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WATER RESOURCES OF THE EDWARDS LIMESTONE IN THE SAN ANTONIO AREA, TEXAS

BY

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WATER RESOURCES OF THE EDWARDS LIMESTONE IN THE SAN ANTONIO AREA, TEXAS

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Abstract

The water discharged from the large springs of San Antonio and most of the deep wells of the San Antonio area comes from a common reservoir in fissures and solution channels in the Edwards limestone.

The water enters the limestone in a zone of outcrop along the Balcones escarpment, which crosses the northern parts of Bexar and Medina Counties and extends a long distance both to the east and west of these counties. It is estimated that the combined annual losses into the limestone from the Medina, Frio, Dry Frio, Nueces, and Sabinal Rivers and Hondo Creek may average as much as 150,000 acre-feet a year, the equivalent of a continuous flow of about 134,000,000 gallons a day. Smaller streams also contribute to the underground reservoir, and additional recharge is provided from rainfall on the outcrop of the limestone by direct penetration and by seepage from innumerable storm-water channels.

From the outcrop the limestone dips to the south and southeast beneath younger formations to increasingly greater depths. At San Antonio the top of the limestone is from 400 to 1,000 feet beneath the land surface, and in the southernmost part of Bexar County about 3,000 feet. The water moves from the outcrop through channels that are somewhat tortuous, its movements being generally toward the southeast but in places approximately at right angles to the dip, along fault lines which in general have east-west trends. Water moves underground to the San Antonio area from areas of intake at least as far west as the Medina River and perhaps much farther. Some water may move from the vicinity of San Antonio toward the northeast and eventually appear in the Comal Springs, but the volume thus discharged is believed to be relatively small. This question is, however, to be given further study. Very little water moves down the dip toward the Gulf.

The San Antonio and San Pedro Springs afford large natural spillways for the Edwards limestone reservoir in Bexar County. The springs occur along faults that permit water in the limestone under artesian pressure to escape into cracks and channels in the overlying rocks and thence to flow to the surface. The public and industrial water supplies of San Antonio, nearly all the water used for irrigation, and a large part of the stock and farm supplies are obtained from wells in the Edwards limestone. In 1934 the estimated combined discharge of the San Antonio and San Pedro Springs amounted to about 13,000 acre-feet and the combined discharge of the Edwards wells to about 95,000 acre-feet -- a total of about 108,000 acre-feet, the equivalent of a continuous discharge of about 97,000,000 gallons a day. It is estimated that during the last 20 years (1915-34) an average of about 120,000 acre-feet a year, or about 107,000,000 gallons a day, was discharged by the springs and wells. A large part of this water was unused. At least one-third of the water discharged from the wells was wasted.

On the outcrop the water in the limestone is unconfined, and there is a water table. Down the dip the water is under pressure, and wells that penetrate the limestone in the lowlands of San Antonio and adjacent areas to the east, south, and southwest of the city have a flow. The artesian pressures vary within fairly wide limits and are an index of the amount of water in underground storage. The pressures rise almost immediately during heavy general rains. At such times large quantities of water sink into the reservoir at the outcrop and produce a quick rise in the water, the effect of which is communicated promptly by transmission of pressure many miles down the dip. A short time after the rains the pressures usually begin to decline. The records show that a remarkable uniformity attends the rise and fall of pressure over large areas in Bexar County, both in time of occurrence and in magnitude. The flow both from the springs and the artesian wells varies with the artesian pressures. The San Antonio Springs cease to flow when the pressures decline and the altitude of the water levels in nearby artesian wells falls below 668 feet. They begin to flow again when the altitude rises above that level. The record of artesian pressures in the area are reassuring, as it shows clearly that there has at no time been any long-continued overdraft approaching dangerous depletion. Moreover, the

artesian pressures were about as high in the summer of 1935 as in 1915, showing that there had been no material net decrease in the storage in the reservoir during a period of 20 years in which the average annual rainfall was about equal to the 61-year mean. Therefore, it is reasonable to expect that unless the streams that furnish the recharge are regulated or unless the climate changes toward greater aridity the reservoir will continue to yield about as much as it did between 1915 and 1934.

It appears probable that before the artesian wells were put down the San Antonio and San Pedro Springs were the only large outlets of the underground reservoir in Bexar County, and the average annual recharge to the reservoir was nearly balanced by the average annual discharge of the springs; also, that since the well development began the discharge has been divided between the springs and artesian wells. The wells have made the water supply more accessible where it is needed, but it is believed that they have not materially increased the average annual yield of the underground reservoir.

The water from the San Antonio and San Pedro Springs and from the wells in the greater part of San Antonio and in the area to the northeast, north, and west is almost uniformly a calcium carbonate water of good quality, although somewhat hard. South of a fault that passes through the southern part of the city the water is highly mineralized, is generally impregnated with hydrogen sulphide, and gives off a disagreeable odor. The two types of water, however, come from the common reservoir.

It is concluded that the withdrawals from the underground reservoir by wells can be increased with safety, but the unutilized water of the springs and wells must be put to beneficial use if an additional demand of large magnitude is to be met. The discharge of the springs has already been materially decreased by withdrawals from wells, and further reduction will follow increased draft by the wells. It is not impossible that the springs could be brought under control by impounding water above them by means of a low dam. Waste from the artesian wells can be stopped if the wells are closed by a cap or valve when they are not in use, as is required by the laws of Texas.

INTRODUCTION

Purpose of investigation

The supply of ground water in the general area in which San Antonio is situated, with special reference to the ground-water resources of the Edwards limestone, is the subject of an investigation started in the fall of 1932 as part of a survey of the ground-water resources of Texas by the United States Geological Survey in cooperation with the State Board of Water Engineers.

In several places in Texas the extensive development of ground water has been followed by a material lowering of the water table or by a large decline in the artesian head and pronounced shrinkage in the area of artesian flow. This has not occurred at San Antonio, but during several years since 1924 the artesian pressures in the San Antonio area have persistently remained below normal. The artesian pressure in the Edwards limestone determines the rate of discharge of the springs and flowing wells in this area. Moreover, the springs at the head of the San Antonio River cease to flow when the pressure falls below the amount necessary to raise the water levels in neighboring artesian wells to an altitude of about 668 feet above the sea. The springs have been quiescent a considerably larger proportion of the time during the decade 1926-35 than they were in the preceding decade. By some this is thought to indicate that there has been a decline in the average artesian pressure due to heavy draft on the artesian wells. To a degree this condition has become a matter of public concern and has led to the present investigation, which was undertaken in response to public request. The chief purpose of the investigation has been to obtain as much information as possible regarding the capacity of the artesian reservoir in the San Antonio area and the approximate amount of water that can be withdrawn from it each year without seriously depleting the supply. The investigation has included a study of the recharge of this reservoir, the discharge from it by springs and wells, and the fluctuation in water levels and artesian pressures in observation wells.

The investigation is being made under the direction of O. E. Meinzer, geologist in charge of the division of ground water in the Geological Survey. In the geologic studies connected with the investigation, both in the field and in the preparation of this report, substantial assistance has been given by L. W. Stephenson, chief of the section of Coastal Plain geology in the Survey. Valuable aid has also been given by several engineers and geologists of San Antonio and by officials of the city water department.

Previous ground-water investigations

The geology and artesian-water supplies of the San Antonio area were discussed by Hill and Vaughan[1] in 1898. These investigators were the first to point out that the Edwards limestone is the principal source of the water discharged by the springs and artesian wells of the Balcones fault zone.

A list of about 60 wells in Bexar County was given by Taylor[2] in 1907. The springs of the Balcones fault zone, including the San Antonio and San Pedro Springs, were described in 1927 by Meinzer.[3]

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1 Hill, R. T., and Vaughan, T. W., Geology of the Edwards Plateau and Rio Grande Plain adjacent to Austin and San Antonio, Tex.: U. S. Geol. Survey 18th Ann. Rept., pt. 2, pp. 193-322, 1898.

2 Taylor, T. U., Underground waters of the Coastal Plain of Texas: U. S. Geol. Survey Water-Supply Paper 190, pp. 55-56, 1907.

3 Meinzer, O. E., Large springs in the United States: U. S. Geol. Survey Water-Supply Paper 557, pp. 27-39, 1927.

The results of investigations in the area, together with a summary of the work of others, are given in a paper by Muir.[4] The results of an investigation made at the request of the city council are described in a report by Potter,[5] which includes a general discussion of the development of water from wells in the Edwards limestone in and around San Antonio. The geology and ground-water conditions in a part of the area have been briefly described by Stephenson.[6]

The geology and ground-water resources of the San Antonio district are described by Sellards.[7]

Information on the geology of Bexar County is given by Deussen,[8] who also gathered a considerable amount of information on the ground waters of the San Antonio area which has not been published. This information has been used freely in the present investigation.

Importance of ground water in the area

Ground water contributes a great deal to the attractiveness of San Antonio and to the welfare of its people.

Relatively little surface water is available in this locality without storage, the run-off of the local streams being intermittent and flashy. But the area contains springs that are among the largest in Texas, and abundant supplies of water suitable for municipal and industrial uses and irrigation can be obtained from wells almost anywhere in the city and in an area of considerable size adjacent to it. In the lower parts of the area the wells flow.

The San Antonio River is fed by springs and by artesian wells. The river winds through the heart of the city, and its clear waters, together with the verdure in the parks along its banks, present a picture of uncommon beauty. The springs of the city are in two groups -- the San Antonio Springs, at the head of the river in the northern part of the city, immediately north of Brackenridge Park, and the San Pedro Springs, about 2 miles southwest of the San Antonio Springs, in San Pedro Park. The San Pedro Springs give rise to San Pedro Creek, which discharges into the San Antonio River below the city.

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4 Muir, A. H., The geology of the artesian water supply of the San Antonio area, St. Louis, 1911.

5 Potter, Alexander, A report upon and an appraisement of the water supply system of the city of San Antonio, Tex., San Antonio, 1912.

6 Stephenson, L. W., The camps around San Antonio, printed on the reverse side of the topographic map of the San Antonio quadrangle, edition of 1919.

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

8 Deussen, Alexander, Geology of the Coastal Plain of Texas west of the Brazos River: U. S. Geol. Survey Prof. Paper 126, 1924.

The availability of a perennial flow of spring water in the San Antonio River in this vicinity led to the founding of the city. One of the most ancient Indian settlements or pueblos in the region was situated at the springs. Between 1718 and 1731 the Spaniards established a military post and five missions along the river in this vicinity and employed the natives in the cultivation of farms and gardens irrigated by the spring water. The winding courses of some of the streets in the older parts of the city are due to the fact that they were laid out to follow the ancient ditches.

The importance of the available supply of ground water in the San Antonio area has become more and more apparent. The city has grown rapidly. The population in 1910 was 96,614; by 1920 it had increased to 161,379, and in 1930 it was 231,542. With the increase in population the demand for water for domestic and industrial use and irrigation has grown at a corresponding rate, and this has been met by larger and larger withdrawals of ground water.

CLIMATE

Temperature

The winter climate in this part of Texas is mild, and in recent years San Antonio has become one of the most popular winter resorts in the Southwest. According to records of the United States Weather Bureau the annual mean temperature is 69° and the seasonal means are, for winter, 54°; spring, 69°; summer, 83°; fall, 70°. The highest temperature recorded is 107° , and the lowest 4°. The average annual rainfall is not very heavy, but in most years there is enough to insure fair crops of corn, cotton, and grain. Irrigation is usually considered necessary, however, for the profitable production of garden truck and small fruits.

Rainfall

The United States Weather Bureau has obtained long-time records of rainfall at several localities in this part of Texas. The records that are of special significance in connection with this report are those obtained at San Antonio; at Hondo, about 45 miles west of San Antonio; and at Boerne, about 50 miles north of San Antonio. San Antonio and Hondo are south of the intake area of the Edwards limestone reservoir, which supplies the San Antonio district; Boerne is north of it. According to the Weather Bureau the average rainfall at San Antonio during 61 years was

27.33 inches; at Hondo during 39 years, 27.28 inches; at Boerne during 42 years, 32.41 inches.

Some significant facts are disclosed by a study of the records obtained at these stations and others in southwestern Texas. The average annual rainfall varies with both the latitude and the altitude. It increases from west to east and is greater on the Edwards Plateau than on the lower lands of adjacent parts of the Coastal Plain. Heavy rains are usually general over a wide area. They commonly increase in magnitude from west to east and are heavier on the Edwards Plateau than on the Coastal Plain. In occasional storms the volume of rainfall has increased from east to west. During the storm of July 1932, for example, the precipitation was 0.26 inch at Austin, 4.91 inches at San Antonio, 3.02 inches at Boerne, 10.65 inches at Hondo, and 20 inches at Uvalde, about 45 miles west of Hondo.

The records at San Antonio, Hondo, and Boerne are usually in fairly close agreement, so far as trends in rainfall are concerned. If the rainfall during a particular month is above normal at one of these stations it is almost certain to be high at the other two, and the same is true of subnormal rainfall. A few outstanding exceptions to this rule have been recorded, but on the whole the records at San Antonio are a reasonably accurat index of the annual and periodic fluctuations in rainfall with which this report is chiefly concerned. Some of the facts disclosed by a study of the San Antonio records are as follows. In most years some rain falls every month. April, May, and September have the highest average precipitation, and December, January, and February the lowest. The lowest annual precipitation was 10.11 inches in 1917, and the highest was 50.30 inches in 1919. The years of subnormal and supernormal precipitation during the period of record were about equal in number, but they tended to occur in groups. The average for the 17 years of record between 1871 and 1890 was 31.48 inches, or about 4 inches above the 61-year average. No records were obtained at San Antonio for three years of these two decades -- 1876, 1883, and 1884 -- but the mean rainfall in those years was normal or above at Galveston, San Angelo, and Brownsville and at New Ulm, near Austin. The mean from 1891 to 1910 was 24.45 inches, or about 3 inches below the average. The mean for 1911 to 1920, including the very wet year 1919, was a fraction of an inch above the average, but for that decade exclusive of 1919 it was about 2 inches below the average. The means for 1921 to 1930 and for 1931 to 1934 were respectively 1.41 inches and 0.93 inch below the average. The records seem to suggest, therefore, that the mean rainfall during the last 35 years may have been somewhat below the long-time average. The mean during the last 20 years, however, has been about the same as the 61-year average.

The longest period of subnormal precipitation apparently was from October 1, 1908, to August 31, 1913, the accumulated deficiency below the average during the 59 months being 41.35 inches. Other outstanding dry periods were November 1, 1896, to November 30, 1899, with an accumulated deficiency of 26.65 inches, and July 1, 1924, to December 31, 1927, with an accumulated deficiency of 21.95 inches. In the wet years a relatively large part of the excess precipitation occurs during a few heavy storms; in the dry years such storms are infrequent. For example, in 1919, the year of heaviest precipitation, 22.4 inches fell in 11 days, scattered over a period of several months. More recently, in 1932, 15 inches fell in 4 days, and in May and June 1935, 10 inches fell in 3 days. In the comparatively wet fall and winter of 1930-31 there were 7 days in October, January, and February in which the precipitation exceeded 1 inch. On the other hand, during the dry period of 43 months from July 1, 1924, to December 31, 1927, there were only 17 days in which the precipitation exceeded 1 inch.

TOPOGRAPHY

The northern part of Bexar County, amounting to somewhat less than one-third of its area, lies on the Edwards Plateau. The remainder of the county is on the Coastal Plain. These areas are separated by the abrupt southward-facing Balcones escarpment, which crosses the county in a nearly east-west direction, passing about a mile south of Helotes, in the western part of the county, and a short distance north of Bracken, which is just across the east boundary in Comal County.

The Edwards Plateau in Bexar, Medina, and Uvalde Counties covers practically the same area as the outcrop areas of the Glen Rose limestone and Edwards and associated limestones shown on the map. It is an area of pronounced relief, and its topography contrasts strongly with that of the Coastal Plain. From the Balcones escarpment northward and in some places southward is a belt in which the resistant Edwards limestone crops out in both valleys and hills, or at least forms the sides or the tops of the hills. This belt is characterized by broken topography with deep, steep-walled, flat-bottomed and relatively narrow valleys. From this belt northward for a considerable distance beyond the county boundary the less resistant Glen Rose limestone underlies the surface, and although the relief in that area is nearly as great as in the belt to the south, the valleys are much wider and the slopes are more gentle.

The Coastal Plain in Bexar County consists in part of a gently rolling plain and in part of moderately hilly country. The rolling plain in most places is underlain by marls, marly clays, and clayey to clean sandstones that weather easily and form deep loamy black or yellow sandy soils. These soils are generally very fertile. The hills are in most places underlain by limestones or highly indurated sandstones or are capped by gravel and owe their existence to the resistance to erosion afforded by these rocks.

GEOLOGY AND ITS RELATION TO THE OCCURRENCE OF GROUND WATER

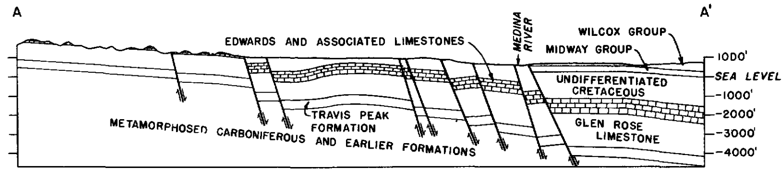
This report is chiefly concerned with the Edwards and associated limestones and their ability to take in water at the outcrop and to transmit the water long distances underground to the springs and artesian wells of the San Antonio district. Brief consideration is given below, however, to water in other formations that underlie Bexar County. A generalized section of these formations with a statement of their water-bearing properties is given in the table on page 67.

The outcrop areas of the Glen Rose limestone and the Edwards and associated limestones (Georgetown and Comanche Peak limestones and Walnut clay) are shown on the accompanying map. In traveling southward and southeastward from the Edwards outcrop along the lines A-A' and B-B' successively younger formations of Cretaceous and Eocene age are crossed. These formations are not differentiated on the map. The structure of the rocks and the order in which they occur along the lines A-A' and B-B' is shown in figure 6.

Generalized section of the geologic formations of the San Antonio area, Texas

System	Series	Formation or group	Thickness (feet)	Water-bearing properties
Quaternary.	Recent.	Stream and terrace gravel.	- -	Water-bearing in places in stream valleys.
	Pleistocene.	Terrace gravel including Leona formation.	0 - 90	Yields potable water for stock and domestic wells in some places.
Tertiary(?).	Pliocene(?).	Uvalde gravel.	0 - 20	Is not known to yield water to wells.
Tertiary.	Eocene.	Mount Selman formation.	(?)	- - -
		Carrizo sand.	200	Yields water of good quality to wells.
		Wilcox group.	650±	Yields water to stock and domestic wells, usually rather highly mineralized.
		Midway group.	650±	- - -
Cretaceous.	Upper Cretaceous (Gulf).	Navarro group.	300±	Is not known to yield water to wells.
		Taylor marl.	300±	Is not known to yield water to wells.
		Anacacho limestone.	200±	Is not known to yield water to wells.
		Austin chalk.	130±	Yields potable to highly mineralized water in varying quantities to domestic, stock, and irrigation wells.
		Eagle Ford clay.	30	Does not yield water to wells.
	Lower Cretaceous (Comanche).	Buda limestone.	60	Is not known to yield water to wells.
		Del Rio clay.	60	Does not yield water.
		Georgetown limestone.	40±	Is not commonly water-bearing but yields water to some wells.
		Edwards limestone.	500±	Chief water-bearing formation in the area. Is the source of the large springs and yields water to many pumped and flowing wells.
		Comanche Peak limestone.	40	Does not yield water.
		Walnut clay.	20	Does not yield water.
		Glen Rose limestone.	1,000-1,200	Yields more or less highly mineralized water to domestic and stock wells on the Edwards Plateau.
		Travis Peak formation.[1]	450±	Yields only small supplies where it has been reached by wells.
Pre-Cretaceous rocks.		Undifferentiated schists.[1]	- -	Probably would not yield water. Rocks lie too deep for practicable water well drilling.

1 Does not crop out in this area.



GEOLOGIC SECTION ACROSS BEXAR COUNTY ALONG LINE A–A'

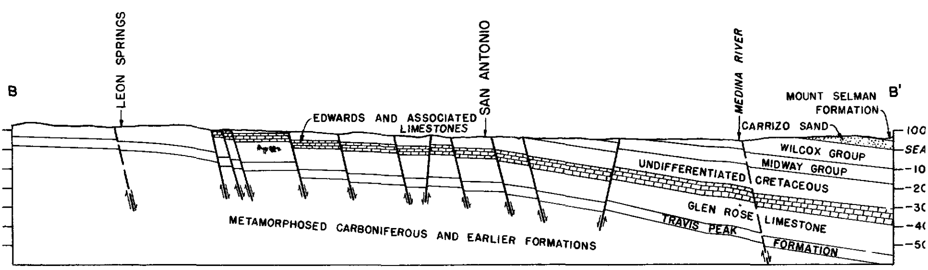


FIGURE 6. GEOLOGIC SECTION ACROSS BEXAR COUNTY ALONG LINE B–B'

SCALE

1 0 1 2 3 4 5 6 MILES

The Travis Peak formation underlies the area at depths of about 500 feet near the northern boundary of Bexar County and about 5,000 feet near the southern boundary. It is about 450 feet thick and consists of a lower conglomeratic phase, often called the "Basement sands", which grade upward into fine sands and shales. At Dallas, Fort Worth, and Austin this formation has yielded large quantities of water. In northwestern Uvalde County an oil test is reported to have encountered large quantities of "fresh" water in the formation, but in the vicinity of San Antonio several wells have penetrated the formation and according to reports have encountered only small supplies of water.

The Glen Rose limestone overlies the Travis Peak formation and is the oldest formation exposed in the area. It is between 1,000 and 1,200 feet thick and 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. 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 levels 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. South of the Balcones escarpment the Glen Rose is apparently almost impervious, for it yields very little water to wells.

The Walnut clay and the Comanche Peak limestone are essentially not water-bearing and therefore will not be further described.

The Edwards limestone crops out chiefly north of the Balcones escarpment, but it is exposed in a few places south of the escarpment, as indicated on the map. It consists of about 500 feet of gray to white massive, hard, dense semicrystalline limestone that is very resistant to erosion. It contains numerous beds of nodular chert and is in most places poor in fossils. In many places it is honeycombed and cavernous and yields water freely to wells. However, in a few areas the formation lacks the usual cracks and solution channels, and wells in these areas yield little or no water. The Edwards limestone is the chief water-bearing formation in the region and supplies the springs at San Antonio and most of the wells south of the Balcones escarpment. The occurrence of water in the Edwards is the subject of the greater part of the report that follows.

The Georgetown limestone is an argillaceous buff to brownish-buff fossiliferous limestone about 40 feet thick. In general it is not very permeable, but a few wells apparently draw some water from it.

The Del Rio clay yields no water, but when the well driller strikes this easily identified formation he knows that his drill is 100 feet or less above the Edwards limestone.

The Buda limestone and the Eagle Ford clay are not known to yield appreciable supplies of water to wells.

The Austin chalk has a thickness of about 130 feet and is a rather massive fossiliferous buff chalky limestone. In Bexar County it is cavernous in many places, as indicated by Robber Baron's Cave and other caverns reported near Brackenridge Park, in the northern part of San Antonio. Where similar caverns exist beneath the water table, wells striking them yield large quantities of water. In general, however, the Austin is not as consistent a water-bearing formation as the Edwards, and in many parts of the area the water may be more or less heavily impregnated with hydrogen sulphide.

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. An illustration of this close agreement is afforded by the records of water-level fluctuations in the wells of D. T. Atkinson and Amos Lorenz. (See table 7.) These wells are in the Alamo Heights district, in the northeastern part of San Antonio, and are about a mile apart. The Atkinson well draws from the Austin chalk, and the Lorenz well from the Edwards limestone. Similar agreement in the altitude and fluctuations of the water surfaces in wells ending in the two formations is shown in the vicinity of the Republic Cement mills, on the Missouri-Kansas-Texas Railroad about 5 miles northeast of San Antonio; in the southern part of the city in the vicinity of the Mission pumping plant; and in the irrigated area south of San Antonio and west of Somerset Road. Where the Austin crops out near the faults, water that enters it may eventually reach the Edwards through fissures along the fault planes. At Alamo Heights the sewage has been discharged into wells ending in the Austin chalk. This sewage must have an outlet somewhere. Apparently the most convenient outlet is in the fractured area in the vicinity of the San Antonio Springs. There is no assurance that the sewage may not pass downward in this area and enter the Edwards reservoir, at times when the artesian pressure is low, and later appear in the Edwards wells, or it might move through the Austin itself and be discharged from that formation directly into the springs. Of course storm water may enter the Edwards limestone through the Austin chalk at the springs on the San Antonio River or on San Pedro Creek whenever the artesian pressure declines to such an extent that these springs cease to flow.

The Cretaceous formations above the Austin and the Midway group do not yield water to wells in Bexar County, so far as is known.

The Wilcox group crops out in the southern and southeastern parts of the county and yields water that ordinarily is somewhat highly mineralized.

The Carrizo sand crops out in the southernmost part of the county. This is one of the most prolific water-bearing formations in Texas, but so far as has been learned no wells of very large yield have been developed in the formation in Bexar County.

The Mount Selman formation underlies a very small area at the southernmost corner of the county, but no wells that draw water from it were found in the county.

In different parts of the county sand and gravel in the Leona formation and in Recent deposits yield water sufficient for domestic use and stock.

GEOLOGIC STRUCTURE

In the northern part of the county, on the Edwards Plateau, the rocks are relatively flat and free from faulting. In the central part of the county, in the Balcones fault zone, they dip Gulfward at comparatively steep angles and are extensively faulted. The Balcones escarpment in its present form is almost if not entirely an erosional escarpment situated mainly along a discontinuous fault that brings resistant Edwards limestone on the north side against less resistant younger formations on the south side. In a few places it follows the contours of hills capped by the Buda limestone, overlying the easily eroded Del Rio clay, and where the Buda is faulted into position opposite the Edwards there is no trace of an escarpment at the fault. The fault most generally followed by the escarpment passes just north of New Braunfels, in Comal County, where it has a throw of about 500 feet. This fault extends with gradually decreasing throw to Bracken, near Cibolo Creek, where it divides into several minor faults, and the escarpment becomes lower. For a distance of several miles west of Cibolo Creek there are several minor escarpments, and it is difficult to determine which should be regarded as the Balcones escarpment. From Cibolo Creek several faults converge toward the west and join to form a large fault with a throw of about 600 feet 1 mile south of Helotes, but at this point the trace of the fault lies about a quarter of a mile north of the escarpment. Near the west side of Bexar County this fault is divided into two faults, the larger of which leaves the escarpment and extends toward Quihi, in Medina County, where it has a throw of nearly 1,000 feet. The other follows the escarpment into central Medina County, where its displacement becomes very small. There are numerous other faults, some of them with displacements of 500 feet or more, and most of them have a trace that extends a little south of west, but as in most places the formations on both sides of the fault are of nearly equal resistance to erosion, only a few of them are reflected by the topography. The traces of the major recognized faults in Bexar County are shown on the map, and their effect in displacing the formations is shown on the cross sectional diagrams in figure 6. In most of the faults the downthrow is on the south side, but south of San Antonio (see map) there is a large fault and in some places several faults on which the downthrow is on the north.

In general the formations dip toward the south and are either monoclinal or only slightly folded, but in western Bexar County there is a broad anticline that plunges to the southwest.

THE EDWARDS LIMESTONE AS A GROUND-WATER RESERVOIR

The Edwards limestone is more soluble than most other limestones and has become honeycombed or cavernous by solution channeling over wide areas both on the Edwards Plateau and in the Balcones fault zone south of the plateau. These openings are interconnected for long distances and form extensive underground reservoir systems, which, to a large extent, control the available supply of water in the region -- both surface and underground. On the plateau several miles back of the margin the beds of the Edwards limestone are almost flat but have a slight dip to the east and southeast, about equal to the slope of the surface of the land. On this account and because of its resistance to erosion the limestone constitutes a very large part of the surface of the higher lands of the plateau. The valleys of most of the larger streams have cut through the formation to the underlying beds of the Glen Rose limestone and Travis Peak formation, and in places the limestone has been completely or almost completely removed by erosion from the interstream highlands, as well as from the valleys. It has been almost entirely eroded away in a belt of varying width extending from Uvalde County northeastward beyond Austin and crossing the extreme northern parts of Medina and Bexar Counties. South of this eroded belt the formation has been lowered by flexing and faulting and appears in outcrop in a belt along the Balcones escarpment. Thence it dips Gulfward under younger formations to increasingly greater depths. At San Antonio the top of the limestone is from 400 to 1,000 feet below the land surface, and in the southernmost part of Bexar County about 3,000 feet. Essentially, therefore, there are two distinct systems of Edwards reservoirs in the region, one on the Edwards Plateau, the other in and south of the Balcones fault zone. The two systems are separated by the belt in which the continuity of the Edwards is persistently interrupted by erosion.

The plateau reservoir system is located in areas in which the Edwards formation caps a large part of the interstream uplands and absorbs a high proportion of the rainfall. In these areas the water sinks through cracks and solution channels to the lower part of the formation, where it is prevented from going deeper by the relatively impermeable beds of the underlying formations. The water table in the body of ground water thus accumulated in many places is above the valleys of the larger streams, and the water moves laterally by gravity in the beds of the limestone, which are almost horizontal, and largely appears in the valleys as springs, usually along the base of the Edwards limestone. Similar springs issue along the contact between permeable and impermeable beds in the Glen Rose limestone and Travis Peak formation, but the largest contribution of spring water comes from the Edwards. These contact springs are the source of the perennial rivers of the Edwards Plateau, which are famous for the clearness of their waters and the relative constancy of their flow. The largest, named from east to west, are the Llano, Blanco, Guadalupe, Medina, Frio, Nueces, and Devils' Rivers. The streams furnish large quantities of water for hydroelectric power and for irrigation and add greatly to the beauty and attractiveness of the areas through which they flow.

The lower or fault-zone reservoir occurs in the body of the formation that extends Gulfward from the Balcones escarpment. (See map.) Extensive exploration by wells in this reservoir in Bexar County has shown that under large areas the limestone is traversed by an intricate system of openings. In some places the openings are small, apparently being confined to joint planes and fissures. In others they consist of solution channels of varying sizes, the largest good-sized caverns.

In places the limestone is honeycombed by small solution channels, which in the aggregate provide a large amount of open space. The largest and most extensive systems of openings occur in the vicinity of faults and tend to center around the faults and large springs at San Antonio. The honeycombed and cavernous phases of the limestone yield very large quantities of water to wells. The small openings may yield little or no water. The occurrence of the different types usually varies considerably from place to place. Even in the district in and around San Antonio, where the largest number of successful wells have been drilled, it not infrequently happens that closely spaced wells have widely different yields. For example, in downtown San Antonio, of four flowing wells of about equal depth put down within a distance of a few hundred feet, three had a flow of only a few gallons a minute, but the fourth had a flow of more than a thousand gallons a minute.

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In the Balcones outcrop area and in most of the north-central part of Bexar County water of good quality is usually obtained from wells in the Edwards limestone. Down the dip in the southern part of the county the water is highly mineralized and not suitable for some uses. The line of demarcation between the two types of water is indicated on the map by the line D-D'. This line has been accurately drawn where wells in the Edwards limestone are fairly closely spaced, but elsewhere its location is only approximately correct and may be changed somewhat as a result of further studies in the area. North of the line the water from most of the wells is fairly fresh, indicating that the circulation of the water in the Edwards reservoir is comparatively free. South of it the water contains a very much larger quantity of dissolved minerals, indicating that there is little circulation and that the water has been trapped in the formation for a long time. The universal occurrence of water of high mineral content in the Edwards in the southern part of the county is evidence that the underground reservoir in the Balcones fault zone is definitely limited in that direction and that there is little or no movement of water down the dip toward the Gulf.

The fault-zone reservoir is fed by rainfall and by seepage from streams on the outcrop of the Edwards limestone along the Balcones escarpment. This outcrop in Bexar County and the greater part of Medina County, as before stated, is shown on the map. The reservoir is not directly connected with the reservoir system of the plateau but is connected hydrologically with that system by the spring-fed streams of the plateau that lose heavily by seepage in crossing the outcrop. The principal natural outlets of the reservoir are springs that emerge along fault planes, among the largest of which are the Barton Springs, at Austin; the San Marcos Springs, at San Marcos; the Comal Springs, at New Braunfels; the San Antonio and San Pedro Springs, at San Antonio; the Las Moras Springs, at Brackettsville; and the San Felipe Springs, at Del Rio. These springs are among the largest and best known in the southwestern part of the United States and are the sources of good-sized rivers and creeks.

Recharge to reservoir

In the outcrop area of the Edwards limestone along the Balcones escarpment the beds usually dip to the south or southeast at an angle materially greater than the slope of the surface. Therefore, in traveling in these directions the beds become progressively lower, first occupying only the tops of the hills, then the slopes as well as the hilltops, then dropping down to the level of the valleys, and finally disappearing beneath the rocks of younger formations. This structural arrangement predominates but is disturbed by faulting in many places. The arrangement is ideal for the intake of water by the permeable beds of the limestone. The streams cross the outcrop area nearly at right angles to the strike, and most of them flow for miles on the Edwards limestone. In these stretches the water level in the Edwards reservoir is below the level of the streams, and the streams lose heavily into the reservoir. Ground-water recharge is also provided from rainfall on the outcrop by direct penetration and by seepage from innumerable small drainage channels that ordinarily carry water only during and for brief periods after exceptionally heavy rains. Some recharge may occur from permeable beds in the Glen Rose in localities where the Edwards is faulted down against such beds.

The United States Geological Survey and the State Board of Water Engineers have maintained gaging stations for many years on practically all the larger streams that cross the outcrop. On several of them stations have been operated both above and below the outcrop, and series of current-meter measurements have been made between the stations to determine the extent of losses or gains in different parts of the intervening reaches. Such measurements have been made on the Guadalupe River, which crosses the outcrop area 35 to 40 miles northeast of San Antonio; on the Medina River, which crosses it about 30 miles northwest of the city; and on the Frio and Nueces Rivers, which cross it respectively about 75 and 90 miles west of the city. The records obtained on the Medina River are considered the most significant, because, as pointed out in the section on artesian pressure gradients and movement of ground water, the ground water contributed to the Edwards reservoir by this stream undoubtedly reaches the San Antonio area. The records of most of these measurements have been published in water-supply papers of the Geological Survey.

Since 1922 three gaging stations have been maintained on the Medina River in the vicinity of the Medina Reservoir, the dam of which is about 30 miles northwest of San Antonio. The upper station, usually called the

"Pipe Creek station", is a short distance upstream from the upper end of the reservoir and is above the main outcrop of the Edwards. The other two are about 4 miles below the reservoir dam, within a few hundred feet of the lower boundary of the Edwards outcrop. One of these lower stations is on the Medina Irrigation Canal; the other on the river on the diversion dam at the canal intake. During 1930 an intermediate gaging station was maintained about 2,000 feet below the reservoir, near Mico post office.

The gaging records show that in the 11 years from 1923 to 1933 about 422,000 acre-feet, or an average of about 38,500 acre-feet a year, was lost from the river and reservoir between the Pipe Creek station and the canal intake. The loss was due in part to evaporation, chiefly from the reservoir, but the evaporation was at least partly balanced by storm-water inflow from the tributary drainage area between Pipe Creek and the canal intake, comprising about 190 square miles. Most of the loss was caused by seepage into the Edwards limestone.

The best information available on losses from the Medina River on a part of the Edwards outcrop is contained in the records for 1930. During that year about 16,000 acre-feet was lost from the 3½-mile stretch of the river below the reservoir, between the Mico station and the diversion dam, all of which is on Edwards limestone. A few hundred acre-feet of the loss consisted of evaporation from the surface of the river and diversion reservoir and transpiration by vegetation along the river, but nearly all of the loss was due to seepage into the Edwards. The volume of water carried by the river in this stretch in 1930 was slightly below the 11-year average, and the loss by seepage was therefore probably somewhat less than the average.

In the absence of accurate data on evaporation from the Medina Reservoir and the inflow between the Pipe Creek and lower gaging stations, the losses from the river into the Edwards limestone during the 11-year period mentioned of course cannot be closely computed. It is believed, however, that they amounted to an average of at least 30,000 acre-feet a year, the equivalent of a continuous discharge of about 27,000,000 gallons a day. This is more water than is used for public supply by the water department of San Antonio.

A seepage investigation on July 9, 1931, disclosed that the entire discharge of Hondo Creek, amounting to 13.9 second-feet, sank on the Edwards outcrop about 50 miles northwest of San Antonio.

It was shown by measurements in June 1925 that the entire flow of the Frio River, amounting to about 40 second-feet, and the entire flow of its principal tributary, the Dry Frio, amounting to about 10 second-feet, disappeared on the Edwards outcrop. Gaging stations were operated simultaneously on the Frio River from October 1923 to September 1927 at Concan, just above the outcrop of the Edwards, and at Frio Town, about 40 miles below the outcrop. From studies of the records obtained at these points it is estimated that during the 4 years the average annual losses from the river into the Edwards limestone were from 40,000 to 50,000 acre-feet.

An extensive program of stream gaging has been carried out along the Nueces River on the Edwards outcrop and above and below the outcrop. The results of these measurements are discussed at considerable length in another paper,[9] in which the conclusion is reached that during 6 years, from October 1927 to September 1933, the losses from the river into the Edwards reservoir amounted to an average of at least 36,000 acre-feet a year, and perhaps considerably more.

On the basis of these figures it appears probable that the combined annual losses into the Edwards from the Medina, Frio, Dry Frio, Nueces, and Sabinal Rivers and Hondo Creek may average as much as 150,000 acre-feet, the equivalent of a continuous flow of about 134,000,000 gallons a day. Moreover, several smaller streams furnish supplies which in the aggregate probably amount to thousands of acre-feet a year.

The regimen of the streams of the Edwards Plateau has an important effect on the performance of the underground reservoir in the fault zone. The streams are fed in large part from the underground water systems of the plateau, and this ground-water inflow is nearly uniform for long periods. After heavy rains the ground-water discharge usually increases greatly and may be sustained at relatively high but slowly declining stages for a long time. In some dry years, such as 1925, the discharge of the streams of the plateau consists almost entirely of ground water. The rainfall in 1925 was exceedingly low, among the lowest on record at San Antonio and Uvalde. Nevertheless, the combined ground-water discharge of the Medina, Nueces, and Frio Rivers in that year amounted to about 70,000 acre-feet, most of which was derived from the Edwards reservoir of the plateau and entered the lower part of the Edwards reservoir in the Balcones fault zone.

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

During heavy rains and for a few days afterward the streams carry large quantities of storm water. This water, both in the larger streams and in innumerable small drainage channels, also contributes heavily to the fault-zone reservoir. The approximate amount of storm-water recharge from some of the larger streams is indicated by the stream-gaging records, but comparatively little is known regarding the recharge from the small streams and by direct penetration of rainfall. The records of artesian pressure and spring discharge at San Antonio give considerable information as to the time and relative magnitude of the total recharge during and after heavy rains. The artesian pressure in the vicinity of San Antonio rises almost immediately during exceptionally heavy general rains. At such times large quantities of water sink into the reservoir at the outcrop and produce a quick rise in the water table, the effect of which is communicated promptly by transmission of pressure many miles down the dip. The discharge of the San Antonio Springs also increases quickly when the rainfall is heavy, provided the pressure in the artesian reservoir at the beginning of the storm is sufficient to raise the water to or nearly to the level of the outlet of the springs. If the pressure is low before the storm it may be increased considerably and still fail to reach a point that will cause the springs to flow.

The records show that since 1913 there have been only a few periods of pronounced rise in the artesian pressure and spring discharge but that after these periods both the artesian pressure and the spring discharge were maintained at relatively high stages for months or even years. The periods of high recharge indicated by the rises are as follows: 1913, October to December; 1914, April and May; 1915, April and May; 1919, February, July to October; 1921, March and September; 1922, April; 1923, November and December; 1924, March to May; 1926, April and May; 1930 and 1931, October to February; 1932, July to September; 1935, April, May, and June.

It is apparent from a study of the records that the amount of the ground-water recharge is affected by the intensity of the rains and their distribution in time as well as by the amount of the rainfall. Intense general rains in which 3 to 8 inches falls in 2 or 3 days or a succession of moderately heavy rains in rapid sequence are almost certain to cause heavy recharge. Rains that are widely distributed in time and slow rains continuing over many days apparently provide very little recharge. Rains in winter contribute more to the ground water than rains of similar magnitude in summer. There is also a rather definite relation between the amount of storm run-off in the streams that cross the outcrop and the amount of ground-water recharge.

Although exceptionally heavy recharge on the outcrop during heavy rains is accompanied or followed by a rise in the artesian pressures at San Antonio, the recharge from the relatively uniform ground-water flow of the streams supplied by the underground reservoirs of the Edwards Plateau may not have an apparent effect on the pressure. This recharge is going on constantly, though in varying amounts.

Discharge from reservoir

The water that reaches the Edwards limestone reservoir in the San Antonio area is for the most part discharged from the reservoir by the springs and deep wells of the area. A minor part passes out of the area by underground movement.

Discharge by springs

The San Antonio and San Pedro Springs afford large natural spillways for the Edwards reservoir in Bexar County. The springs occur along faults that permit water in the Edwards limestone under artesian pressure to escape into cracks and channels in the overlying rocks and thence to flow to the surface. The San Antonio Springs emerge on low land in the valley of Olmos Creek along the line of a fault several miles long that crosses the northern part of San Antonio. (See map.) In the vicinity of the springs the fault has a throw of several hundred feet, and the top of the Edwards on the upthrown side is about 400 feet below the surface. The same fault affords a passageway for the San Pedro Springs, about 2½ miles to the southwest. The fault is believed to continue to the northeast and to cross Salado Creek about 3 miles northeast of the San Antonio Springs. Small springs that rise in the gravel along Salado Creek in that vicinity may derive their water from the Edwards limestone.

The United States Geological Survey and the Texas State Board of Water Engineers have carried on an extensive program of spring and stream discharge measurements in the Balcones fault zone and the southern part of the Edwards Plateau. All the large springs of the Balcones fault zone have been measured repeatedly, and from several of them continuous discharge records covering periods of years have been obtained.

San Antonio Springs

When first measured by the United States Geological Survey, in December 1895, the San Antonio Springs [10] had a discharge of 49 second-feet. In November 1896 they had a discharge of 29 second-feet. They ceased flowing in the later part of 1897 and were dry also during parts of 1898 and 1899. In September 1900 they had a discharge of 103 second-feet. The table below gives the results of several measurements of the discharge of the San Antonio River at Hot Wells, a short distance below the mouth of San Pedro Creek.

Discharge of San Antonio River at Hot Wells

	Second-feet		Second-feet
December 1897	11	June 1904	61
March 1898	9	September 1905	117
June 1899	10	June 1906	54
September 1900	125	September 1910	18
October 1901	41	November 1911	16
March 1904	65		

During about 17 years of the period between 1914 and 1935 a gaging station was maintained on the San Antonio River a few miles below the San Antonio Springs by the United States Geological Survey and the Texas Board of Water Engineers. The station was established October 23, 1914, at the Commerce Street Bridge, 3½ miles below the springs. On February 29, 1916, it was moved upstream two blocks, to Presa Street, and on April 9, 1920, it was transferred downstream about a mile to South Alamo Street. All three sites are above the mouth of San Pedro Creek. The station was discontinued in November 1929. It was reestablished at Alamo Street November 1, 1932, and maintained in connection with the ground-water investigation until November 30, 1934. A supplementary gaging station was maintained from April 1, 1933, to November 30, 1934, a few hundred feet above the Josephine Street Bridge, in the north-central part of the city about 1½ miles below the San Antonio Springs.

Both the San Antonio River and San Pedro Creek carry considerable storm water at times, but the periods of such inflow are ordinarily brief. On this account and because of the uniformity of the discharge of the springs it is possible to estimate with fair accuracy the amount of ground water represented in the gaging records. Part of the flow of

10 Taylor, T. U., The water powers of Texas: U. S. Geol. Survey Water-Supply Paper 105, p. 24, 1904. Taylor, T. U., and Lamb, W. A., Surface water supply of western Gulf of Mexico and Rio Grande drainages: U. S. Geol. Survey Water-Supply Paper 210, p. 45, 1907.

about 30 flowing wells is emptied into the San Antonio River between the springs and the lower gaging station, and this well discharge is included in the gaging records. In fact, the flow of the river was maintained entirely by artesian wells for months at a time in 1918, 1928, 1929, and 1934. The gaging station near Josephine Street is above all wells that contribute to the flow of the river except three belonging to the city that are used to fill the municipal swimming pool at the north end of Brackenridge Park and to maintain a stream in the park when the springs are not flowing. These wells were unused in the spring of 1933 but were used more or less regularly during the remainder of the time the Josephine Street station was in operation.

The estimated monthly ground-water discharge of the San Antonio River, consisting of the discharge of the San Antonio Springs plus inflow from artesian wells, from February 1, 1915, to October 31, 1929, and from November 1, 1932, to November 30, 1934, is given in table 1, at the end of this paper. This record is considered of special significance in connection with the ground-water investigation, and therefore the daily, monthly, and yearly discharge of the streams and the apparent relation of the flow to the rainfall have been carefully studied. The regimen of the stream is discussed at considerable length in the following paragraphs.

The measurements were started in February 1915, following a period of 17 months in which the precipitation at San Antonio amounted to 59.29 inches -- an accumulation of about 21 inches above the 61-year average. At the beginning of the measurements the ground-water flow averaged about 100 second-feet, and the discharge in February and March 1915 amounted to about 6,000 acre-feet a month. After a rainfall of 11.64 inches in April the ground-water discharge increased more than 50 percent, and from April to August it averaged about 10,500 acre-feet a month. During the 10 months from September 1915 to June 1916 the rainfall was low, the deficiency below the average amounting to 11.70 inches. In this period the discharge of the river declined steadily for 7 months, reaching a monthly low of about 4,600 acre-feet in March 1916. It then increased to an average of 5,500 acre-feet a month in April, May, and June. From July to September 1916 the rainfall was high, amounting to 13.33 inches. This failed to increase the ground-water flow of the river, which averaged only about 5,000 acre-feet a month from July to September.

From October 1916 to March 1918 the rainfall was subnormal, the accumulated deficiency during the 18 months being about 21 inches. In the first 8 months of this period the discharge of the river declined gradually, and then for 10 months it remained relatively constant at a low stage.

From April 1918 to January 1919 the rainfall was above normal, the surplus being 7.08 inches. Nevertheless, the discharge of the river remained small and most of the time was supplied entirely from wells.

The period from April to October 1919 was the wettest 7-month period in the history of the Weather Bureau station at San Antonio, the precipitation amounting to 39.96 inches, of which 31.16 inches fell in June, July, August, and September. In the next 8 months the estimated ground-water discharge of the river amounted to about 100,000 acre-feet, the equivalent of a continuous flow of about 134,000,000 gallons a day, or more than for any other period of equal length in the 17 years covered by the records.

In 1920 the rainfall was more than 7 inches below normal. Nevertheless, the stage of the river remained high throughout the year, and the total ground-water discharge for the year was the greatest in the period of the record.

During the 3½ years from January 1920 to June 1924 the rainfall averaged somewhat above normal, the accumulated excess being 8.18 inches, and most of the time the ground-water discharge remained high, the average being 5,600 acre-feet a month. Pronounced rises in the ground-water discharge followed rains of 5.91 inches in March 1921; 8.27 inches in September 1921; 12.84 inches in April, May, and June 1922; 3.55 inches in October 1922; 3.24 inches in April 1923; and 8.50 inches in November and December 1923. A rainfall of 4.59 inches in June 1921 failed to produce a rise.

From July 1924 to December 1925 the rainfall was materially below average, the accumulated deficiency being 10.66 inches. During the first 12 months of this period the discharge slowly but persistently declined, and then for 6 months it remained at a low stage. In 1926, from January to June, the rainfall was 8.74 inches above normal, and the ground-water discharge of the river increased from a monthly average of about 2,000 acre-feet in January, February, and March to about 5,800 acre-feet in April, May, and June.

From July 1926 to April 1928 the rainfall was 10.53 inches below normal, and the discharge was small, the monthly average being only about

1,800 acre-feet, or a little more than the average amount contributed by the wells.

From May 1928 to October 1929 the rainfall was about $3\frac{1}{2}$ inches above normal, but the springs failed to respond, the discharge of the river averaging only about 1,000 acre-feet a month, all of which was contributed by wells, and the San Antonio Springs did not flow. A rainfall of 7.73 inches in May 1929 had little effect on the stream discharge.

The gaging station was not operated from November 1929 to October 1932. One measurement in November 1930 gave a discharge of 45 second-feet.

In the first 9 months of 1932 the rainfall was above normal, owing to rains in July, August, and September amounting to 21 inches. Shortly afterward, on November 1, 1932, the South Alamo Street station was re-established. In November and December 1932 and the first 4 months of 1933 the monthly average discharge of the river amounted to about 4,300 acre-feet. The last 3 months of 1932 and the whole of 1933 constituted a dry period, the accumulated deficiency below normal amounting to 12.79 inches. During this period the river discharge persistently declined, reaching a monthly low of 2,480 acre-feet in December 1933.

In the first 4 months of 1934 the rainfall was 4.23 inches above normal. The ground-water discharge began to increase in the later part of January, and during March and April the average monthly discharge was about 4,400 acre-feet, or a little more than it was during the corresponding months in 1933. During the last 8 months of 1934 the rainfall was 3.97 inches below normal, the river declined rapidly in May, and from June until the station was discontinued, on November 30, it was supplied entirely from wells.

In January to April 1935 the rainfall was about normal, but in May and June torrential storms that were the heaviest in many years occurred, the precipitation amounting to 22.48 inches, or nearly 17 inches above normal. These rains brought the discharge of the springs to a high stage, and when the river was measured, on July 2, 1935, it had a flow of 165 second-feet, or at the rate of about 10,000 acre-feet a month, practically all of which was ground water. This was the highest discharge since the fall of 1924.

The record is summarized below. The average annual ground-water discharge of the river (discharge of San Antonio Springs plus inflow from artesian wells) during the 17 years of record was about 48,000 acre-feet, or about 4,000 acre-feet a month. The smallest, 11,900 acre-feet, occurred in 1918, and the largest, 115,500 acre-feet, in 1920. The average annual discharge from 1915 to 1924 was about 66,300 acre-feet, equivalent to a continuous discharge of about 90 second-feet. The average annual discharge in the 5-year period 1925-29 was about 24,000 acre-feet, and in the 2-year period 1933-34 about 32,000 acre-feet, and the average for the 7 years of these two periods was about 26,000 acre-feet. However, the average annual rainfall from 1914 to 1924 was 27.09 inches, as compared with 25.20 inches in 1924-29 and 26.95 inches in 1932-34. The longest period of continuous low flow, 39 months, occurred from August 1926 to October 1929, when the average monthly discharge amounted to only about 1,400 acre-feet, the equivalent of a continuous discharge of 23 second-feet. Most of this water was supplied from artesian wells, and the greater part of the time the springs were not flowing. The measurements were stopped at the end of October 1929, but it is reported that the low flow continued until the following September, or altogether for 50 months.

The deficiency during 1926 to 1930 is perhaps the most outstanding feature of the record. The rainfall in both 1928 and 1929 was materially above the 61-year average, and during the 4 years 1926-29 it was slightly above the average. On the other hand, 1925 was particularly dry, the precipitation amounting to only 14.99 inches, and, as pointed out in the section on rainfall, there were only a few heavy rains during the 43 months from July 1, 1924, to December 1927. Under these conditions of rainfall the opportunities for ground-water recharge are not good, and these conditions doubtless helped to keep the ground-water discharge at a low ebb in 1928 and 1929. It is believed, however, that the deficiency was intensified and the period of shortage prolonged by the heavy draft on the underground reservoirs through wells.

At the time this is written (July 1935) the springs are discharging more water than at any time since the fall of 1924, a notable recovery having been produced by the heavy rains in May and June.

San Pedro Springs

The San Pedro Springs were measured by the United States Geological Survey only a few times prior to 1916. The recorded discharge is as follows: December 1895, 9 second-feet; November 1896, 12 second-feet; September 1900, 9 second-feet; March 16, 1904, 9 second-feet. On July 20, 1916, a gaging station was established on San Pedro Creek at Commerce Street, about 1½ miles below the springs. On March 14, 1920, this station was moved downstream about three-quarters of a mile to a point a few hundred feet south of Arsenal Street. The station was discontinued in November 1929, but it was reestablished at the old site near Arsenal Street on November 1, 1932, and maintained in connection with the ground-water studies until November 30, 1934.

There is some artesian-well inflow into San Pedro Creek between the springs and the Arsenal Street gaging station. According to current-meter measurements the pick-up from this source was 4.3 second-feet on November 9, 1932, and 2.1 second-feet on October 24, 1933.

Table 2, at the end of the report, gives the estimated monthly ground-water discharge of San Pedro Creek at the Commerce Street and Arsenal Street gaging stations, representing the discharge of the springs plus the inflow from wells between the springs and the gaging station. The average annual discharge during the 17 years of record was about 5,000 acre-feet, the equivalent of a continuous discharge of about 7 second-feet. The years of high and low discharge correspond fairly closely with the years of high and low discharge of the San Antonio River, but the range in the annual discharge is considerably smaller. The smallest amount reported was in 1918 and the largest in 1920. Two prolonged periods of low flow occurred -- one of 22 months from April 1917 to January 1919, in which the average monthly discharge was 212 acre-feet, representing an average flow of about 3½ second-feet, and one of 16 months from August 1928 to November 1929, in which the average monthly discharge was about 220 acre-feet. It is worthy of note that the second period of minimum flow began nearly 2 years after the start of the prolonged low period recorded for the San Antonio Springs.

Salado Creek Springs

Small springs in Salado Creek, in part above the crossing of the San Antonio-Austin road and in part between the Austin and Rittiman roads, may come from the Edwards limestone. The discharge of these springs apparently ranges from a fraction of a second-foot to about 3 second-feet. Available records of their flow are as follows: May 8, 1919, 3.0 second-feet; November 14, 1932, 2.0 second-feet; December 5, 1932, 1.4 second-feet; April 14, 1933, 1.8 second-feet; May 20, 1933, 1.0 second-foot; July 17, 1933, 1.5 second-feet; October 23, 1933, 1.0 second-foot; May 7, 1934, 0.9 second-foot; June 25, 1934, 1.0 second-foot; August 28, 1934, 0.7 second-foot; October 29, 1934, 1.5 second-feet. It is estimated that the discharge of the springs averaged about 1.4

second-feet, or about 900,000 gallons a day, in 1933, and about 0.8 second-foot, or about 500,000 gallons a day, in 1934. The total discharge in each of these years amounted to only a few hundred acre-feet, and as there is some uncertainty as to whether or not the water is coming from the Edwards limestone it is not included in the computations that follow.

Discharge from San Antonio and San Pedro Springs in 1934

In 1934 the total discharge of San Antonio River at the South Alamo Street bridge amounted to about 25,700 acre-feet (table 1), the total discharge of San Pedro Creek near Arsenal Street amounted to about 4,070 acre-feet (table 2), and the combined discharge of the river and creek was thus about 29,800 acre-feet. These discharge records include a large amount of inflow from artesian wells between the springs and gaging station, and perhaps some inflow from the gravel along the stream during heavy rains and for brief periods thereafter. Table 3 gives the discharge of the river at the gaging station near the Josephine Street Bridge, about 1-3/4 miles below the springs. The records at this station represent much more closely the actual discharge of the springs than those obtained at Commerce and South Alamo Streets. However, they include some inflow from city-owned wells that are used at times to supply the municipal swimming pool in Brackenridge Park and to maintain the flow of the river through the park when the springs are very low or are not flowing. The ground-water discharge at the Josephine Street gaging station from April to December 1933 amounted to about 17,600 acre-feet, and during the full year 1934 about 12,200 acre-feet. Most of the water passing the station in 1933 was spring water, but in 1934 a part of the discharge, roughly estimated at 2,000 acre-feet, came from wells. On this basis the discharge of the San Antonio Springs themselves in 1934 amounted to about 10,200 acre-feet.

It is computed that wells contributed about 1,000 acre-feet to the discharge of San Pedro Creek above the gaging station in 1934, and that the discharge of the springs themselves amounted to about 3,000 acre-feet. Thus, as computed, the combined discharge of the San Antonio and San Pedro Springs in 1934 amounted to about 13,000 acre-feet.

Discharge from wells

The public and industrial water supplies of San Antonio and nearly all the water used for irrigation in Bexar County are obtained from wells in the Edwards limestone. Until about 50 years ago the San Antonio and San Pedro Springs and shallow wells in the gravel were the chief sources of water supply in the area. The drilling of wells to the artesian reservoirs in the Edwards limestone was started in the later part of the decade between 1880 and 1890, when several wells drilled by George W. Brackenridge for the public supply of San Antonio were among the first to be put down. According to Hill and Vaughan[11] there were more than 40 artesian wells at or near San Antonio prior to 1907, of which 30 had a reported combined flow of 30,000,000 gallons a day. Nine of these wells are listed as belonging to the San Antonio Waterworks Co. Taylor[12] reports that prior to 1907 there were more than 100 artesian wells in Bexar County and gives a partial description of 68 of them. He states that some of the wells were among the strongest in the State.

In the course of the present investigation detailed descriptions were obtained of nearly all the Edwards limestone wells in the county that have a flow or are equipped with a power pump, together with a fairly large number of farm and ranch wells, most of which are pumped with windmills. Altogether about 400 wells in the county were visited, of which about 160 are in San Antonio. The approximate discharge from most of the wells has been computed, either from available records or from estimates or measurements made in the field. From these data and from available information regarding the length of time the wells are allowed to flow or are pumped during the year, an inventory has been compiled giving the estimated total discharge from wells in the Edwards limestone in Bexar County in 1934. A summary of the inventory is given in the following paragraphs.

Public supplies.--The city operates three pumping plants, all close to the San Antonio River -- one in the southern part of Brackenridge Park, another in the downtown section on Market Street, and the Mission plant, near the southern boundary of the city close to the confluence of the river and San Pedro Creek. According to Potter[13] the average quantities of water delivered by the city amounted to about 8,750,000 gallons a day in 1908, and to about 13,250,000 gallons a day in 1911. The average quantities delivered from June 1925 to September 1934 are given in table 4, which was compiled from data furnished by the City Water Board. The table shows that

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11 Hill, R. T., and Vaughan, T. W., Geology of the Edwards Plateau and Rio Grande Plain adjacent to Austin and San Antonio, Tex., with reference to the occurrence of underground waters: U. S. Geol. Survey 18th Ann. Rept., pt. 2, pp. 290-298, 1897.

12 Taylor, T. U., Underground waters of the Coastal Plain of Texas: U. S. Geol. Survey Water-Supply Paper 190, pp. 55-56, 1907.

13 Potter, Alexander, A report upon and an appraisement of the water-supply system of the city of San Antonio, Tex., pp. 32 and 48, 1912.

the average daily delivery during this period of about 9 years was about 22,500,000 gallons, representing about 69 acre-feet a day, or about 25,000 acre-feet a year. The largest amount was delivered in 1927, and the smallest in 1929.

Independent public supplies are provided by the United States Government at Fort Sam Houston, Kelly Field, Duncan Field, Randolph Field, and Camp Normoyle and by the suburban communities Alamo Heights, Woodlawn Hills, South San Antonio, and San Fernando addition. Many of the San Antonio hotels and offices are supplied from privately owned wells. It is computed that in 1934 the water used for public supply by the city, by independent public agencies, and by the city hotels and office buildings averaged about 28,000,000 gallons a day, representing about 31,400 acre-feet a year.

Industrial supplies.--Practically all industrial requirements for water in Bexar County are supplied by privately owned wells. The heaviest industrial demands are for water for cooling machinery and air-conditioning theaters, hotels, and office buildings at San Antonio, and a large part of the water used for this purpose is emptied into the San Antonio River or San Pedro Creek. The total supply of water from wells in the Edwards limestone used in 1934 for cooling and by various industries in the county, chiefly factories, ice plants, dairies, breweries, slaughter houses, and cement mills, is estimated at about 16,200 acre-feet, or about 14,500,000 gallons a day. Of this quantity about 10,500 acre-feet, or about 9,400,000 gallons a day, was emptied into the San Antonio River and San Pedro Creek.

Swimming pool and river supply in Brackenridge Park.--It is estimated that about 2,000 acre-feet of well water was contributed to the San Antonio River in Brackenridge Park in 1934. This water was used to supply the municipal swimming pool and maintain a flow in the park when the springs were very low or not flowing.

Irrigation.--Artesian water from wells has been extensively developed for irrigation in two areas in Bexar County -- one east of San Antonio along Salado Creek, the other in the southwestern part of the city and in contiguous territory south and southwest of the city limits. It is estimated that about 4,500 acres was irrigated from wells in these two areas in 1934 and that the water used for irrigation amounted to about 20,000 acre-feet, or an average of about 18,000,000 gallons a day, if it had been equally distributed throughout the year. This represents about 4.5 acre-feet to the acre. Some irrigation water is obtained from artesian wells in other parts of the county, but the amount is small. Several irrigation wells of large yield obtain water from the Austin chalk, but it is believed that the water of most such wells has its source in the Edwards limestone and has moved upward through fractures into the Austin. A large part of the irrigated land is supplied from flowing wells, many of which are allowed to flow when not needed and some of which flow all the time.

Salado Creek wells.--Among the notably strong flowing wells of the San Antonio area are two Government-owned wells and a well belonging to the Salado Water Co. on the Fort Sam Houston reservation, adjacent to Salado Creek. These three wells have an average combined flow of 20 to 22 second-feet. They empty into Salado Creek to supply stock and some domestic needs on farms several miles downstream. Apparently only a relatively small part of the water is utilized during most of the year. Measurements of the discharge of these wells from May 8, 1919, to July 2, 1935, are given in table 5. The combined discharge of the three wells in 1934 amounted to about 16,000 acre-feet, or about 14,000,000 gallons a day.

Farm and ranch supplies.--An average of about 1,500,000 gallons a day, or about 1,680 acre-feet a year, is used for domestic purposes and stock in rural communities and on the farms.

Miscellaneous wells.--In the flowing-well area south and southwest of San Antonio there are numerous ranch wells of relatively large flow, a part of which are allowed to flow all the time, some of them not being provided with caps or valves. Some of these wells are used for irrigation in a small way; others are used only for domestic supply, and most of the discharge is emptied into the nearest stream. Most of these wells yield sulphur water, but a few yield fresh water. One of the fresh-water wells that empties into the Medina River has a flow of about 4½ second-feet, or about 2,900,000 gallons a day. In 1934 the total volume of water discharged by wells of this class amounted to about 7,800 acre-feet, or about 7,000,000 gallons a day.

Total discharge from springs and wells in 1934

The table below gives a summary of the estimated discharge from the San Antonio and San Pedro Springs and from wells in the Edwards limestone in Bexar County in 1934. It should be remembered that some of the figures for well discharge are based on rather rough estimates.

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Discharge in 1934 from San Antonio and San Pedro Springs and wells

	Total (acre-feet)	Average (million gallons a day)
Springs:		
San Antonio	10,200	9.10
San Pedro	3,000	2.85
Wells:		
Public supplies	31,400	28.00
Brackenridge Park (swimming pool and river supply)	2,000	1.78
Industrial supplies	16,200	14.50
Irrigation	20,000	17.88
Farm and small town supplies	1,680	1.50
Salado Creek flowing wells	16,000	14.28
Miscellaneous wells	7,800	7.00
Total	108,280	96.89

According to the computations and estimates in the table and paragraphs preceding it, the total discharge of water from the Edwards limestone in Bexar County in 1934 amounted to about 108,300 acre-feet, of which about 13,200 acre-feet came from the San Antonio and San Pedro Springs and the remainder from wells. Of the discharge from wells about 12,500 acre-feet was emptied into the San Antonio River and San Pedro Creek, about 16,000 acre-feet was emptied into Salado Creek, and about 66,600 acre-feet was consumed, emptied into the sewers, or otherwise disposed of.

It is believed that the withdrawals from wells in the county in 1934 were not much above the average annual withdrawals during the last 20 years. The deliveries by the city reached a peak in 1927, and the mean of the annual averages shown in table 4 is probably only a few million gallons a day above the 20-year average. During the last two decades some irrigation wells have been abandoned, and new wells have been put down, but the net change has not been very great. There has been considerable increase in recent years in the use of water for industrial purposes, especially for cooling theaters and office buildings, but most of this water is later emptied into the San Antonio River and

San Pedro Creek and taken into account in the estimates of the ground-water discharge of these streams given in tables 1 and 2.

It is estimated from all the available data that during the last 20 years an average of around 120,000 acre-feet a year, or 107,000,000 gallons a day, was discharged from the San Antonio and San Pedro Springs and from Edwards limestone wells in Bexar County, of which 45,000 to 50,000 acre-feet passed the gaging stations on San Antonio River and San Pedro Creek, and 70,000 to 75,000 acre-feet was discharged by Edwards limestone wells exclusive of those that empty into the river and creek above the gaging stations. In reaching these figures tables 1 and 2 were largely used as a basis for computation, and it was estimated that during the period the average annual discharge from wells, exclusive of those that empty into the river and creek, was about 90 percent of the discharge from such wells in 1934.

Waste from wells

The investigation has shown that large quantities of water from wells in the Edwards limestone are wasted in the San Antonio area, chiefly from flowing wells. Much of the well water that is used for cooling is used inefficiently or wasted. The water could be aerated and used over and over again instead of being emptied into the streams or sewers after one cooling operation. Moreover, many wells of this class are allowed to flow continuously. When the San Antonio Springs are not flowing or have a very small discharge water emptied into the river from the wells serves a useful purpose, because it helps to maintain a flow in the river in the central and southern parts of the city. However, the discharge of the wells and the amount emptied into the river tend to be the greatest when the artesian pressures are high and the discharge from the San Antonio Springs is at high stages. Many of the irrigation wells are allowed to flow when they are not needed, and some of them flow all the time. Relatively large quantities of water are wasted from flowing ranch wells in the area south and southwest of San Antonio, mostly from wells that discharge highly mineralized water impregnated with hydrogen sulphide. (The normal Edwards water and the highly mineralized water come from the same reservoir, and the common supply is depleted to an equal extent by the withdrawal of water of either type.) The water discharged by the three wells of very large flow on Salado Creek near Fort Sam Houston is largely wasted.

The total quantity of well water that is wasted each year probably amounts to at least one-third of the total annual discharge from wells.

Fluctuation in artesian pressure

Without doubt the artesian pressure in the Edwards limestone reservoir in this locality has always fluctuated within fairly wide limits. In the outcrop area of the formation water in great quantities is absorbed during heavy rains, the water table rises promptly, and the effect of this rise is quickly transmitted by hydraulic pressure many miles down the dip. A sudden rise in the artesian wells follows, and the springs begin to flow, or, if already flowing, the discharge increases. After the rise the artesian pressure usually begins to decline. If the interval between rains is long the pressure declines materially, and as it declines the flow of the springs decreases. The San Antonio Springs cease to flow when the altitude of the static water levels in neighboring wells falls below about 668 feet. During recent years the springs have been inactive a considerable part of the time. Some of the residents of San Antonio believe that in the past when there were no artesian wells or the number of wells was comparatively small the springs never stopped flowing. This belief is not in accord with the records. Taylor[14] states that about 1895 the San Antonio River began to fail and that by the later part of 1897 it had entirely ceased north of the city. He gives the following figures (see p. 93) showing fluctuations in artesian pressure as disclosed by height of water in standpipes at the waterworks plant on Market Street and at the former upper power house in Brackenridge Park a short distance below the San Antonio Springs. These records show a range in head of 15.5 feet at Market Street between 1893 and 1900 and a total rise in head of 16.9 feet at the upper power house between January 1 and May 24, 1900. It is reported that in 1900 the flow of the river regained its former volume.[15] This is not surprising in view of the increase in artesian pressure indicated by these records.

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14 Taylor, T. U., The water powers of Texas: U. S. Geol. Survey Water-Supply Paper 105, pp. 23-25, 1904.

15 Taylor, T. U., and Lamb, W. A., Surface water supply of western Gulf of Mexico and Rio Grande drainages: U. S. Geol. Survey Water-Supply Paper 210, p. 45, 1906.

Artesian head in city wells, in feet above the pumps

Market Street		Brackenridge Park	
Date	Artesian head	Date (1900)	Artesian head
May 1893	42.10	January 1	1.80
December 1897	33.80	February 1	6.76
April 1898	31.60	March 1	13.76
April 29, 1900	43.00	April 1	13.77
May 1, 1900	44.10	May 1	15.57
May 5, 1900	45.10	May 24	18.74
May 9, 1900	46.20	June 1	17.99
May 22, 1900	47.10	July 1	14.65
		August 1	12.76
		September 8	12.10
		October 1	11.47
		November 1	11.38
		December 1	10.51

On January 15, 1911, the city water department began to keep a record of the artesian pressure at the Brackenridge pumping plant, by reading the water level below an ell at the top of a well just west of the old plant. Measurements were discontinued at this well on March 1, 1930. Since then the pressure at midnight on the intake header to the pumping plant has been recorded nearly every day. The draw-down at that hour is relatively small. Also, since 1922 the city water department has taken one or more pressure readings each year on a well at the Mission pumping plant.

In connection with the present investigation a continuous recording gage has been maintained since November 11, 1932, on an unused well belonging to the Beverly Lodges, just north of Fort Sam Houston. This well is somewhat remotely located from any pumping of consequence, and the graph drawn by the gage is an accurate record of changes in artesian pressures over a wide area. During the investigation periodic measurements have been made to determine fluctuations in artesian pressure in about 40 selected wells spaced over a large part of Bexar County and eastern Medina County. This is done by measuring with a steel tape the depth to the water surface below a fixed measuring point, or in flowing wells by taking the pressure at a fixed point. The altitudes of the measuring points on all the wells

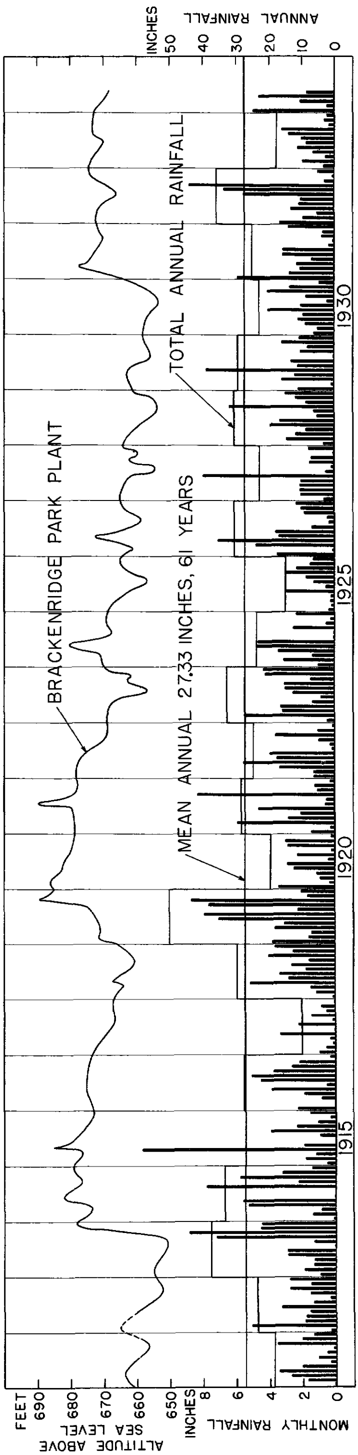

FIGURE 7.-GRAPHS SHOWING FLUCTUATION OF ARTESIAN WATER LEVEL AT BRACKENRIDGE PARK PUMPING PLANT AND RAINFALL AT SAN ANTONIO, TEXAS.

have been determined by leveling and in this way the measurements are referred to sea level. The observation wells include two in eastern Medina County that were measured in February 1930, in connection with the investigation of the ground waters of Uvalde and Medina Counties. One of these wells is 3 miles east of Castroville, and the other at Lacoste. Measurements were started in the fall of 1932 on several wells located mostly in two lines leading out from San Antonio -- one line to the northwest and the other to the northeast. During August and September 1933 more observation wells were selected, and since then other wells have been added as the need for them became apparent. Since the fall of 1933 the measurements have been made nearly every month.

Fluctuations at Brackenridge pumping plant

The records of artesian pressure obtained at the Brackenridge pumping plant have been referred to a common datum, and the altitude to which the artesian water would rise is indicated graphically in figure 7. The diagram shows that during the period of record the artesian pressure at San Antonio varied a great deal. The lowest water level, about 651 feet above sea level, was recorded during the summer of 1913, after the longest period of subnormal precipitation in the history of the Weather Bureau station at San Antonio. (See p. 65.) The highest, about 689 feet, was recorded in October 1919, after several months in which the rainfall was the highest on record, and again in July 1921. The artesian pressure in the later part of the summer of 1913, according to officials of the water department, was the lowest recorded since the city began to pump water from wells, 40 to 50 years ago. After heavy rains in September and October 1913, however, the water level rose about 27 feet, to 678 feet, by the end of the year. After some irregularity in 1915, it declined through 1916 and 1917 and reached a low of 661 feet during the late summer of 1918. The peaks of 689 feet in 1919 and 1921 were followed by a low point of 656 feet in 1923. A level of 680 feet was reached in the summer of 1924, however, and this was not again attained until June 1935. The low level of 653 feet, within 2 feet of the minimum of 1913, was reached in the summer of 1930.

In general the periods of high and low pressure agree closely with periods of high and low flow of the San Antonio Springs, and sudden rises in pressure synchronize with sudden increases in the discharge of the springs. Some disagreement is noted, particularly during short-time peaks or decreases in pressure. This may be due in considerable part to the effect on the pressure record of fluctuations in the volume of pumpage in the immediate vicinity of the gage.

Fluctuation in well at Beverly Lodges

The record obtained by the recording gage on the well at the Beverly Lodges shows that the water level is practically never still. (See figure 8.) The water has a high and low level each day, corresponding inversely with the high and low hourly rate of pumpage in the San Antonio area. During the periods of heavy pumping in the summer the fluctuations amount to about 1 foot, but during the winter, when the total daily pumpage is less than in summer, there is not so much variation in the hourly rate of pumpage and the diurnal fluctuations amount to about 0.3 foot. As a general rule the highest level is reached about 5 o'clock in the morning in summer and about 8 o'clock in winter, and the lowest from 7 to 8 o'clock in the evening in summer and from noon until 4 o'clock in winter. Regular weekly fluctuations also occur. The water level usually rises somewhat with the week-end decline in the rate of pumping and falls gradually during the week. There is frequently a sudden rise of 5 to 9

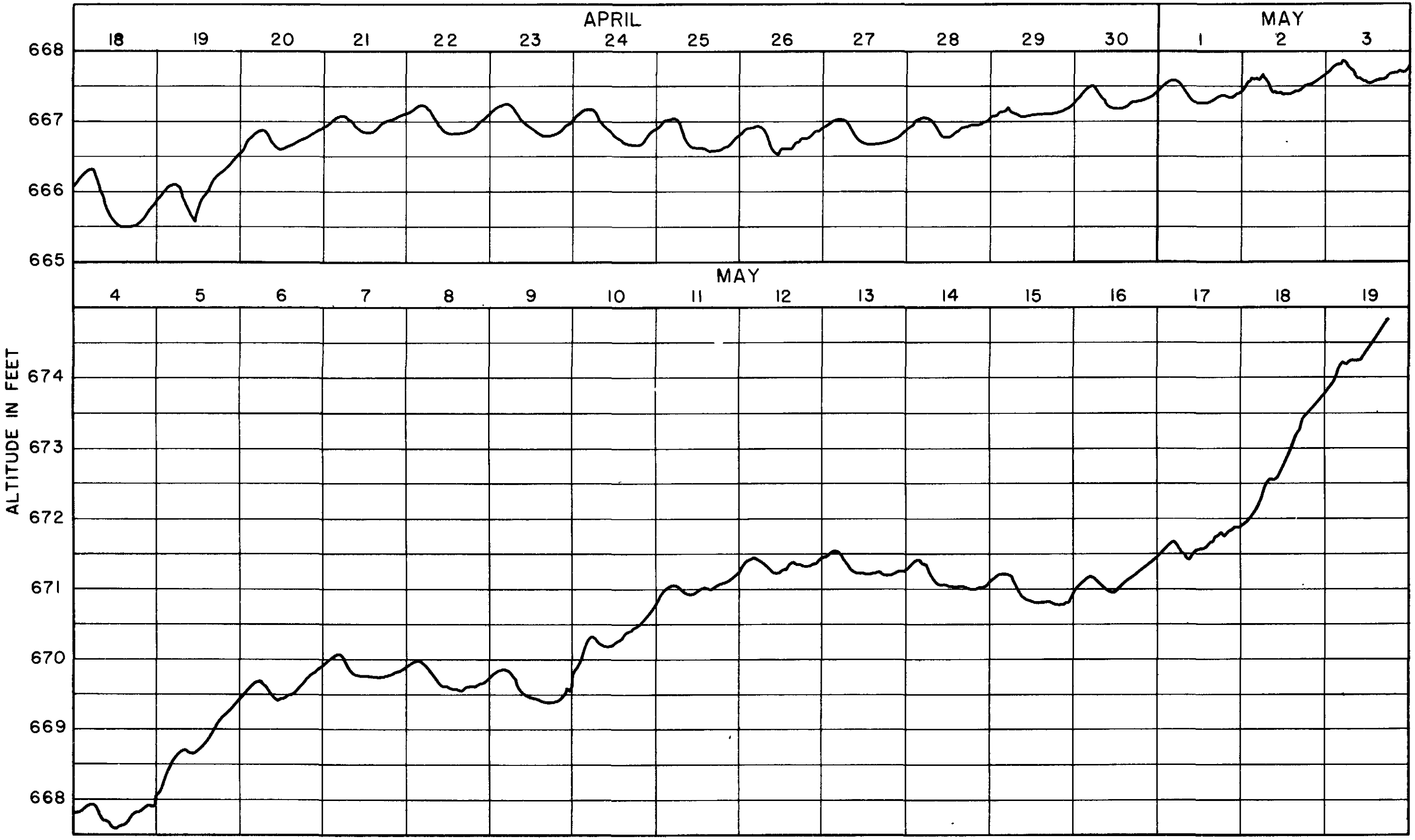

FIGURE 8.- HYDROGRAPH OF THE BEVERLY LODGES WELL, SAN ANTONIO, TEXAS, SHOWING RISE OF WATER LEVEL FOLLOWING HEAVY RAINS IN APRIL AND MAY 1935.

inches after heavy local showers in San Antonio, due apparently to a sudden decrease in the rate of pumpage. The water level normally rises slowly during the fall and winter and declines during the spring and summer. These seasonal fluctuations are clearly due to seasonal changes in the draft on the wells. Finally and most significantly of all, the water levels are an index of recharge to the underground reservoir. Several pronounced rises that occurred during the period of record were plainly due to recharge from heavy rains that fell north of San Antonio.

Some of the more important details of the record from November 11, 1932, to June 8, 1935, as recorded by the gage at Beverly Lodges are given below.

During the winter and spring of 1932-33, in addition to minor fluctuations, there was a net rise amounting to about 1 foot -- to an average level of about 676 feet. Beginning with the increased pumpage during the early summer the level declined persistently, reaching about 671 feet on July 28, 1933. On July 29 and 30 there was a rise of about 1 foot. There were small rises of less than 1 foot on August 15, 24, 30, September 16, 23-26, 1933, and January 17 to February 3, 1934, and after each small rise there was a steady decline. All these small fluctuations were probably due to temporary changes in the rate of pumping from wells in San Antonio.

The period from November 1932 to December 1933 was one of extremely low rainfall, the accumulated deficiency at San Antonio during the 14 months being 11.14 inches. The first subsequent rises that can be correlated with the rainfall occurred with a precipitation at San Antonio of 0.12 inch on February 28, 1934, and with one of 1.55 inches on March 1, 1934. The water level began to rise rapidly about noon on February 28 from an altitude of 672.5 feet and reached 674.7 feet by noon March 5. The next rise, amounting to 2.1 feet, occurred April 4 to 9 and was apparently due to rains on April 4, 5, and 6 of 0.54, 1.08, and 0.92 inches, respectively, at San Antonio. In the period from July 25 to August 2 rains occurred amounting to 4.33 inches at San Antonio and 5.30 inches at Boerne. These rains were accompanied by a sharp rise in the water level in the well, beginning at an altitude of 666.8 feet at noon on July 25 and reaching 670.8 feet on August 5. From August 1934 to the middle of February 1935 the water level fluctuated a little under 670 feet. During the later part of February, March, and the early part of April 1934 there was a general decline.

The period from April 19 to June 15, 1935, was one of the wettest on record, the total precipitation at San Antonio amounting to about 24 inches. Most of the rain fell in seven storms, as follows: April 19, 1.36 inches; April 24, 0.52 inch; May 2 to 5, 3.16 inches; May 9 and 10, 6.11 inches; May 18 and 19, 1.58 inches; May 28 and 29, 1.86 inches; June 9 to 15, 7.37 inches. The hydrograph recorded by the gage from April 19 to May 19 shows that each of the heavy rains was accompanied or quickly followed by a sharp rise in the water level in the well, and that the net gain during the month amounted to about $8\frac{1}{2}$ feet (fig. 8). The times and amounts of the principal rises were as follows: April 19 to 21, about 0.75 foot; April 26 to May 3, about 0.9 foot; May 4 to 6, about 2 feet; May 10 to 12, about $1\frac{1}{2}$ feet; May 16 to 19, about $3\frac{1}{2}$ feet. A gain of even greater magnitude occurred in June, but the graph is not available, having been destroyed by field mice. On June 25 the water level stood at an altitude of 685.16 feet as determined by a measurement with a steel tape. The total rise from April 19 to June 25 amounted to about 19 feet, and at the time of the last measurement the water had reached a level about 10 feet above the level at the start of the record, in November 1932.

Fluctuations in miscellaneous observation wells

A study of the records of miscellaneous measurements shows that the fluctuations in artesian pressure throughout the area are in close agreement most of the time and that the graph of the recording gage on the well at Beverly Lodges gives an accurate picture of the major fluctuation features. The remarkable uniformity that attends the rise and fall of pressure, both in time of occurrence and in magnitude, is shown by the records of measurements in 12 of the observation wells from April 20 to October 11, 1934. These wells are located along a line (CC' on map) about 40 miles long, extending northeastward from the vicinity of Castroville to San Antonio and thence to and beyond Wetmore. The results of the observations on these wells during the period are given in table 6 and are shown graphically in figure 9. The lines in the figure represent the altitude of the water surface in the wells at different times. The position of the wells as shown represents to scale their air-line distances from the Bexar County courthouse. The outstanding feature of this record is the remarkable uniformity in the rise and fall in pressure along the entire 40-mile line. During the greater part of the period the movement was continuously downward, the total decline being greatest in wells 1 to 4, 20 to 12 miles

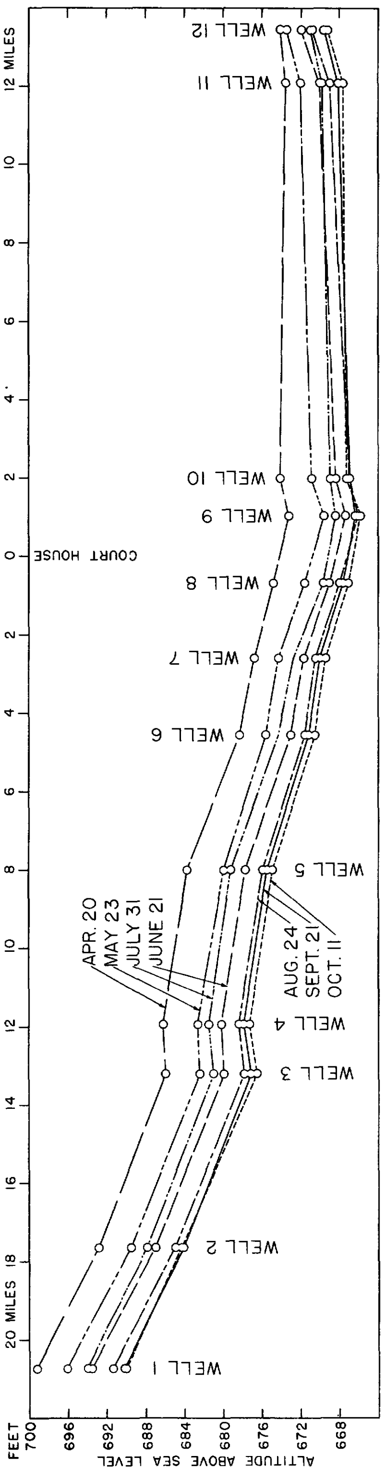

FIGURE 9.- DIAGRAM SHOWING ARTESIAN WATER SURFACE, ALONG LINE C-C' ON MAP ON DATES INDICATED IN 1934.

southwest of San Antonio, and least in wells 11 and 12, at the northeast extremity of the line, near Wetmore. Between the measurements of June 21 and July 31 a general rise occurred in all the wells measured except well 12; the greatest rise was in wells 4 and 5, and the least in well 11. The pressure in well 12 declined between the two measurements. According to the recording gage at the Beverly Lodges the rise began about noon on July 25 and had reached a point within 0.2 or 0.3 foot of the maximum on July 31.

Of all the observation wells (see table 7), two near the Medina-Bexar County line have shown the greatest fluctuations in artesian head during the full period of record. One of these wells is 6 miles southeast of the Medina dam and belongs to Alfred Bourquin; the other is $8\frac{1}{2}$ miles southeast of the dam and belongs to Mrs. Kate Benke. In the Bourquin well the water level rose about 11 feet between January 9 and April 20, 1934, 7 feet between June 21 and July 31, 1934, 34 feet between April 9 and May 21, 1935, and 32 feet between May 21 and June 28, 1935. In the Benke well the total rise amounted to $12\frac{1}{2}$ feet between the June and July measurements in 1934 and to about 90 feet between the April and June measurements in 1935. In both wells each pronounced rise was followed by a sharp decline. Such fluctuations usually occur in or near areas of very heavy ground-water recharge.

The artesian pressures increased greatly in nearly all the observation wells between the measurements of April and June 1935, the average rise amounting to about 20 feet. In four observation wells between the Bourquin and Benke wells and San Antonio the average rise amounted to about 25 feet. The Beverly Lodges well, near Fort Sam Houston, northeast of San Antonio, displayed a rise of 19 feet. Wells 1 to 6 along the line CC' (see map), southwest of San Antonio, had rises ranging from 26 feet in well 1, at the west end of the line, down to 19 feet in well 6, near San Antonio. The observation wells northeast of San Antonio had the smallest gain, the rise ranging downward from 19 feet near San Antonio to 15 feet in well 12, at the northeast end of the line.

The records of artesian pressure therefore afford good evidence that heavy recharge to the underground reservoir comes from outcrop areas northwest of San Antonio, in the direction of Medina Lake.

Artesian-pressure gradients and movement of ground water

The direction in which water is moving in an underground reservoir can be determined if the shape of the water table or the direction of the artesian-pressure gradients is known. In an underground reservoir in a fairly homogeneous sand, sandstone, or gravel the direction and amount of slope in artesian head can usually be accurately mapped from a moderate number of observation wells. It is much more difficult to map the pressure gradients in such a formation as the Edwards limestone, in which there is very little uniformity in the transmission capacity of the formation from place to place. The openings in the Edwards vary in size from caverns in which the movement of water is almost as free as it is in a river and involves little loss in hydraulic head down to minute joints and cracks in which the movement is resisted by great friction and is attended by large loss in head. To make an accurate artesian-pressure map under these circumstances a very large number of observation wells is required. In the vicinity of San Antonio wells in the Edwards limestone are closely spaced, but in most of the remainder of Bexar County and in Medina and Comal Counties they are rather widely separated.

During the summer of 1934 levels were run to connect many wells in the Edwards limestone throughout Bexar County, and the altitude of reference points at the surface of the wells was determined. In October 1934, within a period of a few days, the distance of the water level above or below these reference points was measured. During the same period the altitude of the water levels in several wells in Uvalde and Medina Counties was determined. From these data lines of equal artesian pressure have been drawn and are shown on the map. The lines are more nearly accurate for the vicinity of San Antonio than for some other parts of the area covered, where they may show only the major trends in artesian gradients.

The data indicate that in October 1934 the altitude of the artesian-pressure surface in the vicinity of the Edwards outcrop on the Frio River in Uvalde County was about 1,000 feet, in the vicinity of the outcrop on the Hondo River about 800 feet, in the vicinity of the outcrop on the Medina River over 740 feet, in the vicinity of San Antonio about 665 feet, and in the vicinity of the Comal Springs, at New Braunfels, about 625 feet. The differences in artesian pressure are therefore sufficient to cause water to move toward San Antonio from three known points of heavy intake to the west and northwest (see pp. 75-77) and from San Antonio toward the Comal Springs.

The area of relatively high artesian pressure in the vicinity of the outcrop on the Medina River indicates that the recharge in that area is heavy and supports the conclusions reached from measurement of the fluctuation of water levels that this is among the principal recharge areas to the Edwards limestone. It is believed that the water follows a somewhat tortuous course, entering the formation along the Medina River and moving down the dip to the large fault that passes near Quihi. The movement of the water down the dip is halted by the fault, which in this area is of sufficient throw to bring the Edwards limestone opposite a relatively impermeable formation of Upper Cretaceous age. The water therefore moves toward the northeast along the fault to the vicinity of the Benke and Bourquin wells, where the throw is less than the thickness of the Edwards. There the water passes across the fault into the downthrown portion of the Edwards and joins the main body of water in that part of the formation.

The relation of the Hondo Creek, Frio River, and Sabinal River areas to the San Antonio district is not so clearly established as that of the area along the Medina River. The contours in Medina County, as shown on the map, have a general east-west trend and indicate that the general direction of movement of the artesian water is toward the south. However, practically no surface outlet for the water in that direction is available, and there is reason to believe that there is no large submarine outlet. It seems likely that the largest and best-defined solution channels follow the fault lines, which also in general have east-west trends, and that the water moves through these channels in large volume to the east or west or in both directions with but little loss of head. If this theory is correct the pressure contours are farther apart and actually have north-south trends where they cross these major solution channels, but such trends are not revealed by the records of the widely spaced observation wells.

The magnitude of the faulting in the vicinity of Helotes is sufficient to offset the Edwards limestone completely and apparently to prevent the movement of ground water across the fault. In the large area north and northeast of San Antonio where the Edwards limestone crops out the faulting is not sufficient to affect the movement of the ground water appreciably. This outcrop area probably contributes water to the Edwards limestone in the eastern part of the county and may contribute water to western Comal County and ultimately to Comal Springs. Some ground water may also reach Comal Springs from the vicinity of San Antonio by a relatively narrow and tortuous course through the highly faulted area along Cibolo Creek north of Bracken. It is believed that not much water is lost from the San Antonio area in this way, but the available evidence is not conclusive, and the subject is to be given further study.

Safe yield of reservoir

The Edwards limestone underlies all of Bexar County from the outcrop south (see map), but in the greater part of the southern third of the county it lies too deep to be reached economically by water wells, and the water in the formation is highly mineralized. The area in which the formation contains water suitable for most purposes is a belt that extends across the county, averaging about 15 miles in width and covering about 500 square miles. If in this belt the Edwards limestone contains a volume of gravity water equal to only 2 percent of its own volume, the supply in storage in the limestone beneath Bexar County amounts to about 6,000 acre-feet for each foot of thickness of the formation. If the formation has an average thickness of 500 feet its total storage amounts to about 3,000,000 acre-feet, or about 23 times the estimated combined average yearly discharge of the springs and wells during the last 20 years (pp. 89-91). Most of this stored water could not be withdrawn, however, without causing excessive lowering of the water levels in the wells.

The highly mineralized character of the water in the Edwards limestone in the southern part of Bexar County indicates that there is not much movement of water down the dip. Probably, therefore, the wells and the San

Antonio and San Pedro Springs are the only outlets of much consequence from the artesian reservoir under Bexar County, and before wells were put down the springs were almost the only outlets. During the last 20 years the mean rainfall has been about equal to the 61-year average recorded at San Antonio. The artesian pressures in June 1935 were apparently about as high as they were in 1915, and therefore there has not been much change in reservoir storage. It is assumed that during this period no water moved out of the area and that ground-water discharge occurred entirely through the San Antonio and San Pedro Springs and through wells. The average combined annual discharge of the springs and wells during the 20 years is estimated at about 120,000 acre-feet (p. 91). This figure, therefore, is believed to represent a rough approximation of the minimum future yield of the underground reservoir.

If the assumption is true that there is little movement of water underground from the San Antonio area, it is clear that the unutilized water of the springs and artesian wells must be put to beneficial use if an additional demand for water supplies of large magnitude is to be met. It is practically impossible to predict the amount of salvage that can be accomplished. It is believed that the normal discharge of the springs has already been materially reduced by withdrawals from wells, as indicated by the fact that the artesian pressure remained low and the springs quiescent a large part of the time from 1926 to 1930, a period of about average rainfall. Further lowering of the artesian pressures will result in further reductions in the discharge of the springs. Probably not all the spring water can be salvaged, but a large part of it can be. If in the spring of 1935 the artesian water levels at San Antonio had been about 17 feet lower than they were, the springs would not have started to flow in response even to the unusually heavy rains of May and June. It is not impossible that the springs could be brought entirely under control by impounding water above them by means of a low dam at the extreme north end of Brackenridge Park. If this is done and the flow of the springs is stopped, the artesian pressure in the underground reservoir would be increased somewhat, and this might cause the water to escape to the surface somewhere else. The plan is believed to merit serious consideration, however, and it is recommended for careful study.

Quality of the water

The water from the Edwards limestone in the greater part of San Antonio and in the area to the northeast, north, and west is almost uniformly a calcium carbonate water of good quality, although somewhat hard. Most of the 43 Edwards limestone wells that were sampled in that area yield water having between 200 and 270 parts per million of hardness, and none yield water having more than 300 parts per million. As a rule the water contains less than 30 parts per million of sulphate and less than 20 parts per million of chloride. A few of the wells in that part of the area, however, representing only a small proportion of the Edwards wells, yield waters moderately high in calcium sulphate.

South of the fault that passes through the southern part of San Antonio the water from Edwards limestone wells is highly mineralized, containing at least 4,000 parts per million of dissolved solids. In this area the water contains large amounts of calcium and magnesium sulphate and sodium chloride. It is in general strongly impregnated with hydrogen sulphide and gives off a disagreeable odor. The line of demarcation between the normal Edwards water north of the fault and the highly mineralized water south of the fault is so sharp as to suggest that the fault retards free circulation of the water from the north to the south side and that this lack of circulation has been the chief cause of the high mineralization of the water south of the fault. The approximate location of the boundary between the normal and highly mineralized Edwards waters is shown on the map by the line DD'.

CONCLUSIONS

The springs and artesian wells of the San Antonio area have their source in a common reservoir in the Edwards limestone. This reservoir is fed by seepage from streams and by direct penetration of rainfall on the outcrop of the limestone along the Balcones escarpment, which crosses the northern parts of Bexar and Medina Counties and extends a long distance farther both east and west. Opportunities for ground-water recharge on this outcrop are exceptionally good. In many places on the outcrop the limestone is honeycombed or cavernous. Water in large quantities sinks into these openings to a water table and then moves down the dip under cover into the artesian reservoir. Recharge occurs during heavy rains by direct penetration and by seepage from storm-water run-off. Additional, practically continuous recharge is furnished by the numerous spring-fed streams of the Edwards Plateau that cross the outcrop. The reservoir, therefore, not only has its own storage facilities but also receives the benefits of the storage and regulation afforded by the underground reservoir system of the Edwards Plateau.

Water moves underground to the San Antonio area from areas of intake on the outcrop at least as far west as the Medina River and perhaps much farther west. It is believed that very little water escapes underground down the dip toward the Gulf. Some water probably moves out of the area toward the northeast along the strike of the formation and eventually appears in the Comal Springs, but the volume is believed to be relatively small. Accordingly, it is concluded that before the artesian wells were put down the San Antonio and San Pedro Springs were the only large outlets of the underground reservoir, and the average annual recharge to the reservoir was nearly balanced by the average annual discharge of the springs; also that since the well development began the discharge has been divided between the springs and artesian wells, and the flow of the springs has been lessened by an amount approximately equal to the withdrawals from wells. The wells are valuable in making the water supply more accessible where it is needed, but it is believed that they have not materially increased the average annual yield of the underground reservoir.

The relation between recharge of an artesian reservoir and discharge from it are indicated by the fluctuations in the artesian pressure. If water is coming into the reservoir faster than it is moving out the pressure rises. If the opposite is true, the pressure drops. If the draft on the reservoir is very heavy the decline in pressure is likely to be large, and if the safe limit of withdrawals is exceeded the decline is likely to continue persistently until the artesian wells stop flowing, and the water levels may finally drop so low that it is no longer practicable to pump.

The record of artesian pressures in the San Antonio area is reassuring, as it shows clearly that there has at no time been any long-continued overdraft approaching dangerous depletion. The community owes the security of its water supply to natural conditions -- (1) a large water supply; (2) a large underground reservoir; (3) an automatic control over the discharge of the springs afforded by the artesian pressures. Thus the flow of both groups of springs varies with the pressures, and the flow of the San Antonio Springs stops when the artesian head declines to about 668 feet with reference to sea level.

It is estimated that in the 20-year period from 1915 to 1935 the yield of the underground reservoir averaged about 120,000 acre-feet a year, or about 107,000,000 gallons a day. The artesian pressures were about as high in the summer of 1935 as in 1915, showing that there has been no material net decrease in the storage in the reservoir during this period. The average annual rainfall during the 20-year period was about equal to the 61-year mean. Therefore, it is reasonable to expect that unless the streams are regulated in a manner that will decrease recharge or unless the climate changes toward greater aridity, the reservoir will continue to yield about as much as it did between 1915 and 1935. If any considerable body of water is escaping from the San Antonio area to the Comal Springs, further well development will tend to divert this water from the springs and thereby to increase the future yield of the reservoir in the San Antonio area. If in the future power or irrigation projects are constructed that will provide for the elimination of the present large seepage losses into the Edwards reservoir from the streams that now contribute heavily to recharge, the yield of the underground reservoir in the San Antonio area will undoubtedly be greatly reduced.

If the draft from wells in the San Antonio area is materially increased, the artesian pressures will fall lower than heretofore, some of the flowing wells in the upper part of the basin will stop flowing, and the flow of the other wells will be reduced. Meanwhile, however, the discharge of the springs will be reduced, and the San Antonio Springs will be quiescent during longer periods than otherwise, and this reduction in spring flow will tend to conserve water that would otherwise go to waste, especially during high stages of the springs. Thus increased beneficial use of the water supply obtained from wells will to a great extent be balanced by the conservation at the springs. Waste from the flowing wells can be stopped if the wells are closed by a valve or cap when they are not in use.

The outstanding conclusions are, first, the underground water resources of the San Antonio area are very large; second, the withdrawals from the underground reservoir by wells can be materially increased with safety; third, without increasing the draft by wells, much more water can be put to beneficial use than now, if the waste is stopped and the water used with reasonable economy. It should be possible, for example, to irrigate an area several times the size of that now irrigated in the San Antonio district with the water that is now wasted in a variety of ways.

Well water is not considered wasted that is discharged into the San Antonio River to maintain an adequate flow at times when the San Antonio Springs do not flow or have a very small flow. It is unthinkable that the beauty of the river should not be perpetuated.

Table 1. - Estimated monthly ground-water discharge of San Antonio River at San Antonio, Tex., 1915 to 1934, in acre-feet

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1915	.....	5,720	6,520	9,700	10,700	8,330	10,500	13,600	8,090	7,130	6,070	5,780	98,000+
1916	5,700	4,890	4,630	5,600	5,750	5,130	4,880	5,220	4,970	5,090	4,820	4,980	61,660
1917	4,850	4,330	3,760	2,020	2,270	1,540	1,510	1,500	1,400	1,470	1,380	1,460	27,490
1918	1,440	1,270	1,290	1,370	1,390	810	880	880	830	660	540	550	11,910
1919	1,230	2,060	1,880	2,390	2,710	2,720	5,260	5,510	6,830	13,000	13,600	12,600	69,790
1920	15,000	12,400	12,500	10,800	10,200	9,400	8,790	8,220	7,320	7,270	6,840	6,820	115,560
1921	6,700	5,460	7,800	6,940	6,050	5,700	5,210	4,250	7,500	6,620	5,850	4,940	73,020
1922	4,610	3,530	3,830	6,010	6,070	6,600	5,430	4,730	4,040	3,650	4,260	4,480	57,240
1923	3,450	3,670	4,020	4,690	4,100	3,250	2,900	1,940	2,960	3,260	4,350	8,000	46,590
1924	8,100	7,600	9,800	9,900	11,100	11,700	10,200	8,110	7,230	7,020	5,580	5,540	101,880
1925	5,090	4,020	4,070	3,150	3,080	2,120	1,620	2,200	1,650	1,800	1,940	1,850	32,590
1926	2,100	1,850	2,340	4,260	7,800	5,430	4,040	2,840	2,200	2,150	2,110	2,250	39,370
1927	1,960	1,830	2,240	1,780	1,700	2,470	1,830	1,520	1,320	1,540	1,340	1,240	20,770
1928	1,310	990	1,210	1,160	1,500	1,030	940	1,000	960	1,000	850	760	12,710
1929	870	500	600	910	890	1,270	1,340	1,150	1,450	1,800	(*)	.....	**14,000
1930	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
1931	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
1932	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	4,570	4,700	......
1933	4,340	3,610	4,530	4,380	3,780	3,050	2,290	2,500	2,870	2,820	2,360	2,480	39,010
1934	2,800	3,170	4,580	4,220	2,560	1,190	1,270	1,730	1,070	1,090	990	**930	25,700

* Gaging station discontinued. ** Estimated.

Table 2. - Estimated monthly ground-water discharge of San Pedro Creek at gaging station on Commerce and Arsenal Streets, San Antonio, Tex., 1915 to 1934, in acre-feet

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1915	....	....	....	....	....	....	....	....	....	....	....	....	.....
1916	....	....	....	....	....	....	....	320	380	510	470	490	.....
1917	820	660	330	270	290	290	190	170	150	180	200	180	3,730
1918	230	250	270	180	250	230	210	180	180	180	220	110	2,490
1919	260	320	320	380	450	510	570	790	590	1,050	1,000	900	7,140
1920	730	790	810	860	830	660	600	600	510	680	700	560	8,330
1921	540	500	540	490	500	480	480	400	280	600	460	490	5,760
1922	480	490	450	520	610	600	570	510	460	460	500	470	6,120
1923	470	420	340	450	430	310	410	340	400	420	440	420	4,850
1924	524	480	700	920	1,260	1,000	700	670	590	360	510	460	8,174
1925	460	420	410	420	400	360	360	390	490	420	400	390	4,920
1926	430	420	470	580	880	630	570	460	480	420	400	370	6,110
1927	340	320	400	390	450	480	380	330	280	320	290	350	4,330
1928	310	300	280	270	320	360	270	170	170	200	170	200	3,020
1929	280	200	250	240	260	220	300	260	220	210	230	*230	2,900
1930	....	....	....	....	....	....	....	....	....	....	....	....	.....
1931	....	....	....	....	....	....	....	....	....	....	....	....	.....
1932	....	....	....	....	....	....	....	....	....	....	450	470	.....
1933	450	420	480	560	560	300	380	320	310	330	400	380	4,890
1934	460	420	440	360	390	300	310	320	250	280	270	*270	4,070

* Estimated.

Table 3. - Monthly discharge of San Antonio River at Josephine Street gaging station, San Antonio, Tex., April 1933 to November 1934, in acre-feet

Month	Total	Storm water	Ground water	Month	Total	Storm water	Ground water
1933				1934			
April	3,530	.....	3,530	January	1,720	280	1,440
May	2,800	.....	2,800	February	1,700	.....	1,700
June	2,420	.....	2,420	March	2,420	230	2,190
July	1,670	70	1,600	April	3,340	630	2,710
August	1,640	50	1,590	May	1,700	.....	1,700
September	1,780	20	1,760	June	494	.....	494
October	1,520	.....	1,520	July	547	140	407
November	1,110	.....	1,110	August	486	.....	486
December	1,250	.....	1,250	September	292	.....	292
				October	307	.....	307
				November	280	20	260

Table 4. - Average quantities of water delivered by the city of San Antonio, 1925-1934, in millions of gallons a day

[1 million gallons a day = about 3.07 acre-feet a day = about 1.55 second-feet]

Month	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
January	....	19.7	20.9	20.0	18.2	19.9	17.7	16.9	16.7	17.0
February	....	23.7	22.1	19.5	20.8	20.6	18.9	18.9	19.8	19.0
March	....	19.2	19.3	18.0	17.4	16.2	16.3	18.2	16.7	16.9
April	....	20.7	25.2	22.6	21.1	21.8	19.5	24.2	21.8	20.2
May	....	20.8	26.4	21.0	22.8	19.9	21.5	20.0	25.1	21.5
June	31.6	25.8	25.7	24.2	27.3	25.9	28.1	26.4	26.9	33.5
July	31.2	24.1	27.7	28.2	22.1	27.4	24.2	23.8	30.2	31.6
August	29.5	29.1	34.3	30.8	30.8	32.0	28.2	25.9	23.3	24.9
September	24.7	28.6	28.7	23.7	26.8	27.9	31.9	21.1	22.7	25.2
October	22.0	23.6	22.8	21.5	20.9	19.3	25.4	17.9	19.6	....
November	20.8	22.3	24.4	19.0	18.3	19.0	21.9	18.6	19.2	....
December	20.4	20.4	19.5	18.7	17.2	17.2	16.6	16.3	18.1	....
Average	....	23.1	24.7	22.3	22.0	22.3	22.5	20.7	21.7	....

Table 5. - Discharge of flowing wells on the Government reservation on Salado Creek near Fort Sam Houston, Tex., in second-feet

Date	Government-owned wells (2 wells)	Salado Water Co.'s well	Date	Government-owned wells (2 wells)	Salado Water Co.'s well
May 8, 1919	11.9	9.1	Oct. 23, 1933	12.4	12.3
Nov. 14, 1932	8.7	11.4	May 7, 1934	10.7	10.1
Dec. 5, 1932	8.8	11.6	June 25, 1934	10.6	11.3
Jan. 14, 1933	....	12.4	Aug. 28, 1934	12.8	11.1
Apr. 14, 1933	9.5	11.3	Oct. 29, 1934	9.6	12.6
May 20, 1933	3.7	10.2	July 1, 1935	....	*24.4
July 17, 1933	6.8	14.4			

* Combined discharge of 3 wells.

Table 6. - Altitude, in feet above sea level, of artesian-water surface (1934) used in drawing curves in figure 9

Well No.	Owner	Distance from courthouse (miles)	Apr. 20	May 23	June 21	July 31	Aug. 24	Sept. 21	Oct. 11
1	Fritz Weiblen	20.7 SW.	699.07	696.09	693.56	693.95	691.27	690.24	690.08
2	Robert Mechler	17.7 SW.	692.67	689.38	686.90	687.77	684.87	684.05	684.24
3	Fuller's earth plant	13.4 SW.	685.93	682.28	679.75	680.88	677.71	677.02	676.39
4	A. J. Vogt	12.0 SW.	686.13	682.46	680.10	681.44	678.34	677.79	677.18
5	Robert Boenig	8.0 SW.	683.62	679.82	677.56	679.09	675.82	675.40	674.81
6	Lake View Addition	4.5 SW.	678.21	675.49	672.93	......	671.48	671.09	670.49
7	Unknown	2.6 SW.	676.71	674.25	671.65	......	670.41	669.96	669.43
8	R. Keilman	0.6 SW.	674.69	671.51	688.91	669.59	667.88	667.56	667.02
9	Sunset Wood & Coal Co.	1.0 NE.	673.07	669.48	667.33	668.28	665.98	666.25	665.78
10	Southern Ice Co.	2.0 NE.	673.96	670.79	668.31	668.88	666.92	666.87	667.18
11	John Eisenhauer	12.1 NE.	673.47	672.01	670.03	669.78	668.95	668.07	667.62
12	H. H. Classen	13.5 NE.	674.11	673.45	671.89	671.02	670.83	669.65	669.25

Table 7. - Water levels in observation wells in the San Antonio area, Tex., in feet above or below measuring point

(Owner, distance and direction of well from county courthouse at San Antonio, and description and altitude of measuring point.)

Westmoorland College; 3½ miles NW.; top of casing, 715.94 feet.

1933	
Aug. 25	-40.57
Sept.18	-40.30
Oct. 12	-40.88
Nov. 20	-40.98
Dec. 18	-41.08
1934	
Jan. 18	-40.89
Feb. 19	-40.23
Mar. 19	-39.59
Apr. 18	-38.98
May 21	-40.50
June 19	-43.59
July 30	-42.34

J. H. Landa; 4½ miles NW.; top of pipe clamp, 773.09 feet.

1932	
Oct. 29	-94.77
1933	
Apr. 9	-94.44
July 18	-98.00
Aug. 17	-98.42
Sept.18	-98.19
Oct. 17	-98.55
Nov. 20	-98.70
Dec. 18	-99.00
1934	
Jan. 18	-98.58
Feb. 19	-98.23
Mar. 19	-97.34
Apr. 18	-96.0
May 21	-98.3
June 19	-100.75
July 27	-101.11
Aug. 22	-102.36
Oct. 12	-103.84
Nov. 20	-103.39
Dec. 19	-103.39
1935	
Jan. 31	-103.08
Mar. 1	-102.85
Apr. 8	-103.74
May 20	-93.25
June 26	-82.05

Davis Heights Addition; 4 miles N.; top of pipe clamp at ground level, 761.46 feet.

1933	
Aug. 24	-86.75
Sept.18	-86.20
Oct. 17	-86.77
Nov. 20	-86.88
Dec. 18	-86.95
1934	
Feb. 19	-86.21
Mar. 19	-85.40
Apr. 18	-84.74
June 19	-89.37
Aug. 22	-90.90
Sept.19	-91.40
Oct. 12	-92.02
Oct. 25	-92.50
Nov. 20	-91.45
Dec. 19	-91.43
1935	
Jan. 31	-91.37
Mar. 1	-90.98
Apr. 8	-91.84
May 20	-81.69
June 26	-70.60

Mrs. Mattke; 3 miles N.; top of pipe clamp at ground level, 773.89 feet.

1933	
Aug. 24	-101.5
Sept.18	-100.89
Oct. 17	-101.49
Nov. 20	-101.48
Dec. 18	-101.46

Mrs. Mattke - Cont'd.

1934	
Jan. 18	-101.33
Feb. 19	-100.90
Mar. 19	-100.20
Apr. 19	-99.22
June 19	-104.12
July 27	-103.86
Aug. 22	-105.54
Sept.19	-105.81
Oct. 12	-106.42
Oct. 25	-106.72
Nov. 19	-105.69
Dec. 19	-105.44
1935	
Jan. 31	-105.41
Apr. 8	-105.92
May 19	-97.75
June 26	-89.38

Amos Lorenz; 5½ miles NNE.; top of pipe clamp, 821.16 feet.

1932	
July 19	-151.75
Oct. 19	-146.00
1933	
July 17	-149.55
Aug. 18	-149.38
Sept.19	-149.04
Oct. 18	-149.78
Nov. 21	-149.76
Dec. 20	-149.73
1934	
Jan. 19	-149.38
Feb. 20	-149.05
Apr. 19	-147.38
June 20	-152.31
Aug. 23	-153.68
Sept.20	-154.01
Oct. 10	-154.4
Nov. 20	-153.9
Dec. 19	-153.92
1935	
Feb. 4	-153.67
Mar. 1	-153.26
Apr. 8	-154.15
May 19	-145.65
June 26	-135.85

D. T. Atkinson; 5 miles NNE.; top of casing 4 inches above ground, 803.54 feet.

1932	
July 20	-132.07
Oct. 19	-128.60
1933	
Jan. 23	-128.49
Apr. 10	-129.20
July 17	-132.13
Aug. 18	-132.00
Sept.19	-131.61
Oct. 18	-132.31
Nov. 21	-132.32
Dec. 20	-132.31
1934	
Jan. 19	-132.00
Feb. 20	-131.60
Mar. 20	-130.92
Apr. 19	-130.13
May 22	-132.58
June 20	-134.89
July 27	-134.83
Aug. 23	-136.24
Sept.20	-136.55
Oct. 12	-137.20
Oct. 25	-137.51
Nov. 19	-136.56
Dec. 20	-136.39
1935	
Jan. 31	-136.22
Mar. 1	-135.83
Apr. 8	-136.70
May 19	-128.63
June 26	-118.78

Southern Ice Co.; 2 miles ENE.; top of concrete base at ground level, 710.34 feet.

1933	
Aug. 7	-38.76
Sept.19	-37.79
Oct. 18	-38.95
Nov. 21	-38.68
Dec. 20	-38.70
1934	
Jan. 20	-38.64
Feb. 20	-37.95
Mar. 20	-37.74
Apr. 19	-36.38
May 22	-39.55
June 20	-42.03
July 27	-41.46
Aug. 23	-43.42
Sept.20	-43.47
Oct. 8	-43.16
Oct. 25	-44.33
Nov. 19	-43.11
Dec. 20	-42.76
1935	
Jan. 31	-42.85
Mar. 1	-42.42
Apr. 8	-43.28
May 19	-34.73
June 27	-26.24

Sunset Wood & Coal Co.; 1 mile ENE.; top of valve 38 inches above ground level, 678.40 feet.

1933	
Aug. 4	-7.99
Sept.18	-6.77
Oct. 18	-7.87
Nov. 21	-7.84
Dec. 20	-6.67
1934	
Jan. 18	-7.11
Feb. 20	-6.16
Mar. 20	-5.54
Apr. 19	-5.33
May 22	-8.92
June 20	-11.07
July 27	-10.12
Aug. 22	-12.42
Sept.19	-12.15
Oct. 12	-12.62
Oct. 25	-12.74
Nov. 19	-11.53
Dec. 20	-11.31
1935	
Jan. 31	-11.20
Mar. 1	-10.64
Apr. 8	-11.68
May 19	-3.26
June 27	Flows

Moore Building; ¼ mile NE.; top of horizontal pipe 16 inches above floor at well, 645.66 feet.

1933	
July 26	+25.4
Sept.19	+27.9
Oct. 18	+23.9
Nov. 21	+26.6
Dec. 20	+26.6
1934	
Jan. 18	+27.2
Feb. 20	+26.8
Mar. 20	+27.9
Apr. 19	+28.2
May 22	+25.4
June 20	+22.4
July 27	+24.3
Aug. 22	+21.5
Sept.19	+21.7
Oct. 12	+21.7
Oct. 25	+21.9
Nov. 19	+22.6
Dec. 20	+21.4

Moore Building - Cont'd.

1935	
Jan. 31	+23.1
Mar. 1	+23.3
Apr. 9	+22.9
May 21	+31.2
June 27	+39.3

R. Keilman; 1 mile NW.; top of 6-inch standpipe 60 inches above ground, 672.11 feet.

1933	
Aug. 1	+.75
Sept.18	+1.29
Nov. 20	+.25
Dec. 18	+.36
1934	
Jan. 18	+.69
Feb. 19	+.93
Mar. 19	+1.36
Apr. 19	+2.58
May 21	-.60
June 19	-3.20
July 27	-2.52
Aug. 22	-4.23
Sept.19	-4.55
Oct. 11	-5.09
Oct. 25	-5.95
Nov. 19	-4.36
Dec. 20	-3.90
1935	
Jan. 31	-3.75
Mar. 1	-3.50
Apr. 8	-4.08
May 21	+4.00
June 27	+12.75

Mrs. L. M. Hubble; 2 miles WNW.; top of 1½-inch plug 22 inches above ground, 665.23 feet.

1932	
July 21	+9.5
Oct. 18	+14.1
Nov. 18	+13.0
1933	
Apr. 9	+11.8
July 18	+9.0
Aug. 17	+9.2
Sept.18	+9.2
Oct. 17	+8.8
Nov. 20	+8.6
Dec. 20	+8.6
1934	
Jan. 18	+9.0
Feb. 19	+9.4
Apr. 19	+10.8
May 21	+8.5
June 19	+5.9
July 27	+7.2
Aug. 22	+4.48
Sept.19	+4.25
Oct. 11	+3.71
Oct. 25	+3.25
Nov. 19	+4.40
Dec. 20	+4.51
1935	
Jan. 31	+4.58
Feb. 28	+4.80
Apr. 8	+4.10
May 20	+12.45
June 27	+23.6

Unknown; 3 miles WNW.; top of 1-inch pipe about 1.5 feet above ground, 677.60 feet.

1933	
Jan.	Flow
Apr. 8	-.07
July 18	-3.05
Aug. 17	-2.88
Sept.18	-2.60
Oct. 17	-3.34
Nov. 20	-3.35
Dec. 20	-3.40

Unknown - Cont'd.

1934	
Jan. 18	-3.25
Feb. 19	-2.74
Mar. 19	-2.06
Apr. 19	-0.89
May 21	-3.35
June 19	-5.95
July 27	-4.88
Aug. 22	-7.19
Sept.19	-7.64
Oct. 11	-8.17
Oct. 25	-8.73
Nov. 19	-7.92
Dec. 20	-7.59
1935	
Jan. 31	-7.36
Feb. 28	-7.28
Apr. 8	-8.16
May 20	+0.25
June 27	+10.50

Lakeview Addition; 4⅛ miles W.; top of pump base 1 foot above ground, 711.26 feet.

1933	
Aug. 25	-34.90
Sept.18	-34.61
Oct. 17	-35.35
Dec. 20	-35.55
1934	
Jan. 18	-35.42
Feb. 19	-34.94
Mar. 19	-34.18
Apr. 19	-33.05
May 21	-35.77
June 19	-38.33
Aug. 22	-39.78
Sept.19	-40.17
Oct. 11	-40.77
Oct. 25	-41.28
Nov. 19	-40.21
Dec. 20	-40.10
1935	
Feb. 1	-40.17
Feb. 28	-39.78
Apr. 9	-40.44
May 21	-31.04
June 28	-21.18

N. H. White; 2½ miles SW.; packing box on valve 6 inches above ground, 652.53 feet.

1933	
Sept.15	+21.0
Oct. 18	+21.5
Nov. 20	+22.5
Dec. 20	+23.1
1934	
Jan. 18	+21.9
Feb. 19	+21.9
Mar. 19	+22.4
Apr. 19	+23.3
May 21	+19.2
June 19	+18.0
July 27	+19.2
Aug. 22	+16.4
Sept.19	+16.4
Oct. 9	+16.6
Oct. 25	+15.7
Nov. 19	+17.5
Dec. 20	+17.8
1935	
Jan. 31	+16.9
Feb. 28	+18.7
Apr. 8	+18.0
May 21	+26.7
June 27	+35.0

School Board of San Antonio; 3½ miles S.; top of concrete cap on well, 622.57 feet.

1933	
Aug. 21	+38.1
Sept.19	+39.0
Oct. 18	+38.4
Nov. 20	+37.8
Dec. 20	+37.6
1934	
Jan. 18	+37.6
Feb. 19	+38.0
Mar. 19	+39.0
Apr. 19	+39.0
May 21	+37.7

School Board - Cont'd.

1934	
June 19	+35.6
July 27	+33.7
Aug. 22	+33.7
Sept.19	+33.7
Oct. 9	+33.5
Oct. 25	+32.8
Nov. 19	+34.0
Dec. 20	+33.0
1935	
Feb. 1	+33.6
Feb. 28	+33.8
Apr. 10	+34.0
May 21	+37.0
June 27	+47.8

San Antonio & Aransas Pass R. R. roundhouse; 1½ miles S.; top of 8-inch cross at top of casing, 2½ feet above ground, 629.55 feet.

1933	
Aug. 2	+45.0
Sept.18	+45.2
Oct. 18	+45.2
Nov. 20	+44.6
Dec. 20	+44.5
1934	
Jan. 18	+44.6
Feb. 19	+45.2
Mar. 19	+46.2
Apr. 19	+46.7
May 21	+44.1
June 19	+41.1
July 27	+42.3
Aug. 22	+39.8
Sept.19	+39.5
Oct. 9	+39.9
Oct. 25	+38.8
1935	
Apr. 10	+40.2
May 21	+49.5
June 27	+58.5

Robert Boenig; 8 miles W.; top of clamp about 1 foot above ground, 745.45 feet.

1933	
Sept.20	-63.30
1934	
Jan. 4	-64.65
Apr. 20	-61.83
May 23	-65.63
June 21	-67.89
July 31	-66.36
Aug. 24	-69.63
Sept.21	-70.05
Oct. 11	-70.64
Oct. 12	-70.90
Nov. 20	-70.10
Dec. 21	-70.29
1935	
Feb. 3	-70.14
Mar. 2	-69.92
Apr. 9	-70.74
May 21	-61.26
June 28	-49.13

A. J. Vogt; 12 miles W.; top of clamp 1 foot above ground, 765.97 feet.

1933	
Sept.15	-81.70
1934	
Jan. 4	-82.60
Apr. 20	-79.84
May 23	-83.51
June 21	-85.87
July 31	-84.53
Aug. 24	-87.63
Sept.21	-88.18
Oct. 11	-88.79
Nov. 20	-88.26
Dec. 21	-88.58
1935	
Feb. 3	-88.40
Mar. 2	-88.31
Apr. 9	-89.08
May 21	-79.25
June 28	-66.56

Fuller's earth plant; 14 miles WSW.; top of concrete pump base 2 feet above ground, 790.15 feet.

1933	
Sept.15	-105.20
1934	
Jan. 4	-106.67
Apr. 20	-104.22
May 23	-107.87
June 21	-110.40
July 31	-109.27
Aug. 24	-112.44
Sept.21	-113.13
Oct. 11	-113.76
Nov. 20	-113.28
Dec. 21	-113.70
1935	
Feb. 3	-113.68
Mar. 2	-113.52
Apr. 9	-114.28
May 21	-104.50
June 28	-91.68

Robert Mechler; 18 miles WSW.; top of clamp 1½ feet above ground, 810.64 feet.

1933	
Sept.15	-118.34
1934	
Jan. 4	-120.11
Apr. 20	-117.97
May 23	-121.26
June 21	-123.74
July 31	-122.87
Aug. 24	-125.77
Sept.21	-126.59
Oct. 9	-126.40
Nov. 21	-127.05
Dec. 21	-127.47
1935	
Feb. 3	-127.58
Mar. 2	-127.50
Apr. 9	-128.37
May 21	-118.84
June 28	-103.86

Fritz Weiblen; 21 miles W.; top of clamp 6 inches above ground, 797.33 feet.

1930	
Feb. 19	-119.50
1934	
Jan. 4	-99.81
Apr. 20	-98.26
May 23	-101.24
June 21	-103.77
July 31	-103.38
Aug. 24	-106.06
Sept.21	-107.09
Oct. 9	-107.25
Nov. 21	-107.97
Dec. 21	-108.55
1935	
Feb. 3	-108.63
Mar. 2	-108.73
Apr. 9	-109.35
June 28	-83.78

G. A. Kuentz; 13 miles WNW.; top of pipe clamp 6 inches above ground, 849.02 feet.

1933	
Sept.21	-158.23
1934	
Jan. 9	-160.66
Apr. 20	-153.87
May 23	-158.97
June 21	-161.88
July 31	-160.49
Aug. 24	-163.80
Sept.21	-165.14
Oct. 11	-165.66
Dec. 21	-168.16
1935	
Feb. 4	-166.36
Mar. 2	-165.90
Apr. 9	-166.50
May 21	-150.35
June 28	-133.58

Wm. Edgar; 26 miles WSW.; top of pipe clamp at ground level, 851.78 feet.

1934	
Jan. 5	-166.80
May 23	-168.43
June 21	-170.75
July 31	-170.31
Sept.21	-174.05

J. C. Stinson; 24 miles W.; top of pipe clamp 2 feet above ground, 847.42 feet.

1934	
Jan. 8	-146.24
Apr. 20	-143.99
May 23	-146.92
June 21	-149.55
July 31	-149.31
Aug. 24	-151.96
Sept.21	-153.43
Oct. 8	-153.50
Nov. 21	-154.57
Dec. 21	-155.32
1935	
Feb. 3	-155.38
Mar. 2	-155.55
Apr. 9	-156.44
May 21	-146.48
June 28	-128.72

Alfred Bourquin; 22 miles WNW.; top of pipe clamp about 2 feet above ground, 928.78 feet.

1934	
Jan. 9	-174.73
Apr. 20	-163.62
May 23	-172.40
June 21	-176.59
July 31	-169.26
Aug. 24	-180.77
Sept.21	-184.27
Oct. 10	-185.83
Nov. 20	-188.7
1935	
Feb. 3	-192.72
Feb. 4	-192.78
Mar. 2	-196.30
Apr. 9	-194.02
May 21	-160.25
June 28	-128.42

Mrs. Kate Benke; 20 miles WNW.; top of pipe clamp 6 inches above ground, 1,044.64 feet.

1933	
Sept.22	-287.40
1934	
May 23	-287.21
June 21	-292.65
July 31	-280.09
Aug. 24	-296.96
Sept.21	-300.71
Oct. 10	-302.55
Dec. 21	-303.77
1935	
Feb. 3	-309.52
Feb. 4	-309.56
Apr. 9	-310.26
May 21	-255.27
June 28	-219.52

R. W. Barham; 16 miles NW.; hole in pump base at ground level, 1,050.33 feet.

1934	
Mar. 19	-78.00
Apr. 18	-76.20
May 21	-77.74
June 19	-77.76
July 30	-75.92
Aug. 22	-78.20
Sept.19	-78.24
Oct. 12	-78.26

R. W. Barham - Cont'd.

1934	
Nov. 20	-77.93
Dec. 19	-78.04
1935	
Feb. 2	-78.00
Feb. 28	-77.73
Apr. 10	-77.39
May 20	-65.83
June 28	-71.11

A. L. Fuller; 16 miles NW.; top of pipe clamp 1 foot above ground, 1,043.81 feet.

1933	
Sept.27	-162.72
1934	
Jan. 19	-171.40
Feb. 19	-164.77
Mar. 1	-167.65
Mar. 19	-176.6
Apr. 18	-168.40
May 21	-168.0
June 19	-193.+
July 30	-166.32
Oct. 12	-169.86
Dec. 19	-170.19
1935	
Feb. 2	-172.15
Apr. 10	-172.80
May 20	-69.74
June 28	-134.05

Theo. Biering; 15 miles NW.; top of pipe clamp, 987.74 feet.

1932	
Oct. 18	-262.7
Nov. 18	-263.00
1933	
Jan. 15	-265. ?
Apr. 9	-264.2
July 18	-269.42
Aug. 17	-271.2
Sept.18	-272.93
Oct. 17	-274.29
Nov. 20	-275.62
Dec. 18	-277.04
1934	
Jan. 19	-277.82
Feb. 19	-277.58
Apr. 18	-274.00
May 21	-271.51
June 19	-272.56
July 30	-273.85
Sept.19	-276.95
Oct. 13	-278.32
Nov. 20	-280.24
Dec. 19	-282.13
1935	
Feb. 2	-282.78
Apr. 10	-283.56
May 20	-278.83

Ben Biering; 14 miles NW.; top of casing, 969.04 feet.

1932	
Oct. 18	-245.9
Nov. 18	-246.65
1933	
Jan. 15	-247.95
Apr. 9	-247.81
July 18	-253.37
Sept.18	-256.79
Oct. 17	-257.98
Nov. 20	-259.32
Dec. 18	-260.66
1934	
Jan. 19	-261.57
Feb. 19	-260.96
Mar. 19	-259.56
Apr. 18	-256.75
May 21	-254.15
June 19	-256.05
July 30	-257.88
Aug. 22	-259.02
Sept.19	-261.01
Oct. 13	-262.23
Nov. 20	-264.09
Dec. 19	-265.90
1935	
Feb. 2	-266.53
Feb. 28	-266.12
Apr. 10	-266.94
June 28	-230.10

Adolf Benke; 12½ miles N W.; top of pipe clamp, 907.33 feet.

1932	
July 21	-205.2
Oct. 18	-201.15
Nov. 18	-201.48
1933	
Apr. 9	-201.56
July 18	-205.43
Aug. 17	-206.68
Sept.18	-207.64
Oct. 17	-208.23
Nov. 20	-209.31
Dec. 18	-210.23
1934	
Jan. 19	-210.82
Feb. 19	-210.08
Mar. 19	-208.98
Apr. 18	-207.52
May 21	-206.45
June 19	-208.04
July 30	-210.04
Aug. 22	-210.33
Sept.19	-212.00
Oct. 11	-213.
Nov. 20	-214.55
Dec. 19	-215.49
1935	
Feb. 2	-215.86
Feb. 28	-215.69
Apr. 10	-216.40
May 20	-212.00
June 28	-188.62

George Calvert; 9½ miles NW.; top of pipe clamp, 876.57 feet.

1932	
July 21	-191.3
Oct. 18	-185.9
Nov. 18	-186.71
1933	
Apr. 9	-187.0
July 18	-191.17
Aug. 17	-191.51
Sept.18	-191.65
Oct. 17	-192.23
Nov. 20	-192.65
Dec. 18	-193.03
1934	
Jan. 19	-192.65
Feb. 19	-192.04
Mar. 19	-190.96
Apr. 18	-189.76
May 21	-191.84
June 19	-194.61
July 30	-193.61
Aug. 22	-196.39
Sept.19	-197.54
Nov. 20	-198.14
Dec. 19	-198.51
1935	
Feb. 2	-198.39
Feb. 28	-198.05
Apr. 10	-198.70
May 20	-182.90
June 28	-171.28

Alfred Reininger; 8 miles NW.; top of pipe clamp, 892.13 feet.

1932	
July 21	-213.10
Oct. 18	-208.27
Nov. 18	-208.84
1933	
Jan. 15	-208.55
Apr. 9	-209.30
July 18	-213.04
Aug. 17	-213.08
Sept.18	-212.98
Oct. 17	-213.60
Nov. 20	-213.85
Dec. 18	-214.04
1934	
Jan. 19	-213.59
Feb. 19	-213.19
Mar. 19	-212.15
Apr. 18	-211.36
May 21	-213.56
June 19	-216.24
July 30	-215.15
Aug. 22	-217.88
Sept.19	-218.67
Oct. 12	-219.39
Nov. 20	-218.93
Dec. 19	-219.01

Alfred Reininger - Cont'd.

1935	
Feb. 2	-218.98
Apr. 10	-219.42
May 20	-207.84
June 28	-196.32

F. A. Fitch; 6½ miles NW.; top of pipe clamp, 881.83 feet.

1932	
July 21	-203.85
Oct. 18	-199.45
Nov. 18	-199.97
1933	
Jan. 15	-199.70
Apr. 8	-200.50
July 18	-204.06
Aug. 17	-204.00
Sept.18	-203.89
Oct. 17	-204.50
Nov. 20	-204.72
Dec. 18	-204.86
1934	
Jan. 19	-204.45
Feb. 19	-204.05
Mar. 19	-203.15
Apr. 18	-202.42
May 21	-204.55
June 19	-207.29
July 30	-206.12
Aug. 22	-208.72
Sept.19	-209.45
Oct. 12	-210.18
Nov. 20	-209.60
Dec. 19	-209.75
1935	
Feb. 2	-209.58
Feb. 28	-209.22
Apr. 10	-210.02
May 20	-199.40
June 28	-187.85

Ed Haag; 7 miles N.; top of pipe clamp about 6 inches above ground, 782.81 feet.

1933	
Sept.29	-109.77
1934	
Feb. 20	-109.99
Mar. 20	-109.24
Apr. 19	-108.34
May 22	-110.80
June 20	-112.89
Aug. 23	-114.76
Sept.20	-115.00
Oct. 11	-115.4
Nov. 20	-114.94
Dec. 19	-115.00
1935	
Feb. 4	-114.70
Mar. 1	-114.36
Apr. 10	-115.18
May 20	-105.00
June 26	-93.87

Albert Theis; 10½ miles NNE.; top of casing about 1 foot above ground, 821.57 feet.

1933	
Oct. 2	-138.81
Oct. 18	-139.68
Nov. 21	-139.92
Dec. 20	-140.77
1934	
Jan. 19	-140.49
Feb. 20	-137.57
Mar. 20	-136.43
Apr. 19	-135.51
May 22	-134.51
June 20	-137.2
July 30	-137.66
Aug. 23	-139.84
Sept.20	-140.24
Oct. 10	-140.15
Nov. 20	-139.15
Dec. 19	-142.47
1935	
Feb. 4	-139.30
Mar. 1	-135.75
Apr. 10	-137.30
May 20	-124.84
June 26	-108.00

John Eisenhauer; 12 miles NNE.; top of casing, 874.82 feet.

1932	
July 20	-202.64
Oct. 19	-200.55
1933	
Jan. 16	-200.18
Apr. 10	-200.56
July 17	-203.68
Aug. 18	-203.33
Oct. 18	-203.58
Nov. 21	-203.89
Dec. 20	-204.00
1934	
Jan. 19	-203.83
Feb. 20	-202.98
Mar. 20	-201.81
Apr. 19	-201.35
May 22	-202.81
June 20	-204.79
July 30	-205.04
Aug. 23	-205.87
Sept.20	-206.75
Oct. 10	-207.20
Nov. 20	-207.37
Dec. 19	-207.42
1935	
Feb. 4	-206.81
Apr. 10	-207.63
May 20	-200.68

H. H. Classen; 13 miles NNE.; top of pipe clamp, 908.65 feet.

1932	
July 20	-235.08
Oct. 19	-233.4
1933	
Jan. 16	-233.38
July 17	-235.68
Sept.19	-236.28
Nov. 21	-236.77
Dec. 20	-237.04
1934	
Jan. 19	-237.17
Feb. 20	-235.88
Mar. 20	-234.57
Apr. 19	-234.54
May 22	-235.20
June 20	-236.76
July 30	-237.63
Aug. 23	-237.82
Sept.20	-239.00
Oct. 10	-239.40
Nov. 20	-240.00
1935	
Feb. 2	-239.48
Mar. 1	-238.62
Apr. 10	-239.18
June 26	-224.25

I. G. Yates; 14 miles NNE.; top of casing, 949.22 feet.

1932	
July 20	-260.0
Oct. 19	-261.5
1933	
Apr. 10	-262.95
July 17	-263.42
Aug. 18	-262.40
Oct. 18	-263.64
Nov. 21	-263.75
Dec. 20	-263.95
1934	
May 22	-260.7

Pruitt and others; 15 miles SW.; top of valve about 4 feet above ground, 594.12 feet.

1933	
Aug. 26	+93.5
Oct. 20	+93.3
1934	
May 22	+91.2
Oct. 10	+87.7

Southern Pacific Railroad; 21 miles WSW.; top of pipe, 725.49 feet.

1930	
Feb. 19	-50.50
1934	
Jan. 5	-33.21
June 28	-37.45
Aug. 31	-39.66
Oct. 9	-39.73

Ed Bacon; 13 miles NNW.; top of casing 1 foot above ground, 1,004.92 feet.

1933	
Dec. 22	-289.08
1934	
Mar. 2	-289.50
Oct. 12	-292.68
1935	
Mar. 1	-292.28

A. A. Rothe; 4½ miles ENE.; top of clamp 1.6 feet above ground, 678.07 feet.

1932	
Nov. 13	-1.88
1934	
Feb. 7	-4.81
Oct. 8	-10.31