BULLETIN 5412

GROUND-WATER RESOURCES OF THE SAN ANTONIO AREA, TEXAS

A PROGRESS REPORT OF CURRENT STUDIES

By

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Prepared in cooperation with the Geological Survey,
United States Department of the Interior
and the
City of San Antonio

August 1954

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ABSTRACT

This progress report gives a summarized description of the ground-water resources of the San Antonio area in south-central Texas, with particular attention to the Edwards limestone aquifer. The purpose of the study is to determine the sources of the water in the aquifer which supplies several thousand wells and several large springs including Comal Springs (the largest in the southwest), and to determine as accurately as possible the perennial yield of the aquifer. The Edwards limestone aquifer is defined to include, in addition to the Edwards limestone itself, the overlying Georgetown limestone and the underlying Comanche Peak limestone, because they are comparatively thin and no confining beds separate the limestones. The area of study, covering about 6,000 square miles, takes in Bexar, Medina, Uvalde, and Bandera Counties and parts of Real, Kerr, Kendall, Comal, Zavala, Frio, and Wilson Counties.

In the Cretaceous system besides the Edwards limestone aquifer, the main water-bearing formation is the Glen Rose limestone - both are a part of the Comanche series which here has a maximum thickness of about 2,300 feet. The Gulf series, ranging from about 500 to 1,500 feet in thickness, yields very little water but helps serve as a confining layer to maintain pressures in the deeper artesian reservoir. The most productive part of the Edwards limestone aquifer lies within the main Balcones fault zone which extends in a westerly direction completely across the central part of the San Antonio area. Here the artesian water circulates freely along fractures, including faults, and in secondary caverns formed by solution. Wells within this belt commonly yield 500 to 3,000 gallons a minute or more each. Large flows have been encountered in wells drilled along the southern part of this belt in and near San Antonio. Many faults with displacements ranging from a few feet to nearly 1,000 feet, cross the area in an easterly or northeasterly direction. They are normal faults, with the downthrow usually to the south or southeast, and are roughly parallel. The direction of movement of ground water is largely controlled by the larger faults.

The studies prove rather conclusively that the main recharge areas for water in the Edwards limestone aquifer are in northwestern Bexar and northern Medina and Uvalde Counties, especially where streams flow across long stretches of honeycombed or cavernous limestone. The volume of water in storage varies considerably in response to heavy rainfall or droughts; however, over long periods of time, the perennial yield of the Edwards artesian reservoir in the San Antonio-Comal Springs localities is on the order of 320 to 330 million gallons a day. Unless the streams

that furnish important recharge are regulated or unless there is a persistent trend toward greater aridity, the reservoir probably will continue to yield about this amount of water. Evidence presented shows a flattening of the artesian-pressure surface around San Antonio, which probably reflects local withdrawals by wells and increased permeability of the aquifer. At San Antonio the maximum water-level decline below the "spillway level" provided by San Pedro Springs has been about 35 feet. The decline in the artesian-pressure surface at San Antonio has resulted in increased beneficial use of a large volume of water that otherwise would flow to waste from uncontrolled wells.

The water from the large springs and wells throughout the main fault-zone reservoir is moderately hard but of generally good quality. South of the main Balcones fault zone the water is highly mineralized and generally contains hydrogen sulfide. The two types of water come from a common reservoir, but from portions of it that differ in permeability and vigor of circulation.

The Carrizo sand of Tertiary age crops out across the southern part of the San Antonio area. It stores a large volume of excellent water and contains potential supplies on the order of half a million to a million gallons a day or more per well. Some of this water, however, is committed to important irrigation districts down the dip in Atascosa County. The Leona formation of Pleistocene age yields water to many wells for irrigation in northeastern Zavala County, and in southern Medina County several wells have been developed in sands of the Wilcox group for irrigation.

Maps are presented indicating the water-yielding characteristics of the important aquifers in the San Antonio area and water levels in the Edwards limestone aquifer, and hydrographs showing the fluctuation of water levels from 1931 to 1953. One hydrograph shows the close relation between the discharge of Comal Springs, the water level in a representative artesian well, and the precipitation at a representative U. S. Weather Bureau station.

PURPOSE AND SCOPE OF THE INVESTIGATION

In the San Antonio area, Texas, ground-water usage has more than doubled during the past 15 years. Because the ground water is a resource vital both to industrial and agricultural development and to a high standard of living, the demand for ground water continues to increase. In fact, the availability of ground water is becoming one of the most critical factors in the continuing development of many areas in this Nation, especially in centers of rapid industrial and military expansion such as the San Antonio area.

The San Antonio Water Board took particular note of these expansions during and immediately after World War II, and very soon recognized the importance of ground water to the progress of the area for which San Antonio is the trade center. Very little surface water is available without storage because the runoff of local streams is intermittent and flashy. Therefore, the importance of ground water became even more forcefully apparent with the local large development of permanent military establishments at the start of the Korean conflict, which resulted in an accelerated influx of population. The San Antonio area, in south-central Texas (fig. 1), was favorably located for industrial and military growth - land was available for both industrial plants and an expanded farming program, markets and rail and highway transportation were at hand, and the climate was almost ideal for extensive military training, particularly in basic flying. Abundant labor, electric power, and water supply all appeared promising. San Antonio became known popularly as "the fastest growing major city in the United States."

In 1949 the San Antonio Water Board requested the cooperative assistance of the Texas State Board of Water Engineers and the United States Geological Survey in making a comprehensive study of the ground-water resources of the greater San Antonio area (covering all or parts of several counties), paying particular attention to the Edwards limestone aquifer. That aquifer is the principal source of water supply for the area, and, in fact, is one of the most important aquifers in Texas. Funds were allotted for the work by the city and these offerings were matched by the State and the Geological Survey in a cooperative agreement. Studies on the three-way coordinated program were begun in September 1949. Subsequent developments in the expanded defense program for San Antonio with the attendant large increase in requirements for fresh water, coupled with the long period of drought conditions, brought on a general decline of artesian pressures to record lows in the late summer of 1952 and even greater lows in the summer of 1953. In July 1953, the water levels were 35 feet below the "spillway level" of San Pedro Spring. Many wells had ceased to flow, or, where no flows had existed, the water levels declined until pump bowls had to be lowered.

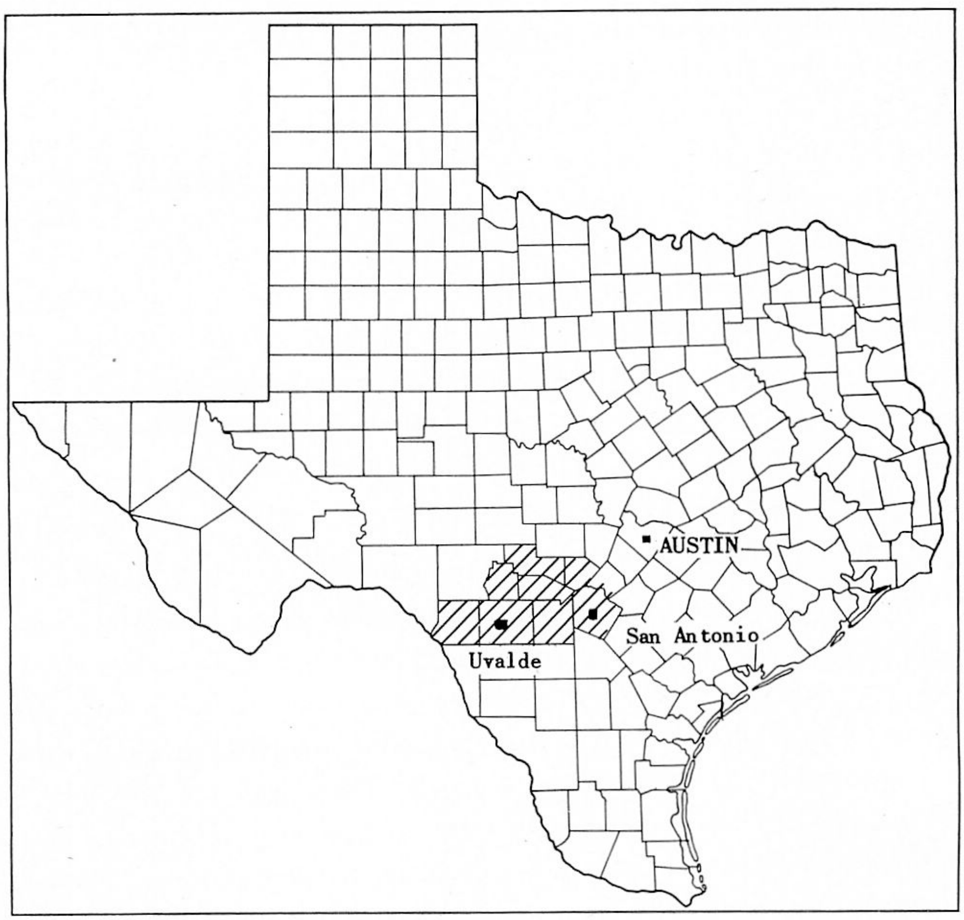

FIGURE 1.- Map of Texas showing general area of this study.

A geologic and hydrologic background for the area already existed as the results of State and Federal investigations dating back many years. The U. S. Geological Survey, in cooperation with the Texas State Board of Water Engineers, has been making some studies of various parts of the Balcones fault zone, including the San Antonio area, more or less continuously for about 20 years. These studies have been of a general nature and carried out as a part of the broader ground-water investigations throughout the State. One of the most comprehensive reports resulting from the studies (Livingston, Sayre, and White, 1936) covered Bexar County and contiguous parts of Medina and Comal Counties and was published as Geological Survey Water-Supply Paper 773. It gives a summary of the results of an investigation consisting of mapping the geology, collecting information on wells including water samples for analyses, and measuring the yields of the springs and some of the wells. Another report (Livingston, 1947), published by the Texas Board of Water Engineers, includes detailed records of wells, such as logs, water levels, and chemical analyses of water samples from springs and wells in Bexar County, which information was not given in the earlier water-supply paper.

A bibliography appended to this report gives a list of references and reports that contain information on the geology and ground water of this area.

The citizens of San Antonio and the agencies investigating water resources realized by 1949 that additional emphasis must be given to detailed study of the Edwards limestone aquifer in and adjacent to the Balcones fault zone, particularly west and northwest of San Antonio, in order to provide a satisfactory basis for effective development of the water resources in the area in future years. It was decided also that some studies should be made of the other important aquifers in the area.

A program of intensive work was set up for that part of the fault zone extending from Comal County westward to Uvalde County and contiguous areas (fig. 2) to include, among other things, field studies of rainfall and runoff, fluctuations of water levels in wells, the volume of water discharged by springs and wells, the quality of water, and detailed mapping of the geology in localities where there is significant interchange of water. Surface water and ground water are very closely and complexly related within this zone - surface water sinks to become ground water in one place and ground water rises to become streamflow in another.

Provision has been made for the preparation and publication of reports on the ground-water resources of the area as a whole that would help in determining the potential yield of the important Edwards limestone aquifer, especially at San Antonio. Consideration is given to the Carrizo-Wilcox sands of Eocene age and the sands of the Trinity group of Cretaceous age. The over-all area of study, which is treated in this progress report in a general way, includes Bexar, Medina, Uvalde, Real, and Bandera Counties and adjoining parts of Edwards, Kerr, Kendall, Comal, Wilson, Atascosa, Frio, and Zavala Counties.

The plan calls also for publication of detailed reports on the geology and ground-water conditions in the individual counties. Most of the field work has been completed and a report is being written on recent detailed studies made in Medina County. A part of the Medina County report, including field records collected during the study, has been prepared for publication as a release of the Texas Board of Water Engineers.

In addition to the usual approach to the study of ground-water resources, it has been found desirable to make especially detailed studies of rainfall-runoff relationships on the Medina, Sabinal, Frio, Dry Frio, and Nueces Rivers and on Hondo and Seco Creeks at places upstream and downstream from the belt of the outcrop of the Edwards limestone aquifer in the zone of faulting, in which large volumes of water are interchanged. Recording rain gages were set up at 6 sites and standard nonrecording instruments at 10 others spaced in such a way that, together with U. S. Weather Bureau stations, comparatively good coverage is afforded. Further studies of streamflow were made possible by a cooperative agreement between the San Antonio Water Board, the Texas Board of Water Engineers, and the Geological Survey, made in the spring of 1952, which provided for establishment of six recording and three nonrecording (wire-weight) gages at carefully selected sites upstream and downstream from the outcrop belt of the Edwards limestone aquifer. Streamflow records of many years' duration are being continued at several other river stations, and miscellaneous measurements are being made on other smaller streams in the area.

The principal objective of the over-all studies is to learn more than has been known regarding the lithology and structure of the rock formations as related to the intake of water and the location of channels or zones of water movement in the underground reservoirs, and to determine as accurately as possible the long-term yield characteristics of those reservoirs in the Balcones fault zone throughout the greater San Antonio area. In order to reach this objective an integrated picture of the whole regimen of rainfall, runoff, infiltration, circulation, and discharge must be developed for the several-county area described above. Although much of the information presented in this report is based on general studies that began in the Balcones fault zone and adjacent regions many years ago, most of it is the outgrowth of ground-water studies that began in the San Antonio area in 1949 as a result of the current cooperative project.

Appreciation and gratitude are expressed for the keen interest and personal assistance of R. A. Thompson, Manager, and W. D. Masterson, former manager (retired) of the City Water Board of San Antonio. Well logs and other data furnished by several engineers, geologists, and drillers of San Antonio have been of valuable aid in the writing of this report.

GEOLOGY AND GROUND-WATER HYDROLOGY OF THE AREA

GEOLOGY AND STRUCTURE

In the San Antonio area the availability of water resources is determined largely by the character, distribution, and structure of the Edwards limestone and associated limestones. The Georgetown limestone above the Edwards yields water to many wells in Bexar County, and it is a part of what is called in this report the Edwards limestone aquifer because it is comparatively thin and there is no confining bed between it and the Edwards limestone. The same is true of the underlying Comanche Peak limestone. Therefore, this report is concerned mostly with those three limestone formations as a unit and their ability to take in water on the outcrop and transmit it long distances underground to the wells and springs in and around San Antonio and New Braunfels. Other aquifers of consequence, however, have been treated briefly. Table 1 gives a generalized section of the geologic formations in the area.

The area of study, covering about 6,000 square miles, lies within parts of two major physiographic provinces - the northern third is on the Edwards Plateau and the remainder is on the Gulf Coastal Plain, the two being separated by the southward-facing Balcones escarpment which in some places is rather indefinite. On the Plateau the rocks are relatively flat and free from faulting. Extending from the escarpment locality Gulfward, however, is the Balcones zone of faulting (see fig. 2). This is a zone ranging in width from about 10 to 30 miles, extending in a westerly direction across Bexar, Medina, and Uvalde Counties, in which the Edwards limestone and associated rocks dip at comparatively steep angles and are extensively jointed and faulted. In the central part of the area of study the limestones are overlain by younger shales, marls, and clays which confine water in the older rocks under artesian pressure. The artesian water circulates freely along the faults and in cavernous zones developed by solution in the rocks. Somewhat farther to the south the Cretaceous marls and sandy clays are in geologic contact with overlying Tertiary marly clays and clayey to clean sandstones which combine to create an effective seal on the limestone aquifer and to prevent natural discharge, deflecting it to such points of discharge as San Pedro Springs to the north. Down the dip in the southern part of the area the rocks have been less extensively broken by faults, and the Edwards limestone aquifer in general has not had a chance to develop consequential permeability. There is little artesian circulation, and as a result the contained waters are sulfurous and comparatively high in dissolved solids.

Table 1.- Generalized section of geologic formations in San Antonio area, Texas

System	Series and group		Formation or group	Thickness (feet)	Water-bearing properties
Quaternary	Recent		Alluvium of lower stream terraces	0-20	Yields potable water to a few wells in stream valleys.
	Pleistocene		Leona formation	0-90	Yields potable water to many domestic and stock wells. Important irrigation supply in Zavala County.
Tertiary (?)	Pliocene (?)		Uvalde gravel	0-20	Not known to be water-bearing.
Tertiary	Eocene		Mount Selman formation	?	Yields relatively little water.
			Carrizo sand	200	Yields abundant water of good quality to wells. Large irrigation supplies in Atascosa County
			Wilcox group, undivided	650±	Yields water to domestic and stock wells. Several irrigation wells in Medina County. Water generally highly mineralized.
	Paleocene		Midway group, undivided	650±	Generally not water-bearing.
Cretaceous	Gulf		Navarro group, undivided	300±	Not known to yield water to wells.
			Taylor marl and Anacacho limestone undivided	150-600±	Not known to yield water to wells.
			Austin chalk	125-400±	Yields potable to highly mineralized water in varying quantities to domestic, stock, and irrigation wells.
			Eagle Ford shale	25-250±	Not known to yield water to wells.
	Comanche	Washita	Buda limestone	40-120	Yields water to several domestic and stock wells near outcrop.
			Grayson shale (Del Rio clay)	55-100±	Does not yield water.
			Georgetown limestone	20-50	Yields water to many wells in Bexar County. Elsewhere generally yields little water. Classed as part of Edwards limestone aquifer.
		Fredericksburg	Edwards limestone	500±	Chief water-bearing formation in area. Is the principal source of the large springs and yields water to many pumped and flowing wells.
			Comanche Peak limestone	40±	Not distinguished from Edwards limestone in wells; forms a part of Edwards limestone aquifer.
			Walnut clay	1-20	Does not yield water.
		Trinity	Glen Rose limestone	1,000-1,200	Yields more or less highly mineralized water to many domestic and stock wells on the Edwards Plateau.
			Travis Peak formation	100-400±	Small yields of highly mineralized water where tested in Bexar County. Furnishes essential public supplies on Edwards Plateau.

The position of the Balcones fault zone is of utmost importance in relation to ground-water resources. Not only does it mark a major change in rock types, but it represents a belt in which a highly productive water-bearing formation lies between comparatively wide belts of formations that are generally not suitable for large ground-water developments. Figure 2 shows the approximate location and relationship of these belts, with brief summaries of the water-yielding characteristics of the important aquifers. The accompanying cross section shows the position of the large faults within the fault zone. Down dip from the Mission well field fault the water in the limestone aquifer is nonpotable.

This complex series of faults and the associated fissures and solutional channels in the Edwards limestone aquifer provide storage space and conduits for one of the most extensive and prolific artesian-water reservoirs in Texas, from which the San Antonio area draws its water supply and which provides the low flow of several streams that cross the Coastal Plain.

The Edwards limestone aquifer forms two distinct ground-water reservoirs - one on the Edwards Plateau on the north, where the rocks dip gently to the east or southeast at a rate about equal to the slope of the land surface, and the other in the main Balcones fault zone described above and shown in figure 2. Erosion has largely removed the Edwards in a belt lying between these two hydrologic systems. On the plateau the limestone forms most of the surface. It absorbs substantial amounts of rainfall that sink through cracks and solutional openings to form an unconfined water body in the lower part of the formation which is underlain by relatively impermeable formations. Moving laterally by gravity through the limestone, much of it appears as springs at or near the base of the Edwards in the valleys that have been cut through the formation. These springs are the source of the perennial streams of the plateau country.

The fault-zone reservoir is one of artesian circulation in the Edwards adjacent to and southward from the Balcones escarpment. Records of the many wells drilled in this zone show that the limestone contains an intricate network of openings that range from small joints and fissures to solutional channels of varying size, some forming rather large caverns. The largest and most extensive openings occur in the vicinity of the major fault planes; however, in many other places the limestone is honeycombed by small cavities and solutional openings which create a large amount of storage space for water. In places the rock is dense or contains only minute openings and will yield little or no water to wells. In recent years some wells encountering this condition have been successfully completed by treatment with acid which enlarges small openings leading to larger openings some distance from the well bores.

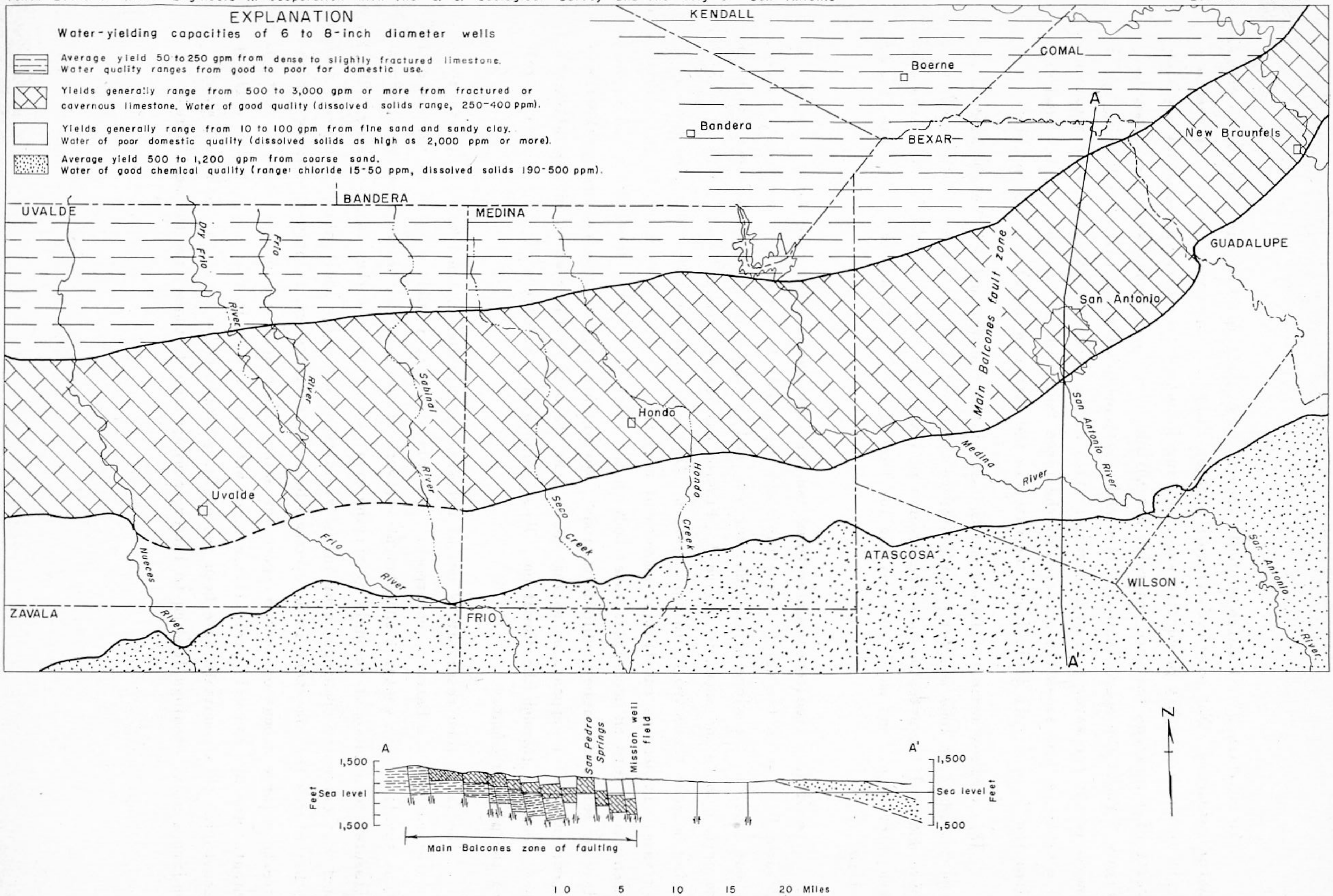

FIGURE 2.– Map indicating the water-yielding characteristics of important aquifers in the San Antonio area, Tex.

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GROUND-WATER RESOURCES

Ground-water resources are replenishable. Therefore, in addition to the question as to the yield of individual wells, there is an important question as to the dependability of aquifers under conditions of sustained long-term use. Local water-bearing properties of the aquifer govern the yield of wells, whereas geologic, climatic, and other conditions covering broad areas and long periods of time may govern the long-term yield. In the San Antonio area, for example, the most important places of intake that supply the Edwards limestone aquifer are many miles away from, and may be affected by conditions not apparent at, the places of withdrawal. The complex hydrologic system here is especially affected by the intensity of rains and their distribution over the outcrop, on the one hand, and the regimen of the streams that drain the Edwards Plateau - especially where they cross the Balcones fault zone, on the other.

In the over-all area covered by this report, most of the available ground water in all the formations originates in the precipitation that falls within the area of study, including part of the adjacent Edwards Plateau to the north. Fortunately, although the precipitation generally is not abundant, the opportunities for rapid infiltration are excellent, especially into the fault-zone reservoir in the central part of the area and along the very sandy rolling outcrop of the Carrizo sand on the Coastal Plain in the extreme southern part of the area.

For the Edwards limestone aquifer, there is a close relationship between the amount of runoff in the streams that cross the faulted limestone outcrop and the amount of recharge. The structural arrangement of the rocks is ideal for intake of water by the permeable beds, which in many places are honeycombed and cavernous. Most of the streams flow for many miles on the limestone, allowing large quantities of water to sink into the porous rock to the water table and thence down the dip under cover of impermeable beds into the artesian reservoir. Intense rainstorms resulting in a large amount of runoff in streams many miles west or northwest of San Antonio usually cause exceptionally heavy recharge accompanied or followed by a sharp rise in the artesian pressure at San Antonio. In addition, much recharge is constantly being provided to the fault-zone reservoir by infiltration of all of the relatively uniform low flow of the streams, which is maintained by the springs that discharge from the large ground-water reservoir on the great plateau. This increment has little or no apparent effect on the artesian pressure at San Antonio, but it helps to maintain the pressure nevertheless. Neither is there any apparent pressure effect from the constant recharge that occurs from permeable beds in the Glen Rose limestone in localities where the Edwards limestone is faulted down against such beds.

Water from the wells and springs throughout most of the fault zone is almost uniformly of good quality. In the extreme southern part of the fault zone and extending down the dip Gulfward throughout the area of study, the water in the Edwards limestone aquifer is comparatively high in dissolved solids and has a disagreeable odor of hydrogen sulfide, indicating a condition of little or no circulation. Deep test wells have penetrated much less permeable rocks here than farther north and have failed to obtain yields as large. These facts are evidence that the underground reservoir is definitely limited on the south and that there is relatively little movement of water towards the Gulf. This is brought out in part by the map of contours of water levels (fig. 3), which shows that the general direction of ground-water movement across central Bexar County is approximately parallel to the main system of faults. The illustration, however, obscures the important fact that most of the movement of water is along the individual faults. Evidence of such movement has been observed in the wide range in yield of wells drilled at varying distances from a fault.

The most favorable places for large-scale withdrawals of ground-water are to be found in the limestones along the belt of faulting where most of the large developments in Bexar and Uvalde Counties have been accomplished. Because of the prolific yields (generally ranging from 500 to 3,000 gallons a minute) usually obtained from wells, large natural flows being not uncommon at lower elevations around San Antonio, the opportunity for water-supply developments from this belt have been and still are good. As explained above, there is a high potential for recharge where the broken and cavernous limestone is in hydraulic connection with the rivers that flow across the belt.

Conditions lend themselves also to excellent opportunities for artificial recharge. In several places in this Nation, such as in western Long Island (Brashears, 1946), overdevelopment of underground reservoirs has brought artificial-recharge practices to the fore as means of maintaining large water supplies.

The second most favorable places for large-scale ground-water withdrawals lie along the southern part of the area of study (see fig. 2), where the Carrizo sand stores a large volume of excellent water, and conditions for infiltration of precipitation are especially favorable over wide areas. These potential supplies are on the order of half a million to a million or more gallons a day per well. Plans for large withdrawals, however, should take into account the current irrigation development from the artesian reservoir down the dip in Atascosa County.

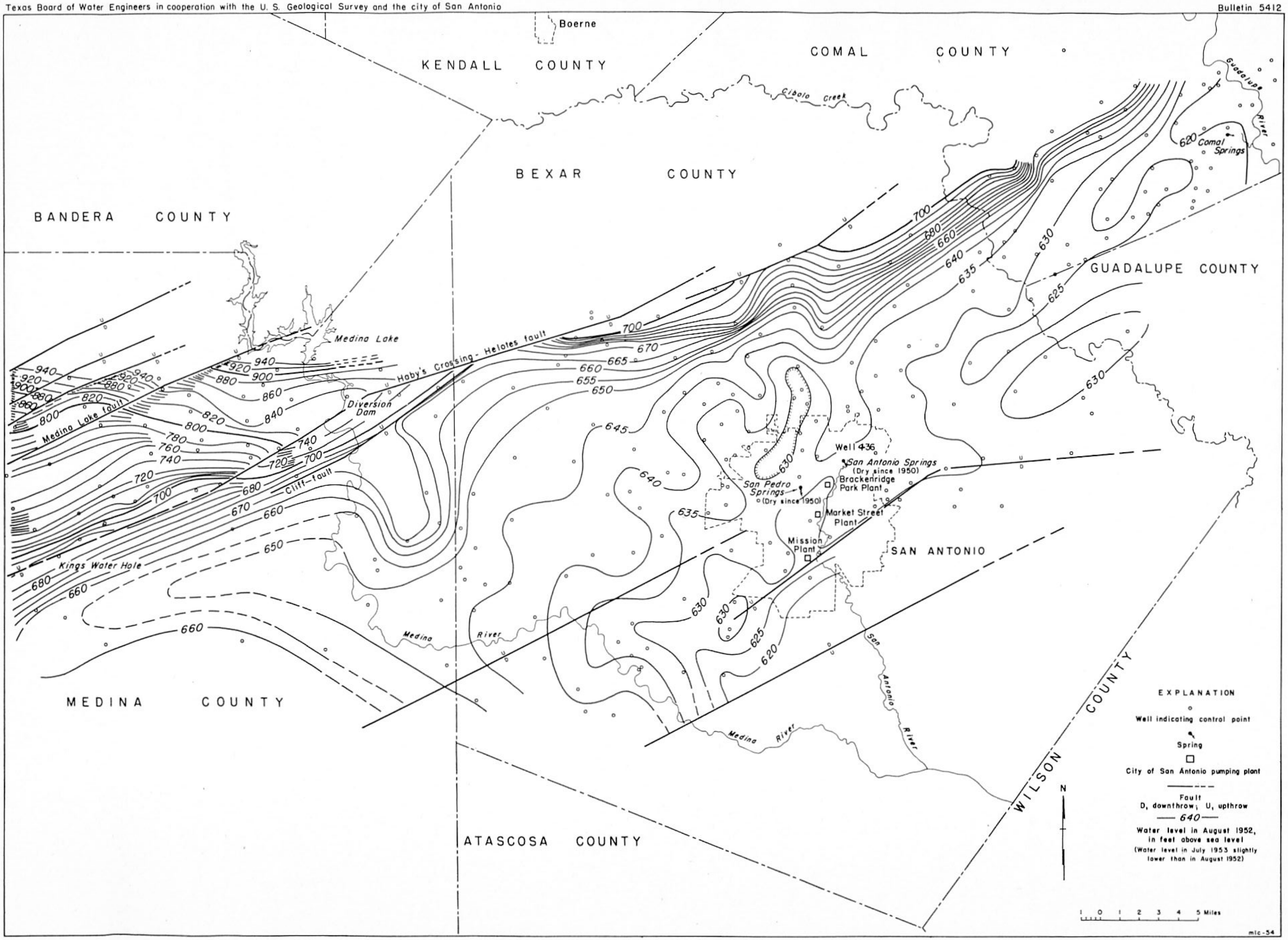

FIGURE 3.-Contour map of water levels in Edwards limestone aquifer, San Antonio area, Texas.

In the Coastal Plain of the southern parts of Bexar, Medina, and Uvalde Counties sands of Wilcox age yield 100 gallons or more a minute to shallow wells. Some of the shallow wells drawing from gravelly terrace deposits of the Leona formation have yields of 300 to 500 gallons a minute under sustained pumping for irrigation. Extensive local development has resulted in sharp declines of water levels and yields in many wells drawing from the Leona formation during the past few years, especially in the northeastern part of Zavala County (see fig. 2).

In the northern part of the area of study the Glen Rose limestone yields varying amounts of water, generally of rather high mineral content, to many domestic and stock wells. A few Army-post wells draw from the Glen Rose limestone to supply a military reservation about 15 miles northwest of San Antonio, and a part of the Bandera public supply probably is derived from it. Most of the wells drilled thus far yield only small amounts of water; however, a few wells will yield 200 to 300 gallons a minute. Under favorable structural conditions the possibilities seem good for certain localities in the Glen Rose limestone to yield fairly large volumes of good water, especially in the reef zones which have been noted at several places on the surface and penetrated many miles downdip by the drill in oil tests. Further exploration will be necessary in order to prove or disprove this reasoning.

According to information currently available (Lang, 1953) the sands of the Trinity group in the San Antonio area are not capable of large yields, the quality of water obtained in them is relatively poor, and the temperatures are relatively high.

HYDROLOGY AND ESTIMATED PERENNIAL YIELD OF EDWARDS LIMESTONE AQUIFER

The Edwards limestone and associated limestones form a great hydrologic unit, the Edwards limestone aquifer, which supplies all the large springs along the Balcones fault zone and, in addition, wells of the city of San Antonio and all other cities along that zone from the Rio Grande to San Marcos. Owing to its geology, the hydrologic characteristics of the aquifer are not everywhere uniform. In the main, however, it is one of the most highly permeable aquifers yet studied by the U. S. Geological Survey. Because of the extreme irregularities of solutional openings and fractures in the limestone, an accurate measure of the capacity of this immense underground reservoir has not been made.

Estimates suggest, however, that its storage capacity probably exceeds the combined capacities of all the artificial surface reservoirs on the Colorado River (Texas) at spillway levels, which is estimated to be 3 million acre feet. Not all the ground water is recoverable, however, because in the deeper parts of the reservoir the water levels cannot practicably be drawn down sufficiently low.

Just as the Colorado River (Texas) dams function to prevent or reduce floods and to produce a relatively uniform flow of the river, the Edwards limestone aquifer absorbs a large part of the rainfall and normally pays it out at a relatively uniform rate through springs. Unlike the surface reservoirs, which lose water by evaporation and capacity by siltation, limestone reservoirs slowly increase in capacity as the rock becomes dissolved by circulating ground water, and evaporation losses are practically nil.

On the basis of studies of chemical analyses and of the normal flow of Comal Springs (George, 1952, p. 37), at New Braunfels, it is calculated that the solid rock dissolved in the water that issues from these springs amounts to 200 tons or roughly 90 cubic yards a day. Analyses of samples of water taken at widespread localities throughout the area of study further reveals that the dissolved rock flows out of every spring and well that discharges from the Edwards limestone aquifer, at a rate of roughly a ton of rock for each million gallons of water. During 1953, for example, it is estimated that the combined discharge of all the wells and springs in the stretch from Uvalde County to Comal County resulted in the removal of approximately 450 tons of solid rock per day. Thus the enlargement by solution of crevices in the limestone, which made the rock an aquifer in the first place, is continuing to this day.

The facts presented in Water-Supply Paper 1138 (George, 1952) suggest that about two-thirds of the discharge of Comal Springs, located 25 miles northeast of San Antonio, comes from an immense ground-water reservoir supplied by recharge localities west of Comal County, largely within Bexar, Medina, and Uvalde Counties. Records show that the average flow of the springs over a 20-year period ending in 1948 was about 210 million gallons a day. A fairly large portion of this water probably moves across Bexar County in the belt between the Balcones escarpment north of San Antonio and the Mission Water Plant in the south part of San Antonio (corresponding roughly to the main Balcones fault zone as shown in fig. 2). The contour map of water levels (fig. 3) indicates that during the summer of 1952 (the same condition existed in the summer of 1953) the level of the ground-water reservoir in and adjacent to San Antonio became very flat and at some places approached the level of Comal Springs, causing a decrease in water movement toward the springs. This condition was the combined result of the long drought period with below-normal recharge to the Edwards limestone aquifer and the increased withdrawals from the aquifer in and around San Antonio.

The general direction of ground-water movement in the Edwards limestone aquifer within the fault zone is believed to be more or less transverse to the contours shown in figure 3. In general the water-level surface slopes towards the south or southeast, which is away from the outcrop of the formation, and is very irregular. Several large faults in northern Medina County appear to control the direction of movement in that part of the area by acting as barriers to cause the water to move southwest locally. However, eventually it crosses the barriers and then moves southward into a wide troughlike feature or "valley" in the central part of the county extending eastward from Hondo, where the gradient changes to an eastward course that leads the water into Bexar County. Further increment occurs from the Medina Lake locality and adjacent localities in Bexar County. The relatively high water levels shown by contours east of the Medina River immediately south of the Cliff fault suggest either that the limestone is less permeable, or that the recharge coming from the Medina Lake locality may be greater, in this locality than in the surrounding area. It is possible also that the relatively high water levels are related to local structural conditions. Whatever the interpretation may be, water moves from that part of the area of relatively high water levels toward the "valley" to the south.

In the western part of the map area, the slope of the water surface is southward to the vicinity of the "valley" at the rate of 30 feet to the mile; along the axis of the "valley" it is almost flat - averaging only about 1 foot to the mile between Hondo and San Antonio. In Bexar County the slope from the Habys Crossing - Helotes fault vicinity to San Antonio is at the rate of 4 to 5 feet to the mile, and across the central part of the county the water surface is nearly flat. The low gradient between Hondo and San Antonio and across central Bexar County toward Comal Springs is evidence of very high permeability, especially in view of the large withdrawals being made at San Antonio from wells of large yield, together with the large discharge of Comal Springs. The closed depression in and adjacent to the northern part of San Antonio may indicate that, although the limestone in this locality is permeable, the openings in it may be small and cause greater friction losses than in the surrounding area, resulting in greater drawdown in the artesian surface in proportion to pumpage. The depression, although in a locality of considerable pumping by widely spaced city wells, lies outside the center of intensive pumping at San Antonio.

Figure 4 shows the month-by-month discharge of Comal Springs, the water level in well 436 in northeast San Antonio, and the precipitation at Boerne, Tex., from 1932 to 1953. A study of the data from several dozen observation wells shows fairly uniform fluctuations in water levels throughout the area, and that the records obtained from well 436 and a few other key wells give an accurate picture of the major fluctuation features. Figures 5 and 6 show the general uniformity of the changes in water levels in wells in Bexar, Medina, and Uvalde Counties.

FIGURE 4.— Discharge of Comal Springs, water level in well 436, and precipitation at Boerne, Tex. 1932–53.

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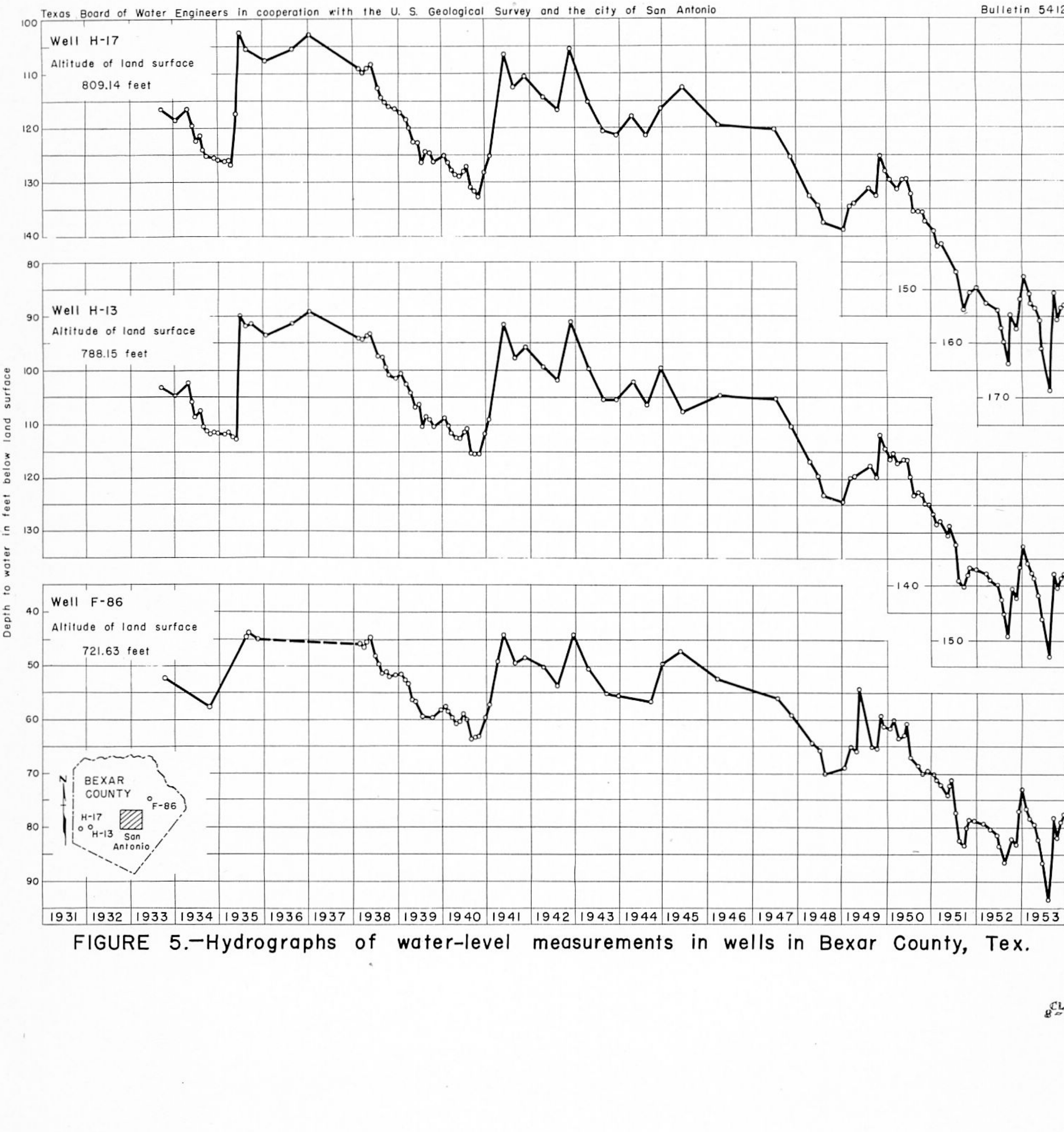

FIGURE 5.—Hydrographs of water-level measurements in wells in Bexar County, Tex.

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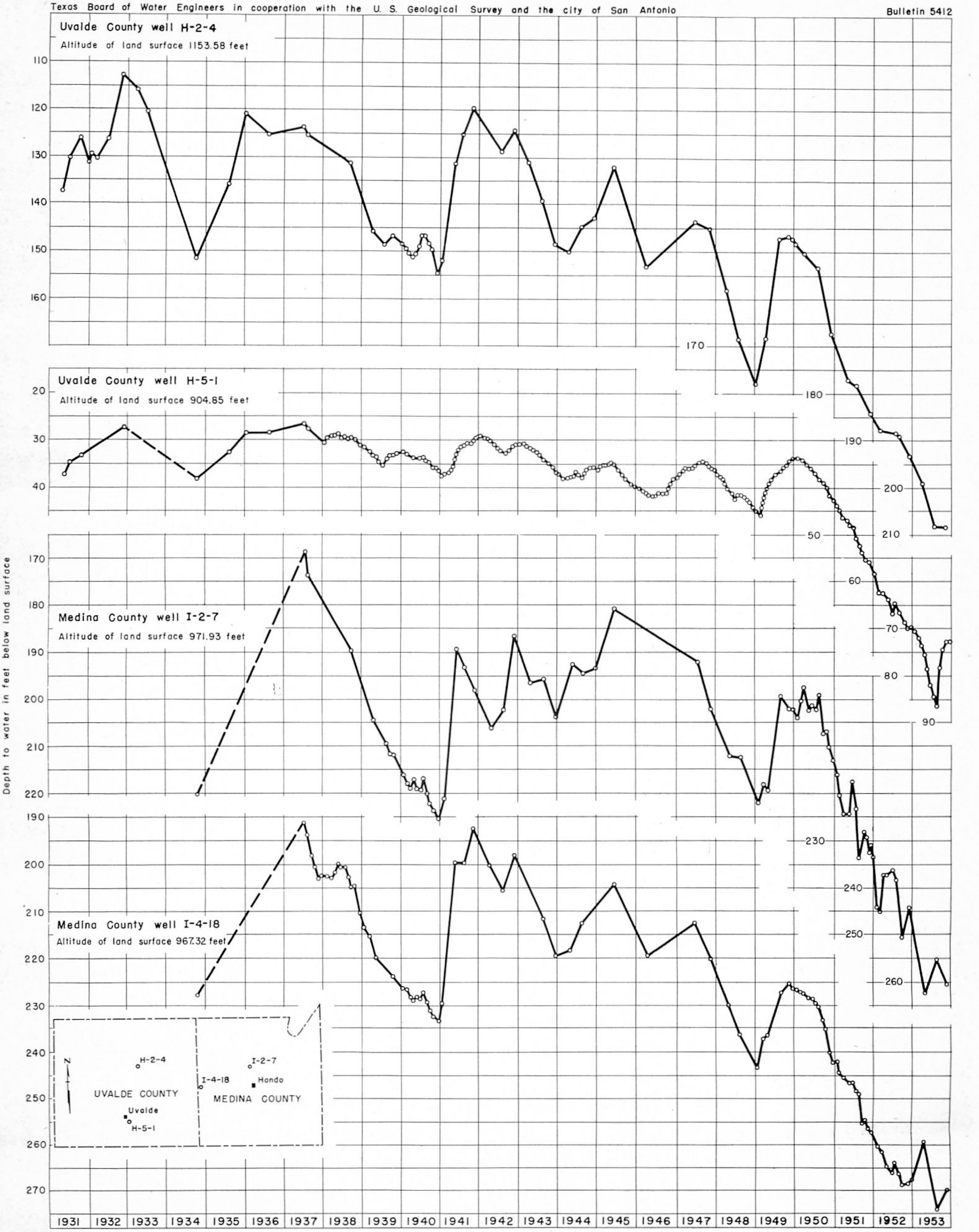

FIGURE 6.- Hydrographs of water-level measurements in wells in Medina and Uvalde Counties, Tex

The rise and fall of the water levels, as illustrated by figures 4, 5, and 6, vary with the rate of recharge on the outcrop of the limestone aquifer, and the rate of recharge in turn varies with the distribution of the rainfall - its amount and intensity. The graph of the accumulated deviation from normal precipitation (fig. 4) shows the periods when rainfall is above, below, or at normal. During periods of below-normal rainfall the water levels in the wells gradually decline. The lowest water levels of record to that date were measured in August 1952 in Bexar County. There was a period of some recovery as a result of the local rains in September and the decrease in withdrawals during the following winter. As the widespread drought continued throughout the recharge area, however, water levels fell to new lows during July 1953. In Uvalde County (fig. 6), which received very little rain in September 1952, the decline remained unbroken and new record lows were established in 1953. Heavy rains, however, may recharge the ground-water reservoir rapidly, and the water levels many miles down the dip to the south of the outcrop may recover in a few wells all they have lost in 2 or 3 years.

During a 20-year period beginning in 1928 in which the storage in the Edwards limestone aquifer remained about in equilibrium in Bexar County, it was estimated that the average combined discharge of the springs and wells in Bexar County was about 110 million gallons a day. In the report on Comal County, George (1952, p. 38) shows that during this period the average flow of Comal Springs was about 210 million gallons a day, of which it is estimated that approximately one-third came from the drainage areas of Cibolo and Dry Comal Creeks, (George, 1952, p. 60). A large part of the remainder must have come out of Bexar Creek.

With average rainfall on the outcrop, it is therefore reasoned that the minimum perennial yield of the Edwards limestone aquifer to wells and springs in Bexar County and the adjacent Comal Springs locality is on the order of 320 to 330 million gallons a day. This estimate involves the assumption that the streams that furnish a large percent of the recharge will not be regulated in such a way as to reduce the recharge from them. In favorable localities artificial recharge practices might even add substantially to the average yield of the reservoir at San Antonio.

The lowering of water levels in and near San Antonio, resulting largely from the pumping of public-supply wells, reduces the gradient and retards the flow from the metropolitan area toward the northeast, where the use of the water currently discharged by Comal Springs, for power generation and irrigation in the downstream area, would be considered a lower beneficial use, at least in comparison with the domestic-use portion of the San Antonio pumpage. Regardless of the effect of the lowering so far as it concerns beneficial use, which is beyond the scope of this report, the reduction of the artesian head at San Antonio to its level of 1950-53 has had one advantage - it has automatically reduced or stopped wastage of large quantites of water, chiefly from flowing wells in and adjacent to the city. In 1934 the waste from wells amounted to at least one-third of the total annual discharge from wells, according to the report by Livingston, Sayre, and White (1936).

USES OF GROUND WATER

Because relatively little surface water is available in the San Antonio area without storage, the increasing importance of the supply of ground water has become more and more apparent through the years. Flow from San Antonio and San Pedro Springs, which fed the San Antonio River, led to the founding of a military post and five missions between 1718 and 1731 by the Spaniards, who employed the native Indians in the cultivation of farms and gardens irrigated by the springs. The springs, however, have ceased to flow during the prolonged droughts of several years duration - notable recorded periods of quiescence were during the latter part of 1897 and parts of 1898, in 1899, in 1918, in 1928-29, and in 1934. During the present prolonged drought there has been little or no spring flow for the past 4 years.

In the early days, besides the springs, a few shallow wells in the alluvial deposits along streams were the chief sources of water supply in the area. About 1885 the drilling of wells to the artesian reservoir was started by George W. Brackenridge for the public supply of San Antonio. In 1907 there were more than 100 artesian wells in Bexar County, of which 30 had a reported combined natural flow of 30,000,000 gallons a day. As San Antonio grew from a population of 96,614 in 1910 to 231,542 in 1930 and approached the half-million mark in 1953, the value of this artesian water supply increased. With the population increase has come a corresponding demand for large expansion in systems to supply water for domestic and industrial uses and for irrigation, and this has been met by larger and larger withdrawals of ground water. By the end of 1953 the current study had revealed that there were between 1,500 and 2,000 wells tapping the Edwards limestone aquifer in Bexar County, of which about 250 were large-capacity supply wells in San Antonio or on the nearby irrigated farms; most of the remainder were domestic and stock wells equipped with small pumps.

In 1946 it was estimated that the average daily discharge of ground water through wells and springs in the Edwards limestone aquifer in Bexar County was on the order of 155 million gallons. In 1952, the average withdrawals in the county amounted to an estimated 164 million gallons a day, and in 1953 they were about 165 million gallons. The following table gives the estimated average withdrawals for various uses in Bexar County in 1951 and 1952.

Table 2.- Estimated average withdrawals of water from Edwards limestone aquifer in Bexar County, 1951 and 1952
(in million gallons a day)

	1951 Withdrawal mgd	1952 Withdrawal mgd
Public supplies		
San Antonio Water Board	62.6	63.9
Independent public supplies	9.7	10.6
Military posts	11.5	12.0
Parks and zoo	2.7	2.8
Sub-total	86.5	89.3
Industrial supplies		
Packing houses, breweries, power plants, laundries, creameries, ice and bottling plants, etc.	17.5	18.0
Office buildings, hotels, theatres, stores, etc. (Includes water discharged into San Antonio River mostly from air-conditioning)	12.0	11.5
Sub-total	29.5	29.5
Irrigation and ranch use		
Field crops and truck	23.0	24.0
Country estates, domestic and stock	12.0	13.0
Salado Creek flowing wells	5.5	4.5
Country clubs	.5	.5
Sub-total	41.0	42.0
Miscellaneous supplies		
Private schools, colleges, tourist courts, etc.	3.0	3.0
TOTAL	160.0	163.8

San Antonio and San Pedro Springs quiescent during 1951 and 1952.

Artesian wells are used for all public supplies, including those for the city of San Antonio, the military posts, and the parks. The total withdrawals for these supplies in Bexar County amounted to an average of about 90 millions gallons a day in 1952 (table 2). Among the users of large quantities of ground water in and around San Antonio, exclusive of the military and municipalities, are the packing houses, breweries, two power plants of the San Antonio Public Service Co., and the irrigators in the truck-garden localities. Ground water has many advantages over surface-water supplies for many uses because of its uniform chemical character, freedom from turbidity, and near-constant temperature. Uniform temperature is especially sought in industrial water supplies where heat exchange is an important factor. Most of the industrial requirements for water (including the air conditioning of business houses and office buildings) are supplied by privately owned wells. The combined average daily withdrawal for industrial use in 1952 was estimated as about 30 million gallons.

For irrigation in Bexar County it was estimated that about 42 million gallons a day was used in 1952, mostly for truck farming east, south, and southwest of San Antonio.

In addition to the 164 million gallons a day withdrawn from the Edwards limestone aquifer in Bexar County (discussed above), it is estimated that ground-water withdrawals from all the geologic formations throughout the entire area of study shown in figure 2 amounted to at least another 135 million gallons a day, making the use of ground water for the whole area total approximately 300 million gallons a day on the average. Outside Bexar County, the largest withdrawals were made from the Edwards limestone aquifer in irrigated localities in south-central Uvalde County; from the Carrizo sand, for irrigation in northern Atascosa County; and from the Leona gravel, for irrigation in northeastern Zavala County. Some irrigation also was being developed in 1951-53 from sands of the Wilcox in southern Medina County.

WATER-SUPPLY PROBLEMS

The principal objectives of the current ground-water program of study for the Balcones fault zone area centering around San Antonio are to complete the geologic mapping in sufficient detail to help evaluate the localities that contribute water to the Edwards limestone aquifer, to delineate the reservoir and learn as much as possible about the location of principal channels of movement within it and the possibilities of artificial recharge to it, and to identify conditions that might exist or develop that would jeopardize the continued large-scale use of water from it. In addition to the study of the Edwards limestone aquifer, the program is aimed at determination of the yield characteristics of other rock formations within the area and their possibilities as potential sources of water supply.

The San Antonio area is in a favorable position with respect to ground-water supplies under present drainage-basin conditions and rate of use. However, there are serious problems that must be recognized in sound planning for large increases in the rate of withdrawals or of engineering plans for altering the surface-runoff pattern. Among the problems of most consequence to be considered are those that relate to the geology of the area, those that relate to engineering projects, those that relate to the regional or local decline in head or storage in the important aquifers, and those that relate to water quality.

PROBLEMS RELATED TO GEOLOGY

The occurrence of ground water in the Balcones fault zone and adjacent areas is especially closely related to the geology. Some formations seem nearly everywhere to yield an abundance of good water, others yield little or no water of any sort or meager supplies of poor quality, and still others are water bearing in some localities but not in all.

The limestones that occur on the Edwards Plateau in northern Bexar, Medina, and Uvalde Counties and in Bandera, Real, and Edwards Counties differ widely in their water-bearing characteristics from those in the belt of faulting; and the sand and sandstone reservoirs in the Coastal Plains, the southern part of the area, are still different in those characteristics. Furthermore, the ground water in the limestones, particularly in the fault zone, occurs mostly under conditions in which permeability is secondary - that is, the rocks have become permeable by development of a network of cracks formed by earth movements after deposition of the limestone and enlarged by solution. These openings are much more prominent in some places than in others and consequently wells spaced only a few feet apart may differ greatly in yield. Prior to drilling, therefore, little assurance can be given of the quantity of water the well will yield when finished. Most wells that are drilled near faults within the main zone of faulting yield large amounts of water. However, wells drilled near the southernmost faults, south and east of San Antonio, yield varying amounts of hydrogen sulfide water containing comparatively large quantities of dissolved solids, or are practically "dry." If records of many wells are available for study a certain average expectancy can be derived. Even so, the yield of individual wells cannot be predicted with confidence.

On the other hand, the sands and gravels of the Carrizo sand and the Wilcox group in a wide belt extending along the southern part of the area of study Gulfward are relatively uniform in permeability and generally yield 500 to 1,200 gallons a minute per well. However, widespread aquifers, uniform in rock character and yield to wells, are the exception rather than the rule. The gravels of the Leona formation, for example, are generally restricted to the larger stream valleys and are variable both in thickness and in yield to wells. The Austin chalk and a few other formations yield moderate supplies of potable water in a few localities. Therefore, in the successful developments of ground-water supplies a thorough knowledge of the geology is essential.

PROBLEMS RELATED TO ENGINEERING PROJECTS

The marked permeability of some rock formations, including the invisible extent of underground caverns and passageways in the Edwards limestone aquifer, the general impermeability of others, the large fluctuations of the water table and artesian pressures over short periods, and the development of solutional openings combine to create varied engineering problems in the San Antonio area. In the limestone terrane west and northwest of San Antonio an important consideration in making quantitative estimates of ground water in storage is a knowledge of the capacity and distribution of the passageways in the limestone at or near the outcrop. These passageways control the volume of water available to move down the dip from the water table under cover into the artesian reservoir that supplies San Antonio and other places. They also furnish the conduits that carry water under pressure throughout the great artesian reservoir.

Pertinent data have been obtained for several hundred wells, including the running of instrumental levels to many observation wells in Bexar, Comal, and Medina Counties, during the current studies. Information is being collected on the relation of precipitation and runoff to the rise and fall of water levels in wells, changes in the discharge of springs, and estimates of withdrawals by wells. These data give relevant information concerning the amount of water in storage in both the water-table and artesian parts of the aquifer, and the direction of ground-water flow. However, no indirect method will determine the size of hidden caverns. Even closely spaced wells can miss large openings. Engineering techniques, on the other hand, are being applied more and more in the field of development of wells in the limestone. Whereas, a few years ago when a well missed the large openings and was abandoned as "dry," today such a well may be satisfactorily treated with acid which enlarges minute openings leading to the larger openings some distance from the well.

In dam-site location, when drilling is used to reveal any weathered zones of rock that may be present, water levels in the holes are measured and pressure applied to learn if the weak rock is permeable. If water levels in wells are lower than the stream bed to be dammed, heavy leakage from the reservoir may occur. An excellent example is the Medina Lake system on the Medina River about 25 miles northwest of San Antonio, where two dams were built on porous limestone and the water table is below the stream bed. Fortunately, for San Antonio, the water lost from the Medina system sinks into the Edwards limestone aquifer and moves in the general direction of the hydraulic gradient many miles into the San Antonio district to help supply the local well fields (fig. 3). In projects involving both surface and underground water it is therefore desirable to know where the water comes from, as well as the capacity of the reservoir. In order to guard against pollution from disposal of waste material into cavernous limestone or coarse sand and gravel, a sanitary engineer must know what effect such disposal will have on the fresh-water supplies. These are some of the timely ground-water problems associated with engineering projects.

HYDRAULIC PRINCIPLES AND PROBLEMS RELATING TO LOWERED WATER LEVELS

Water cannot be withdrawn from underground reservoirs without disturbing the natural balance of inflow and outflow. A local lowering of the water table or the artesian-pressure surface will result, without fail, from the withdrawal of water from a well. For example, when a well (or a well field) is pumped or allowed to flow the water levels in the surrounding parts of the aquifer are lowered, and, conforming to the principles of hydraulics, a slope is created toward the place of withdrawal, causing water to flow to that place from areas of recharge and diverting water that previously flowed to other areas of discharge. The amount of lowering of water level per unit of water withdrawn will depend upon the characteristics of the aquifer. As greater volumes of water are removed from the aquifer, the water levels will become proportionately lower. However, within reasonable limits the lowering of water levels is not cause for concern except as it relates to increasing costs of withdrawal. In spite of the fact that much can be done by proper well spacing to prevent excessive interference, it is inevitable that there will be some loss in head in existing wells as new wells are developed. Proper spacing of wells is, therefore, a weighty consideration in laying out a well field in order to reduce the cost of pumping as much as may be compatible with obtaining the full yield of the aquifer.

Because water can be replenished during periods of abundant rainfall, it is a renewable resource. Over-development of ground-water supplies, can, however, deplete them with resulting hardship and economic loss, especially in irrigated areas.

In some respects, withdrawals from a ground-water reservoir can be compared to those from a surface-water reservoir. It may be desirable to lower the water level temporarily to provide water during droughts, and then permit the reservoir to recover during periods of heavy rainfall. In this way the maximum benefit can be derived from the water, especially by cities and industry, without serious curtailment of its use during the drought. A 4-year drought throughout most of the Edwards Plateau and the localities of important recharge to the Edwards limestone aquifer, together with increasing ground-water withdrawals in excess of replenishment, has resulted in a decline of the water levels in the reservoir to record-low depths. The important provision necessary is that the withdrawals do not consistently remain in excess of the replenishments year in and year out. The aquifer has shown remarkable recoveries in the past after periods of heavy rainfall on the favorable recharge areas. Present studies including networks of rainfall and stream-flow stations and widely selected observation wells for recording water-level fluctuations (described earlier in this report), are aimed at the eventual determination of the average rate of recharge.

If water levels become progressively lower without increased withdrawals or if there is a disproportionate lowering as the result of an increase in withdrawal it may indicate that the perennial yield of the aquifer is being exceeded. Therefore, it is of utmost importance that accurate records be made periodically of withdrawals from an aquifer and of water levels in selected observation wells, and to study their relationship. Records of water levels are very important in areas of recharge to an aquifer to help estimate the amount of increment from rainfall and from streams and other bodies of surface water. Hydrologic studies in the San Antonio area are showing the intimate relationship of surface water to ground water. Ground-water withdrawals have contributed to the reduction of stream flow in some places; certain dams have stored surface water that has contributed to the Edwards limestone aquifer; and it is known that stream diversions along some stretches of certain streams could reduce the replenishment to the aquifer.

PROBLEMS IN QUALITY OF WATER

The value of a water supply for public and industrial uses, and for irrigation, is related directly to the chemical and physical properties of the water. Industry, for example, cannot operate unless this basic natural resource is available in satisfactory quality and sufficient quantity. Municipal water supplies must meet the minimum standards established by the States, many of which have adopted the standards specified by the U. S. Public Health Service for drinking water used on interstate carriers.

All natural waters contain dissolved mineral matter from their contact with soils and rocks, the amount depending primarily on the type of soils or rocks through which they have passed, the length of time of contact, and the pressure and temperature. In addition to these natural factors affecting quality, problems may arise from human activities such as the use of streams and wells for disposal of sewage and industrial wastes, drainage, and salt-water disposal from oil fields. In much of the San Antonio metropolitan area the Austin chalk and alluvial deposits form the land surface and sewage and other wastes have been allowed to enter them. In places, these formations have hydrologic connection with the Edwards limestone aquifer along the fault planes. When the head in the artesian reservoir has been lowered below the head in the overlying reservoirs, as during a prolonged drought together with heavy withdrawals such as is being experienced at the present time, a hazard of contamination develops.

Potable water is found in the outcrop of the Austin chalk in several places in central Bexar County. In other places, the Austin chalk yields water with a hydrogen sulfide odor, and it is believed to be the source of contamination in several wells ending in the Edwards limestone aquifer but not tightly cased through the chalk.

Problems in water quality exist downdip in the Edwards limestone aquifer in southern Bexar and Medina Counties in a belt that in general borders the main part of the Balcones fault zone on the south. In this part of the reservoir, in contrast to that part on the north which yields potable water, is found highly mineralized water having a strong odor of hydrogen sulfide. The water is not uniformly of poor quality, although analyses show that the chloride in several well samples is as high as 2,000 parts per million and the dissolved solids as much as 5,000 parts. In the southeast part of San Antonio within a mile of a large city well field occurs some of the most highly mineralized water found in the artesian reservoir. Its presence poses the danger of encroachment of salty waters into an important well field, should large pressure differentials be established by prolonged heavy withdrawals from the well field.

CONCLUSIONS

The Edwards limestone aquifer forms two immense ground-water reservoirs in the San Antonio area - one an unconfined water body on the Edwards Plateau in the northern part, and the other an artesian water body in the main Balcones fault zone. The hydrologic system on the plateau stores substantial amounts of rainfall and slowly pays it out as spring flow to the perennial streams which have cut their channels into or through the aquifer. The streams furnish practically continuous recharge to the artesian reservoir in the Balcones fault zone as they cross long stretches of honeycombed and cavernous limestone into which the entire normal flow is lost. Thus the artesian reservoir not only has its own storage facilities but also receives benefits of storage and regulation afforded by the system on the Edwards Plateau. In addition, recharge occurs also by direct penetration of rainfall and storm runoff in the favorable outcrop localities in northern Bexar, Medina and Uvalde Counties.

Results of these studies, supplemented by previous studies in the area, suggest that the immense artesian reservoir within the belt of faulting is a common source for the large springs (including Comal Springs at New Braunfels) and several thousand wells in the San Antonio area. The discharge of the springs, the flow or quiescence of the wells and springs in and near San Antonio, and the water levels in the non-flowing wells throughout the area vary with the volume of water in the reservoir. The magnitude of the reservoir is indicated by the uniform temperature and lack of turbidity of the water, and by the relation between water-level fluctuation in wells, rainfall, and the discharge of wells and springs. Any engineering projects constructed in such a way as to alter the present rate of recharge to the Edwards limestone aquifer will have a direct effect on the perennial yield of the aquifer at San Antonio as well as elsewhere along the fault zone.

During a 20-year period beginning in 1928, the stage of the artesian reservoir in the San Antonio area was in approximate equilibrium while the average rate of withdrawals in and around San Antonio was about 110 million gallons a day and Comal Springs had an average daily discharge of about 210 million gallons. Some additional water probably remained unaccounted for in other parts of Bexar County. Thus it is estimated that with average rainfall on favorable recharge localities the minimum perennial yield of the reservoir in central Bexar County and an adjacent part of Comal County is on the order of about 320 to 330 million gallons a day.

Although the Edwards is being put to a severe test by the heavy draft upon it which, coupled with severe drought of several years' duration, has resulted in considerable regional decline in storage, a large reserve of ground water is available. At San Antonio the water levels in July 1953 had declined to about 35 feet below the normal "spillway level" of San Pedro Springs. Except near the outcrop they still are several hundred feet above the top of the aquifer. In effect, lowering of the water levels in and around San Antonio has served as a natural measure of conservation in that the waste from spring flow and unregulated flowing wells that occurs during high stages of the reservoir has been curtailed, resulting in increased beneficial use of that part of the water supply.

The extensive limestone reservoir thus far has not been seriously overdrawn in spite of the fact that many readjustments are having to be made - such as lowering of pump bowls, drilling of additional wells, or, in outcrop localities, the deepening of private wells which originally penetrated only a few feet into the aquifer. Potentialities of the reservoir are very good, because it can be rapidly refilled to overflowing when the precipitation is favorable.

Important reserves of ground water lie in the Carrizo sand in and adjacent to the extreme southern part of the area of study in Atascosa, Frio, and Wilson Counties. These supplies are on the order of half a million to a million or more gallons a day per well of water of excellent quality. Withdrawal of any of this water for use at San Antonio would require extensive well fields and long pipelines. Large withdrawals, moreover, would have to be carefully planned so as to take into account current uses in districts downdip. Detailed quantitative studies are needed of the water-bearing characteristics of the Carrizo, particularly its generally known capabilities for rapid infiltration and the excellent possibilities for artificial recharge in several places on the outcrop.

The Glen Rose limestone in the northern part of the area, although generally considered a less productive aquifer, will require much detailed investigation, particularly in localities where geologic conditions (such as the reef zones) favor the occurrence of water. Further study is needed of the relation between the Glen Rose and Edwards in faulted places where there is a hydrologic contact and possibly important interchange of ground water. Other less productive aquifers will warrant further studies as the demand for small private supplies increases. The basal sands of the Trinity group are deeply buried and where tested, yield comparatively small quantities of highly mineralized warm water in the immediate vicinity of San Antonio.

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