Ground-Water Geology of Bexar County, Texas

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By Ted Arnow

ABSTRACT

The investigation in Bexar County was part of a comprehensive study of a large area in south-central Texas underlain by the Edwards and associated limestones (Comanche Peak and Georgetown) of Cretaceous age. The limestones form an aquifer which supplies water to the city of San Antonio, several military installations, many industrial plants, and many irrigated farms.

The geologic formations that yield water to wells in Bexar County are sedimentary rocks of Mesozoic and Cenozoic age. The rocks strike northeastward and dip southeastward toward the Gulf of Mexico. In the northern part of the county, in an erosional remnant of the Edwards Plateau, the rocks are nearly flat and free from faulting. In the central and southern parts of the county, however, the rocks dip gulfward at gentle to moderately steep angles and are extensively faulted in the Balcones and Mexia fault zones. Individual faults or shatter zones were traced as much as 25 miles; the maximum displacement is at least 600 feet. In general, the formations are either monoclinal or slightly folded; in the western part of the county the broad Culebra anticline plunges southwestward.

Most of the large-capacity wells in Bexar County draw water from the Edwards and associated limestones, but a few draw from the Glen Rose limestone, the Austin chalk, and surficial sand and gravel. The Hosston formation, Glen Rose limestone, Buda limestone, and Austin chalk, all of Cretaceous age, generally yield small to large supplies of water; the Wilcox group and Carrizo sand of Tertiary age yield moderate supplies and alluvium of Pleistocene and Recent age generally yield small supplies.

The Edwards and associated limestones are recharged primarily by ground-water underflow into Bexar County from the west, and secondarily by seepage from streams that cross the outcrop of the aquifer in Bexar County. During the period 1934–47 the recharge to the aquifer in Bexar County is estimated to have averaged between 400,000 and 430,000 acre-feet per year.

Discharge from the aquifer takes place by means of wells and springs and by underflow into Comal and Guadalupe Counties on the northeast. During the period 1934–47 the estimated average discharge from wells and springs was about 174,000 acre-feet per year. The discharge by underflow out of the county during the same period is estimated to have averaged between 220,000 and 260,000 acre-feet per year. Probably only a small amount of water moves downdip southeast of San Antonio. The presence of highly mineralized water in that area suggests that the circulation of water is poor because of the low permeability of the aquifer.

During the period 1934–56 the discharge from the Edwards and associated limestones greatly exceeded the recharge; consequently, water levels in wells

declined. The decline was greatest in the northwestern part of the county, where the water levels in wells dropped as much as 100 feet. The decline was progressively less toward the east, averaging 40 feet along the Bexar-Comal County line. The area of the greatest concentration of discharge, which includes San Antonio and extends to the southwest and northeast, coincides with the area of maximum faulting and maximum recorded yields from wells and is not the area of greatest decline. The ability of the Edwards and associated limestones to transmit and store water in the San Antonio area apparently is so great that the discharge from wells results in much smaller declines of water level than do similar or even smaller discharges in other areas.

The water from the Edwards is almost uniformly a calcium bicarbonate water of good quality, although hard. In the southern part of the San Antonio area the water is charged with hydrogen sulfide; farther downdip it becomes highly mineralized.

INTRODUCTION

LOCATION AND ECONOMIC IMPORTANCE OF THE AREA

Bexar County is in south-central Texas, about 125 miles northwest of the Gulf of Mexico and the same distance northeast of the Mexican border. (See fig. 1.) The area of the county is 1,247 square miles.

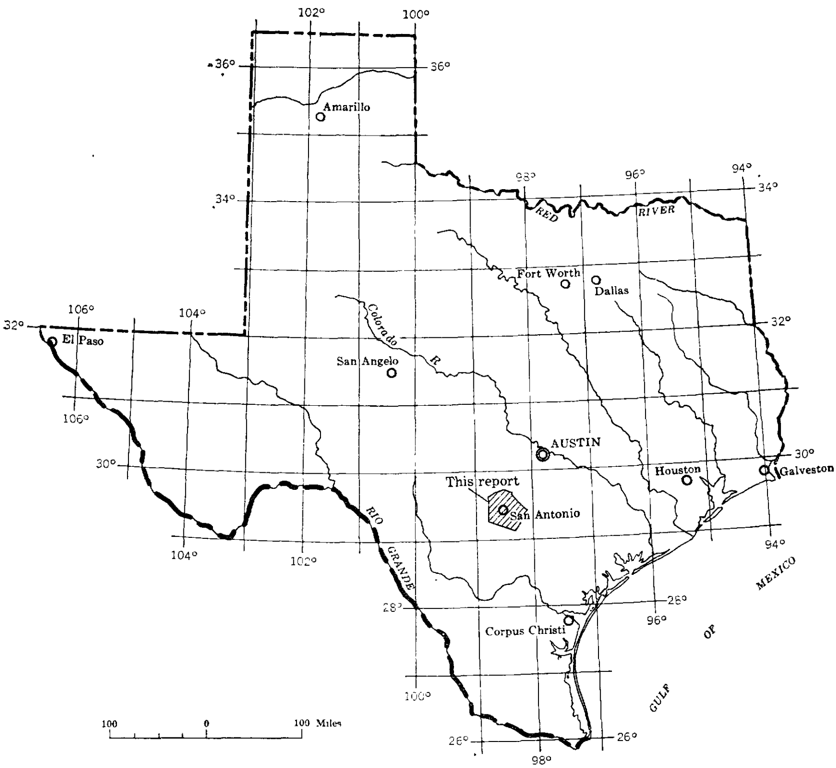

FIGURE 1.—Map of Texas showing location of Bexar County.

San Antonio, near the center of the county, is the third largest city in Texas. The estimated population of the metropolitan area in 1955 was 565,300 (McGregor, 1955, p. 152). The city, founded in 1812, is one of the oldest in the southwestern part of the United States. It is the financial, commercial, and cultural center of southern Texas and is one of the most important military centers in the Nation. There are four major military installations in or adjacent to the city and several others within the county. In 1955, 518 manufacturing or processing plants were in operation in the city, and the chief products were clothing, cement, furniture, meat and other foods, and chemicals.

Large quantities of water are needed to meet the requirements of the rapidly increasing population, the expanding industries, and irrigation. All the water used for municipal, military, or industrial purposes is obtained from wells or springs; San Antonio is one of the largest cities in the United States supplied exclusively with ground water. The continuously increasing demand for water has been met by increasing withdrawals of ground water.

PURPOSE AND SCOPE OF THE INVESTIGATION

The investigation in Bexar County was part of a comprehensive study of the geology and hydrology of 13 counties underlain by the Edwards and associated limestones—an important ground-water reservoir. The program in Bexar County was started in 1932 as a cooperative project of the U.S. Geological Survey and the Texas Board of Water Engineers and was enlarged in 1947 by the cooperation of the San Antonio Water Board. Study was made of the thickness, depth, and areal extent of all water-bearing formations and the source, availability, movement, and quality of the ground water—with special emphasis on the Edwards and associated limestones.

The geology of Bexar County was mapped by A. N. Sayre of the Geological Survey in 1932 and 1933. The collection of well records, pumpage figures, water samples for chemical analyses, and the measurement of water-level fluctuations were started in 1932 and maintained as a continuing program. Preliminary results of the investigation were reported by Livingston, Sayre, and White (1936) and by Livingston (1947). Data for Bexar County were included in reports by Lang (1954) and Petitt and George (1956).

This report contains the geologic map of the county prepared by Sayre in 1932–33, with slight modifications by later workers; a description of the geologic formations; and a discussion of the ground-water reservoir in the Edwards and associated limestones adapted largely from Petitt and George (1956). Well numbers used in this report are the same as those used by Petitt and George (1956, pl. 12, v. 2, pt. 1).

This report was prepared under the direct supervision of R. W. Sundstrom, district engineer of the U.S. Geological Survey in charge of ground-water investigations in Texas, and under the administrative supervision of S. W. Lohman, area chief, and A. N. Sayre, chief of the Ground Water Branch of the Geological Survey. B. M. Petitt, Jr., and A. G. Winslow of the U.S. Geological Survey made many suggestions that facilitated preparation of this report.

TOPOGRAPHY AND DRAINAGE

The topography of Bexar County is closely related to the geologic structure. The northern third of the county, part of the Edwards Plateau, is separated from the West Gulf Coastal Plain by the Balcones fault zone.

The rugged and hilly Edwards Plateau on the upthrown side of the Balcones fault zone ranges in altitude from about 1,100 to 1,900 feet. The plateau is underlain principally by limestone beds which dip very slightly toward the southeast. The plateau, dissected by the headwaters of many small streams, is drained by Cibolo and Balcones Creeks and by the headwaters of southeastward-flowing Culebra, Leon, and Salado Creeks. The characteristic vegetation is juniper and small oak.

The Balcones fault zone trends southwestward across the central part of the county. The zone is underlain by fault blocks composed of limestone and shale beds which dip gently southeastward. The characteristic vegetation is mesquite in the plains and live oak on the low hills. The altitude of the zone ranges from about 700 to 1,100 feet.

The Balcones fault zone is drained, in part, by the San Antonio River, the principal stream in Bexar County. The river heads within the city limits of San Antonio and flows southeastward. Until 1950 the flow of the river was sustained by San Pedro and San Antonio Springs, but since 1950 the springs have been dry and the flow has been sustained by industrial and municipal waste water. Other streams draining the fault zone include tributaries of the Medina River and Cibolo Creek.

The West Gulf Coastal Plain, a rolling prairie, is underlain by beds of marl, clay, and poorly consolidated sand. The beds dip southeastward at a greater rate than those in either the Edwards Plateau or the Balcones fault zone. The area ranges in altitude from about 425 to about 700 feet and slopes southeastward. It is drained by the Medina and San Antonio Rivers and Cibolo Creek and their tributaries.

CLIMATE

Bexar County has a warm subhumid climate. The winters are mild, and temperatures generally are above freezing; the summers are hot, with the daily maximum usually more than 90°F. According to records of the U.S. Weather Bureau, the long-term mean-annual temperature at San Antonio is 68.8°F. The growing season averages about 279 days. Figure 1a shows that the mean monthly temperature ranges from about 51°F in January to about 84°F in July and August.

Precipitation varies from year to year. The rain falls principally in isolated thundershowers and only occasionally in widespread storms. The long-term mean annual precipitation at San Antonio is 27.91 inches. The precipitation, well distributed throughout the year, is greatest during April, May, June, and September. (See fig. 2.)

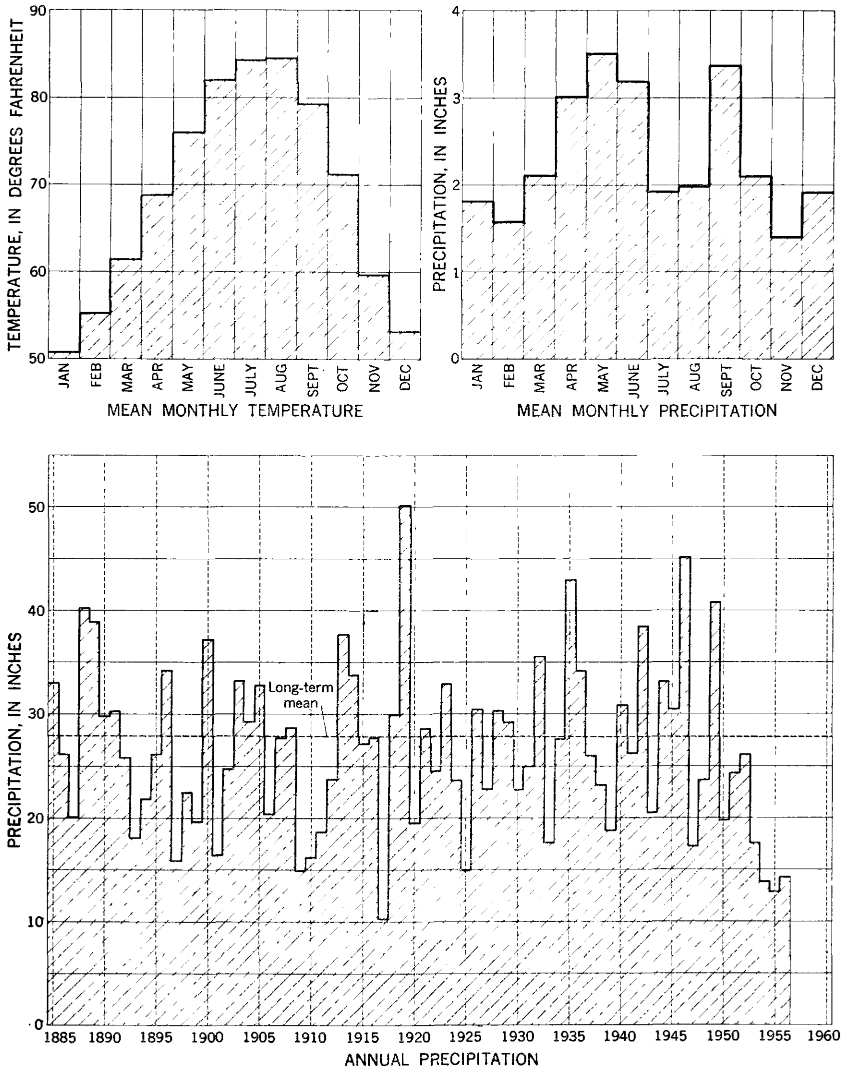

FIGURE 2.—Mean monthly temperature and precipitation and annual precipitation at San **Antonio Airport.**

GEOLOGY AND WATER-BEARING PROPERTIES OF THE FORMATIONS

The geologic formations that yield water to wells in Bexar County are sedimentary rocks of Cretaceous, Tertiary, and Quaternary age. (See table 1.) Igneous rocks are not known to crop out in the county, and none have been reported in the subsurface. Lonsdale (1927, p. 114), however, reported that fragments of serpentine, a metamorphosed igneous rock, were found when wells were drilled in the Somerset oil field. Other metamorphic rocks that constitute the basement beneath the sedimentary rocks are reported to have been found in the drilling of wells throughout the county.

The pattern of outcrop of the formations is shown on the geologic map, plate 1, and geologic sections of the county are shown in plates 2 and 3. Much of the description of the geologic formations that follows has been freely adapted from Livingston, Sayre, and White (1936) and Sellards (1919).

PRE-CRETACEOUS ROCKS

No rocks older than those of Cretaceous age crop out in Bexar County. No water has been reported from pre-Cretaceous rocks in the county.

The rocks of pre-Cretaceous age are variously described in drillers' logs as slate, black limestone, and schist. They have been considered to be of Paleozoic age (Sellards and others, 1932, p. 130). Barnes (1948, p. 9–12) suggested that similar rocks to the north and northeast of Bexar County are metamorphic equivalents of the rocks of Pennsylvanian age which crop out in the Llano uplift, the metamorphism increasing away from the uplift. The surface of the rocks of pre-Cretaceous age in Bexar County dips southeastward toward the Gulf of Mexico; the average change in altitude across the county, including the change due to faulting, is about 130 feet per mile. (See pl. 2.)

TABLE 1.—*Geologic formations and their water-bearing properties, Bexar County, Tex.*

System	Series	Group	Stratigraphic unit	Approximate maximum thickness (feet)	Character of material	Water-bearing properties
Quaternary	Recent and Pleistocene		Alluvium	45	Silt, sand, and gravel	In places yields water of good quality for stock and domestic use.
Tertiary(?)	Pliocene(?)		Uvalde gravel	30	Coarse-grained flinty gravel in matrix of clay or silt	Not known to yield water to wells in Bexar County.
Tertiary	Eocene	Claiborne	Mount Selman formation	200	Sand and clay with iron concretions	Do.
			Carrizlo sand	800	Coarse to medium-grained sand and sandstone; some clay	Yields moderate supplies of potable water for irrigation, domestic, and stock use.
		Wilcox	Undifferentiated deposits	1,070	Thin-bedded sand and sandstone, and some clay, lignite, and calcareous concretions	Yield moderate supplies of water of good to poor quality for domestic and stock use, and for irrigation.
	Paleocene	Midway	Wills Point formation	490	Arenaceous clay containing numerous arenaceous and calcareous concretions	Not known to yield water to wells in Bexar County.
Cretaceous	Gulf	Navarro	Kemp clay, Escondido formation, and Corsicana marl	535	Clay and marl	Do.
			Taylor marl	540	Marl and calcareous clay	Do.
			Anacacho limestone	355	Marly chalk	Do.
			Austin chalk	210	Limestone and argillaceous chalky limestone	Yields small to large supplies of water of good to poor quality for stock and domestic use.
			Eagle Ford shale	40	Calcareous and sandy shale and some argillaceous limestone	Not known to yield water to wells in Bexar County.

	Comanche	Washita	Buda limestone	80	Dense, hard limestone	Yields sufficient water near the outcrop for stock and domestic use.
			Grayson shale	60	Blue clay, weathering greenish and yellowish brown	Does not yield water to wells in Bexar County.
			Georgetown limestone	65	Hard massive limestone and argillaceous limestone	Yield large supplies of water for municipal, industrial, and irrigation supplies. Form the principal aquifer in the county. Water is highly mineralized downdip in the southern part of the county.
		Fredericksburg	Edwards limestone	600+	Hard semicrystalline massive limestone and dolomite and some thin-bedded limestone and marly limestone	
			Comanche Peak limestone	40	Marl and light-gray massive limestone	
			Walnut clay	20	Sandy clay or marl	Not known to yield water to wells in Bexar County.
		Trinity	Glen Rose limestone	1,200	Massive chalky limestone alternating with beds of less resistant marly limestone	Generally yields sufficient water in the outcrop for stock and domestic use. Water from deeper wells generally is more highly mineralized than is water from shallow wells.
			Pearsall formation	260	Shale and limestone	Not known to yield water to wells in Bexar County.
	Pre-Comanche (Coahuila of Mexico)	(Nuevo Leon of Mexico)	Sligo formation	1,100	Limestone, dolomite, and shale	Not known to yield water to wells in Bexar County.
		(Nuevo Leon and Durango of Mexico)	Hosston formation		Limestone, shale, and sandstone	Yields small to moderate supplies of water which becomes more highly mineralized downdip toward the southern part of the county.
Pre-Cretaceous			Sedimentary and metamorphic rocks		Slate, black limestone, and schist	Not known to yield water to wells in Bexar County.

CRETACEOUS SYSTEM

PRE-COMANCHE ROCKS

Imlay (1945, p. 1427) classified the oldest rocks of Cretaceous age in Bexar County as the Hosston and Sligo formations and correlated them with rocks of the Durango and Nuevo Leon groups of the Coahuila series of Mexico. Lozo and Stricklin (1956, p. 74) suggested that the Hosston and Sligo formations are of Comanche age; however, Forgotson (1957, p. 2335), like Imlay, places the Hosston and Sligo in the Coahuila series.

The Hosston and Sligo formations do not crop out in Bexar County. They are underlain by rocks of pre-Cretaceous age and are overlain by rocks of Comanche age. They form a wedge which thins to the north. Plates 2 and 3 show a range in thickness from about 300 feet at the U.S. Government water well at Leon Springs (B–23) to 1,100 feet in the Bur-Kan Petroleum Co. and others, Lee Hubbard 1 in the southwestern part of the county. The thickness of the formations appears to be almost the same along the strike.

The Hosston formation consists of limestone, shale, and standstone. According to Lang (1953, p. 3),

> The sands where penetrated in most wells contain considerable shale and are largely medium- to fine-grained and are very hard and tightly cemented. In the northern part of the county, on the Leon Springs military reservation and in the Helotes area, the sands are especially thin and shaly. Through the central part of the county within the belt of faulting the sand section is considerably thicker and not so shaly.

Some of the sandstones in the Hosston formation are water bearing. Locally they are known as "Travis Peak," "basal sands," or "Trinity sands." In most places elsewhere in Texas, these names are used to refer to water-bearing strata in the lower part of the Trinity group. The confusion in names probably results from the fact that the Hosston appears to be the only formation underlying the Glen Rose limestone that yields significant quantities of fresh water to wells in Bexar County, whereas in some other areas the Pearsall formation (subsurface equivalent of the Travis Peak formation) is productive. Three wells (A–11, A–17, and N–112) were reported by Petitt and George (1956, v. 2, pt. 1, p. 146, 211) to tap the Travis Peak. All three actually tap the Hosston. Six wells (B–3, B–23, E–1, E–10, E–25, and I–39) drilled presumably into the Hosston were abandoned or plugged back, owing to disappointing yields or poor quality of water. Another well (B–24) that taps the Hosston yields 37 gpm (gallons per minute), but the casing record shows that it may draw water also from the Glen Rose. Lang (1953, p. 1–3) indicated that the water-bearing beds in the Hosston have a low permeability, and that wells in them probably have a specific capacity of about 3 to 4 gpm per foot of drawdown. It would be expected, therefore, that large withdrawals from the Hosston formation would cause declines in artesian head throughout a wide area, resulting in high pumping lifts where wells once flowed. In 1956 only three wells in Bexar County were reported to draw water from the Hosston formation. The largest yields reported are 275 gpm from well A-11 in the northwest corner of the county and 230 gpm from well N-112 near the point where U.S. Highway 81 crosses the Medina River.

On the basis of information from nine water and oil wells in Bexar and adjacent counties, Lang (1953, p. 3) concluded that the quality of the water in the Hosston formation ranges from moderately good to poor and that on the whole the water is inferior in quality to the water obtained from the Edwards and associated limestones for the San Antonio municipal supply.

The Sligo formation consists primarily of limestone, dolomite, and interbedded shale. No wells in Bexar County are known to obtain water from it.

COMANCHE SERIES

TRINITY GROUP

PEARSALL FORMATION

The Pearsall formation overlies the Sligo formation in Bexar County. Imlay (1945, p. 1441) suggested that the Pearsall and Travis Peak formations occupy the same stratigraphic positions, Pearsall being the subsurface name and Travis Peak the outcrop name. Because the Travis Peak does not crop out in Bexar County, the name Pearsall is used in this report.

The Pearsall formation is of fairly uniform thickness throughout Bexar County. The maximum reported thickness is 257 feet in the U.S. Government water well at Leon Springs (B-23); the minimum, as interpreted from electric logs, is 135 feet at the Union Producing Co. L. S. McKean 1. (See pls. 2 and 3.)

The Pearsall formation consists principally of shale and limestone. George (1952, p. 15-17) and F. C. Lee (written communication, 1954) reported that the Pearsall (Travis Peak) yields water to wells in Bandera and Comal Counties. However, no wells are known to obtain water from the Pearsall in Bexar County, but it is likely that small quantities of water could be developed in the northern part of the county.

GLEN ROSE LIMESTONE

The Glen Rose limestone, the oldest formation exposed in Bexar County, conformably overlies the Pearsall formation and crops out in the northern part of the county in a belt having a maximum width of almost 11 miles. Downdip from the U.S. Government water well at Camp Bullis (E-25) the Glen Rose increases in thickness from 660 feet to a recorded maximum of about 1,200 feet in the Bur-Kan Petroleum Co. and others; Lee Hubbard 1 in the southwest corner of the county and in the George Parker and C. L. McCune, Tom Goad 1 in the south-central part of the county. (See pls. 2 and 3.)

According to Livingston, Sayre, and White (1936, p. 68–69), the Glen Rose "consists of beds of moderately resistant, massive chalky limestone alternating with beds of less resistant marly limestone. The difference in the resistance of the various beds to erosion has resulted in the development of a striking terraced topography." The Glen Rose is fossiliferous, containing many echinoids and mollusks and a large variety of Foraminifera, the genus *Orbitolina* being especially abundant. The well-known *Salenia texana* zone near the middle of the limestone has been arbitrarily used to divide the Glen Rose into a lower and an upper member. The contact between the lower and upper members, as shown on plate 1 marks the location of the outcrop of the *Salenia texana* zone.

Livingston, Sayre, and White (1936, p. 68-69) stated:

In general the limestone is only moderately permeable and contains water only in small joints and fissures. In places on the outcrop, however, it contains solution channels that range from minute openings to large caverns, some of which take in large quantities of surface water. If these openings were widely interconnected the water level in wells in the formation would be concordant; that they are not widely interconnected is indicated by the fact that the altitudes of the water levels differ greatly, even in wells close together.

Throughout most of its area of outcrop the Glen Rose yields water sufficient only for stock and domestic use, but in places it yields moderately large supplies. Three wells (E–1, E–2, and E–3) at Camp Bullis were pumped at 380, 370, and 350 gpm with specific capacities of 4.6, 5.3, and 3.8 gpm per foot of drawdown, respectively. Southeast of its outcrop, where the Glen Rose dips beneath the surface, it yields very little water to wells.

Water from the Glen Rose limestone is very hard and in some places has an undesirable concentration of sulfate. However, it is commonly used for domestic and livestock supplies. Water from the deeper wells generally is more highly mineralized than the water from shallow wells. The greater content of dissolved solids is primarily due to an increase in calcium or magnesium sulfate.

FREDERICKSBURG GROUP

WALNUT CLAY

The Walnut clay, the basal member of the Fredericksburg group, conformably overlies the Glen Rose limestone in Bexar County. It crops out in scattered small areas in the northern part of the county (pl. 1) and is present in the subsurface except where it and the underlying Glen Rose crop out. Jones (1926, p. 770) reported the Walnut to be as much as 20 feet thick in the southwestern part of the county, but in the area of outcrop the formation generally is thinner.

The Walnut is a sandy clay or marl which is best identified by the presence of small nodules of limestone and specimens of the fossil oyster *Exogyra texana* Roemer. Because the presence of the same fossil species in the marly beds of the overlying Comanche Peak limestone makes it difficult to distinguish between the two formations, they are shown as a unit on the geologic map (pl. 1). No wells in Bexar County are known to obtain water from the Walnut clay.

COMANCHE PEAK LIMESTONE

The Comanche Peak limestone conformably overlies the Walnut clay and, like the Walnut, crops out in scattered small areas in the northern part of Bexar County. (See pl. 1.) According to Livingston, Sayre, and White (1936, p. 67), the Comanche Peak is about 40 feet thick in Bexar County.

The lower part of the Comanche Peak is marl and the upper part is light-gray massive limestone. The marl and the underlying Walnut clay contain *Exogyra texana* Roemer. The two formations are not differentiated on the geologic map.

The nodular appearance of the limestone is its most distinguishing characteristic. However, well drillers do not distinguish the Comanche Peak limestone from the overlying Edwards limestone. It is possible, therefore, that some of the water that drillers report to be in the lower part of the Edwards actually is in the Comanche Peak. The Comanche Peak and the overlying Edwards and Georgetown limestones are included in the aquifer comprising the Edwards and associated limestones. (See p. 24.)

EDWARDS LIMESTONE

The Edwards limestone lies conformably on the Comanche Peak limestone; the beds in the lower part of the Edwards are very similar to those in the upper part of the Comanche Peak. However, the formations are distinguished by their fauna and by their mode of weathering. North of the main fault zone the Edwards caps the hills and uplands. Within the fault zone the Edwards crops out in a west-southwestward-trending belt which is about 7 miles wide in the eastern part of the county, only 1.5 miles wide at its narrowest point about midway across the county, and a little less than 4 miles wide at the Bexar-Medina County line. (See pl. 1.) The thickness of the Edwards is fairly uniform along the strike but becomes greater down-dip. It is about 485 feet at the U.S. Government water well at Camp Bullis (E–25), just south of the area of outcrop, and a little more than 600 feet in several wells in the southern part of the county.

The Edwards consists largely of gray to white hard dense semi-crystalline limestone and dolomite. Generally it is coarsely crystalline, but in places it has a fine, almost lithographic, texture. Most of the limestone is massive, but some is thin bedded. A few layers of limestone are marly, and drillers log them as shale. The dolomitic beds have a sugary texture and when crushed in drilling yield sand-size particles. The "sandstones" and "sandy limestones" reported in the Edwards by many drillers probably are dolomitic beds.

Well-preserved microfossils are rarely found in the Edwards limestone, but beds composed largely of detrital fragments of organic origin are common. The fossils most readily recognized are mollusks of the genera *Monopleura*, *Requienia*, and *Toucasia*.

Chert (flint) is an identifying feature of the Edwards, because it is not found in other Cretaceous formations in Bexar County. It occurs as oval or flattened nodules having distinct boundaries within the limestone as lenticular masses which grade into the limestone and as thin beds parallel to the bedding planes. The chert is not uniformly distributed throughout the Edwards but is confined to distinct horizons; it is not present in the basal or top beds of the formation. In many places the chert has weathered out of the limestone, and fragments are scattered over the surface of the land in great quantity. According to Sellards (1919, p. 25), "The soils derived from the flinty phase of the Edwards formation are prevailingly red, and the belt of country occupied is referred to locally as the 'red lands'."

In many places, both in the outcrop and in the subsurface, the Edwards is extensively honeycombed and cavernous. Drillers frequently report soft or "honeycomb" limestone which is believed to be a rock having a spongelike appearance resulting from the partial solution of the limestone. According to Petitt and George (1956, V.I., p. 16):

Irregularly distributed caverns are found in the outcrop and are indicated down-dip in drillers' logs by such notes as "cavity, 2 feet." Interconnected solutional cavities of all shapes and sizes form more or less linear channels, which generally follow fractures that are associated with and parallel to faults. Beds containing large numbers of fossils appear to be more porous or more susceptible to solution than others.

The Edwards generally yields water freely to wells, but a well that by chance misses the cracks and solution channels may yield little or no water. It has become standard practice to treat all municipal wells with acid in order to increase their yield by enlarging the cracks and solution channels tapped by the wells.

The largest yield in the county was a natural flow of 16,600 gpm, measured in 1942, from the San Antonio Public Service Co. 4 (well 164 in Livingston, 1942, p. 3). This is the largest natural yield from a flowing well known to the Geological Survey. In contrast, a well of similar depth just 40 feet away never has yielded much water.

The Edwards limestone supplies most of the wells in San Antonio and the southern two-thirds of the county. The hydrology of the Edwards and associated limestones is discussed in detail later in this report. (See p. 24.)

WASHITA GROUP

GEORGETOWN LIMESTONE

The Georgetown limestone lies disconformably on the Edwards limestone, but the disconformity is barely evident because the lithology of the two formations is so similar. The Kiamichi formation, a shaly limestone which separates the Edwards and Georgetown in other areas (Sellards and others, 1932, p. 270, 348–359), is not present in Bexar County. The Edwards and Georgetown are best distinguished by faunal differences.

The Georgetown crops out in scattered small areas in a belt extending across the north-central part of the county. (See pl. 1.) According to Imlay (1945, p. 1425) the Georgetown thickens downdip from a minimum of 27 feet in the outcrop to a maximum of 65 feet in the subsurface.

The Georgetown consists of hard massive limestone that contains beds of buff to brownish-buff fossiliferous argillaceous limestone in the upper part of the section. One of the most abundant fossils in the upper part is the brachiopod *Kingena wacoensis* (Roemer).

Well drillers do not distinguish between the Georgetown limestone and Edwards limestone. The Georgetown is part of the aquifer that comprises the Edwards and associated limestones; therefore, the water-bearing properties of the Georgetown as a part of the aquifer is discussed later in this report.

GRAYSON SHALE

The Grayson shale, formerly known as the Del Rio clay, conformably overlies the Georgetown limestone. The two formations, however, can be distinguished readily because they differ in lithology, fossil content, and electrical properties. The outcrops of the Grayson are associated with those of the Georgetown and Buda limestones in a belt extending across the north-central part of the county. (See pl. 1.) The Grayson thickens slightly toward the west and downdip from a recorded thickness of 39 feet in the U.S. Government water well at Camp Bullis (E–25) in the outcrop area to a maximum recorded thickness of about 60 feet in several wells in the southern part of the county. (See pls. 2 and 3.) Holt (1956 p. 28) reported a maximum thickness of 95 feet for the Grayson in Medina County.

The Grayson is predominantly blue clay which weathers greenish-yellow brown. Pyrite and gypsum are scattered throughout the formation, but the most distinguishing characteristic is the presence of large numbers of *Exogyra arietina* (Roemer), a small oyster shaped like a ram's horn. In the outcrop the Grayson generally forms a slope below the more resistant Buda limestone and supports a timber growth that is largely mesquite (*Prosopis juliflora*).

The Grayson shale yields no water to wells in Bexar County. Instead, it serves as an upper confining bed to the Edwards and associated limestones.

BUDA LIMESTONE

The Buda limestone lies conformably on the Grayson shale, but the contact is marked by an abrupt lithologic change both in the outcrop and in the subsurface. (See pls. 2 and 3.) The Buda crops out in scattered small patches which are associated with those of the underlying formations of the Washita group in a belt extending across the north-central part of the county. (See pl. 1.) The Buda thickens slightly to the west. It thickens downdip also, from about 50 feet near the area of outcrop to a maximum recorded thickness of 80 feet in the H. and J. Drilling Co. Annie and Wilson Chaptay 1 in the extreme southern part of the county. (See pl. 2.)

As described by Sellards (1919, p. 31), the Buda limestone—

> * * * is quite uniformly a close-grained, a dense, hard limestone. On surface exposures this rock is usually light-colored, or tinged with gray, yellow, or blue. As seen in well cuttings, the limestone is usually of light color, although a part of the formation frequently shows as a blue rock. Black specks in the limestone is a characteristic frequently referred by drillers in describing the cuttings from wells.

The Buda limestone is relatively impermeable, yielding only enough water for domestic and livestock use near the area of outcrop. Large yields have been reported for a few wells tapping the Buda; however, it is believed that these wells have penetrated fractures along which the water rises from the underlying Edwards and associated limestones.

GULF SERIES

EAGLE FORD SHALE

The Eagle Ford shale, the lowermost formation of the Gulf series, lies unconformably on the Buda limestone, the uppermost formation of the Comanche series. The contact is marked by an abrupt lithologic break. The sequence of the Grayson shale, Buda limestone, and Eagle Ford shale constitutes an excellent marker in the subsurface. (See pls. 2 and 3.)

The Eagle Ford shale crops out in a few scattered small areas in the north-central part of the county. (See pl. 1.) The Eagle Ford thickens downdip but thins toward the northeast. The maximum recorded thickness in Bexar County is 40 feet in the H. and J. Drilling Co., and Wilson Bros. Oil Co., Annie Chapaty 1 in the extreme southern part of the county. (See pl. 2.)

In Bexar County the Eagle Ford shale consists chiefly of flaggy calcareous and sandy shale which is light colored in the outcrop. Interbedded with the shale are layers of hard argillaceous limestone. The Eagle Ford is dark colored in the subsurface, and drillers commonly refer to it as "lignite." According to Sellards (1919, p. 34), the Eagle Ford does not contain true lignite. However, it does contain fish scales and teeth which may help to identify it.

The Eagle Ford shale is not known to yield water to wells in Bexar County.

AUSTIN CHALK

The Austin chalk lies unconformably on the Eagle Ford shale in Bexar County. The Austin crops out in a discontinuous belt extending northeastward across the central part of the county. West of San Antonio the belt has a maximum width of about 6 miles. (See pl. 1.) Much of the outcrop boundary consists of fault lines.

The thickness of the Austin is nearly uniform downdip (fig. 3), but the formation thins considerably toward the northeast. The maximum recorded thickness in Bexar County is 210 feet at the Bur-Kan Petroleum Co. and others, Lee Hubbard 1. (See pl. 3.)

The Austin chalk may be divided lithologically into three parts. The lowermost beds consist of hard thin-bedded limestone; the middle part contains soft massive chalky limestone; and the uppermost beds consist of chalky limestone, some of which is argillaceous. On the surface the rocks are predominantly creamy yellow, whereas in the subsurface they are either blue, white, or yellow. Fossils are particularly abundant in certain beds in the Austin. Among the most common are the oysters *Gryphaea aucella* Roemer, *Exogyra laeviuscula* Roemer, and *Exogyra ponderosa* Roemer.

Records are available for more than 40 wells in Bexar County that obtain water from the Austin chalk. Most of the wells supply only enough water for domestic or stock use, but yields of 500 gpm or more were reported from several wells. Such yields may result when wells have been drilled into subsurface caverns, such as Robber Baron's Cave and other caverns in the outcrop of the Austin near Brackenridge Park in the northern part of San Antonio. In many places the water contains considerable hydrogen sulfide, which is believed to result from the oxidation of pyrite scattered throughout the formation. At least some of the large yields from the Austin are believed to be obtained where it is in hydraulic connection with the Edwards and associated limestones. Livingston, Sayre, and White (1936, p. 70) stated:

In some places in the vicinity of faults or fault zones the altitude of the water surface in wells drawing from the Austin chalk is about the same as that of the water surface in wells drawing from the Edwards, and the water levels rise and fall together. This is good evidence that in such localities water moves freely between the two formations.

ANACACHO LIMESTONE

The Anacacho limestone lies unconformably on the Austin chalk; it crops out in a belt extending northeastward across the central part of Bexar County. (See pl. 1.) The belt is about 5 miles wide except where it is spilt at the Culebra anticline in the western part of the county and by faulting in the central part. The Anacacho thickens downdip and also to the east. The thickness ranges from 0 to a reported 355 feet in the Wellington Oil Co., John Schultz 1. (See pl. 3.) In Bexar County most of the Anacacho is brittle white marly chalk. Much of it consists of shell fragments, and it also contains many whole shells.

The Anacacho limestone is not known to yield water to wells in Bexar County.

TAYLOR MARL

The Taylor marl crops out south of the outcrop of the Anacacho limestone in a broken belt extending across the central part of Bexar County. (See pl. 1.) Much of the contact of the marl with the Anacacho limestone is along a fault plane; most of the contact of the marl with the overlying rocks of the Navarro group is depositional. The thickness of the Taylor marl changes slightly along the strike. (See pl. 3.) The thickness increases appreciably downdip, ranging from about 230 feet near the center of the county to a maximum of 540 feet in the H. and J. Drilling Co. and Wilson Bros. Oil Co., Annie Chapaty 1. (See pl. 2.)

The Taylor marl, mostly marl and calcareous clay, is blue in the subsurface but weathers greenish yellow. Fossils are fairly common, the most notable being the large oyster *Exogyra ponderosa* Roemer.

The Taylor marl is not known to yield water to wells in Bexar County.

NAVARRO GROUP

The Navarro group in Bexar County consists of the Corsicana marl, the Escondido formation, and the Kemp clay. They are mapped together on plate 1 and discussed as a unit below.

The Navarro group crops out in a continuous belt extending east-northeastward across the central part of the county (pl. 1). The width of the belt ranges from less than half a mile to more than 5 miles. The group is exposed also on the north flank of the Culebra anticline in the western part of the county. The Navarro thickens downdip and toward the west, the maximum recorded thickness in the county being 535 feet in the Bur-Kan Petroleum Co. and others, Lee Hubbard 1. (See pl. 3.)

In Bexar County the Navarro group consists chiefly of clay and marl. Well-indurated layers of limestone are present in parts of the group, particularly near the top. According to Sellards (1919, p. 49), the Navarro contains "* * * considerable glauconite which is frequently in such abundance as to give a greenish tinge to the clays and shales of the formation. Within the formation, probably in its upper part, is a greenish glauconitic sandstone, often met with in drilling and usually recorded in the well logs as 'green marl'." The fossils in the Navarro have been described in a comprehensive treatise by Stephenson (1941). Among the most characteristic fossils in the Navarro in Bexar County are the oyster *Exogyra costata* Say and species of the ammonite *Sphenodiscus* Meek.

The Navarro group is not known to yield water to wells in Bexar County.

TERTIARY SYSTEM

PALEOCENE SERIES

MIDWAY GROUP

WILLS POINT FORMATION

In the outcrop the Wills Point formation constitutes so nearly the entire Midway group in Bexar County that it is the only formation of that group shown on the geologic map. (See pl. 1.) Only small outcrops of greensand have been referred questionably to the Kincaid formation (Gardner, 1933, p. 74). However, the Kincaid probably is more extensive in the subsurface. The rocks of the Midway group unconformably overlie the rocks of the Navarro group.

The Wills Point formation crops out primarily in two parallel belts extending northeastward across the southern part of the county. In the southern belt the Wills Point is at the surface along the south side of a fault about 23 miles long. In the southwest corner of the county and westward, the Wills Point is overlapped by the Wilcox group.

According to the section shown on plate 3, the Midway is thickest in the central part of Bexar County, thining gradually toward the east and rapidly toward the west. According to Gardner (1933, p. 75), the Midway group seems to be cut out entirely in the eastern part of Medina County. In the area of outcrop the maximum recorded thickness of the Midway is about 460 feet; at the southern tip of the county, the maximum is 490 feet. (See pl. 2.)

In Bexar County the Wills Point formation consists mainly of sandy clay containing many sandy or limy concretions, which range in weight from a few pounds to several tons. The clay for the most part is greenish gray but weathers yellow brown.

The Midway group is not known to yield water to wells in Bexar County.

EOCENE SERIES

WILCOX GROUP

In southwestern Texas the Wilcox group has long been considered to consist of only one formation—the Indio (Trowbridge, 1923, p. 90). In this investigation the stratigraphic details of the Wilcox have not been studied; the group is discussed below as an undifferentiated unit.

The Wilcox group crops out in a broad, continuous belt that extends across the southern part of Bexar County. The maximum width of the outcrop is about 11 miles, but in the central part of the county the outcrop is broken by a fault along which the Wills Point formation is at the surface. (See pl. 1.) The Wilcox group has a maximum thickness of about 1,000 feet where it crops out in Bexar County, and the maximum recorded thickness in the county is 1,070 feet at the H. and J. Drilling Co. and Wilson Bros. Oil Co., Annie Chapaty 1. (See pl. 2.)

The Wilcox group in Bexar County, composed mostly of thin-bedded sand, sandstone, and clay, also contains thin beds of lignite and concretions of sand and limestone. The rocks are ferruginous, and the sandy soil that develops on them generally is red.

Wells tapping sands of the Wilcox group yield sufficient water for domestic and livestock use; the rate of discharge generally is less than 20 gpm. A few wells supply water for irrigation. Wells N–38 and O–81 discharge 300 and 400 gpm, respectively. The water in the Wilcox generally is very hard; in other respects its chemical quality ranges from good to poor. The poor-quality water has a high sulfate content, derived probably from oxidation of sulfur compounds in the lignite beds.

CLAIBORNE GROUP

CARRIZO SAND

The Carrizo sand, the older of the two formations that constitute the Claiborne group in Bexar County, unconformably overlies the Wilcox group. The Carrizo crops out in a belt that crosses the southern part of the county. The maximum width of the outcrop is almost 6 miles. (See pl. 1.) The Carrizo, as much as 800 feet thick in Bexar County (pl. 2), consists of massive beds of medium-size to coarse sand and a few layers of clay, clayey sand, and ferruginous sandstone. It is light gray and weathers tan, pink, red, or brownish red.

The Carrizo sand in Bexar County yields moderate supplies of water of good chemical quality for irrigation, domestic, and livestock use. It underlies only a small area in the county; consequently, it has been tapped by few wells. To the south in Wilson and Atascosa Counties the Carrizo is an important aquifer capable of yielding large quantities of water for irrigation (Anders, 1957, p. 13–14; Sundstrom and Follett, 1950, p. 109–110).

MOUNT SELMAN FORMATION

The Mount Selman formation conformably overlies the Carrizo sand in Bexar County and crops out in a very small area in the extreme southern part. (See pl. 1.) Its maximum thickness in the county is about 200 feet. The Mount Selman, largely fine sand, silty clay, and clay, contains many ferruginous concretions.

No wells are known to obtain water from the Mount Selman in Bexar Cunty.

TERTIARY(?) SYSTEM

PLIOCENE(?) SERIES

UVALDE GRAVEL

The Uvalde gravel is the oldest and highest terrace deposit in Bexar County. Although originally it may have covered extensive areas in and south of the Balcones fault zone, it now only caps some of the hills. The deposits generally are less than 30 feet thick; they were not mapped during this investigation.

The Uvalde gravel consists of limestone and flint boulders embedded in a matrix of clay or silt, the whole in many places being cemented with caliche. The proportion of flint to limestone boulders increases toward the south away from the Edwards Plateau, which undoubtedly was the source of the gravel.

Because of its topographic position on hilltops, the Uvalde gravel probably contains little or no water.

QUATERNARY SYSTEM

PLEISTOCENE AND RECENT SERIES

ALLUVIUM

A series of terraces, topographically lower than that formed by the Uvalde gravel, is underlain by alluvium of Pleistocene and Recent age. The Recent deposits form the flood plains of the present streams; the Leona formation of Pleistocene age is intermediate in both age and position between the Recent flood-plain deposits and the hillcaps formed by the Uvalde gravel. The Leona formation was named by Hill and Vaughan (1898, p. 254) for a specific set of terrace deposits of Pleistocene age in Uvalde County; the name since has been extended to apply to all the terrace deposits lying between the Recent flood-plain deposits and the Uvalde gravel along all the streams of the area (Sayre, 1936, p. 67).

The thickest and most extensive deposits of alluvium are in the valleys of Salado and Leon Creeks and the San Antonio and Medina Rivers, in the plain east of Salado Creek, and between the Culebra Road and Mitchell Lake on the plain between Leon Creek and the San Antonio River. The alluvium ranges in thickness from 0 to about 45 feet. This investigation did not include mapping of the alluvium.

The alluvium consists largely of gravel, sand, and silt. Gravel deposits along the south side of the Medina River from the Medina County line to Macdona and along Cibolo Creek yield water of good quality to wells for domestic and livestock use.

GEOLOGIC STRUCTURE

The sedimentary rocks in Bexar County strike east-northeastward and dip south-southeastward toward the Gulf of Mexico. In the northern part of the county, north of Helotes and Camp Bullis, the average dip of the rocks is between 10 and 15 feet per mile (George, 1952, p. 33), conforming very closely to the average slope of the land surface. Thus, one formation originally constituted almost the whole surface. This formation is the Edwards limestone, and the surface was part of the Edward Plateau. Erosion has destroyed most of the plateau in Bexar County, the Edwards remaining only as a cap on scattered peaks. (See pl. 1.)

In the southern part of Bexar County, south of Cassin Lake, the average dip of the rocks exceeds 150 feet per mile. Because this dip is much greater than the slope of the surface, progressively younger formations crop out in narrow bands across the county.

Dividing the two areas is a zone of faulting where the formations, although on the whole having only slight dip, have been dropped about 3,000 feet in a distance of about 22 miles. The positions of the faults are shown on plates 1 and 4, and the displacement of the formations due to faulting is shown on plate 2.

The faults are part of two major zones of central Texas—the Balcones and Mexia fault zones. As described by Sellards and Baker (1934, p. 63):

> The two zones are alike in that the faulting is by normal or gravity faults. They differ in that the downthrow in the Balcones zone is usually to the east or southeast while in the Mexia zone the downthrow is prevailingly to the west or northwest. Between the two zones there is thus a great down block or graben. The downthrow in the Balcones zone is not invariably to the east, since faults are present with throw to the west or northwest, producing small grabens. Likewise, in the Mexia zone the downthrow is not wholly to the west, since occasional faults are present with downthrow to the east or southeast. For the most part, the faults trend slightly oblique to the trend of the fault zones and approximately, but not exactly, with the strike of the strata. Folding is seemingly more pronounced in the Balcones zone than in the Mexia zone. In both zones, however, faulting in the hard rock strata becomes or tends to become folding in the softer strata.

All the faults within and north of San Antonio belong to the Balcones system; those south of the graben (see downthrown block passing through southern San Antonio where the Wills Point formation of the Midway group crops out, pls. 1 and 2) belong to the Mexia system.

Many of the faults shown on plates 1 and 2 actually mark the trace of shatter zones; that is, the faults are not single sharp breaks as suggested by the lines, but a series of smaller step faults within a narrow zone. For example, a detailed examination of the electric logs of wells drilled at the Mission Pumping Station in San Antonio (well 10, pl. 2 is one of these wells) indicates that 3 or more faults pass through an area 250 feet wide, but because of limitations of scale the shatter zone is shown by a single line on plates 1 and 2. Although individual faults or shatter zones have been traced for as much as 25 miles, no one fault or shatter zone has been found that extends completely across the county. The displacement along the faults generally is greatest near their middle and diminishes toward their ends. The fault in Bexar County passing about half a mile south of Helotes has the largest known throw, about 600 feet (Livingston, Sayre, and White, 1936, p. 71). In the southern part of San Antonio the throw of the fault that separates the Navarro group from the Midway group exceeds 550 feet. (See pl. 2.) The displacements along several other faults exceed 100 feet.

The major faults trend east-northeastward, but some are intersected by cross or branch faults. In general, the faults have almost straight traces, suggesting nearly vertical fault planes. Some of the faults die out in monoclines. Many are not reflected by the topography, because the formations on both sides are almost equally resistant to erosion.

A major flexure, the Culebra anticline (Sellards, 1919, p. 83), extends from the western part of Bexar County into Medina County. It is an asymmetrical anticline plunging southwestward. The oldest formation exposed along the axis of the arch is the Austin chalk, which is surrounded by successive bands of rocks of Taylor and Navarro age, except where older rocks are in fault contact. The anticline is terminated on both flanks by faults. The presence of another anticline in the southwestern part of the county is suggested by the relationship of the outcrops of the Midway and Navarro groups northeast of Macdona. This structure, whose axis strikes east-northeastward, is terminated at its southwest end by a cross fault.

GROUND WATER IN THE EDWARDS AND ASSOCIATED LIMESTONES

The principal water-bearing formation in Bexar County is the Edwards limestone. The underlying Comanche Peak limestone and the overlying Georgetown limestone also may be water bearing. Because well drillers do not distinguish them from the Edwards limestone, the three formations are considered in this report to constitute a single ground-water reservoir (aquifer) here called the Edwards and associated limestones. This aquifer is a continuous hydrologic unit along the Balcones fault zone from Kinney County on the west at least to Hays County on the northeast (Petitt and George, 1956).

Where the Edwards and associated limestones crop out in the northern part of Bexar County (pl. 1), the water in them is confined only at the bottom by the relatively impermeable Glen Rose limestone; consequently, in this part of the county the water is under water-table conditions, and the water levels in wells are below the top of the aquifer. In the central and southern parts of the county, where the Edwards and associated limestones are buried beneath younger formations, the water is confined at the bottom by the Glen Rose limestone and at the top by the Grayson shale. Here the water is said to be under artesian conditions; that is, the water levels in wells are above the top of the aquifer, and in topographically low areas the wells may flow.

RECHARGE

Recharge to the Edwards and associated limestones in Bexar County occurs, to a small extent, by direct infiltration of precipitation on the outcrop; to a greater extent, by seepage from the streams that cross the outcrop in the Balcones fault zone; and, to the greatest extent, by underflow from Medina County. The amount of recharge by direct infiltration of precipitation on the outcrop is negligible in comparison to the amount of recharge from the other sources.

The aquifer is recharged in Bexar County by seepage from streams in an area drained by Cibolo, Salado, and Leon Creeks (pl. 1). Petitt and George (1956, v. I, p. 35-36) estimated the recharge to the aquifer from Cibolo Creek for the period 1934–53 (table 2). Because Cibolo Creek forms the boundary between Bexar and Comal Counties, some of the recharge occurs in Comal County. It is arbitrarily assumed that half of the recharge enters the aquifer in Bexar County.

TABLE 2.—*Estimated recharge to the ground-water reservoir from Cibolo Creek, in thousands of acre-feet.*

Adapted from Petitt and George, 1956, p. 36

Year	*Recharge*	*Year*	*Recharge*
1934	15.9	1944	103
1935	133	1945	93.2
1936	121	1946	107
1937	48.7	1947	67.2
1938	45.8	1948	14.0
1939	7.5	1949	37.2
1940	24.4	1950	18.2
1941	134	1951	9.5
1942	61.3	1952	62.0
1943	33.9	1953	22.1

Entire period	1,160
Per year	58
Per year in Bexar County	29

In their estimates, Petitt and George (1956, v. I, 39–40) included the recharge from Salado and Leon Creeks in the area between the Cibolo Creek and Medina River drainage basins. (See table 3.) The figures in the table, however, also include recharge to the aquifer in Medina County from the area drained by San Geronimo Creek. Because about 15 perecnt of the total area between the Cibolo Creek and Medina River drainage basins is drained by San Geronimo Creek, 85 percent of the estimated recharge shown in the table is assumed to represent recharge to the aquifer in Bexar County from the area drained by Salado and Leon Creeks.

Thus, during the period 1934–53, the estimated recharge to the Edwards and associated limestones in Bexar County by seepage from streams averaged about 63,000 acre-feet per year.

Although the recharge to the aquifer in Bexar County by underflow cannot be computed directly, it can be estimated by calculating the recharge and the discharge to the surface west of the Bexar-Medina County line and by assuming that the excess of recharge over discharge is accounted for by underflow into Bexar County and by changes in storage. Recharge by underflow can be estimated also by

TABLE 3.—*Estimated recharge to the ground-water reservoir in the area between the Cibolo Creek and Medina River basins, in thousands of acre-feet*

[Adapted from Petitt and George, 1956, v. 1, p. 40]

Year	*Recharge*	*Year*	*Recharge*
1934	15.3	1944	52.9
1935	101	1945	58.1
1936	79.5	1946	76.7
1937	34.9	1947	40.5
1938	33.7	1948	12.8
1939	6.8	1949	30.5
1940	21.4	1950	12.6
1941	84.9	1951	11.3
1942	48.8	1952	36.6
1943	21.5	1953	14.7

Entire period	794
Per year	40
Per year in Bexar County	34

determining the excess of discharge over recharge east of the Bexar-Medina County line. Computations should be made for periods during which changes in storage in the reservoir were negligible. The period 1934–47 was used in estimating underflow into Bexar County because water levels in the reservoir during that period declined only slightly. (See pl. 5.)

The difference between recharge from and discharge to the land surface west of the Bexar-Medina County line averaged about 320,000 acre-feet per year for the period 1934–47, according to data complied by Petitt and George (1956, v. 1, p. 41, 43). The difference between recharge from and discharge to the land surface east of the Bexar-Medina County line for the same period averaged about 350,000 acre-feet per year. Therefore, the average recharge by underflow to Bexar County from Medina County is between these two figures. If the change in storage during the period had been less, the two figures would be more nearly equal.

It is estimated that during the period 1934–47 the average annual recharge to the Edwards and associated limestones in Bexar County was 77,000 acre-feet from infiltration of streamflow (tables 2 and 3) and 320,000 to 350,000 acre-feet by underflow, or a total of about 400,000 to 430,000 acre-feet. The recharge in a particular year may differ considerably from the average. The large annual variation in recharge by seepage from streams causes part of the difference. Water-level fluctuations in observation wells suggest that recharge by underflow from the west also may differ considerably from year to year.

DISCHARGE

Water in the Edwards and associated limestones is discharged to the land surface in Bexar County principally through springs and wells; it is discharged underground to Comal and northern Guadalupe Counties by northeastward and eastward underflow. The discharge by underflow to the south is negligible by comparison. Figure 3 shows the discharge from springs and wells for the period 1934–56 (extension of record by Petitt and George, 1956), the discharge from wells being broken down according to use. The average discharge from wells and springs during the 23-year period was 162 mgd (million gallons per day), or 182,000 acre-feet per year.

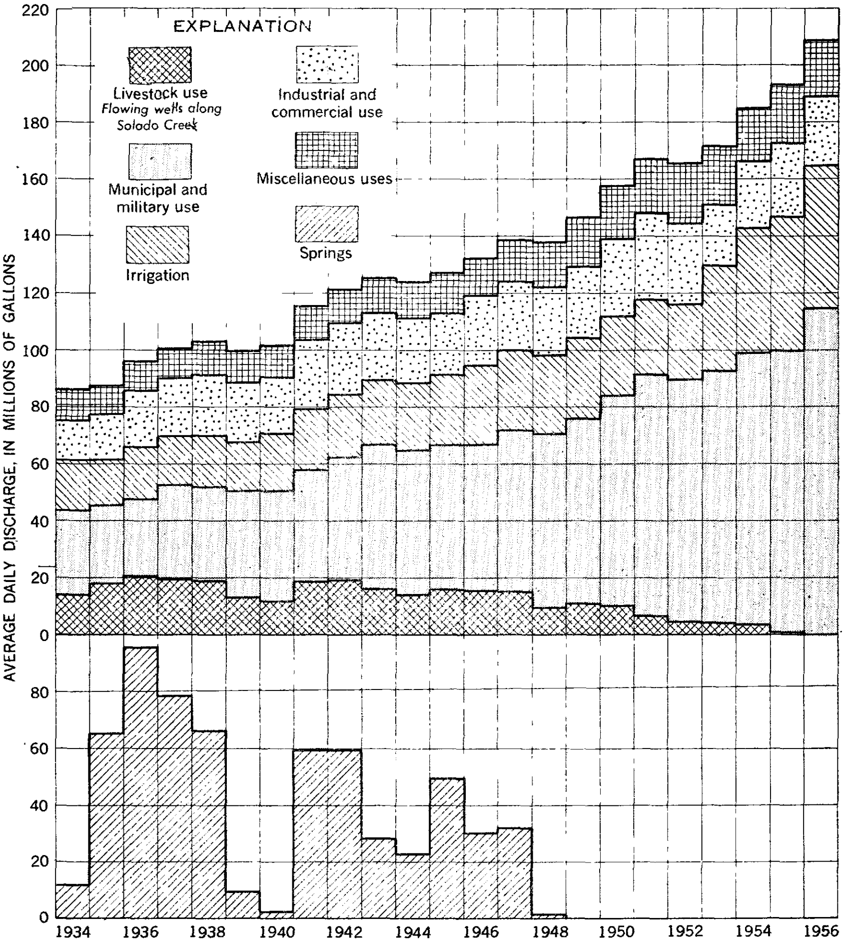

FIGURE 3.—Graph showing discharge from wells and springs in the Edwards and associated limestones, by type of use, 1934–56.

Although the combined discharged from springs and wells fluctuated from year to year from a low of 98 mgd in 1934 to a high of 209 mgd in 1956, no significant overall trend is apparent. Figure 3 shows, however, that the ratio of discharge from springs to discharge from wells has changed considerably. The discharge from springs in Bexar County takes place almost completely through San Antonio and San Pedro Springs, which feed the San Antonio River. The discharge from wells has exceeded the discharge from springs in every year since records were first collected. During the period 1938–48, the discharge from the springs was about 25 percent of the total discharge from springs and wells. During the period 1949–56, however, the springs had little or no flow, and nearly all the discharge was from wells.

The discharge from wells tapping the Edwards and associated limestones in Bexar County has increased almost steadily since 1934. The increase for municipal and military supply and irrigation accounted for 90 percent of the total increase between 1934 and 1956. In 1956 San Antonio was the largest city in the United States whose water supply came entirely from the ground. The discharge from the flowing wells along Salado Creek has not varied as greatly as the flow from springs, but in general the discharge from the flowing wells increased and decreased with increases and decreases in the flow from springs. The wells continued to flow, though at a decreasing rate, through 1955, which was 7 years after the springs ceased flowing. The distribution of discharge from wells producing 10,000 gpd or more in 1954 is shown on plate 6. The discharge is most concentrated in a belt extending northeastward through San Antonio.

The discharge from Bexar County to Comal and northern Guadalupe Counties by underflow may be estimated by the same method used on pages 25, 26 to estimate the recharge from underflow. During the period 1934–47 the annual difference between surface recharge and surface discharge southwest of the northeast boundary of Bexar County averaged about 220,000 acre-feet per year, and northeast of Bexar County it averaged 260,000 acre-feet. The average discharge by underflow out of Bexar County is between these two figures.

MOVEMENT OF WATER

The water in the Edwards and associated limestones, as in all aquifers, moves in the direction of the hydraulic gradient, but the direction of movement cannot be determined exactly, especially in the fault zone, because the configuration of the water surface cannot be determined accurately. The aquifer contains openings ranging in size from minute cracks, in which the movement of water is accompanied by a large loss of head, to caverns through which the water moves freely. In addition, the individual faults that cross the area may act either as conduits of free flow or as barriers to flow. Therefore, many closely spaced observation points would be necessary in order to map the piezometric surface in sufficient detail to show all the changes in direction of movement. Also, even an accurate map would not indicate movement in terms of relative quantities because the hydraulic properties of the aquifer differ greatly from place to place and with direction. Therefore, only the regional direction of movement can be shown.

Plates 7–10 show generalized contours on the piezometric surface in the Edwards and associated limestones in Bexar County in 1934, 1952, 1954, and 1957. Although water levels declined markedly in some areas, the overall pattern of the contours remained essentially unchanged between 1934 and 1957. In and just south of the outcrop of the aquifers the contours in general run east-northeastward across the county, roughly paralleling the strike of the outcrop. South of the outcrop, near the western boundary of the county, the contours bend toward the south, indicating a hydraulic gradient from Medina County toward Bexar County. South of the outcrop, near the eastern boundary of the county, the contours bend toward the north, indicating a hydraulic gradient from Bexar County toward Comal and Guadalupe Counties. The altitude of the water surface at one point on the Bexar-Comal County line declined from about 660 feet above mean sea level in 1934 to about 625 feet in 1957. The altitude at Comal Springs in 1957 was about 620 feet, thus indicating a hydraulic gradient from the Bexar-Comal County line toward Comal Springs.

The hydraulic gradient toward Comal and Guadalupe Counties is reversed at times when the piezometric surface near Selma is mounded as a result of locally greater recharge. The mound is represented on plate 10 by the 625-foot contour near Selma. For about 3 miles near Selma the channel of Cibolo Creek crosses an inlier of the Austin chalk (pl. 1.). Possibly a hydraulic connection between the Austin chalk and the Edwards and associated limestones permits seepage from Cibolo Creek to reach the principal aquifer.

Although the generalized contours on the piezometric surface in the central part of Bexar County show that at least some of the water in the Edwards and associated limestones is moving southeastward downdip, most of the water moves northeastward into Comal and Guadalupe Counties. Water entering the cavernous and honeycombed rock in the area of outcrop undoubtedly moves downdip through interconnected solutional cavities. However, in the severely faulted zone south of the outcrop, some of the faults have been enlarged by solution, forming an extensive series of openings. If as seems likely, the northeastward-trending channels are larger than those trending in the direction of dip, a given flow of water would require less gradient for northeastward than for downdip movement. Therefore, although the contours suggest movement toward the southeast, a greater volume of water moves northeastward nearly parallel to the trend of the contours. (See fig. 4.) If a sufficient number of observation points were available for construction of an extremely detailed map, the contours would cross the large northeastward-trending solution channels at right angles to the direction of flow.

A comparison of the estimated recharge from the surface with the estimated discharge for the period 1934–47 for Bexar, Comal, and Hays Counties (pp. 26, 27) is further evidence that most of the water in the aquifer moves northeastward.

Probably only a small part of the water moves downdip southeastward from San Antonio. South of a line trending northeastward through the southern part of the city the water in the Edwards and associated limestones contains hydrogen sulfide, and farther downdip the water is highly mineralized. (See pl. 11.) The presence of the highly mineralized water indicates that the circulation of the water is poor, owing to the low permeability of the aquifer or a poor escape route. If a large amount of water were moving downdip, the highly mineralized water would have been flushed from the aquifer. The small amount of water that does move southeastward ultimately is discharged by slow upward percolation into younger formations, some of which are nearly impervious.

FLUCTUATIONS OF WATER LEVELS

The fluctuations of water levels in wells penetrating the Edwards and associated limestones in Bexar County (Petitt and George, 1956, v. 2, pt. 3, p. 47–88) represent the net effect of additions of water to and subtractions of water from the reservoir. The amount of water in storage is increased by infiltrating precipitation and streamflow in the outcrop area of the aquifer and by underflow of water into Bexar County from Medina County. The amount of water in storage is decreased by discharge through wells in Bexar County and by underflow of the water into counties downgradient; prior to 1949 it was decreased by discharge from springs also. Changes in storage in Bexar County for the period 1932–56 are indicated in figure 5 by changes in water levels in well 26.

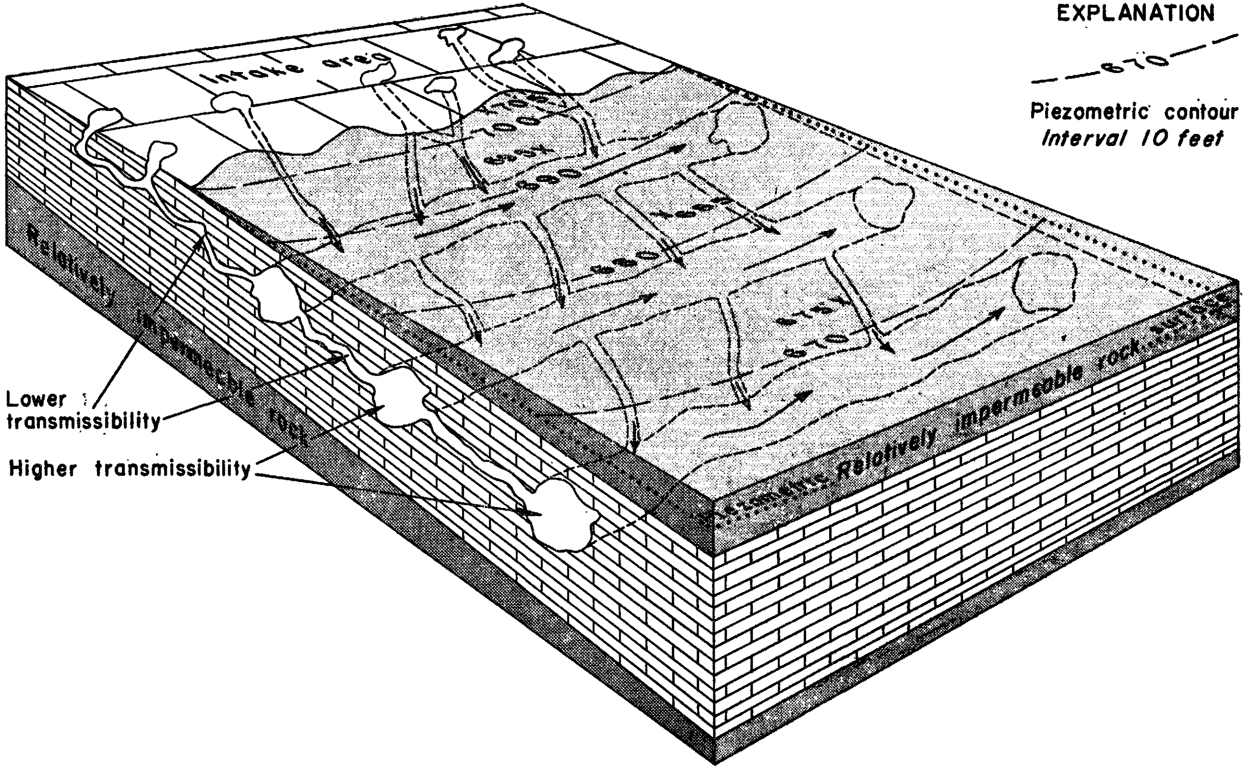

FIGURE 4.—Hypothetical diagram showing how water in the cavernous Edwards and associated limestones may flow approximately parallel to the trend of the regional contours on the piezometric surface. (Adopted from Bennett and Sayre, 1959.)

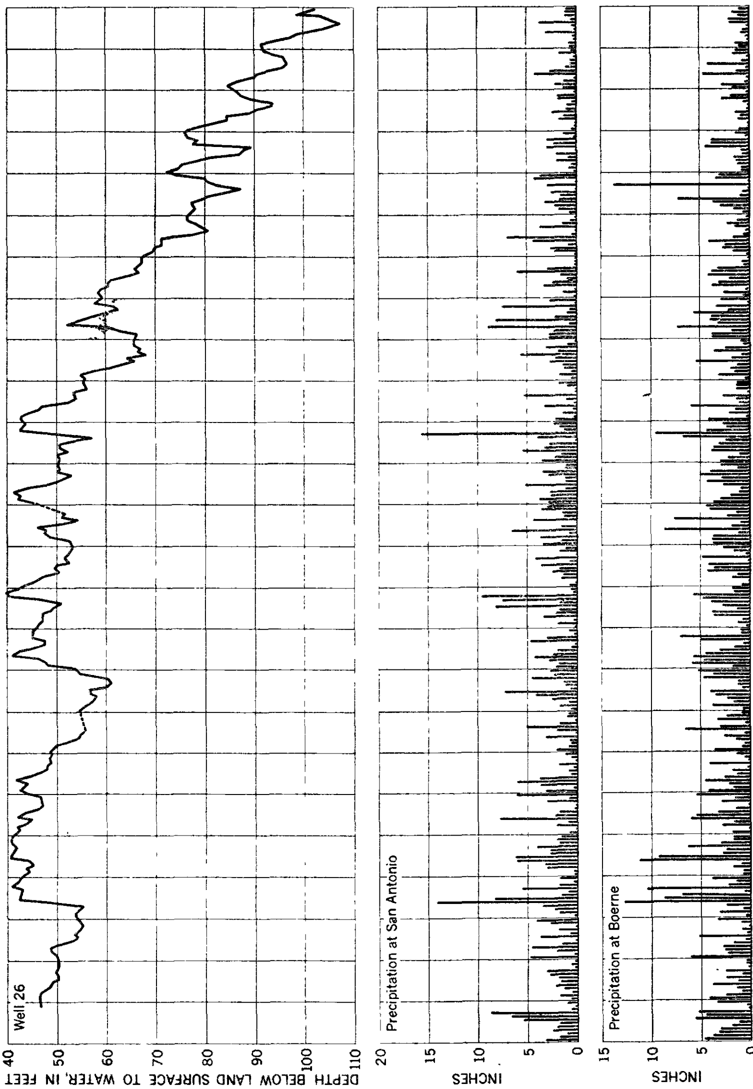

FIGURE 5.—Hydrograph of well 26 and monthly precipitation at San Antonio, Bexar County, and at Boerne, Kendall County. Precipitation data from the U.S. Weather Bureau.

Water-level records are useful in studying the effects of changes in climate and pumping rates. Detailed studies must include consideration of hydrologic factors throughout the entire reservoir and, therefore, are beyond the scope of this report. However, certain relationships of local significance are apparent in figure 5. During three periods, 1932–35, 1938–40, and 1947–56, the water level in well 26 declined, chiefly in response to climatic conditions unfavorable to recharge. The decline during the 1947–56 period was accelerated appreciably by pumping, which has become a factor of progressively increasing significance. However, unless and until pumping exceeds the long-term average rate of discharge, a return to an extended wet climatic cycle should result in the replenishment of the reservoir to near-normal capacity. Rapid rises in water level due to periods of heavy precipitation, for example in the spring of 1935 and the summer of 1946, show the ability of the aquifer to be replenished at a remarkable rate (fig. 5).

Seasonal fluctuations of water levels are related also to changes in pumping and are especially pronounced during the period 1952–56, but they were readily recognizable as early as 1940. In proportion to the total yearly pumpage, the demand for water in the summer has become progressively greater owing to increases in consumptive use, especially irrigation.

The relation between discharge, recharge, and fluctuations of water levels is shown by comparing hydrographs for representative wells in Bexar County (pl. 5) and well 26 (fig. 5) with records of precipitation in the area.

During the period 1948–56 the discharge from the Edwards and associated limestones in Bexar County greatly exceeded the recharge; consequently, water levels declined markedly. Plate 12 shows the distribution of the decline throughout the county during the period 1933–53, nearly all the decline having occurred after 1947. Plate 13 shows the distribution of decline during the period 1954–57. In Bexar County the decline was greatest in the northwest part, just downdip from the outcrop, where it was as much as 100 feet in the 23-year period. In and around the city of San Antonio the decline was considerably smaller, averaging about 50 feet for the 23-year period. The decline was even less toward the east; at one point on the Bexar-Comal County line the decline during the 23-year period was about 40 feet.

As has been stated, the areas of greatest decline of water levels are not the areas of the greatest discharge of water from the aquifer. The actual discharge is very small within the areas where the decline exceeded 60 feet. As shown on plate 6, the discharge from the Edwards and associated limestones is greatest within San Antonio and in an area extending to the southwest and northeast, where the greatest measured decline was less than 60 feet and in much of the area generally was less than 50 feet. This area of small decline and large discharge coincides with the area of greatest faulting and maximum recorded yields from wells, and the data confirm the conclusion that San Antonio lies in a northeastward-trending belt in which the presence of a large number of faults has permitted the development of an extensive system of large solution cavities. Consequently, the ability of the aquifer to transmit and store water in this area is so great that the discharge from wells results in much smaller declines of water level than do similar or even smaller discharges in other areas having fewer and smaller cavities.

QUALITY OF WATER

The quality of the water in the Edwards and associated limestones in Bexar County differs markedly northwest and southeast of a line that runs northeastward through the southeastern part of San Antonio. The line, shown on plate 11, is the approximate boundary between potable water—water free from hydrogen sulfide and containing less than 1,000 ppm of dissolved solids—and water containing hydrogen sulfide and generally containing more than 1,000 ppm of dissolved solids. Plate 11 also shows the dissolved-solids, sulfate, and chloride content of water from representative wells in the Edwards and associated limestones, the Glen Rose limestone, and the Austin chalk in Bexar County. The concentration of other constituents is shown by Petitt and George (1956, v. 2, pt. 3, tables, p. 12–24).

Northwest of the line the water generally is chemically suitable for public supply, though it is hard, and for irrigation. The content of dissolved solids generally is less than 500 ppm, though a few wells yield water having more than 500 ppm. In the outcrop area of the Edwards and associated limestones some of the wells yielding water of poorer quality may have been drilled into the Glen Rose limestone, which contains water that is more highly mineralized than that in the Edwards and associated limestones. Also, in areas where the Edwards and associated limestones are buried beneath younger formations, wells may receive water of poor quality from overlying formations through leaky casing.

Southeast of the line the water in the Edwards and associated limestones contains hydrogen sulfide, and the mineralization increases with distance from the line. The highly mineralized water is not satisfactory for most uses; however, water that contains hydrogen sulfide but is of moderate dissolved-solids content can be used for irrigation. Because the dividing line does not coincide with any known fault, it is believed to represent the southeast limit of extensive solution in the Edwards and associated limestones. Southeast of the line, where solution has been slight, the ground water does not circulate freely; consequently, it contains large amounts of mineral matter dissolved from the containing rocks.

SUMMARY

The Edwards and associated limestones constitute the major aquifer in Bexar County. In the area of outcrop the water is under water-table conditions, but in most of the area south of the outcrop the water is confined under artesian pressure, and flowing wells are common in topographically low areas.

Although the aquifer is recharged to a slight extent by direct infiltration of precipitation on the outcrop and to a moderate extent by seepage from streams that cross the outcrop in Bexar County, it is recharged primarily by underflow from the west. During the period 1934–47 estimated recharge to the county averaged 400,000 to 430,000 acre-feet per year. During the same period discharge from wells and springs averaged about 174,000 acre-feet per year, and underflow out of the county to the east averaged 220,000 to 260,000 acre-feet per year.

Most of the pumping from the aquifer in Bexar County takes place within a wide belt trending northeastward through San Antonio. However, the decline of water levels during the period 1933–56 was greatest in the northwestern part of the county. This fact suggests that the capacity of the aquifer to transmit and store water in the vicinity of San Antonio is so great that discharge from wells in that vicinity results in much smaller declines of water levels than do similar or even smaller discharges in other localities.

Northwest of a line through the southeastern part of San Antonio, the water from the Edwards and associated limestones, although hard, is otherwise of good chemical quality. Southeast of the line the water contains hydrogen sulfide or is highly mineralized, or both, and is chemically unsuitable for most uses.

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