REASSESSMENT OF THE GEORGETOWN LIMESTONE AS A HYDROGEOLOGIC UNIT OF THE EDWARDS AQUIFER, GEORGETOWN AREA, TEXAS

By L.F. Land and M.E. Dorsey

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CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS--Continued

TABLES

METRIC CONVERSIONS

The inch-pound units of measurement used in this report may be converted to metric (International System) units by using the following conversion factors:

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
foot per mile (ft/mi)	0.189	meter per kilometer (m/k)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per mile [$(ft^3/s)/mi$]	0.01760	cubic meter per second per kilometer [$(ft^3s)/km$]
foot squared per day (ft^2/day)	0.09290	meter squared per day (m^2/day)
degree Fahrenheit (°F)	5/9(°F - 32)	degrees Celsius (°C)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level of 1929."

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ABSTRACT

The Edwards aquifer consists of geologic units known as the Comanche Peak (oldest) and Edwards Limestones, Kiamichi Formation, and Georgetown Limestone. The Edwards Limestone is the main water-bearing zone. The shallow geologic units dip to the east-southeast at a slope of 50 to 100 feet per mile in the Georgetown area. The Edwards aquifer extends from the western limits of the outcrop to the transition zone from freshwater to saline water to the east. The downdip continuity of the geologic units is interrupted by several faults in the Balcones fault zone. The aquifer is recharged by the infiltration of precipitation and streamflow in the outcrop and is discharged by springs in the outcrop and by wells, evapotranspiration, and leakage through the overlying confining bed in the confined area. Streams in the area regionally flow from the west to the east.

A reassessment of the uppermost geologic unit of the Edwards aquifer, the Georgetown Limestone, was conducted in the Georgetown area, Texas, using: (1) data from six surveys of streamflow gains and losses and ground-water levels, (2) aquifer tests at three clusters of test wells, (3) variation in water-quality characteristics to indicate ground-water circulation, and (4) previous studies. Data from the six surveys did not show a pattern of corresponding streamflow gains and losses with positive (upward) and negative (downward) head differentials, respectively, between the main water-bearing zone of the Edwards aquifer and the streams. A consistent and corresponding pattern was shown only for the subreach containing Berry Springs.

The aquifer tests consisted of "slug" test analyses to determine the transmissive characteristics of the Georgetown Limestone and produced hydraulic conductivity values ranging from 1.4×10^{-8} to 2.8×10^{-9} centimeters per second at four of the six test wells. The other two test wells did not produce data suitable for conventional aquifer-test analysis.

An analysis of the water-quality characteristics suggests that the Edwards Limestone and the streams have a significant hydraulic connection but the ground-water circulation between the Edwards Limestone and the Georgetown Limestone is very limited. The only area where a high degree of hydraulic connection between the main water-bearing zone of the Edwards aquifer (Edwards Limestone) and the streams was found is near the updip limits of the Georgetown Limestone, where a nearby major fault occurs and where major springs have developed. These findings suggest that the Georgetown Limestone does not function as a unit of the Edwards aquifer but as a regional confining bed with localized avenues that allow flow to and from the underlying Edwards aquifer.

INTRODUCTION

On March 20, 1985, the Texas Water Development Board (TWDB) adopted rules for regulating activities that have the potential for causing pollution of the Edwards aquifer in Williamson County, Texas. During public hearings prior to the adoption of the Williamson County Rules, several concerns were raised about the areal extent of the recharge zone. Most of the concerns were related to the justification of including the Georgetown Limestone as part of the Edwards aquifer. If ground water does not readily move through this formation, then concerns about including it as part of the aquifer and the recharge zone of the aquifer are justified, and a reassessment of the geologic formations which comprise the Edwards aquifer in the area, is in order. In March 1986, the issue of possible recharge to the major water-bearing unit of the Edwards aquifer through the Georgetown Limestone was addressed by the TWDB when they agreed to fund a study of the Edwards aquifer in the Georgetown area (fig. 1).

Purpose and Scope

The purpose for studying the hydrogeologic characteristics of the Georgetown Limestone was to determine if it should continue to be included as a hydrogeologic unit of the Edwards aquifer, or if it should be part of the upper confining bed. More specifically, this study was conducted to determine if water readily moves through the Georgetown Limestone to and from the main water-bearing unit of the Edwards aquifer, the Edwards Limestone. If percolation is significant, a secondary objective was to determine how readily water moves vertically through this unit and to determine the geologic features that convey the water. This report presents the results of the study and the supporting data. The scope of the study was limited to the Georgetown area and primarily to data collected by the U.S. Geological Survey and the Bureau of Economic Geology during 1986 and 1987.

Approach

The study was conducted in a joint effort by the Geological Survey, the Texas Water Development Board, and the Texas Bureau of Economic Geology. The Geological Survey conducted hydrologic investigations related to determining the exchange of water between the aquifer and streams, with emphasis on the vertical movement of water in the Georgetown Limestone. The approach used by the Geological Survey in its part of the study included:

(1) Conducting six streamflow and ground-water-level surveys in an attempt to identify subreaches where streamflow gains and losses occur;
(2) Installing three clusters of three observation wells and monitoring water-levels to estimate the hydraulic properties of the Georgetown Limestone where it occurs between the streams and the Edwards Limestone;
(3) Collecting water-quality samples from selected wells and stream sites and analyzing them for inorganic constituents, pH, specific conductance, and temperature to establish a correlation of water-quality characteristics, if any, in the streams and aquifer in local areas;
(4) Analyzing and interpreting the data; and

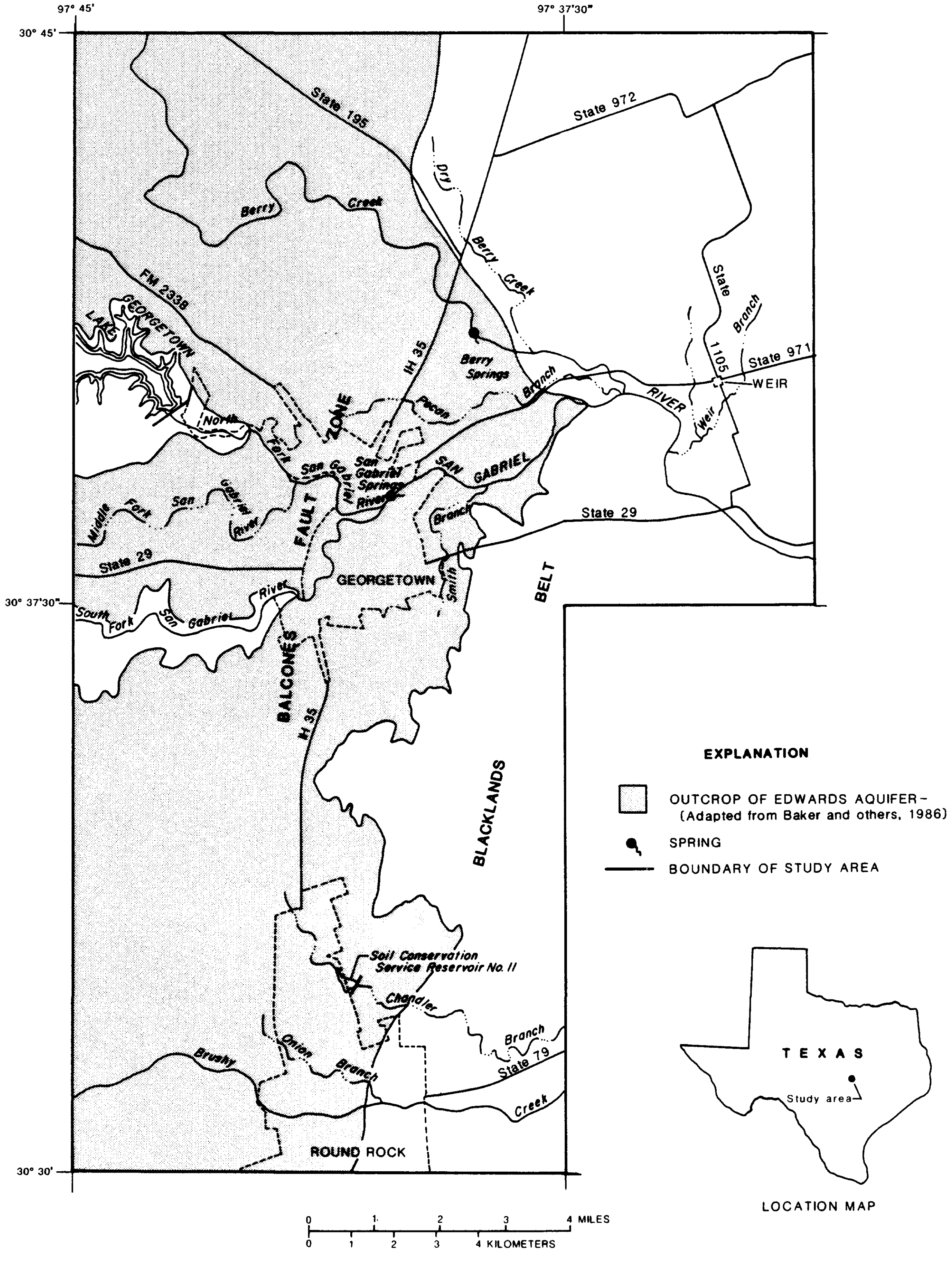


Figure 1.--Location of study area.

(5) Preparing and publishing reports documenting the data and findings.

A summary and compilation of the data collected by the Geological Survey during the course of the study is presented in Dorsey and Slagle (1987).

The TWDB's Water Research and Planning Fund provided funding. The Texas Water Development Board, Water Data Collection, Study and Planning Division performed the observation-well installation, geophysical logging, coring, and laboratory analyses of bulk specific gravity and permeability tests on selected cores taken at each test site. The observation-well clusters were installed near streams to help define the surface-water/ground-water relation.

The study conducted by the Bureau of Economic Geology included fracture analysis, geologic mapping of the study area, analysis of water levels, and chemical analysis of water from selected springs and wells. Water-level recorders were installed on a network of wells and rain gages to determine relations between recharge and rainfall. Water from selected springs and wells was analyzed for inorganic water-quality constituents to determine recharge and discharge patterns of the aquifer. The findings of the study are described in a report by Krietler and others, 1987.

Well-Numbering System

The well-numbering system that is used in this report was developed by the TWDB for use throughout the State. It is based on latitude and longitude and consists of a two-letter county-designation prefix plus a seven-digit well number. The two-letter prefix for Williamson County is ZK.

Each 1-degree quadrangle in the State is given a number consisting of 2 digits from 01 through 89. These are the first two digits of the well number. Each 1-degree quadrangle is divided into 7-1/2 minute quadrangles which are given two-digit numbers from 01 through 64. These are the third and fourth digits of the well number. Each 7-1/2 minute quadrangle is divided into 2-1/2 minute quadrangles which are given a single-digit number from 1 through 9. This is the fifth digit of the well number. Each well or spring that is located within a 2-1/2 minute quadrangle is given a two-digit number beginning with 01, according to the order in which it was inventoried. These are the last two digits of the numbering system. Only the last three digits of the well-numbering system are shown on the maps of the well, spring, and test-hole sites; the second two digits are shown in or near the northwest corner of each 7-1/2 minute quadrangle; and the first two digits are shown by large block numbers.

Acknowledgments

Recognition and acknowledgment are given to Bob Dillard of Round Rock and Mike Heiligenstein of Georgetown for granting the Geological Survey permission to install the test wells on their property, and to many others residents and land owners for allowing the measuring of water levels in their wells and the collection of water samples. Without their cooperation the study could not have been conducted. An expression of appreciation is also given to the TWDB drilling crew--Chris Bufkin, Mark Hayes, and Chad Danner--who drilled and installed the test wells and to Doug Crim for running the geophysical logs of the test holes.

HYDROGEOLOGIC SETTING

The study area encompassed about 150 mi^2 centering on the city of Georgetown. The majority of the 15,000 people living in the area depend on the Edwards aquifer for their domestic water supply. The study area extends across the Balcones fault zone and into the Blackland Belt to the east. The Balcones fault zone is marked by a prominent escarpment that generally rises from an altitude of 700 to 800 ft along the terraced, sloping lowlands of the Blackland Belt to an altitude of 900 to 1,000 ft in the uplands area of the Edwards Plateau. The Blackland Belt is characterized by the flat to rolling terrain with thick fertile soils.

The climate of the area is characterized by short mild winters, long moderately hot summers, moderately high humidity, and southerly winds. The mean annual temperature for 1941-70 at Austin (25 miles to the south of the study area) was 71 °F; the mean maximum temperature for July was 95 °F; the mean minimum temperature for January was 41 °F; and the mean annual precipitation was about 32 inches.

Stratigraphy

As previously defined by Muller and Price (1979) and Baker and others (1986) the geologic units that constitute the Edwards aquifer are in the upper part of the Cretaceous System and include the upper part of the Fredericksburg Group and the lower part of the Washita Group. They lie above the Walnut Formation and below the Del Rio Clay (Brune and Duffin, 1983). These units include, from the oldest to the youngest, Comanche Peak, and Edwards Limestones, Kiamichi Formation, and Georgetown Limestone (Brune and Duffin, 1983). The Edwards Limestone is the main water-bearing unit of the Edwards aquifer. The Kiamichi Formation is less than 10-ft thick and is considered to be hydrologically insignificant in comparison to the other units. Thus, it is grouped with the Georgetown Limestone for purposes of this report. The confining units are the overlying Del Rio Clay and the underlying Walnut Formation (Brune and Duffin, 1983; Baker and others, 1986).

A summary of the stratigraphic units in the Middle Cretaceous System is given in figure 2. The bedrock formations or stratigraphic units and major faults that were delineated by Krietler and others (1987) are shown on figure 3. The outcrop of the geologic units generally form regional northeast-southwest trending bands. The formations in the subsurface are shown on figure 4. They dip to the east-southeast at a slope of 50 to 100 ft/mi (feet per mile) (Krietler and others, 1987). The Balcones fault zone traverses the study area immediately west of the city of Georgetown and is aligned with the strike of the geologic formations. The faults are normal and usually downthrown to the east-southeast. Along the valleys of major streams in the area, the parent geologic material is commonly overlain by Quaternary deposits.

Edwards Aquifer

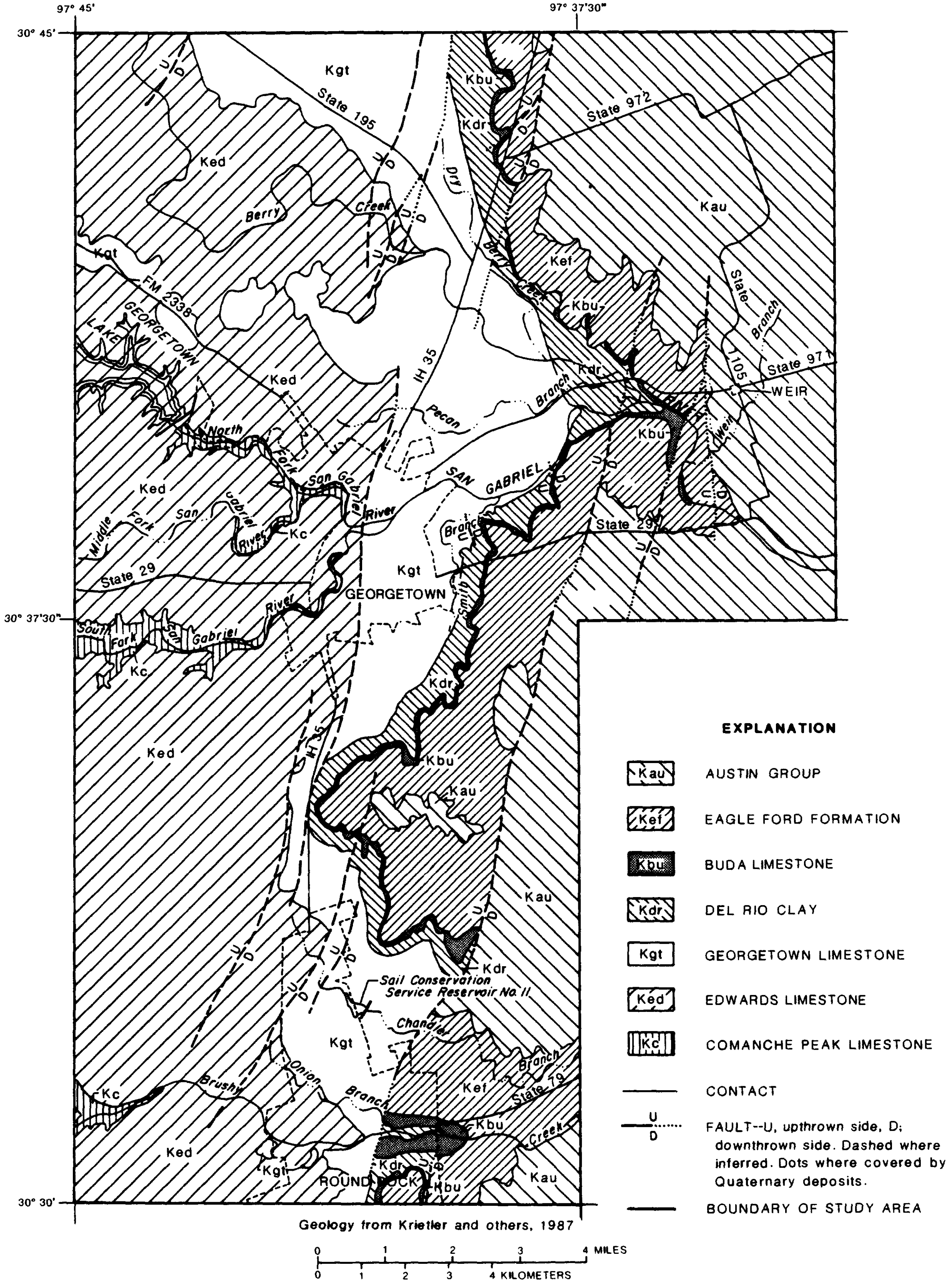
The Edwards aquifer is the only major, regional source of fresh ground water in the Georgetown area. The approximate location of the outcrop, as delineated by Baker and others (1986), includes the Comanche Peak, and Edwards Limestones Formation, and Georgetown Limestone and is shown in figure 1. The

System	Series	Group	Stratigraphic unit	Hydrologic unit	Approximate maximum thickness (feet) *	Character of rocks
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.
	Pleistocene		Terrace deposits		60	Water-stratified deposits of unconsolidated calcareous gravel, sand, silt, and clay, with the coarser materials at the base.
			Onion Creek Marl		50	Water-stratified deposits of calcareous gravel, sand, silt, and clay, often cemented with calcium carbonate.
			High gravel		20	Gravel and sand, sometimes mixed with clay from underlying formations.
Tertiary	Eocene	Midway		Midway	300	Clay, silt, glauconitic sand, and thin beds of limestone and sandstone with gypsum, phosphatic nodules, and calcareous concretions.
Cretaceous	Gulfian	Navarro		Navarro and Taylor Groups	1200	Massive beds of shale and marl with clayey chalk, clay, sand, and some nodular and phosphatic zones.
		Taylor				
		Austin	Igneous rocks	Igneous rocks	700	Altered pyroclastics, limburgite, basalt intrusions and flows, and nontronite.
				Austin Chalk	500	Massive beds of chalk and marl with bentonitic seams, glauconite, and pyrite nodules.
		Eagle Ford	Eagle Ford Formation		45	Massive calcareous shale with thin interbeds of silty and sandy, flaggy limestone.
	Comanchean	Washita	Buda Limestone		50	Massive, fine-grained, burrowed, shell-fragment limestone. The upper portion is harder and bluff-forming
			Del Rio Clay		75	Clay and marl with gypsum, pyrite, and a few thin siltstone and sandstone beds.
			Georgetown Limestone	Edwards and associated limestones	100	Thin interbeds of richly fossiliferous, nodular, massive fine-grained limestone and marl.
		Fredericksburg	Kiamichi Formation		10	Marl, thin limestone seams, clay, and shell aggregates. Not present at the surface in Travis County.
			Edwards Limestone		360	Massive, brittle, vugular limestone and dolomite with nodular chert, gypsum, anhydrite, and solution-collapse features.
			Comanche Peak Limestone		60	Fine-grained, fairly hard, nodular, fossiliferous, marly, extensively burrowed limestone.
			Walnut Formation		120	Hard and soft limestones, marls, clays, and shell beds.

*For Travis County, adjacent county to the southwest.

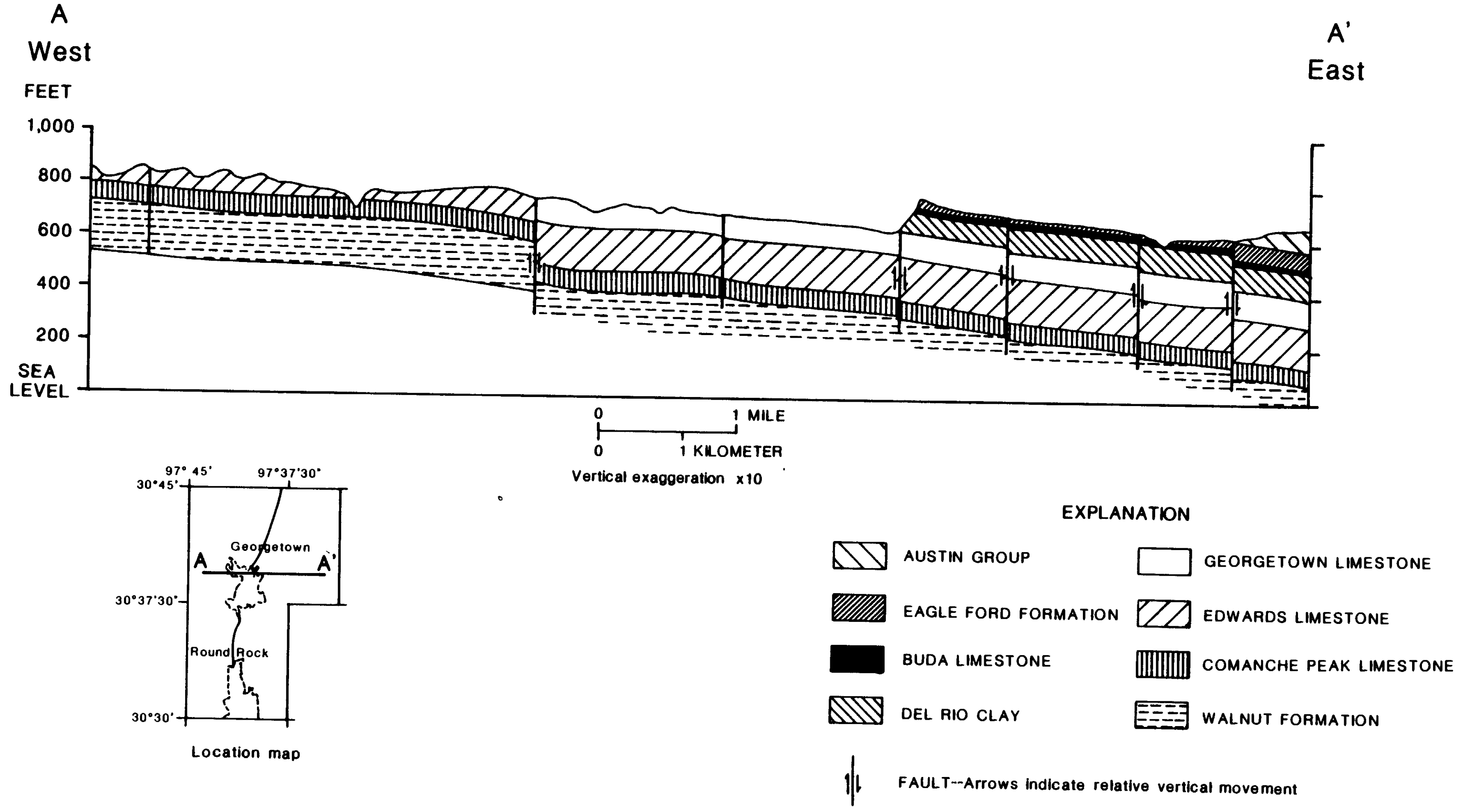
Modified from Brune and Duffin, 1983

Figure 2.–Stratigraphic units.



Geology from Krietler and others, 1987

Figure 3.--Bedrock geology.



From Krietler and others, 1987

Figure 4.--Generalized section along dip of the Edwards aquifer.

configuration of the base of the aquifer is shown in figure 5 (Baker and others, 1986). The maximum thickness of the aquifer in the study area is about 300 ft. The thickness of the aquifer increases slightly in the downdip direction. The updip boundary of the outcrop is located on the western limit of the aquifer. The transition zone from freshwater to saline water is located on the eastern limit of the aquifer in the downdip direction and is generally east of the study area. The outcrop of the aquifer approximates the recharge zone and the unconfined area of the aquifer.

The aquifer is recharged by the infiltration of precipitation and streamflow in the outcrop and is discharged by springs at a few locations along major streams, wells, evapotranspiration, and leakage through the overlying confining bed in the confined area. San Gabriel Springs and Berry Springs (fig. 1) are major discharge points and commonly have a combined discharge of a few cubic feet per second. The quantity of water discharged by wells is estimated to be about 20 ft^3/s (D.L. Lurry, U.S. Geological Survey, written commun., 1988). Unknown quantities of water are discharged by evapotranspiration and vertical leakage. The apparent regional direction of ground-water flow is east (Baker and others, 1986); however, a substantial amount of ground-water flow is toward San Gabriel Springs and the city of Georgetown's well field in the vicinity of San Gabriel Springs, to Berry Springs, and possibly to major springs north of the study area.

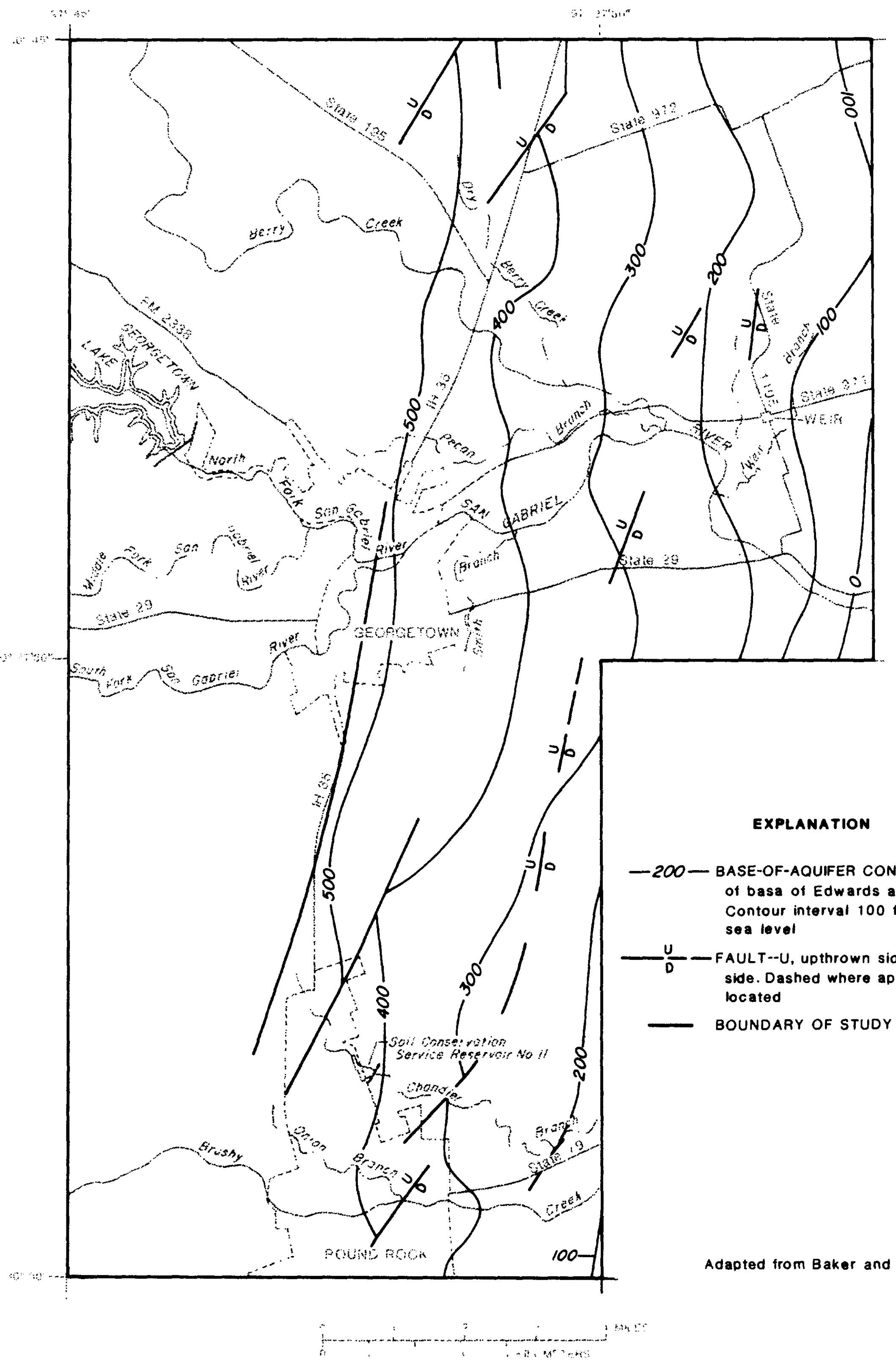
The transmissivity of the Edwards aquifer, estimated from driller's reports of drawdown and yield during well development, generally ranges from 400 to 6,000 ft^2/day along the Balcones fault zone and from 50 to 500 ft^2/day east of the Balcones fault zone (R.M. Slade, U.S. Geological Survey, written commun., 1988). All supply wells in the study area drawing water from the Edwards aquifer are completed in the Edwards Limestone. Thus, these transmissivity values should be associated only with the Edwards Limestone.

The water quality of the Edwards aquifer is suitable for most uses; however, mineralization of the water increases in the downdip direction (Baker and others, 1986). Generally the water is a calcium carbonate type, very hard, and has a pH of about 7.

Streams

The study area is located within the San Gabriel River basin. Streams flow generally to the east and include the North Fork San Gabriel River, South Fork San Gabriel River, San Gabriel River, and Berry Creek, which flow perennially, and Dry Berry Creek, Pecan Branch, Smith Branch, Weir Branch, and Chandler Branch which flow intermittently (fig. 6). Chandler Branch is a tributary to Brushy Creek which flows into the San Gabriel River downstream from the study area. Lake Georgetown is on the North Fork San Gabriel River and regulates flow in the downstream reaches to a great degree. On the Edwards aquifer outcrop, streamflow gains and losses vary with location and climatic conditions.

San Gabriel Springs is located immediately below the confluence of the North and South Forks San Gabriel Rivers and about 0.6 mi east of a major fault. Berry Springs is located north-northeast of the city of Georgetown and about 0.3 mi east of a major fault. The springs issue from the Georgetown Limestone but the water-bearing unit is the Edwards Limestone. The geologic



EXPLANATION

—*200*— BASE-OF-AQUIFER CONTOUR--Shows altitude of base of Edwards aquifer, in feet. Contour interval 100 feet. Datum is sea level

—U/D— FAULT--U, upthrown side, D, downthrown side. Dashed where approximately located

—— BOUNDARY OF STUDY AREA

Adapted from Baker and others, 1986

Figure 5.--Base of the Edwards aquifer.

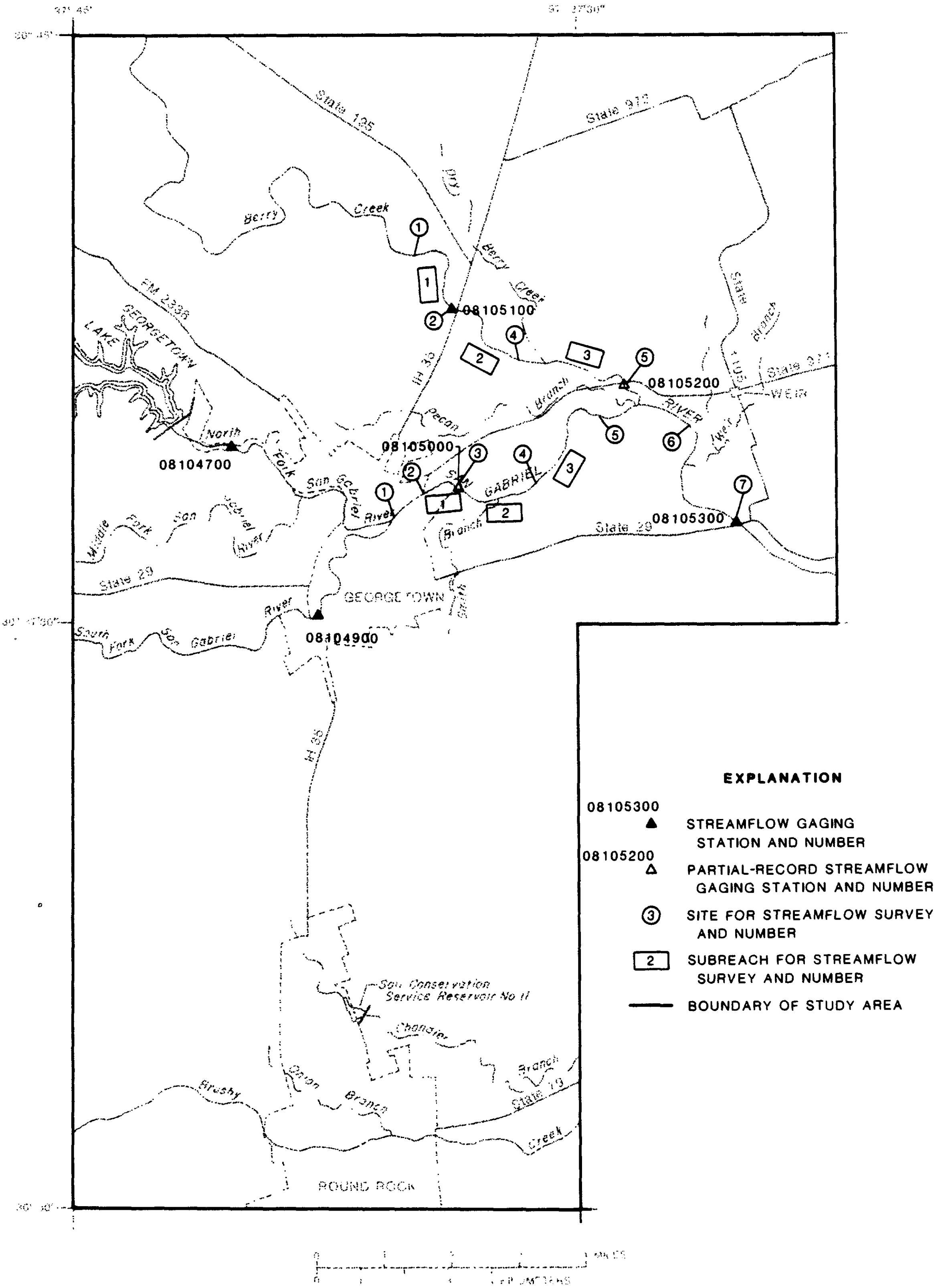


Figure 6.--Locations of streamflow data-collection sites.

features controlling the movement of water to them are unknown as is the reason for their location. In addition to these springs, numerous small and usually intermittent springs occur in the updip part of the Edwards aquifer outcrop.

DATA AVAILABILITY

The data for this study were primarily collected during six streamflow and ground-water-level surveys, during installation and operation of water-level monitoring equipment at three clusters of test wells, and during water-quality surveys of selected wells and stream sites (Dorsey and Slagle, 1987). Additional data are available from the Bureau of Economic Geology (Krietler and others, 1987) and the Statewide monitoring program operated by the Geological Survey. The locations of selected data-collection sites are shown in figure 6.

Streamflow

The Geological Survey operates four continuous record streamflow gages and two partial-record streamflow gages in the study area (fig. 6). Discharge hydrographs for gages 08104700 (North Fork San Gabriel River near Georgetown), 08104900 (South Fork San Gabriel River at Georgetown), 08105000 (San Gabriel River at Georgetown), and 08105300 (San Gabriel River near Weir) are shown in figure 7. Discharge hydrographs for gages 08105100 (Berry Creek near Georgetown) and 08105200 (Berry Creek at State Highway 971 near Georgetown) are shown in figure 8. In the reach below Lake Georgetown, the flow is partly regulated much of the time. The gage at 08105000 provides a continuous record of the stream stage when the stage is between altitudes of 644 and 651 ft. Discharge ranged from 9.90 to 200 ft^3/s during the study when stage was within the measured range. The gage at 08105200 provides a continuous record when the stage is between altitudes of 613 and 616 ft. Discharge ranged from 1.0 to 150 ft^3/s during the study when the stage was within the measured range. The only artificial discharge into these two streams is the wastewater effluent from the city of Georgetown which is a few hundred feet upstream from the 08105000 streamflow gage. There are no known major diversions.

Six streamflow surveys were conducted along the principal streams and tributaries between May 1986 and May 1987. The results of the surveys are shown in figure 9 for the San Gabriel River and in figure 10 for Berry Creek and are tabulated in Dorsey and Slagle (1987). The streamflow measurement sites generally were 0.5 to 1.5 mi apart but varied because of accessibility. The graph of the survey conducted on July 28, 1986, represents streamflow during summer conditions--a period of relatively low water-level conditions in the aquifer and great evapotranspiration rates. The graph of the survey conducted February 17, 1987, represents streamflow during winter conditions--a period of relatively high water-level conditions in the aquifer and lesser evapotranspiration rates.

Ground-Water Levels

A network of wells for the measurement of water levels is shown in figure 11. These wells were measured periodically and concurrently with the six streamflow surveys. Hydrographs of periodic water-level measurements in selected wells are presented in figure 12 to show the variation of the ground-

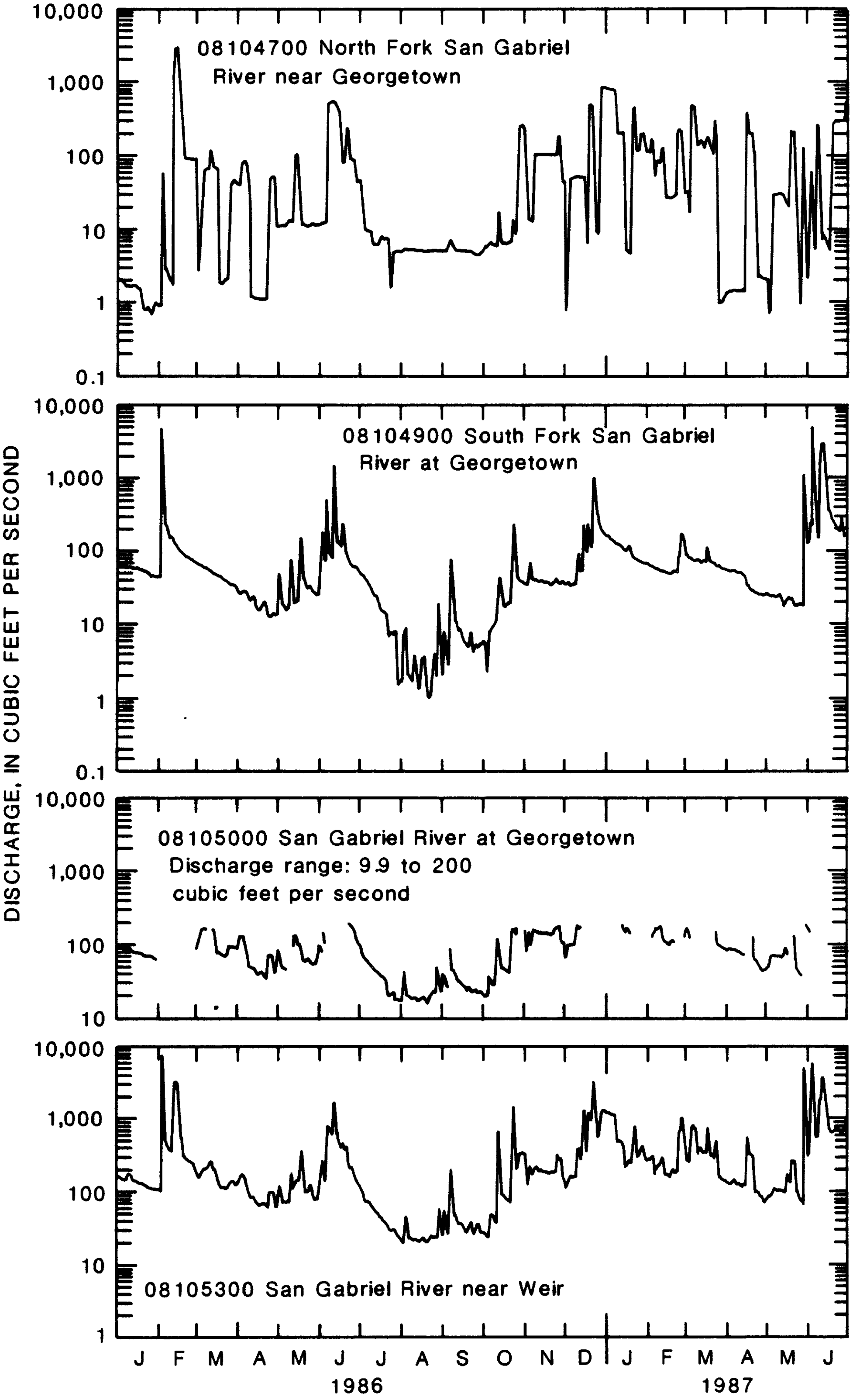


Figure 7.--Discharge hydrographs at streamflow gaging-stations on the San Gabriel River.

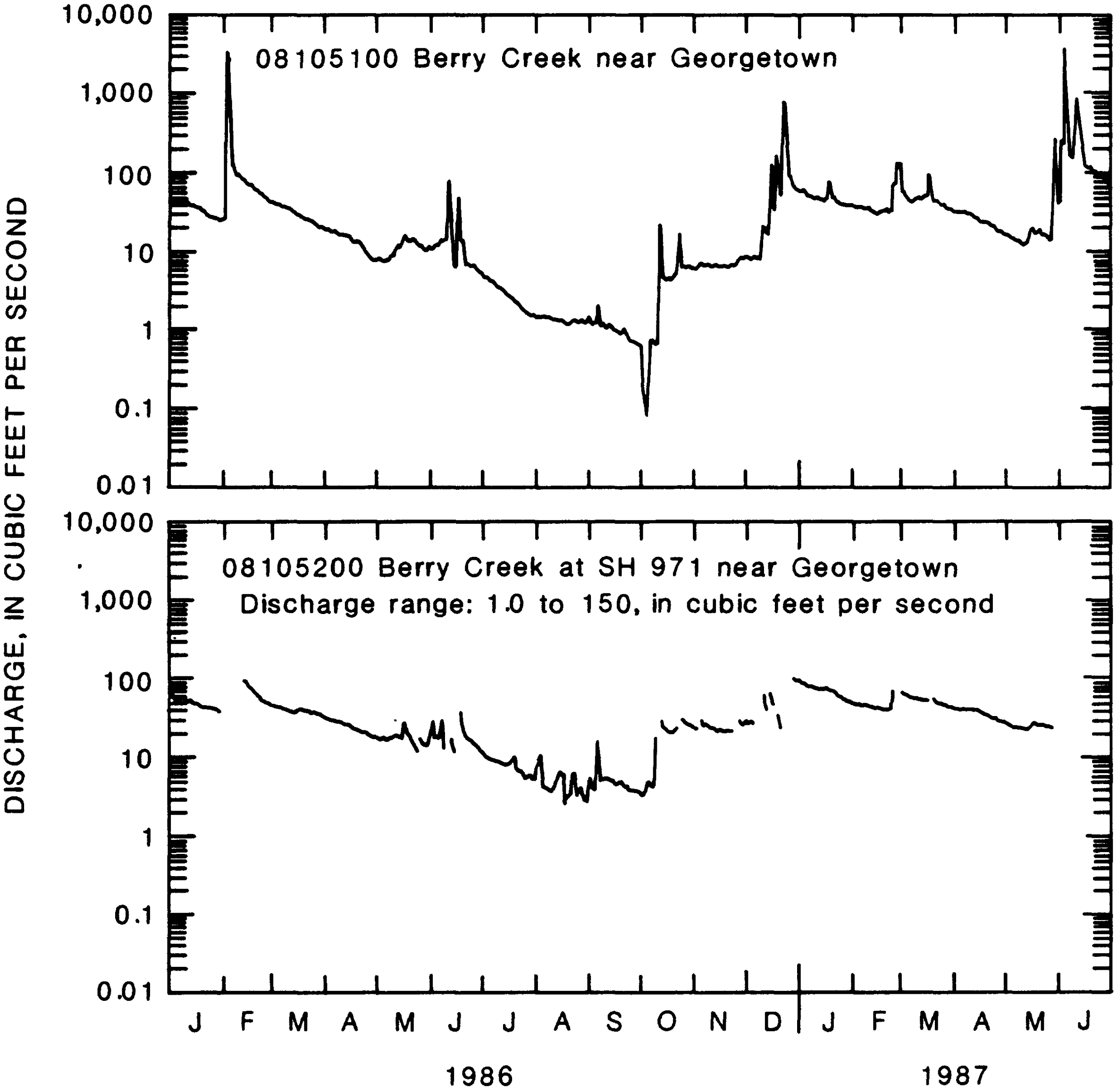


Figure 8.--Discharge hydrographs at streamflow-gaging stations on Berry Creek.

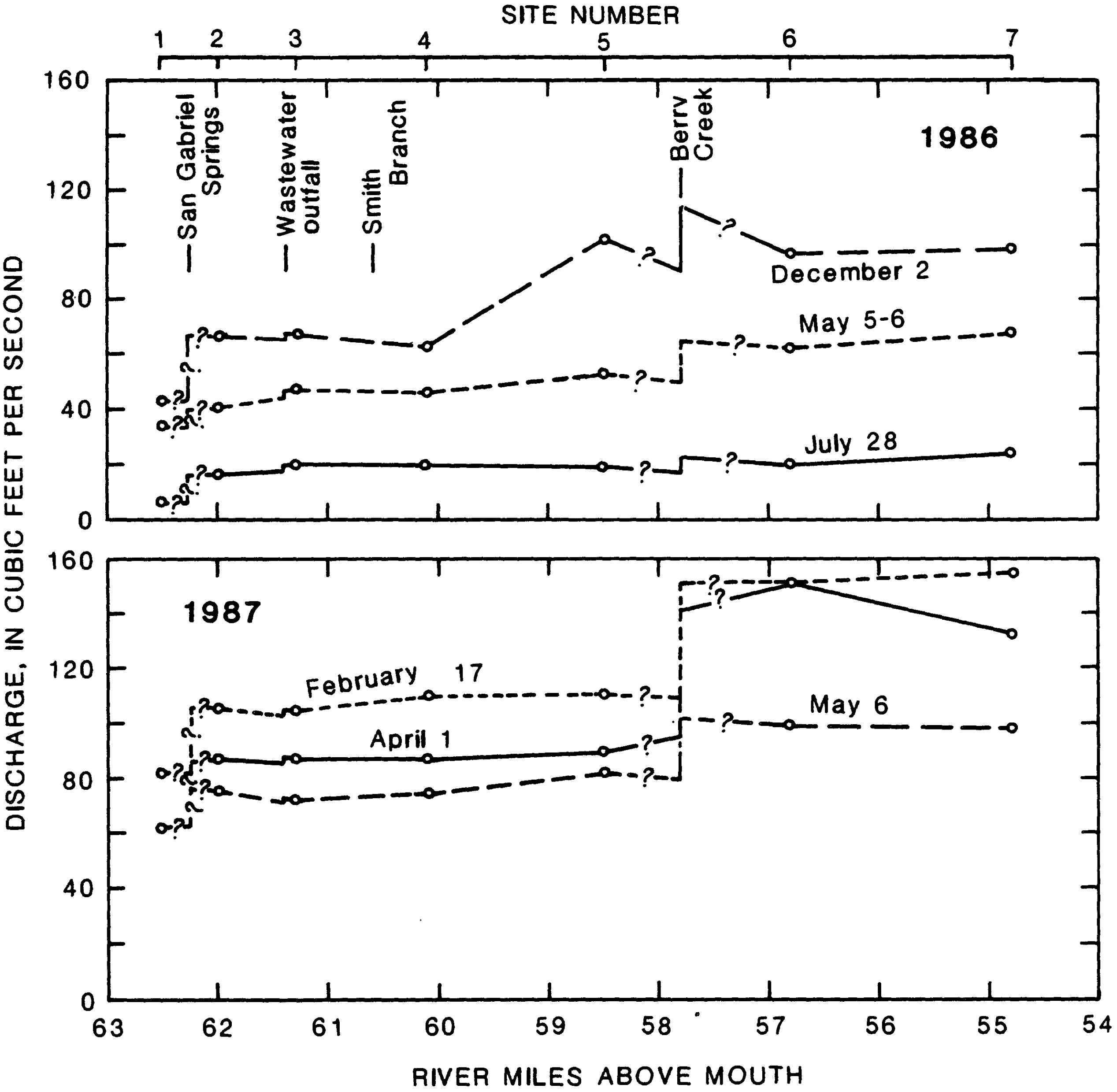


Figure 9.--Streamflow along San Gabriel River for six surveys.

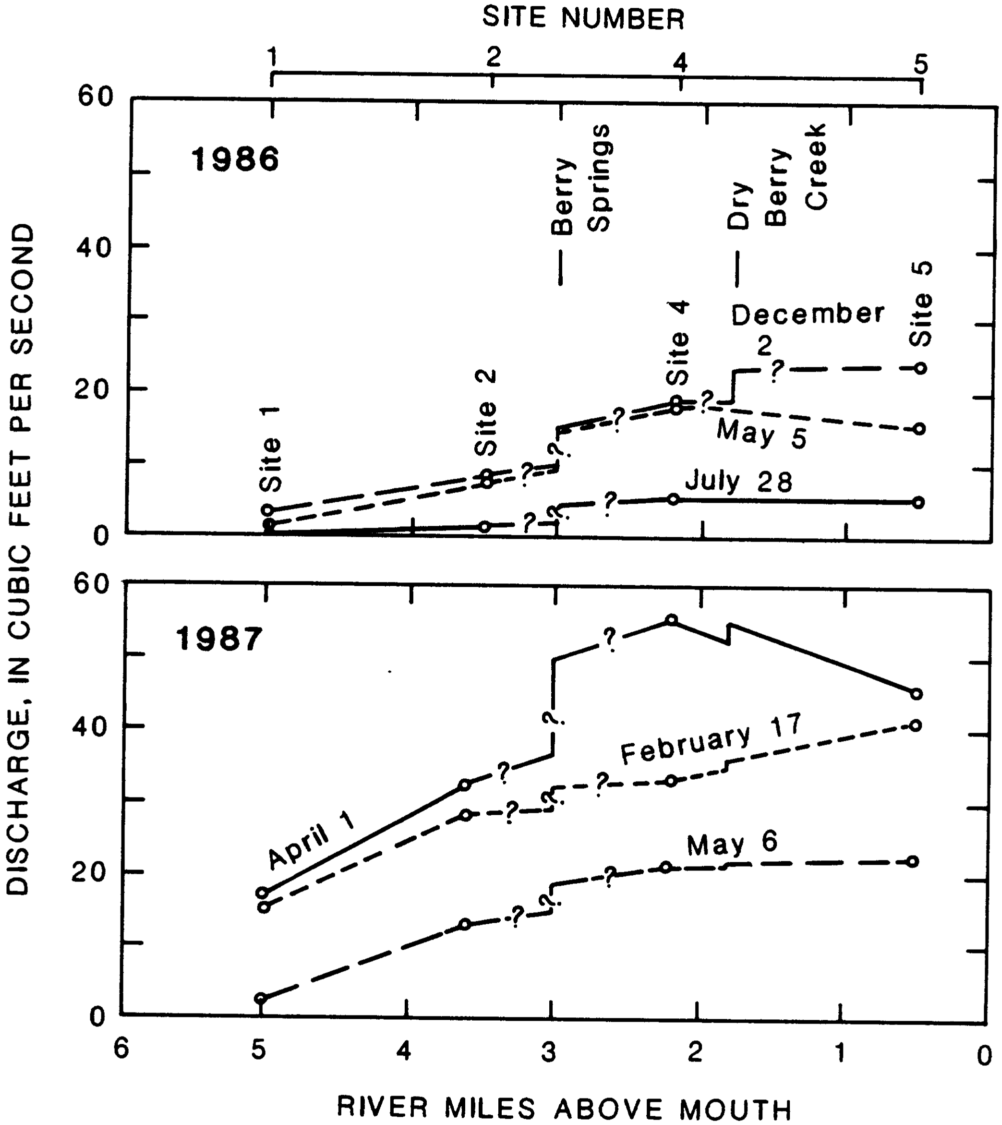


Figure 10.--Streamflow along Berry Creek for six surveys.

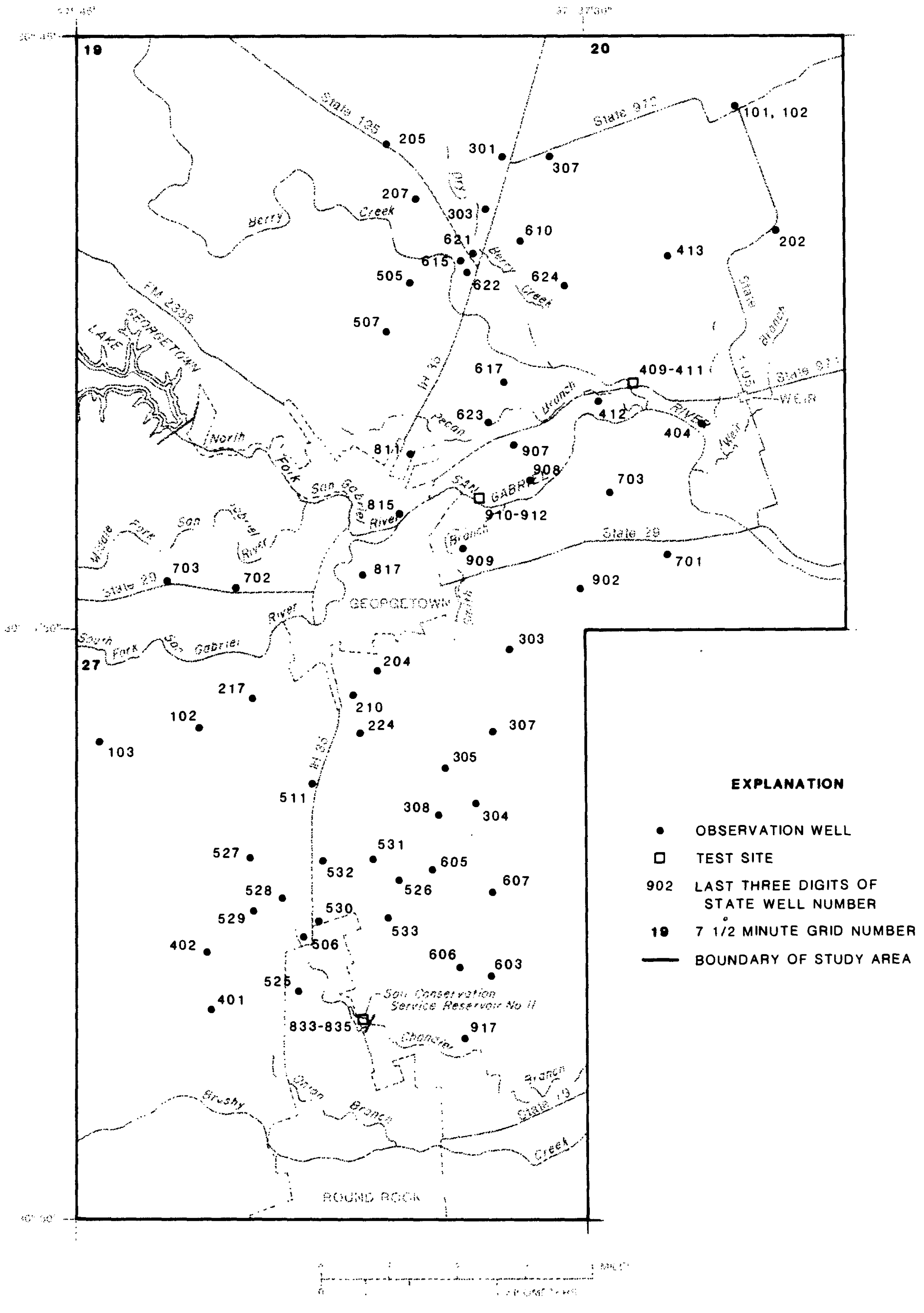
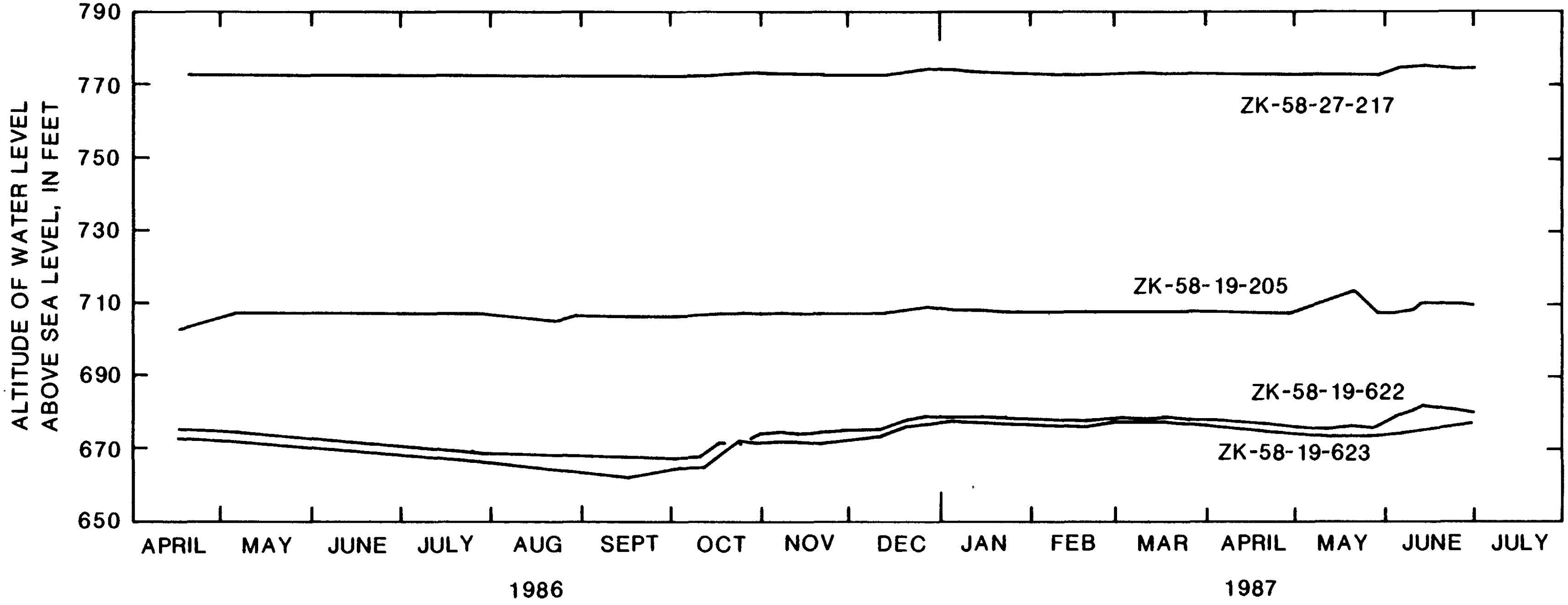


Figure 11.--Locations of observation wells and test-well sites.



Water-level data from Bureau of Economic Geology

Figure 12.--Water-level hydrographs for selected wells.

water conditions during the study. These data were provided by the Bureau of Economic Geology from their network of observation wells. Two water-level contour maps are presented to show the configuration of the ground-water levels during summer conditions (fig. 13) and winter conditions (fig. 14). These maps show that water levels differed by an average of 35 ft between the two seasonal conditions in the confined zone, and by an average of 12 ft in the unconfined zone.

Test-Well Sites

Three test sites with three test wells each were installed by the TWDB adjacent to streams (fig. 6). Each of the three wells at a test site was completed to a different zone--the deepest well is open to the Edwards Limestone and the other two wells are open to different zones within the Georgetown Limestone; one near the Georgetown-Edwards contact and the other near the middle of the Georgetown Limestone. Continuous water-level recorders were installed on all nine observation wells.

The San Gabriel River test-well site is located on the north bank of the San Gabriel River approximately 600 ft downstream from the Missouri-Kansas Railroad bridge. Partial-record streamflow gage 08105000 San Gabriel River at Georgetown, is located approximately 500 ft upstream. The test well drilling, coring, geophysical logging, and installation was conducted during January 1987. Figure 15 shows site and well locations, well completion, and water-level data; figure 16 shows a summary of geologic, geophysical, and hydraulic properties for the deepest well; and figure 17 shows water-level hydrographs for the observation wells and San Gabriel River. The hydrograph for the Edwards well (ZK-58-19-910) shows that the water level was influenced by a nearby pumping well. The well completed near the Georgetown-Edwards contact (ZK-58-19-911) was silted during the first several months. Water was first observed in the well on June 5, 1987. The hydrograph shows that the water level gradually increased until the well was jetted in September to remove the silt. The hydrograph for the well completed near the middle of the Georgetown Limestone (ZK-58-19-912) was dry much of the time and showed gradual declines and erratic fluctuations at other times.

The Berry Creek test-well site is located on the State Highway 971 right-of-way and on the east bank of Berry Creek. Partial-record streamflow gage 08105200, Berry Creek at State Highway 971 near Georgetown, is located at the site. The test well drilling, coring, geophysical logging, and installation was conducted during November 1986. Site and well locations, well completion, and water-level data are shown on figure 18; a summary of geologic, geophysical, and hydraulic properties for the deepest well is shown on figure 19; and water-level hydrographs for each observation well and Berry Creek is shown on figure 20. The water-level hydrographs for the wells developed in the Georgetown Limestone (ZK-58-20-410 and ZK-58-20-411) show a gradual rise in water level during the period of record.

The Chandler Branch test-well site is located on the upstream side of the dam at the Soil Conservation Service (SCS) reservoir No. 11, northeast of the city of Round Rock. A stage recorder is located on the outflow structure of the reservoir. The test well drilling, coring, geophysical logging, and installation were conducted during January and February 1987. Site and well locations, well completion, and water-level data are shown in figure 21; a

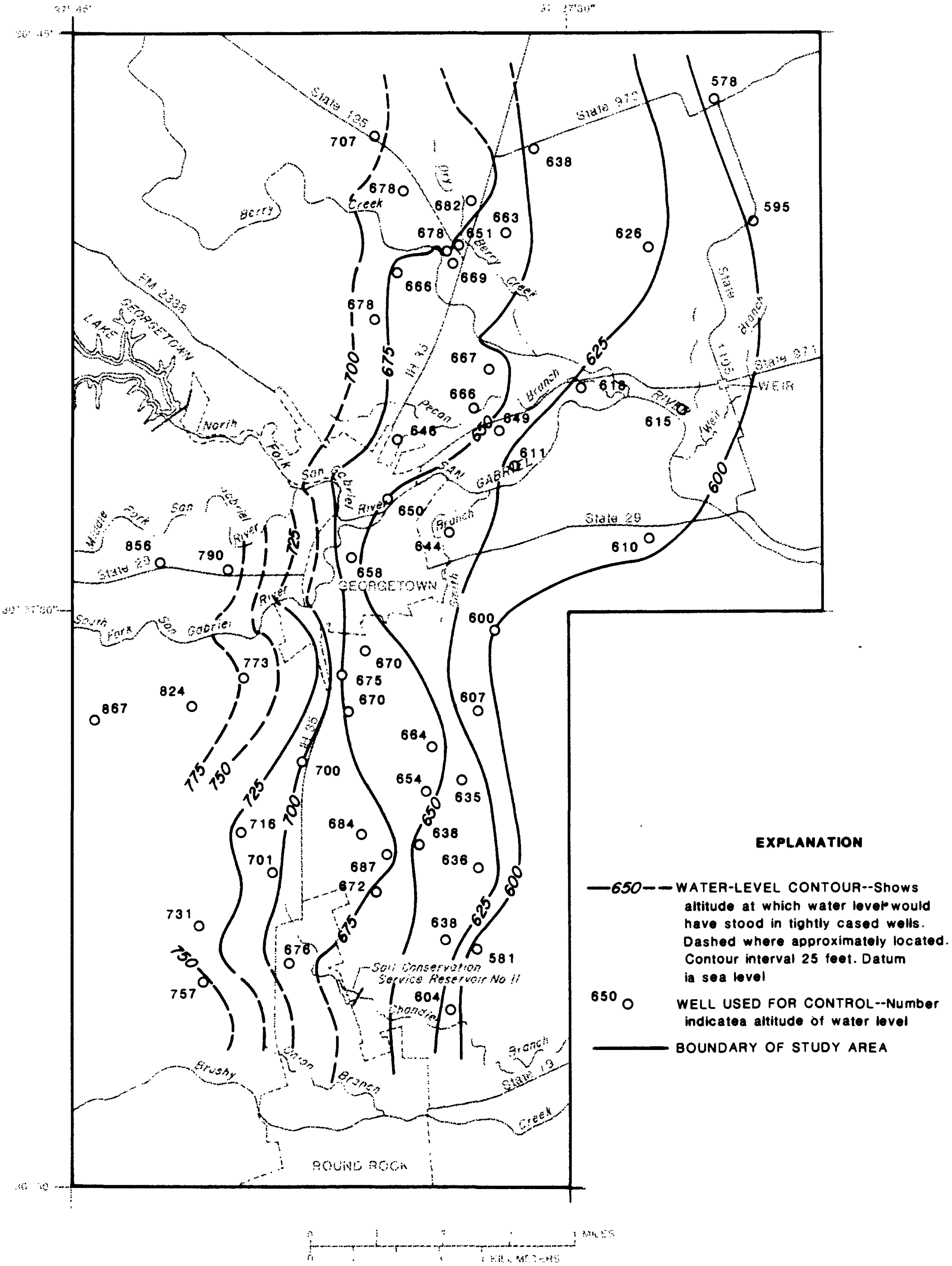


Figure 13.--Ground-water levels during summer conditions, July 28-29, 1986.

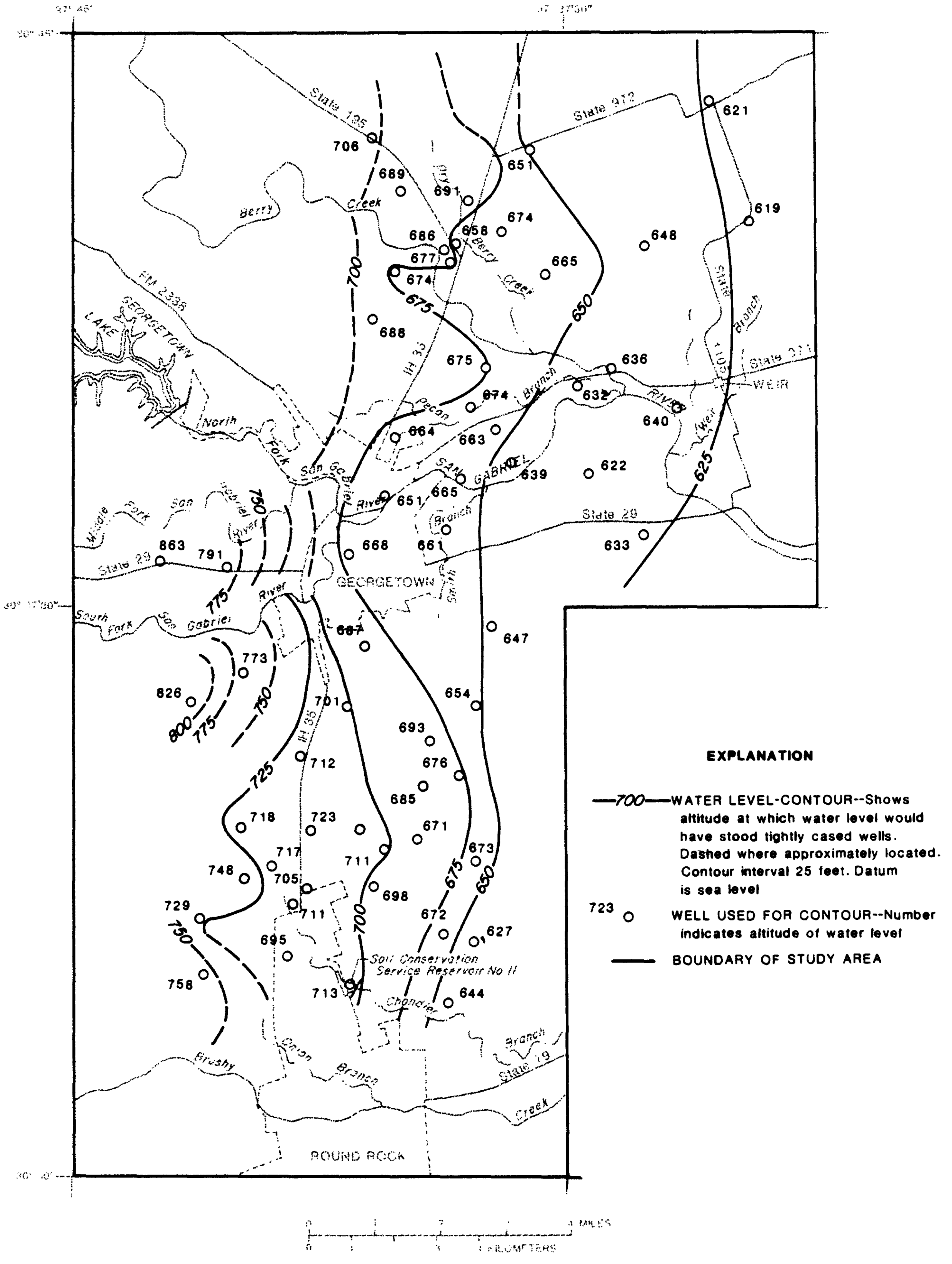


Figure 14.--Ground-water levels during winter conditions, February 13-18, 1987.

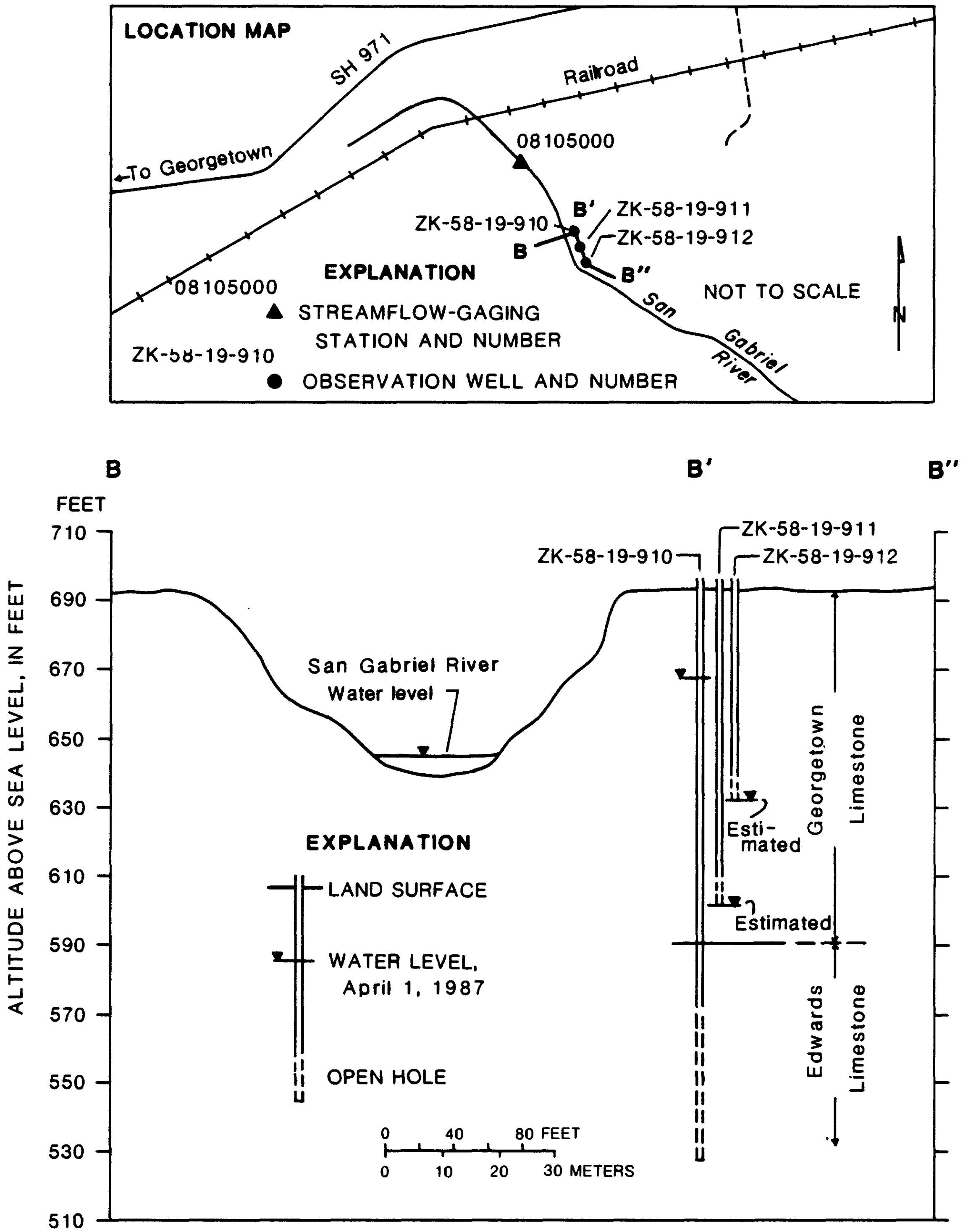
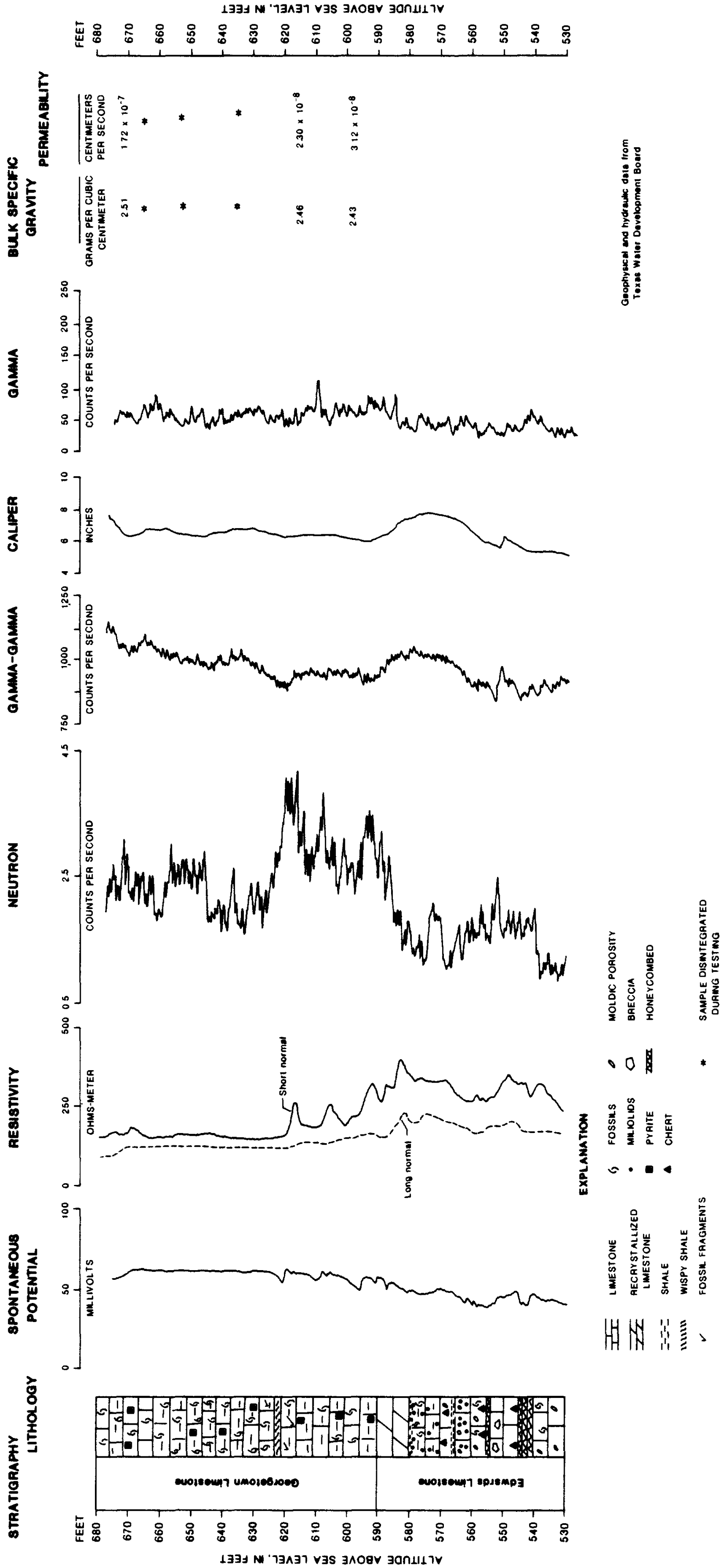


Figure 15.--Location, well completion, and water-level data, San Gabriel River test-well site.



Geophysical and hydraulic data from Texas Water Development Board

Figure 16.--Geologic, geophysical, and hydraulic properties of test well Zk-58-19-910.

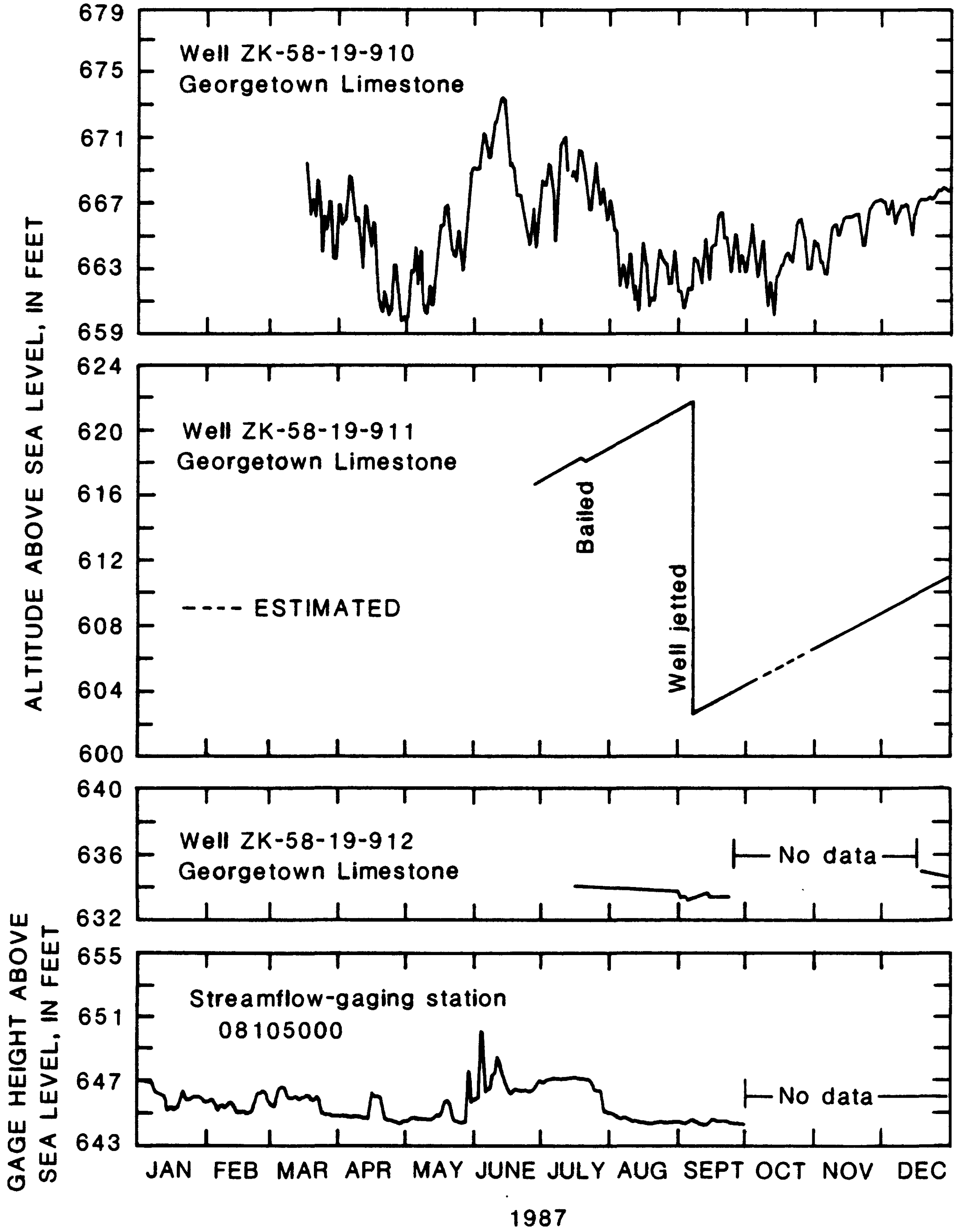


Figure 17.--Water-level hydrographs at San Gabriel River test-well site.

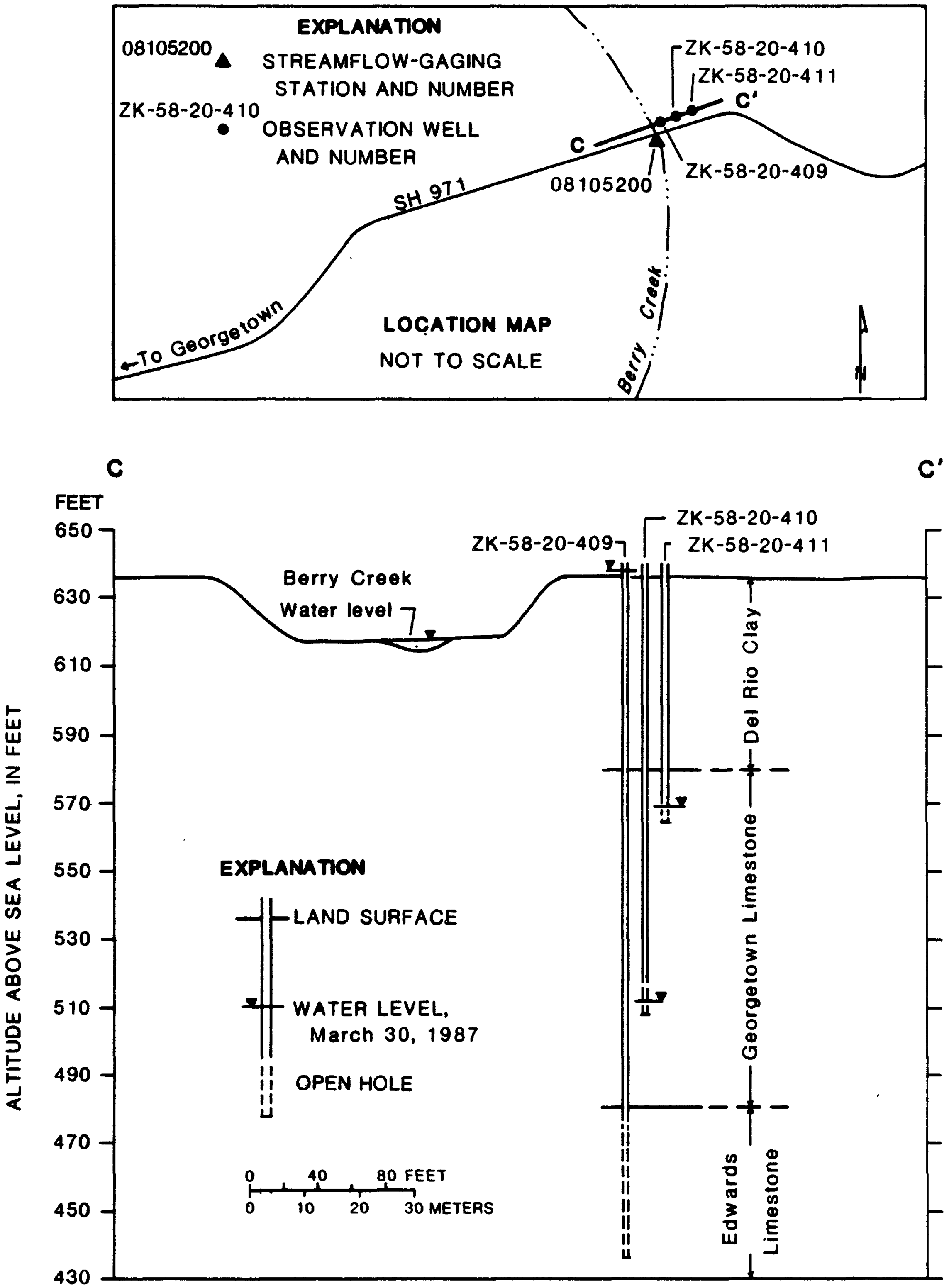
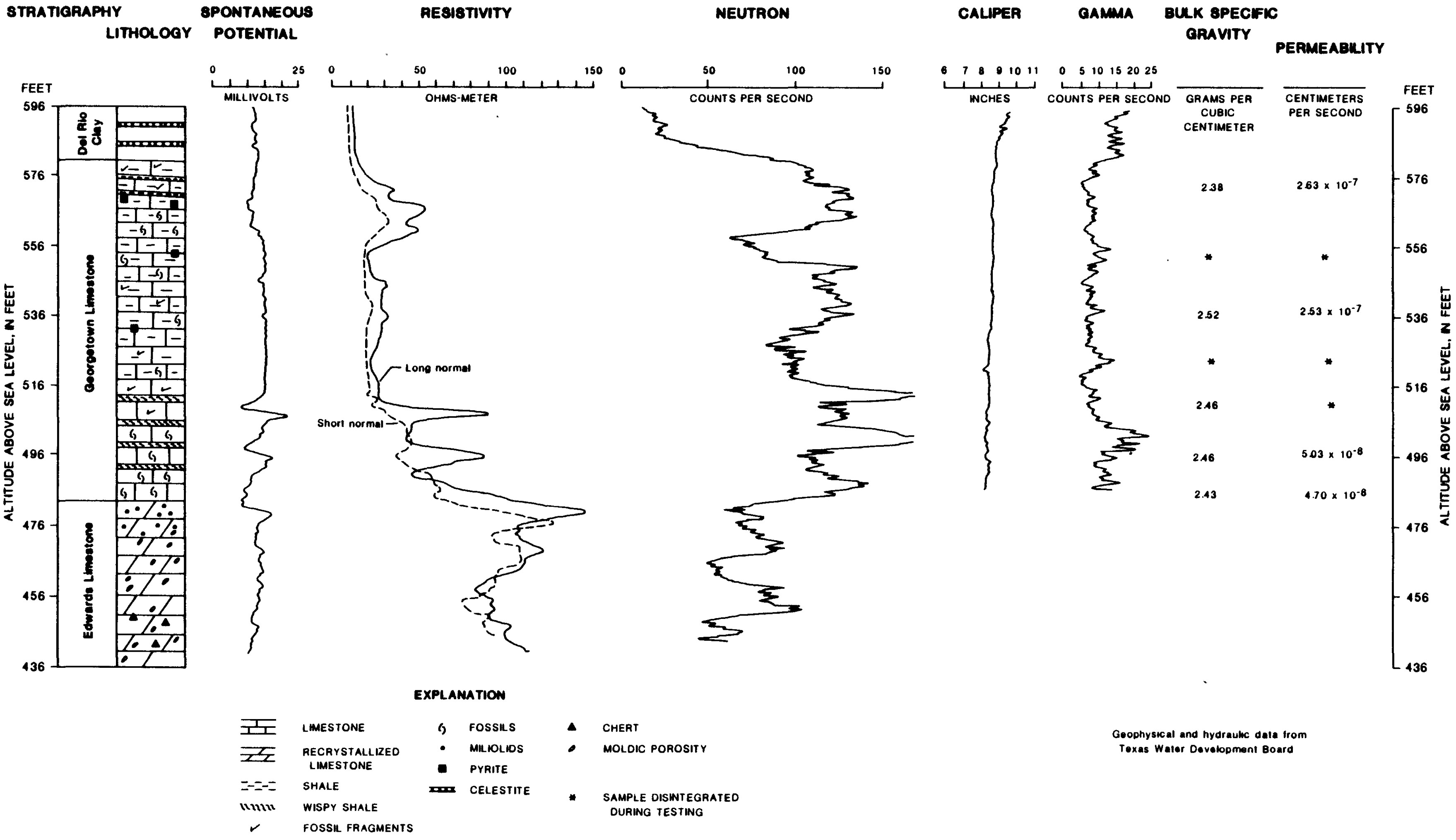


Figure 18.--Location, well completion, and water-level data, Berry Creek test-well site.



Geophysical and hydraulic data from Texas Water Development Board

Figure 19.--Geologic, geophysical, and hydraulic properties of test well ZK-58-20-409.

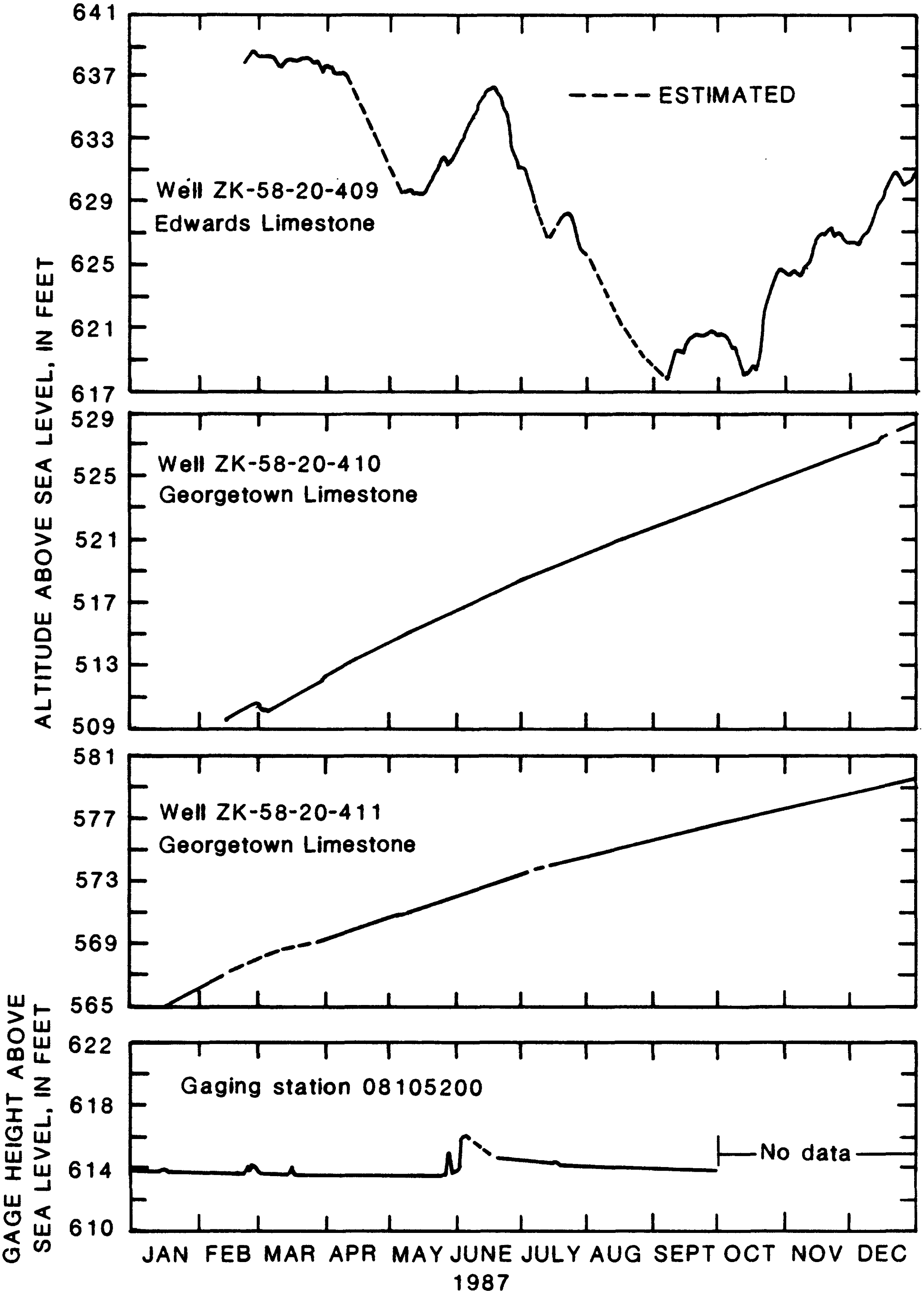


Figure 20.--Water-level hydrographs at Berry Creek test-well site.

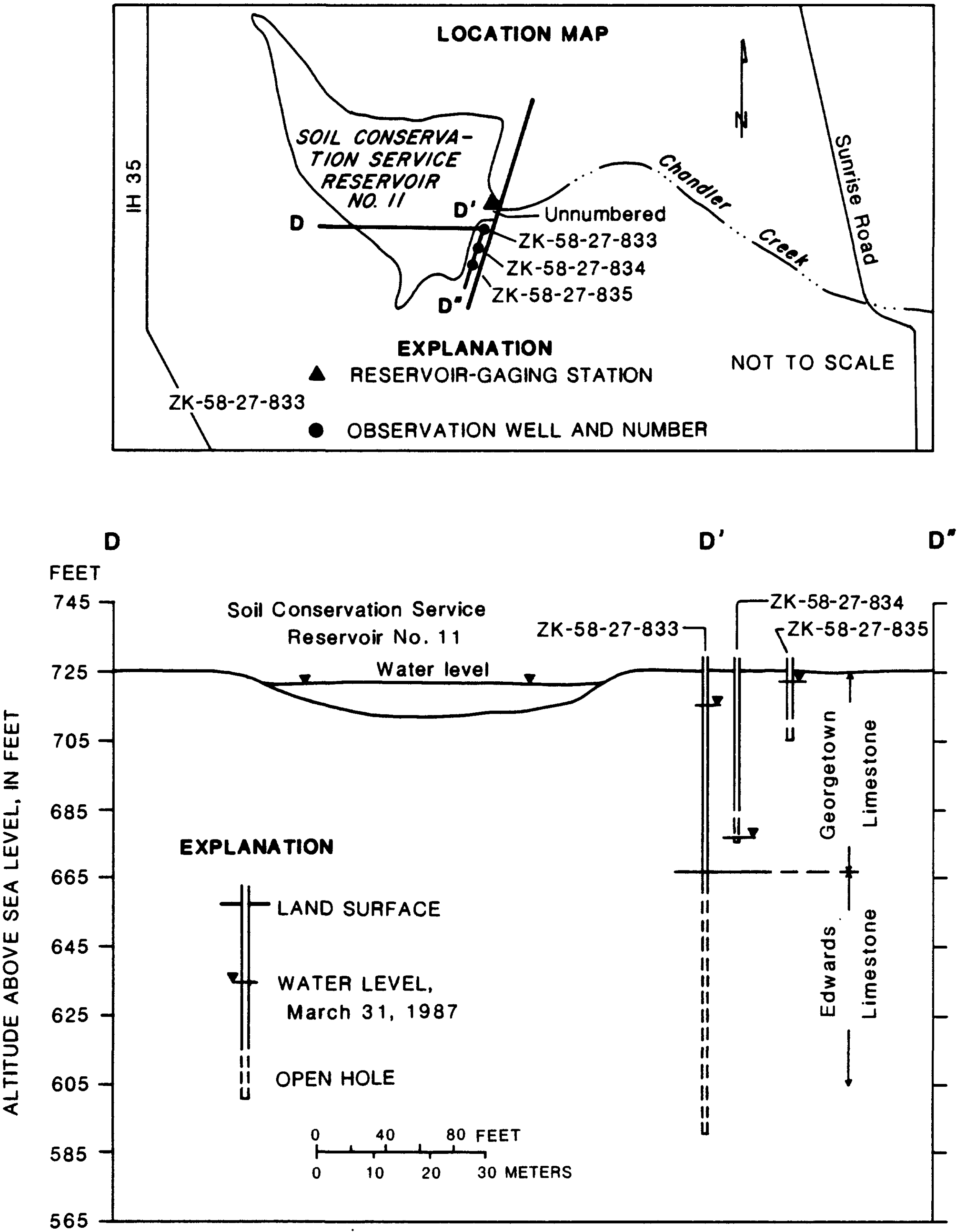


Figure 21.--Location, well completion, and water-level data, Chandler Branch test-well site.

summary of geologic, geophysical, and hydraulic properties is shown in figure 22; and a comparison of the water-level hydrographs for the observation wells and SCS reservoir is shown in figure 23. A comparison of the hydrographs shows that the water level in the Edwards well (ZK-58-27-833) has a pattern similar to water levels measured in the reservoir as did the well completed near the middle of the Georgetown Limestone (ZK-58-27-835), which is the shallowest well and is open to a zone with considerable amount of rock rubble. However, the hydrograph for the well completed in the Georgetown Limestone near the Georgetown-Edwards contact (ZK-58-27-834) shows a gradual increase in water level throughout the period of record.

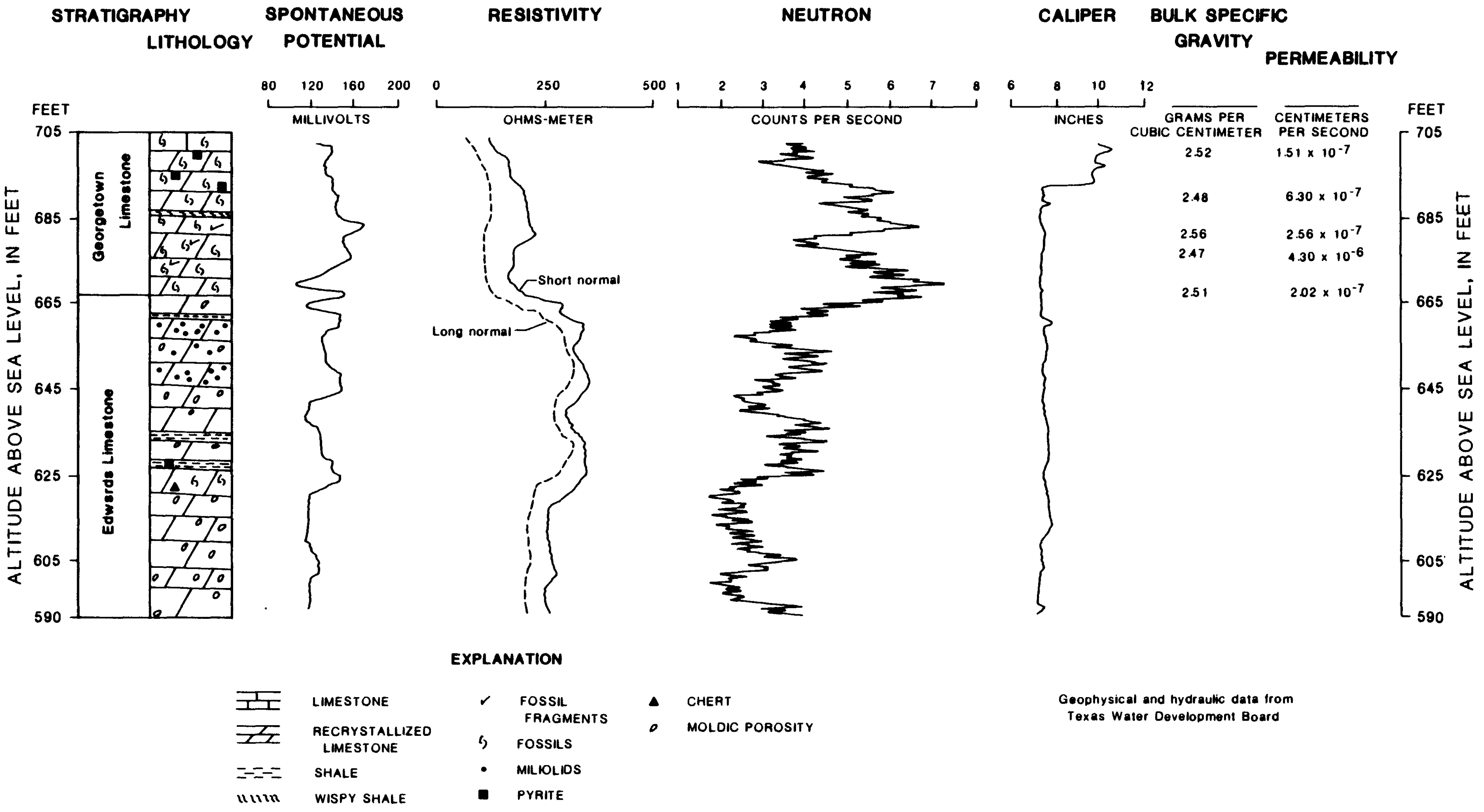
Water Quality

In an attempt to better understand the movement of water between the aquifer and streams, samples were collected from 11 wells and 4 stream sites for inorganic chemical analysis. In addition to laboratory analyses of water samples from selected sites, field measurements of specific conductance, pH, and temperature usually were made at stream sites and selected wells. The specific-conductance data collected from the wells and streams during the survey on May 4 to 8, 1987, which represents approximate average water-level conditions during the study period, are shown in figure 24. Dissolved solids concentrations in samples from wells ranged from 320 to 1,300 mg/L (milligrams per liter) and samples from streams ranged from 251 to 290 mg/L.

SURFACE-WATER AND GROUND-WATER INTERACTION

One means of estimating the ability of the Georgetown Limestone to transmit water is to show the interaction between the streams and the aquifer. The selected approach is to determine if a relation between streamflow gains and losses and the head differentials between the main water-bearing zone of the Edwards aquifer and the streams exists. Data for this analysis were obtained from six concurrent surveys of streamflow and ground-water levels. The streamflow surveys consisted of measurements made at several sites where the streams cross the outcrop of the Georgetown Limestone and the alluvial and terrace deposits overlying the Georgetown Limestone. Sites were selected on the San Gabriel River, on Berry and Dry Berry Creeks, and on the Chandler, Onion, Weir, and Pecan Branches. The distance between the sites commonly ranged between 0.5 and 1.5 miles. The streamflow surveys were conducted with the intention of computing the gain or loss for each subreach. The computation is made by subtracting the discharge at the downstream site from the discharge at the adjacent upstream site and adjusting for any surface inflows or diversions. The accuaracy of the streamflow measurements were usually estimated to be within 5 percent of the actual discharge. In an extreme case where measurements at adjacent sites had opposite errors, the error in the computed gain or loss would be about 10 percent of the streamflow.

To facilitate this type of analysis, the streamflow should be steady along the reach and throughout the duration of the survey. In nature, steady flow conditions seldom occur. The most frequent cause of unsteady flow on the San Gabriel River during the surveys was the irregular pattern of releases from Lake Georgetown. To the extent possible, the U.S. Army Corp of Engineers held the release steady for several days prior to and during the survey. Another cause for unsteady flow is storm runoff. To the extent possible, the



Geophysical and hydraulic data from Texas Water Development Board

Figure 22.--Geologic, geophysical, and hydraulic properties test well ZK-58-27-833.

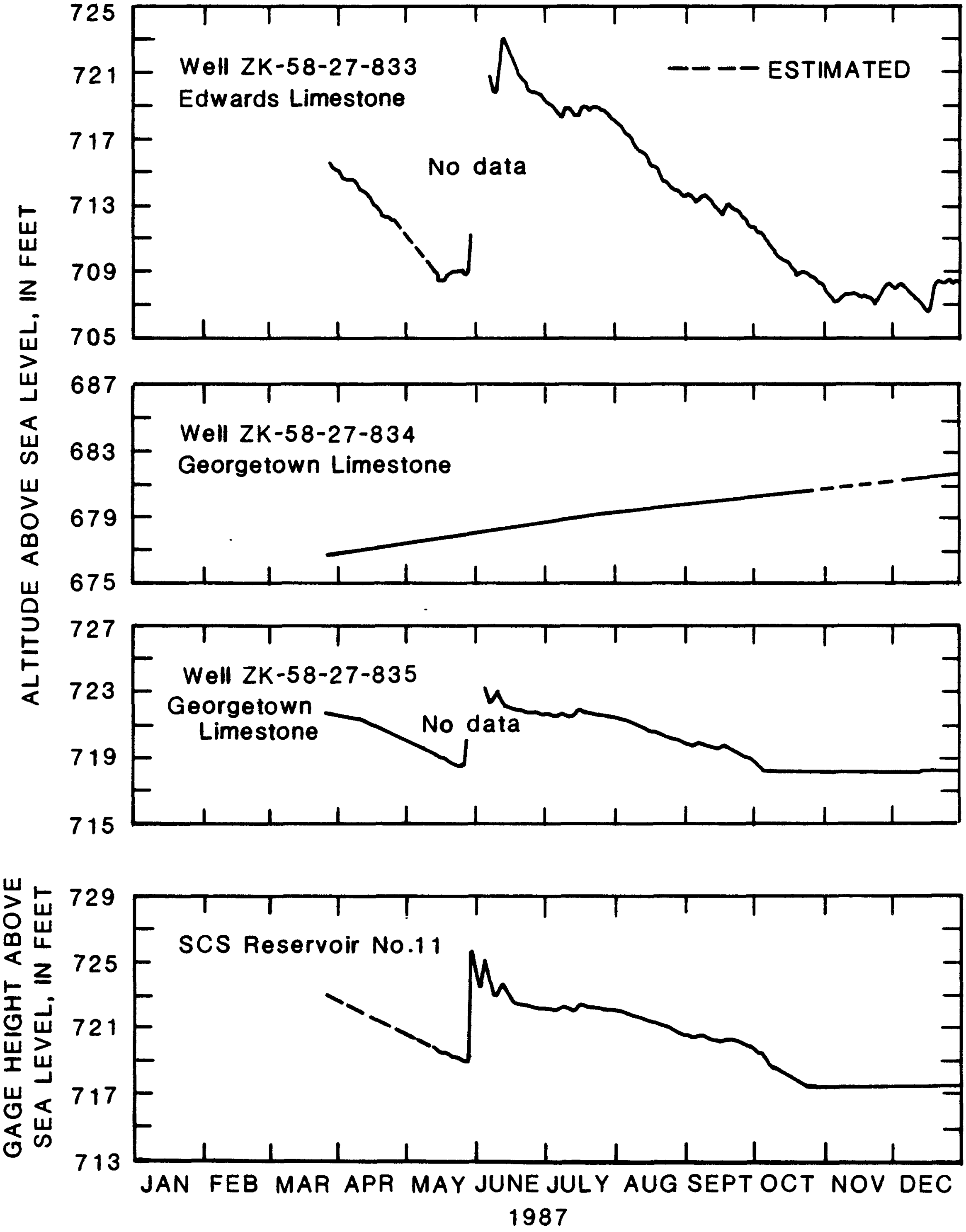


Figure 23.--Water-level hydrographs at Chandler Branch test-well site.

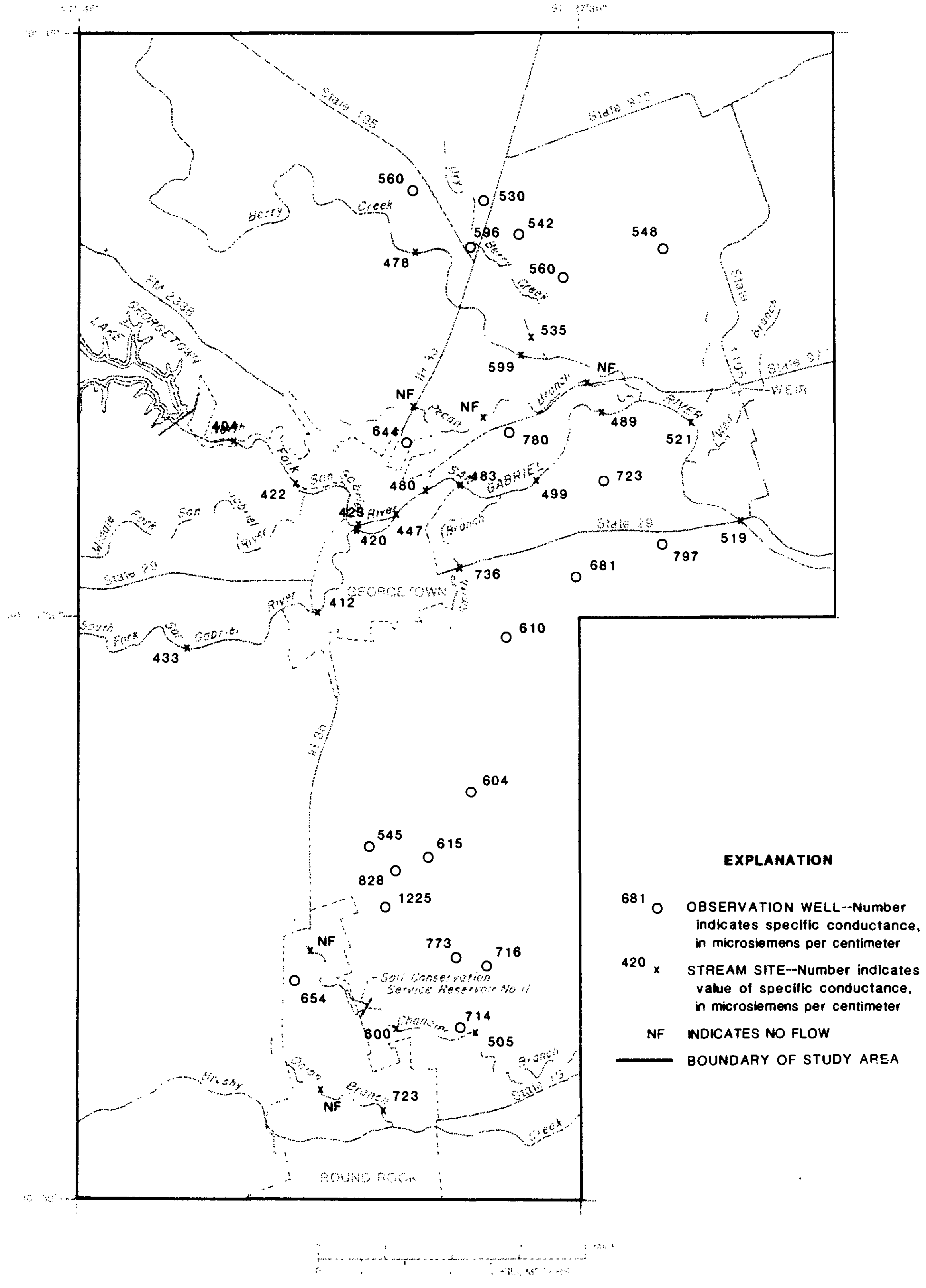


Figure 24.--Variations in specific conductance in streams and the Edwards aquifer, May 4-8, 1987.

surveys were scheduled to avoid encountering runoff from storms. Generally, the efforts were successful in obtaining reasonably steady flows except for the Dec. 2-5, 1986, survey on the San Gabriel River. Prior to the survey a sharp and temporary reduction of discharge from Lake Georgetown, shown by the hydrograph at station 08104700 (North Fork San Gabriel River near Georgetown), had not cleared the reach, as shown by the hydrograph at station 08105300 (San Gabriel River near Weir) (fig. 7).

Seasonal conditions can cause changes in the streamflow gains and losses. The least impact occurs during the winter when evapotranspiration, and miscellaneous diversions are at a minimum. The greatest impact occurs during the summer, especially in the very hot and dry periods when these water losses may be significant. During this time, the major loss of streamflow is believed to be to a shallow alluvial aquifer along the stream. The water table is shallow along the major streams, and plants can obtain most of their water requirements from this source. The water loss to plants lowers the water table which either reduces the natural ground-water inflow into the stream or begins to divert water from the stream to the alluvial aquifer.

Bank storage and release, the temporary storage or drainage of ground water from a shallow aquifer in hydraulic connection with a stream during and immediately following an increase or decrease of stream stage, can prevent a direct identification of the source of water in streamflow gains or the recieving aquifer of streamflow losses. If a survey is preceded by a flood wave (a rise and fall in stream stage), some water would have gone into the banks during the rise and would begin to return during and following the fall in stage, or the reverse may also occur. In the study area, this flow to and from bank storage could be mistaken for the the exchange of water between the streams and the Edwards aquifer. Channel storage can cause a similar impact but is of a lesser magnitude and duration.

The ground-water level surveys consisted of measuring the depth to water and the computation of water-level altitudes in about 60 wells open to the main water-bearing zone of the Edwards aquifer. Data from wells in the immediate vicinity of the streamflow-measuring sites along with the estimated altitude of the water surface at stream sites were used to compute the head differential across the Georgetown Limestone. The hydraulic head differentials are computed by estimating the altitude of the land surface at the selected wells and the altitude of the stream's water surface from 7-1/2 minute USGS topographic maps and subtracting the ground-water levels from the surface-water levels. The topographic maps are contoured at 10-ft intervals and are considered to be accurate to 5 ft. Because the estimates are made in local areas, the differentials are also believed to be accurate to 5 ft.

Using the ground-water level data from a nearby well with the streamflow-gaging site data probably creates an error of 5 ft. The accumulative error would be 10 ft. However, relative error among the surveys at given sites is believed to be insignificant. Another error can be caused by the observation well being recently pumped or being influenced by a nearby discharging well. A pumping error would cause the measured water levels to show a lower altitude than the actual regional water levels. To the extent possible, care was taken during the field visits to assure that the well had not been recently pumped and to wait a sufficient length of time for the recovery of water levels.

In an attempt to determine if an exchange of water between the main water-bearing zone of the Edwards aquifer and the streams occurs, the relations between the streamflow gains and losses and head differentials were examined graphically. To readily compare the changes along the stream, the absolute change in streamflow for given subreaches was converted to the change in streamflow per mile. The two graphs are overlain as an aid in establishing the existence or nonexistence of a cause-effect relation. For the cause-effect relation to exist, a positive (upward) head differential would produce a positive change (gain) in streamflow in a subreach and vice versa.

San Gabriel River

The relations between the streamflow gains and losses and the head differentials are shown in figure 25 for the San Gabriel River. The streamflow data and the observation well data are presented in Dorsey and Slagle (1987). The observation wells used to compute the head differentials include:

Stream site number	Well number(s)
2	ZK-58-19-811 and 909 (average)
3	19-909
4	19-908
5	20-412

For convenience, the subreaches are numbered (fig 6). Their designations follow:

Subreach number	Site numbers	River mile
1	2 - 3	60.6 - 61.3
2	3 - 4	60.1 - 60.6
3	4 - 5	58.5 - 60.1

San Gabriel Springs occurs in the subreach between river mile 61.3 and 62.0. This subreach is excluded from the analysis. The Georgetown Limestone is exposed at the surface or to the Quaternary deposits downstream to about river mile 59.

Figure 25 shows that the head differential is almost always positive along the reach except during the July 1986 survey. During this survey the head differential is negative upstream of river mile 58.5 and positive downstream. Streamflow gain or loss appear to have little pattern either along the reach or from one survey to the next. In terms of consistency along the reach for a given survey, the February 1987 survey showed a very slight gain along almost the entire reach. Because of the winter condition discussed earlier, this survey is believed to be the most accurate and representative.

To evaluate the need for considering evapotranspiration factors that may be significant in the summer, a comparison is made between the winter and early spring surveys and the early summer and summer surveys. The streamflow gain and loss graphs do not show a consistent and significant numerically less gain or loss between the two groups. On this basis it is believed that the evapotranspiration losses are minor. Because water has to move from the stream to the alluvial aquifer for significant losses to evapotranspiration, it is believed that there is only a minor interchange of water (hydraulic connection) between the stream and the alluvial aquifer.

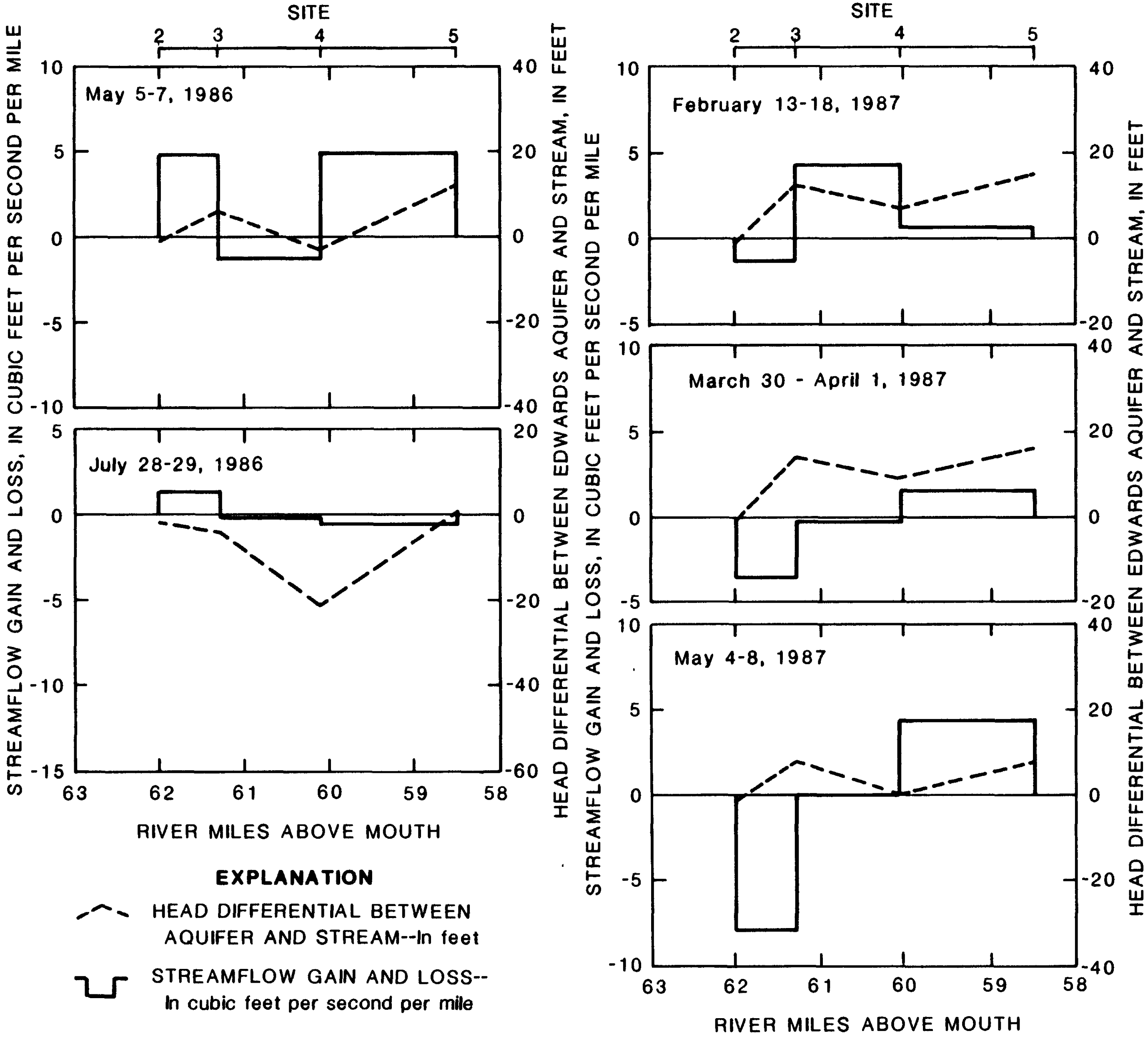


Figure 25.--Streamflow gains and losses and head differentials between Edwards aquifer and San Gabriel River for five surveys.

The graphs in figure 25 do not show a pattern of greater head differential corresponding to a numerically greater streamflow gain or loss and vice versa except for subreach 3. In this subreach, the values are not directly proportional to each other, which is needed to establish a strong cause-effect relation. Thus, these data suggest that no significant exchange of water between the main water-bearing zone of the Edwards aquifer and the San Gabriel River occurs where the Georgetown Limestone separates the two.

Berry Creek

The relation between the streamflow gains and losses and head differentials is shown graphically in figure 26 for Berry Creek. The streamflow data and observation well data are presented in Dorsey and Slagle (1987). The observation wells used to compute the head differentials include:

Stream site number	Well number(s)
1	ZK-58-19-505
2	19-622
4	19-617
5	20-412

Because well ZK-58-19-412 is hydraulically upgradient a short distance from stream site number 5, its water level is lowered by 5 ft.

For convenience, the subreaches are numbered (fig 6). Their designations follow.

Subreach number	Site numbers	River mile
1	1 - 2	3.6 - 5.0
2	2 - 4	2.2 - 3.6
3	4 - 5	0.5 - 2.2

Berry Springs is in subreach 2. The Georgetown Limestone is exposed or is in contact with the alluvium from river mile 4.5 to about river mile 1.0 (fig 3). Thus, part of subreach 1 does not have a separation of the Edwards Limestone and Berry Creek by the Georgetown Limestone.

Inspection and comparison of the head differentials show a consistent pattern along the reach. At site 1 (river mile 5.0) the head differentials are always negative (downward), and at the other sites the head differentials are always positive (upward), except for site 5 which has a small negative value for the July 1986 survey. The magnitudes in head differentials vary seasonally, about 15 ft greater in the summer than in the winter. Inspection of the streamflow gain and loss graphs shows that gains always occurred in subreaches 1 and 2 and losses always occurred in subreach 3 except during the Feb. 1987 and May 1987 surveys. Because Berry Springs occurs in subreach 2, a gain in this subreach is expected. This spring is submerged in a ponded section of the creek and can not be measured directly. These data indicate that summer conditions may have a significant effect on streamflow gains only in subreach 1.

A comparison of the gains and losses during the summer (July 1986) survey with the winter (February 1987) survey shows that: Subreach 1 has a substantially less gain in the summer than in the winter; Subreach 2 has comparable

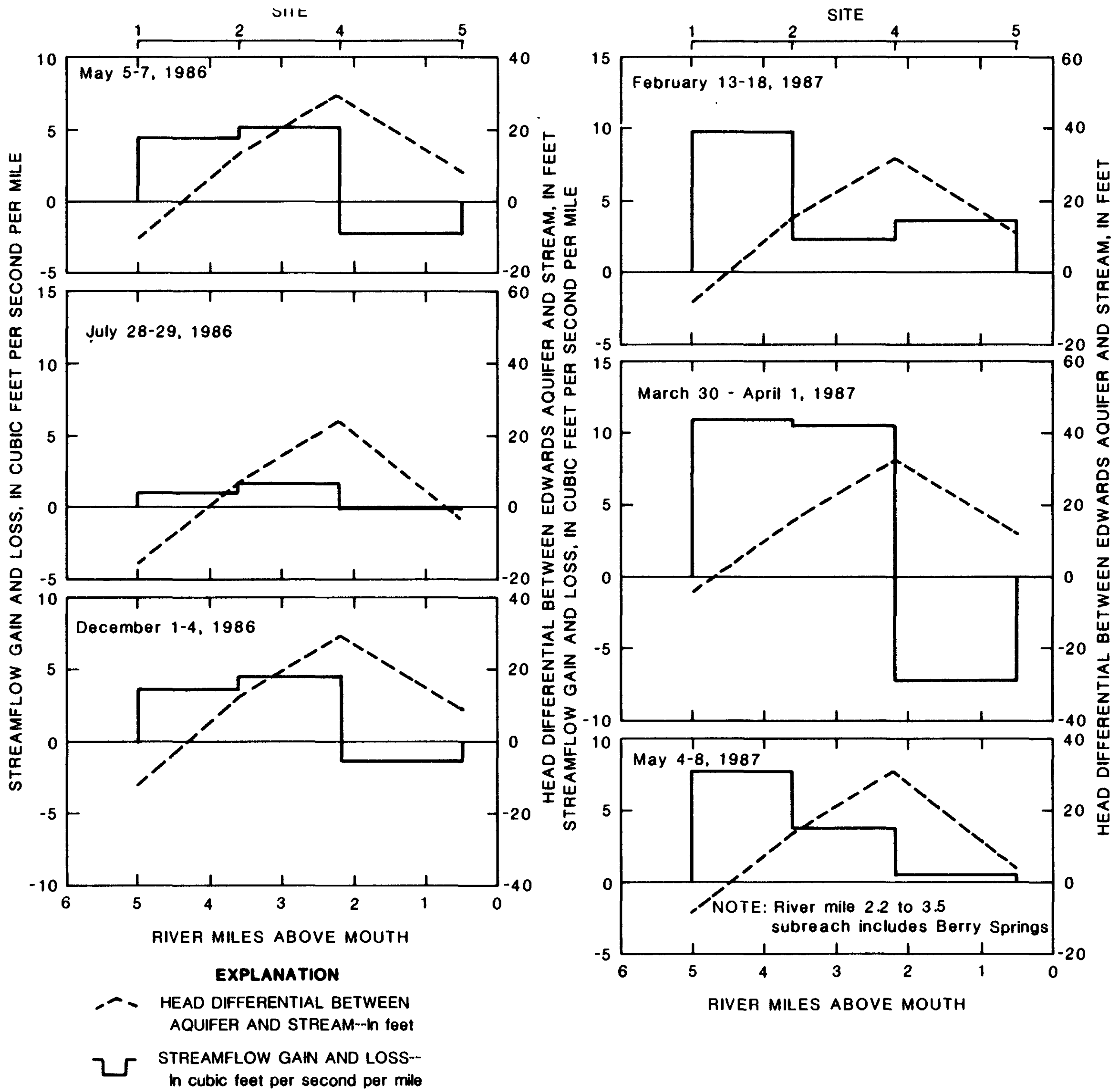


Figure 26.--Streamflow gains and losses and head differentials between Edwards aquifer and Berry Creek for six surveys.

gains; and Subreach 3 has a change from a slight loss in the summer to a modest gain in the winter.

A study of the graphs (fig. 26) for establishing a cause-effect relation shows a consistent relation of a positive head differential and streamflow gains only in subreach 2 where Berry Springs is located. In subreach 1, the average head differentials varied from a slight positive to a slight negative but the streamflow was always gaining. However, part of the subreach is exposed directly to the Edwards Limestone. In subreach 3, the relation is often violated because there is almost always a positive head differential but the stream usually loses flow. Based on hydraulic principles, the change in streamflow gain should be proportional to the change in the head differential for given subreaches. For subreach 2, a pattern of greater gains for greater average head differentials and vice versa is consistent for all surveys except February 1987 and March-April 1987. Relatively high flow conditions (fig. 11) occurred during these two surveys. Allowances for a 5 to 10 percent error in the measurements would cause the computed streamflow gains to be consistent with the other results. Thus, a cause-effect relation between the head differentials and the streamflow gains and losses can be established only in subreach 2.

TRANSMISSIVE CHARACTERISTICS OF THE GEORGETOWN LIMESTONE

At the beginning of the study, the concept for determining the transmissive characteristics of the Georgetown Limestone was to relate the fluctuations of water levels in the Georgetown Limestone with the fluctuations in the Edwards Limestone and a nearby surface-water body. Based on the past inclusion of the Georgetown Limestone in the Edwards aquifer, it was anticipated that a subdued and somewhat delayed reponse of a water-level change in the stream would occur in the Georgetown Limestone. Inspection of the hydrographs given in figures 17, 20, and 23, show that this did not occur except for two of three wells at the Chandler Branch site. Thus, the original approach for determining the transmissive characteristics by relating water-level fluctuations was not possible.

A review of the hydrographs of water levels in wells completed in the Georgetown Limestone indicated that another analytical technique for computation of transmissive characteristics may be appropriate. The technique is known as a "slug" test (Lohman, 1972). In our case, the test began at the time the well was developed by washing it with water and jetting out the water with air. Later, water-level recording instrumentation was installed and operated on each well. Water-level data for about 1 year are available for analysis.

The "slug" test method is described by Lohman (1972, p. 27-29). This method assumes a "slug" of water is suddenly injected or removed from a well and the water levels are measured repeatedly to provide a record for computing the water-level changes with time. The method is applicable only to fully penetrating wells in confined aquifers having rather low transmissivities. The method requires plotting the ratio of initial head change in the well to the head change at time t against time t on a semilog graph. This graph is matched with a type curve for the computation of transmissivity. The parameters used in the analysis are:

H_o = Initial head change in the test well
H = Head change in the test well at time t
T = Transmissivity
t = Time since test began
r_c = Radius of well in section of water-level fluctuation

A match line provides values of t and Tt/r_c^2. Knowing the value of the well radius provides the necessary information to compute the transmissivity. The hydraulic conductivity is computed by dividing the transmissivity by the length of the well's open hole or screen length.

Two wells at each of the three test sites were constructed in the Georgetown Limestone and were considered for analysis. The wells were:

San Gabriel River: ZK-58-19-911 and 912
Berry Creek: ZK-58-20-410 and 411
Chandler Branch: ZK-58-27-834 and 835

An evaluation of the available test data and wells with regard to the mathematical assumptions of the "slug" test method indicates that the selected method is suitable. Even though the drawdown was not instantaneous, in relative terms of the duration of the test and the rate of water-level recovery, it is reasonable to assume that the "slug" was instantaneous. With regard to the fully penetrating well assumption, the layering of the Georgetown Limestone and the interbedding of clay and shale (figs 16, 19, and 22) is believed to cause the vertical permeability to be only a fraction of the horizontal permeability. Thus, vertical water movement is not believed to have a significant effect on the recovery of water levels or the results of the analysis.

The shallow wells at San Gabriel River (ZK-58-19-912) and Chandler Branch (ZK-58-27-835) did not have water-level responses that could be associated with a "slug" test. Well ZK-58-19-912 stayed dry for an extended period and when it did contain water, the water-levels could not be related to any causes and were often erratic. Well ZK-58-27-835 showed water-level fluctuations very similar to the water-level fluctuations in the nearby surface-water reservoir.

The procedure for analyzing the remaining four wells involved the preparation of data sets containing (1) an estimated altitude of water level in the well before the test began, (2) an estimated water level in the well immediately after the test started, (3) borehole diameter, (4) an estimate of the storage coefficient, and (5) a time series of depth to water-level measurements since the test began. From these data, a time series of head change since the test began and a ratio of H/H_o was computed. The corresponding H/H_o and time t points were plotted on a semilog graph and are shown in figure 27. The initial attempt to match the data points with the type curve usually showed a divergence from the type curve during the early times. Adjusting the initial head decline, which was first assumed to extend to the bottom of the hole, proved to be very sensitive in changing the arc of

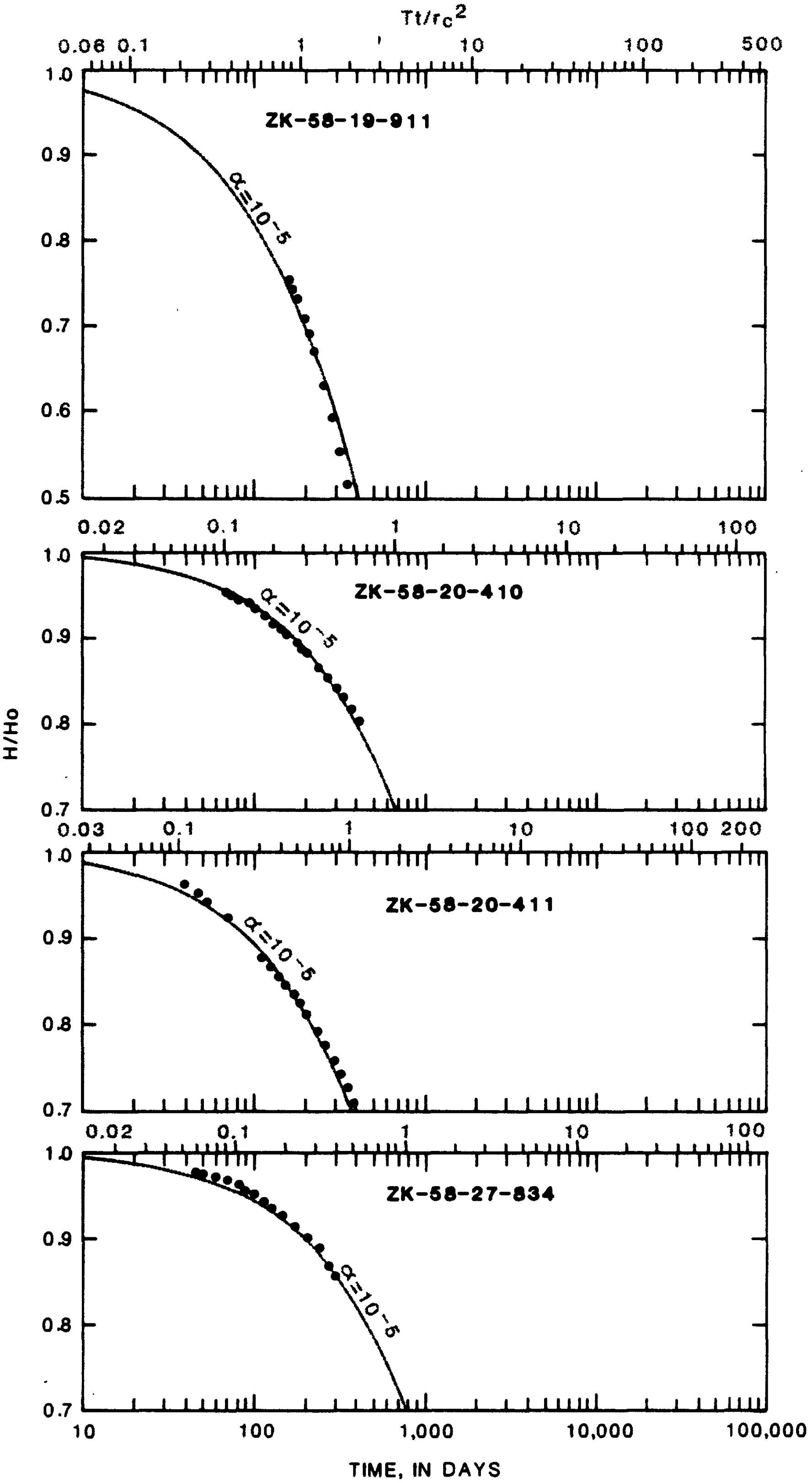


Figure 27.--Drawdowns and type curve for four test wells in Georgetown Limestone.

the data points during the early times. Changes of 1 to 3 ft were sufficient to greatly improve the overall match.

An inspection of the driller's records showed that the holes were 1 to 2 ft deeper than planned, thus, providing a reason for increasing the depth of the test holes. If some water remained in the hole after jetting or if it contained some mud or rock, the initial head declines would be slightly less than a head decline to the bottom of the hole. The selected procedure was to adjust the initial head decline up to 3 ft of the planned depth to improve the curve match. An evaluation of the adjustment showed that it had only a slight effect on the computed transmissivity. In addition to the computation of the transmissivity, the well depth, affected by the length of the open hole, is important in computing the hydraulic conductivity. The data and selected parameters are given in table 1.

An overlay of the time series H/H_0 data on the type curve for alpha = 1×10^{-5} is given in figure 27 for the four test wells. This alpha value was selected because the storage coefficient is estimated to be 1×10^{-5} (Lohman, 1972). The diameter of the borehole was estimated to be 6-3/8 in (6-1/8 in for the bit and 1/4 in for over reaming). The computed hydraulic conductivities are given in table 1.

A comparison of the hydraulic conductivities computed by the "slug" tests can be made with laboratory-determined values for core samples taken from the deepest hole at each test site. The laboratory-determined values were determined by the Materials Laboratory of the TWDB. The number of test core samples varied from five to seven in each of the deep test holes and were selected at rather uniform intervals in the Georgetown Limestone but only from solid or nearly solid rock layers. The laboratory permeability values from the core sample interval nearest the well opening in the adjacent test well are also tabulated in table 1. These laboratory values appear to be one to two orders of magnitude greater than the hydraulic conductivity values computed from the "slug" test analyses. This deviation is expected because of the selective sampling of core for laboratory tests and laboratory tests typically producing values substanitally greater than field tests.

An independent means of verifying the hydraulic conductivities computed by the "slug" test analyses is by comparing the results with the unit specific capacity (well discharge per unit of drawdown per unit of thickness) of the test well. A verification would be assummed if the ratio between the hydraulic conductivity computed by the "slug" test procedure and the unit specific capacity is nearly constant. The unit specific capacity was calculated during a 1 month period and about 6 months after the test began. The discharge was determined by the volume accumulated during the month, the drawdown was estimated in the middle of this month, and the thickness was obtained from well data. The unit specific capacity values were converted to centimeter per second for computation of the ratio. The ratio ranged from 2.65 to 2.94; however, two of the ratios were nearly the same--2.73 and 2.74--for the test wells at the Berry Creek site. The other two were within 8 percent of the intermediate ratios. These unit specific capacity tests suggest that the computed hydraulic conductivities are comparable among the wells.

Table 1.--Summary of aquifer-test analyses for Georgetown Limestone test wells

[ft, foot; ft^2/day, foot squared per day; cm/s, centimeter per second; ft^3/day/ft/ft, cubic foot per day per foot per foot]

Description	Well Number: ZK-58-			
	19-911	20-410	20-411	27-834
Altitude of static water level (ft)	660.0	633.0	623.0	718.0
Total depth of well (ft)	92.5	132	73	50
Length of open hole (ft)	9.5	12	11	11
Initial decline in head (ft)	57.5	130	61	42
"Slug" test				
Match line:				
time (days)	180	680	370	800
Tt/r_c^2	1.0	1.0	1.0	1.0
Transmissivity (ft^2/day) (10^{-4})	3.9	1.0	1.9	.88
Hydraulic conductivity (cm/s) (10^{-9})	14	3.0	6.2	2.8
Unit specific capacity (ft^3/day/ft/ft) (10^{-6})	15	3.2	6.4	2.7
Laboratory permeability (cm/s)[1] (10^{-8})	3.12	5.03	26.3	25.6
Ratio of hydraulic conductivity and unit specific capacity (dimensionless)	2.65	2.73	2.74	2.94

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[1] Core sample taken from a test hole at the site and from an interval nearest the open hole interval of the well. Analyses by the Texas Water Development Board.

GROUND-WATER CIRCULATION BASED ON WATER-QUALITY DATA

One of the selected approaches for testing the water-bearing properties of the Georgetown Limestone was to study the variation of water-quality characteristics between the Edwards Limestone of the Edwards aquifer and nearby streams and between the Edwards Limestone and the Georgetown Limestone. Where the Georgetown Limestone separated the Edwards Limestone from the streams, similar water-quality characteristics of the two water bodies would suggest that the Georgetown Limestone readily conveys water between the two. A similar characteristic available in water-quality samples from wells open only to the Edwards Limestone or the Georgetown Limestone would suggest a significant circulation between the two geologic units. The water-quality data available for this analysis are summarized in a trilinear diagram given in figure 28 and tabulated in Dorsey and Slagle (1987). Data are available in the Berry Creek and IH-35 (Interstate Highway) area and at the Berry Creek and Chandler Branch test sites.

In the Berry Creek and IH-35 area, four wells and two streams were sampled. The wells draw water from the Edwards Limestone and range in depth from 147 to 200 ft. The streams are Berry and Dry Berry Creeks and the sampling sites are at IH-35. The dissolved-solids concentrations range from 320 to 350 mg/L for the ground-water samples and from 250 to 270 mg/L for the stream samples. The results of the inorganic analysis from the laboratory are plotted on a trilinear diagram in figure 28. Points 1 to 4 represent the wells and points 5 and 6 represent Berry and Dry Berry Creeks, repectively. These data cluster, therefore very similar water-quality characteristics are indicated. However, a review of the geologic map (fig. 3), streamflow distribution along Berry Creek (fig. 10), ground-water map (fig. 14), and the extent of Berry and Dry Berry Creeks suggests that a significant source of water in the two streams at these sites is from an area where the Edwards Limestone is exposed at the streambed or from faults that provide a direct connection between the Edwards Limestone and the stream. However, this data set is not conclusive as to whether or not the Georgetown Limestone readily conveys water from the Edwards Limestone to the streams or is a source of water to the streams.

At the Berry Creek test site the three test wells were sampled. The two shallow wells are open hole at depths between 62 to 72 ft and 120 to 128 ft, which is in the Georgetown Limestone. The deepest well is open hole at depths between 161 and 200 ft which is in the Edwards Limestone. The water in the Edwards aquifer at this location is in the transition zone from the freshwater to the west and the saline water to the east. The dissolved-solids concentration is 420 mg/L and in the Edwards Limestone well the concentrations at the four wells at the Berry Creek and IH-35 area average about 340 mg/L. The dissolved-solids concentrations of water from the Georgetown Limestone wells were, from shallow to deep, 1,300 and 950 mg/L. On the trilinear diagram in figure 28, points 7 to 9 represent wells from the shallowest to the deepest. Point 9, the Edwards Limestone well, plots near the clustering. However, points 7 and 8 are located close together and at considerable distance from point 9 and the clustering. This shows different types of water in the Georgetown Limestone and the Edwards Limestone at this location and suggests a very limited ground-water circulation between these two geologic units and between the Georgetown Limestone and the Edwards aquifer hydraulically upgradient.

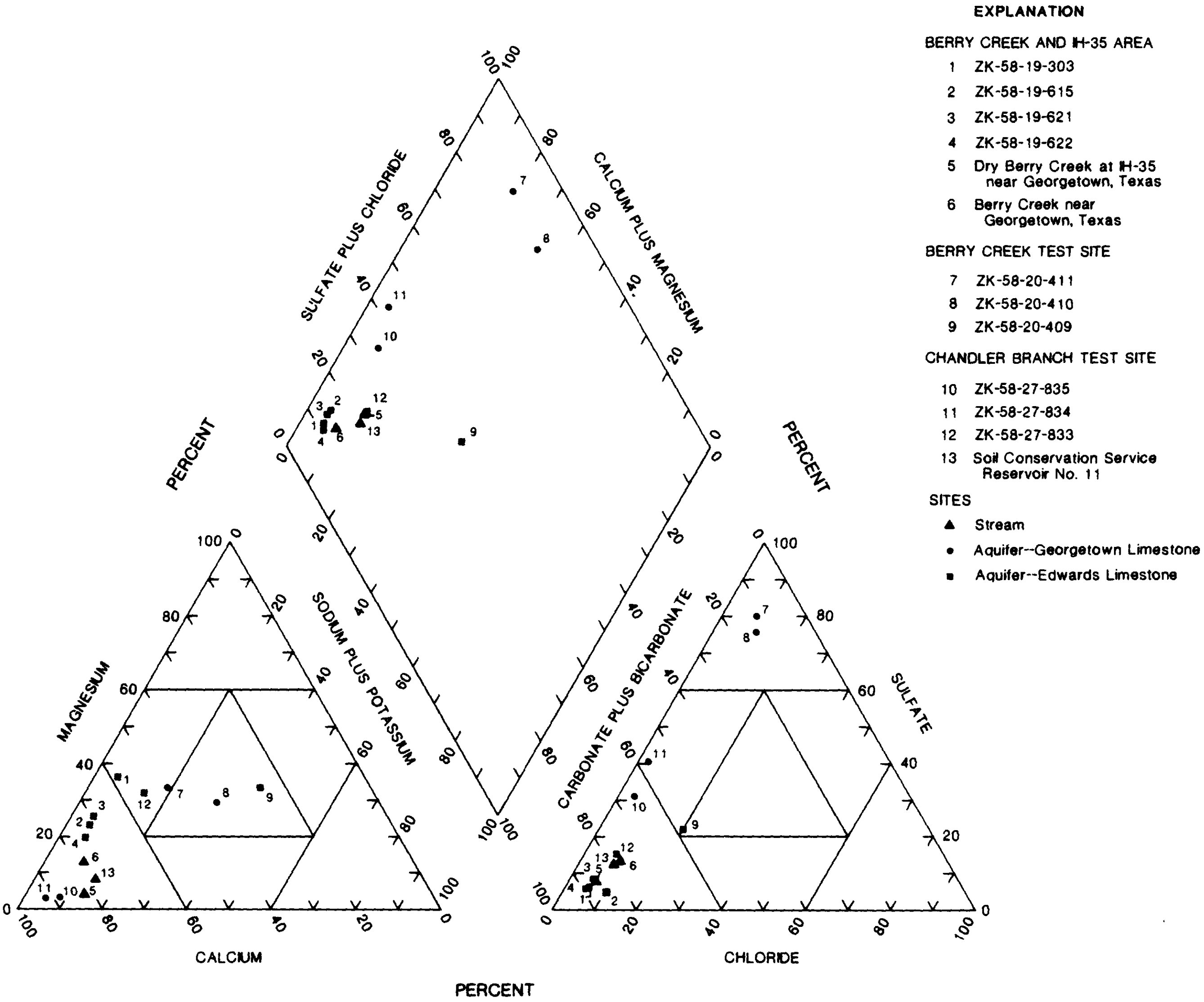

Figure 28.--Trilinear diagram of selected water-quality analyses

At the Chandler Branch test site, water analyses are available from the three test wells and the adjacent SCS reservoir. The well openings are 15 to 20 ft, 40 to 50 ft, and 65 to 135 ft below land surface. The shallowest two wells are open to the Georgetown Limestone and the deepest to the Edwards Limestone. These wells are on a berm immediately upstream from the dam (fig. 21). The shallowest well is completed in some rock rubble and appears to be in direct hydraulic connection with the reservoir (fig. 23). The dissolved solids concentrations varied from 180 mg/L in the reservoir, to 310 mg/L in the Edwards Limestone well, to 380 mg/L in the shallow Georgetown Limestone well, and to 470 mg/L in the deep Georgetown Limestone well.

Points 10 to 12 in figure 28 represent water from the shallowest to deepest wells and point 13 represents water from the reservoir. Water from the reservoir and the Edwards Limestone well plot within the clustering, but the water from the Georgetown Limestone wells plot near each other but at a limited distance from the clustering. It was expected that the water from the reservoir and the shallow well would plot close together because of the apparent high degree of hydraulic connection between the two as indicated by the water-level hydrographs shown in figure 23. However, these data only show a similarity of water-quality characteristics between the surface water and the water in the Edwards Limestone well and a slight dissimilarity between these two and water from the Georgetown Limestone wells. Thus, an active ground-water circulation pattern is evident between the surface-water system and the Edwards Limestone of the Edwards aquifer, but the circulation between the Edwards Limestone and the Georgetown Limestone is limited. These results are consistent with the findings at the Berry Creek and IH-35 area and the Berry Creek test site.

REASSESSMENT OF THE GEORGETOWN LIMESTONE AS A UNIT OF THE EDWARDS AQUIFER

A determination on whether or not the Georgetown Limestone should be included as a geologic unit in the Edwards aquifer is based on the definition of ground-water terms and how the determined transmissive characteristics of the Georgetown Limestone correspond to ground-water definitions. The definitions of the selected terms, from Lohman and others (1972) follow:

> Aquifer--a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs....
>
> Confining bed--a body of "impermeable" material stratigraphically adjacent to one or more aquifers. In nature, however, its hydraulic conductivity may range from nearly zero to some value distinctly lower than that of the aquifer. Its conductivity relative to that of the aquifer it confines should be specified or indicated by a suitable modifier such as slightly permeable or moderately permeable.

The relation between the streamflow gains and losses and the head differential between the main water-bearing zone of the Edwards aquifer and the streams is not consistent along the San Gabriel River and Berry Creek except for the subreach on Berry Creek where Berry Springs occurs. In this subreach, the variation in magnitudes can be considered to be consistent after an allowance for possible measurement errors. Based on these findings, the

Georgetown Limestone appears to function as a confining bed instead of a unit of an aquifer.

An analysis of the aquifer tests at four of the six test wells produced hydraulic conductivity values similar to clay instead of values similar to sand or gravel. One of these four wells is located at each of the test sites. These tests confirm that the Georgetown Limestone has the transmissive characteristics of a confining bed except in local settings.

A study of the variation of the water-quality characteristics between the Edwards Limestone and the streams in an area where it is separated by the Georgetown Limestone is inconclusive as to the hydraulic characteristics of the Georgetown Limestone. However, the water-quality characteristics at all the stream and reservoir sites are similar to those in water from wells open to the Edwards Limestone. The water-quality characteristics of the Edwards Limestone and the Georgetown Limestone are considered to be different at one site and somewhat different at a second site.

In assessing the regional extent and uniformity of the Georgetown Limestone as a confining bed, consideration is given to the uniformity of the results from the gain/loss surveys and the aquifer tests and the producing zone selected by drillers in the installation of supply wells in the area. Strong regional extent and uniformity of the Georgetown Limestone are suggested because of the consistency of the test results and the complete consistency that no supply wells are open to the Georgetown Limestone even though it is a shallower formation and almost always has sufficient saturated thickness to develop a supply well, however, three exceptions are noted. One is at the Chandler Branch test-well site. The other two exceptions are San Gabriel Springs and Berry Springs.

For the Chandler Branch test well site, the very similar fluctations of water levels in the Edwards Limestone well and the SCS Reservoir suggest a very high degree of hydraulic connection (an ineffective or nonexistent confining bed) even though one of the Georgetown Limestone wells showed the Georgetown Limestone to have the transmissive characteristics of a confining bed. Possible explanations are that the test site is in an area where the Georgetown Limestone is only about 60 ft thick and is probably thinner in the upper reach of the reservoir, and a major fault and probable associated fractures are nearby. The fault occurs in the upper reach of the reservoir (fig. 3). The great degree of permeability in the shallow Georgetown Limestone well at this site suggests that a stratum exists to convey water from the reservoir to a fault which could function as a drain into or from the main water-bearing zone of the Edwards aquifer. The extent of the highly permeable stratum is not known. Because of the streamflow gain-loss surveys, the occurrence of similar conditions along streams is not believed to be common. If permeable zones or conduits in the Georgetown Limestone do occur elsewhere, they are expected to be located near the updip extent of the Georgetown Limestone. This area is usually associated with a major fault.

Water issuing from San Gabriel Springs and Berry Springs passes through the Georgetown Limestone. The geologic features conveying the water from the main water-bearing zone of the Edwards aquifer to the surface is believed to have started as fractures that have become channelized by dissolution over time.

SUMMARY AND CONCLUSIONS

In the process of formulating pollution control rules for the Edwards aquifer in Williamson County in 1985, concerns were raised regarding the inclusion of the Georgetown Limestone in the recharge zone of the Edwards aquifer. In response to these concerns, the Texas Water Development Board cooperated with the Texas Bureau of Economic Geology and the Geological Survey in geologic and hydrologic studies to reassess the assignment of the Georgetown Limestone as a hydrogeologic unit.

The part of the study conducted by the Geological Survey consisted of determining the exchange of water between the main water-bearing zone of the Edwards aquifer and the land surface, and the transmissive characteristics of the Georgetown Limestone. The study approach was to conduct six surveys of streamflow gains and losses along the major streams and concurrent surveys of ground-water levels, to install three clusters of test wells and to conduct aquifer tests in each of the wells, and to collect surface and ground-water-quality samples. The study by the Bureau of Economic Geology included fracture analysis, geologic mapping, measurement of water levels, chemical analysis of water samples from selected springs and wells, and comparison of ground-water-level changes and rainfall.

The study area encompasses about 150 mi^2 centering on the city of Georgetown. It extends from the Edwards Plateau to the west, across the Balcones fault zone, and into the Blackland Belt to the east. The only major aquifer in the area is the Edwards aquifer which is comprised of the Comanche Peak (oldest) and Edwards Limestones, Kiamichi Formation, and Georgetown Limestone. The outcrop of the aquifer trends along the Balcones fault zone and dips to the east-southeast. The limit of the aquifer to the west is the extent of the outcrop, and to the east it is the transition zone from freshwater to saline water. It is unconfined in the outcrop area and is confined by the Del Rio Clay east of the outcrop. In the confined area the aquifer is about 300 feet thick.

The streams in the area are in the San Gabriel River basin and generally flow to the east. In the outcrop of the Edwards aquifer there are gaining and losing subreaches that vary by location and hydrologic conditons. The major gains are from San Gabriel and Berry Springs.

The ability of the Georgetown Limestone to convey water was tested first by attempting to determine the existance or nonexistance of a cause-effect relation between the streamflow gains and losses with the head differential across the Georgetown Limestone. These heads were measured in the main water-bearing zone of the Edwards aquifer and the water surface of the stream. The data available for this analysis were from six concurrent surveys of streamflow and ground-water levels. The streamflow gains and losses were plotted along with the head differential for a graphical analysis. Along the San Gabriel River, a corresponding relation between the streamflow gains and losses and the head differentials was not evident. The analysis along Berry Creek produced the same finding except where Berry Springs occurs.

The second test consisted of an analysis of the water-level data collected in the test wells and the adjacent surface-water body. This analysis did not show a relation between the wells completed in the Georgetown

Limestone with the well completed in the main water-bearing zone of the Edwards aquifer nor with the surface-water body. An exception occurred at the Chandler Branch site where the shallow Georgetown Limestone well and the Edwards aquifer well had water-level fluctuations similar to the stage fluctuations in the reservoir. An analysis of the water-level fluctuations in the Georgetown Limestone wells was performed with a "slug" test analysis. Four of the six wells had suitable data for this analysis. The hydraulic conductivities of the four wells ranged from 1.4×10^{-8} to 2.8×10^{-9} cm/sec. At least one well at each of the three sites was in this group.

The third test consisted of a study of the variation of water-quality characteristics between the Edwards Limestone of the Edwards aquifer and nearby streams and between the Edwards Limestone and the Georgetown Limestone. The variation of the water-quality characteristics between the Edwards Limestone and the streams in an area where it is separated by the Georgetown Limestone is inconclusive as to the hydraulic characteristics of the Georgetown Limestone. However, the water-quality characteristics at all the stream and reservoir sites is similar to water from wells open to the Edwards Limestone. The water-quality characteristics of the Edwards Limestone and the Georgetown Limestone is considered to be different at one site and somewhat different at a second site. Thus, an active ground-water circulation pattern is evident between the surface-water system and the Edwards Limestone of the Edwards aquifer, but the circulation between the Edwards Limestone and the Georgetown Limestone is shown to be limited.

The consistency of the findings in the evaluation of the relations between streamflow gains and losses and head differentials, the hydraulic conductivities in the Georgetown Limestone test wells, the patterns of water-quality characteristics, and the consistency that no supply wells produce from the Georgetown Limestone suggests that the transmissive characteristics of the Georgetown Limestone are regional and rather uniform. However, a high degree of hydraulic connection across the Georgetown Limestone can occur in the updip limits of the Georgetown Limestone where a major fault exist and where springs discharging from the Edwards aquifer and through the Georgetown Limestone occur.

This study determined that the Georgetown Limestone should not be included as a hydrogeologic unit in the Edwards aquifer in the Georgetown area. Instead, the Georgetown Limestone should be considered a hydrogeologic unit of the overlying confining bed of the Edwards aquifer with localized averages that allow flow to and from the underlying Edwards aquifer. This conclusion is based on the definitions of aquifer terms, the surface-water/ground-water interaction, the computed or estimated transmissive characteristics of the Georgetown Limestone, and the dissimilarities of water-quality characteristics of the Georgetown Limestone and the Edwards Limestone.

REFERENCES CITED

Baker, E.T., Jr., Slade, R.M., Jr., Dorsey, M.E., Ruiz, L.M., and Duffin, G.L., 1986, Geohydrology of the Edwards aquifer in the Austin area, Texas: Texas Water Development Board Report 293, 215 p.

Brune, G., 1975, Major and historical springs of Texas: Texas Department of Water Resources Report 189, 94 p.

Brune, G., and Duffin, G.L., 1983, Occurrence, availability and quality of ground water in Travis County, Texas: Texas Department of Water Resources Report 276, 219 p.

Dorsey, M.E., and Slagle, D.L., 1987, Hydrologic and geologic data for the Edwards aquifer recharge zone near Georgetown, Williamson County, Texas, 1986-87: U.S. Geological Survey Open-file Report 87-691, 66 p.

Krietler, C.W., Senger, R.K., and Collins, E.W., 1987, Geology and hydrology of the northern segment of the Edwards aquifer with an emphasis on the recharge zone in the Georgetown, Texas area: Bureau of Economic Geology, The University of Texas at Austin, 115 p.

Lohman, S.W., 1972, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 70 p.

Lohman, S.W., and others, 1972, Definitions of selected ground-water terms--revisions and conceptual refinements: U.S. Geological Survey Water-Supply Paper 1988, 21 p.

Muller, D.A, and Price, R.D., 1979, Ground-water availablitiy in Texas--Estimates and projections through 2030: Texas Department of Water Resources Report 238, 77 p.