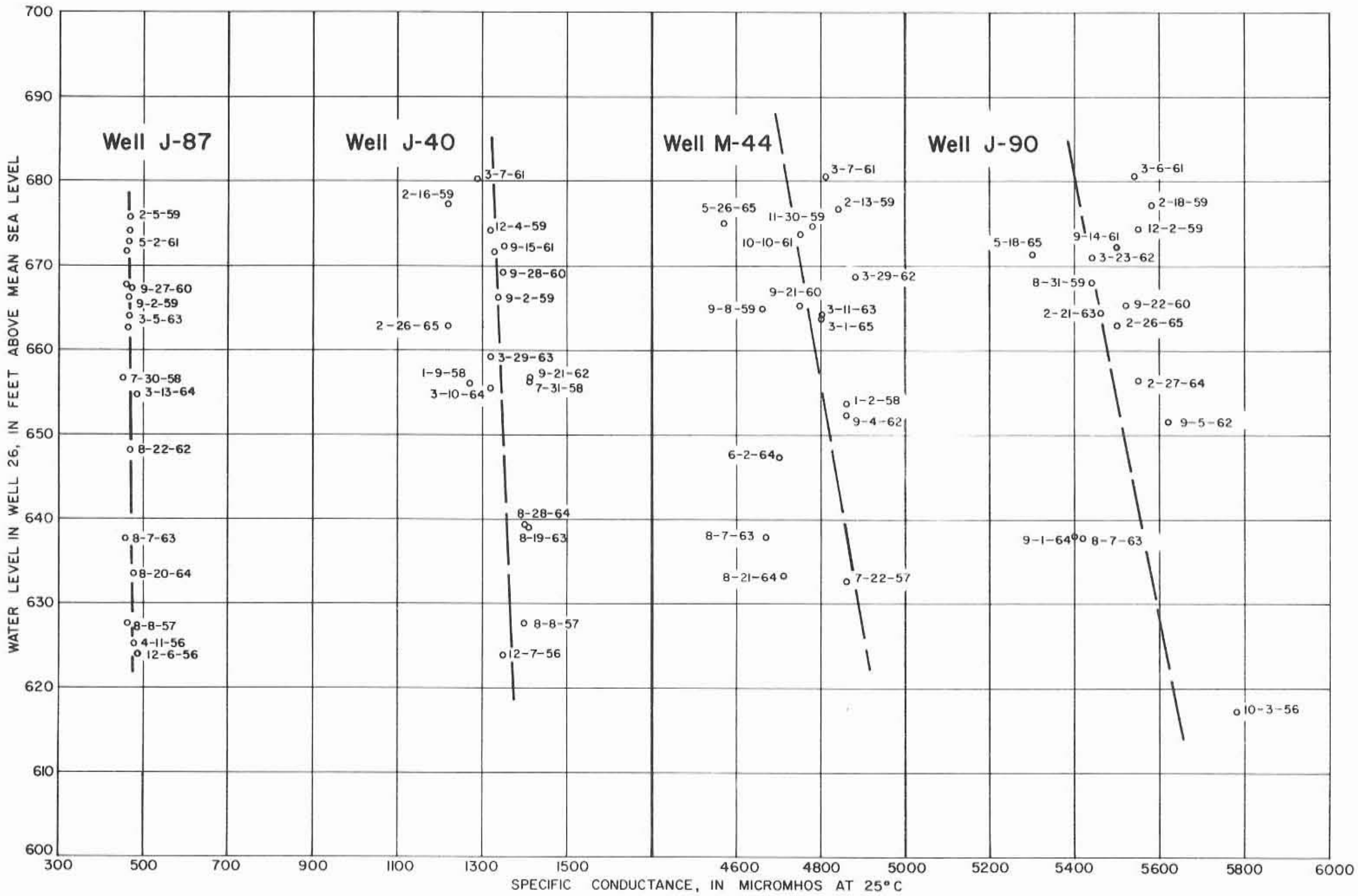

Figure 11

Relation of Specific Conductance of Water from Selected Wells in the Edwards and Associated Limestones in Bexar County to Altitude of Water Level in Well 26

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higher thermal gradient and probably does not circulate as freely. In effect, the quality and temperature of the water in the zone of transition probably correspond to the degree of restriction of movement of water. A continued increase in the restriction of movement downdip in the zone of transition may explain the lag in the changes in the quality of the water in the more saline areas corresponding to the changes in the quality of water near the bad-water line. The probable cause of the decrease in circulation downdip in this zone is a general decrease in permeability of the limestones forming the aquifer.

If the trend during the period of record (Figure 11) can be assumed to prevail while the aquifer head drops from 620 to 500 feet above mean sea level in well 26, the net increase in mineralization of the water in well J-40 will then be about 7 percent. Under these conditions, therefore, the maximum impairment of the quality of the water in well J-40 during the pumping season will depend on the amount of withdrawals. Consequently, continued observations at key wells are especially necessary during periods of low stage in aquifer head in order to detect not only changes in the quality of water in the zone of transition but also the possible encroachment of bad water into the good-water area.

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