Report 326

Evaluation of Water Resources in Bell, Burnet, Travis, Williamson and Parts of Adjacent Counties, Texas

January 1991

Texas Water Development Board

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Evaluation of Water Resources in Bell, Burnet, Travis, Williamson and Parts of Adjacent Counties, Texas

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ABSTRACT

This report is a summary of the results of an investigation of potential water supply and water quality problems conducted under the critical area program, Chapter 52 of the Texas Water Code, in Williamson and parts of adjacent counties in Central Texas. The purpose of the investigation was to determine if the study area is experiencing or is likely to experience within the next 20 years critical problems with ground-water supply or ground-water quality in the Edwards aquifer and the Trinity Group aquifer, and whether an underground water conservation district should be created in order to address such problems. The study was conducted jointly by staff of the Texas Water Development Board and the Texas Water Commission.

The study area consists of parts of six counties: Bastrop, Bell, Burnet, Milam, Travis, and Williamson. The study is bounded on the north by the Lampasas and Little Rivers, on the south by the Colorado River, on the west by the updip limit of the outcrop of the Travis Peak Formation, and on the east by the downdip limit of fresh to slightly saline water (3,000 milligrams per liter dissolved solids) in the lower member of the Trinity Group aquifer. The study area contains portions of both the Trinity Group and Edwards aquifers covering 2,710 square miles with a 1985 estimated population of 457,039. Some cities in the study area include Austin, Round Rock, Georgetown, Taylor, Burnet, Salado, Cedar Park, Leander, Elgin, and Manor. The economy is primarily industrial and commercial in the area near Austin, with farming and ranching the primary activities in the remainder of the study area.

The principal aquifers in the study area are the Trinity Group aquifer and the Edwards aquifer, both of Cretaceous age. The Wilcox aquifer, which is also a major aquifer, supplies water to only a small part of the study area in Bastrop County. Minor aquifers in the area are the Ellenburger Group and the Marble Falls LImestone in Burnet County, and alluvium and terrace deposits associated with the Colorado River in Travis County. Other geologic units in the study area are known to yield small amounts of water to domestic and livestock wells.

The Trinity Group aquifer yields small to moderate amounts of water to wells due to relatively low permeabilities in the western part of the study area. Yields are greater in the eastern half of the study area, because of increased thickness and decreased cementation in the aquifer's lower unit. Discharge from well pumpage in the Trinity aquifer in 1985 was 7,705 acre-feet. The estimated ground-water availability from the Trinity in the study area is 6,700 acre-feet per year.

Quality of ground water available in the Trinity aquifer ranges from fresh to slightly saline, often with high levels of iron, hardness, fluoride, sodium bicarbonate, and dissolved solids. Water quality typically deteriorates in a downdip direction as a result of impaired circulation.

Availability of water in the Edwards aquifer is limited. The amount of water available from storage in the aquifer is not known, but is

considered to be small due to the low average porosity. Another indication of low storage capability is the rapid and significant decline of water levels in wells during period of low recharge or high pumpage. The availability of ground water under drought conditions is calculated to be 7,464 acre-feet annually, and is based on the amount of springflow plus well pumpage during a drought of record. In 1985, approximately 15,919 acre-feet of ground water was pumped from the Edwards aquifer.

Water quality in the Edwards aquifer is good, generally less than 500 mg/l dissolved solids along the Interstate Highway 35 corridor area. Ground water in the Edwards becomes more mineralized downdip in the aquifer toward the east. Water quality deteriorates rapidly within a relatively short distance, with increases in sulfate, chloride, and dissolved solids.

Ground-water problems in the study area include a lack of reliable supplies for both short-term drought demand and long-term economic development. During late summer dry spells and drought, water levels drop quickly in the Edwards aquifer due to low area-wide storage and low permeabilities in the Trinity. Current utilization of both aquifers exceeds the amount projected for a long-term safe yield (drought reliable) supply. Water quality in both aquifers in the eastern portion of the study area presents problems for public supplies. High concentrations of sulfate, chloride, fluoride, and dissolved solids often do not meet Texas Department of Health standards for public water supply systems.

An underground water conservation district is not the most appropriate management approach for the study area at this time. The increasing reliance on surface water presents issues which are generally outside the purview of ground water districts. Most of the water resource problems can be addressed through existing entities. The varied interests in the area preclude the consolidation of political support needed to create a district. Finally, many area residents indicated that they would not support an additional taxing entity.

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INTRODUCTION

Purpose and Scope

In 1985, the Texas Legislature recognized that certain areas of Texas were experiencing, or would experience in the foreseeable future, critical underground water problems including water shortages, significant declines in water levels, underground water contamination including saltwater intrusion, and waste of ground water. To address this problem, House Bill (H.B.) 2 was enacted by the Sixty-ninth Legislature which changed the procedures for creating locally controlled underground water conservation districts. Such districts allow underground water problems to be solved by local management. H.B. 2 authorized the Texas Department of Water Resources (now divided into two agencies - the Texas Water Development Board and the Texas Water Commission) to designate such areas as Critical Areas and initiate district creation.

In February 1987, a study area was initiated to identify the existing water problems in the study area using a joint team representing the Texas Water Commission and the Texas Water Development Board.

The report presents a summary of the available hydrogeologic data and a discussion of the occurrence and use of ground water in the study area. Problems associated with ground-water use and with the impact of man's activities are also discussed. The report also contains all the maps and figures developed for the report.

A discussion on the occurrence and availability of surface water, along with the results of projections of future population and water requirements, and conclusions regarding the extent and severity of water supply and ground water quality problems are presented.

Location and Extent

The study area as shown in Figure 1 includes portions of Bastrop, Bell, Burnet, Milam, Travis, and Williamson Counties and has an areal extent of approximately 2,710 square miles. The area is bounded on the south by the Colorado River; on the west by the updip limit of the outcrop of the Travis Peak Formation just west of Burnet, Texas; on the north by the Lampasas-Burnet County line, then along the Lampasas River, Stillhouse Hollow Lake, and Little River; and on the southeast by the downdip limit of slightly saline water in the Trinity Group aquifer.

Topography, Soils, and Vegetation

Most of the land surface expressions in the study region are the result of stream erosion of relatively flat or gently dipping rocks that are exposed on the surface. Along its southern and eastern edges, the region has gently rolling prairies with low relief and a well developed, dendritic drainage. Soils here consist of dark calcareous clays, sandy loams, and clay loams in the uplands, while dark gray to reddish-brown calcareous clay loams and clays are found in the bottomlands. Vegetation in the uplands consists of tall bunch grasses and scattered mesquite; white elm, hackberry, and pecan are usually found in the bottomlands.

The region overall has moderately high relief with tabular divides, small limestone capped mesas, sharp-cut valleys, and a thorough dendritic drainage. The soils are dark, stony, shallow to deep calcareous clays in the uplands and reddish-brown to dark gray clay loams and clays in the bottomlands. Tall bunch grasses, scattered mesquite, some live oak, and cedar grow in the uplands while oak and juniper are also found in the bottomlands.

Elevations range from slightly under 350 feet along the Little River in Milam County to the southeast to slightly over 1,500 feet above mean sea level in Burnet County to the northwest. Drainage is to the southeast by the Lampasas, Little, San Gabriel, and Colorado Rivers and their tributaries.

Climate

The climate of the region covered by this report is characterized by long, hot summers and short, mild winters. The average minimum temperature for January, the coldest month, ranges from 37° F (3° C) in the northwest to 41° F (5 ° C) in southeast. The average maximum temperature for July, the warmest month, is 96° F (36° C) throughout most of the study region. The average annual temperature for the period 1951-1980 ranged from 66° F (19° C) in the northwest to 68° F (20° C) in the east (Carr, 1967).

The average annual precipitation ranges from 28 inches in the west to 35 inches in the east. These figures are based on National Weather Service records for the 30-year period, 1951-1980. The average annual gross lake-surface evaporation for the period 1940-1965 ranged from 60 inches in the east to 80 inches in the northwest (Kane, 1967).

Population and Economy

In 1985, approximately 457,000 people lived within the region covered by this report. This represented about 2.8 percent of the 1985 State's population. Almost 78 percent of the region's population lived in urban areas having 1,000 or more inhabitants in 1985. Some of the urban areas are the Cities of Austin, Bartlett, Burnet, Cedar Park, Elgin, Georgetown, Granger, Leander, Manor, Round Rock, and Taylor. The remaining inhabitants lived in rural areas or smaller communities. The counties within the study area provide many widely varied interests and pursuits. The principal ones are education, research and science-oriented industries, recreation, armed forces, government, and agriculture. The University of Texas at Austin main campus and several smaller colleges are located within the study area.

The principal manufacturing plants are in or near larger cities; however, some plants in smaller cities process local products, especially those related to agriculture. Diversified manufactured goods include computer equipment, plastics, furniture and clothing. Austin, although having light industry, derives a large part of its economy from the activities of State and other governmental entities. Killeen, just north of the study area, is the home of Fort Hood, the largest free world armored post.

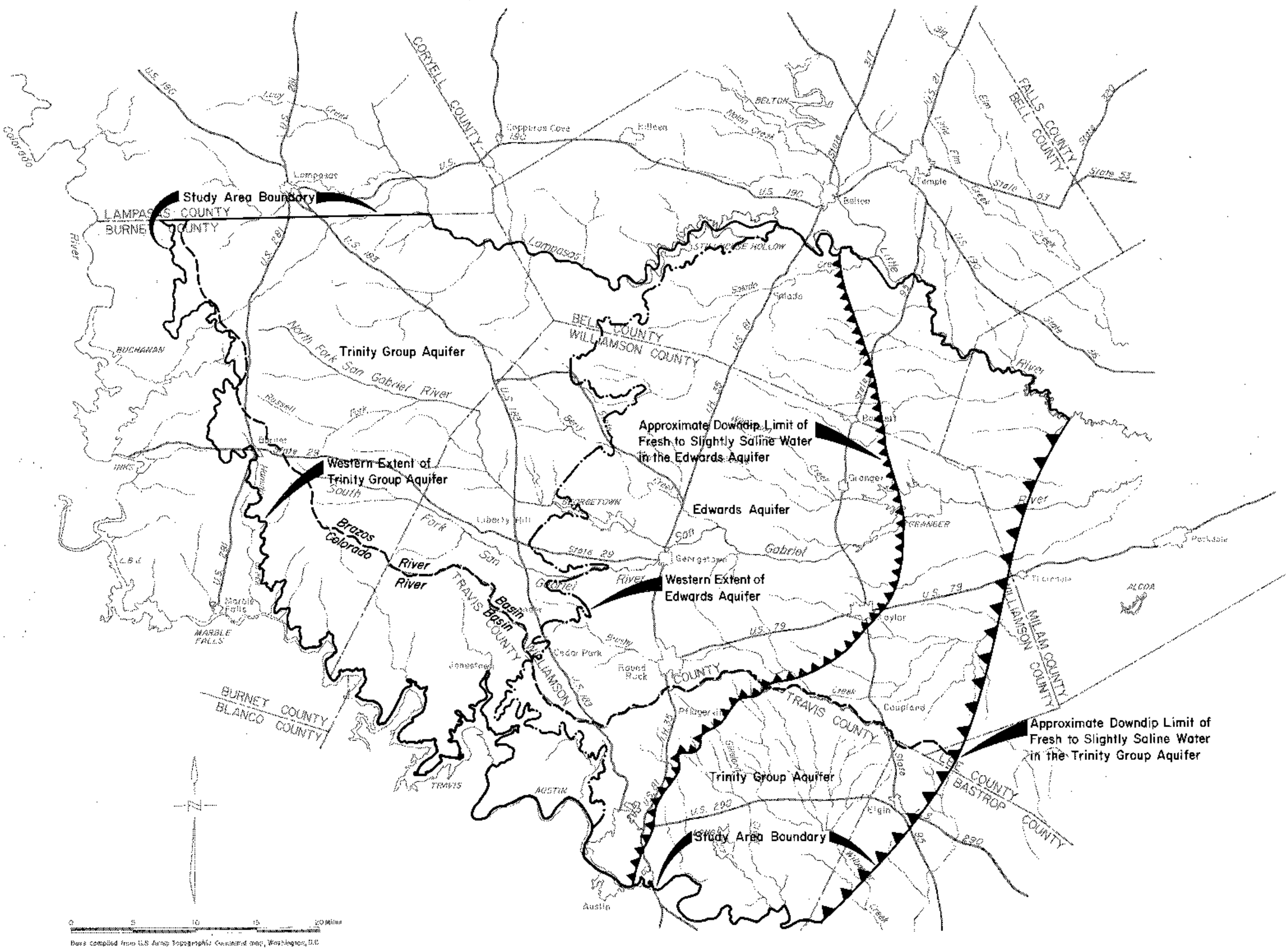

Figure 1
Boundary of Study Area and Extent of the
Trinity Group and Edwards Aquifers

Agriculture also contributes to the economy of the study area. Farming includes raising various small grains, garden and truck vegetables and fruits, peanuts, and various types of livestock. Dairy farming is practiced throughout the region and is of local importance. Ranching consists of raising cattle, goats, hogs, and sheep.

Industrial activities include the production of lime, stone, sand, and gravel. Several quarries produce building stones, lime for agriculture, and crushed stone for highway construction and other uses. A number of sand and gravel pits operate in the alluvium and terraces along the Colorado River. Some oil and gas are also produced within the study area.

One of the valuable natural resources within the study area lies in the recreational value of the Hill Country and its associated lakes and springs. Lake Travis, Lake Austin, Town Lake, Inks Lake, Lake Georgetown, Granger Lake, and Stillhouse Hollow Lake provide recreation for many people.

Previous Investigations

Portions of the study region have been described in previous publications related to geology and ground-water resources. Some of the investigations leading to these publications were conducted by the U. S. Geological Survey, Texas Water Development Board, Bureau of Economic Geology of the University of Texas at Austin, private concerns, educational institutes, and individuals fulfilling partial requirements for advanced degrees. Texas Water Development Board Reports 195 and 293, and Texas Department of Water Resources Report 276, are the primary reports used during this investigation.

In addition to the above publications, several reports describing the geology and ground-water resources in areas smaller than counties have been prepared from time to time. The most important ones are listed in the selected references at the end of the report.

Acknowledgments

The Texas Water Development Board and Texas Water Commission are indebted to the property owners within the study area who permitted access to their properties and supplied information concerning their wells and to water well drillers, city officials, water superintendents, officials of independent water districts, and consultants, for information, assistance, and cooperation rendered throughout this investigation. The cooperation of federal and other State agencies is also gratefully acknowledged.

GEOHYDROLOGY

Stratigraphy and Structure of the Water-Bearing Units

Stratigraphic units that contain usable water in portions of the study area range in age from the Ordovician Ellenburger Group to Recent alluvium. Of these, the most important water-bearing units are of Cretaceous age. Table 1 summarizes the approximate maximum thickness, lithologic characteristics, and water-bearing properties of these units.

The structural features most affecting the Cretaceous and Tertiary Systems are the erosional surface upon which beds in these systems were deposited, the Bend Arch and Llano Uplift on the west, the McGregor High near the town of McGregor located southwest of Waco in McLennan County, and the Balcones and Luling-Mexia-Talco Fault Zones which are approximately parallel and pass in a slightly northeasterly trend through the eastern part of the study area. The regional structure and generalized geologic outcrops are shown in Figure 2.

The irregular erosional surface upon which Cretaceous formations were deposited generally slopes to the east and southeast. This surface consists of rocks belonging to the Permian, Pennsylvanian, and pre-Pennsylvanian Systems in the western part of the area, the Pennsylvanian System in the west-central part, the Ouachita folded belt in the east-central part, and the Jurassic System in the eastern part. The ridges and valleys which make up the pre-Cretaceous surface had a direct effect upon the lower Cretaceous deposition in that thicker accumulations of sediments were laid down in the valleys and thinner accumulations on the ridges such as the McGregor High, where the Hosston Formation (lower Cretaceous) is absent or markedly thinner than in surrounding areas.

On the west, the Llano Uplift and the Bend Arch also had an effect upon sediments containing the Cretaceous aquifers. The Llano Uplift, a structural dome with a core of igneous and metamorphic rocks, stood as an island during lower Cretaceous deposition. It acted as a source of sediments, and affected the depositional environment of the Cretaceous rocks immediately east of the Uplift area. Meanwhile, extending north as an "arm" off the Llano Uplift area, the Bend Arch area received marginal facies lower Cretaceous sediments of conglomerates, sands, and sandy shales, followed by limestones and marls as Cretaceous seas advanced.

The Balcones Fault Zone extends from Travis County through Waco to Hill County. The Luling-Mexia-Talco Fault Zone approximately parallels the Balcones Fault Zone on the east and extends from Bastrop County northeasterly through central Limestone County. The Balcones Fault Zone has produced displacements of 400 feet or greater. The Luling-Mexia-Talco Fault Zone has produced displacements of 700 feet and more. These displacements may cause blockage or restriction of ground-water movement downdip, and also may contribute to contamination by allowing poor quality water to enter along fault planes. These undesirable conditions probably affect Cretaceous aquifers over a greater area than those in the Tertiary. The western boundary of the Luling, Mexia-Talco Fault Zone appears

Table 1
Geologic Units and Their Water-Bearing Properties

System	Series	Group	Stratigraphic Unit	Hydrologic Unit	Maximum Thickness (feet)	Character of Rocks	Water-bearing Properties *
Quaternary	Recent		Alluvium	Alluvium and terrace deposits	60	Water-stratified deposits of unconsolidated calcareous gravel, sand, silt and clay, with coarser materials usually concentrated in the lower section.	Yields small to very large quantities of fresh to slightly saline water chiefly along the Colorado River in eastern Travis County.
	Pleistocene		Terrace deposits		60	Water-stratified deposits of unconsolidated calcareous gravel, sand, silt and clay, with the coarser materials at the base.	Yields very small to moderate quantities of fresh to moderately saline water.
			High gravel		20	Gravel and sand, sometimes mixed with clay from underlying formations.	
Tertiary	Eocene	Wilcox	Simsboro Sand Member	Wilcox	200	Fine-to-coarse sand and sandstone, sandy clay, with lenses of limestone and lignite.	Yields small to moderate quantities of fresh to moderately saline water.
		Midway		Midway	300	Clay, silt, glauconitic sand, and thin beds of limestone and sandstone with gypsum.	Yields very small quantities of fresh to moderately saline water.
Cretaceous	Gulf	Navarro Taylor		Navarro and Taylor Groups	820	Massive beds of shale and marl with clayey chalk, clay, sand and some nodular and phosphatic zones.	Yields very small quantities of fresh to moderately saline water
		Austin		Austin Chalk	425	Massive beds of chalk and marl with bentonitic seams, glauconite and pyrite nodules.	Yields small to very small quantities of freshwater.
	Comanche	Eagle Ford			30	Massive calcareous shale with thin interbeds of silty and sandy, flaggy limestone.	Not known to yield water in the study area.
		Washita	Buda Limestone		50	Massive, fine-grained, burrowed, shell-fragment limestone. The upper portion is harder and bluff forming.	Not known to yield water in the study area.
			Del Rio Clay		60	Clay and marl with gypsum, pyrite and a few thin siltstone and sandstone beds.	Not known to yield water in the study area.
			Georgetown Formation	Edwards and associated limestones	90	Thin interbeds of richly fossiliferous, nodule, massive, fine-grained limestone and marl.	Yields small to very large quantities of freshwater, especially from caverous zones in the Edwards limestone.
		Fredericksburg	Kiamichi Formation		15	Marl, thin limestone seams, clay, and shell aggregates.	Not known to yield water in the study area.
			Edwards Limestone		185	Massive, brittle, vugular limestone and dolomite with nodular chert gypsum, anhydrite and solution-collapse features.	Yields small to very large quantities of freshwater, especially from cavernous zones.
			Comanche Peak Limestone		50	Fine-grained, fairly hard, nodular fossiliferous marly, extensively burrowed limestone.	Yields little or no water in the study area.
			Walnut Formation		110	Hard and soft limestones, marls, clays, and shell beds.	Yields little or no water in the study area.
		Trinity	Paluxy Formation	Upper Trinity	10	Fine-grained quartz sand, in part indurated by calcium carbonate cement. Locally contains thin beds of limestone and marl.	Yields very small to moderate quantities of fresh and occasionally slightly saline water.
			Glen Rose: Upper Member		430	Alternating beds of limestone, dolomite, shale, and marl with some anhydrite and gypsum.	
			Glen Rose: Lower Member	Middle Trinity	430	Massive, fossiliferous limestone and dolomite in the basal part grading upward into thin beds of limestone, shale, marl and gypsum. Corbula martinae bed at top.	Yields very small to moderate quantities of fresh to moderately saline water in the study area.
			Travis Peak: Hensell Sand Member		75	Sand gravel, conglomerate, sandstone, siltstone, and shale in western Travis County. Grades into sandy limestone and dolomite in eastern Travis County.	
			Travis Peak: Cow Creek Limestone Member		80	Massive, often sandy, dolomitic limestone, frequently forming cliffs and water falls. Contains gypsum and anhydrite beds.	
			Travis Peak: Hammett Shale Member		30	Shale and clay with some sand, dolomite limestone in eastern Travis County. Grades into sandy limestone and dolomite in eastern Travis County.	Not known to yield water in the study area.
			Travis Peak: Sligo Member	Lower Trinity	140	Limestone, dolomite, occasionally sandy and shale. Thins to the west and is not present in northwest Travis County	Yields small to moderate, and with acidizing large quantities of fresh to moderately saline water.
			Travis Peak: Hosston Member (Sycamore Sand in outcrop)		815	Basal sand and conglomerate grading upward into a mixture of sand siltstone, and shale with some limestone beds.	
Pennsylvanian	Lower Pennsylvanian	Strawn			800	Alternating beds of sandstone and shale with some conglomerates.	Not known to yield water in the study area.
		Bend	Smithwick Shale		500	Shale with sandstone and siltstone in the upper portion. Metamorphosed to phillites and quartzites, lies the Ouachita Fold Belt.	Not known to yield water in the study area.
			Marble Falls Limestone		400	Cavernous, massive siliceous, fossiliferous limestone.	Yields small to moderate amounts of usable quality water in Burnet and Lampasas Counties.
Ordovician	Lower Ordovician	Ellenburger			1,500	Cavernous crystaline, fossiliferous limestone and dolomite.	Yields small to moderate amounts of usable quality water in Burnet and Lampasas County.

* **Yields of Wells:** Small – less than 25 gallons per minute (gpm)
Moderate – 25 to 200 gpm
Large – more than 200 gpm

Chemical Quality of Water: Fresh - less than 1,000 milligrams per liter (mg/l)
Slightly Saline – 1,000 to 3,000 mg/l
Moderately Saline - 3,000 to 10,000 mg/l
Very Saline – 10,000 to 35,000 mg/l

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to be a controlling factor in the downdip limit of fresh to slightly saline water occurring in the lower Cretaceous aquifers.

Cretaceous formations dip east-southeast at a rate of about 15 feet per mile in the northwest part of the study area. This dip rate increases to as much as 200 feet per mile east of the Balcones and Luling-Mexia-Talco Fault Zones.

Tertiary beds lie on an erosional surface sloping southeastward over rocks belonging to the Cretaceous age. Dip rates vary from 100-200 feet per mile toward the southeast except in fault blocks within the Luling-Mexia-Talco Fault Zone. The attitude of the fault blocks determines the rate and direction of the dip of the beds which in turn affects the rate and direction of movement of the ground water. Also, the faulting may subject ground water in these beds to contamination by providing a direct passageway along the fault planes for surface water runoff to enter the aquifers.

Those formations or stratigraphic units which are exposed at the surface are shown on the geologic map on Figure 3. The geologic units generally crop out in northeast-southwest trending bands. However, in western Travis County, where topographic relief is prominent, the outcrops of the various units are controlled principally by surface elevation.

Geological sections (Figures 4 through 7) show the stratigraphic relationship and structural attitude of each unit. Two of the sections (Figures 5 and 7) are oriented in a downdip direction and two (Figures 4 and 6) lie along the strike of the formations.

Trinity Group Aquifer

Due to their hydrologic relationships, the water-bearing rocks of the Trinity Group aquifer have been organized into the following aquifer units: (a) the lower Trinity aquifer consisting of the Hosston and Sligo Members of the Travis Peak Formation; (b) the middle Trinity aquifer consisting of the Cow Creek Limestone and Hensell Sand Members of the Travis Peak Formation; and the lower Glen Rose Formation; and (c) the upper Trinity aquifer consisting of the upper member of the Glen Rose Formation and the Paluxy Formation.

Lower Trinity

Stratigraphic units which make up the lower Trinity aquifer, in ascending order, are the Hosston and Sligo Members of the Travis Peak Formation (Table 1).

Total thickness of the lower Trinity aquifer ranges from less than 100 feet in Lampasas County to over 900 feet in the downdip area in Milam County. The thickening of the Hosston and Sligo is well illustrated in Figure 5.

Regionally, beds of the lower Trinity aquifer dip east-southeast (Figure 8). In the vicinity of the Balcones Fault Zone, the dip may be much steeper.

The calcareous facies of the Travis Peak Formation consists of a lower calcareous conglomeratic unit, a middle calcareous unit, and an upper

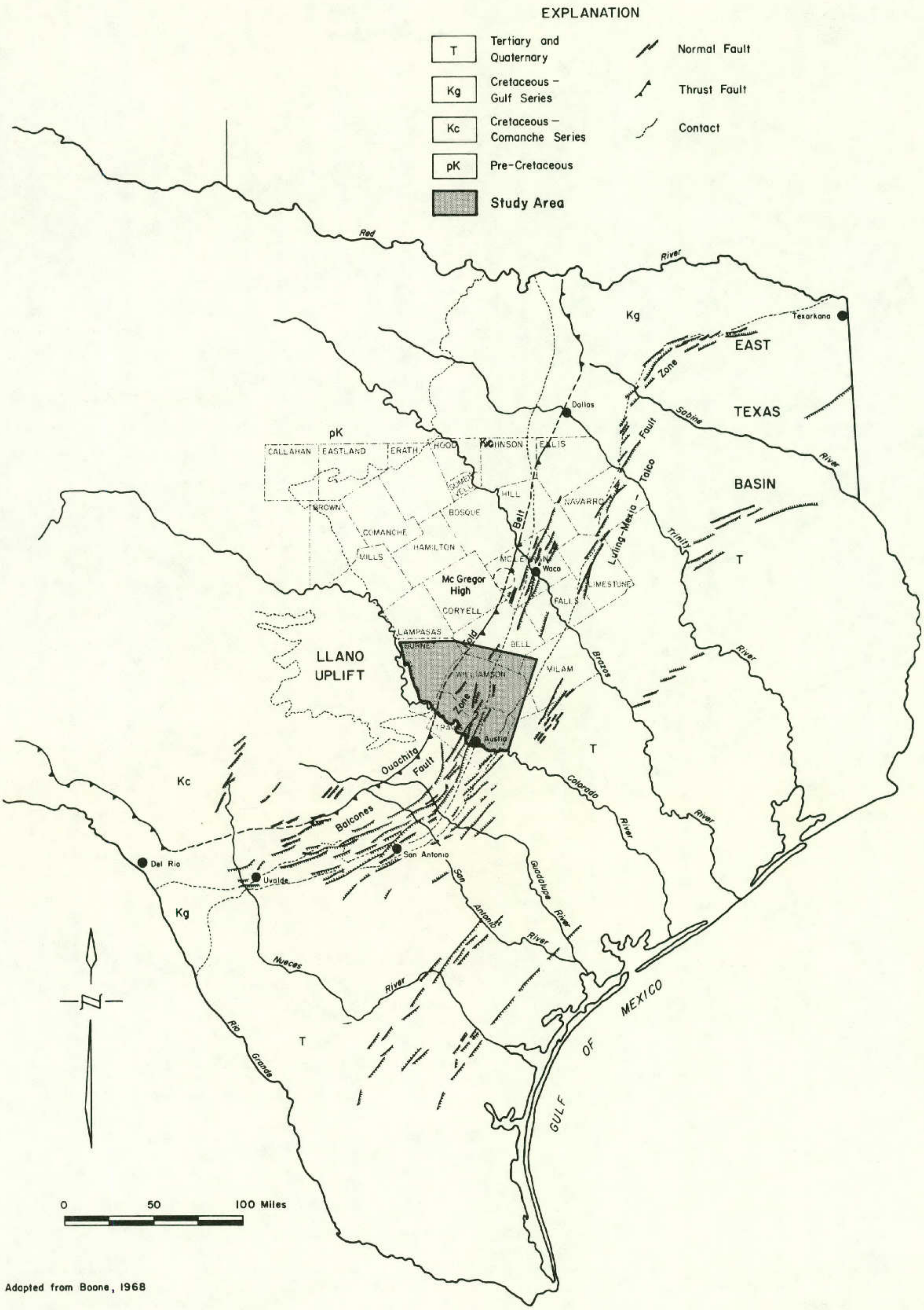


Figure 2
Regional Structure and Generalized
Geologic Outcrops

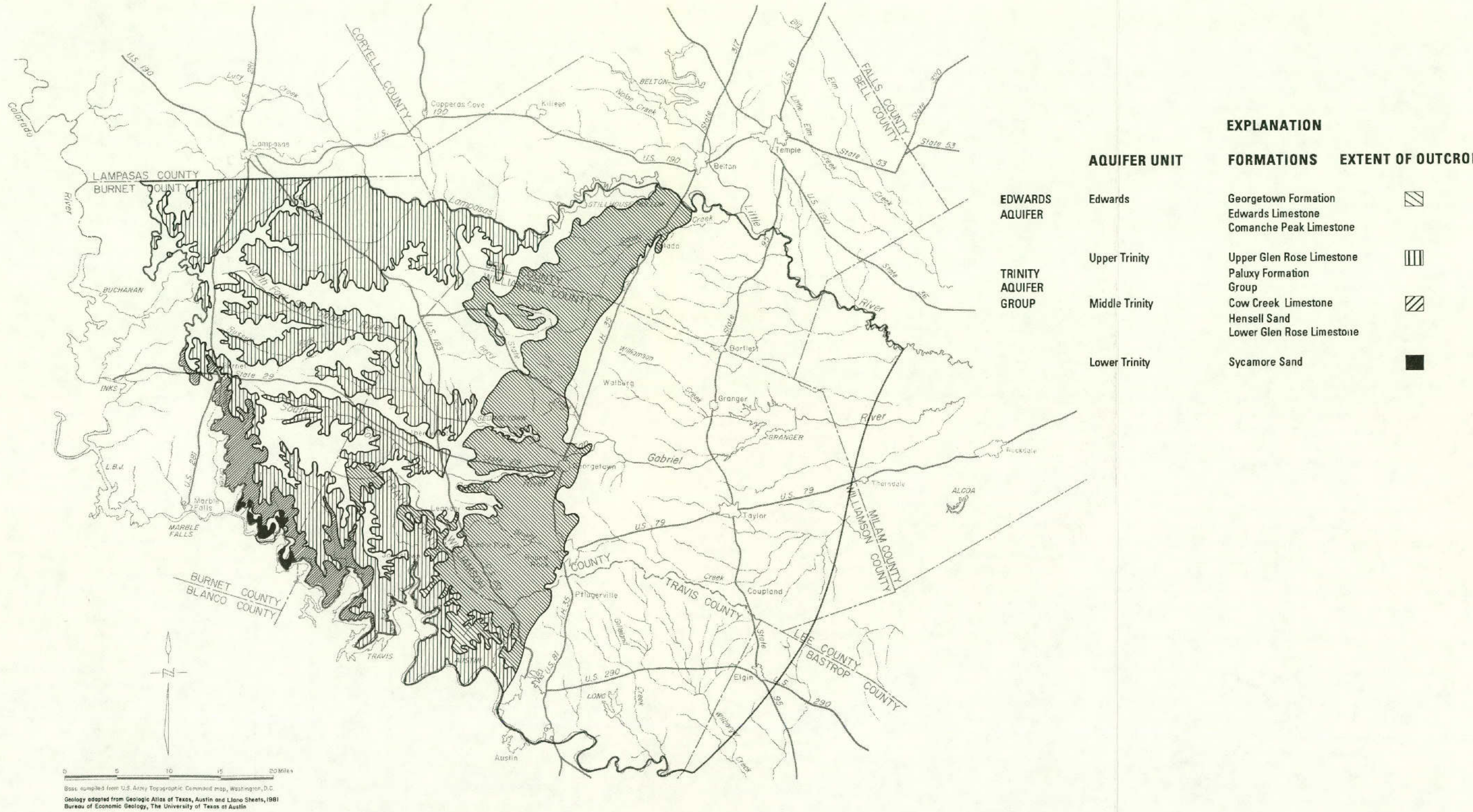


Figure 3
Geologic Map of the Study Area Showing the Trinity Group and Edwards Aquifers

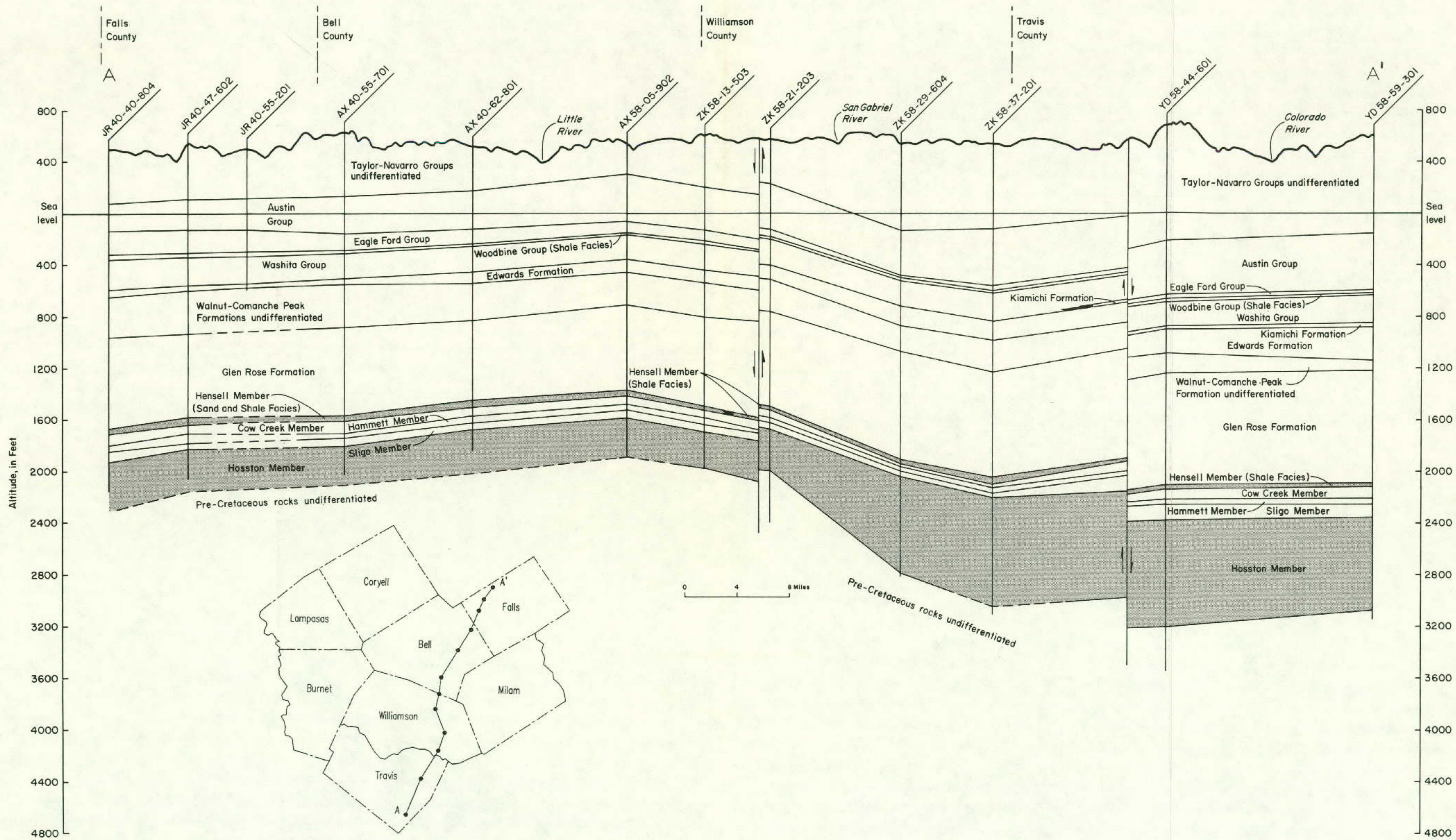


Figure 4
Geologic Section A-A', Falls, Bell, Williamson and Travis Counties

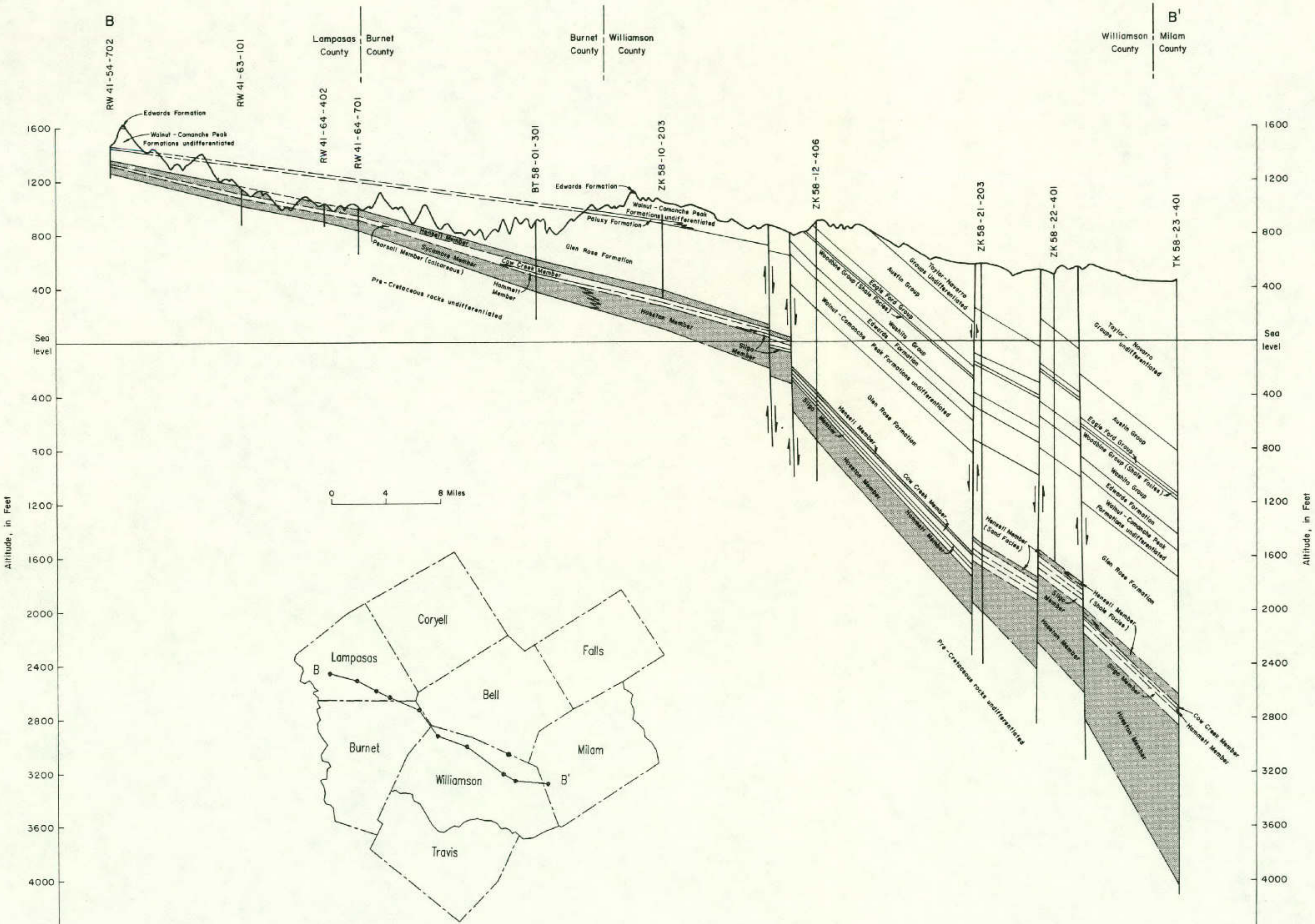


Figure 5
Geologic Section B-B', Lampasas, Burnet, Williamson and Milam Counties

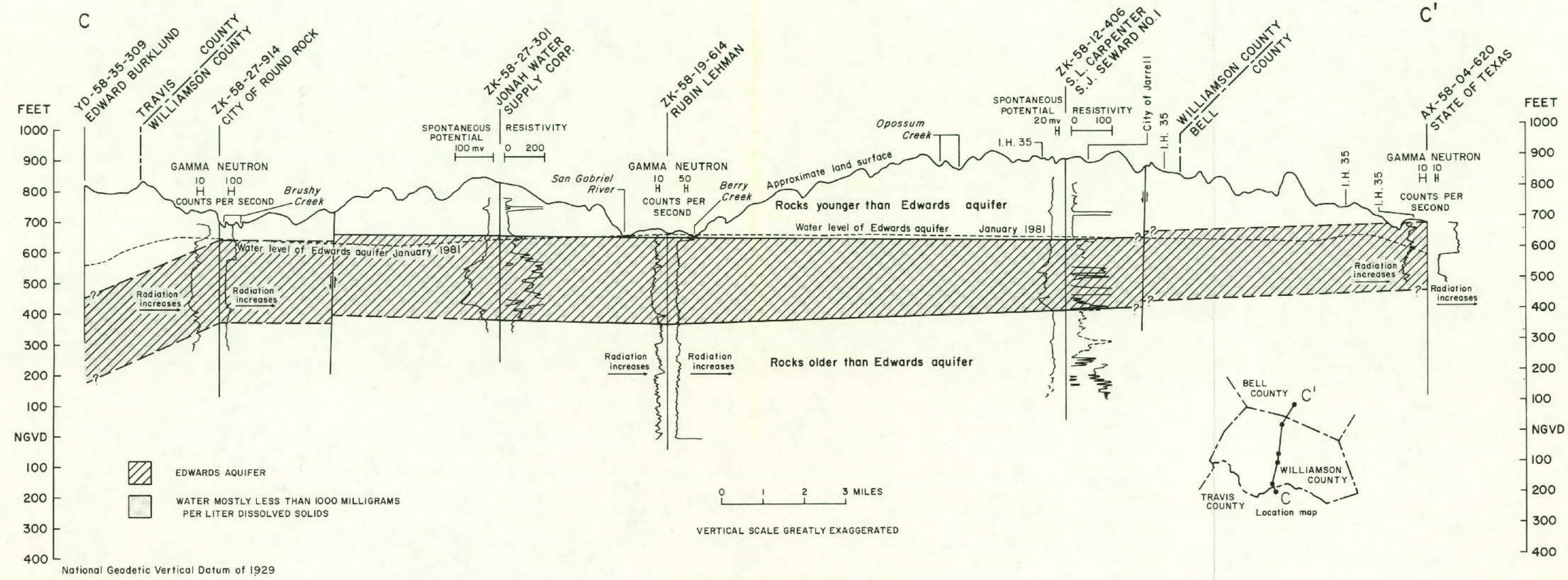


Figure 6
Geologic Section C-C', Through Williamson and Southern Bell Counties

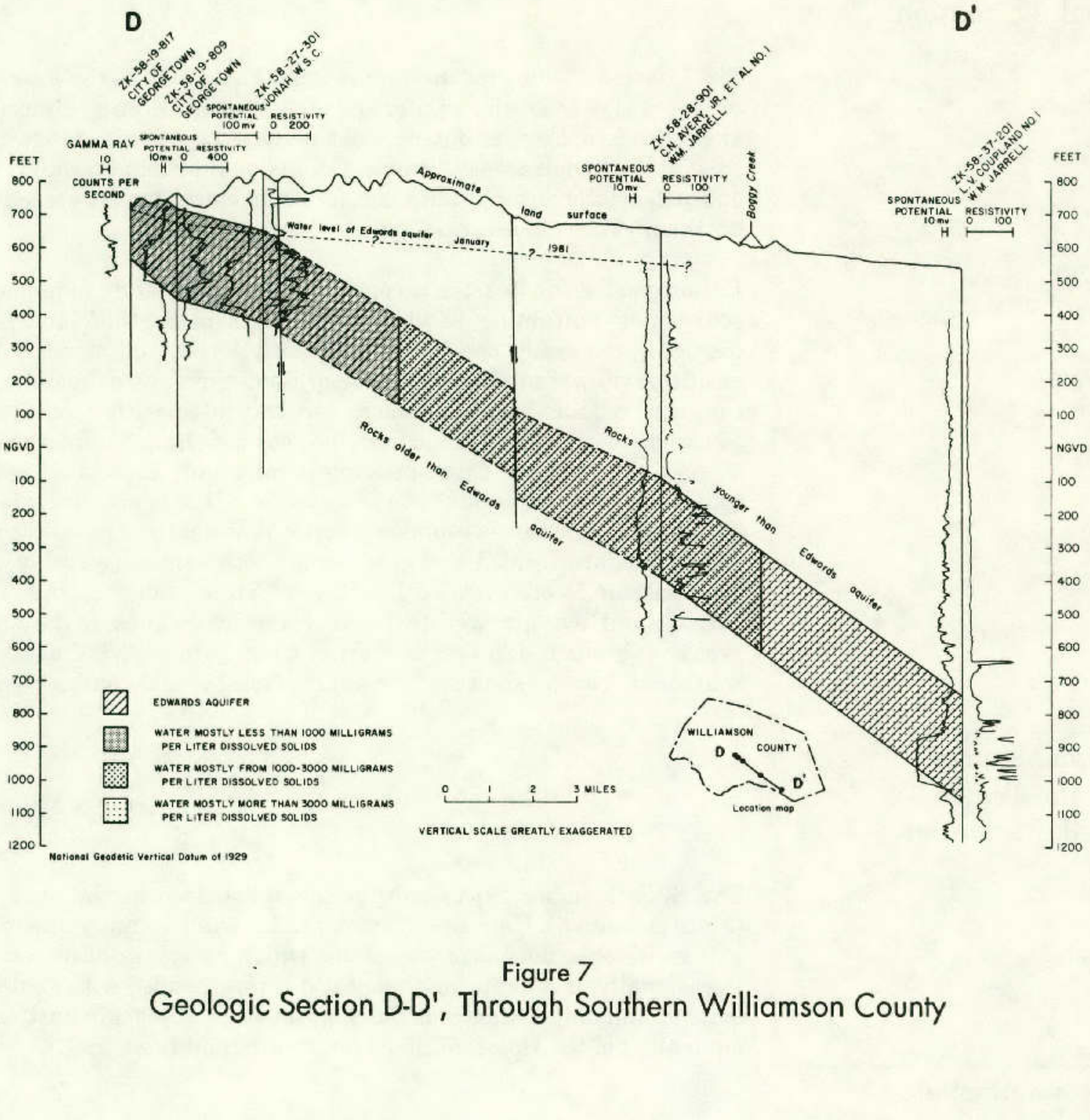


Figure 7
Geologic Section D-D', Through Southern Williamson County

calcareous clastic unit. The lower unit is a conglomerate consisting of limestone and dolomite pebbles with a calcareous cement and is named the Sycamore Sand Member in the outcrop (equivalent to the Hosston Member) is the subsurface downdip. The calcareous facies of the Travis Peak Formation occurs in Bell, Burnet, Lampasas, and Williamson Counties as shown in Figures 8 through 11.

Hosston Member of the Travis Peak Formation

The Hosston Member of the Travis Peak Formation is the lowest rock unit of the lower Trinity aquifer and is equivalent to the Sycamore Sand at the surface. Surface outcrops of the Sycamore Sand are scarce and exist only in small areas of Burnet County as shown in Figure 3. In the subsurface, the lower Trinity aquifer or its equivalent is present from northeast Texas to central Texas.

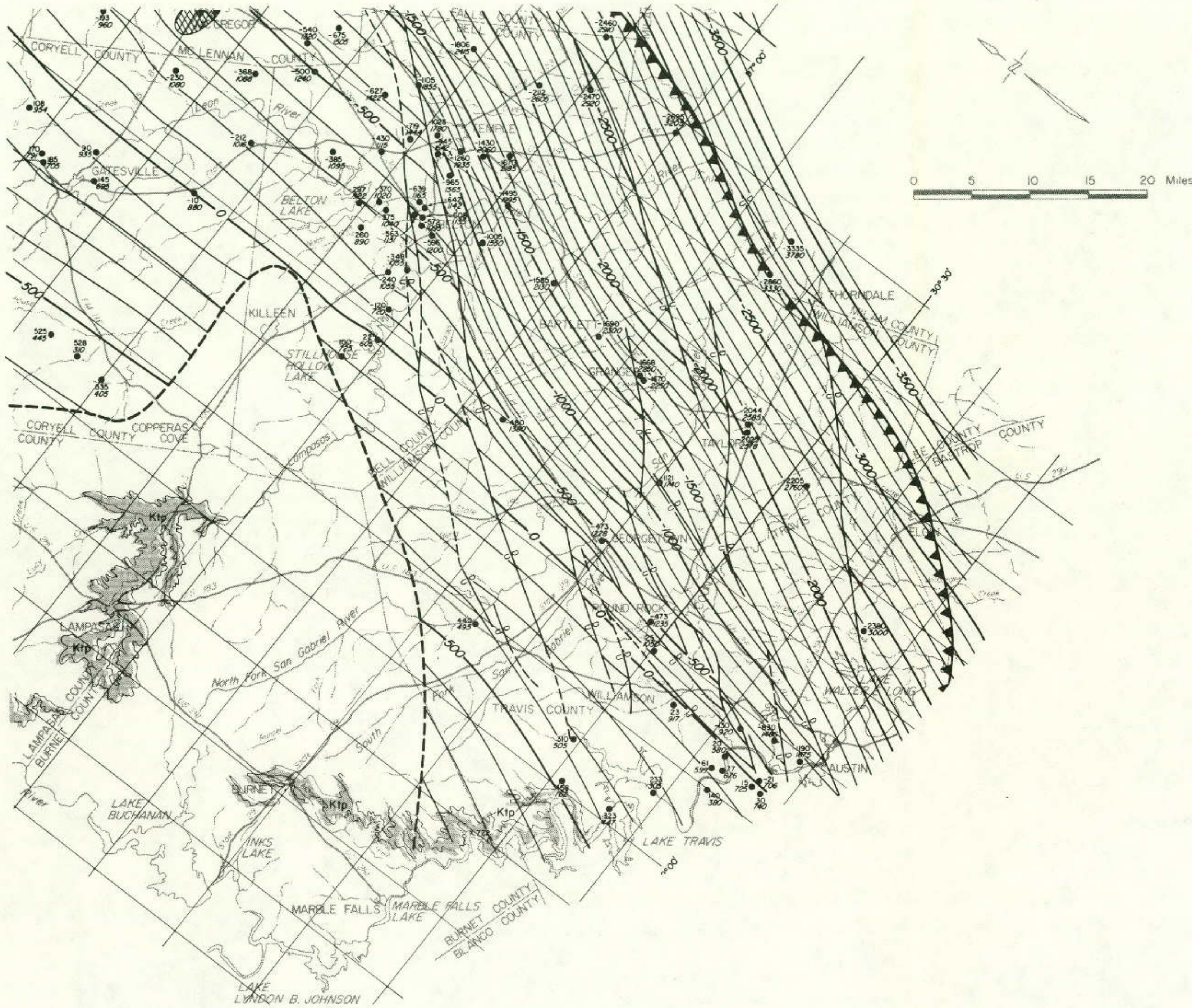
Lithologically, the Hosston is composed of pebbly, sandy conglomerate, sometimes containing sandstone boulders more than one foot in diameter, generally poorly sorted, multicolored, and cemented with calcite or silica; fine- to very course-grained sand and sandstone, gray, tan, and reddish-brown in color, and cemented with calcite or less commonly with silica cement; variously colored shales; and occasionally streaks of limestone. Cross-bedding is commonly associated with the conglomerate beds, and the sand ranges from thin to massively bedded. The conglomerate beds commonly occur at or near the base. Clays and shales are interbedded and gradational both vertically and laterally. The Hosston is often called the "lower Trinity sand" or the "second Trinity sand" by water well drillers. It varies in thickness in the downdip areas from about 125 feet in Burnet County to over 800 feet in the southeast. The net sand thickness of the Hosston is shown on Figure 10.

Sligo Member of the Travis Peak Formation

The Sligo Member exists only in the subsurface in the study area (Figures 4 and 5). Here the Hosston grades transitionally upward into a fossiliferous, dolomitic limestone which is crystalline to chalky. Occasionally, it is sandy or shaley and is interbedded with shale. This transitional unit is known as the Sligo and it is, at least in part, the age equivalent of the Hosston (Stricklin, Smith, and Lozo, 1971).

Hammett Shale Member of the Travis Peak Formation

The Hammett Shale Member of the Travis Peak Formation is impermeable and acts as a hydrologic barrier which separates the lower and middle Trinity aquifers (Table 1). The Hammett is the result of the second transgressive marine phase which covered the Sligo and the eroded surface of the Hosston with shaley marine sediments. The Hammett is predominantly a shale, gray to buff in color, with some dolomitic limestone in the upper part. Its dip corresponds generally with that of the Sligo and Hosston Members, and the unit has a relatively constant thickness.



EXPLANATION

950
430
Well used for control
Top number indicates altitude of top of the Hosston Member, in feet above or below (–) mean sea level
Bottom number indicates depth to top of the Hosston Member, in feet below land surface

×
1000
Outcrop control point
Number indicates altitude of top of the Hosston Member, in feet above mean sea level

900
Line showing approximate altitude of top of the Hosston Member
Interval 100 feet
Datum is mean sea level

Outcrop of Travis Peak (Ktp) Formation

Approximate area where the Hosston Member is not present

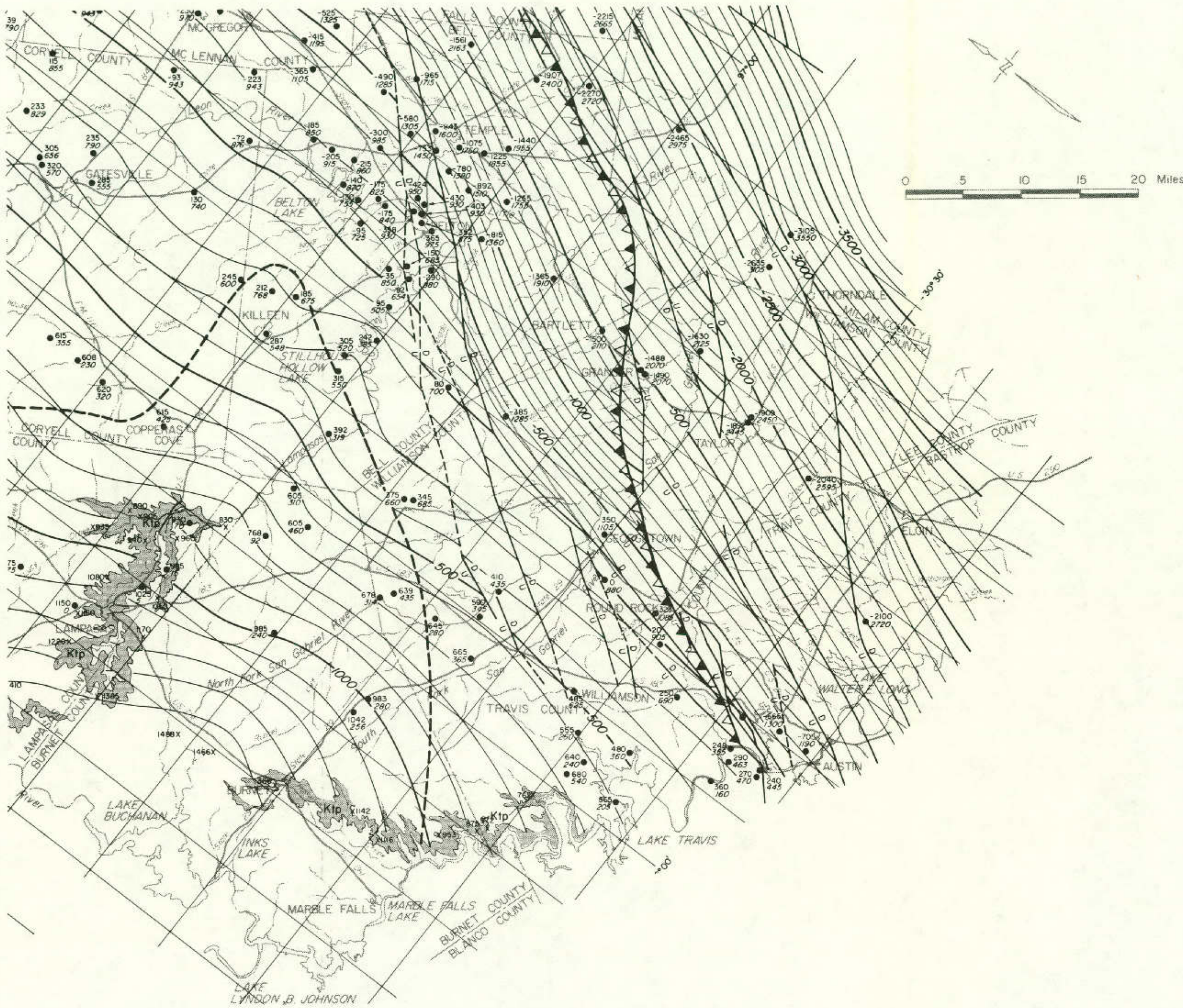
Contact
Dashed where covered or approximately located

U D
Fault
U, upthrown side; D, downthrown side
Dashed where approximately located

Approximate downdip limit of fresh to slightly saline water in the Hosston Member

Approximate eastern limit of the calcareous facies of the Travis Peak Formation

Figure 8
Approximate Altitude of and Depth to Top of the Hosston Member of the Travis Peak Formation



EXPLANATION

•
-895
1500
Well used for control
Top number indicates altitude of top of the Travis Peak Formation, (top of Hensell Member and top of calcareous facies), in feet above or below (-) mean sea level
Bottom number indicates depth to top of the Travis Peak Formation, in feet below land surface

×
1050
Outcrop control point
Number indicates altitude of top of the Travis Peak Formation, in feet above mean sea level

900
Line showing approximate altitude of top of the Travis Peak Formation
Interval 100 feet
Datum is mean sea level

Outcrop of Travis Peak (Ktp) Formations

Contact
Dashed where covered or approximately located

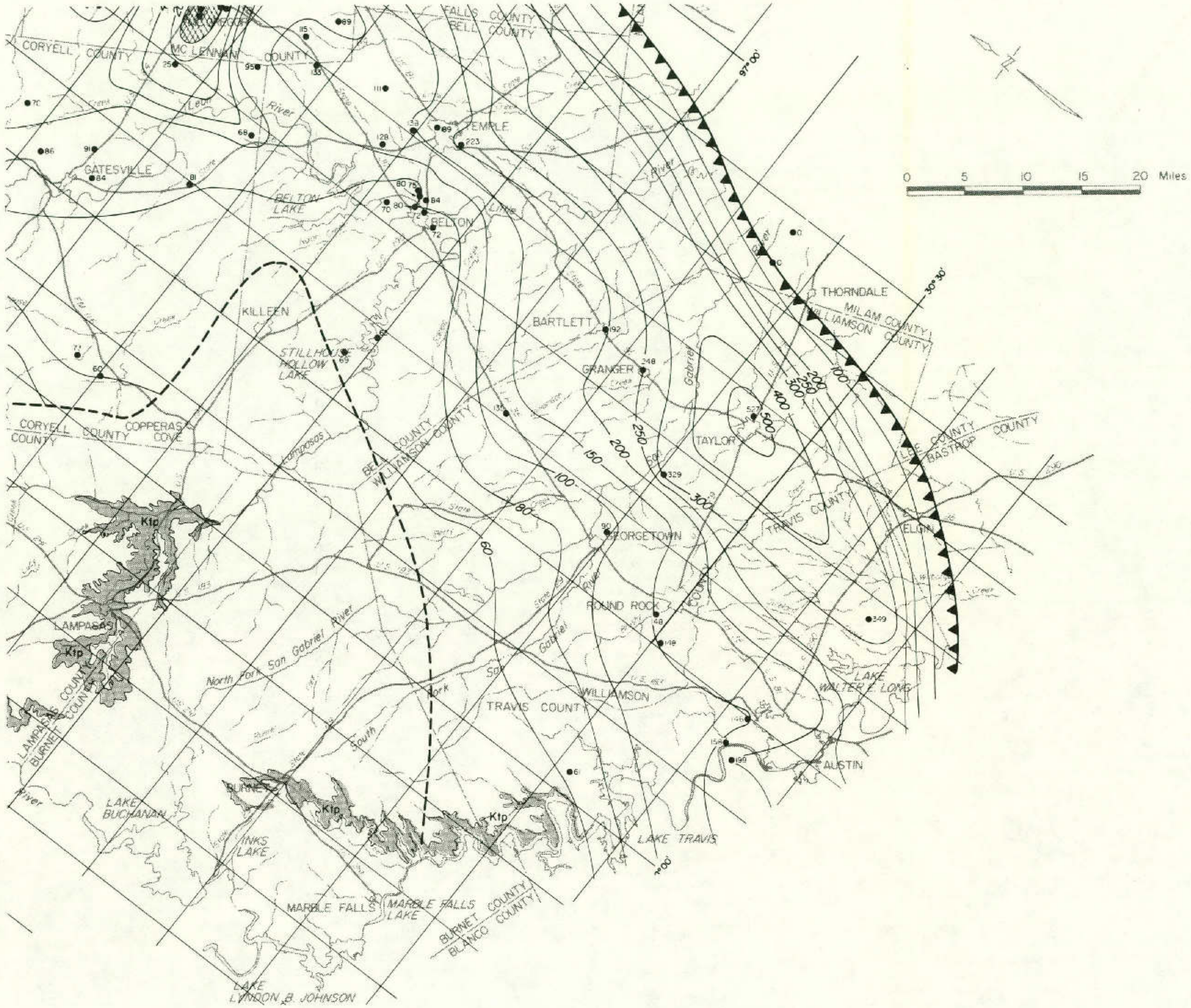
U D
Fault
U, upthrown side; D, downthrown side
Dashed where approximately located

Approximate downdip limit of fresh to slightly saline water in the Hensell Member

Approximate downdip limit of the sand facies in the Hensell Member

Approximate eastern limit of the calcareous facies of the Travis Peak Formation

Figure 9
Approximate Altitude of and Depth to Top of the Travis Peak Formation



EXPLANATION

● 59
Well used for control
Number indicates net thickness of sand containing fresh to slightly saline water in the Hosston Member of the Travis Peak Formation, in feet

20
Line showing approximate net thickness of sand containing fresh to slightly saline water in the Hosston Member of the Travis Peak Formation
Interval is variable

Outcrop of Travis Peak (Ktp) Formations

Approximate area where the Hosston Member is not present

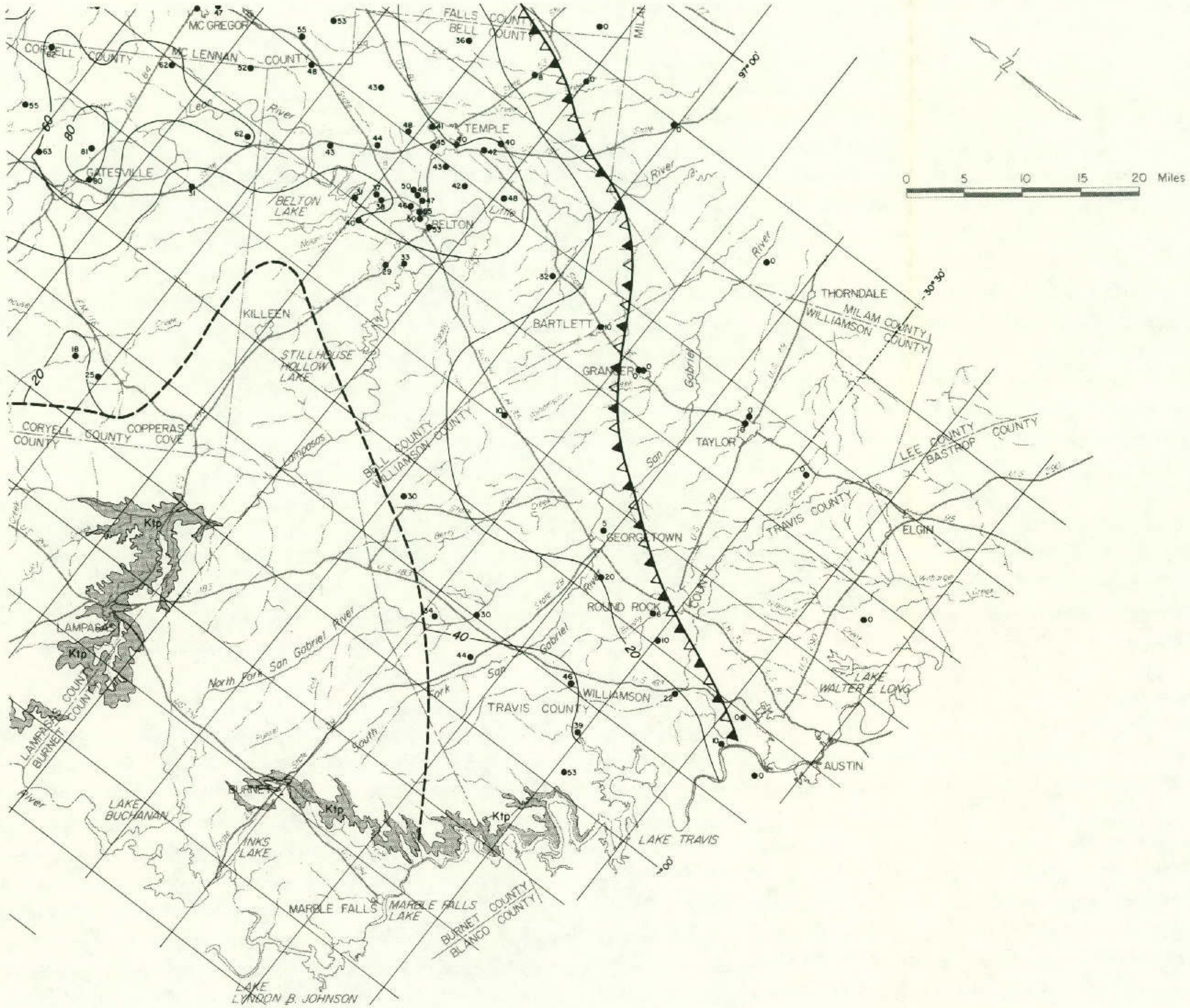
Contact
Dashed where covered or approximately located

Approximate downdip limit of fresh to slightly saline water in the Hosston Member

Approximate eastern limit of the calcareous facies of the Travis Peak Formation

Figure 10

Approximate Net Thickness of Sand Containing Fresh to Slightly Saline Water in the Hosston Member of the Travis Peak Formation



EXPLANATION

44

Well used for control
Number indicates net thickness of sand containing fresh to slightly saline water in the Hensell Member, in feet

40

Line showing approximate net thickness of sand containing fresh to slightly saline water in the Hensell Member
Interval 20 feet

Outcrop of Travis Peak (Ktp) Formations

Contact
Dashed where covered or approximately located

Approximate downdip limit of fresh to slightly saline water in the Hensell Member

Approximate downdip limit of the sand facies in the Hensell Member

Approximate eastern limit of the calcareous facies of the Travis Peak Formation

Figure 11

Approximate Net Thickness of Sand Containing Fresh to Slightly Saline Water in the Hensell Member of the Travis Peak Formation

Middle Trinity

Stratigraphic units which are included in the middle Trinity aquifer, listed in order from oldest to youngest, are as follows: Cow Creek Limestone and Hensell Sand Members of the Travis Peak Formation, and the lower member of the Glen Rose Formation.

Cow Creek Limestone Member of the Travis Peak Formation

The Cow Creek Limestone overlies the Hammett Shale and is composed of cream to tan colored, massive, often sandy, dolomitic, fossiliferous limestone with some gypsum or anhydrite beds. It is occasionally porous due to the presence of vugs and fractures. The thickness of the Cow Creek ranges from 0 to 80 feet in the study area. The Cow Creek gradually thins in a westward direction, eventually becoming indistinct with only a few limestone lenses present. The dip of the Cow Creek is approximately the same as the Hosston.

The Cow Creek may yield small amounts of water in the area near or adjacent to its outcrop.

Hensell Sand Member of the Travis Peak Formation

Overlying the Cow Creek Limestone is the Hensell Sand which is often called the "first Trinity" or "upper Trinity sand." It consists of poorly sorted, cross-bedded conglomerate cemented with silica and varicolored sand, sandstones, silts, clays, and shales. Conglomerate usually occurs near the base and is found only in the area of or immediately adjacent to the outcrop. The grain size and amount of sand decreases in a southeastward direction, grading into silts and sandy shales. Farther to the southeast, the Hensell grades into sandy limestone and dolomite beds which are difficult to distinguish on electric logs from the underlying Cow Creek and overlying lower member of the Glen Rose Formation.

In Burnet and parts of Bell and Williamson Counties and to the west of the Balcones Fault Zone, the Hensell has a regional dip to the east. In the area east of the fault zone, the Hensell dips to the southeast. Variations from the regional pattern occur locally. The general east and southeast dip of the Hensell and the increased rate of dip in the fault zone are illustrated on Figure 9.

Total thickness of the Hensell varies from 15 feet to 75 feet within the area containing fresh to slightly saline water. The net sand thickness of the Hensell is shown on Figure 11.

Lower Member of the Glen Rose Formation

The Glen Rose Formation crops out in the northern, northwestern, western, central, and southwestern parts of the study area in Bell, Burnet, Travis, and Williamson Counties. The outcrop areas are shown on Figure 3. The Glen Rose overlies the Travis Peak Formation and underlies the Paluxy Formation.

The Glen Rose Formation is composed primarily of limestone with some shale, sandy shale, clay, sandstone, and anhydrite. The Glen Rose Formation is subdivided into a lower and upper member. The lower member consists of massive, fossiliferous limestone and dolomite in the basal part, grading upward into thin beds of limestone, shale, marl, anhydrite, and gypsum. A thin accumulation of the fossil clam Corbula martinae (Whitney, 1952) forms an iron-stained ledge marking the top of the lower member of the Glen Rose. The "Corbula bed," which is about one foot thick, is traceable over a wide outcrop area in central Texas and is easily distinguished as a highly resistive bed on electric logs. Consequently, it serves as a convenient boundary between the lower and upper members of the Glen Rose Formation.

Upper Trinity

Stratigraphic units which are included in the upper Trinity aquifer, listed in order from oldest to youngest, are as follows; Upper member of the Glen Rose Formation and Paluxy Formation.

Upper Member of the Glen Rose Formation

The upper member of the Glen Rose Formation consists of shale and marl alternating with thin beds of impure limestone and dolomite. Beds of gypsum and anhydrite may occur, but often these have been dissolved, leaving solution channels. Gypsum and anhydrite are not known to occur in surface outcrops and usually not above the water table, since they have been removed by solution (Stricklin, Smith, and Lozo, 1971). A stair-step topography, formed by the alternating beds of limestone and shale of marl, typifies the upper member of the Glen Rose.

From a featheredge at the Burnet-Lampasas County line, the Glen Rose gradually thickens southeastward and has a maximum thickness of 900 feet in Milam County as shown on Figure 4. The Glen Rose produces fresh to slightly saline water in localized areas on or adjacent to its outcrop to small domestic and livestock wells.

Paluxy Formation

The Paluxy Formation is present only in a very small area in the eastern and northeastern part of Burnet County. It consists of fine-to very fine-grained, compact, white quartz sand, partially indurated with calcium carbonate, interbedded with silty and calcareous clay and shale. Some lenses and thin beds of limestone and marl occur locally. The Paluxy is approximately ten feet thick. There are no known wells completed in the Paluxy in Burnet County.

Edwards and Associated Limestones

Table 1 summarizes the water-bearing properties of the Edwards and associated limestones aquifer. The Edwards and associated limestones represent the upper portion of the Fredericksburg Group and the lower portion of the Washita Group of the Cretaceous System. They lie above the Walnut Formation and below the Del Rio Clay. Collectively, these limestones are considered the principal aquifer in the study area, which is referred to as the Edwards (Balcones Fault Zone) aquifer, or simply, Edwards aquifer. The limestones include, in ascending order, the Comanche Peak Limestone, Edwards Limestone, Kiamichi Formation, and Georgetown Formation. The Edwards and associated limestones supply small to large amounts of water to wells and constitute an important aquifer in the area south of the Lampasas River in Bell County and along and east of the Balcones Fault Zone. The Edwards is present in Bell County north of the Lampasas River, and yields small quantities of water for domestic and livestock use.

The Comanche Peak Limestone consists of marly, grayish-white limestone containing nodules and fossils. It has considerable flaking and jointing which gives it a fractured appearance. The Comanche Peak reaches 50 feet in the subsurface, and it pinches out to the east and south (Garner and Young, 1976). Because it is believed to be hydrologically connected with the Edwards Limestone, the two formations are not separated on the geologic sections (Figures 6 and 7). The Comanche Peak does not appear to be present south of the Colorado River. This formation yields little or no ground water within the study area.

The location of the outcrop of the geologic formations comprising the Edwards aquifer is shown in Figure 12. The outcrop includes the Edwards Limestone, the underlying Comanche Peak Limestone, and the overlying Georgetown Formation, all of early Cretaceous age. The outcrop is considerably wider in Williamson and Bell Counties as well as in Hays County than it is in most of Travis County where a combination of intense faulting and large topographic variations has narrowed the aquifer's exposure. In places on the north side of the Colorado River in Austin, the outcrop has been completely removed by faulting, whereas along the Williamson and Bell County line the outcrop is about ten miles wide.

In the subsurface, the Edwards Limestone consists of brittle, thick-bedded to massive limestone, commonly limestone dolomitic, containing minor beds of shale, clay, and siliceous limestone. Beds of chert and flint are common. "Honeycomb" limestone beds are also common and represent voids, many interconnected, from which shell material has been dissolved. Dolomitic beds commonly have a sugary texture and often are designated as "sandstone" or "sandy limestone" by many drillers.

About ten feet of marl, clay, thin limestone seams, and shell aggregates make up the Kiamichi Formation. It is recognizable only in the subsurface in Travis County where it can readily be picked on geophysical logs. It is equivalent to the "Regional Dense Bed" (Rose, 1972). In Northern Travis County, it separates the Edwards Limestone and the Georgetown Formation, and in the southern part of the county, it occurs within the Edwards Limestone.

The altitude of the top of the Edwards aquifer throughout the study area is illustrated in Figure 13. The depth to the top is given at well locations, based on available data. An approximate depth to the top at any particular location can be determined by subtracting the altitude of the top of the aquifer as estimated from contour lines on the map from the altitude of the land surface at that particular location. The outcrop of the Edwards aquifer, as shown on the map, represents the aquifer's eroded top that is exposed at the land surface.

The aquifer dips to the east-southeast at an average slope of 70 to 75 feet per mile (ft/mi). The slope of the aquifer surface, as well as its depth and elevation, varies significantly over short distances in areas of intense faulting. The faulting has caused the aquifer surface to be highly irregular, but generally stair-stepped downward in the dip direction.

The greatest depth to the top of the Edwards aquifer, where it still contains water having generally less than 3,000 mg/l of dissolved solids, is approximately 1,200 feet below land surface at Taylor in eastern Williamson County. The shallowest occurrence of water having generally 3,000 mg/l of dissolved-solids concentration occurs midway between I.H. 35 and the Barton Creek confluence with the Colorado River. At this location, the top of the aquifer is only about 150 feet deep.

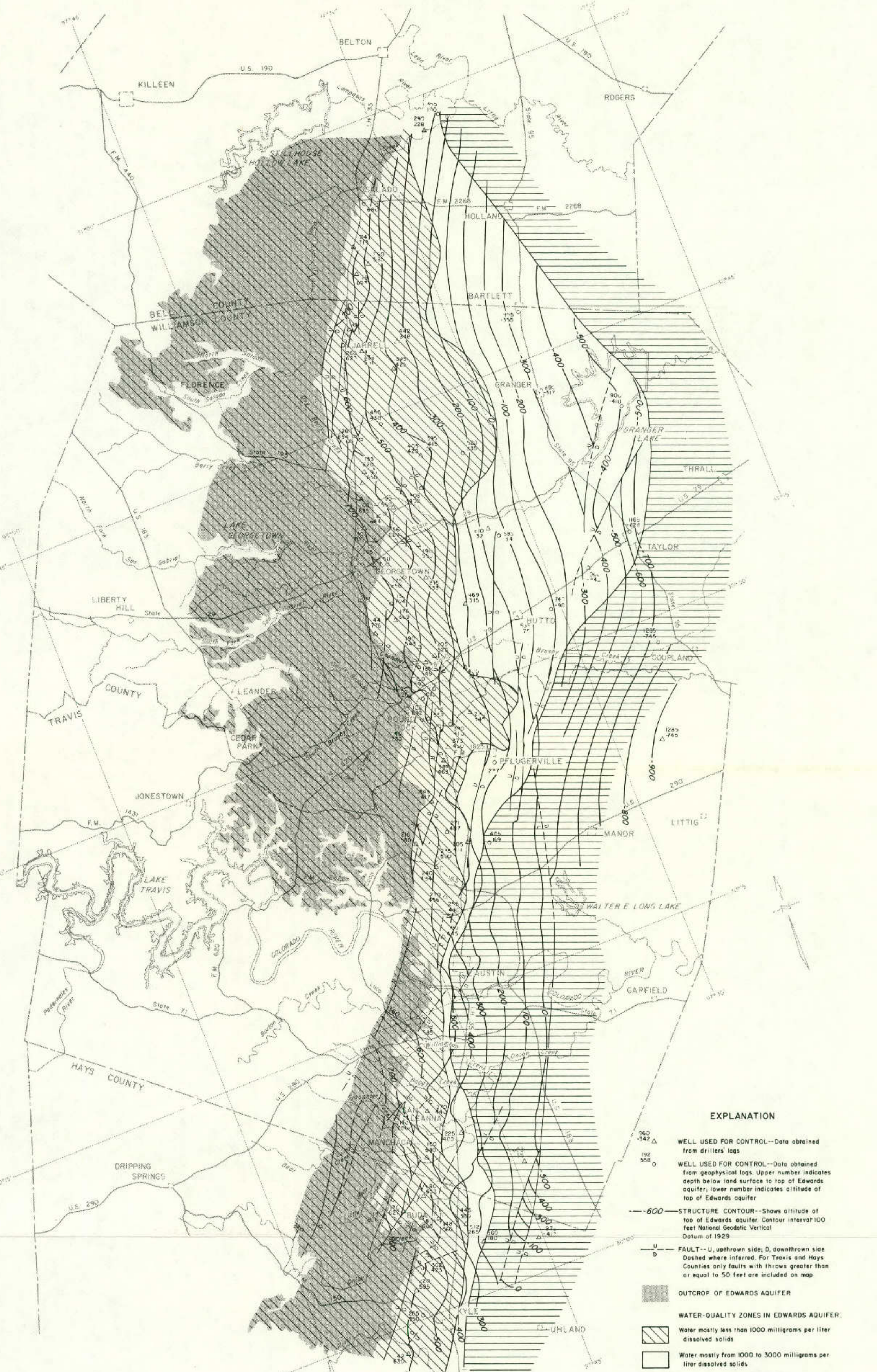
The top of the aquifer is identified in the subsurface by an abrupt change in the character of the rocks. Driller's logs and geophysical logs of boreholes show a marked change in lithology at the contact of the overlying Del Rio Clay, which is 60 feet thick, and the hard Georgetown Limestone at the top of the aquifer.

The configuration of the base of the Edwards aquifer is shown in Figure 14. The base, which dips towards the east-southeast at a slope of 70 to 75 ft/mi, is cut by numerous faults. These faults have caused the base to be offset a few feet to several hundreds of feet along the fault planes. The individual faults extend laterally for distances ranging from a fraction of a mile to more than ten miles.

The base of the Edwards aquifer extends from the land surface at many places along the western edge of the aquifer's outcrop to depths of hundreds of feet east of the outcrop. The depth of the base, where the aquifer contains water having generally 3,000 mg/l or more of dissolved solids, ranges from about 1,500 feet below land surface at Taylor to about 550 feet approximately one mile west of I.H. 35 at the Colorado River in Austin.

The Edwards aquifer yields water much more readily than the underlying rocks because of its greater secondary permeability. Consequently, the base of the Edwards aquifer is defined as the base of the rocks having the greater water-yielding capabilities.

Figure 12
Geologic Map of the Edwards and Associated Limestones



Structural mapping by L.M. Ruiz (Travis and Hays Counties) and by G.L. Duffin (Williamson and Bell Counties)

Figure 13
Approximate Altitude of and Depth to Top of the Edwards Aquifer

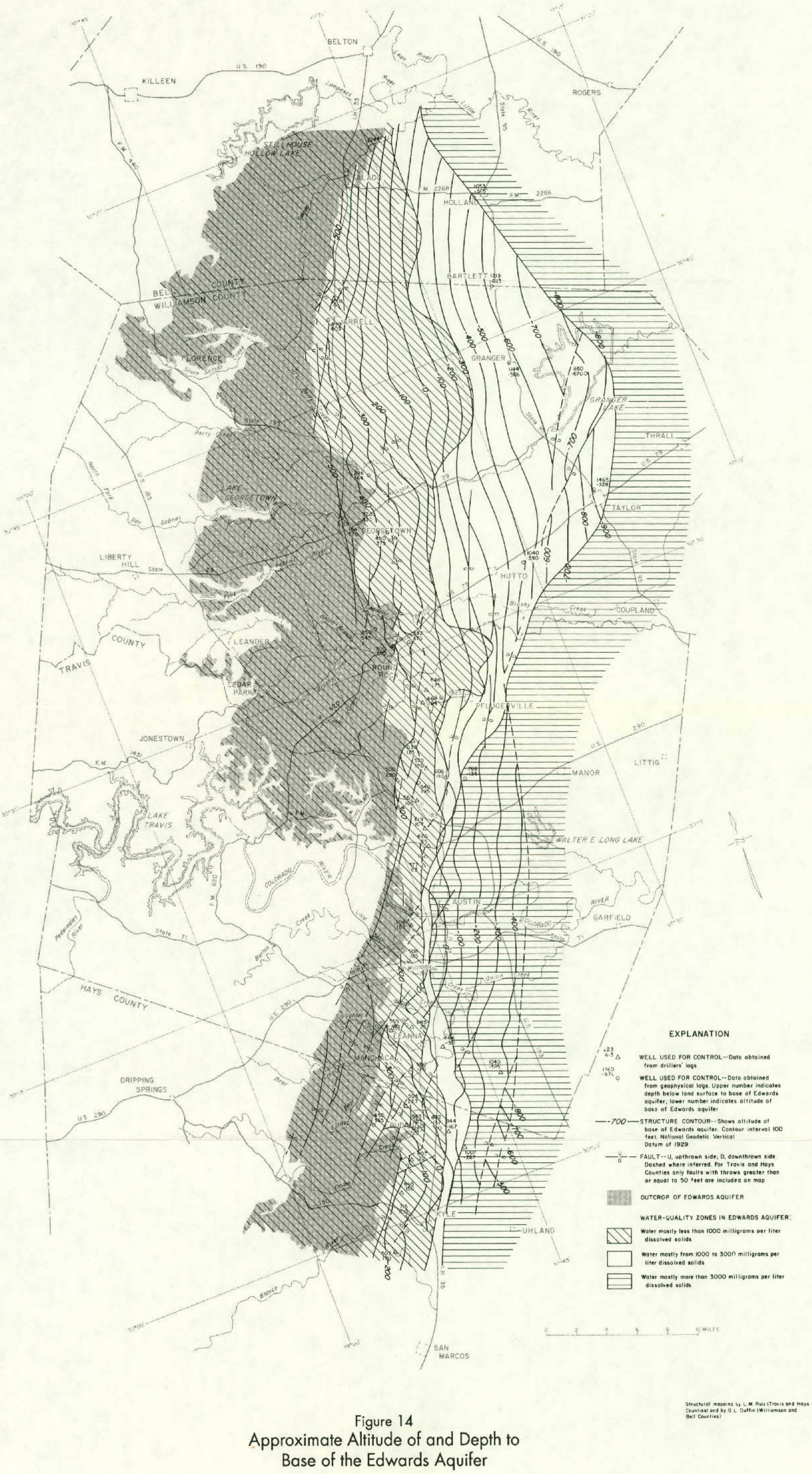


Figure 14
Approximate Altitude of and Depth to Base of the Edwards Aquifer

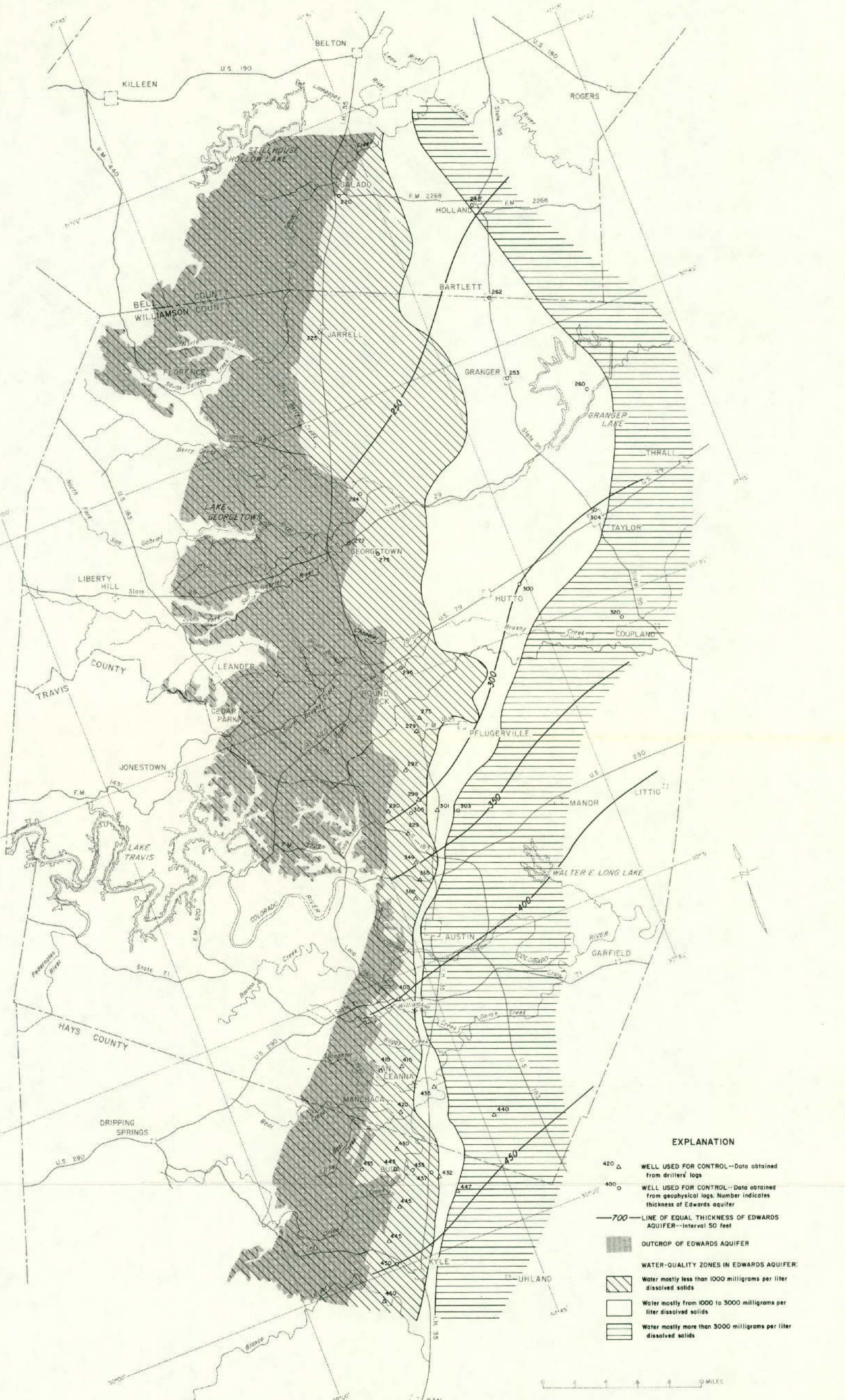


Figure 15
Approximate Thickness of the Edwards Aquifer

The uneroded thickness of the Edwards aquifer decreases from south to north along the strike and increases from west to east downdip as shown on Figure 15.

From Kyle to Belton, the uneroded thickness of the Edwards aquifer decreases from about 450 feet in eastern Hays County to about 225 feet in southern Bell County. This decrease in thickness is illustrated in the hydrogeologic strike section C-C' (Figure 6). The increase in total thickness of the aquifer from west to east is relatively slight, usually less than 50 feet within any one county when compared to the change in thickness in a north-south direction. The increase in thickness in the downdip direction is shown on the hydrogeologic dip section (Figure 7).

The Georgetown Formation is a nodular limestone, usually gray to tan, massive, and interbedded with layers of marl or marly shale. It is fossiliferous, commonly contains burrows filled with fossil fragments, and also contains some minor solution zones. Downdip thicknesses of the formation range from 40 to 90 feet.

Wilcox Group

The Wilcox Group overlies the Midway Group and outcrops in a belt 10 to 20 miles in width from southeastern Williamson County northeastward through southeastern Limestone County. It includes a widespread deltaic accumulation of lignitic or carbonaceous sand and interbedded shale interfingering coastward with marine deposits. The sands are generally silty, cross-bedded, and lenticular while the shales are lignitic, silty, and sandy. Near the middle of the Wilcox Group, there is a massive sand facies — the Simsboro Sand Member of the Rockdale Formation. This unit contains a greater percentage of fine- to coarse-grained sand than the upper and lower units of the Wilcox Group and, on electric logs, is distinctive from the constant repetitions of alternating sandstone and shale characterizing those units. The Simsboro Sand attains a thickness in some areas exceeding 800 feet.

The Wilcox Group yields small to large quantities of fresh to moderately saline water in and several miles downdip from the outcrop. The water wells that supply water to the City of Elgin are completed in the Simsboro Sand Formation. Southwest Milam Water Supply Corporation has wells completed in the Wilcox Group and supplies ground water in northwest Milam and eastern Williamson Counties.

Quaternary System

Scattered remnants of terrace deposits and stream or river alluviums, ranging in age from Pleistocene to Recent, occur in the east-southeast portions of the study area. For the purposes of this report, these are collectively considered in this discussion.

Terrace deposits are of Pleistocene age. Relatively young terrace deposits occur along the Colorado River. These consist of gravel, sand, silt, and clay, sometimes cemented with calcium carbonate, with the coarser materials concentrated at the base. They occur at higher elevations than the more recent floodplain deposits. The older Onion Creek Marl, which has a maximum thickness of 50 feet, is found only in small areas along Onion Creek in southern Travis County. It contains calcareous gravel and is often cemented with calcium carbonate. Thin sheets of gravel and sand (20 feet or less) representing very old terraces are found on the ridges in eastern parts of Travis, Williamson, and Bell Counties. These are known as high gravel deposits and because they are so thin, they have been mixed by plowing with the clays of the underlying Navarro and Taylor Groups. Terrace deposits can have a maximum thickness of 60 feet, with the thickest sediments located along the Colorado River. These terrace deposits produce very small to moderate amounts of fresh to moderately saline ground water under water-table conditions.

Stream or river alluviums of Recent or Holocene age are composed of up to 60 feet of unconsolidated material, chiefly gravel, sand, and silt. The thickest floodplain deposits, which also have the greatest areal extent, are found along the Colorado River in eastern Travis County. In this area, they rest upon the underlying Navarro and Taylor Groups. Small areas of thin alluvium can also be found in scattered localities along minor tributaries throughout the study area. Alluvium deposits yield small to very large quantities of fresh to slightly saline water.

OCCURRENCE AND AVAILABILITY OF GROUND WATER

Trinity Group Aquifer

Source and Occurrence

Primary sources of ground water in the Trinity Group aquifer are rainfall which falls on the outcrops and infiltration of surface water from unlined earthen ponds, lakes, and streams on or crossing its outcrops.

The outcrop of surface extent of the lower Trinity hydrologic units is limited. The Sycamore Sand which is the surface outcrop of the Hosston Member of the Travis Peak Formation occurs near the Colorado River in southeast Burnet and western Travis Counties, Figure 3. On the surface, the Sycamore is composed chiefly of a conglomerate which is not very permeable, except when weathered. In addition, the unit is capped by tight, reddish-brown clayey soils. Sycamore wells are not known to produce water in the outcrop, and the member appears to be largely non-water bearing. However, beneath the surface of Lake Travis more permeable facies of the aquifer exist, and these are subject to recharge from the lake.

In the subsurface, the lower Trinity aquifer is overlain by the impervious Hammett Shale Member of the Travis Peak Formation and, as a result, artesian conditions occur. The aquifer is completely water saturated and hydrologically connected through the joints and cavities in the limestone of the Sligo Member of the Travis Peak Formation, as well as the pore spaces in the sands of the Hosston Member. The hydrostatic pressure is sufficient to cause static water levels to rise above the aquifer and, in some cases, to cause the wells to flow.

Ground water in the middle Trinity aquifer occurs under water-table conditions in the outcrop area near the Colorado River and Lake Travis in Burnet and Travis Counties. In these areas, the units of the aquifer are not completely water-saturated. Water occurs in the void spaces of the gravels, sands, and silts in the Hensell Sand, and in marly and sandy beds, cavities, joints, and faults in the Cow Creek Limestone and the lower member of the Glen Rose Formation. The basal limestone sequence of the lower member of the Glen Rose contains vugs and solution channels which carry significant quantities of water.

Artesian conditions exist downdip because the Hensell Sand is overlain by relatively impervious shales and limestone of the lower member of the Glen Rose. The aquifer is completely water saturated, and the hydrostatic pressure is great enough to cause static water levels to rise above the top of the aquifer. In some areas, wells developed in the middle Trinity aquifer will flow, particularly those drilled in lower elevations along Lake Austin and in the City of Austin.

Where the Paluxy Formation is present in parts of Burnet County, it is hydrologically connected with the upper member of the Glen Rose Formation.

This is particularly true where the limestone is jointed and cut by faults and solution channels. Water enters the aquifer from rainfall and infiltration from stock ponds and also from Lake Travis, which is in contact with the aquifer in its lower reaches.

Ground water in the upper Trinity aquifer occurs primarily under water-table conditions in the outcrop area. Water occurs in the void spaces of the Paluxy Formation, and in sandy and marly beds and solution zones of the upper member of the Glen Rose Formation. In addition, perched water tables and artesian conditions occur locally in the outcrop area due to sand lenses and limestones interbedded with shales within the upper member of the Glen Rose.

Artesian conditions exist in the subsurface, where the aquifer is completely water saturated and the hydrostatic pressure is great enough to cause water levels to rise above the aquifer. However, no flowing wells or springs in the upper Trinity aquifer were located within the study area.

Recharge, Movement, and Discharge

Recharge to the Trinity Group aquifer is derived primarily from rainfall on the outcrop, underflow, vertical leakage, and seepage from lakes and streams. The upper and lower members of the Glen Rose Formation and the Hensell Sand Member of the Travis Peak Formation outcrop over the western portions of the study area; therefore, these units receive the maximum amount of recharge. The Hosston Member of the Travis Peak Formation probably receives very little recharge from rainfall because of its limited surface outcrop and the type of soils.

A study by Ashworth (1983) on the Lower Cretaceous formations in the Guadalupe River basin determined that approximately 4 percent of precipitation on the outcrop area can be considered as effective recharge to the aquifer. Klemt and others (1975) determined that an estimated 3 percent of the average annual precipitation is available as effective recharge. Their study was confined principally to the Brazos, Colorado, and Trinity River basins. Muller and Price (1979) reporting on the quantity of ground water available in the State of Texas on an average annual basis through the year 2030, determined that approximately 1.5 percent of the average annual precipitation falling on the outcrop (effective recharge) can be transmitted through the Trinity Group aquifer. The methodologies for determining ground-water availability in Texas are discussed in Texas Water Development Board Report 238 (Muller and Price, 1979).

The amount of annual effective recharge to the Trinity Group aquifer in the study area is estimated based on the amount of outcrop in the study area as a percentage of the total outcrop in each river basin by county. These percentages were then applied to the county-basin totals of annual effective recharge as determined from Muller and Price (1979) and used as estimated annual effective recharge within the study area.

The amount of annual effective recharge to the Trinity Group aquifer within the study area is estimated to be a little over 5,500 acre-feet per year.

Ground water in the Trinity Group aquifer moves slowly downdip to the south and east-southeast. The direction of the ground-water movement is perpendicular to the water-level contour lines and toward lower elevations as shown in Figure 16. Water-level measurements indicate the hydraulic gradient of the potentiometric surface is about 10 to 100 feet per mile in most of the study area. In areas of continuous pumping, the direction of ground-water movement is toward these points of discharge from all directions. An elongated cone of depression, aligned in a southeast direction has developed as a result of ground-water pumpage in portions of Williamson and Travis counties as shown on Figure 16. Because of low permeability and numerous confining beds, movement of ground water in the upper member of the Glen Rose is generally in the same direction as the slope of the land surface.

There are no known springs discharging from the lower Trinity aquifer in the study area. Most of the discharge occurs from flowing wells and pumpage. Discharge from the middle and upper Trinity aquifers is from pumping and flowing wells and springs.

Pumping from wells constitutes the artificial discharge from the Trinity Group aquifer. In 1985, approximately 7,705 acre-feet of ground water was pumped from the Trinity (Table 2). Most of this ground water was discharged from well fields of various cities, water suppliers, and industrial users.

Hydraulic Characteristics

Coefficients of transmissibility, permeability, and storage for different aquifers are shown in Table 3. This table was compiled from existing literature and aquifer tests conducted by Texas Water Development Board personnel. Data from the aquifer tests were analyzed using the Theis nonequilibrium formula, as modified by Walton (1962). Permeability coefficients were computed by dividing the test transmissibility coefficients by the effective sand thickness. The approximate total coefficient of transmissibility was computed by multiplying the total fresh-water sand thickness by the well's permeability coefficient.

Aquifer tests indicate that the artesian portion of the Hosston Member of the Travis Peak Formation is characterized by permeability ranging from approximately 14 to 171 gallons per day per square foot [(gal/d)/ft^2]. The Hosston thickens considerably downdip; therefore, coefficient of transmissibility values up to 45,000 gallons per day per foot (gal/d)/ft can be expected in the downdip areas. In Williamson County, a transmissibility value as high as 34,800 (gal/d)/ft is shown on Table 3. The Hosston Member in Williamson County is believed to be much more porous than it is in other counties in the study area and also does not contain large quantities of calcareous or siliceous cement or shale.

Table 2
1985 Ground-Water Usage in Acre-feet by Aquifer, Category, and Major Cities (1980 Population of 1,000 or greater) in the Study Area

Aquifer	Municipal	Manu-facturing	Power	Irrigation	Mining	Livestock	Total
Carrizo-Wilcox	1,296	33	0	0	0	43	1,372
Trinity	7,146	43	0	11	0	505	7,705
Edwards	13,773	308	0	2	1,665	171	15,919
Others [1]	658	137	0	65	0	84	944
Totals	**22,873**	**521**	**0**	**78**	**1,665**	**803**	**25,940**

[1] Quaternary alluvium and terrace deposits.

City	County	Aquifer	Pumpage (acre-feet)
Elgin	Bastrop	Carrizo-Wilcox	1,009
Bartlett	Bell-Williamson	Trinity	349
Burnet	Burnet	Trinity	792
Manor	Travis	Trinity	178
Georgetown	Williamson	Edwards	3,227
Granger	Williamson	Trinity	140
Leander	Williamson	Trinity	452
Round Rock	Williamson	Edwartds	4,786
Taylor	Williamson	Trinity	2,029
		Total	**12,962**

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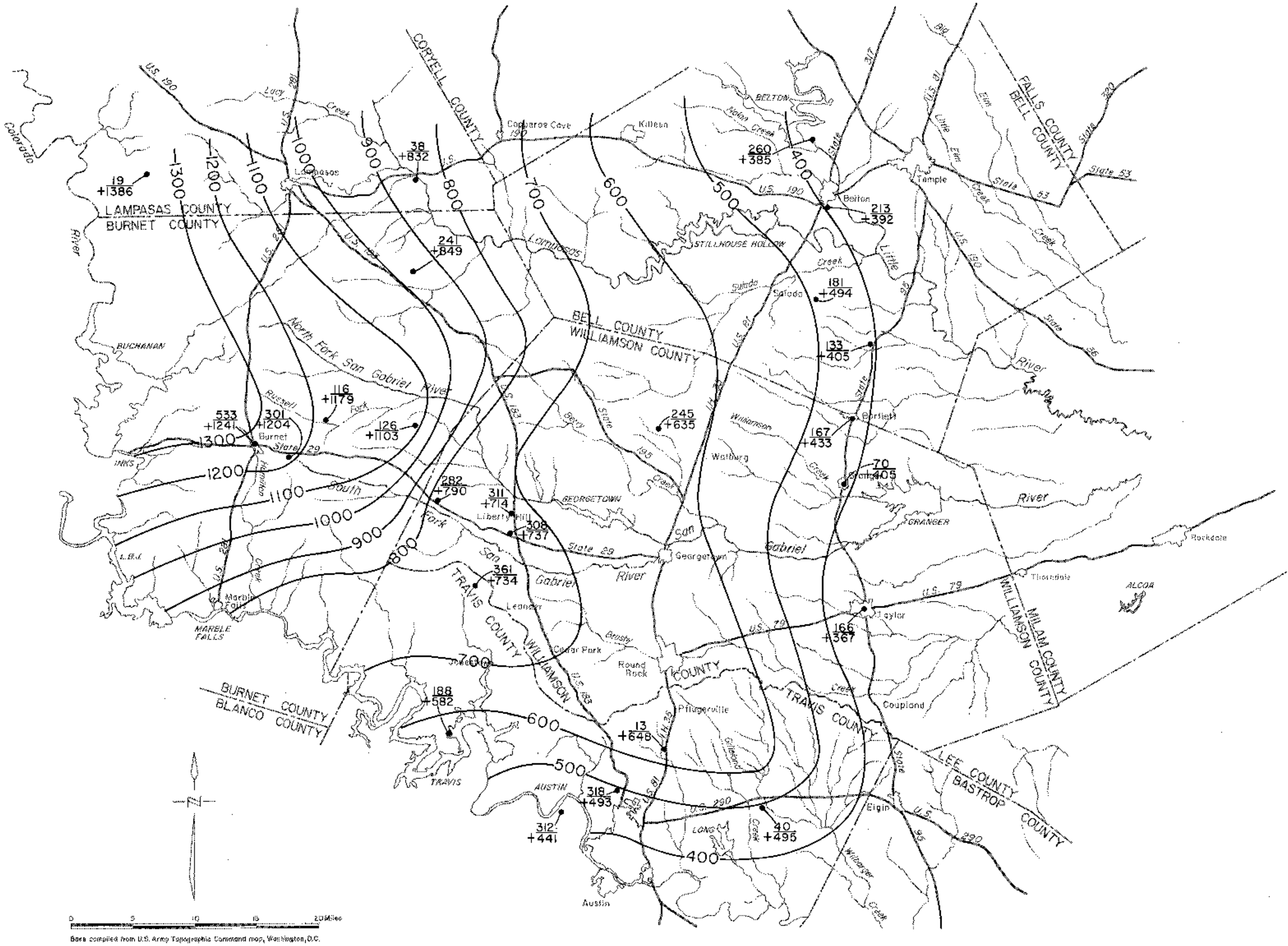

Figure 16
Approximate Altitude of Water Levels in Selected Wells
Completed in the Trinity Group Aquifer, Spring, 1986

EXPLANATION

—500— WATER-LEVEL CONTOUR
Shows altitude at which water level would have stood in a tightly cased well.

311/714 WELL USED FOR CONTROL
Upper number indicates depth below land surface to water level in well.
Lower number indicates altitude of water level in well.

Table 3
Results of Pumping Tests in Study Area (Modified from Table 4 in TWDB Rept. 195)

Aquifer:
- Kgr — Glen Rose Formation
- Kcgru — Upper Member of the Glen Rose Formation
- Kcgrl — Lower Member of the Glen Rose Formation
- Ktp — Travis Peak Formation
- Khe — Hensell Member of the Travis Peak Formation
- Kho — Hosston Member of the Travis Peak Formation

Coefficient of transmissibility values shown are the averages from drawdown and recovery test data unless indicated differently by footnotes.

Well	Aquifer	Coefficient of Transmissibility from Test (gpd/Ft)	Effective Sand Thickness (feet)	Coefficient of Permeability (gpd/ft^2)	Total Fresh Water Sand Thickness (feet)	Approximate Total Coefficient of Transmissibility (gpd/ft)	Coefficient of Storage	Drawdown or Recovery (feet)	Time After Well Turned On or Off (hours)	Average Yield (gpm)	Specific Capacity (gpm/ft)
Bell County											
AX-40-53-505	Kho	8,100 [1]	5	85	95	8,100	--	36.4	41.00	120.0	3.3
AX-40-54-501	Ktp	14,100	--	--	--	--	--	33.4	6.00	170.0	5.1
AX-40-59-102	Kgr,Ktp	40 [1]	39	1	39	40	--	377.0	4.66	35.0	0.1
AX-40-60-801	Khe,Kho	8,700 [2]	90	97	90	8,700	0.000043	105.0	24.00	390.0	3.7
AX-40-60-901	Khe,Kho	8,300 [2]	99	84	99	8,300	--	91.0	24.00	500.0	5.5
AX-40-60-904	Khe,Kho	9,600 [2]	108	89	108	9,600	0.000042	103.0	24.00	440.0	4.3
AX-40-60-905	Khe,Kho	8,800 [2]	104	85	104	8,800	0.000050	153.0	16.00	520.0	3.4
Burnet County											
BT-57-15-705	Ktp	1,000 [3]	--	--	--	--	--	--	0.50	47.0	1.0
BT-57-24-101	Ktp	1,000	51	20	51	1,000	0.000042	--	--	--	--
BT-57-24-103	Ktp	800	51	16	51	800	--	50.0	4.00	50.0	1.0
Travis County											
YD-58-33-403	Kho	140	10	14	--	--	--	106.0	4.17	24.0	0.2
YD-58-43-702	Kcgrl	700	15	47	225	10,500	--	22.6	40.37	12.8	0.6
YD-58-43-703	Kho	600	--	--	--	--	--	53.2	8.03	19.6	0.4
YD-58-43-801	Kcgru	1,400	--	--	--	--	--	50.5	1.68	40.0	0.8
YD-58-44-201	Kho	1,900 [1]	60	32	310	9,800	--	50.9	1.10	48.8	1.0
YD-58-51-103	Kcgrl	2,870 [1]	25	115	--	--	0.000019	72.4	5.02	87.0	1.2
Williamson County											
ZK-58-10-210	Khe	1,800	32	56	32	1,800	--	47.5	4.00	60.0	1.3
ZK-58-10-202	Khe	1,800	32	56	32	1,800	0.000023	--	--	--	--
ZK-58-18-401	Ktp	5,400	60	90	80	7,200	--	9.8	3.00	25.1	2.6
ZK-58-21-202	Kho	34,800	203	171	248	42,500	--	56.3	4.00	310.0	5.5
ZK-58-21-203	Kho	25,200	203	124	248	30,800	0.000077	--	--	--	--
ZK-58-29-604	Kho	28,500	423	67	527	35,500	--	163.9	4.00	1,089.0	6.6

[1] Aquifer coefficients computed from recovery test.
[2] Aquifer coefficients obtained by averaging certain transmissiblity and storage values, W. F. Guyton and W. O. George, 1943.
[3] J. R. Mount, 1962.

Data available for the values of the coefficients of storage for the hydrologic units of the Trinity Group aquifer range from 0.000019 to 0.000077.

Test data included in Table 3 pertaining to the middle Trinity aquifer in the downdip region show coefficients of permeability ranging from approximately 47 to 115 [(gal/d)/ft^2] in Travis County and 56 [(gal/d)/ft^2] in Williamson County. Because of the extreme range in permeability and variation in thickness of the different members of the aquifer, coefficient of transmissibility values of 0 to 4,000 (gal/d)/ft may be expected.

Two pumping tests conducted on wells completed in the Hensell Sand Member of the Travis Peak Formation in Williamson County show transmissibilities of 1,800 (gal/d)/ft. This agrees reasonably well with the values obtained from wells completed in the lower Glen Rose in Travis County at 700 to 2,870 (gal/d)/ft. Lack of sufficient test data prohibits assigning a coefficient of storage range for the Hensell Member; however, storage values should be less than those of the Hosston Member.

Lack of test data prohibits assigning a coefficient of permeability and coefficient of transmissibility for the upper Trinity aquifer. No information was available to estimate the coefficient of storage.

Water Levels

The approximate altitude of the 1986 water levels from observation wells completed in the Trinity Group aquifer is shown in Figure 16. The hydraulic gradient is generally toward the east and southeast, but is influenced locally by the topography.

The changes in water levels of observation wells completed in the Trinity Group aquifer are illustrated by hydrographs in Figure 17, together with a water-level decline map for the period 1975 to 1986. The long-term water-level declines from 1975 to 1986 in the Hensell and Hosston Members have developed around Belton, Bartlett, Granger, and Taylor. Cones of depression have occurred in western Williamson County and north of the Colorado River in Travis County. The declining water levels are due to the low permeability of the water-producing sands and the ground-water pumpage by industrial and public supply users.

Chemical Quality

Ground water in the Trinity Group aquifer can be described as a calcium carbonate type water in the western part of the study area, becoming a sodium sulfate or chloride type downdip. The water is usually of neutral pH and very hard and its quality ranges from fresh to slightly saline in most cases. The quality of the water tends to decrease downdip to the southeast. Low permeability, restricted water circulation, and increase in temperature cause the ground water to become more highly mineralized in the downdip portion of the aquifer. Other constituents or properties such as nitrate, chloride, sulfate, and hardness are generally low over most of the area, except adjacent to the calcareous facies where chloride, sulfate, and hardness

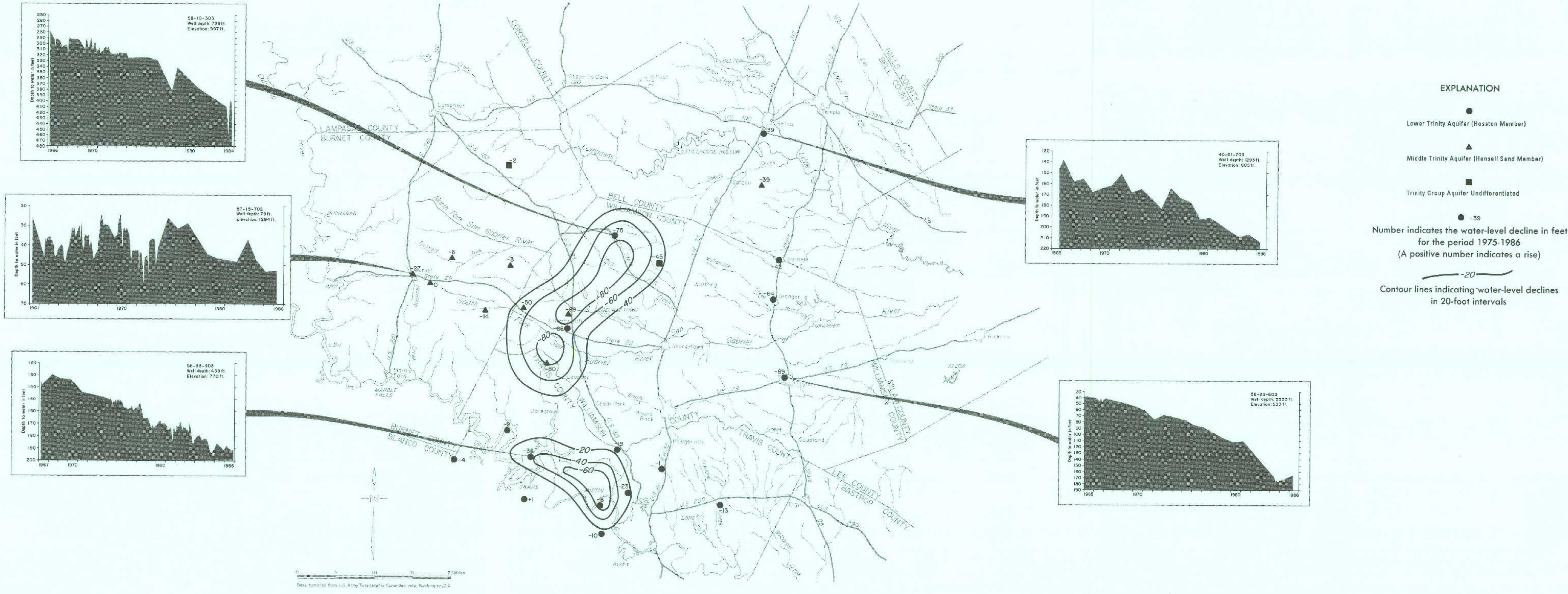

Figure 17
Water Level Declines in the Trinity Group Aquifer, 1975-1986, and Selected Water-Level Hydrographs

Figure 18

Sulfate, Chloride, and Dissolved-Solids Content in Water From Selected Wells in the Lower, Middle, and Upper Trinity Aquifers

exceed the U. S. Public Health Service Standards. Treatment other than chlorination for public supply is generally not exercised.

Records of chemical analyses from selected wells for Burnet, Bell, Williamson, and Travis Counties can be found in Texas Water Development Board (TWDB) Reports 195 and 293 and Texas Department of Water Resources (TDWR) Report 276. Sulfate, chloride, and dissolved-solid content from selected wells completed in the lower, middle, and upper Trinity aquifers are shown in Figure 18.

Ground water from the Trinity is used primarily for domestic and public supply purposes, although generally the ranges of major constituents exceed U. S. Public Health Service standards. This water has been and continues to be used, due to the unavailability of a more suitable supply, without any apparent ill effects on the users. Manufacturing use of ground water in this area is negligible since the water is generally unsuitable because of its high iron, hardness, and sodium bicarbonate contents.

Utilization and Development

Early settlers who came to the study area used water from springs because of the ready availability of a constant flow, and because it was a source of power. The influx of settlers was accelerated by the establishment of the Republic of Texas in 1836, and by the annexation of Texas to the United States in 1845.

As the population increased, most of the choice land located near or downstream from springs was soon taken. The remaining settlers had no choice but to dig wells in order to provide their household and livestock with water. These dug wells rarely exceeded 40 feet in depth and were confined largely to areas of land where a well could easily be dug.

A revolution in use of ground water in the area, and in Texas, began in 1857. In that year, the Texas Legislature authorized the drilling of an artesian well, probably the first drilled well in Texas. This well was to be drilled in Austin on the Capitol grounds and according to Shumard (1860) was "to determine whether an abundant supply of good water could be obtained at the surface near the Capitol Building." The well was drilled with horse and steam power and was abandoned when the drill pipe was lost in the hole. However, when it was discovered that flowing wells could be obtained in many parts of the county, the drilling of deep wells greatly accelerated.

During this investigation, a field inventory was conducted updating the existing compilations of information on municipal, industrial, and irrigation wells, using the 1985 Texas Water Development Board survey of ground and surface water users within and adjacent to the study area. In addition to the survey, Texas Department of Water Resources Report 276 and TWDB Reports 195 and 293 were used in the inventory.

The locations of selected municipal and industrial water wells and well fields completed in the Trinity Group aquifer and their average yields are shown in Figure 19. This map does not include some of the privately owned wells used for public supply or any wells used for domestic, irrigation, and other purposes.

A little less than 26,000 acre-feet of ground water was pumped from the Cretaceous and Quaternary aquifers in the study area in 1985 as shown in Table 2. The 1985 ground-water pumpage from the Trinity Group aquifer was approximately 7,705 acre-feet, which is about 30 percent of the total usage.

A total of 22,873 acre-feet of ground water was pumped for municipal purposes. Municipal pumpage from the Trinity Group aquifer was about 7,146 acre-feet, which represents 31 percent of the total municipal usage. Most of the ground water used by towns, small communities, and developments is produced from the lower Trinity aquifer. The City of Taylor was the largest user of ground water from the Trinity Group aquifer, with about 28 percent of the total ground water pumped from the Trinity for municipal use.

Ground water used for irrigation in the study area from the Trinity Group aquifer was about 11 acre-feet in 1985. A total of 43 acre-feet of ground water was used for manufacturing purposes. There was an estimated total of 803 acre-feet of ground water used in 1985 for livestock purposes. The Trinity Group aquifer supplied 505 acre-feet of ground water for livestock needs. This represents about 63 percent of the total ground water used for livestock.

Flowing wells are used to a small extent for irrigation and domestic and livestock purposes. Spring flow is used chiefly for domestic and livestock purposes and recreational functions. Most of the spring flow goes unused, except to augment surface water supplies in downstream reservoirs.

Availability of Ground Water for Development

Availability in some parts of the study area was calculated as a percentage of the total availability in each river basin by county, as modified from TDWR Report 238, "Ground-Water Availability in Texas" (Muller and Price, 1979).

The amount of recharge available in the study area is based on the amount of outcrop area in the study area as a percentage of the total outcrop in the county-basin. The amount of ground water available in storage for the Trinity Group aquifer was also adjusted. The availability was based on the areal extent of the downdip or artesian portion of the aquifer in the study area as a percentage of the total availability for the county-basin.

The average annual amount of ground water available from the Trinity Group aquifer within the study area is estimated to be a little over 6,700 acre-feet per year. In 1985, approximately 7,705 acre-feet of ground water was pumped from the Trinity Group aquifer in the downdip area for municipal, manufacturing, livestock, irrigation, power and mining purposes.

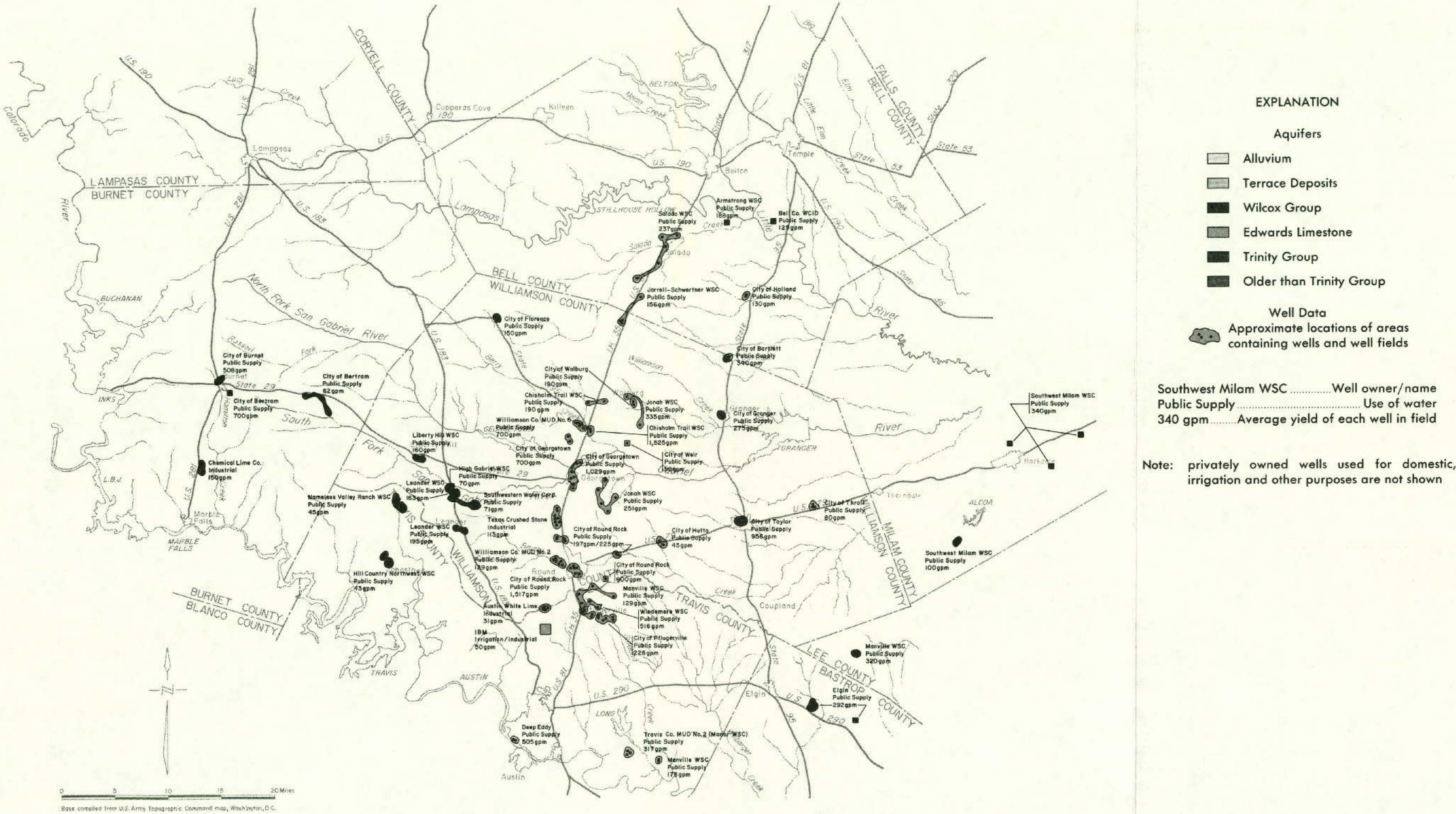

Figure 19
Selected Well Field Areas of Municipal and Industrial Water Wells, Producing Aquifers, and Approximate Average Yields of Wells

Development of ground water in the Trinity Group aquifer should be primarily confined to the upper and lower members of the Glen Rose Formation, and the Hensell Sand Member of the Travis Peak Formation because these hydrologic units crop out over the western part of the study area; therefore, those units receive the maximum amount of recharge. Future lower Trinity aquifer development should be confined locally to areas that are not experiencing marked declines in water levels.

Edwards and Associated Limestones Aquifer

The Edwards (Balcones Fault Zone) aquifer supplies ground water to at least ten counties in Central Texas; however, there are several hydrologic divides that separate the aquifer into independent systems.

The portion of the Edwards aquifer extending from Brackettville in Kinney County just south of the City of Kyle in Hays County is known as the San Antonio region, and the area from Kyle to the Colorado River is referred to as the Austin or Barton Springs region. The area north of the Colorado River extending into northern Travis, Williamson, and Bell Counties is the portion of the Edwards aquifer that is included within the scope of this study and referred to as the northern region of the Edwards aquifer.

Source and Occurrence

The source of ground water in the Edwards and associated limestones aquifer is from infiltration of rainfall and by seepage from streams that cross the outcrop. Because of the high rate of streamflow seepage into the underlying Edwards, some streams crossing the outcrop flow only during flood stage.

Water occurs primarily in the solution-collapse zones in the Edwards Limestone. These zones contain large caverns and underground channels through which large quantities of ground water can readily move. In addition to the solution zones which parallel the bedding planes, a network of steeply dipping faults and joints are present, especially in the Balcones Fault Zone. These faults and joints intersect the water-bearing beds, providing channels along which water can move.

West of the Balcones Fault Zone, erosional remnants of the aquifer strata cap the hills. Here, the aquifer is not completely water-saturated and water-table conditions prevail. In the Balcones Fault Zone, the entire aquifer is usually saturated and water occurs under artesian conditions. The hydrostatic pressure is sufficient to cause static water levels to rise above the top of the aquifer and in many cases to cause springs to flow. If wells are drilled, they can also flow at the surface.

Recharge, Movement, and Discharge

The recharge zone in the northern sector of the Edwards aquifer consists of mainly gently rolling terrain, whereas the Austin region is characterized by steeper and more highly dissected terrain. Both areas contain numerous scattered dissolution features consisting of sinkholes and caves.

Ground-water flow in both sectors of the aquifer is similar, but the areal distribution of surface recharge and discharge is different. Recharge occurs when the aquifer is replenished from surface water after a major rainfall event or through stream seepage.

In the Austin region of the Edwards aquifer, recharge occurs in the main channels of six creeks crossing the outcrop. Recharge volumes are known because a water budget analysis has been done using streamflow gages to determine how much water seeps into the ground in the streambeds. A water budget analysis of total recharge and discharge could not be determined in the northern region because the five streams crossing the outcrop are losing water to the ground and gaining through springs, depending on the elevations between the ground-water levels and the streambeds in some locations. Streams which cross the outcrop of the Edwards are: Brushy Creek, San Gabriel River (South Fork), San Gabriel River (North Fork), Berry Creek, and Salado Creek. Streamflow studies conducted by the U. S. Geological Survey in 1978-79 on these five streams indicated that increased flows occurred in downstream directions for most reaches on each stream. This study determined that in general the streams serve as points of aquifer discharge rather than recharge. Portions of the main channel of Brushy Creek are known to accept large volumes of water where it crosses a series of faults near Round Rock.

Recharge in the northern region of the Edwards occurs in tributaries, and infiltration from precipitation on the outcrop. Surface runoff and precipitation infiltrates the aquifer through faults, fractures, sinkholes, and caves. These features have been dissolved out, which allows rapid infiltration as well as rapid movement of ground water within the aquifer. Another complicating factor concerning the recharge and discharge measurement is the amount of subsurface recharge from the underlying Trinity Group aquifer.

An estimate of the amount of annual effective recharge that can be developed from the Edwards aquifer from the work done by Muller and Price (1979). It is based on the 1956 reported minimum spring flow at Barton Springs in the Colorado River basin, and 1956 minimum spring flow at Salado Springs plus the estimated Edwards ground-water withdrawals for 1956 in the Brazos River basin. These estimates do not include ground water in storage. The amount of effective recharge to the Edwards aquifer in the study area is then calculated based on the amount of outcrop area as a percentage of the total outcrop in the river basin by county. The amount of available recharge to the Edwards aquifer within the study area is estimated to be a little more than 7,400 acre-feet per year.

A study on the availability of ground water from the Edwards aquifer for the City of Georgetown was conducted by William F. Guyton Associates, Inc. (1987). The estimates of ground water available were based on: hydrographs of water levels in the area; 1985 municipal pumpage for the City of Georgetown; estimated 1985 total reported municipal pumpage from other major users; estimated 1985 industrial and domestic pumpage; and 1985 total average springflows from Berry, Salado, and San Gabriel Springs.

The study indicated that the City of Georgetown in 1985 pumped about 4 to 4.5 MGD (million gallons a day). During late August 1985, after more than a month of relatively low precipitation, the total of major springflows from Berry, Salado, and San Gabriel was 19 MGD. Total municipal pumpage during late August 1985 was estimated to be about 12 MGD. An estimated 5 MGD of industrial and domestic pumpage was added to these discharges, giving a total estimated discharge from the aquifer of 36 MGD.

The report assumed that if water in storage was not used, since its volume and availability are unknown, and all major springflow could be used by pumping wells, then the 36 MGD could be used as an expected yield from the Edwards aquifer during a normal summer. It was also assumed that if Georgetown's 1985 total pumpage was maintained, the City could develop an average ground-water supply of about 9 MGD during periods of normal to high rainfall.

The position of the potentiometric surface and depth to water in wells in the Edwards aquifer during January-February, 1981 are shown in Figure 20. This period represents a time when rainfall and pumpage were about normal for the area for about a year. Thus, fluctuation in ground-water levels in the aquifer were also considered to be normal.

The potentiometric surface has an extensive easterly slope. Consequently, ground water moves chiefly in this direction because it is the predominant direction of the hydraulic gradient. In a zone of the aquifer where a high degree of anisotropy exists, such as along faults, the direction of movement may be substantially different from the regional hydraulic gradient. South of the Colorado River, a strong northerly component of ground-water movement prevails from Buda to the Barton Springs area near the Colorado River. North of the Colorado River, a moderate southerly component indicates that ground water is moving south to the river from the north-central part of the City of Austin. North of the City of Austin in Round Rock, Georgetown, Jarrell, and Salado areas, water moves basically eastward.

The Edwards aquifer in the Austin region is slightly to moderately developed by wells, and springs are by far the greatest portion of the discharge from the aquifer. In the San Antonio region, by way of contrast, pumping from the Edwards aquifer by the City of San Antonio and by irrigators is intensive. Whereas, in the Austin region, the aquifer is not pumped for municipal use by the City of Austin or used extensively for irrigation. The total amount of ground water discharged by wells in the northern region when compared to the San Antonio region of the Edwards aquifer is comparatively small. However, the study conducted by Guyton Associates, Inc. (1987) for the City of Georgetown indicated that the total pumpage was 47 percent of the flow from the three main springs in the area.

Barton Springs are considered to be large springs, with an average annual flow of approximately 50 cubic ft/second (CFS) or 36,199 acre-feet for the period 1917-81, and ranked as the fourth largest springs in Texas. Although not as large as Barton Springs, there are numerous springs issuing from the northern region of the Edwards. Several small springs are located along the Colorado River and Mt. Bonnell fault, with larger springs located near the eastern edge of the outcrop of the aquifer. Many smaller springs are found east in the outcrop in Williamson County, extending north into Bell County. The three main springs in the northern region are: San Gabriel Springs, Berry Creek Springs, and Salado Springs.

Between 1955 and 1973, the U.S. Geological Survey maintained a gaging program on Salado Creek near Salado Springs. For shorter periods within this interval, flow measurements were also made on Berry Creek and the San Gabriel River. Figure 21 shows plotted spring flows for Salado Springs from the Survey's intermittent measurements for the period 1950 through 1973.

According to Brune (1975), the lowest average annual flow measurements for Salado Springs was 4.6 CFS (3,330 acre-feet) in 1956; and the maximum known discharge for the springs was 55 CFS (39,819 acre-feet/year).

Hydraulic Characteristics

The hydraulic properties of the Edwards are generally undetermined due to lack of sufficient data. The seemingly random occurrence of solution channels in limestone aquifers makes it difficult, if not impossible, to determine transmissibilities and permeabilities in any given area.

Data on the values of specific yield and coefficient of storage for the Edwards aquifer in the study are not readily available.

Water Levels

An indicator of the effects of changes in pumpage and variations in precipitation over the years is the fluctuation of water levels in wells. Water levels in wells in the Edwards aquifer fluctuate over a wide range in most of the study area.

Like springflows, water levels have been low in years of low rainfall and have recovered during wet years. The water levels in the mid-1950's were considered to be record lows, but with the increased pumpage during the late-1970's, the water levels have equaled or have been lower than those of the 1950's.

In order to monitor changes and trends in the water levels, an extensive network of observation wells has been selected in the study area. Some of these wells are equipped with recorders that monitor water levels continuously. The locations of selected observation wells in the Edwards aquifer are shown on the map of the January-February, 1981 water levels (Figure 20), and pertinent hydrographs are illustrated on Figure 22.

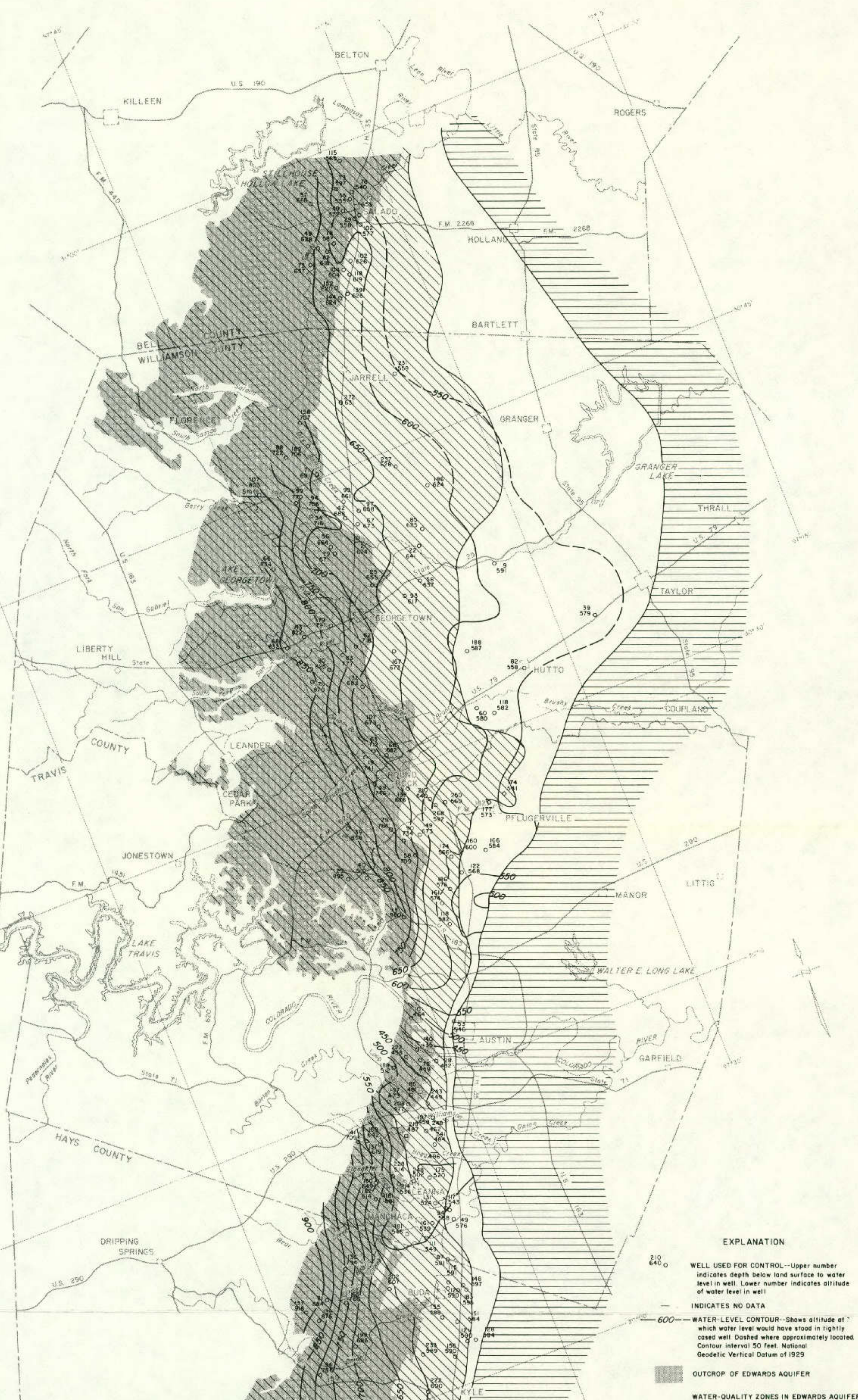

Figure 20

Approximate Altitude of Water Levels in Wells in the Edwards Aquifer, January-February, 1981

Large changes in water levels of 50 to 100 feet are indicated by the hydrograph 58-36-402 in Travis County near the City of Pflugerville. All fluctuations are basically in response to wet and dry periods. Low water levels are indicated near the end of the drought in 1956, but these levels rose 100 feet by 1958. In 1984, the water levels fell to nine feet below the previous record low of 1956. This well is located near the center of pumpage for Pflugerville, relatively far from the outcrop, and not near any major Edwards springs. Because it is located in the artesian portion of the aquifer and away from natural recharge, its water levels are subject to wide fluctuations as a result of pressure changes created by nearby pumpage.

Well 58-27-504 located in Williamson County is near the area of ground-water pumpage associated with Round Rock and at the edge of the outcrop of the aquifer where water-table or semi-artesian conditions prevail. The aquifer in this area receives maximum recharge and acts as a storage reservoir for the artesian portion of the aquifer. This storage capacity tends to buffer wide fluctuations in nearby water levels. The drought of the 1950's is clearly indicated by the consistently low water levels through 1956. After the drought, sharp rises of 40 feet occurred in response to more than 50 inches of rainfall during 1957. Increases in pumping for public supply and industrial purposes since 1977 have caused water levels to equal or drop below the 1956 level.

The water levels in well 58-20-102 in Williamson County in the City of Walburg show the influence of municipal pumping and only a slight response to recharge from rainfall. During the 20 years from 1966 to 1986, the water levels show a slight trend downward. This well, located about five miles east of the recharge area, is 603 feet deep.

Water-level fluctuations in southern Bell County are represented by a livestock well 58-04-801 near Prairie Dell. This 175 foot deep well, less than a mile east of the recharge area of the Edwards aquifer, indicates that the water levels changed only slightly over the period of record. From 1966 to 1986, the maximum fluctuation in water levels has been only 11 feet. Variations in annual rainfall may be largely responsible for the water-level fluctuations.

Ground-water recharge to the Edwards aquifer is still essentially in balance with discharge from the aquifer as shown by the hydrographs. One of the most illustrative things about the hydrographs is the magnitude of water-level declines and the quickness of recovery. Even though some of the recent droughts have been less severe than that of the 1950's, the effect of the increase in pumpage becomes evident. The stress that is put on the aquifer by the increased pumpage causes large and rapid declines in water levels, both near the pumpage centers and areally, as pumpage exceeds recharge.

Chemical Quality

The quality of water in the Edwards aquifer is directly affected by the total environment of the water, from its origin as rainfall to its ultimate discharge from wells and springs in the aquifer. Most of the dissolved matter in the ground water is from the solution of substances in the rocks that compose the aquifer. Other constituents found in water from

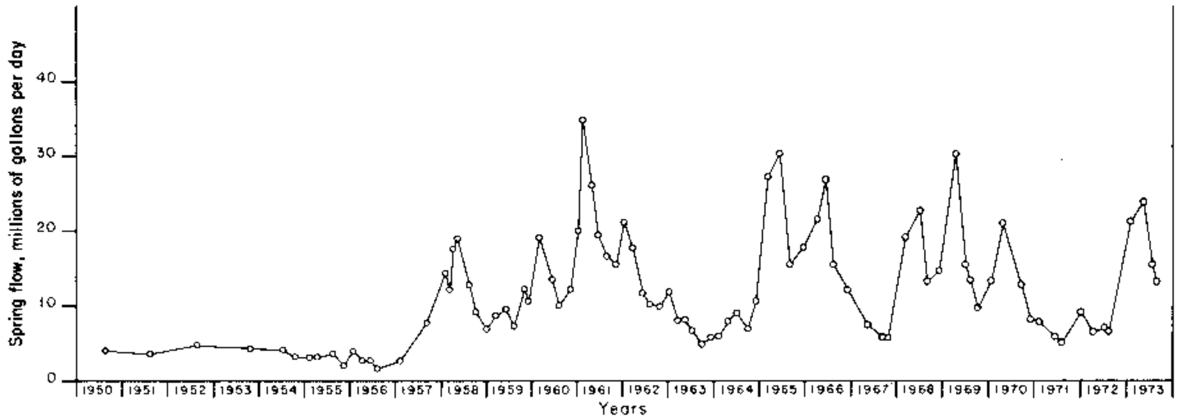

Figure 21.—Intermittent Discharge Measurements of Spring Flow at Salado Springs

Figure 22
Locations of Selected Water-Level Hydrographs of
Wells Completed in the Edwards Aquifer

the Edwards aquifer originate outside the aquifer between the time the relatively pure rainfall falls upon the earth and its latter entry into the aquifer. During this time, various constituents, possibly including human-related contaminants, are carried by the recharge water into the aquifer.

Ground water in the Edwards and associated limestones aquifer may be described as a calcium carbonate, and sometimes magnesium carbonate type water, generally becoming a sodium sulfate water downdip. Still farther downdip, it becomes a sodium chloride water.

Decreasing water circulation near faults, increasing temperature as the depth of the aquifer increases, and solution of the rocks cause the ground water to become more highly mineralized downdip.

Sulfate, chloride, and dissolved-solids concentrations in water at specific sites in the Edwards aquifer are given in Figure 23. The map serves as a quick and practical guide to concentrations of these important chemical constituents, as well as to the sum of the total dissolved constituents from place to place.

The quality of water from the Edwards aquifer varies throughout the Austin and northern regions. Mineralization of the water increases from the recharge areas on the west to the downdip areas on the east. The dissolved-solids concentration typically increases from 200 to 400 milligrams per liter (mg/l) in the recharge zone, to 1,000 mg/l and then 3,000 mg/l at variable distances to the east.

The increase in mineralization with distance from the recharge area is much more rapid in Travis and Hays Counties than in Williamson and Bell Counties. Intensive faulting of the ground-water reservoir in Hays and Travis Counties has created numerous barriers to ground-water movement in an easterly direction. This retardation of ground-water movement has caused the dissolved-solids concentration of the water to reach the 1,000 and 3,000 mg/l limits as near as one to two miles east of the Edwards aquifer outcrop near the Colorado River in Travis County. In Williamson and Bell Counties, where faulting is less severe, the Edwards aquifer contains water having less than 3,000 mg/l of dissolved solids greater distances downdip. In Williamson County, water having generally less than 1,000 mg/l dissolved solids concentrations extends as much as 10 miles east of aquifer outcrop, and water having generally from 1,000 to 3,000 mg/l extends beyond this limit an additional 10 to 12 miles in places.

Sulfate and chloride concentrations, like those of dissolved solids, increase from west to east. For example, at the recharge zone, where the dissolved solids concentrations are about 200 to 400 mg/l, sulfate and chloride are 10 to 30 mg/l. Moving eastward from the recharge zone, sulfate and chloride concentrations increase to 200 mg/l as dissolved solids increase to 1,000 mg/l. At the eastern extremes of the aquifer where dissolved solids are near 3,000 mg/l. sulfate and chloride concentrations may exceed 800 to 500 mg/l, respectively.

Additional data on the chemical quality can be found in many reports listed in the selected references, and in the tables found in TWDB Reports 195, 293, and TDWR Report 276.

Utilization and Development

The earliest settlers living over the northern region of the Edwards aquifer relied on water from streams and springs. Some of the early trading posts were established next to springs. A number of saw and grist mills used the water power from springs. The springs were used as a stop on the Chisholm Cattle Trail from 1867 to 1895. They have always been popular for swimming and recreation.

As areas became more populated and small communities grew into towns and cities, a need developed for a centralized water system to meet the water demands. Most of these communities chose to develop their ground-water sources rather than rely on the intermittent supply of surface water. Ground water was more reliable and usually less expensive than building a reservoir and a water treatment and conveyance system. However, because water was available from the Colorado River and numerous springs, there was no need for Austin to develop ground water from the Edwards.

The biggest development of water wells completed in the Edwards has occurred primarily in Williamson County. Users of Edwards water include the Cities of Round Rock, Georgetown, Jarrell, Bartlett, and numerous water supply corporations. The City of Pflugerville, in Travis County, also uses ground water from the Edwards for public supply purposes.

Georgetown's first public supply well was a 90 foot, hand-dug well, completed in 1910. Prior to the completion of this well, the city pumped water from the San Gabriel River Springs, located northeast of Georgetown.

In 1934, the City of Round Rock drilled its first public supply well. Prior to this time, the city did not have any water distribution and relied on privately owned wells located within the town to supply water to other householders. Existing springs along Brushy Creek were also used by the people as a source of water.

As stated earlier in the report, an updated field inventory was done in and adjacent to the study area, providing the locations of municipal and industrial water wells and well fields and estimated average yields of wells, using the 1985 TWDB Survey of ground water and surface water users and Texas Department of Water Resources Report 276 and TWDB Reports 195 and 293.

The locations of selected wells and well fields completed in the Edwards aquifer, along with the average yields in gallons per minute, are shown in Figure 19.

In 1985, approximately 15,919 acre-feet of ground water was pumped from the Edwards aquifer, which represented about 61 percent of the total ground water used in the study area (Table 2).

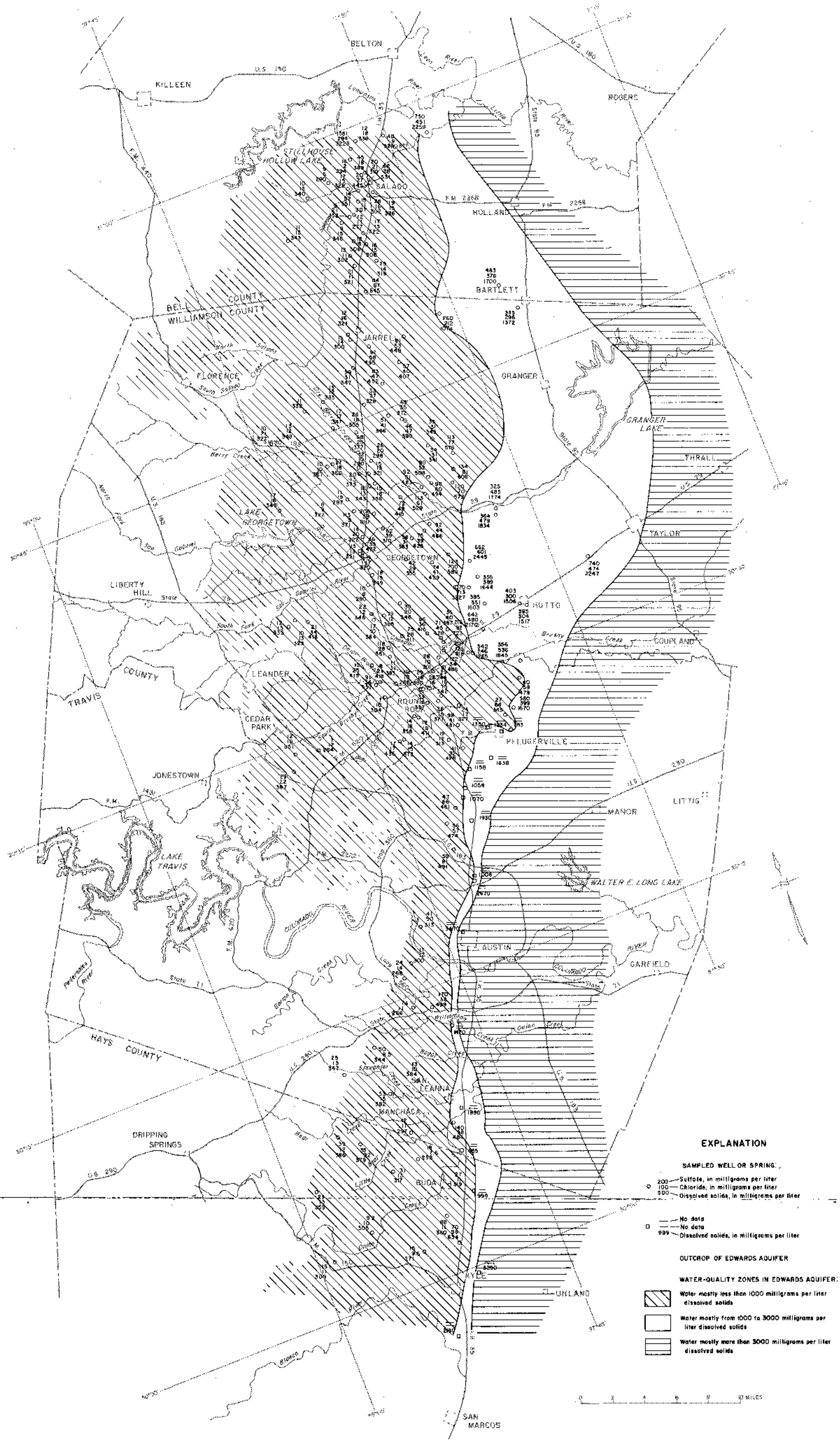

Figure 23

Sulfate, Chloride, and Dissolved-Solids Concentrations in Water From Selected Wells in the Edwards Aquifer

A total of 22,873 acre-feet of ground water was pumped for municipal purposes. Municipal pumpage from the Edwards aquifer was about 13,773 acre-feet, which represents 60 percent of the total municipal usage from the Edwards aquifer. Georgetown and Round Rock were the largest users of ground water from the Edwards aquifer, with about 58 percent of the total ground water used for municipal purposes. Ground water used for irrigation in the study area from the Edwards aquifer was about 2 acre-feet in 1985.

In 1985, a total of 308 acre-feet of ground water from the Edwards aquifer was used for manufacturing. Most of the reported manufacturing pumpage was water used by quarries and limestone processors.

In 1985, a total of 1,665 acre-feet of ground water from the Edwards aquifer was used for mining.

There was an estimated total of 803 acre-feet of ground water used in 1985 for livestock purposes. The Edwards aquifer supplied 171 acre-feet of ground water for livestock needs. This represents about 21 percent of the total usage.

Availability of Ground Water for Development

Ground-water availability in the study area was calculated as a percentage of the total availability in each river basin by county, as modified from TDWR Report 238, "Ground-Water Availability in Texas".

A lack of historic data on pumpage and springflow hinders the calculation of average annual recharge. Therefore, the estimate of annual recharge to the Edwards aquifer in the study area is based on the combined minimum springflow and well pumpage in 1956. The amount of ground water available under drought conditions from the Edwards aquifer within the study area has been estimated to be a little less than 7,500 acre-feet per year. Water-well hydrographs, however, indicate that average annual recharge is greater. In fact, approximately 15,919 acre-feet of ground water was used from the Edwards aquifer in 1985, and currently more water is being withdrawn than is available as recharge under drought conditions. Continued withdrawals at this rate and additional development will result in mining of ground water, that is, the removal of water from aquifer storage.

Other Aquifers

Other hydrologic units which produce small to moderate amounts of ground water in the study area are the Marble Falls Limestone, Austin Chalk, Navarro and Taylor Groups, and alluvium and terrace deposits. The alluvium and terrace deposits are the larger producers of ground water in the area.

The Marble Falls Limestone outcrops in the north-central part of Burnet County at the Lampasas-Burnet County line. Ground water occurs in cavities and fractures in the limestone near the outcrop area. Wells producing from the aquifer may yield as much as 2,000 gal/min. The quality of water produced from the aquifer is usually suitable for most purposes in and near the outcrop area.

In the Austin Chalk and Navarro and Taylor Groups, ground water usually occurs in the upper, weathered outcrop portion of the units, which is the most permeable. The Austin Chalk contains numerous fractures and joints which are water saturated. Water can also be present in the softer marls which occur throughout the Austin Chalk. The Navarro and Taylor Groups contain montmorillonitic clays, which are known for their swelling and shrinking characteristics. During dry periods, large cracks may open in the surface of the outcrop, which may allow water to enter the water-bearing unit. Ground water occurs primarily under water-table conditions in the Austin Chalk and Navarro and Taylor Groups.

The Austin Chalk and Navarro and Taylor Groups yield small amounts of fresh to moderately saline water for livestock and irrigation purposes. In 1985, there was no reported pumpage from water wells completed in the Austin Chalk and Navarro and Taylor Groups.

The Wilcox Group crops out in the western parts of Bastrop County and the southeastern part of Williamson County, and extends in a northeast direction into Lee and Milam Counties.

The Wilcox consists chiefly of fine to coarse sand and lesser amounts of clay, sandy clay, sandstone, and silty shale with a few lenses of limestone and lignite. Near the middle of the Wilcox Group, there is a sand facies equivalent to the Simsboro Sand Member which contains the greater percentage of fine to coarse-grained sand.

Rainfall which falls on the outcrops of the Wilcox Group is the principal source of natural recharge. In addition to precipitation, the Wilcox also receives recharge from infiltration of surface water runoff in unlined earthen ponds and streams on or crossing its outcrop. Ground water generally occurs under water-table conditions in the outcrop area of the Wilcox Group.

The Wilcox yields small to moderate quantities of fresh to slightly saline water outside the study area to many wells for domestic, livestock, and public supply users. The City of Elgin, along with water supply corporations located outside the study area, furnish water into the study area from wells completed in the Wilcox Group.

The locations of selected wells and well fields completed in the Wilcox Group aquifer and alluvium and terrace deposits, along with average yields (gpm) of wells, are shown in Figure 19.

In 1985 ground water used within the study area from the Wilcox Group and Recent Alluvium and Terrace Deposits was approximately 2,316 acre-feet (Table 2). Municipal pumpage from the Wilcox Group and Recent alluvium and terrace deposits was approximately 1954 acre-feet. An estimated 362 acre-feet of ground water was used for manufacturing, livestock, and irrigation.

Municipal usage reported for the City of Elgin from the Wilcox Group aquifer was about 1,009 acre-feet.

Recent alluvium and terrace deposits which occur in the eastern portion of the study area are treated as one undifferentiated hydrologic unit because of their similar hydrologic and lithologic characteristics. The Recent alluviums are located adjacent to rivers and streams in Travis, Williamson, and Bell Counties. The largest outcrop area and thickest alluvium deposits are located along the Colorado River in eastern Travis County and consist of unconsolidated materials of gravel, sand, and silt.

Primary sources of ground water to the alluvium and terrace deposits are rainfall, and lakes and streams which cross their outcrop. Water occurs primarily in the void spaces between particles of gravel and sand, and moves slowly downdip to the east and south, generally parallel to the recharging streams and rivers. It is usually under water-table conditions and the aquifer may not be completely saturated.

In Travis County, (TDWR, 1983), the amount of recharge to the alluvium and terrace deposits was computed for the area along the Colorado River between Town Lake and the east county line.

Five percent of the mean annual rainfall, or 1.68 inches, was used as an estimate of average annual recharge over the outcrop area of the Colorado River alluviums and terrace deposits in Travis County.

The total number of acres of alluvium and terrace deposits outcropping north of the Colorado River within the study area was applied to 1.68 inches of mean annual rainfall, giving a little less than 3,800 acre-feet per year of effective recharge.

Pumpage from wells accounts for nearly all the discharge from Recent alluviums. A small amount is believed to return to stream channels in the form of seepage during periods of low streamflow. Springs at the base of the terrace deposits account for most of their discharge.

Alluvium and terrace deposits are used extensively as a source of public supply and domestic water. The City of Austin primarily uses surface water from the Colorado River, but also uses some ground water from the alluvium deposits within the study area. Several smaller communities such as Thrall and other municipal water-supply corporations use ground water from the alluvium and terrace deposits. The locations of entities using water wells completed in the Recent alluvium and terrace deposits, along with the average yields (gpm) of wells are shown in Figure 19.

As previously mentioned, in 1985 there was a total of 2,316 acre-feet of ground water used from the Wilcox Group and Recent alluvium and terrace deposits. The 1985 ground-water usage for municipal supplies in the study area from the alluvium and terrace deposits was approximately 658 acre-feet.

POTENTIAL METHODS FOR INCREASING RECHARGE

Artificial recharge occurs when natural recharge is modified to increase recharge to the aquifer. In the broadest sense, artificial recharge includes not only planned replenishment, but also additions to the ground water that are incidental to other activities. The objectives of artificial recharge include maintaining an infiltration rate, increasing the area in which water is in contact with the aquifer outcrop. Modifications to increase recharge can occur in the aquifer's outcrop and downdip where water can be injected into the aquifer by injection wells.

Artificial recharge can be done by direct and indirect methods. Direct methods include structures such as ponds, check dams, pits, or ditches to increase the amount of water infiltrating from the surface into the ground water. Water can be injected into the ground water through wells and shafts. Indirect methods of recharge includes the movement of water from streams or lakes into underground formations.

Methods of Artificial Recharge Within the Study Area

The direct method of artificial recharge that might apply to the Trinity Group aquifer is the use of injection wells. The Trinity is limited as to surface exposure, the subsurface units are well cemented, and soils on the outcrop are tight with clay loams and sandy clays, which limit the amount of surface recharge and migration to the water table. The direct methods of artificial recharge that might be used in the Edwards aquifer would be runoff-control structures, injection wells, and natural openings.

Objectives of an Artificial Recharge Investigation

Prior to the planning and construction of any large artificial recharge project, a detailed investigation of the area to be modified should be undertaken. The objectives of such an investigation are as follows: (a) preparation of detailed soil maps of the aquifer's outcrop ; (b) preparation of lithologic and structural maps of the aquifer in the outcrop and downdip areas; (c) determine horizontal and vertical permeabilities of the saturated and dry zones of the aquifer; (d) determine the extent and location of natural recharge; (e) outline the areas where artificial recharge appears feasible and determine the quantity and quality of recharge water which may be captured; and (f) develop a quantitative tool which can evaluate proposed recharge modifications in terms of water-level changes with time.

The above objectives will require a detailed test hole program to determine formation and soil changes in the outcrop, and extensive laboratory testing of the samples to determine permeability and infiltration rates. Geophysical surveys should be used to supplement test hole information. Also, computer programs could be used to simulate the aquifer's response to recharge and process geologic and data. These data processing programs should locate and plot zones of low permeability or infiltration, and indicate whether or not they are continuous over large areas.

Some of the legal and institutional issues to be considered before the project is started are: (a) by whom and how will the project be financed; (b) who would benefit from storing water underground; (c) who would build and operate the project; and (d) would land be affordable as well as available?

Other items to be considered are the costs and benefits of the project. The costs would include such things as laboratory analyses, mathematical computer models, quantity and quality of the source water, surface and subsurface conditions, and location of the project. Some of the benefits derived from such a project might be a larger and more dependable supply of water, a decrease in pumping lifts, and a decrease in evaporation losses.

GROUND-WATER PROBLEMS

Water-Level Declines

Water-Level Fluctuations in the Trinity Aquifer

Water levels in wells completed in the Trinity aquifer, located mainly in the western part of the study area, show relatively small seasonal variations as compared with those in the Edwards aquifer located further to the east. More importantly, water levels have been gradually declining since the early to mid-1960's as shown in Figure 17. These declines are taking place in most of the wells completed in the Hensell and Hosston Members of the Travis Peak Formation. Some of the major declines have developed around the cities of Belton, Bartlett, Granger, and Taylor. Cones of depression have developed in western Williamson County and north of the Colorado River in Travis County.

At the present time, water levels in the lower Trinity aquifer in the eastern part of the study area are significantly lower than in the Edwards aquifer. The steady declines are due to the low permeability of the water producing sands and pumpage of ground water which is used for industrial and public supply purposes. The overall decline of the water levels in the Trinity aquifer can have a significant effect on the hydrology and chemical quality of the deeper parts of the Edwards aquifer.

Water-Level Fluctuations in the Edwards Aquifer

An indicator of the effects of changes in pumpage and variations in precipitation over the years is the fluctuation of water levels in wells. Water levels in Edwards aquifer wells fluctuate over a wide range in most of the study area.

Small water-level variations have occurred from wells in the northern and western parts of the study area, whereas variations of as much as 100 feet have been observed in wells completed in the artesian portion of the Edwards aquifer. Hydrographs of water levels in Edwards aquifer wells within the study area have shown a general trend of water levels rising as a result of major recharge events and water levels declining during relatively dry periods, especially during the summer.

Like springflows, water levels have been low in years of low rainfall and have recovered during wet years. Major rainfall events generally occur during late spring and fall and coincide with rapid water-level rises. The rate of water-level declines depends on the amount of recharge that replenishes the aquifer and amount of artificial discharge of ground water through pumpage. A hydrograph located southeast of Georgetown, observed by Sanger (Kreitler, 1987), showed a close correlation between precipitation and water-level variation for the period between 1981 and 1986. Sanger observed that the water-level pattern from this hydrograph showed a hydrologic system that can be recharged and depleted relatively quickly. The rapid response indicated an aquifer system that has a relatively low storage capacity, but high permeability. The water levels in the mid-1950's were considered to be record lows, but with the increased pumpage during the late-1970's; the water levels have declined to levels that are as low or lower than those in the 1950's.

The water-level declines during 1984 indicate that increased pumpage during the last several years has had a significant effect on the potentiometric surface. Round Rock and Georgetown have increased their monthly pumpage significantly during the last decade. Large changes in water levels have been observed. Fluctuations in the past have been basically in response to wet and dry periods, but recent pumping conditions may reflect removal of water from storage.

Contamination

Susceptibility to Contamination

Aquifers are susceptible to contamination from both surface and near-surface sources. Factors which affect this susceptibility include: infiltration potential of the soils; permeability of an aquifer where it crops out at the surface, i.e., its recharge zone; protection by an overlying less permeable zone; depth to the water table; capacity for attenuation of contaminants in the soil and in the unsaturated or vadose zone of an aquifer; and the amount of recharge available to transport contaminants downward to an aquifer. Related factors which can affect aquifer susceptibility to contamination on a larger, regional scale are a large areal extent of an aquifer's recharge zone, the type of land use on the recharge zone, and the level of urban, agricultural, or other commercial development.

The Sycamore and Hensell Sands of the Trinity Group aquifer in the study area, as compared with the other aquifers, are relatively less susceptible to contamination in their outcrop area or recharge zone. Soils in this area are clay loams and sandy clay loams with a low infiltration potential (Klemt and others, 1975). The Glen Rose Formation where it is characterized by fractures and solution cavities and cropping out at the surface is a sensitive area. Depths to ground water in these outcrop areas are shallow, ranging from 30 to 90 feet. The areal extent of these recharge areas is, however, small compared with the areal extent of the confined portion of the Trinity Group aquifer. Figure 3 shows the recharge zone or outcrop area of the Trinity Group aquifers as a narrow band at the western edge of the study area. The land use on these recharge areas is predominantly ranchland with the exception of a small area in the City of Burnet.

The Edwards aquifer in the study area is especially susceptible to contamination from both surface and near-surface sources of contamination. Soils in the Edwards outcrop area are thin or absent, with little or no capacity to retard contaminant movement.

Permeability in the Edwards aquifer is characterized by solution enlargement of fractures (faults, joints) and void spaces created by solution collapse. Such cavernous permeability in the recharge zone allows rapid movement of water and contaminants from the surface to the saturated portion of the aquifer. Attenuation of contaminants in such a system is minimal, except where recharge features such as sinkholes or caves are filled in with fine-grained soil material.

Figure 3 shows that the outcrop or charge zone of the Edwards aquifer occurs as a discontinuous belt parallel to and west of Interstate Highway 35. Because of its proximity to the City of Austin, the Interstate Highway 35 and State Highway 183 corridors in the recharge zone areas have experienced a large increase in development since the late 1970's. Land use patterns have changed and are continuing to change from predominantly ranchland to a mix of suburban, commercial, and rural land use. The change in land use and the increasing density of development in this area places a greater number and more varied types of contamination sources, such as septic tanks, urban runoff, sewage discharges, and hazardous and toxic materials, close to the aquifer.

River alluvium and terrace deposits are generally susceptible and locally can be sensitive to contamination. These deposits consist of varying amounts of sand, clay, and gravel. Typically, these deposits are coarse and more gravelly at the base with finer sand and clay in the upper portions. These deposits are, however, variable, and gravel often occurs at the surface. Soils developed on these deposits are also variable, ranging from silty clay to sandy loam to gravelly sand. In general, permeabilities in these deposits are moderate to high, except where the deposits are predominantly clay. Depths to ground water are shallow ranging from a few feet to about 30 feet. The areal extent of these deposits is significant and includes areas along the Colorado, San Gabriel, and Little Rivers and along Brushy Creek, and in the interstream divides between Brushy Creek, the San Gabriel River, and the Little River. Land use is predominantly agricultural, with most of the area cultivated farm land and some devoted to pasture and rangeland. These areas are not anticipated to experience significant changes in land use. Some areas near the cities of Round Rock, Georgetown, and Austin may be subject to some suburban residential and commercial development.

POPULATION AND WATER DEMAND PROJECTIONS

Population Growth

The population of the study area increased significantly, over 25 percent, during the period from 1980 to 1985. Table 4 gives population figures for the study area for 1980 and 1985, and population projections for 1990, 2000, and 2010. These population data shows that each county area in the study area experienced a high rate of growth except the study area portion of Bell County. The population of Williamson County grew by almost 40 percent from 1980 to 1985. A great deal of this growth is associated with increased economic activity and development of the City of Austin and its environs. The study area and Texas overall have experienced a dampening of economic growth since 1985. While data is not currently available from the Bureau of the Census to illustrate this situation, recent economic activity and population growth are discussed in a report by the Capitol Area Planning Council (CAPCO, 1987).

Despite the current slowdown in economic growth, the City of Austin and the study area are likely to experience continued growth in economic activity and population throughout the rest of this century. Population growth for the study area was projected for 1990, 2000, and 2010 as shown in Table 4. The population of the study area is forecast to increase 35 percent by the year 2000 to 709,509 and by almost 50 percent through the 20-year planning period to 901,906. Most of this growth is projected to occur in Williamson and northern Travis Counties.

Water Requirements

Total water use of the study area for 1980 was estimated at 90,477 acre-feet and for 1985, 118,084 acre-feet. Of this total, 81.4 percent in 1980 and 84.8 percent in 1985 were for municipal use, 5.5 percent and 4.8 percent respectively for manufacturing use, 7.8 percent and 5.6 percent for power generation, 1.3 percent and 0.9 percent respectively for irrigation use, 2.5 percent and 2.4 percent respectively for livestock use, and 1.5 percent in both years for mining operations. Municipal use, by far the largest use category, totaled 73,663 acre-feet in 1980 and 100,168 acre-feet in 1985. Total ground water use in the study area for 1980 and 1985 are 19,549 and 25,940 acre-feet respectively. Municipal use accounted for most of the ground water used in the study area. Table 5 gives water use data for 1980 and 1985 and projected annual water requirements for the decades 1990, 2000, and 2010. Current and future water requirements are given for municipal use, broken down for cities and county other, and for all other uses combined.

Projections of future water requirements are based upon Texas Water Plan High Series population projections and projected High Series per capita water use (TDWR, 1984). Water requirements in the study area are forecast to increase by 65 percent from 1985 to 194,324 acre-feet annually in the year 2000. Total water use is expected to

Table 4.
Current and Projected Population in the Study Area

	1980	1985	1990	2000	2010
Major Cities [1]	284,039	356,117	395,713	527,892	664,299
County Other	78,246	100,922	124,487	181,617	237,607
Total	**362,285**	**457,039**	**520,200**	**709,509**	**901,906**
Bastrop	5,742	6,975	8,089	10,671	13,453
Bell	9,106	8,968	9,038	15,459	21,020
Burnet	7,363	9,005	10,627	13,880	17,052
Milam	740	899	926	996	999
Travis	263,202	325,662	361,327	467,876	575,929
Williamson	76,132	105,530	130,193	200,627	273,453
Total	**362,285**	**457,039**	**520,200**	**709,509**	**901,906**

[1] Cities with population greater than 1,000.

more than double from 1985 to 2010, to 243,417 acre-feet annually. The greatest demand and the greatest increase for any use category for each period is in the category of municipal use. Other categories of use experienced little increase over the 20-year planning period, as illustrated in Table 5.

High Series projections for municipal water requirements are based on probable drought conditions per capita use (TDWR, 1984). Municipal water use projections for the study area are 126,674 acre-feet annually for the decade beginning in 1990, 174,124 acre-feet annually for the decade 2000, and 220,419 acre-feet annually for the decade 2010. The relatively small areas of Bastrop and Milam Counties do not affect significantly the total water demand in the study area in 2000 and 2010. The areas of Bell and Burnet counties included in the study area are projected to have relatively small increases in population. These areas are projected to contribute respectively about 2,000 acre-feet annually and 1,400 acre-feet annually of additional demand for municipal use by 2010. Northern Travis and Williamson Counties account for over 95 percent of total study area municipal water requirements for the decades 2000 and 2010. Northern Travis County municipal water requirements are forecast to be 122,619 acre-feet annually by 2000 and 150,938 acre-feet annually by 2010. Williamson County municipal water requirements are estimated at 43,407 acre-feet per year in 2000 and 59,157 acre-feet per year by the year 2010.

Water requirements in the industrial sector, including manufacturing, power, and mining uses, are projected to increase only a small amount over the 20-year planning period. Manufacturing use shows the largest projected increase, from 5,623 acre-feet in 1985 to a 2010 projection of 9,370 acre-feet. Almost all of the increase in manufacturing use is projected to occur in northern Travis County. Mining use, occurring predominantly in Williamson County, is expected to increase only slightly by 2010 and power generation use, occurring exclusively in Travis County, is projected to remain at 1980 levels.

Table 5.
Current and Projected Water Use
(both surface and ground water) in acre-feet

	1980	1985	1990	2000	2010
Major City [1] Municipal Use	63,882	83,953	105,651	142,301	178,772
County Other Municipal Use	9,781	16,215	21,023	31,823	41,647
Total Municipal Use	73,663	100,168	126,674	174,124	220,419
Other Uses [2] Total	16,814	17,916	17,207	20,200	22,998
Total Use	90,477	118,084	143,881	194,324	243,417

[1] Cities with populations greater than 1,000
[2] Includes manufacturing, power, irrigation, mining, and livestock

Water requirements in the agricultural sector, including irrigation and livestock uses, are estimated to increase only slightly by 2010. Agricultural sector use will place only a small demand on study area resources during the 20-year planning period. Total irrigation and livestock water use in 1985 was 3,952 acre-feet and projections for 2010 are 4,255 acre-feet annually.

Water Supply - Next 20 Years

Introduction

The projected population and water demand data described in the previous sections were combined with estimates of ground and surface water availability and used to develop estimated allocations of water resources in the study area over the next 20 years. A number of assumptions and considerations were employed in the methodology used to develop the allocations. These include assumptions regarding ground and surface water availability, priorities in allocation, and other local constraints and considerations.

For surface water, the firm yield of reservoirs in the study area is taken as the availability. The firm yield is based on the amount of water available in each particular reservoir during the drought of record for that watershed. The availability of ground water from the Edwards aquifer is based on maintenance of springflow with no allowance for depletion of water from aquifer storage. The availability of ground water from the Trinity Group aquifer is taken as a percentage of the average annual rainfall over the outcrop area plus an apportioned amount of water from artesian storage. The amount apportioned from storage is calculated by depleting the amount of water in artesian storage to a potentiometric surface level 100 feet above the top of the aquifer over the 50-year period from 1980-2030. The method does not allow for dewatering of the aquifer.

Allocation involves the assignment of available water resources to meet the needs of the different user groups and for various uses in the study area. The process of allocation is essentially a planning tool to aid state and local entities in determining the best use of area water resources. There are certain priorities established in the state water planning process (TWDB) to efficiently match user groups, uses, and water sources. The methodology used in this study assigns the first level of allocation to major cities and large public water suppliers and targets surface-water supplies. Surface-water supplies are allocated to manufacturing and power use. Uses for livestock, mining, and irrigation are allocated to "local" surface-water supplies in the form of stock ponds and run-of-the-river diversions. Ground water is then allocated to supply remaining needs. Other municipal use comprising from rural water supply companies is given priority in the allocation of ground water.

In the study area, water imports are an essential source of supply. In allocating water resources it was assumed that there would be no interbasin transfers of surface water, except for the use of Lower Colorado River water by the City of Cedar Park. The new agreement on water rights in the Lower Colorado River does, however, allow the City of Austin to deliver surface water outside the Colorado River basin. Other assumptions include the allocation of imported ground water from the Carrizo-Wilcox aquifer east of the study area to the limit of need. Surface water from the Colorado River is also allocated to the limit of need in the northern part of the Colorado River basin in the study area.

Other considerations of local and economic factors influenced the allocation process. With regard to ground-water availability, the local nature of occurrence, the difficulty or feasibility of ground water development, and public water supply water quality criteria were taken into account in determining ground-water availability in certain parts of the study area. Some economic factors which were considered included the current investment of an entity in its water utility system and the costs of developing treatment and conveyance facilities for development of surface water.

Sources of Ground Water

Development and Availability

The Trinity Group aquifer outcrops in the western parts of the study area in portions of Burnet, Bell, Travis, and Williamson Counties and extends southeast below the surface into Bastrop, Lee, Milam, and Williamson Counties. It varies in total thickness in the downdip areas from about 125 feet in Burnet County to 1,000 feet in the southeast. Yields of large-capacity wells vary from less than 50 gpm to 1500 gpm. The chemical quality of the ground water is fresh, but exhibits a gradual deterioration with distance from the outcrop area and toward the south-southeast.

The Edwards (Balcones Fault Zone) aquifer extends from the Colorado River through Travis, Williamson, and Bell Counties in the central part of the study area. The thickness increases from less than 250 feet in Bell County to a little over 350 feet north of the Colorado River in Travis County. Yields of large-capacity wells range up to 2,000 gpm. Ground water produced from the aquifer is relatively hard, but in most of the study area the quality ranges from 500 to 1,000 mg/l total dissolved solids.

The Wilcox Group crops out in the western part of Bastrop County and the southeastern part of Williamson County and extends in a northeast direction into Lee and Milam Counties. The Carrizo-Wilcox yields small to moderate quantities of fresh to slightly saline water outside the study area to many wells for domestic, livestock, and public supply uses. There are several water supply corporations located outside the study area that furnish ground water from the Carrizo-Wilcox into the study area. It is not considered a major source of supply for the study area.

Throughout the study area, there are other local aquifers including alluvium and terrace deposits and the Marble Falls Limestone. The alluvium and terrace deposits occur in the eastern portion of the study area adjacent to rivers and streams in Travis, Williamson, and Bell Counties. The largest outcrop and thickest alluvium deposits are located along the Colorado River in eastern Travis County. The alluvium and terrace deposits are used as a source of public supply and domestic purposes. The Marble Falls Limestone aquifer within the study area crops out in the north-central part of Burnet County at the Lampasas-Burnet County line. Wells producing from the aquifer may yield as much as 2,000 gpm. The quality of water produced from the aquifer is usually suitable for most purposes in and near the outcrop area. The ground water availabile from these aquifers is local in nature and is not considered a significant contribution to the regional water supply for purposes of this study.

Increased use of ground water from the Trinity and Edwards aquifers has been substantial as regional population has grown, particularly around the Cities of Round Rock, Georgetown, and Taylor. In 1985 there was a little over 7,700 acre-feet of ground water used from the Trinity aquifer for municipal, manufacturing, irrigation, and livestock uses (Table 2). The estimated amount of ground water available on an annual basis from the Trinity aquifer is slightly more than 6,700 acre-feet. These figures indicate that there is an overdraft of approximately 1,000 acre-feet per year taking place. In 1985, there was approximately 15,900 acre-feet of ground water used from the Edwards aquifer for municipal, manufacturing, irrigation, mining, and livestock (Table 2). The estimated annual amount of ground water available from the Edwards aquifer is slightly less than 7,500 acre-feet, leaving a deficit of 8,400 acre-feet per year. Localized ground water from alluvium and terrace deposits and from the Marble Falls Limestone is available for public supply and domestic and livestock usage.

Potential for Additional Development

The best potential method for increasing the amount of ground water to the Edwards aquifer from artificial recharge would be runoff-control structures, which could impound the water during storms and released to streams during periods of droughts. These control structures could be located near the upstream boundary of the recharge zone. The potential for increasing the amount of ground water to the Trinity aquifer by artificial recharge is not as favorable as the Edwards aquifer because of low permeabilities and numerous confining beds which impede the movement of the water to the zone of saturation.

The drought yield availability of ground water in the study area's major aquifers has been exceeded by the current level of aquifer development. There is no potential for further development of the major aquifers in the area without posing the risk of supply shortages during extended droughts. Some additional development of minor aquifers in the area is possible, but only in local areas. Such development will not contribute significantly to the regional ground-water supply.

Sources of Surface Water

Development and Availability

There are currently five major reservoirs in the Brazos River basin and eight major reservoirs in the Lower Colorado River basin that lie within or near the study area. Of these existing reservoirs, four in the Brazos River basin with a total of 201,475 acre-feet of firm yield and two are in the Lower Colorado River basin with an estimated total of 1.75 million acre-feet of yield are available to supply water for municipal and other uses. The locations of these reservoirs are shown in Figure 24. The development of additional surface-water resources within the study area in the next 20 years is possible but the number of sites is limited and the restrictions imposed by cost and feasibility are significant.

Potential projects within the study area in the Brazos River basin include construction of a new reservoir on the South Fork of the San Gabriel River west of the City of Georgetown and modification of the dam at Lake Granger to increase the conservation pool elevation and thereby the amount of storage and the firm yield of the reservoir. The U.S. Army Corps of Engineers considers the latter project on Lake Granger to be the more feasible of the two projects (U.S. Army Corps of Engineers, 1987). Costs involved in land acquisition for the South Fork project render the project unfeasible. Additional water can be made available from reservoirs in the study area through the development of additional surface-water supplies in other areas of the Brazos River basin "system". Construction of new reservoirs in the basin can provide water to users downstream of the study area reservoirs, thus freeing water in area reservoirs currently reserved for "system" use. The Brazos River Authority has considered the construction of South Bend Reservoir on the main stem of the Brazos River in Young County and the construction of a new reservoir in the downstream portion of the basin. Some additional surface water may become available directly from existing or new reservoirs outside the study area such as by the construction of Lake Caldwell, in Milam and Burleson Counties on a tributary of the Brazos River near Lake Somerville. Water could be provided from this new reservoir or from Lake Somerville to the study area. This is considered a long-term solution and not practical within the 20-year planning period.

The firm yields of these reservoirs are currently fully committed by local contract and downstream system commitments. Present commitments are contracts for currently available water for a specified time frame which in all cases covers the 20-year planning period of this study. Future options are agreements for water in the reservoirs which is currently used to meet system commitments to downstream users, but which may be freed sometime in the future dependent on the construction of another reservoir to supply those downstream uses. It is important to note that at this time, there has been discussion and efforts toward such new reservoir development, but no contractual commitments or regulatory approvals have been received for dam or reservoir construction.

There are several potential sites for new reservoirs and the development of additional surface-water supplies for municipal, manufacturing, and other water needs in the Lower Colorado River below the Highland Lakes which may affect the study area in the future. Possible reservoir projects include the Colorado Coastal Plains Reservoir (Columbus Bend Project) on the main stem of the Colorado River near the City of Columbus, the La Grange Project on the mainstream near the City of La Grange, the Clearview Project near the City of Bastrop, the Cummins Creek Project also near Columbus, and the Allens Creek Project in Austin County. Two other potential reservoir projects for cooling water needs are the Baylor Creek and Cedar Creek Projects (TDWR, 1978). The Columbus Bend Project and the Baylor Creek Project are considered necessary in the Texas Water Plan to meet water needs in the Lower Segment of the basin through the year 2020 (TDWR, 1984).

A more detailed description of the allocation of future supplies cannot be given pending development of a water management plan for the Highland Lakes involving the City of Austin and the Lower Colorado River Authority (LCRA). It is generally assumed that sufficient surface- water supplies will be available from either the City of Austin or the LCRA for the northern portion of Travis County and parts of Burnet County in the study area for the 20-year planning period.

Uses

The results of projections of population and water demand discussed in the previous section indicate the distribution of demand by use category for the 20-year planning period. Most apparent is the dramatic increase in the water requirements for municipal use as illustrated in Table 5, due primarily to population increases. Both the "Major City" and "County Other" municipal use categories are projected to experience large increases in demand. All other uses combined showed relatively much smaller increases over the planning period.

The major city municipal use category, which is comprised of cities with a population greater than 1,000, can be broken down by city and examined for the significance of changes in water demand over the planning period. Table 6 lists these cities in the study area with their 1985 reported water use and projected annual use in 1990, 2000, and 2010. These data show that annual water use is projected to more than double by the year 2010 for almost all of the study area's major cities. A notable exception is the City of Round Rock. These relatively low future demand projections produced by the forecasting model are considered anomalous by the authors.

The second category of municipal use, termed "County Other" use, is comprised of water provided by organized water systems for small towns and rural residents. Data for "County Other" municipal use are listed by county in Table 7, and include reported water use for 1985 and projected annual use for the decades 1990, 2000, and 2010. Table 7 illustrates a similar trend of increasing water demand for municipal uses outside of the larger cities in the study area. Water use is projected to more than double over the planning period for all these areas except the small portion of Milam County in the study area.

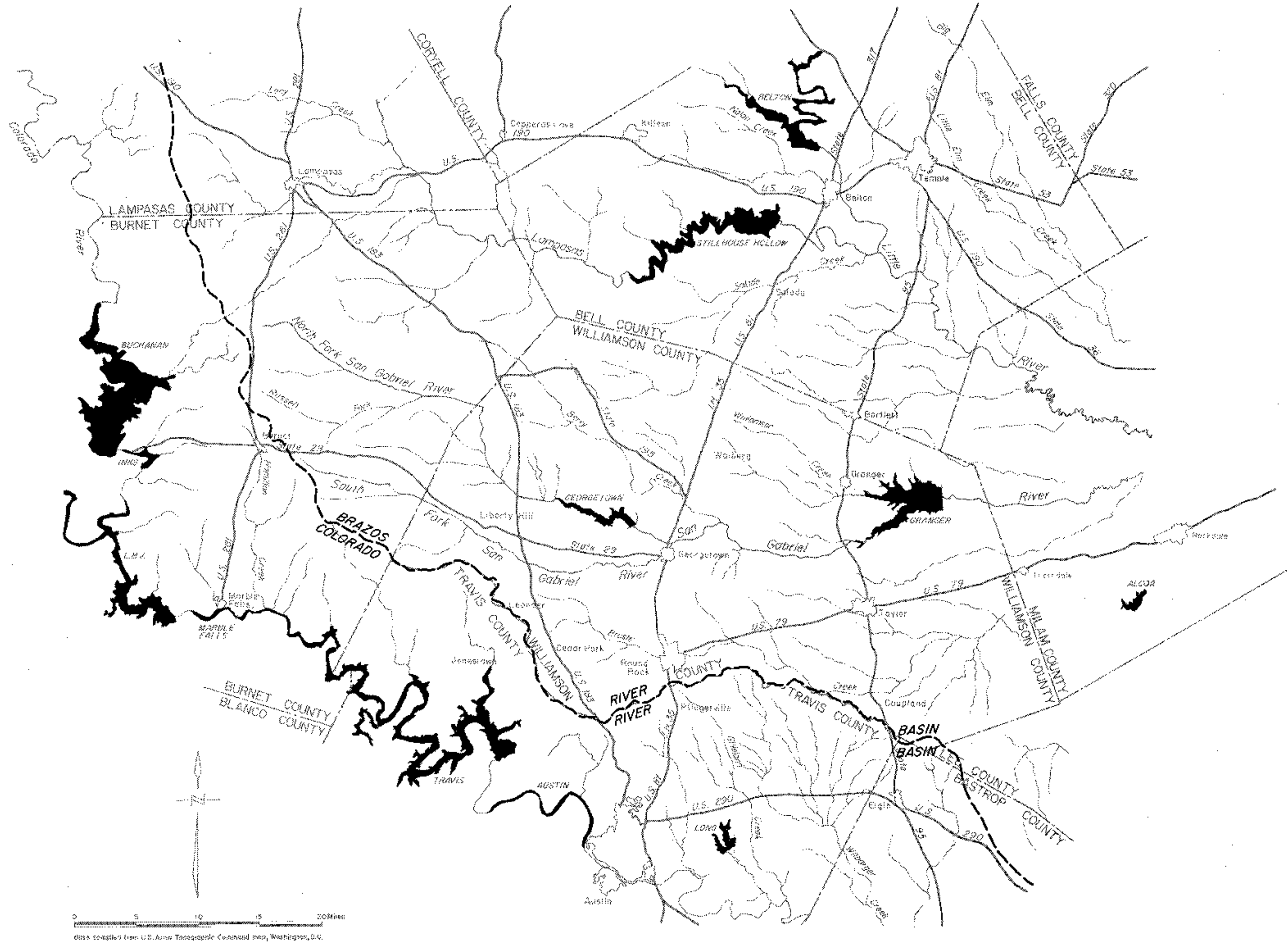

Figure 24
Surface-Water Reservoirs in the Study Area

Table 6.
Municipal Water Requirements for Major Cities in Acre-Feet

Entity	1985 [1]	1990	2000	2010
Elgin	1,009	1,180	1,559	1,956
Bartlett	349	418	612	830
Burnet	792	1,278	1,603	1,969
Austin	66,253	86,232	111,792	137,611
Manor	178	268	354	436
Cedar Park	1,128	1,125	1,763	2,404
Georgetown	3,227	5,276	7,923	10,800
Granger	(485) [2]	851	1,340	1,826
Leander	452	876	1,376	1,876
Round Rock [3]	8,396	5,666	10,054	13,704
Taylor	2,029	2,481	3,925	5,350

1 Reported use.
2 1980.
3 1980 use was reported to be 2,753 acre-feet.

Table 7.
"County Other" Municipal Water Requirements in Acre-Feet

County [1]	1985 [2]	1990	2000	2010
Bastrop	237	311	451	468
Bell	996	1,444	2,566	3,469
Burnet	687	1,076	1,469	1,804
Milam	130	160	178	179
Travis	5,974	7,341	10,657	13,118
Williamson	8,191	10,691	16,502	22,509

1 Portion of county in study area.
2 Reported use.

Allocation

In order to determine the adequacy of available water supplies in the study area to meet projected study area water demands, the water requirements projected for the planning period were balanced against estimated availability of ground and surface-water supplies.

Several assumptions were made in allocating water resources in the study area to various uses and various sectors or entities in the different geographic areas. These assumptions are made in order to develop a planning approach for the best utilization of an area's water resources. It is generally assumed that major cities in the study area possess sufficient surface-water supplies where available. Surface-water supplies are available in the study area and this study assumes that cities and some of the larger water supply purveyors will acquire surface water and will build the necessary treatment and distribution systems. The study then assigns the greater part of the study area ground-water availability to meet the demands of the rural or county other municipal use. In the case of the relatively small portions of Milam and Bastrop counties included in the study area, which rely on ground water "imported" from the Carrizo-Wilcox aquifer to the east, it is assumed that this source will continue to meet the demands for water in this area. It is also assumed in the allocations that the water requirements for uses other than municipal use will be met primarily by surface-water sources supplied through cities or through utilization of local surface-water supplies, such as small surface-water impoundments or run-of-the-river use.

The total water requirements for all use categories in the study area, as shown in Table 8, for the decades 1990-1999, 2000-2009, and 2010-2019 are respectively 143,881, 194,324, and 243,417 acre-feet annually. The total ground-water supply available by decade to meet these demands is respectively 16,373, 17,032, and 17,800 acre-feet annually. The utilization of current sources and the development of additional sources of surface water can provide up to 129,130, 196,074, and 251,752 acre-feet annually for the decades 1990, 2000, and 2010. The total of available supplies in the study area for each of these decades, given in Table 8, is 145,503, 213,106, and 269,552 acre-feet annually.

The total available supplies were allocated to meet projected requirements based on the type of water use and the importance of that use in the study area as reflected in the demand projections. The greatest part of future water requirements is for municipal use. All other use categories show a much smaller increase over the planning period and account for a relatively small percentage of the total water demand. These use categories are considered here in the aggregate as non-municipal use. For non-municipal uses throughout the study area, allocations were set such that future demands would be met primarily by surface-water sources for manufacturing and power uses and local supplies for the remaining uses. The municipal use category is subdivided into major city municipal use and "County Other" or rural municipal use, each considered separately. Major city water demands for the decades beginning in 1990, 2000, and 2010 are respectively 105,651, 142,301, and 178,772 acre-feet annually. Ground water supplies available and allocated to meet these demands are 5,860, 6,825, and 7,814 acre-feet annually. The total available annual supply

Table 8
Water Resources in the Study Area – Projected
Water Supplies and Demands – Decades Commencing 1990, 2000, and 2010

	Water Supply			Water Demand			Surplus or Shortage			
Decade	In Area	Import	Total	In Area	Export	Total	Municipal Cities	Municipal County	Other	Total
1990-1999										
Ground Water	14,544	1,829	16,373	none	none					
Surface Water	129,130	0	129,130	none	none	143,881	+8,169	-6,547	—	+1,622
Total	**143,674**	**1,829**	**145,503**							
2000-2009										
Ground Water	14,630	2,402	17,032	none	none	194,324	+28,130	-9,348	—	+18,782
Surface Water	196,074	0	196,074							
Total	**210,704**	**2,402**	**213,106**							
2010-2019										
Ground Water	14,855	2,945	17,800							
Surface Water	251,752	0	251,752	none	none	243,417	+34,791	-8,656	—	+26,135
Total	**266,607**	**2,945**	**269,552**							

Import – Transfer of water from outside the Study Area
Export – Transfer of water outside the Study Area
Units in acre-feet per year
Tabulated surface water demands do not include some livestock and irrigation needs which will continue to be met from local, unregulated surface supplies.

including surface and ground water allocated for each decade is respectively 113,820, 170,431, and 213,563 acre-feet annually, giving a surplus of 8,169, 28,130, and 34,791 acre-feet annually. Municipal "County Other" water requirements for 1990, 2000, and 2010 are respectively 21,023, 31,823, and 41,647 acre-feet annually. Total available supply allocated to meet municipal demands for each decade, including surface and ground water, is 14,476, 22,475, and 32,991 acre-feet annually, leaving a shortage of 6,547, 9,348, and 8,656 acre-feet annually. The shortage in "County Other" municipal supplies occurs in Williamson County.

The supply shortages in "County Other" municipal use category for each decade in the planning period are offset by the surpluses in the major city municipal use allocation of supplies. Table 8 shows, in terms of regional water supplies, that a surplus of available water exists in the study area and that water requirements for each decade of the planning period can be met on an annual basis. The surpluses are 1,622, 18,782, and 26,135 acre-feet annually for the decades 1990, 2000, and 2010 respectively. Addressing the issue of shortages, though, is necessary and will require cooperation among cities and rural water supply corporations in the study area.

Conjunctive Use of Surface and Ground Water

Analysis of reported water use in 1985 (TWDB data, 1987) indicates that the study area with the exception of the City of Austin relied on ground water to meet municipal or public supply demand. The Texas Water Plan in 1984 (TDWR, 1984) pointed out the need for conjunctive use of surface and ground water to meet near-future water requirements in several of the counties included in the study area, especially Williamson County. At the present time, efforts have been made by many of the water supply entities in the study area to acquire supplementary surface-water supplies and construct distribution systems to deliver water to users. The results of this study, as discussed in the above section, suggest that conjunctive use of available ground-water and surface-water supplies will be necessary to meet the water requirements of the study area during the next 20 years. Additional surface-water supplies will have to be developed in the Brazos River basin to meet future water needs in the study area over the planning period.

Other considerations favoring conjunctive use of ground and surface water are the relative costs of developing ground and surface water and the improvement of ground-water quality through mixing with surface water. The cost of surface water includes the purchase of land to be flooded by a reservoir, the construction of the dam, the purchase of the surface water, the construction of conveyance facilities, and the construction and operation of a water treatment facility. Typically the cost of surface water can be up to three times higher than ground water, which does not require purchase of the water or extensive treatment. In much of the eastern part of the study area, ground-water quality in the Trinity Group aquifer and the deeper parts of the Edwards aquifer is of poorer quality. The water often does not meet the Texas Department of Health (TDH) standards for public drinking water supply for the constituents of sulfate, fluoride, and dissolved solids. Ground water produced from these aquifer zones can be mixed with better quality surface water to provide good quality water, meeting TDH standards.

In the study area, the major water user, the City of Austin, has relied on surface water diverted from the Colorado River to meet its water needs for many years. The remainder of the study area has, however, depended on ground water almost exclusively to meet their needs; of the cities in Table 6, only the cities of Austin and Round Rock did not rely on ground water exclusively for their municipal needs. The City of Round Rock, which used ground water exclusively prior to 1984, supplements its ground-water pumpage with surface water obtained from Lake Georgetown. The relative percentages of ground water and surface water contributions to Round Rock's 1985 reported use were approximately 57 percent ground water and 43 percent surface water. For the category of "County Other" municipal use and the data presented for 1985 reported use shown in Table 7, two county areas, Bastrop and Burnet Counties, relied exclusively on ground water with the remaining county areas utilizing a mix of surface and ground water. Reported ground-water use was significantly higher than surface-water use for 1985 in Bell and Williamson counties. In Travis County, the amounts of surface-water use and ground-water use were nearly equal. Milam County use was provided predominantly by surface-water sources, though the total amount of reported 1985 use is small compared to the use in the other areas.

Over the next 20 years in the study area, conjunctive use of surface and ground water is expected to increase significantly. Entities in the area have commenced and are planning the continuing development of surface-water resources and the facilities for treatment and conveyance. The Brazos River Authority and the Lower Colorado River Authority are working with local entities to provide the raw surface water. Surface water will be provided from Lakes Georgetown, Stillhouse Hollow, and Granger to meet area needs.

All of the major cities in the study area except Manor and Elgin are expected to develop and use surface water for a significant portion of their water requirements during the next 20 years. The cities of Round Rock and Georgetown have each constructed a surface water treatment plant, and are presently using water from Lake Georgetown and reducing their ground-water pumpage. The City of Cedar Park is expected to continue using surface water from LCRA and to utilize water they have contracted in Lake Stillhouse Hollow. The City of Burnet has recently acquired surface water from LCRA and is presently using surface water and curtailing its ground-water use. The City of Leander is working with water suppliers and the Brazos River Authority to plan conveyance and treatment facilities to use contracted water in Lake Stillhouse Hollow, possibly by the year 2000. The cities of Granger and Bartlett are also working with local water suppliers to utilize water in Lakes Stillhouse Hollow and Granger and decrease their ground-water use. The City of Taylor is working with neighboring entities to develop, over the next decade, surface water contracted out of Lake Granger.

Water supply companies, which supply water to small towns and rural areas, are also working with the cities and river authorities to utilize surface water. Conjunctive use of surface and ground water by these entities will also increase over the next 20 years. A significant exception may be Burnet County, where ground water is expected to remain the primary source of water. The small part of Bastrop County in the study area is also expected to continue its reliance on ground water. For the study area portions of Bell and Williamson Counties, water supply corporations are presently supplying some surface water and will provide significantly more over the 20-year planning period as additional facilities are constructed to utilize contracted water in Lakes Stillhouse Hollow and Granger. Conjunctive use of surface and ground water in the small portion of Milam County in the study area is expected to continue at its present level for the extent of the planning period. Travis County is expected to see a large increase in the use of surface water, in part resulting from the construction of the City of Austin's proposed Water Treatment Plant No. 4. Construction of this plant and the water rights agreement between the City of Austin and the LCRA will allow the distribution of surface water to a large part of northern Travis County and reduce or eliminate ground-water use by a number of entities.

Problems Over the 20-Year Planning Period

Water Supply Shortage

The available ground-water supplies from the major aquifers, the Edwards and Trinity Group aquifers, and other small local ground-water supplies are insufficient to meet even current drought condition demands in the study area. Conjunctive use is currently employed by some entities in the area on a small scale, and the City of Austin relies on surface water for most of its needs. It will be necessary to increase dramatically the amount of surface water use in the study area to meet future demands. Surface water is available and committed to local entities to meet the annual demands during the period 1990-1999. Meeting this demand will require, however, full development and utilization of existing and proposed treatment and distribution systems by the major cities in the study area. A significant shortage of supply for "County Other" municipal use occurs for the 1990 decade. This shortage can be alleviated and the demands met through supplies provided by the major cities or through the development of distribution systems for water committed to some of the larger rural water supply corporations. It is the opinion of the authors that the former method is the more feasible of the two. It should be noted that the development of sufficient distribution system capacity is not feasible by the year 1990, but could probably occur several years into the decade.

For the decade 2000-2009, additional surface-water development becomes necessary. Water available in Lake Stillhouse Hollow which is currently committed to downstream users can be made available to local entities if another reservoir can be constructed in the Brazos River basin to meet downstream water commitments. Local entities in the study area have acquired options to utilize this water when and if it becomes available. Use of this water supply is necessary to meet the demands of the study area in the year 2000.

Water-Level Declines

Long-term water levels in the Trinity aquifer have been declining since the beginning of the period of record. These declines are taking place in most of the wells completed in the Trinity aquifer. Some of the major declines in water levels of wells completed in the Hensell and Hosston Members have developed around the Cities of Belton, Bartlett, Granger, and Taylor. These steady declines are due to the low permeability of the water-producing sands and heavy pumpage (withdrawal) of ground water for industrial and public supply purposes.

Water levels in the Edwards aquifer are affected by changes in pumpage and variation in precipitation. Like springflow, water levels have been low in years of low rainfall, but have recovered during wet years. The rate of water-level declines depends on the amount of recharge that replenishes the aquifer and the amount of artificial discharge of ground water through pumpage.

Extensive development of the Edwards aquifer in the study area did not occur until the mid-1970's. Prior to that time, springflow and water levels were controlled by climatic conditions. At the present time, the effects of pumpage during short periods of droughts have been a controlling factor. Increased pumpage during periods of droughts has caused a decrease in springflow, lowering of water levels below historical levels, and water shortages.

If current ground-water withdrawals are continued, a drought equal to or greater in severity to that of the 1950's could result in significant water-level declines and create major water shortages for many of the existing ground-water systems relying on the Edwards.

Continued population growth is predicted for the study area and will put a greater stress on the Edwards aquifer, thus increasing the frequency of ground-water shortages during short periods of droughts. It is also likely that the expanded pumpage will lower water levels and intercept the natural discharge of springs, causing a decrease or cessation of the flows.

CONCLUSIONS AND RECOMMENDATIONS

The study area has experienced significant ground-water problems. There were large drops in water levels in wells during the drought of 1984, and some wells were reported unusable. Greatly increased population and water demand in the area during the early 1980's resulted in additional ground-water development and increased pumpage. Ground-water pumpage for the study area is in excess of the established ground-water availability, resulting in long-term water- level declines in the Trinity Group aquifer and large seasonal water-level fluctuations in the Edwards aquifer. These particular ground-water conditions constitute critical problems for the study area.

The availability of surface water in the area and the development of this resource can, however, provide sufficient supplies to meet future demands over the 20-year planning period. Both current and future efforts in developing surface water can reduce reliance on ground water. Conjunctive use of both surface and ground water and reduction of water demands through conservation will be necessary to preserve the ground-water supply and provide water to the area to meet future needs.

Ground-water problems in the study area may be solved through control strategies implemented by both state and existing local entities. Recommended is continuation of existing efforts and additional voluntary efforts to restrict further ground-water development and limit ground-water pumpage where surface supplies have been developed or will become available. Continued conversion to surface water is encouraged so that demand on area aquifers is reduced. Also strongly recommended is that increased efforts be made toward long-term conservation and contingency planning for drought and other emergencies through the development of conservation plans by entities in the study area. Each major user and supplier should develop and implement a conservation plan aimed at reduction of long-term per capita water use which would include all or a combination of the water conserving measures outlined by the Texas Water Development Board.

Water-quality problems are best solved through the coordinated efforts of both state and local government. Recommended is the continuation and expansion of the Texas Water Commission's Edwards Aquifer Rules as a regional approach for the protection of the aquifer. In addition, the development and implementation of ground-water quality protection programs at the local level are recommended and encouraged to complement and enhance state efforts. The establishment of more formal methods of cooperation with local governments is also needed.

Also recommended is a locally controlled, well or well-field specific approach for additional water-quality protection for all aquifers in the study area. It is urged that local entities, located over aquifer recharge zones in the study area, work with state agencies to implement ground-water protection programs; and that the appropriate local government adopt water-quality protection and control measures. Finally, increased efforts by local entities in public education on ground-water protection issues is recommended. The area should not be designated a critical area because of existing efforts underway to protect and improve water quality.

An underground water conservation district is not the most appropriate management approach for the study area at this time. The increasing reliance on surface water presents issues which are generally outside the purview of ground water districts. Most of the water resource problems can be addressed through existing entities. The varied interests in the area preclude the consolidation of political support needed to create a district. Finally, many area residents indicated that they would not support an additional taxing entity.

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