Prepared in cooperation with the Middle Pecos Groundwater Conservation District, Pecos County, City of Fort Stockton, Brewster County, and Pecos County Water Control and Improvement District No. 1

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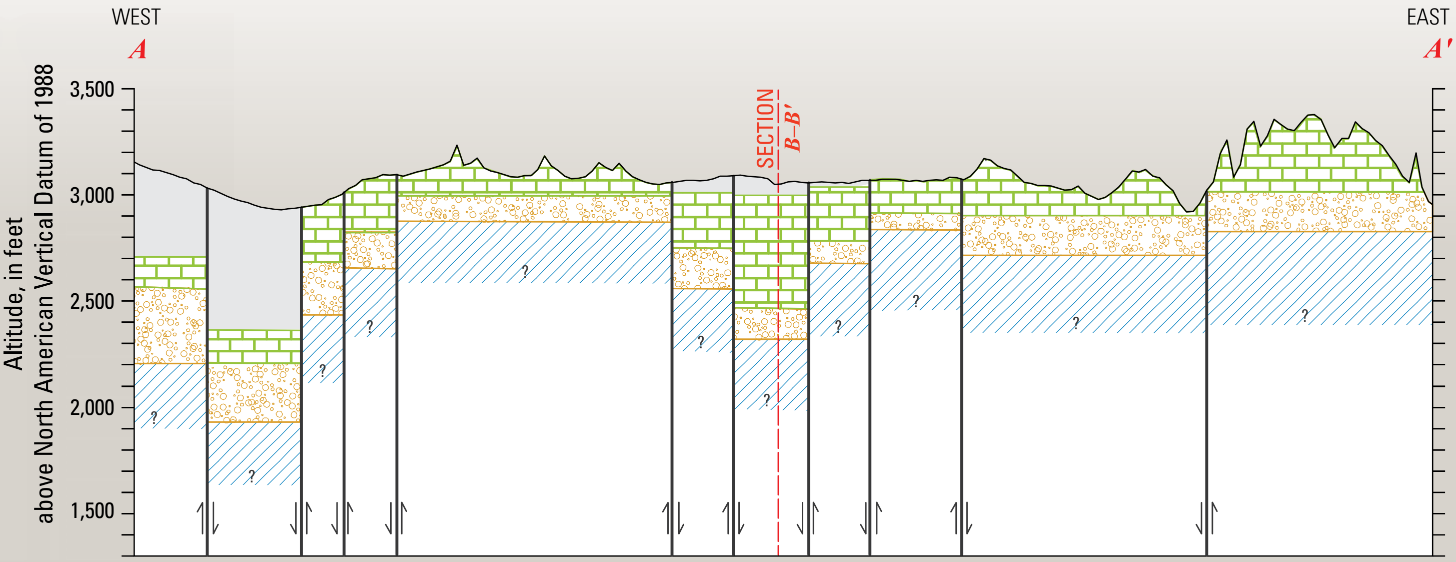

Scientific Investigations Report 2012–5124
(Revised July 10, 2012)

U.S. Department of the Interior
U.S. Geological Survey

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By Johnathan R. Bumgarner, Gregory P. Stanton, Andrew P. Teeple, Jonathan V. Thomas, Natalie A. Houston, Jason D. Payne, and MaryLynn Musgrove

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KEN SALAZAR, Secretary

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
	Radioactivity	
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)
	Specific capacity	
gallon per minute per foot [(gal/min)/ft)]	0.2070	liter per second per meter [(L/s)/m]
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Transmissivity*	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
gallon per day per foot of drawdown (gal/d/ft)	0.01242	meter squared per day (m^2/d)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD83).

Altitude, as used in this report, refers to distance above the vertical datum.

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [$(ft^3/d)/ft^2$]ft. In this report, gallon per day per foot of drawdown (gpd/ft) is used for convenience.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Tritium concentrations are given in units of picocuries per liter (pCi/L) and Tritium Units (TU). Based upon a tritium half-life of 12.32 years 1 TU is equal to 3.22 pCi/L (Lucas and Unterweger, 2000).

Explanation of Isotope Units

The values for stable-isotope ratios discussed in this report are referenced to the following standard materials:

Element	Ratio	Standard identity and reference
Hydrogen	Hydrogen-2/hydrogen-1	Vienna Standard Mean Ocean Water (VSMOW) (Casciotti and others, 2002)
Oxygen	Oxygen-18/oxygen-16	Vienna Standard Mean Ocean Water (VSMOW) (Casciotti and others, 2002)

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Abstract

A conceptual model of the hydrogeologic framework, geochemistry, and groundwater-flow system of the Edwards-Trinity and related aquifers, which include the Pecos Valley, Igneous, Dockum, Rustler, and Capitan Reef aquifers, was developed as the second phase of a groundwater availability study in the Pecos County region in west Texas. The first phase of the study was to collect and compile groundwater, surface-water, water-quality, geophysical, and geologic data in the area. The third phase of the study involves a numerical groundwater-flow model of the Edwards-Trinity aquifer in order to simulate groundwater conditions based on various groundwater-withdrawal scenarios. Resource managers plan to use the results of the study to establish management strategies for the groundwater system.

The hydrogeologic framework is composed of the hydrostratigraphy, structural features, and hydraulic properties of the groundwater system. Well and geophysical logs were interpreted to define the top and base surfaces of the Edwards-Trinity aquifer units. Elevations of the top and base of the Edwards-Trinity aquifer generally decrease from the southwestern part of the study area to the northeast. The thicknesses of the Edwards-Trinity aquifer units were calculated using the interpolated top and base surfaces of the hydrostratigraphic units. Some of the thinnest sections of the aquifer were in the eastern part of the study area and some of the thickest sections were in the Pecos, Monument Draw, and Belding-Coyanosa trough areas. Normal-fault zones, which formed as growth and collapse features as sediments were deposited along the margins of more resistant rocks and as overlying sediments collapsed into the voids created by the dissolution of Permian-age evaporite deposits, were delineated based on the interpretation of hydrostratigraphic cross sections. The lowest aquifer transmissivity values were measured in the eastern part of the study area; the highest transmissivity values were measured in a faulted area of the Monument Draw trough. Hydraulic conductivity values generally exhibited the same trends as the transmissivity values.

Groundwater-quality data and groundwater-level data were used in context with the hydrogeologic framework to assess the chemical characteristics of water from different sources, regional groundwater-flow paths, recharge sources, the mixing of water from different sources, and discharge in the study area. Groundwater-level altitudes generally decrease from southwest to northeast and regional groundwater flow is from areas of recharge south and west to the north and northeast. Four principal sources of recharge to the Edwards-Trinity aquifer were identified: (1) regional flow that originated as recharge northwest of the study area, (2) runoff from the Barilla, Davis, and Glass Mountains, (3) return flow from irrigation, and (4) upwelling from deeper aquifers. Results indicated Edwards-Trinity aquifer water in the study area was dominated by mineralized, regional groundwater flow that most likely recharged during the cooler, wetter climates of the Pleistocene with variable contributions of recent, local recharge. Groundwater generally flows into the down-dip extent of the Edwards-Trinity aquifer where it discharges into overlying or underlying aquifer units, discharges from springs, discharges to the Pecos River, follows a regional flow path east out of the study area, or is withdrawn by groundwater wells. Structural features such as mountains, troughs, and faults play a substantial role in the distribution of recharge, local and regional groundwater flow, spring discharge, and aquifer interaction.

Introduction

The Edwards-Trinity aquifer is a vital groundwater resource for agricultural, industrial, and municipal uses in the Trans-Pecos region of west Texas (fig. 1) (Barker and Ardis, 1996; Freese and Nichols, LBG-Guyton, 2010). A better

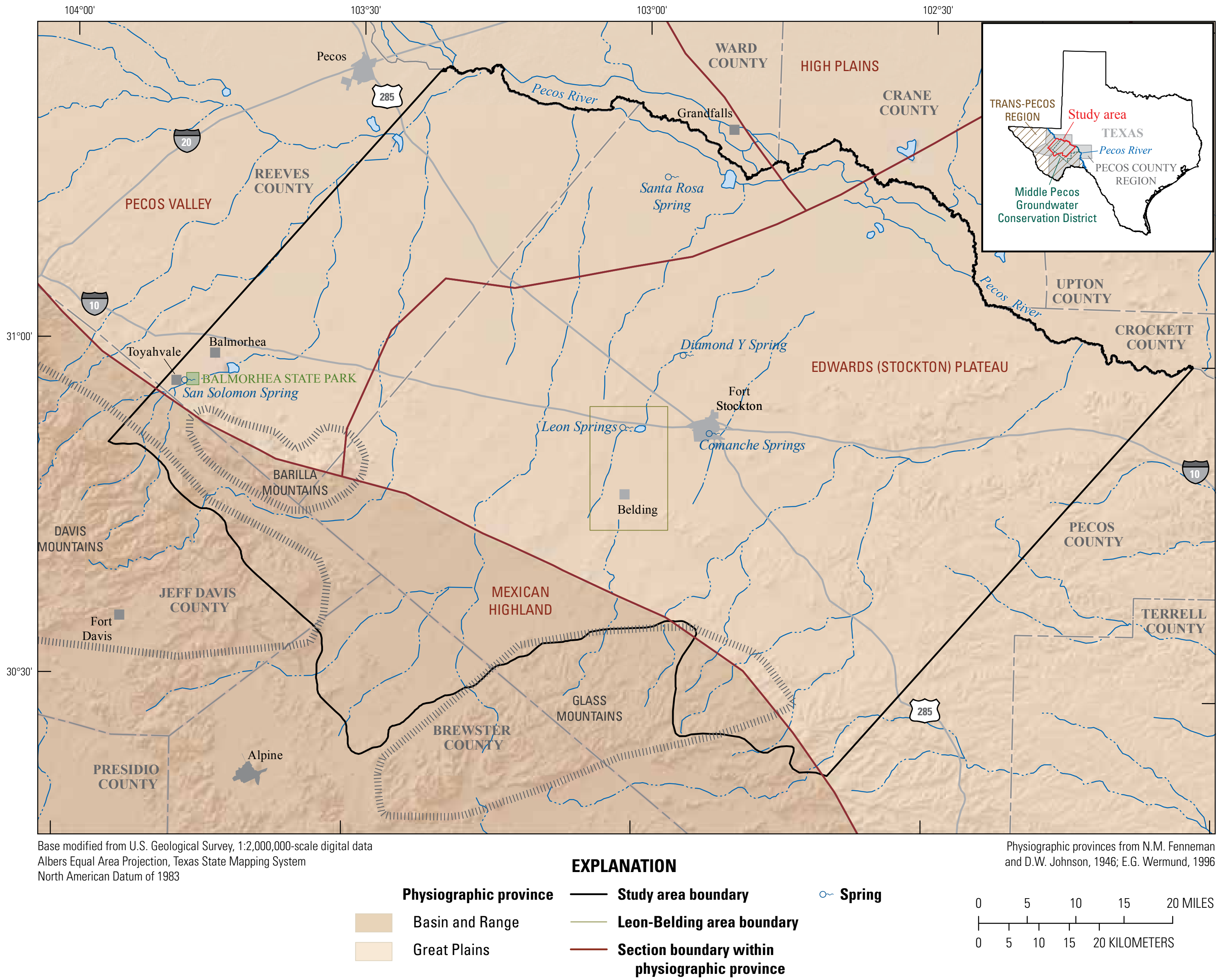


Figure 1. Location and physiographic provinces of the Pecos County region study area in the Trans-Pecos region, Texas.

understanding of the hydrogeologic setting and processes that control the distribution, quality, and availability of water in the aquifer is required for optimal resource management. In general, a comprehensive, integrated analysis of available scientific data facilitates a better understanding of an aquifer system, which enables water-resource managers to establish long-range and short-range aquifer management strategies that support present and projected aquifer uses. Resource managers would like to know more about the future availability of water in the Edwards-Trinity aquifer in Pecos County, Texas, and the effects of the possible increase or temporal redistribution of groundwater withdrawals. In order to provide resource managers with that knowledge, the U.S. Geological Survey (USGS), in cooperation with the Middle Pecos Groundwater Conservation District, Pecos County, City of Fort Stockton, Brewster County, and Pecos County Water Control and Improvement District No. 1, completed a comprehensive, integrated analysis of available hydrogeologic data in order to develop a conceptual model of the Edwards-Trinity and related aquifers in the study area in parts of Brewster, Crane, Crockett, Jeff Davis, Pecos, Reeves, Terrell, and Ward Counties (hereinafter referred to as the Pecos County region study area) (fig. 1). The Edwards-Trinity and related aquifers (hereinafter referred to as the groundwater system) include the Pecos Valley, Igneous, Dockum, Rustler, and Capitan Reef aquifers. The Edwards-Trinity aquifer was the focus of the investigation presented in this report, and the related aquifers were studied in terms of how they potentially interact with and affect the Edwards-Trinity aquifer.

Development of the conceptual model is the second phase of a three-phase groundwater-availability study being conducted in the Pecos County region by the USGS and the cooperators. The first phase was to collect groundwater, surface-water, geochemical, geophysical, and geologic data in the study area and develop a geodatabase of historical and collected data (Pearson and others, 2012). The data compiled in the first phase of the study were used in this report to develop the conceptual model. The third phase of the study involves a numerical groundwater-flow model of the Edwards-Trinity aquifer in order to simulate groundwater conditions based on various groundwater-withdrawal scenarios.

The conceptual model of the hydrogeologic framework, geochemistry, and groundwater-flow system in the 4,700 square-mile (mi^2) study area was developed in an effort to better understand the groundwater system and establish a scientific foundation for resource-management decisions. Lithologic information obtained from well reports and geophysical data was used to describe the hydrostratigraphy and structural features of the groundwater system and aquifer-test data were used to estimate aquifer hydraulic properties. Groundwater-quality data (hereinafter referred to as geochemical data) were used to evaluate groundwater-flow paths, water-rock interaction, aquifer interaction, and the mixing of water from different sources. Groundwater-level data were also used to evaluate aquifer interaction as well as to develop a potentiometric-surface map, delineate regional groundwater divides, and describe regional groundwater-flow paths.

Several scientific investigations have been done to collect and compile physical and chemical data, describe the hydrogeologic processes, and develop conceptual and numerical groundwater-flow models of the Edwards-Trinity aquifer in the Trans-Pecos region. Pearson and others (2012) documented the methods used to compile the available groundwater, surface-water, geochemical, geophysical, and geologic information used to develop the conceptual model described in this report. The data compiled by Pearson and others (2012) include existing data in the study area and data collected by the USGS. The Thornhill Group, Inc. (2008) and Daniel B. Stephens and Associates (2010) developed conceptual and numerical groundwater-flow models of the Edwards-Trinity aquifer that focused on 100 mi^2 near Belding, Tex., referred to hereinafter as the Leon-Belding area (fig. 1). The Leon-Belding area is an agricultural area about 7 miles (mi) southwest of Fort Stockton that includes about 30 mi^2 of cultivated land. Water primarily from the Edwards-Trinity aquifer is used for irrigation purposes in the Leon-Belding area. Using the conceptual and numerical groundwater-flow models, simulations to project future aquifer conditions in the Leon-Belding area based on various groundwater-withdrawal scenarios were published (Thornhill Group, Inc., 2008; Daniel B. Stephens and Associates, 2010). Anaya and Jones (2009) developed a 44,000-mi^2 regional groundwater-flow model of the Edwards-Trinity and Pecos Valley aquifers in central and western Texas to determine the availability of groundwater based on projected needs. As part of the USGS Regional Aquifer Systems Analysis (RASA) program, Barker and Ardis (1996) described the hydrogeologic framework of the Edwards-Trinity aquifer system on a broad, regional scale in west-central Texas that included the Pecos Region study area. Small and Ozuna (1993) investigated the Edwards-Trinity aquifer in the Pecos County region; they broadly described the hydrogeology of the groundwater system, defined the groundwater-level and water-quality characteristics of the aquifer, determined post-development changes in water levels and water quality, and described relations between groundwater levels and flow from Comanche Springs in Fort Stockton, Tex.; Comanche Springs were historically important to this region for water supply and recreation but have not flowed continuously since the 1950s (Small and Ozuna, 1993).

Purpose and Scope

This report documents the development of a conceptual model of the Edwards-Trinity and related aquifers in the Pecos County region, Tex., using data collected by the USGS during 2009–11 and historical data from 1930–2011 collected by various State and local agencies and compiled by the USGS (Pearson and others, 2012). The parts of the conceptual model are described, including the hydrogeologic framework, geochemistry, and groundwater flow of the groundwater system in the study area. The methodologies used for analyzing the well-log and geophysical datasets and the construction of the hydrogeologic framework and the principal chemical properties of water in the study area and geochemical endmembers used to describe the chemical characteristics of water from different sources are described. Finally, the chemical properties of water and groundwater-level information are described in context with the hydrogeologic framework; regional groundwater flow, aquifer recharge, the mixing of water from different sources, and groundwater discharge are qualitatively assessed.

Description of the Study Area

The study area covers about 4,700 mi^2 of the Trans-Pecos region of Texas west of the Pecos River, and its boundaries were defined to include the extent of the field-collected data gathered for this study (fig. 1) (Pearson and others, 2012). The southwestern and southern boundaries of the study area are rimmed by the Barilla and Davis Mountains in northeastern Jeff Davis County and southwestern Reeves County and the Glass Mountains in northeastern Brewster County and southern Pecos County. The northeastern boundary of the project study area is the Pecos River, and the southeastern and northwestern boundaries were aligned to the data cells of the Texas Water Development Board (TWDB) Groundwater Availability Model (GAM) of the area (Anaya and Jones, 2009). The southwestern boundary was modified using the “active” part of the GAM model. The western part of the Middle Pecos Groundwater Conservation District (MPGCD) management area (Pecos County is the MPGCD management area) is in the study area. Altitude ranges from 6,350 feet (ft) in the southwestern part of the study area in the Davis Mountains in Jeff Davis County to 2,150 ft in the northeastern part of the study area near the Pecos River in Pecos County. The climate in the study area is arid, characterized by scant rainfall and large amounts of evaporation. The average annual rainfall during 1970–2000 at Fort Stockton was approximately 14 inches (National Weather Service, 2011). Rainfall, as recorded at Fort Stockton, annually is quite variable; during 2000–10, 2004 was the wettest year with an annual rainfall of about 26 inches and 2008 was the driest year with an annual rainfall of about 6 inches (National Weather Service, 2011). Potential annual evaporation of as much as 109 inches has been estimated (Boghici, 1997). Temperatures during 1970–2000 ranged from an average low of about 32 degrees Fahrenheit (ºF) in January to an average high of about 96ºF in July (National Weather Service, 2011). The study area is in the Pecos Valley, Edwards Plateau, and High Plains sections of the Great Plains physiographic province, and the Mexican Highland section of the Basin and Range Province (fig. 1) (Fenneman and Johnson, 1946). West of the Pecos River, the Edwards Plateau section of the Great Plains Province is also referred to as the Stockton Plateau (Wermund, 1996).

Geologic and Hydrogeologic Setting[1]

There were several periods of seawater inundation and erosion during the geologic history of the Trans-Pecos region of west Texas. Sedimentary rocks of Pennsylvania, Permian, Triassic, and Cretaceous age; Tertiary-age igneous rocks; and Cenozoic-age alluvium are present in the subsurface, and many are exposed at the surface in the study area (Texas Water Development Board, 1972). This study focuses on subsurface rocks deposited from the Permian to the Quaternary Period (table 1 at end of report). During the Permian Period, this region of western Texas was a shallow sea; marine sandstones, limestone, and shale were deposited in the basin. In the later part of the Permian Period, the basin became more isolated and the deposition of sediments changed to gypsum, anhydrite, halite, and associated salts. Several geologic structures also formed in the study area during the Permian Period (fig. 2). The Central Basin Platform is a structural high in the northern part of Pecos County that divides the Permian Basin into the Delaware and the Midland Basins (Ashworth, 1990). The Val Verde Basin was separated from the Delaware Basin by the development of a reef complex during the Permian Period (Small and Ozuna, 1993). Dissolution of Permian-age evaporite deposits that began at the time of deposition and continued through the Cretaceous Period caused the Permian beds to collapse and form a north-south depositional trough called the Belding-Coyanosa trough (fig. 2) (Armstrong and McMillion, 1961; Boghici, 1997). By the Triassic Period, the sea retreated and a sequence of nondeposition, erosion, and then deposition of fluvial and deltaic sediments took place. During the Jurassic Period, this region of western Texas was above sea level, erosion was the dominant process, and the land surface was tilted to the southeast (Barker and Ardis, 1996). As a result, there are no Jurassic rocks in the geologic record of the study area. During the Cretaceous Period, sea level once again rose and the deposition of continental sediments changed to shallow marine sediments (Barker and Ardis, 1996). Cretaceous deposition included the filling of the structural troughs that had begun forming in the Permian and Triassic Periods, which resulted in thicker units in these areas. The Cretaceous Period was the last marine deposition event in the study area. Tertiary Period volcanism deposited extrusive igneous rocks following the Cretaceous marine deposition (George, and others, 2011). Continental sediments of sand and gravel were deposited during the Tertiary and Quaternary Periods (Texas Water Development Board, 1972). During the Cenozoic Era, two depositional troughs that roughly trend north-south formed in the central and western parts of the study area because of the continued dissolution

[1]This section modified from Pearson and others (2012, p. 3).

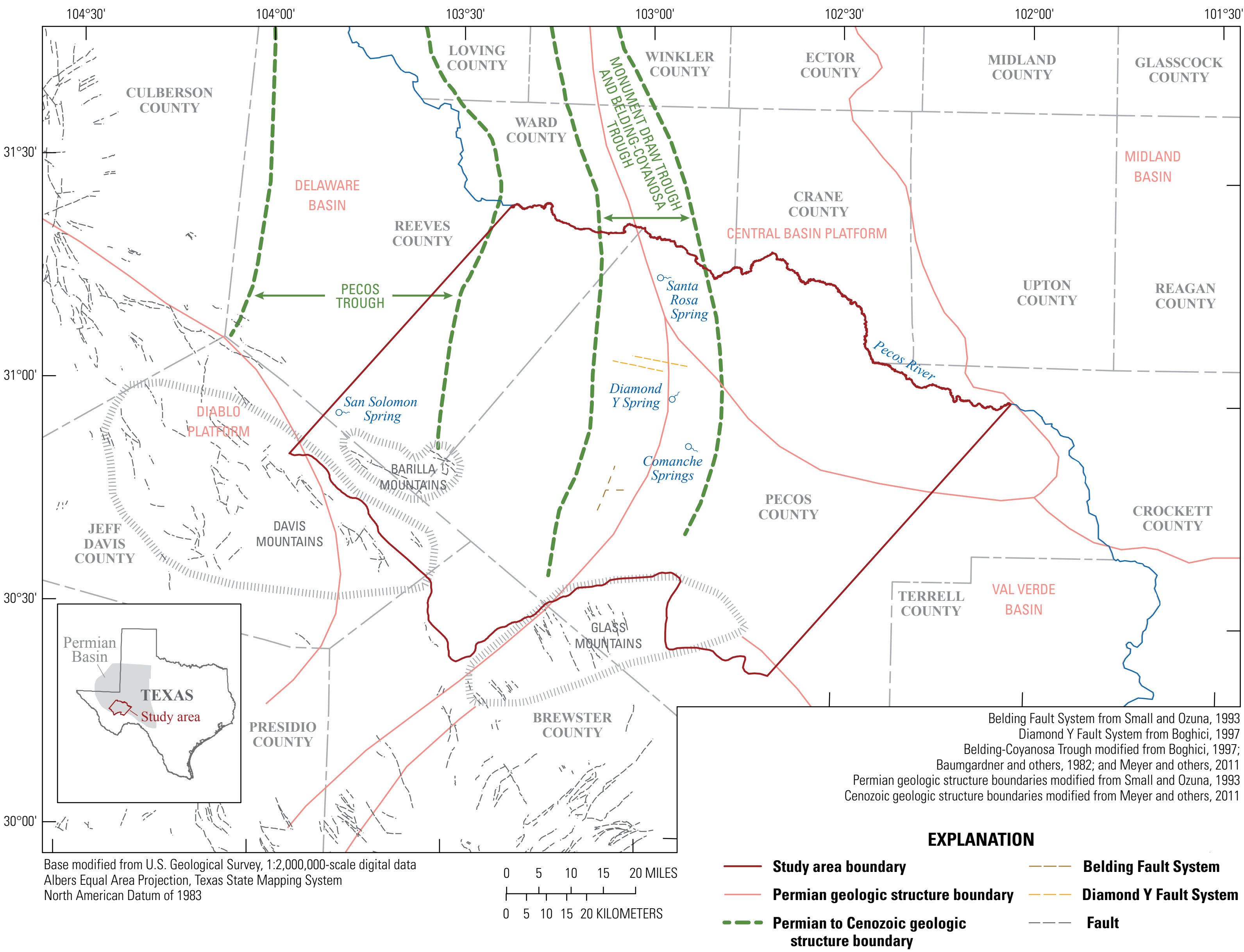


Figure 2. Generalized boundaries of geologic structural features in the Pecos County region study area, Texas.

of the Permian-age evaporite deposits and collapse of the overlying sediments (Armstrong and McMillion, 1961). These troughs subsequently filled with Cenozoic-age alluvium and are known as the Monument Draw (central) and Pecos (western) troughs (fig. 2). For simplicity, hereinafter, the name “Monument Draw trough” will be used to represent both the Cenozoic-age Monument Draw and Permian to Cretaceous-age Belding-Coyanosa troughs because the spatial extents and separation of these structural features are not well defined.

The geologic setting contributed to the formation of two major and four minor aquifers in the study area (figs. 3 and 4, table 1). The Pecos Valley aquifer is a major aquifer composed of Cenozoic-age alluvium consisting of unconsolidated silt, sand, gravel and clay (fig. 3) (Small and Ozuna, 1993). In the northern part of the study area, the Pecos Valley aquifer uncomformably overlies the Edwards-Trinity aquifer, the other major (and primary) aquifer in the study area (fig. 3). Minor aquifers include the Igneous, Dockum, Rustler, and Capitan Reef aquifers (fig. 4). The Igneous aquifer consists of Tertiary-age igneous and volcaniclastic rocks. Located in the southwestern part of the study area, the Igneous aquifer uncomformably overlies the Cretaceous-age Edwards-Trinity aquifer. The Edwards-Trinity aquifer is composed of lower Cretaceous-age rocks of limestone, marl, and clay of the Washita Group; limestone of the Fredericksburg Group; and sand, limestone, and shale of the Trinity Group (fig. 3, table 1). The Edwards part of the aquifer is composed of upper Cretaceous rocks of the Fredericksburg and Washita Groups, which locally are referred to as the Edwards and Sixshooter Groups (Brand and DeFord, 1958; Small and Ozuna, 1993; Smith and others, 2000). The Fort Lancaster Formation, the Burt Ranch Member, and the Fort Terrett Formation make up the Edwards Group and occur in the eastern part of the study area (Rose, 1972; Smith and Brown, 1983; Small and Ozuna, 1993). The Boracho Formation, the University Mesa Marl, which is a facies change equivalent of the Boracho Formation, and the Finlay Formation make up the Sixshooter Group and occur in the western part of Pecos County (Brand and DeFord, 1958; Small and Ozuna, 1993; Smith and others, 2000). The Buda Limestone, which overlies the Boracho Formation, is present east of Fort Stockton. Regionally, the Buda Limestone, the Fort Lancaster Formation, and the Burt Ranch Member form the Washita Group. The Fort Terrett and Finlay Formations form the Fredericksburg Group. The Trinity group is composed of the Maxon Sands, the Glen Rose Formation, and the Basal Cretaceous Sand (Anaya and Jones, 2009). The individual formations in the Trinity Group are not separated for the purposes of this report. Locally the Trinity Group is known as the Trinity Sands (Small and Ozuna, 1993; Rees and Buckner, 1980).

The Dockum aquifer is a minor aquifer and is composed of Triassic-age rocks of the Dockum Group (fig. 4) (Bradley and Kalaswad, 2003). The stratigraphic nomenclature of the Dockum Group has been updated and regionalized in the literature as better information became available (Lehman, 1994a, b; Bradley and Kalaswad, 2003). In Pecos County, a sand unit within the Dockum aquifer is recognizable in some geophysical logs, but the individual formations of the Dockum Group are not separated for the purposes of this report. Locally, the Dockum aquifer is also known as the Santa Rosa aquifer (Small and Ozuna, 1993). The boundaries of the Dockum aquifer are not explicitly defined in this report and might extend beyond the general aquifer boundaries shown in figure 4.

The Rustler and Capitan Reef aquifers are minor aquifers composed of Permian-age rocks (fig. 4). The Rustler aquifer is composed of mostly dolomite, anhydrite, and some limestone of the Rustler Formation. A basal unit consists of sand, conglomerate, and some shale (Small and Ozuna, 1993; LBG-Guyton, 2003). The boundaries of the Rustler aquifer are not explicitly defined in this report and might extend beyond the general aquifer boundaries shown in figure 4. The Capitan Reef aquifer consists of reef, fore-reef, and back-reef facies of dolomite and limestone of the older Capitan Limestone.

Water is supplied to the region from groundwater; the Pecos River, which is the main surface-water drainage and forms the northeastern boundary of the study area; and springs that discharge from groundwater sources. San Solomon Spring in Balmorhea State Park in Reeves County near Toyahvale, Tex., is currently (2012) the largest spring in the Trans-Pecos region (Sharp, 2001). San Solomon Spring provides water for irrigation, recreation, and endangered-species habitat (fig. 1) (Texas Water Development Board, 2005). Santa Rosa Spring is near Grandfalls, Tex., and at one time, this spring supplied water for irrigation. Santa Rosa Spring did not flow from the 1950s until the late 1980s, at which time flow resumed at a decreased rate (Freese and Nichols and LBG-Guyton, 2010). Until the 1950s, Comanche Springs were the largest springs in the Trans-Pecos region and sixth largest in the State (Sharp, 2001). Comanche Springs first went dry in 1955 and perennial flow ceased in 1961 (Texas Parks and Wildlife Department, 2012). According to Freese and Nichols and LBG-Guyton (2010), Comanche Springs have flowed occasionally since 1987. Diamond Y Spring, which are located north of Fort Stockton, support habitat for endangered species (Freese and Nichols and LBG-Guyton, 2010). The San Solomon, Santa Rosa, Comanche, and Diamond Y Springs were sampled for this study (Pearson and others, 2012). Finally, the four springs are in faulted areas, and it is likely the presence of faults contributed to the formation of the springs (Armstrong and McMillion, 1961; Baumgardner and others, 1982; Small and Ozuna, 1993; Veni, 1991; Boghici, 1997; Sharp and others, 1999; Texas Water Development Board, 2005; Anaya and Jones, 2009). Furthermore, it is likely that structural features such as faults, joints, bedding planes, and fractures influence all of the groundwater-flow components of the groundwater system (that is, recharge, local and regional flow, and discharge), not just spring flow.

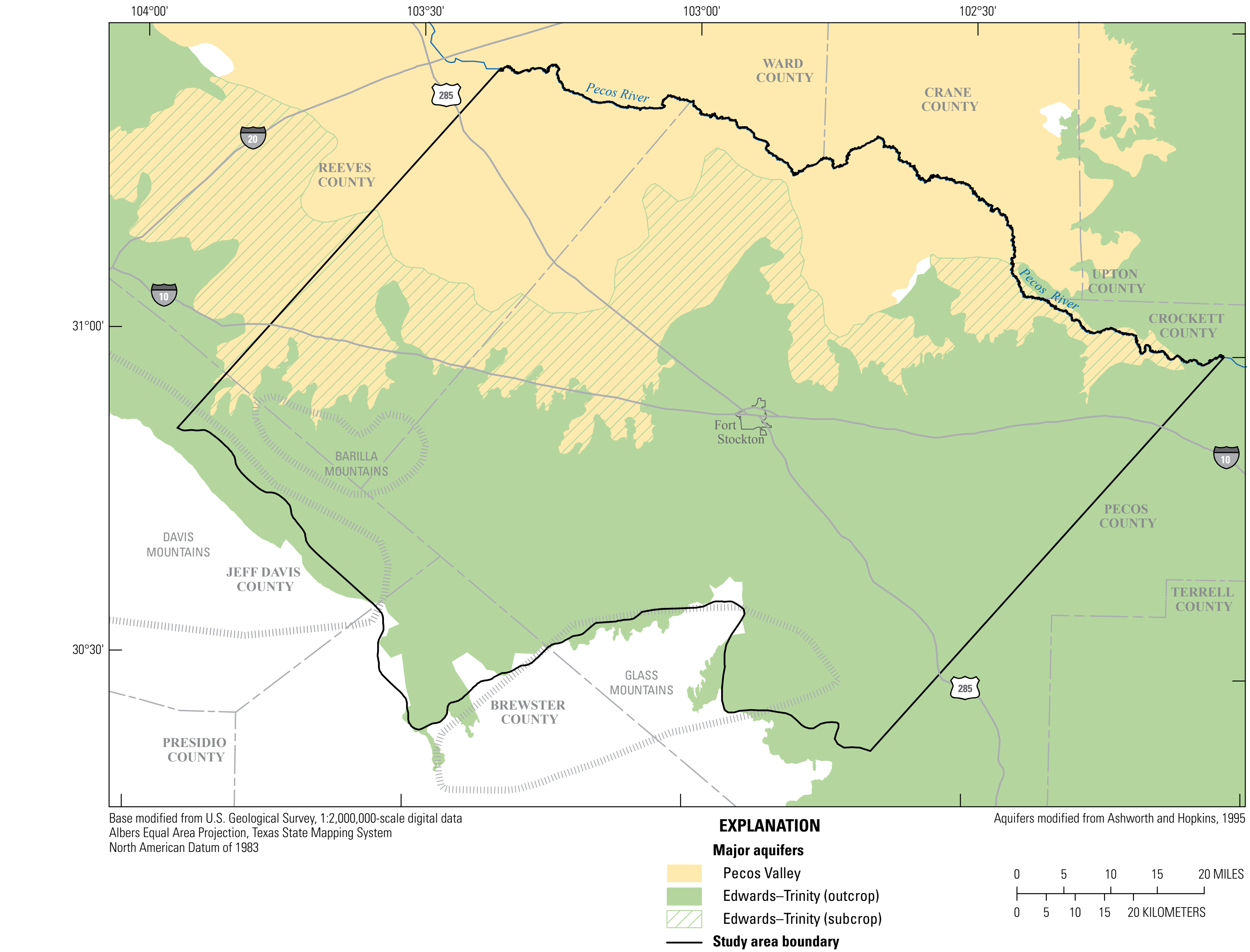


Figure 3. Major aquifers in the Pecos County region study area, Texas.

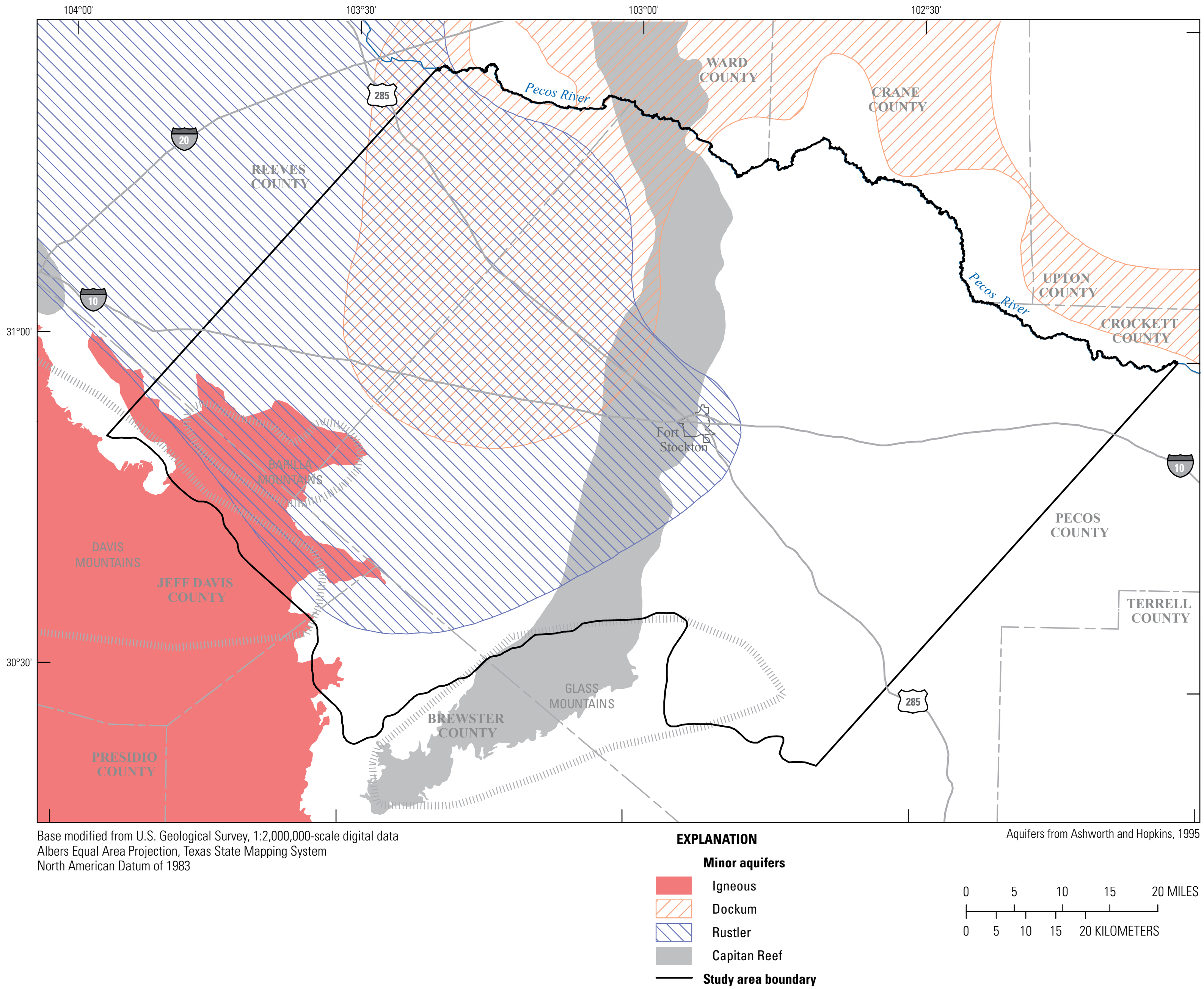


Figure 4. Minor aquifers in the Pecos County region study area, Texas.

Hydrogeologic Framework

The hydrogeologic framework of the conceptual model comprises the hydrostratigraphy, structural features, and hydraulic properties of the groundwater system. Well-log data were compiled and supplemented with data gathered through borehole and surface geophysics. The data were then analyzed to map the tops and bases of the hydrostratigraphic units that compose the Edwards-Trinity aquifer and the lateral and vertical relations of overlying and underlying aquifers in order to develop the hydrostratigraphy of the study area (table 1). The data also were used to evaluate the structural features such as bed orientation, unit thickness, and fault zones. The top, base, and thickness of the aquifer, as discussed in this report, refer to the hydrostratigraphic units that compose the aquifer, not just the saturated portion of the hydrostratigraphic units. Aquifer tests were performed and supplemented by historical aquifer-test data to assess the hydraulic properties of the Edwards-Trinity aquifer. Pearson and others (2012) detail the methods used for collection, analysis, and quality control of most of the data used in this report.

Interpretive Methods of the Hydrostratigraphic Analysis

Well reports, borehole geophysical logs, and surface geophysical soundings (Pearson and others, 2012) were evaluated to determine the lithologies, hydrostratigraphic units, and tops and bases of the hydrostratigraphic units, creating datasets for characterizing vertical and lateral hydrostratigraphic extents. More than 2,000 data records for wells in or near the study area were acquired from various sources and evaluated for applicability to the study. A total of 662 records were found to contain pertinent data of applicable vertical extent within the study area (table 2 at end of report). These records were supplemented by 44 geophysical logs, 4 time-domain electromagnetic (TDEM) soundings, and 13 audio-magnetotelluric (AMT) soundings collected by the USGS as part of the first phase of this study (Pearson and others, 2012). Drilling and well-completion log data from 500 sites were used to help identify the depths to tops and bases of the formations. Depths to the tops and bases of the formations and structural features were entered into a geospatial database by altitude and spatial location for correlation among neighboring wells creating a regional network of correlated points. Geophysical logs are typically reliable sources for subsurface information. Incorrect or missing information including incorrect location information, missing or incorrect header information, unknown well completion, poor tool calibrations, and unsuitable borehole environments can introduce errors during the interpretation of hydrostratigraphic information. Geophysical logs with incorrect or missing information were not used to interpret the hydrostratigraphy.

Well Reports

Producing zones, well yield, and lithologic characterization were interpreted from 296 well reports. All well reports used in this study have been compiled from Daniel B. Stephens and Associates (2010; 201 data points) and Meyer and others (2011; 95 data points).

Borehole Geophysics

Borehole geophysical data such as natural gamma, formation resistivity, and caliper are commonly used to characterize and identify stratigraphic units; these data exist for many wells in the study area and were collected during previous scientific investigations, petroleum explorations, or both. The Railroad Commission of Texas (RRC) Geophysical Log Database (Railroad Commission of Texas, 2010) contains 1,979 publicly available well logs in or near the study area; however, most of the well logs did not meet project requirements because the types of geophysical tools that were used did not yield data useful for modeling purposes or the depth interval studied did not include the water-bearing formations. Each geophysical log was evaluated to determine if the log penetrated the desired stratigraphic units and provided useful data for determining the tops and bases of stratigraphic units or data for identifying other structural features. Information used to supplement well reports were 230 borehole geophysical logs (28 from University Lands (2011), 23 from USGS, 51 from RRC, and 128 from TWDB). The borehole geophysical logs used to help determine the tops and bases of hydrostratigraphic formations were natural gamma, electric, and electromagnetic induction logs.

Natural Gamma Logs

Natural gamma logs provide a record of gamma radiation detected at depth in a borehole. Fine-grained sediments that contain abundant clay tend to be more radioactive than quartz-grain sandstones or carbonates (Keys, 1997). The natural gamma, electric, and electromagnetic induction logs collectively can be useful to identify lithologies and contact depths of the strata penetrated in the borehole.

Electric Logs

Electric logs use a series of electrodes mounted on the downhole probe and a surface electrode in the ground to measure potential (or voltage) that varies with the electrical properties of fluids and rock materials. Electric logs require an uncased, fluid-filled hole to allow the current to flow into the formation. Electric logs include the following data: normal resistivity, lateral resistivity, spontaneous potential, and single-point resistance.

Normal resistivity logs are useful for determining and correlating various lithologies but also are affected by the resistivity of the fluids in the borehole and formation (Keys, 1997). The lateral resistivity log increases the resolution and decreases the effect of adjacent beds in comparison with the normal resistivity logs (Keys, 1990). Spontaneous potential (SP) is one of the oldest logging techniques and uses a very simple method of measuring the potentials produced by various salinity conditions (Keys, 1990). SP is a function of the chemistry of fluids in the borehole and adjacent rocks, the temperature, and the clay present and is not related directly to porosity and permeability (Keys, 1997). The single point resistance (SPR) log uses the same circuitry as SP and shows the resistance measured between the electrode in the well and an electrode at the land surface (Keys, 1990).

Electromagnetic Induction Logs

Electromagnetic (EM) induction probes measure conductivity in air- or water-filled holes and perform well in open holes or polyvinyl chloride (PVC) cased holes. The measurement of conductivity commonly is reciprocated to provide logs with curves of both resistivity and conductivity (Keys, 1997). Conductivity is affected by the salinity of borehole and formation fluids and the type of lithology encountered. Generally, pure carbonates, sands, and gravels have lower conductivity (thus higher resistivity) than clays or shales (Keys, 1997).

Surface Geophysics

Surface geophysical resistivity methods can be used to detect changes in the electrical properties of the subsurface using noninvasive surface-based instrumentation (Zohdy and others, 1974). These methods are useful in order to fill data gaps in areas where borehole methods cannot be used. The electrical properties of soil and rock are determined by water content, porosity, clay content and mineralogy, and conductivity (or reciprocal of electrical resistivity) of the pore water (Lucius and others, 2007). Resistivity measurements can be used to construct graphical images of the spatial distribution of electrical properties of the subsurface. Comprehensive descriptions of the theory and application of surface geophysical resistivity methods, as well as tables of the electrical properties of earth materials, are presented in Keller and Frischknecht (1966) and Lucius and others (2007).

TDEM soundings were collected at four different locations (Pearson and others, 2012). Each of the locations was near a well where borehole geophysical logs also had been collected by the USGS. These locations were selected so that the TDEM results could be compared to the nearby borehole geophysical logs to determine if this geophysical method would supply useful data. Figure 5 shows an example comparison of a TDEM sounding and a nearby borehole geophysical log. The TDEM data collected throughout the area show good inversion results with the root mean squared (RMS) errors for all soundings less than 4 percent (Pearson and others, 2012), but few TDEM results were available at the depths needed to determine the tops and bases of formations. Consequently, AMT was determined the better method to obtain information necessary to determine the tops and bases of formations.

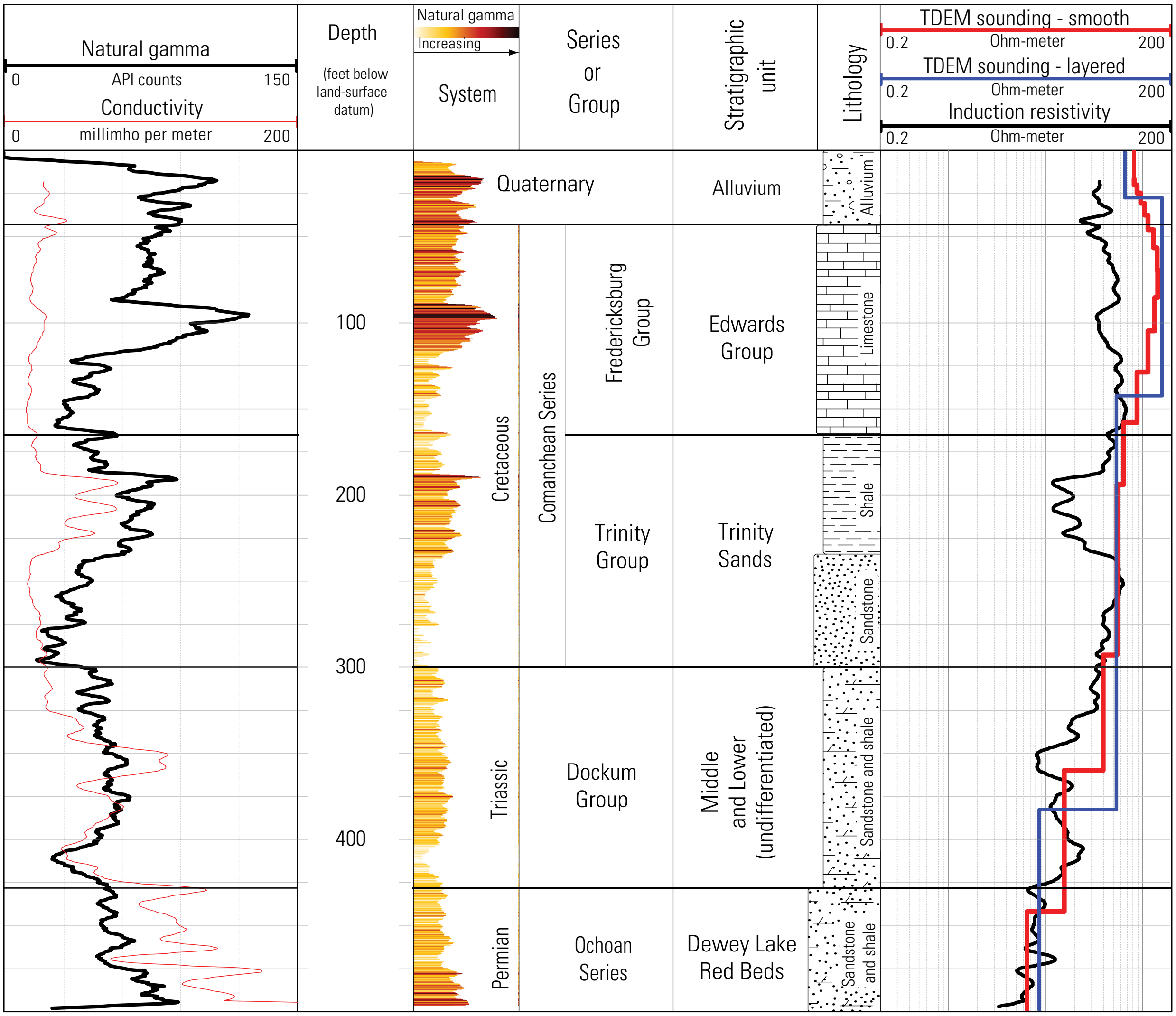
Thirteen AMT soundings (AMT01 through AMT13) were collected in the study area (Pearson and others, 2012). Four of the 13 soundings were collected near wells (AMT 07, 08, 11, 12) from which borehole geophysical logs were collected by the USGS. These locations were selected so that the AMT soundings could be compared to the nearby borehole geophysical logs, which aided in the interpretation of the AMT soundings. Figure 6 shows an example comparison of an AMT sounding and a nearby borehole geophysical log. The remaining nine sounding locations (table 2) were selected where little or no other compiled data were available. An explanation of the processing and inversion methodologies performed on the TDEM and AMT data is provided by Pearson and others (2012).

Hydrostratigraphic Unit Interpretation

Lithologic descriptions and borehole geophysical logs obtained from existing reports were interpreted to identify the vertical extents (tops and bases, hereinafter referred to as picks) of hydrostratigraphic units. Once all of the existing data was compiled, a geospatial analysis was done to identify data gaps. Using picks from all the existing reports, the 44 additional borehole logs and 9 AMT soundings (fig. 7), three-dimensional surfaces were interpolated to represent the tops and bases of applicable hydrostratigraphic units.

Hydrostratigraphic picks were made from stratigraphic and lithologic descriptions and were compiled from existing reports. Logs with information concerning the tops and bases of various geological stratigraphic units were selected from published reports and databases as the basis for subsequent hydrostratigraphic picks on geophysical logs (fig. 8) (Meyer and others, 2011; Herald, 1957). Multiple types of geophysical logs were compiled for each borehole geophysical site in the study area and evaluated for use; however, the majority of the logs that fit project requirements regarding the type of geophysical data and depth interval were natural gamma logs. Natural gamma logs were most useful, in part, because of their versatility; they are one of the few geophysical tools that can be run in steel casing, which is present in many wells in the area, and they typically provide a good indication of clay content.

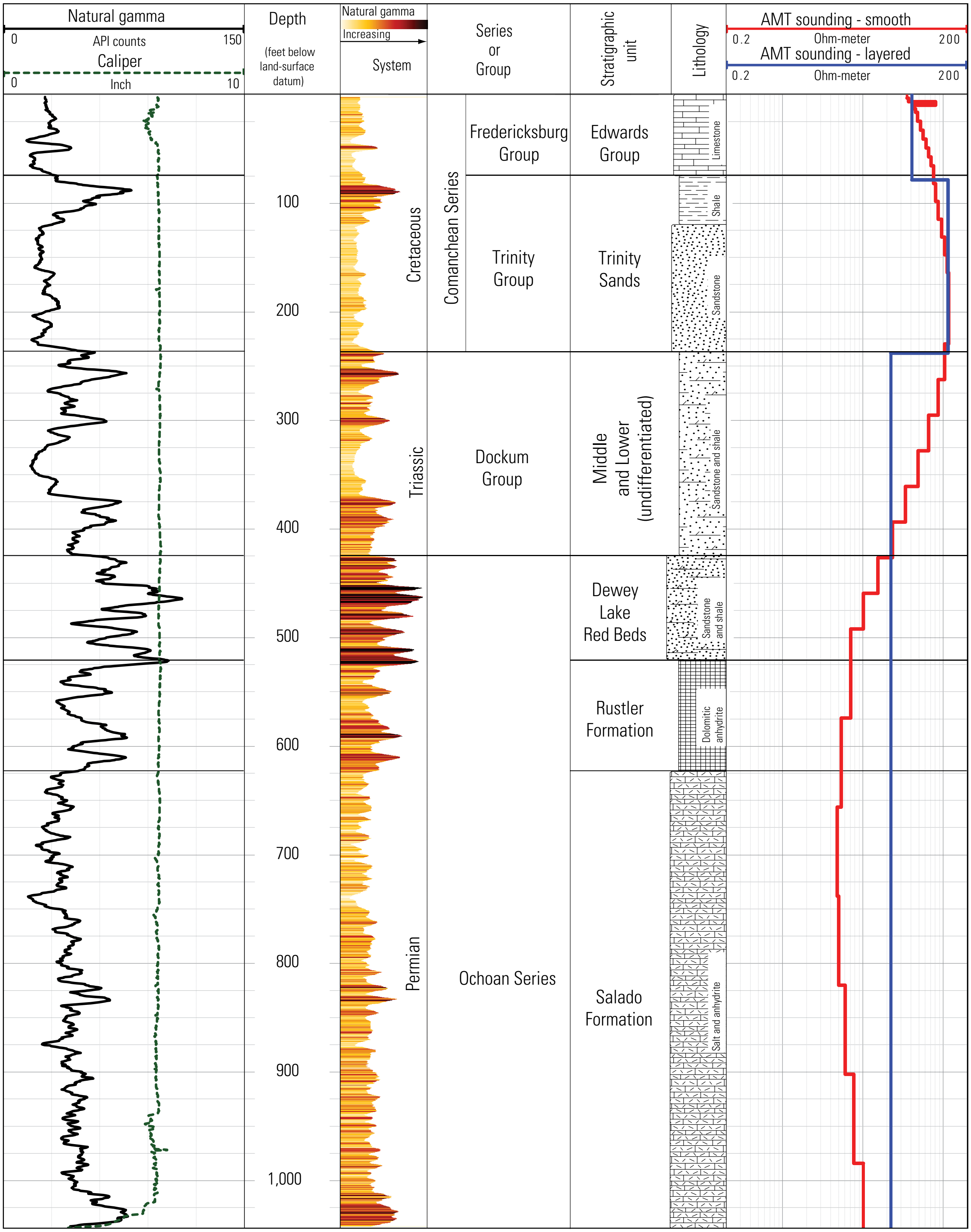
Picks for the Edwards part of the Edwards-Trinity aquifer (Fredericksburg and Washita Groups) and the Trinity part of the Edwards-Trinity aquifer (Trinity Group) were made because, although they are both units of the same aquifer, they have different hydrologic and lithologic characteristics (table 1). In order to determine stratigraphic picks for the Trinity Group, surface geophysical inverse modeling results were interpreted with layered-earth electrical scenarios in which each layer represents a separate electrical layer (Pearson and others, 2012). These electrical layers were then associated with the stratigraphic layers, which in turn were used to



Note: Land surface datum, 3;238.70 feet above North American Vertical Datum 1988; API counts, American Petroleum Institute counts; TDEM Sounding, Time-domain electromagnetic sounding; TDEM Sounding - Smooth, smoothed inverse resistivity modeling results; TDEM Sounding - Layered, layered-earth resistivity modeling scenario

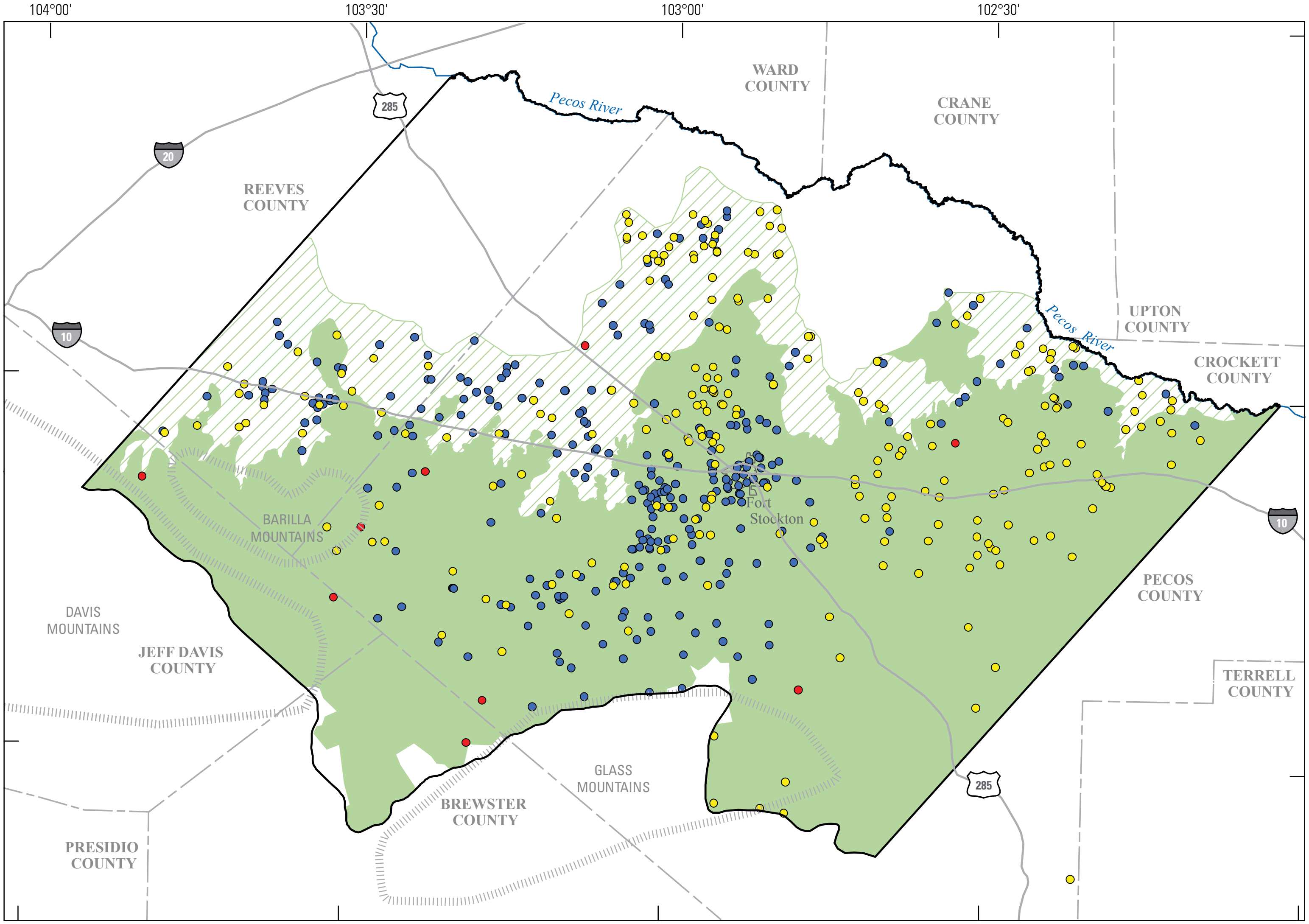
Figure 5. Example log for well 304711103003301 showing natural gamma, and induction conductivity/resistivity borehole geophysical properties, time-domain electromagnetic (TDEM) soundings, and stratigraphic layers for the Pecos County region study area, Texas.

identify water-bearing hydrogeologic units. For the TDEM inverse modeling results, a layered-earth resistivity model was created where this model was used as the layered-earth electrical scenarios (Pearson and others, 2012). Because the AMT inverse modeling software does not iterate a layered-earth resistivity model, another method to obtain the layered-earth electrical scenarios was developed. The layered-earth electrical scenarios for the AMT soundings were interpreted based on electrical changes in the smooth inverse modeling results (fig. 9). The resistivity values of these layers were selected at peak points along the smooth inverse modeling results, and the corresponding resistivity value was assigned to that layer. The top and bottom depths of each layer were interpreted by making the difference of the areas between the layered-earth electrical scenario layer and the smooth inverse modeling results directly above and below the depth pick equal to zero. Most of the AMT soundings were laterally anisotropic at the sounding location. For these soundings, a resistivity curve was made for the magnetic response (TM), the electrical response (TE), and a combination of the two responses (TMTE). Each of the three responses was interpreted individually to develop three layered-earth electrical scenarios followed by an average layered-earth electrical scenario. For the soundings that had little or no lateral variation in the subsurface, the TMTE response was calculated and interpreted. One disadvantage of surface geophysical techniques is the vertical resolution decreases with depth. The accuracy of the picks made from the surface geophysical methods was considered to be about plus or minus 10 percent of the depth.



Note: land surface datum, 4;354.39 feet above North American Vertical Datum of 1988; API Counts, American Petroleum Institute counts; AMT Sounding, audio-magnetotelluric sounding; AMT Sounding - Smooth, smoothed inverse resistivity modeling results; AMT Sounding - Layered, layered-earth resistivity modeling scenario

Figure 6. Example log for well 302630102503801 showing natural gamma borehole geophysical properties, audio-magnetotelluric sounding (AMT08), and stratigraphic layers in the Pecos County region study area, Texas.



Base modified from U.S. Geological Survey, 1:2,000,000-scale digital data
Albers Equal Area Projection, Texas State Mapping System
North American Datum of 1983

Aquifer modified from Ashworth and Hopkins, 1995
Lithologic and geophysical data from
Daniel B. Stephens and Associates, 2010;
Meyer and others, 2011;
Texas Water Development Board, 2011;
Railroad Commission of Texas, 2010;
University Lands, 2011;
and U.S. Geological Survey, 2011

0 5 10 15 20 MILES
0 5 10 15 20 KILOMETERS

EXPLANATION

- **Edwards-Trinity aquifer (outcrop)**
- **Edwards-Trinity aquifer (subcrop)**
- **Study area boundary**

Method of hydrostratigraphic picks

- Pick reviewed from lithological descriptions in well reports
- Pick made from interpreted borehole geophysical log
- Pick made from interpreted audio-magnetotelluric sounding

Figure 7. Locations where geological and geophysical data were used to determine the tops and bases (picks) of hydrostratigraphic subdivisions in the Pecos County region study area, Texas.

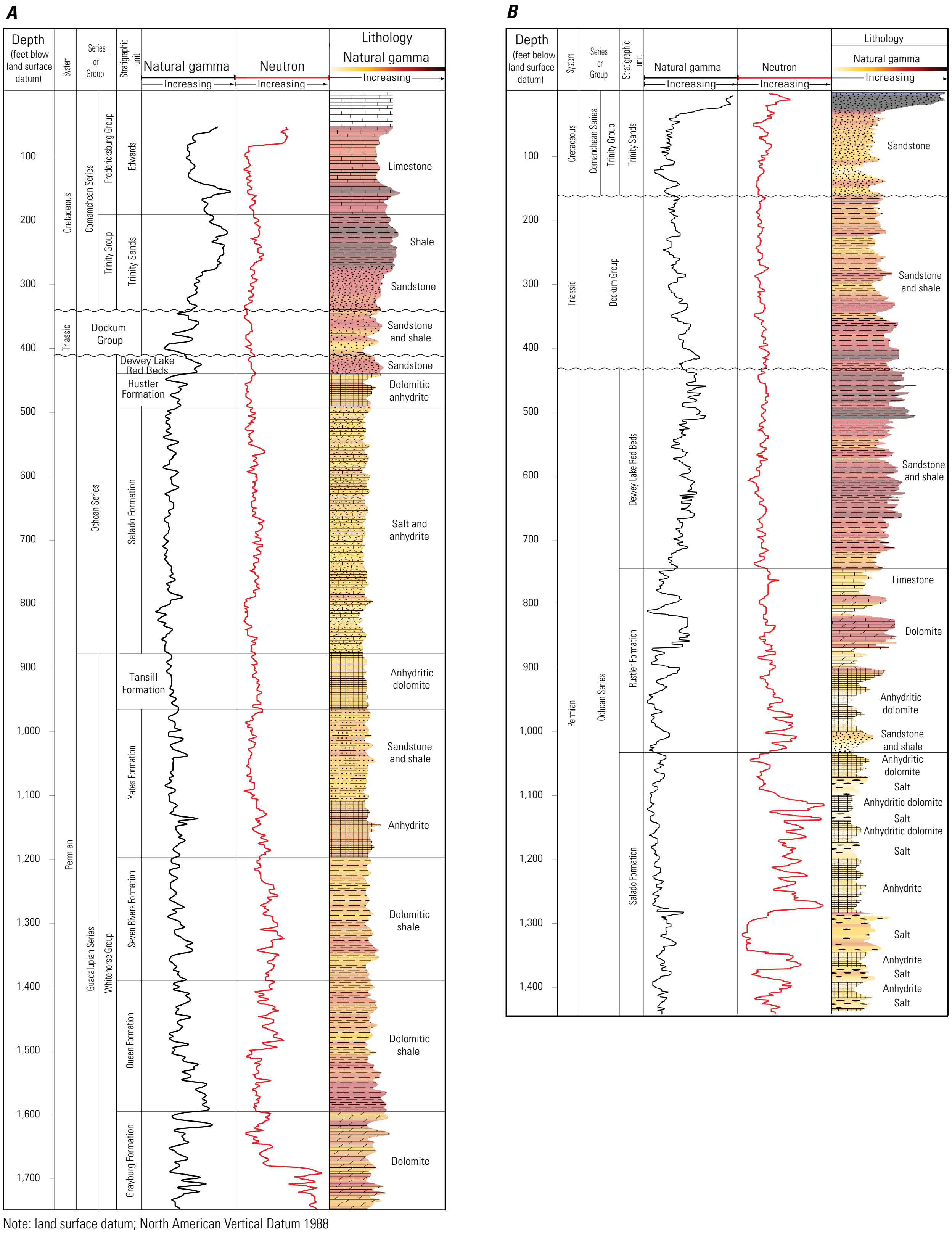


Figure 8. Example logs with geophysical properties of Permian, Triassic, and Cretaceous-age stratigraphic layers in *A*, northern Pecos County and *B*, northwestern Pecos County in the Pecos County region study area, Texas (modified from Herald, 1957).

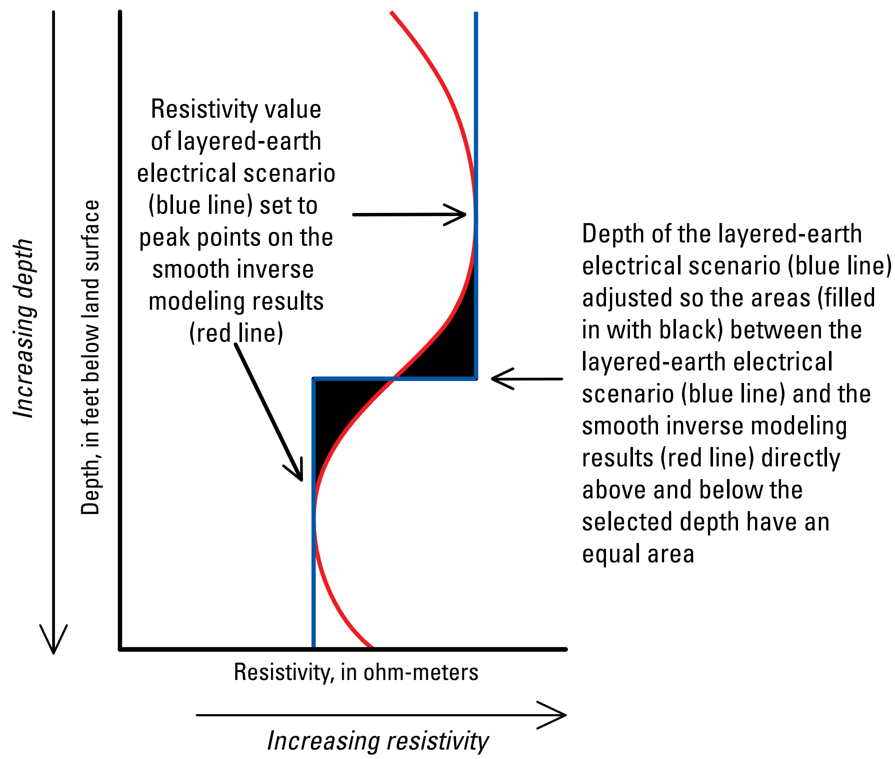


Figure 9. Schematic showing the procedure to develop layered-earth electrical scenarios for the audio-magnetotelluric smooth inverse modeling results for the Pecos County region study area, Texas.

The layered-earth electrical scenarios obtained for applicable AMT soundings were compared to nearby well data in order to interpret the electrical signature of the Trinity Group compared to the borehole geophysical log picks (fig. 7, table 3 at end of report). Based on the AMT-log comparison, the Trinity Group was determined to be moderately resistive (approximately 50 ohm-meters) and was generally the first resistive layer below the first conductive layer. This information was used to interpret the depth of the Trinity Group in the nine AMT soundings that were not near a well.

The layered-earth electrical scenarios for the four AMT soundings near wells (AMT07, AMT08, AMT11, and AMT12) resulted in the identification of different electrical layers. Each layer was identified as electrically conductive (referred to as a conductor) or electrically resistive (referred to as a resistor). Four scenarios of conductors and resistors were identified. The scenarios from AMT07 and AMT08 were similar with three (AMT07) or four layers (AMT08) identified; for both soundings, the four layers (in top-down order from the surface) were sequentially conductor, resistor, conductor, and resistor (fig. 10a). The second scenario (AMT12) consisted of five layers with a near-surface resistor followed by a conductor, which was followed by three layers progressively becoming more resistive (fig. 10b). The last scenario (AMT11) consisted of five or six layers with alternating conductive and resistive layers where the five-layer scenario had a resistor at surface and the six-layer scenario had a conductor at surface (fig. 10c). Three of the four soundings (AMT07, AMT08, and AMT11) resulted in layers that matched closely (within the accuracy of AMT measurements; Pearson and others, 2012) to the picks made from the borehole geophysical logs. The one exception was the pick for the bottom of the Trinity Group at AMT08 which was substantially lower (greater than 150 ft lower or 50 percent of the AMT depth pick) than the pick made from the borehole geophysical log. The fourth sounding (AMT12) did not resolve the Trinity Group likely because the unit was too thin to identify.

The layered-earth electrical scenarios for the remaining nine AMT soundings consisted of similar scenarios as the AMT soundings located near the wells. These scenarios are grouped into three pairs of scenarios. The first pair of scenarios, which was equivalent to the layer-earth electrical scenarios found at AMT07 and AMT08 (fig. 10a), had three (AMT06) and four layers (AMT13); in top-down order from the surface, conductor, resistor, and conductor electrical layers were identified with an additional resistor below the bottom conductor in the fourth layer. The second pair of scenarios, which was equivalent to the layered-earth electrical scenario found at AMT12 (fig. 10b), consisted of four (AMT10) or five layers (AMT04 and AMT05) with a near-surface resistor

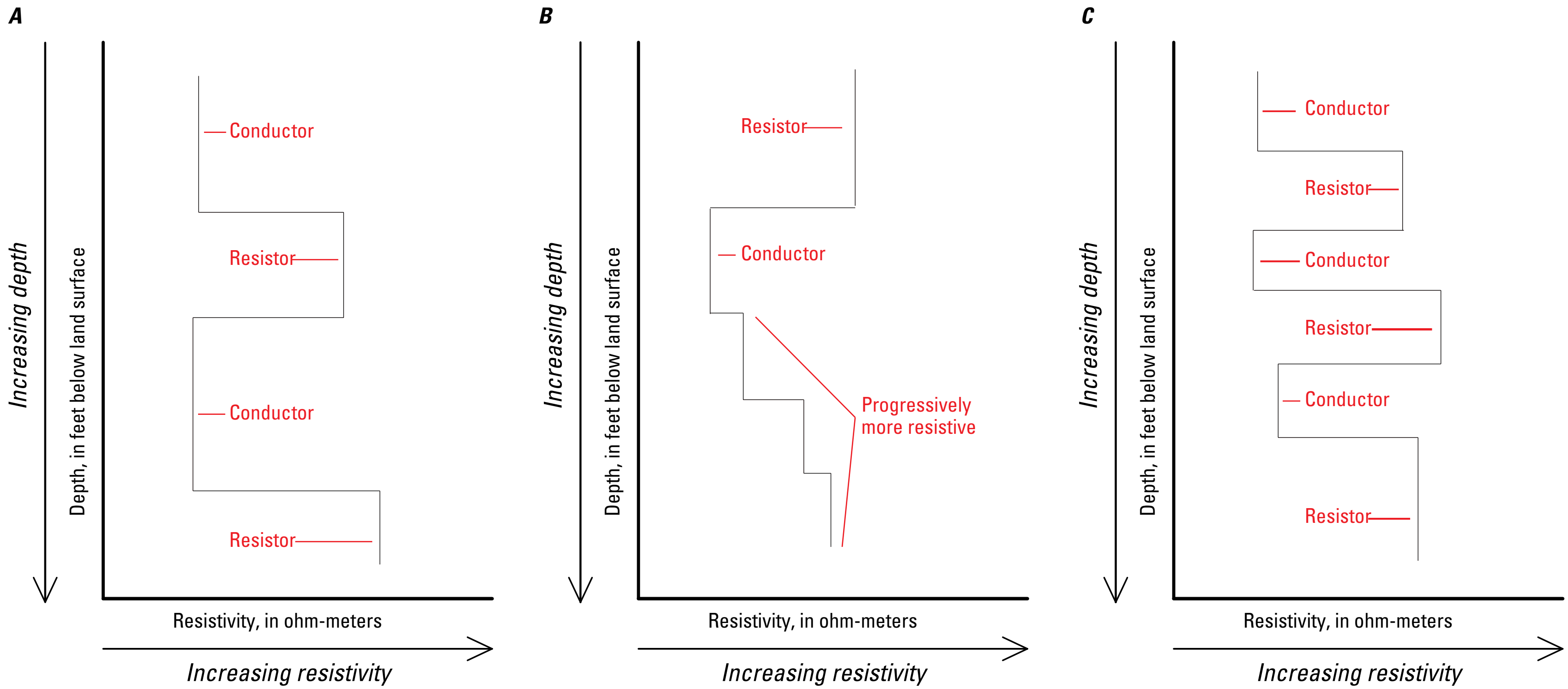


Figure 10. Schematic diagram of three (*A*, *B*, and *C*) layered-earth electrical scenarios for the Pecos County region study area, Texas.

followed by a conductor, which was followed by two or three layers progressively becoming more resistive. The pair of scenarios, which was equivalent to the layered-earth electrical scenario found at AMT11, had five or six alternating resistive and conductive layers; the five-layer scenario had a resistor at surface (AMT01, AMT03, and AMT09) and the six-layer scenario had a conductor at surface (AMT02).

The general electrical responses of the Trinity Group were interpreted using the picks made from the borehole geophysical logs and comparing those depths with the picks made from the AMT soundings. The Trinity Group was moderately resistive (between 15-160 ohm-meters) with a calculated log-mean of 50 ohm-meters. The most resistive part of the Trinity Group layer was found in the southeastern part of the study area, and the least resistive part of the Trinity Group layer was found near the northern edge of the study area. Because borehole geophysical logs provided high vertical resolution in the subsurface, the picks made from the borehole geophysical logs were preferentially chosen as the final picks over nearby TDEM and AMT soundings.

After the geophysical logs and soundings were compiled and interpreted and hydrostratigraphic picks were determined, grids were created for each surface using kriging interpolation techniques. Geosoft, Inc. (2012) contains a complete description of the kriging methods used for grid interpolation. Preliminary grids were used to identify outliers and areas requiring review. To aid in identifying outliers, the residual was calculated as the difference between the hydrostratigraphic pick at each geophysical log or AMT sounding to the interpolated grid value. All locations with a residual greater than an absolute value of 15 ft were evaluated through a correlation process to determine data-point uncertainty. The correlation process involved the comparison of the pick at a given site to the picks made at nearby sites to determine if it “correlated” with the nearby well picks. If the pick varied by more than 15 ft from the nearby picks and seemed to not coincide with overall hydrostratigraphy of the area, it was removed from the final grid. Throughout the process, all stratigraphic picks were reviewed and revised as needed to provide a better understanding of the stratigraphic unit.

Structural Interpretations

Changes in altitude of the tops and bases of aquifer units, unit thicknesses, and normal-fault zones of the Edwards-Trinity aquifer were interpreted using the surfaces created from the interpolation of the hydrostratigraphic picks. Fault zones were delineated based on the interpretation of cross sections of the interpolated top and base surfaces of the Edwards-Trinity aquifer units and are similar to faults delineated previously for the underlying Rustler aquifer (INTERRA Incorporated, 2011). Displacement along fault zones is included in the final interpretation of the tops, bases, and thicknesses of the aquifer units.

Changes in altitude of the top of the Edwards-Trinity aquifer, which is, in general, the top of the Edwards part of the aquifer (upper Cretaceous), closely matched those of the land-surface altitudes throughout most of the study area. The altitude of the top surface of the Edwards-Trinity aquifer was highest in the southern part of the study area near the Glass Mountains (about 4,315 ft; fig. 11). For comparison purposes, the altitude ramps in figures 11, 12, and 13 are the same and include the minimum altitude in the base surface of the Edwards-Trinity aquifer and the maximum altitude in the top surface of the Edwards-Trinity aquifer. The altitude decreased to the northeast and the lowest altitude near the northeastern edge of the study area at the Pecos River was about 2,250 ft. The Edwards-Trinity aquifer dipped more sharply than the slope of the land surface in two locations. The first location was near the north-central boundary of the study area in the Monument Draw trough (fig. 2) where the altitude of the top of the Edwards-Trinity aquifer drops to about 2,020 ft, which was the lowest interpolated altitude for the top of the Edwards-Trinity aquifer. The other location where the altitude of the top of the Edwards-Trinity aquifer dropped substantially was in the northwestern part of the study area in the Pecos trough (fig. 2) where the altitude was about 2,450 ft.

Changes in altitude of the top of the Trinity Group (fig. 12) closely matched those of the top of the Edwards-Trinity aquifer (fig. 11) in most of the study area. The altitude of the top surface of the Trinity Group was highest in the southern part of the study area near the Glass Mountains (about 4,230 ft; fig. 12). The altitude decreased to the northeast similar to the top of the Edwards-Trinity aquifer and the lowest altitude near the northeastern edge of the study area at the Pecos River was about 2,250 ft. The lowest altitude of the top of the Trinity Group was near the north-central boundary of the study area in the Monument Draw trough (fig. 2) where the altitude was about 1,960 ft.

The base surface of the Edwards-Trinity aquifer (fig. 13) had similar spatial trends as the top of the Trinity Group (fig. 12) and the top of the Edwards-Trinity aquifer (fig. 11). The highest altitude of the base of the Edwards-Trinity aquifer was in the southern part of the study area near the Glass Mountains (about 4,110 ft). Similar to the top of the Trinity Group of the Edwards-Trinity aquifer, the altitude of the base of the Trinity Group decreased to the northeast, which is consistent with findings by Barker and Ardis (1992). The lowest altitude for the base of the Edwards-Trinity aquifer (about 1,555 ft) was in the north-central part of the study area in the Monument Draw trough (fig. 2).

The thickness of the Edwards-Trinity aquifer in the study area was calculated as the difference in altitudes between its top and base (fig. 14). About 50 percent of the aquifer was between 234 and 362 ft thick, about 25 percent was less than 234 ft thick, and about 25 percent was more than 362 ft thick. The minimum thickness was 5 ft and the maximum thickness was about 797 ft. The thickness of the Edwards part of the aquifer in the study area was calculated as the difference in

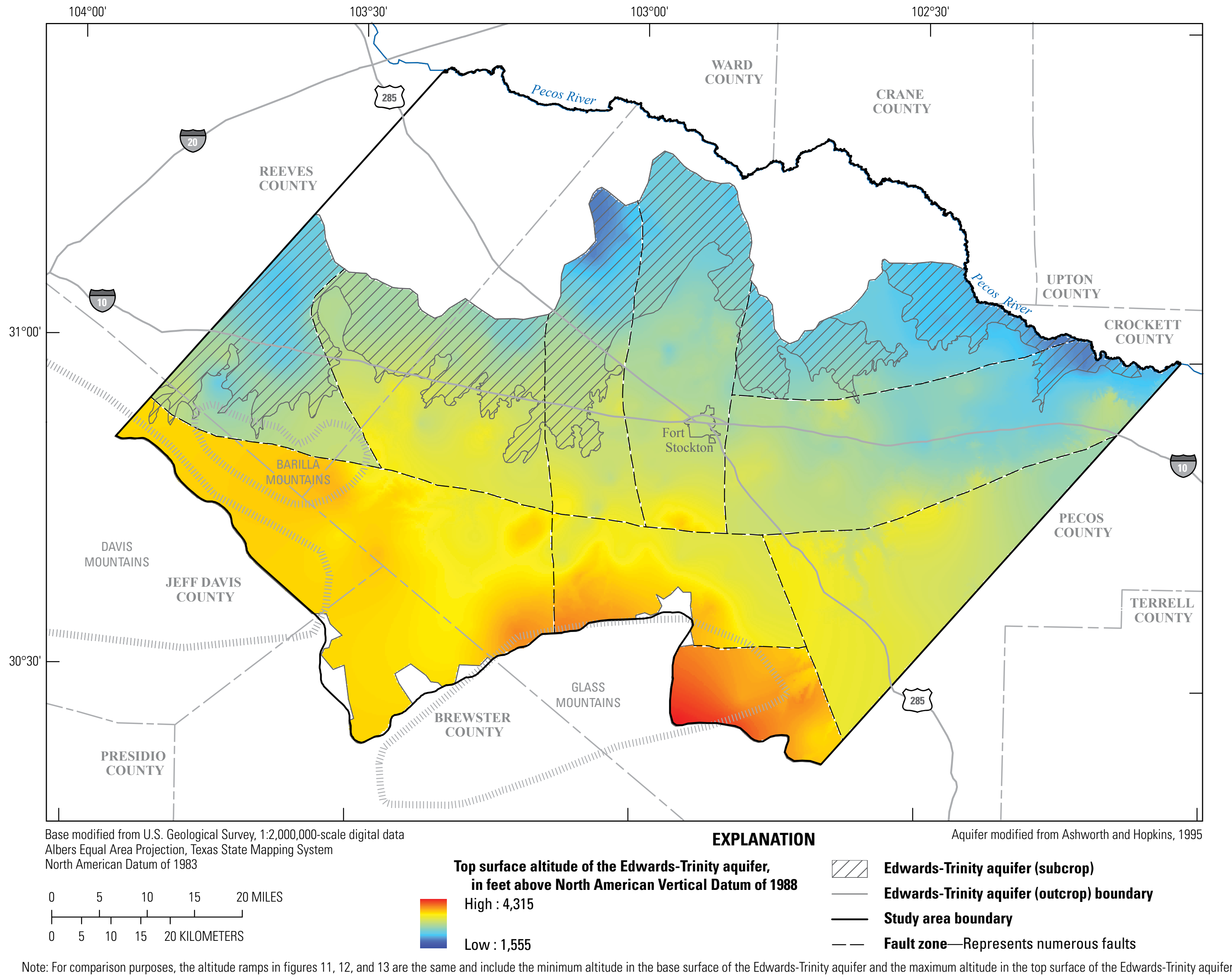


Figure 11. The altitude of the top surface of the Edwards-Trinity aquifer estimated by interpolating the tops and bases of hydrostratigraphic subdivisions in the Pecos County region study area, Texas.

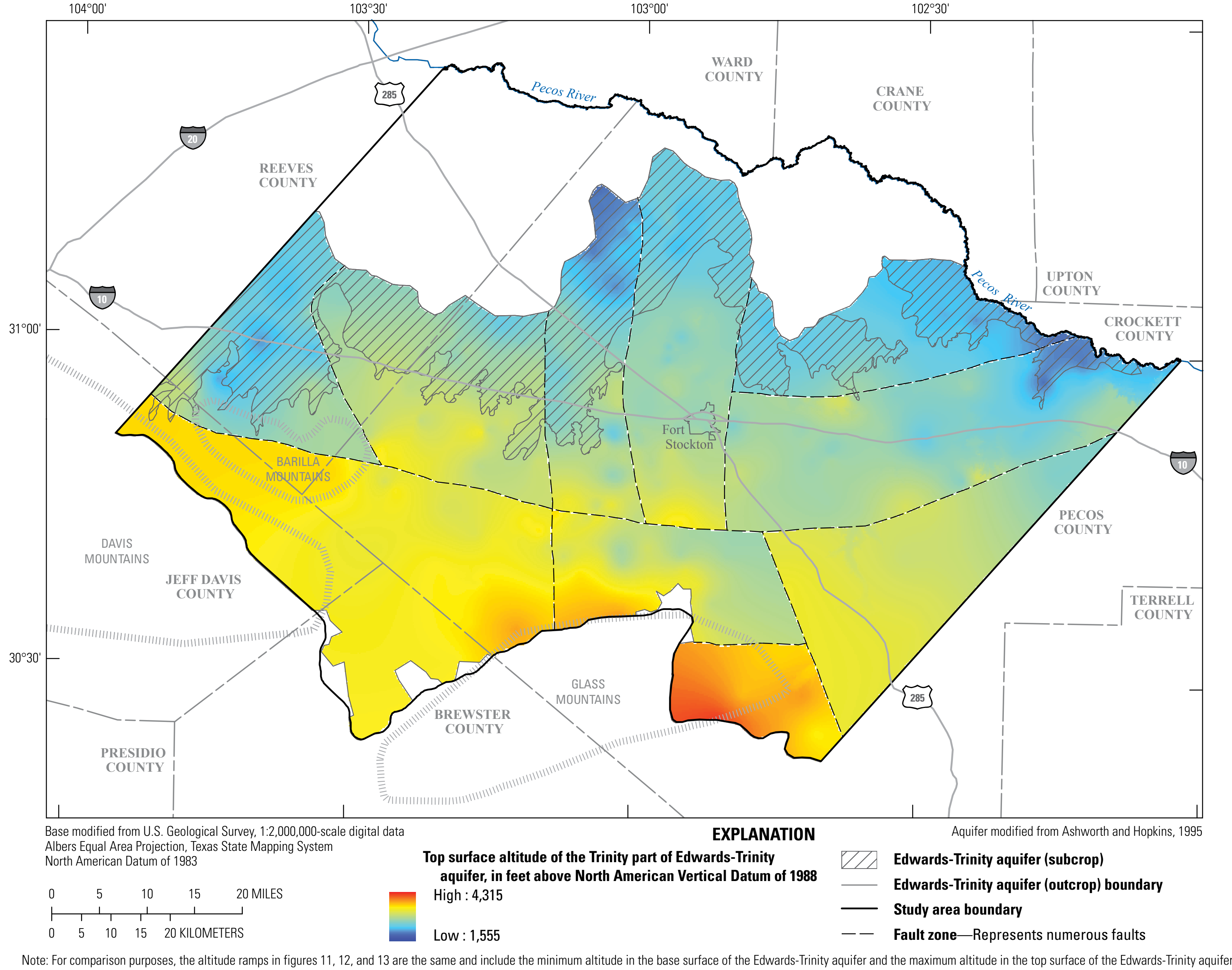


Figure 12. The altitude of the top surface of the Trinity part of the Edwards-Trinity aquifer estimated by interpolating the tops and bases of hydrostratigraphic subdivisions in the Pecos County region study area, Texas.

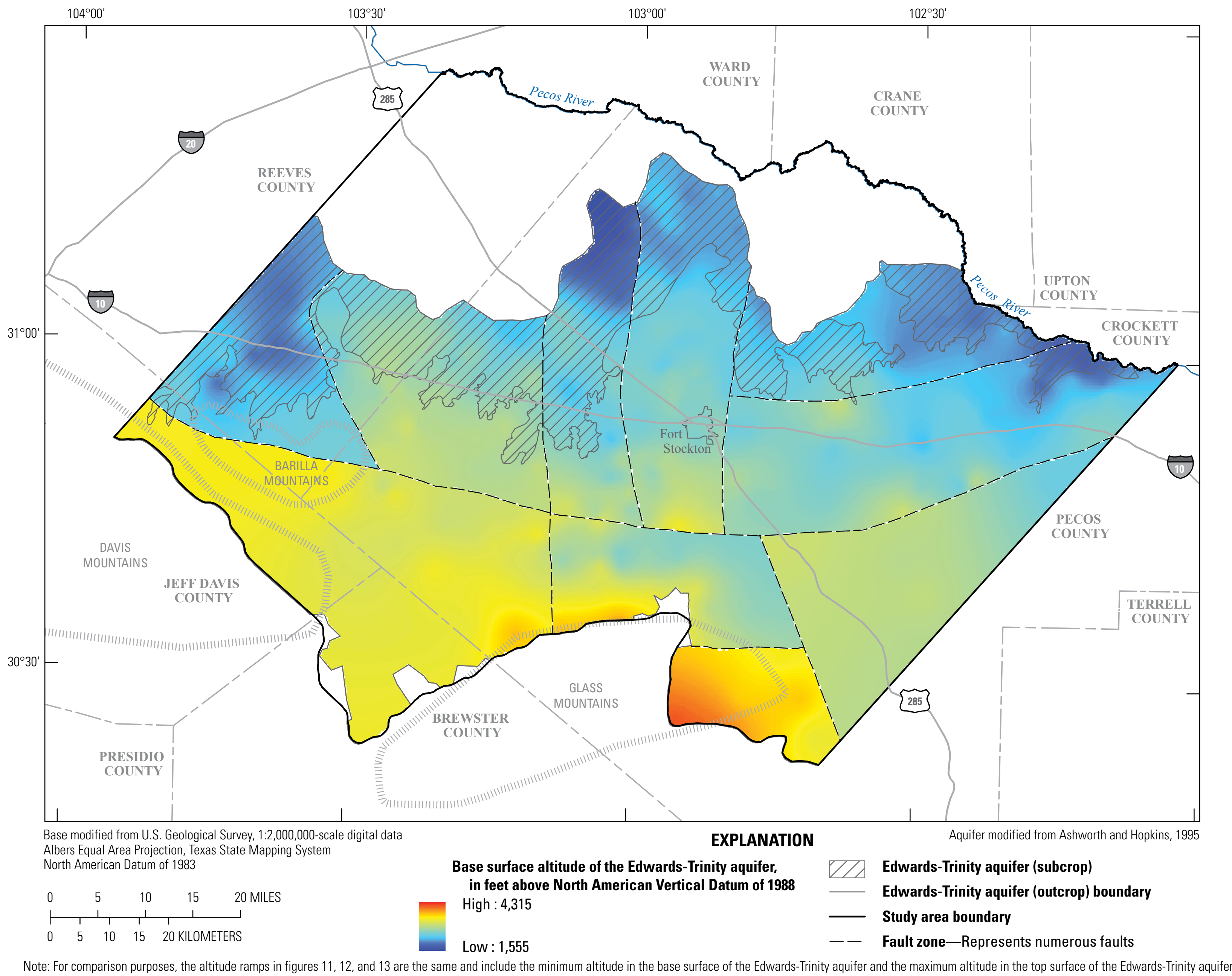


Figure 13. The altitude of the base surface of the Edwards-Trinity aquifer estimated by interpolating the tops and bases of hydrostratigraphic subdivisions in the Pecos County region study area, Texas.

altitudes between the top of the Edwards-Trinity aquifer and the top of the Trinity Group (fig. 15). About 50 percent of the Edwards part of the aquifer was between 44 and 169 ft thick, about 25 percent was less than 44 ft thick, and about 25 percent was more than 169 ft thick. The minimum thickness was 0 ft and the maximum thickness was about 723 ft. The thickness of the Trinity Group in the study area was calculated as the difference in altitudes between the top of the Trinity Group and the bottom of the Edwards-Trinity aquifer (fig. 16). About 50 percent of the Trinity Group was between 144 and 224 ft thick, about 25 percent was less than 144 ft thick, and about 25 percent was more than 224 ft thick. The minimum thickness was 3 ft and the maximum thickness was about 543 ft.

Some of the thinnest sections of the Edwards-Trinity aquifer were in the eastern part of the study area, near the northwestern slope of the Glass Mountains, and near the northeastern slope of the Davis Mountains. It was determined that the aquifer was often thickest in the central part of the study area in the Monument Draw trough and at the western edge of the study area in the Pecos trough, which is consistent with findings by Barker and Ardis (1992). There were three areas of the Edwards-Trinity aquifer where substantial thickness variations were identified; in two areas, the thickness of the aquifer increased appreciably per unit of horizontal length (fig. 14). In the areas west of Fort Stockton and north of the Glass Mountains, the base of the Edwards-Trinity aquifer dips at a higher angle to the north than does the top of the Edwards-Trinity aquifer. In the third location, a valley exists in the top of the Edwards-Trinity aquifer between the Glass Mountains and the Davis Mountains that did not appear in the base of the Edwards-Trinity aquifer, which resulted in a thinner section of the aquifer.

Some of the thinnest sections of the Edwards part of the aquifer (fig. 15) were in the eastern part of the study area, near the northwestern slope of the Glass Mountains, and in the down-dip part of the Pecos trough (fig. 2). Based on interpretation of the data, it is likely that many of the thinnest sections of the Edwards part of the aquifer are associated with active or paleo-erosional features. Some of the thickest sections of the Edwards part of the aquifer were generally in the southern and central parts of the study area in the Monument Draw trough (fig. 2).

Some of the thinnest sections of the Trinity Group of the Edwards-Trinity aquifer were in the eastern part of the study area and in the ridge that separates the Pecos and Monument Draw troughs (fig. 2). Some of the thickest sections of the Trinity Group were in the western part of the study area in the Pecos trough and in the central part of the study area in the Monument Draw trough.

Faults in the study area likely formed as growth and collapse features as sediments were deposited along the margins of more resistant rocks and structures, such as the Glass Mountains, and as sediments collapsed into the voids created by the dissolution of Permian-age evaporite deposits. Figures 17 and 18 show examples of the roughly west-east (A–A′) and south-north (B–B′) orientated cross sections that were used to delineate the fault zones. The dips of these fault zones were not evaluated for this study. Also, although the Cretaceous (Edwards-Trinity) and Triassic (Dockum and underlying units) aquifers are shown in figures 17 and 18, the actual thicknesses of the Triassic units were not estimated for this study and are shown for reference only. Each fault zone represents a series of parallel and transverse faults that result in an overall displacement between two adjacent fault blocks. Fault zones (figs. 11–18) delineate domains in the hydrogeologic framework that generally align with previously identified structural features such as the Pecos and Monument Draw troughs (fig. 2). Some fault blocks, which are fault-bounded areas, shown in the cross sections (figs. 17 and 18), particularly those in the Pecos and Monument Draw trough areas, are not represented in the surface fault-zone delineations (figs. 17–18) because of the coarse resolution of the surface delineation. Also, there is likely extensive faulting at a relatively higher resolution not shown in each of the fault blocks in the cross sections.

The displacement along the delineated fault zones was calculated as the average displacement of combined faults within a given delineated fault block (figs. 11–16). For example, the displacement of the graben (an elongate trough or basin bounded by high-angle normal faults that dip toward one another [Neuendorf and others, 2005, p. 277]) that contains the Monument Draw trough (FB03) in cross section A–A′ (fig. 17) relative to the adjacent horst (an elongate block bounded by normal faults that dip away from one another [Neuendorf and others, 2005, p. 307]) that includes deposits (FB04; fig. 17) that approximately overly the Capitan Reef aquifer (fig. 4) was calculated as the difference between the average basal altitudes of the two fault blocks in the graben and the average basal altitudes of the two fault blocks in the horst. Displacement along the trend of a fault zone varied depending on the basal altitudes of the adjacent fault blocks at a given location. The maximum interpreted displacement at a location along a delineated fault zone was about 1,025 ft and is located along the FB01 and FB07 fault zone (figs. 17 and 18) in the Barilla Mountains (fig. 2). The minimum interpreted displacement at a location along a delineated fault zone was about 1 ft and is located along the FB03 and FB04 fault zone (figs. 17 and 18) near Belding, Tex. (fig. 1).

Cross section A–A′ originates at the western boundary of the study area in the Pecos trough (fig. 2) and extends to the eastern boundary of the study area (fig. 17). This section shows 11 horizontal horst, graben, and stairstep fault blocks (faults expressed as numerous small fractures, breccia, or fault gouges [Neuendorf and others, 2005, p. 231]). Each of these fault blocks likely contains a series of faults that result in a cumulative displacement along the fault zones. The Pecos trough (fig. 2) near the western boundary is in a graben (FB01; fig. 17) created by the dissolution of Permian-age evaporite deposits and the subsequent collapse of overlying units. It is possible that Edwards-Trinity units are not connected between fault blocks within the Pecos trough and, thus, create a barrier

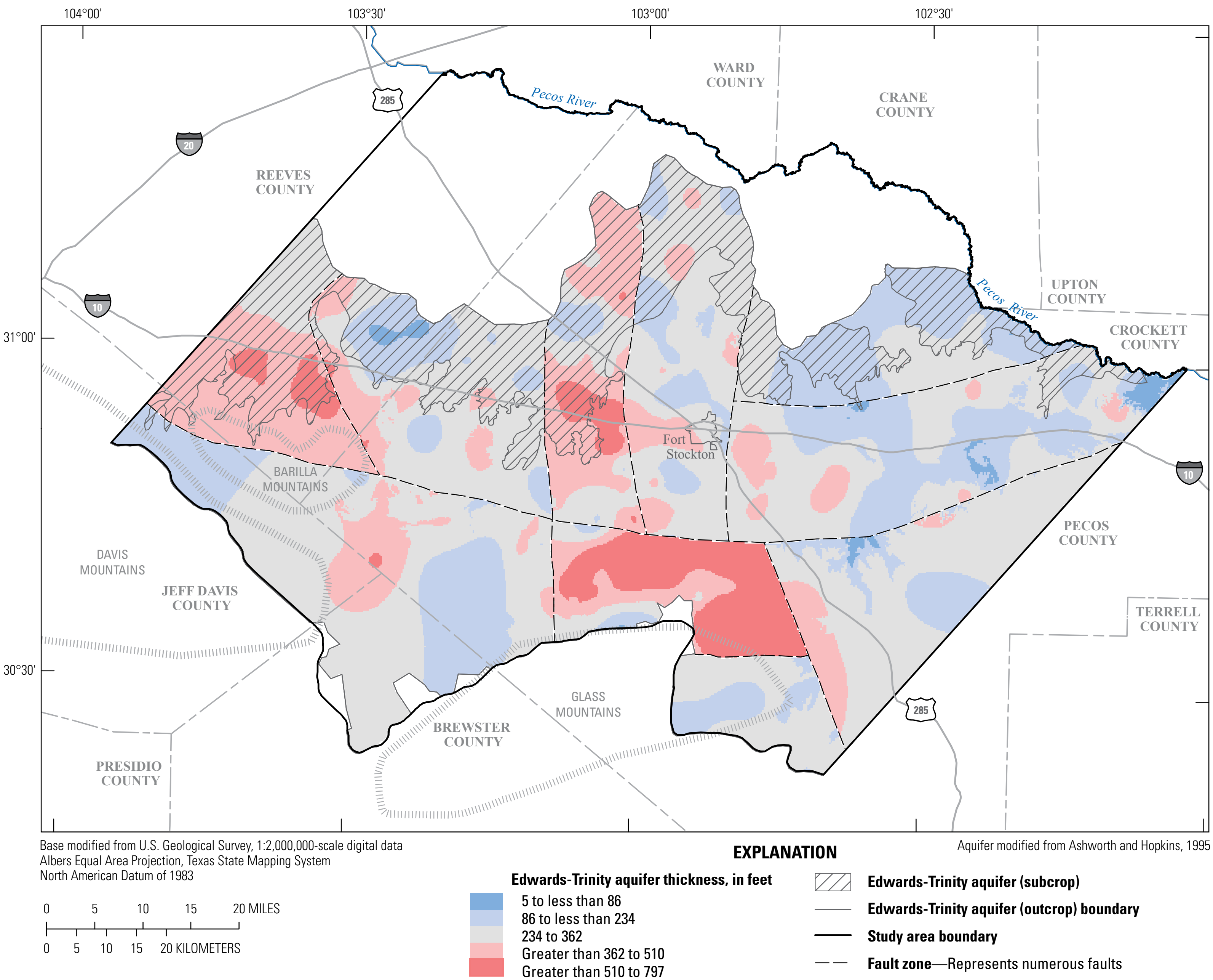


Figure 14. The thickness of the Edwards-Trinity aquifer in the Pecos County region study area, Texas, calculated as the difference between the altitudes of the top and base surfaces of the Edwards-Trinity aquifer.

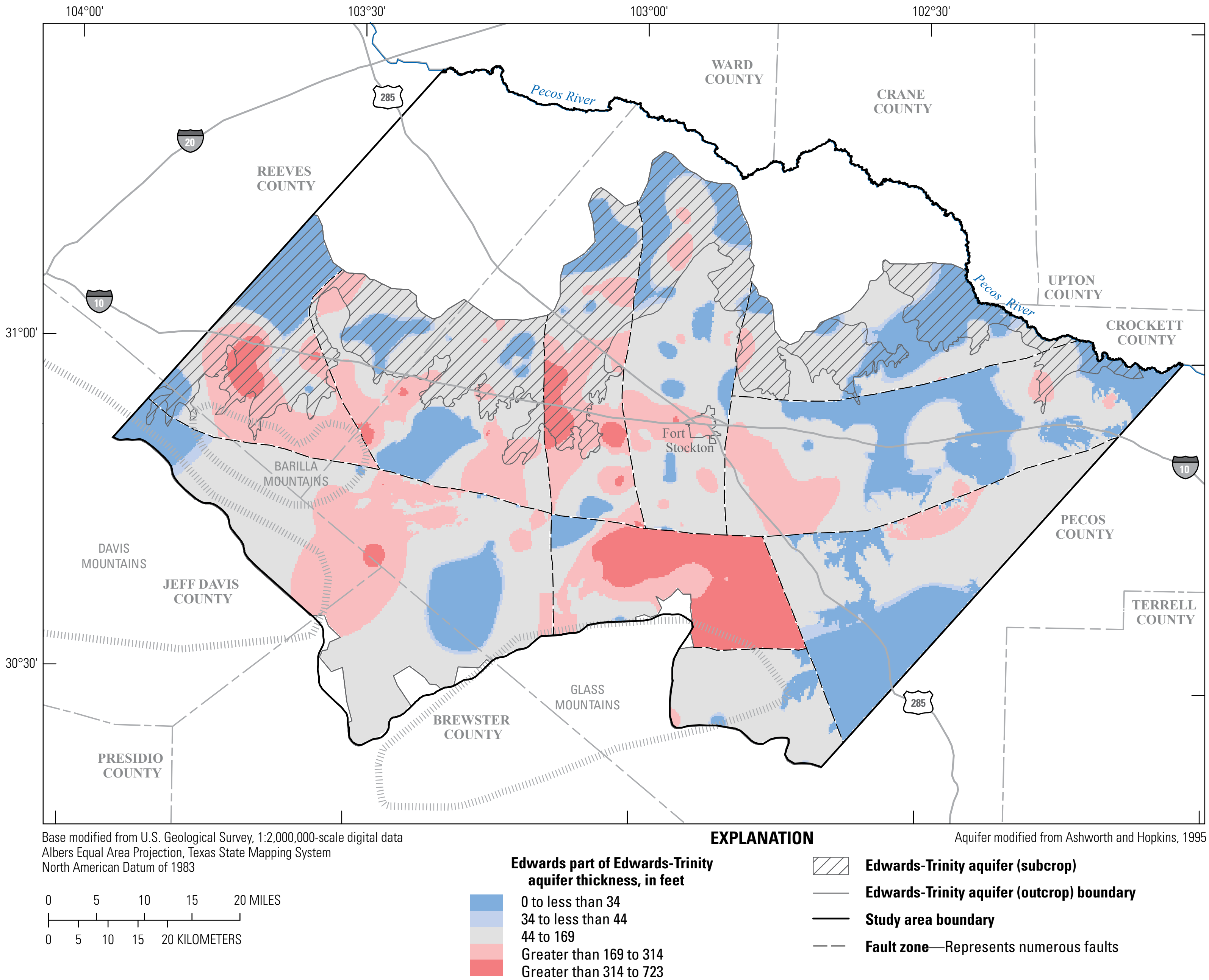


Figure 15. The thickness of the Edwards part of the Edwards-Trinity aquifer in the Pecos County region study area, Texas, calculated as the difference between the altitudes of the top and base surfaces of the Edwards part of the Edwards-Trinity aquifer.

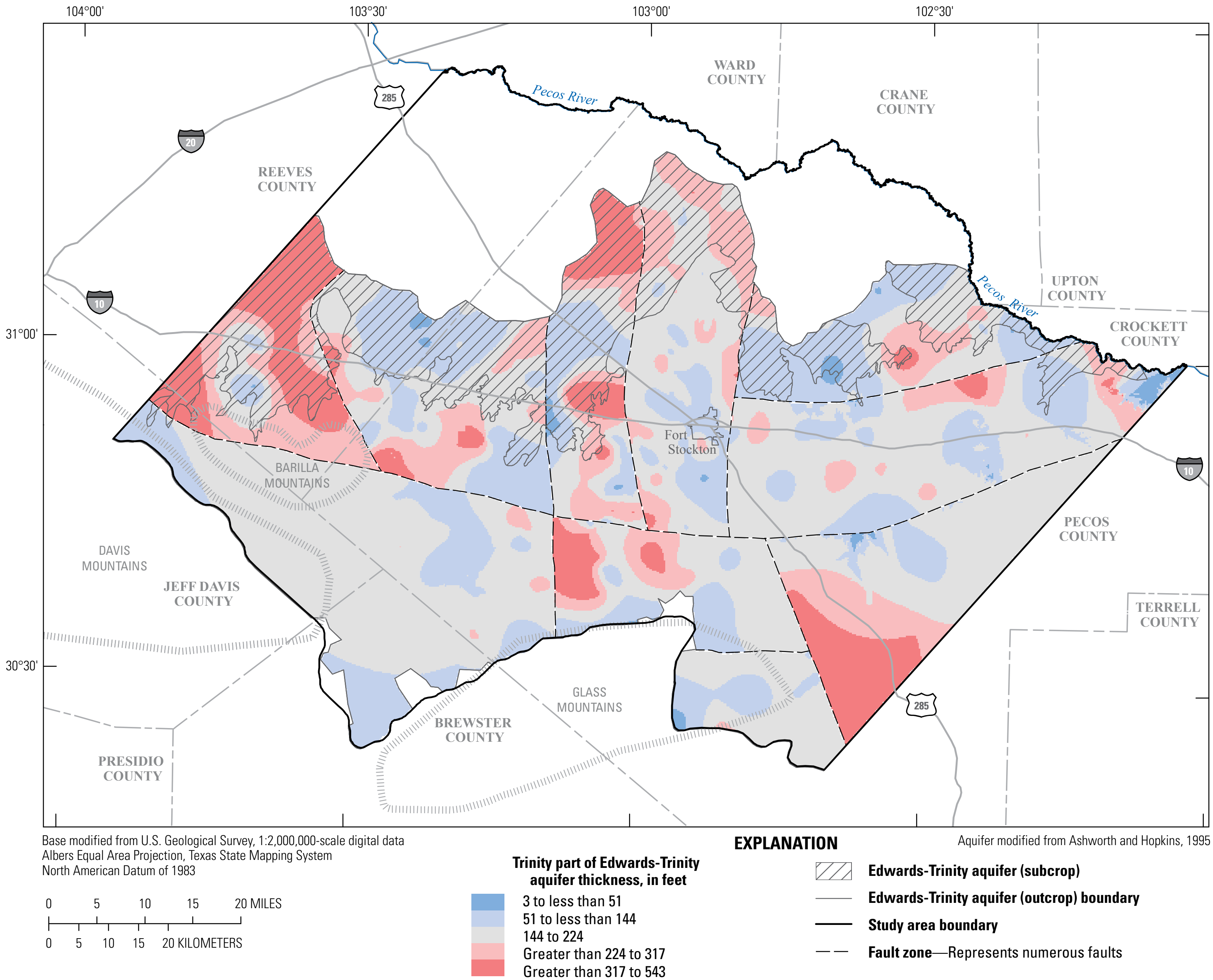


Figure 16. The thickness of the Trinity part of the Edwards-Trinity aquifer in the Pecos County region study area, Texas, calculated as the difference between the altitudes of the top and base surfaces of the Trinity part of the Edwards-Trinity aquifer.

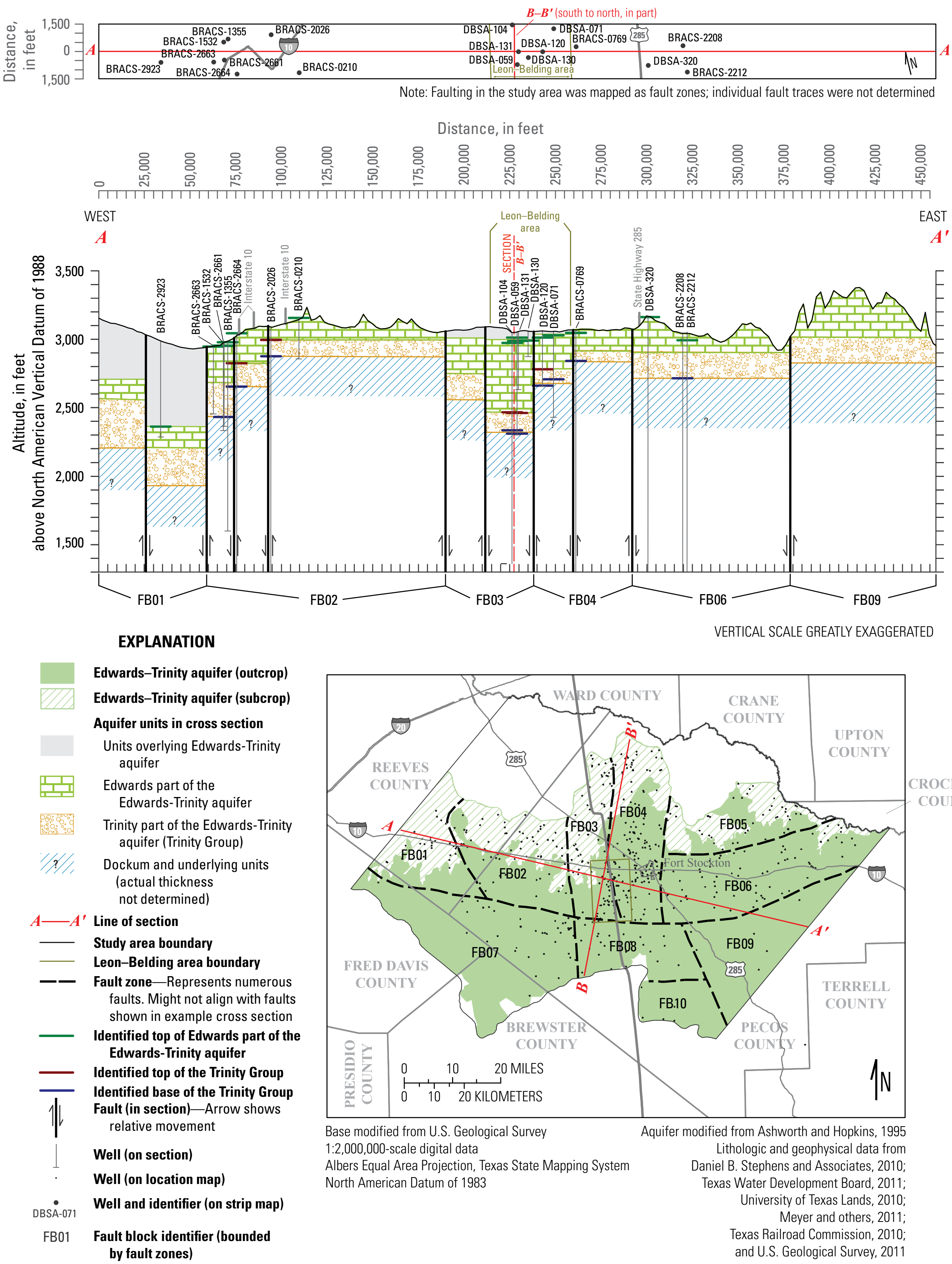


Figure 17. Generalized map and detailed cross section *A–A′* in the Pecos County region study area, Texas.

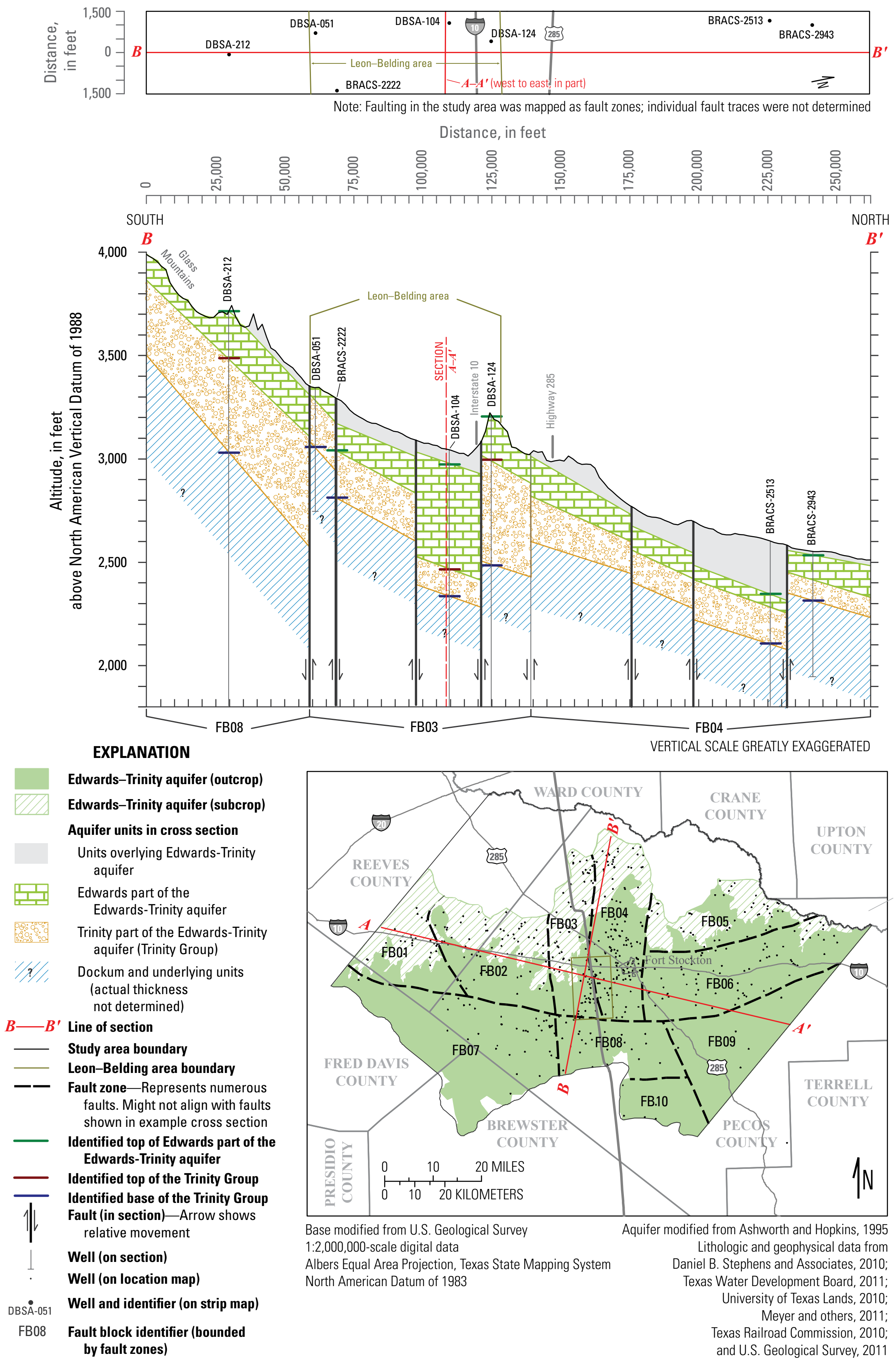


Figure 18. Generalized map and detailed cross section *B–B′* in the Pecos County region study area, Texas.

to flow, but the disconnection at this location is not confirmed and, if it does exist at this location, may not be laterally continuous. Faults east of, and adjacent to, FB01 (fig. 17) stairstep up to a horst (FB02; fig. 17) formed from deposits that overlie more resistant rock units and form a ridge between the Pecos and Monument Draw troughs (fig. 2). Stairstep faults east of the ridge, also created by the dissolution of Permian-age evaporite deposits, form the graben (FB03; fig. 17) that is part of the Monument Draw trough (fig. 2). The next series of stairstep faults form a horst (FB04; fig. 17) to the east of the Monument Draw trough (fig. 2) and are in Cretaceous rocks that overlie the Capitan Reef aquifer (fig. 4). Cross section A–A′ is completed by a graben (FB06; fig. 17) and horst (FB09; fig. 17) that formed east of the Capitan Reef aquifer (fig. 4) (FB04; fig. 17).

Cross-section B–B′ originates in the Glass Mountains (fig. 2) along the southern boundary of the study area and extends north to the down-dip extent of the Edwards-Trinity aquifer (fig. 18). There are a series of stairstep fault zones, horsts, and grabens that separate the downthrown trough fault blocks (FB08 and FB03; fig. 18) in the south from the deposits overlying the Capitan Reef aquifer (fig. 4) (FB04; fig. 18) to the north. The intrablock faults correlate closely with thickness variations in the Edwards-Trinity aquifer (figs. 14–16). Also, the fault zones shown in the cross section are likely a fraction of those that formed as growth faults along the margins of the Glass Mountains and resistant Permian-age deposits along the Capitan Reef aquifer and as collapse features from the dissolution of Permian-age evaporite deposits.

Aquifer Tests and Hydraulic Properties

Aquifer-test data collected at 47 groundwater wells were compiled from other reports or agencies such as the TWDB Groundwater Database (Texas Water Development Board, 2011), Thornhill Group, Inc., (2008, 2009), and Meyers (1969) and used in this study. One aquifer test was completed with ambient and pumping borehole flowmeter measurements by the USGS as part of this study.

Transmissivity is an aquifer hydraulic property that is defined by the rate water is transmitted horizontally through a unit width of an aquifer under a unit hydraulic gradient. It equals the hydraulic conductivity of an aquifer multiplied by the aquifer thickness (or saturated thickness if unconfined) (Fetter, 1988). Higher transmissivity values correlate with higher yields and less drawdown in a well. Previously reported transmissivity values were calculated using one or more of the following methods: the Thiem equilibrium formula (Thiem, 1906), the Theis nonequilibrium formula (Theis, 1935), the Jacob modified formula (Cooper and Jacob, 1946), or methods documented in Ferris and others (1962) and Wenzel (1942).

Most historical aquifer-test data included pump rate or yield in gallons per minute and drawdown, in feet. These data were used to estimate the hydraulic properties (specific capacity and transmissivity) in the study area. Specific capacity can be used to provide the maximum yield for a well and to estimate the transmissivity of an aquifer. Specific capacity is obtained by dividing the pump rate or yield by the total drawdown. Using the Jacob modified formula (Cooper and Jacob, 1946), Driscoll (1986) developed an approximating formula for estimating transmissivity from specific capacity in confined and unconfined aquifers. Transmissivity was estimated from specific capacity using Driscoll's equation for an unconfined aquifer if previously published transmissivity values were not available (Driscoll, 1986, appendix 16D). Driscoll's equation is:

$$T = 1{,}500 \times Q/s \text{ (for an unconfined aquifer)} \qquad (1)$$

where

T is transmissivity, in gallons per day per foot of drawdown;

Q is well yield or pumping rate, in gallons per minute;

s is drawdown at any point in the vicinity of a well discharging at a constant rate, in feet; and

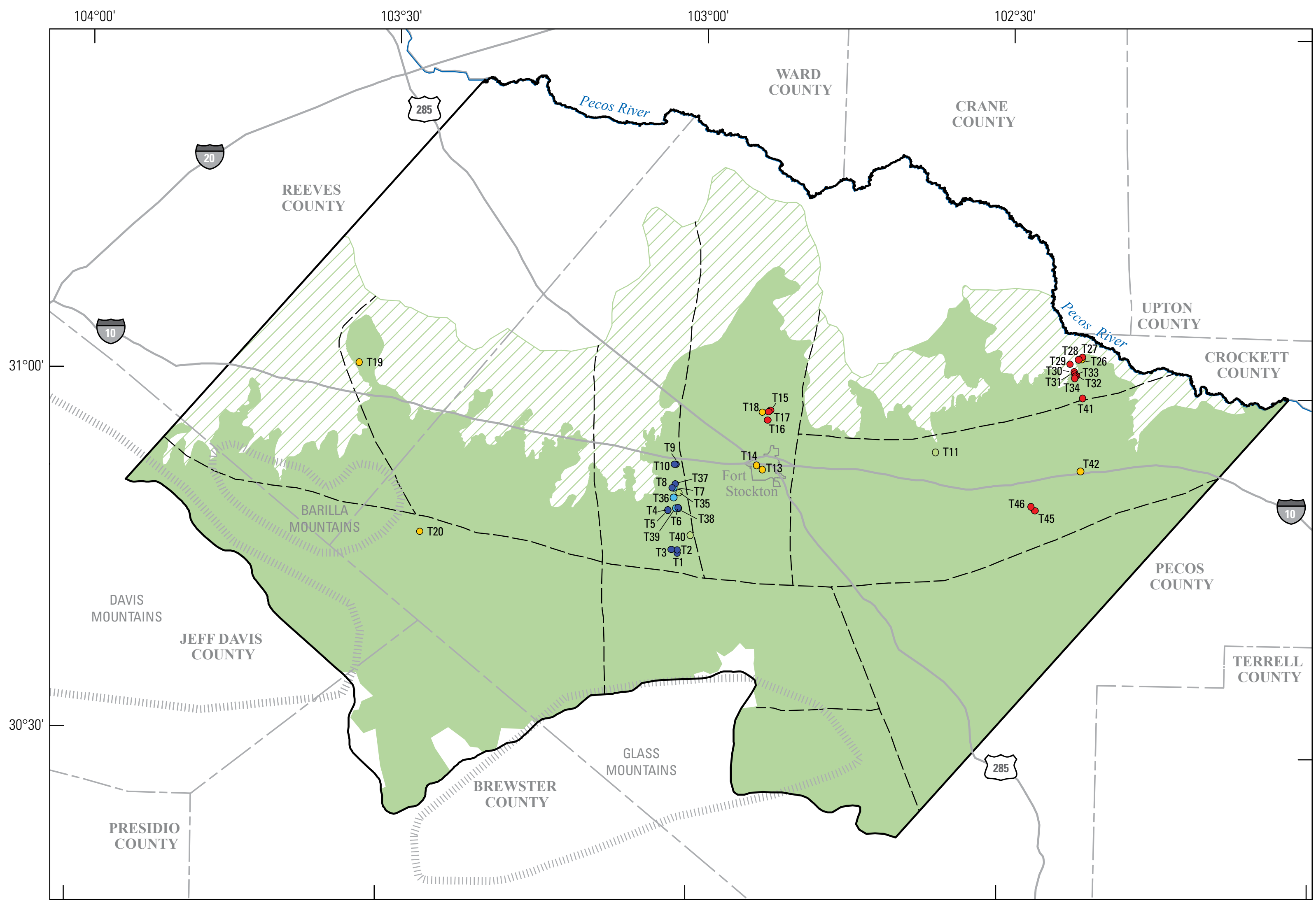
Q/s is specific capacity, in gallons per minute per foot of drawdown.

The calculated and estimated transmissivity values ranged from 1,500 to 1,216,000 gallons per day per foot of drawdown [(gal/d/ft)]. The transmissivity value and data source for each well used in this dataset are shown in table 4, at end of report.

Figure 19 shows the distribution of the log of transmissivity values measured in the Edwards-Trinity aquifer in the study area. Although the tests were done at different pumping rates and durations, which limits direct comparison of the results, the map provides a general understanding of transmissivity distributions across the study area. The highest transmissivity values were measured in the Monument Draw trough (fig. 2), which is also one of the thickest parts of the Edwards-Trinity aquifer, and the lowest values were measured in the eastern part of the study, near some of the thinnest parts of the aquifer. Hydraulic conductivity values, which were calculated using the transmissivity values and estimated saturated thickness of the aquifer (Ritzema, 1994), generally showed the same patterns as the transmissivity values (table 4). Faulting within the FB03 fault block (figs. 17–18) in the Leon-Belding area of the Monument Draw trough (figs. 1–2) likely contributed to higher transmissivity values in that area.

Geochemistry

Variations in the chemistry of groundwater are caused by constituents dissolved in water, reactions among these constituents, reactions between these constituents and minerals in the rocks through which the water flows (water-rock



Base modified from U.S. Geological Survey, 1:2,000,000-scale digital data
Albers Equal Area Projection, Texas State Mapping System
North American Datum of 1983

Aquifer modified from Ashworth and Hopkins, 1995

0 5 10 15 20 MILES

0 5 10 15 20 KILOMETERS

EXPLANATION

Edwards-Trinity aquifer (outcrop)

Edwards-Trinity aquifer (subcrop)

Study area boundary

Fault zone—Represents numerous faults

Aquifer-test sites and site identification number (table 4)—Log of transmissivity, in gallons per day per foot of drawdown

T46 **7.31–8.80**

T14 **8.81–10.28**

T35 **10.29–11.77**

T36 **11.78–13.25**

T37 **13.26–14.74**

Figure 19. The log of transmissivity values calculated and estimated using aquifer-test data from wells completed in the Edwards-Trinity aquifer in the Pecos County region study area, Texas.

interaction), and mixing of water from different sources (Hem, 1992; Small and Ozuna, 1993). Interpreting chemical variability in an aquifer provides insight into the quality of the groundwater, hydrologic flow paths, potential recharge sources, extent of water-rock interaction, and groundwater mixing pathways. In order to assess the groundwater chemistry (geochemistry) of the Pecos County region, geochemical samples were collected in the study area in 2010 and 2011 from 38 wells completed in the Pecos Valley, Igneous, Edwards-Trinity, Rustler, Dockum, and Capitan Reef aquifers and four springs as part of the first phase of this study (fig. 20, table 5 at end of report). Pearson and others (2012) describe the methods used for collection, laboratory analysis, and quality control of the data that were collected or compiled for the study area and used in this report. An important revision and update in this report is aquifer codes for several wells contained in the geodatabase, which was developed by Pearson and others (2012), were changed when the sampling interval of the wells were compared to the hydrogeologic framework developed in this phase of the study (table 6 at end of report).

Analysis of the geochemical samples provided insight into the chemical characteristics of water from different sources and different aquifers. Distinct chemical characteristics of these water samples were used to qualitatively evaluate aquifer interaction, groundwater-flow paths, water-rock interaction, mixing of water from different sources, and to identify likely source waters and geochemical endmembers.

Although the Edwards-Trinity aquifer was the focus of the geochemical sampling, samples were collected from other aquifers in the groundwater system in an effort to understand how water from these sources might interact with and affect the Edwards-Trinity aquifer. Only those analytical results most relevant to the understanding of flow paths, potential recharge sources, and mixing pathways of the groundwater system are discussed in this report. Geochemical results are available from the U.S. Geological Survey National Water Information System (NWIS) (U.S. Geological Survey, 2011) and from Pearson and others (2012).

Overview of Geochemical Data

Geochemical physical properties and constituents used to evaluate aquifer interaction, groundwater-flow paths, water-rock interaction, and mixing of water in the groundwater system include specific conductance, hydrochemical facies, sulfate and chloride concentrations, silica concentrations, stable isotopes of oxygen and hydrogen, strontium isotopes, environmental tracers, and concentrations of organic compounds and nutrients (tables 7 and 8 at end of report). These results were used in combination to identify the chemical characteristics of water from different sources and to determine how water from different sources might be mixing in the groundwater system. The qualitative geochemical analysis does not include a quantitative evaluation of residence times in the aquifer nor does it include geochemical flow-path modeling of the groundwater system.

Specific Conductance

Specific conductance measures the ability of water to conduct an electrical current and is related to the ion concentration; typically, there is a monotonic relation between specific conductance and the dissolved-solids concentration (Hem, 1992). The specific-conductance values measured in waters in the study area (table 7) are comparable to previously published data (Small and Ozuna, 1993; Uliana and Sharp, 2001; Thornhill Group, Inc., 2008; Texas Water Development Board, 2011). Specific-conductance values were generally quite variable within and between different aquifers. Higher specific conductance values reflecting more saline water were associated with relatively high concentrations of selected major ions, including chloride (Cl), sulfate (SO_4), sodium (Na), calcium (Ca), and magnesium (Mg). Rainwater has very low specific conductance values (specific-conductance values usually less than 25 microsiemens per centimeter at 25 degrees[µS/cm]) (National Atmospheric Deposition Program, 1997). Compared to rainwater, groundwater typically has higher specific conductance resulting from the dissolution of subsurface minerals and rock matrix. Specific conductance in geochemical samples collected in the study area ranged from 273 to 7,260 µS/cm (table 7). The higher specific conductance values in the study area might be caused by the groundwater mixing with more saline groundwater or dissolution of evaporites. In the absence of other sources of salinity, specific conductance values would likely increase along groundwater-flow paths as a result of progressive water-rock interaction.

Specific conductance of water in the four Pecos Valley aquifer wells ranged from 362 to 1,690 µS/cm with an average value of 1,020 µS/cm and median value of 1,020 µS/cm (fig. 20, table 7). Samples collected from sites Q7 and Q15, which are wells completed in the Igneous aquifer, had specific conductance values of 331 and 408 µS/cm, respectively. The average specific conductance value measured in samples from the Igneous aquifer (370 µS/cm) was the lowest of the sampled hydrostratigraphic units. Specific conductance values measured in the samples collected from 20 wells completed in the Edwards-Trinity aquifer ranged from 273 to 7,260 µS/cm with an average value of 2,340 µS/cm and median value of 1,830 µS/cm. The large range of specific conductance values in samples collected from the Edwards-Trinity aquifer indicates that processes such as mixing with recent, local recharge, mixing with more saline water sources, and progressive water-rock interaction along regional groundwater-flow paths might influence groundwater compositions. Higher specific conductance values in the Edwards-Trinity aquifer (relative to the median) generally were measured in samples collected from wells completed in the Monument Draw trough (sites Q14, Q16, Q18, Q22, Q23, Q24, Q26, and Q37); from site Q35, which

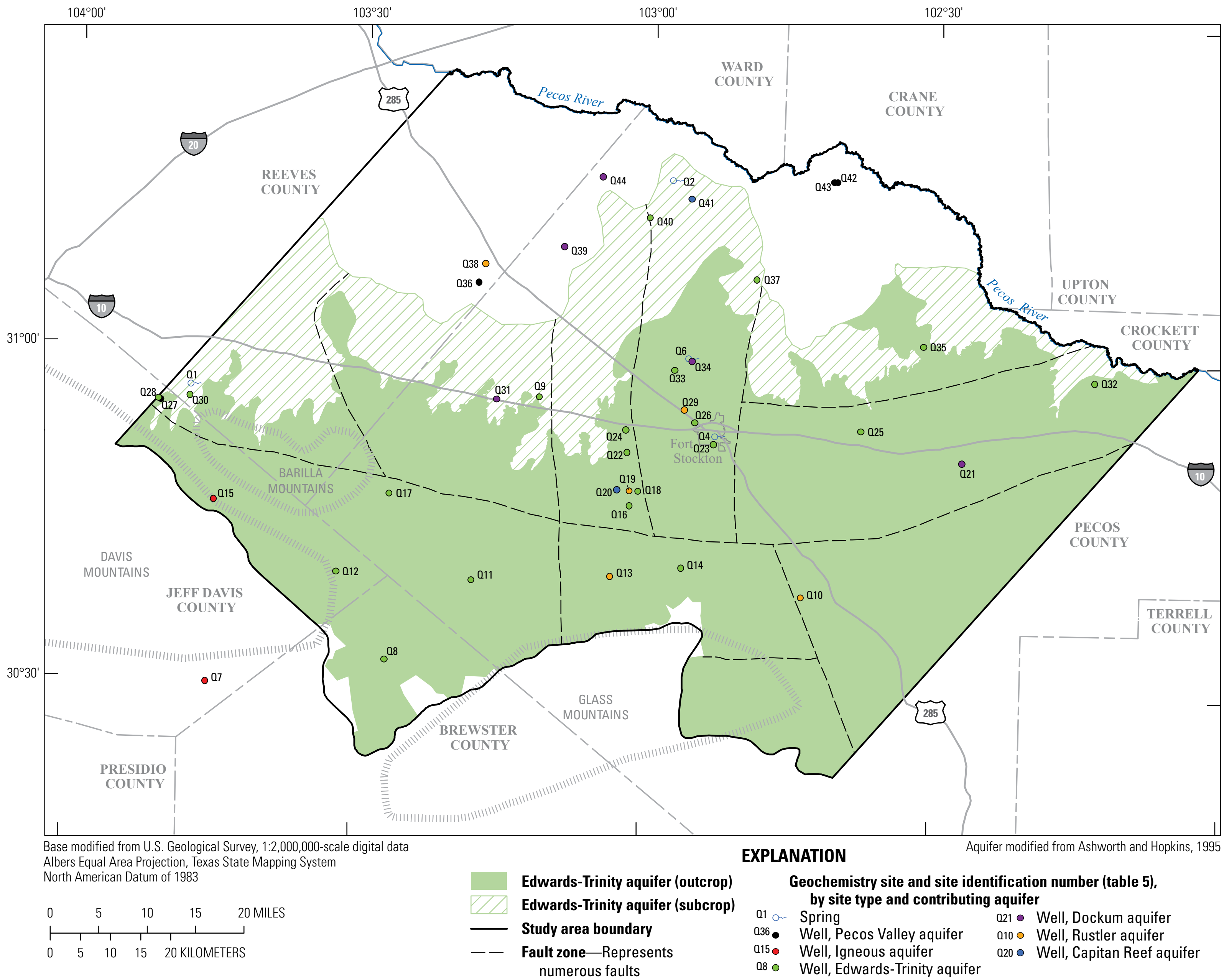


Figure 20. Locations of groundwater-well and spring sites for geochemical data collection in the Pecos County region study area, Texas.

is located near the down-dip extent of the aquifer; and from site Q30, which is near the western boundary of the study area. Specific conductance values in samples collected from the five wells completed in the Dockum aquifer ranged from 736 to 3,200 µS/cm with an average value of 1,680 µS/cm and median value of 1,560 µS/cm. Specific conductance values in samples collected from the five wells completed in the Rustler aquifer ranged from 553 to 3,980 µS/cm with an average value of 2,030 µS/cm and median value of 2,050 µS/cm. Samples collected from sites Q20 and Q41, which are wells completed in the Capitan Reef aquifer, had specific conductance values of 2,290 and 4,160 µS/cm, respectively. The average specific-conductance value measured in samples from the Capitan Reef aquifer (3,230 µS/cm) was the highest of the sampled hydrostratigraphic units. The specific conductance measured in samples collected from the four springs in the study area (sites Q1, Q2, Q4, and Q6) ranged from 2,430 to 6,730 µS/cm with an average value of 4,710 µS/cm and median value of 4,840 µS/cm. The average specific-conductance value measured in samples from the spring sites was higher than the samples collected from any of the hydrostratigraphic units (fig. 20, table 7).

Hydrochemical Facies

The composition of groundwater principally is controlled by the composition of recharge water, water-rock interaction, and the mixing of water from different sources. The term “facies” refers to a classification scheme used to describe water in terms of the major cation and anion milliequivalents composition (figs. 20 and 21, table 7). A trilinear (“Piper”) diagram (Piper, 1953) is a useful tool for evaluating the relative abundance of major cations and anions and classifying facies or water types. Hydrochemical facies were complex and varied between and within the aquifers in the study area. Variations in facies were predominantly associated with different locations in the study area and likely result from localized groundwater processes and progressive mineralization along groundwater-flow paths. Facies ranged from simple, such as Na-HCO_3 type water, to complex, such as Na-Ca-Mg-SO_4-Cl-HCO_3 type water.

Sulfate and Chloride Concentrations

Variations in SO_4 and Cl concentrations in groundwater and their relations with other major and trace elements can be used to qualitatively assess water-rock interaction with evaporite deposits, such as anhydrite ($CaSO_4$), gypsum ($CaSO_4 \cdot 2H_2O$), and halite (NaCl). The groundwater SO_4 and Cl concentrations measured in the study area (figs. 20 and 22, table 7) are comparable to previously published data (Small and Ozuna, 1993; Uliana and Sharp, 2001; Thornhill Group, Inc., 2008; Texas Water Development Board, 2011) and the variability in ranges generally corresponded with specific conductance. SO_4 concentrations in the Pecos Valley aquifer ranged from 11.8 to 3,020 milligrams per liter (mg/L) with an average value of 1,440 mg/L and median value of 1,360 mg/L, and Cl concentrations ranged from 7.16 to 4,770 mg/L with an average of 2,190 mg/L and median value of 2,000 mg/L. SO_4 concentrations were 12.9 and 16.0 mg/L and Cl concentrations were 8.39 and 8.81 mg/L for samples from wells completed in the Igneous aquifer (sites Q7 and Q15, respectively). SO_4 concentrations in the Edwards-Trinity aquifer ranged from 12.2 to 2,010 mg/L with an average value of 537 mg/L and median value of 358 mg/L, and Cl concentrations ranged from 5.16 to 1,370 mg/L with an average value of 363 mg/L and median value of 282 mg/L. Relatively higher concentrations of both SO_4 and Cl were measured in samples collected from Edwards-Trinity aquifer sites Q14, Q16, Q18, Q22, Q23, Q24, Q26, Q30, Q35, and Q37, which are the same wells with relatively high specific conductance. SO_4 concentrations in the Dockum aquifer ranged from 91.8 to 586 mg/L with an average value of 296 mg/L and median value of 335 mg/L, and Cl concentrations ranged from 58.2 to 675 mg/L with an average value of 265 mg/L and median value of 195 mg/L. SO_4 concentrations in the Rustler aquifer ranged from 52.5 to 2,270 mg/L with an average value of 748 mg/L and median value of 357 mg/L, and Cl concentrations ranged from 23.5 to 332 mg/L with an average value of 194 mg/L and median value of 179 mg/L. SO_4 concentrations in samples collected from wells completed in the Capitan Reef aquifer (sites Q20 and Q41) were 421 and 2,320 mg/L, and Cl concentrations were 370 and 354 mg/L, respectively. The SO_4 concentration relative to the Cl concentration measured in samples collected from two sites (site Q29, completed in the Rustler aquifer and site Q41, completed in the Capitan Reef aquifer), deviated from the generally linear pattern of the rest of the measured values (fig. 22). The relatively higher concentration of SO_4 at these sites indicates groundwater interaction with a higher SO_4 source compared to the other sites, possibly from evaporite deposits of anhydrite and gypsum. SO_4 concentrations measured in spring water (sites Q1, Q2, Q4, and Q6) ranged from 437 to 1,890 mg/L with an average value of 1,220 mg/L and median value of 1,270 mg/L, and Cl concentrations ranged from 431 to 1,220 mg/L with an average value of 849 mg/L and median value of 873 mg/L.

Silica Concentrations

Variations in silica (Si) concentrations in groundwater can be used to qualitatively assess water-rock interaction with rocks composed of silicate minerals (Hem, 1992). The groundwater Si concentrations measured in the study area (fig. 20, table 7) are comparable to previously published data (Texas Water Development Board, 2011). Si concentrations in the Pecos Valley aquifer ranged from 22.6 to 53.5 mg/L with an average value of 34.0 mg/L and median value of 29.8 mg/L. Si concentrations were 43.6 and 43.4 mg/L in samples collected from wells completed in the Igneous aquifer (sites Q7 and Q15, respectively) with an average value of 43.5 mg/L, which was the highest average value among the

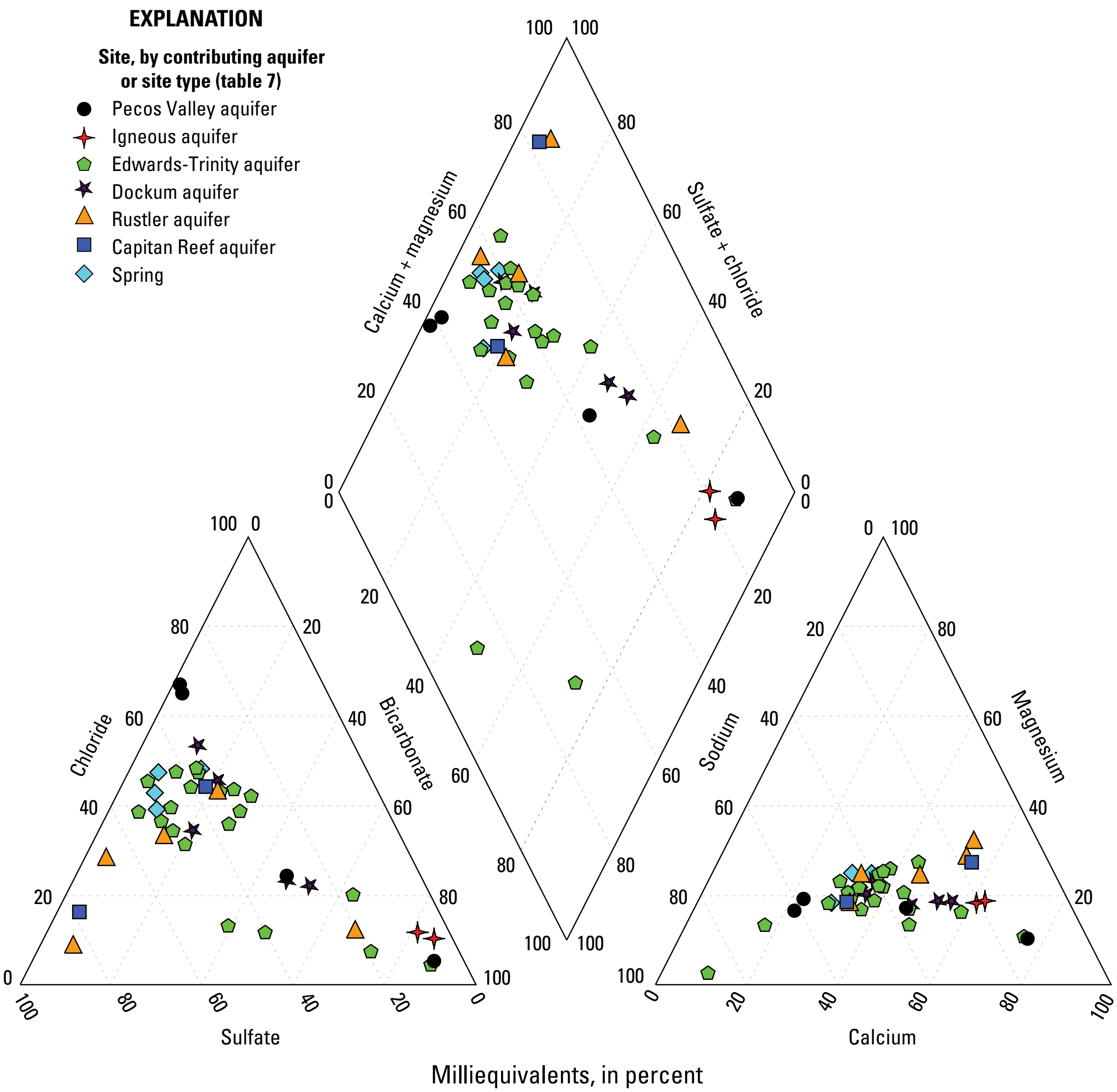


Figure 21. Trilinear diagram showing relations between major cations and anions in groundwater and spring water collected in the Pecos County region study area, Texas.

aquifers. Si concentrations in the Edwards-Trinity aquifer ranged from 10.4 to 52.0 mg/L with an average value of 21.6 mg/L and median value of 20.8 mg/L. Si concentrations in the Dockum aquifer ranged from 11.1 to 30.9 mg/L with an average value of 19.8 mg/L and median value of 16.2 mg/L. Si concentrations in the Rustler aquifer ranged from 0.479 to 19.6 mg/L with an average value of 13.4 mg/L and median value of 14.0 mg/L. Si concentrations in samples collected from wells completed in the Capitan Reef aquifer (sites Q20 and Q41) were 21.0 and 13.9 mg/L. Si concentrations measured in spring water ranged from 22.8 to 35.4 mg/L with an average value of 28.9 mg/L and median value of 28.7 mg/L.

Stable Isotopes

Citing the work of Faure (1986), Uliana and others (2007, p. 338) noted that oxygen and hydrogen isotopes of the water molecule are indicators of conditions present at the time and place of groundwater recharge. The ratios of oxygen-18/oxygen-16 isotopes ($\delta^{18}O$ in per mil) and hydrogen-2/hydrogen-1 (δD in per mil) are compared to the global meteoric water line (MWL) of Craig (1961), which represents the composition of rainfall around the globe. Stable isotope values for groundwater and spring water in the study area also were compared to annual weighted mean precipitation values (-6.50 per mil and -44.0 per mil for $\delta^{18}O$ and δD, respectively,

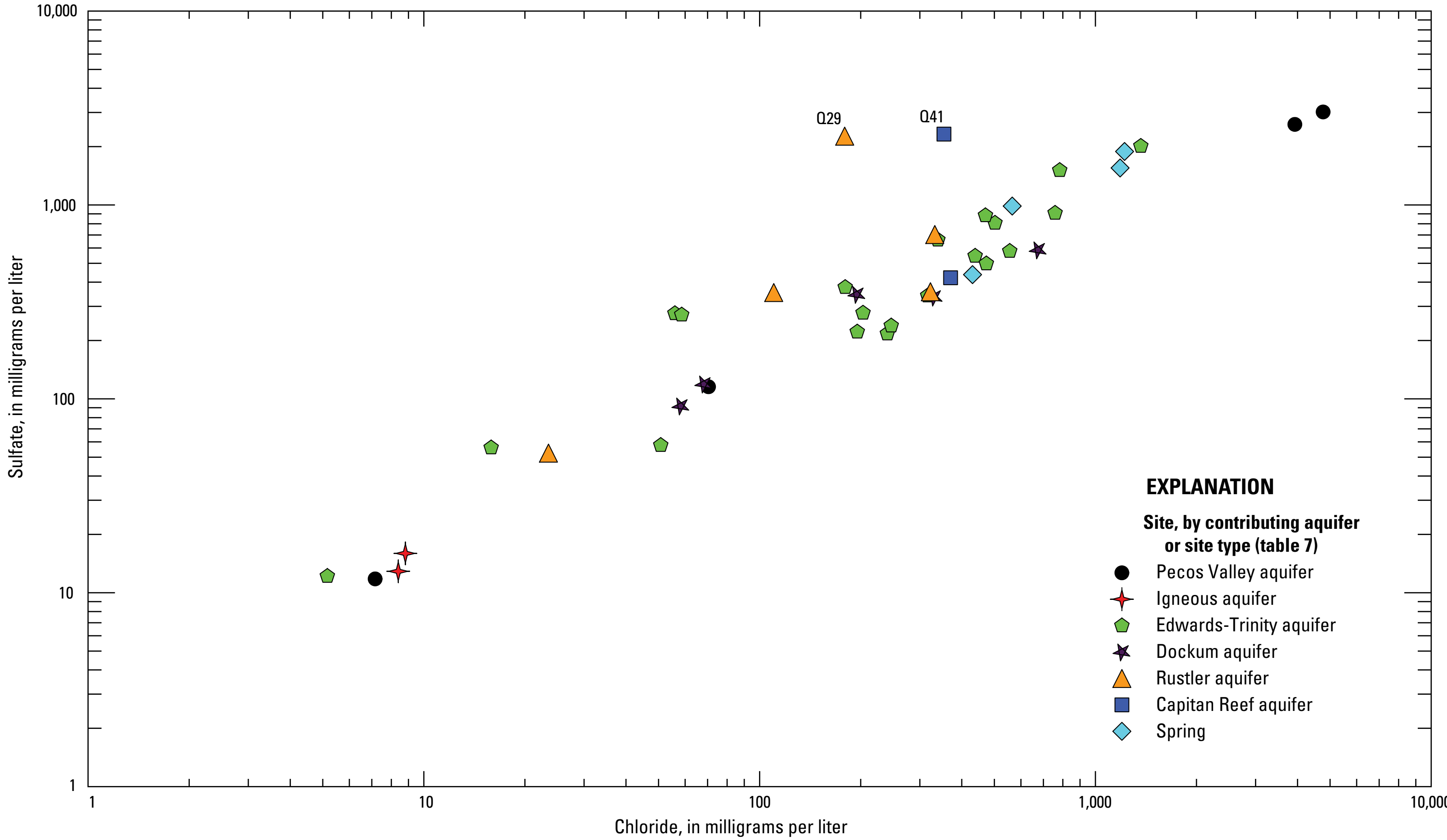


Figure 22. Relation between sulfate concentrations and chloride concentrations for samples collected from groundwater and spring sites in the Pecos County region study area, Texas.

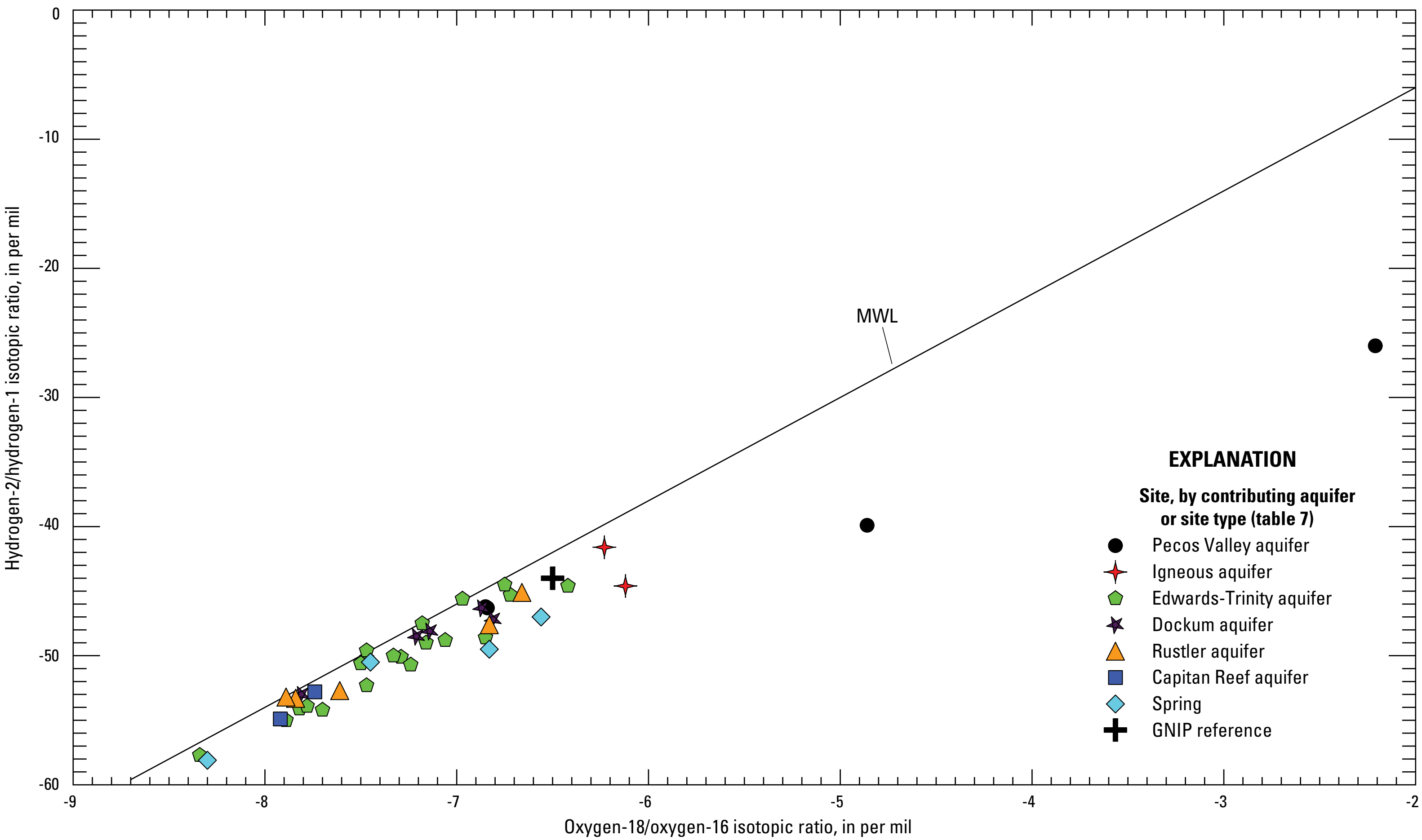
1962–1988) from the nearest Global Network of Isotopes in Precipitation (GNIP) station (site 7622500 at Chihuahua, Mexico, about 300 miles southwest of Fort Stockton, Tex., at an altitude of about 4,670 ft [International Atomic Energy Agency, 2011]) and to estimates of stable isotope values in precipitation for the Trans-Pecos region made by Uliana and others (2007). Stable isotope results of samples collected for this study were compared to those of Uliana and others (2007) to help determine if the isotopic compositions measured were consistent with recent, local recharge (recharge during the Holocene and in the study area) or if the isotopic composition was indicative of other hydrologic processes (fig. 23, table 7). Uliana and others (2007) estimated that precipitation presently occurring to the south and west of the study area would have $\delta^{18}O$ values that range from -7.50 to -5.70 per mil. Stable isotope values that plot along the MWL near the present precipitation estimates likely reflect a dominant component of water that recharged under recent, local climatic conditions (hereinafter referred to as young water). Values that plot along the MWL and lower than the present precipitation estimates are consistent with a component of water that recharged during the wetter, cooler climate of the late Pleistocene (hereinafter referred to as old water) (Uliana and others, 2007). For the purposes of this study, samples with $\delta^{18}O$ values from -8.34 per mil (the lowest measured value, at site Q30) to -7.50 per mil are considered to be dominated by old water; values greater than -7.50 per mil are considered to be young water. Values that substantially deviate from the MWL indicate that the water has been affected by processes such as evaporation or extensive water-rock interaction.

The $\delta^{18}O$ and δD values for samples collected in the Pecos County region study area are comparable to those reported by Uliana and others (2007). Groundwater in the Pecos Valley aquifer is predominately consistent with recent, local recharge (figs. 20, 23, and 24, table 7). The values measured in samples collected from sites Q42 and Q43 in the Pecos Valley aquifer substantially deviate from the MWL and indicate some evaporation of the water likely occurred prior to recharge (fig. 23). $\delta^{18}O$ and δD values for samples from the Igneous aquifer had the highest values along the MWL; these samples likely represent recent, local recharge water. $\delta^{18}O$ and δD values for samples from the Edwards-Trinity aquifer lie along the MWL but cover a broad range from -8.34 to -6.42 per mil in $\delta^{18}O$ values; this range, with values higher and lower than -7.50, indicates that the Edwards-Trinity aquifer groundwater samples include varying mixtures of recent, local recharge and water that recharged during different climatic conditions. The lowest Edwards-Trinity aquifer $\delta^{18}O$ value was measured at site Q30, which is interpreted to be dominated by older (Pleistocene) recharge; the highest value, which was similar to values measured for the Igneous aquifer, was measured in samples from site Q9, which is consistent with recent, local recharge. $\delta^{18}O$ and δD values for samples from the Dockum aquifer are consistent with recent, local recharge. $\delta^{18}O$ and δD values measured for samples from the Rustler aquifer in the Monument Draw trough (sites Q13, Q19, and Q29), from the Capitan Reef aquifer, and from San Solomon and Comanche springs (sites Q1 and Q4, respectively) indicate these water samples are dominated by older recharge. The values for samples from the remaining two Rustler wells (sites Q10 and Q38) indicate the groundwater reflects recent, local recharge. $\delta^{18}O$ and δD values for samples from Santa Rosa and Diamond Y springs (sites Q2 and Q6, respectively) are consistent with recent, local recharge, but also fall slightly below the MWL. Because a discharge orifice could not be located at either of these springs, pools created by the springs were sampled (Pearson and others, 2012). Evaporation could have occurred from the pool and surface runoff from land adjacent to the spring pools could also have flowed into these pools. The extent of these processes is unknown but might account for stable isotope values slightly below the MWL.

Strontium Isotopes

Strontium (Sr) commonly substitutes for Ca in mineral complexes in low-temperature aqueous geochemical environments and is a common trace element in carbonate rocks (Musgrove and others, 2009; Banner, 2004). As a result, Sr isotopes have been used to evaluate sources of dissolved constituents to groundwater and water-rock interaction processes and to gain insights into regional groundwater-flow paths and groundwater mixing (Musgrove and Banner, 1993; Banner and others, 1994; Uliana and others, 2007; Musgrove and others, 2009). The Sr isotopic ratio ($^{87}Sr/^{86}Sr$) often provides a useful diagnostic signal of the source of dissolved constituents to a fluid because $^{87}Sr/^{86}Sr$ undergoes negligible fractionation during mineral-solution reactions (Banner, 2004). This lack of fractionation makes them particularly useful in tracing regional groundwater-flow paths and identifying mixing relations in regional flow systems (Banner and Kaufman, 1994). Uliana and others (2007) detail the origins of many $^{87}Sr/^{86}Sr$ signatures in the Trans-Pecos region.

Because of water-rock interaction processes and negligible fractionation, groundwater that is in equilibrium with the strontium-bearing minerals in aquifer rocks is expected to have $^{87}Sr/^{86}Sr$ values that reflect the isotopic ratio of the minerals (Banner and Kaufman, 1994; Uliana and others, 2007). The average $^{87}Sr/^{86}Sr$ value reported by Cameron and others (1996) for igneous rocks in the Davis Mountains was 0.7067 and Uliana and others (2007) used a range of values from 0.7030 to 0.7080. Permian and Cretaceous-age carbonate and evaporite rocks should range from 0.7068 to 0.7084 (Burke and others, 1982; Brookins 1988; Denison and others, 1998). In general, siliciclastic rocks often have higher $^{87}Sr/^{86}Sr$ values than carbonate rocks because many siliciclastics contain rubidium-87 (^{87}Rb)-bearing minerals (Faure, 1986). ^{87}Rb is radioactive and decays to ^{87}Sr, which increases the $^{87}Sr/^{86}Sr$ ratios in siliciclastic rocks. Therefore, the siliciclastic rocks that compose the Pecos Valley and Dockum aquifers, as well as siliciclastic rocks that are components of the predominately carbonate Permian and Cretaceous-age units (table 1), likely have higher $^{87}Sr/^{86}Sr$



[MWL, global meteroric water line; GNIP, Global Network of Isotopes in Precipitation station 7622500 at Chihuahua, Mexico]

Figure 23. Relation between oxygen-18/oxygen-16 and hydrogen-2/hydrogen-1 isotopic ratios for samples collected from groundwater and spring sites in the Pecos County region study area, Texas, and the global meteoric water line (Craig, 1961).

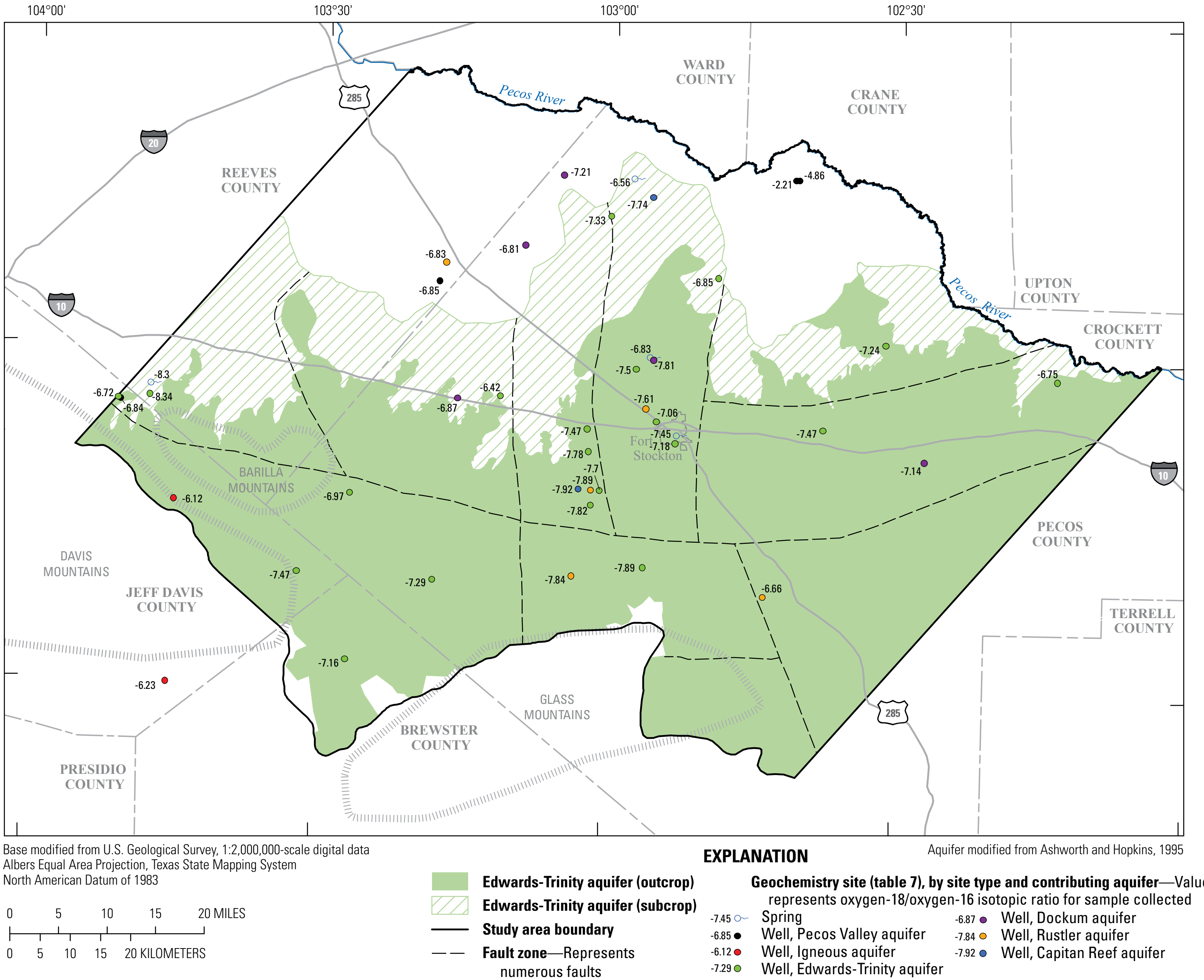


Figure 24. Oxygen-18/oxygen-16 isotopic ratios for samples collected from groundwater and spring sites in the Pecos County region study area, Texas.

values than the carbonate rocks in the groundwater system. For example, although outside the Pecos County region study area, Langman and Ellis (2010) reported a $^{87}Sr/^{86}Sr$ value of 0.7091 for a rock sample collected from the Dockum Group in the southern High Plains region of Texas.

Ratios of $^{87}Sr/^{86}Sr$ measured in water samples collected in the study area (figs. 20, 25, and 26, table 7) are comparable to those reported by Uliana and others (2007). Ratios of $^{87}Sr/^{86}Sr$ in samples collected from the Pecos Valley aquifer ranged from 0.70799 to 0.70839. $^{87}Sr/^{86}Sr$ values in samples collected from the Igneous aquifer were 0.70727 and 0.70757 (sites Q7 and Q15, respectively). These values were low relative to the other aquifers, reflecting interaction with low $^{87}Sr/^{86}Sr$ igneous rocks. $^{87}Sr/^{86}Sr$ values in samples collected from the Edwards-Trinity aquifer covered a broad range from 0.70788 to 0.70979; the higher $^{87}Sr/^{86}Sr$ values in this range (greater than 0.70900) were measured in samples from nearly all of the wells completed in the Monument Draw trough: site Q25, in the eastern part of the study area, site Q11 in the southern part of the study area, and site Q30 near the western boundary of the study area (fig. 20). Also, because 14 of the 20 Edwards-Trinity aquifer $^{87}Sr/^{86}Sr$ values were higher than the expected range of values for groundwater interacting with Cretaceous-age carbonate rocks (0.7068 to 0.7084; Burke and others, 1982), it is expected that there are alternative or additional sources (siliciclastics) of Sr within the interpreted complex stratigraphy and structural geology of the Pecos County region (fig. 2, table 1). $^{87}Sr/^{86}Sr$ values in samples collected from the Dockum aquifer ranged from 0.70843 to 0.70975; values greater than 0.70900 were measured at site Q34, which is a well completed in Monument Draw trough, and at site Q21, which is near the eastern boundary of the study area. $^{87}Sr/^{86}Sr$ values in samples collected from the Rustler aquifer ranged from 0.70758 to 0.70977 and $^{87}Sr/^{86}Sr$ values in samples collected from the Capitan Reef aquifer sites Q20 and Q41 were 0.70969 and 0.70751, respectively. Like Cretaceous-age carbonate rocks, the expected range of $^{87}Sr/^{86}Sr$ values for water interacting with the Permian-age carbonate and evaporite rocks of the Rustler and Capitan Reef aquifers is from 0.7068 to 0.7084 (Brookins 1988; Denison and others, 1998), and values higher than this range indicate an alternative or additional source for Sr in the groundwater. $^{87}Sr/^{86}Sr$ ratios in samples collected from the four springs ranged from 0.70898 to 0.70991 and were generally high relative to other samples and higher than the values expected for groundwater interacting with carbonate and evaporite rocks of Permian and Cretaceous age.

Environmental Tracers

Among their many uses, environmental tracers are useful for understanding when groundwater recharge occurred, isolating the water from the atmosphere. Samples were collected at select sites in the study area and analyzed for tritium (^{3}H) and (or) helium-3 (^{3}He) to gain insights regarding the age of the groundwater. ^{3}H is a radioactive isotope of hydrogen with a half-life of 12.32 years and commonly is measured in picocuries per liter (pCi/L) or tritium units (TU), in which 3.22 pCi/L equals 1 TU (Lucas and Unterweger, 2000). ^{3}H in rainfall has two sources, natural cosmogenic ^{3}H or that produced by the widespread atmospheric testing of nuclear weapons that began around 1950 and continued until about 1970. Given its relatively short half-life, the presence of ^{3}H in groundwater is indicative of groundwater recharge that occurred in the last 60 years (that is “post-bomb” recharge; Clark and Fritz, 1997). The input of ^{3}H to the atmosphere as a result of nuclear testing elevated ^{3}H concentrations in rainfall compared to pre-bomb concentrations for more than 50 years (beginning in the 1950s), with concentrations peaking in the 1960s. ^{3}H concentrations in rainfall since 2006 have globally decreased to approximately pre-bomb background levels of about 2 to 10 TU (Clark and Fritz, 1997; Phillips and Castro, 2003).

Interpreting groundwater ages with ^{3}H is qualitative in that it can provide insight into distinguishing between pre-bomb and post-bomb water but not determine apparent ages. The $^{3}H/^{3}He$ method, which is based on the radioactive decay of ^{3}H to ^{3}He, can be used to estimate groundwater ages at a higher resolution than using only ^{3}H concentrations (Schlosser and others, 1988; Schlosser and others, 1989; Solomon and Cook, 1999). Samples were collected for ^{3}H-^{3}He analysis, but these results were not available at the time this report was prepared (March 2012). ^{3}H decay is not the only possible source of ^{3}He, and groundwater-age determination required an assessment of other possible ^{3}He sources. That assessment typically includes measurement of helium-4 (^{4}He) to aid in distinguishing between He sources (Thatcher and others, 1977).

Sites with ^{3}H concentrations greater than 1 TU were considered to potentially represent water with a sufficient component of post-bomb water for ^{4}He screening and potential $^{3}H/^{3}He$ dating (fig. 20, table 8). Eight of the 23 samples had ^{3}H concentrations greater than 1 TU (sites Q4, Q7, Q15, Q17, Q23, Q27, Q28, and Q43). ^{4}He screening results indicated that the samples from all of these sites are potentially datable using the $^{3}H/^{3}He$ method. Thus, based on the ^{3}H and ^{4}He concentrations, at least some component of the groundwater collected at these sites is likely post-bomb recharge. The low ^{3}H concentrations measured in the majority of collected samples (15 out of 23) indicate that groundwater in the study area likely is predominantly pre-bomb recharge.

Organic Compounds and Nutrients

Organic compound (pesticide and herbicide) and nutrient concentrations in groundwater in the study area are potential indicators of surface-water infiltration and anthropogenic influences on groundwater. Detectable concentrations of organic compounds in a groundwater sample likely result from infiltration of rain or irrigation water following the surface application of pesticides and herbicides. Nutrient concentrations in groundwater (predominantly in the form

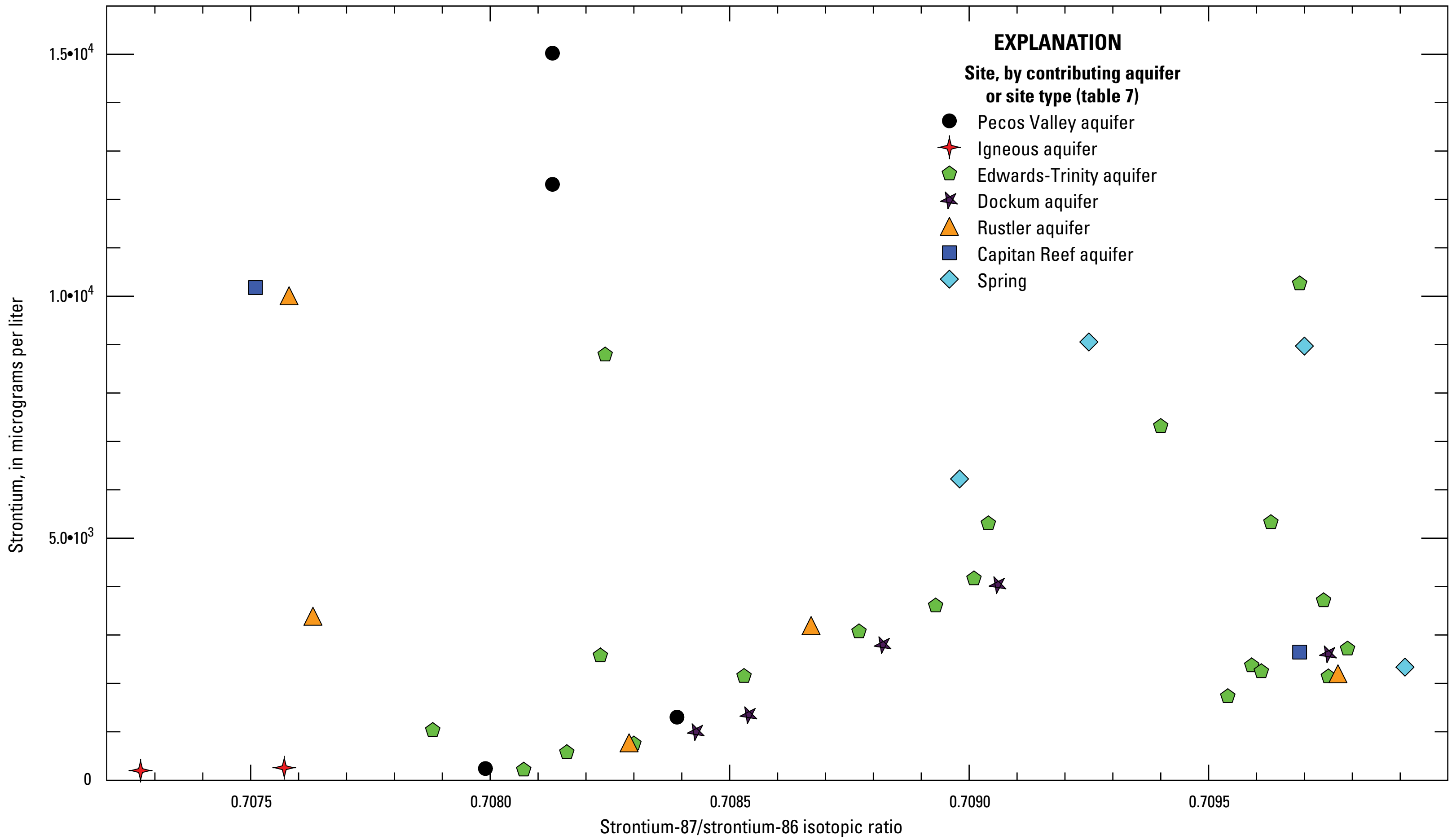


Figure 25. Relation between strontrium-87/strontium-86 isotopic ratio and strontium concentration for groundwater and spring samples collected in the Pecos County region study area, Texas.

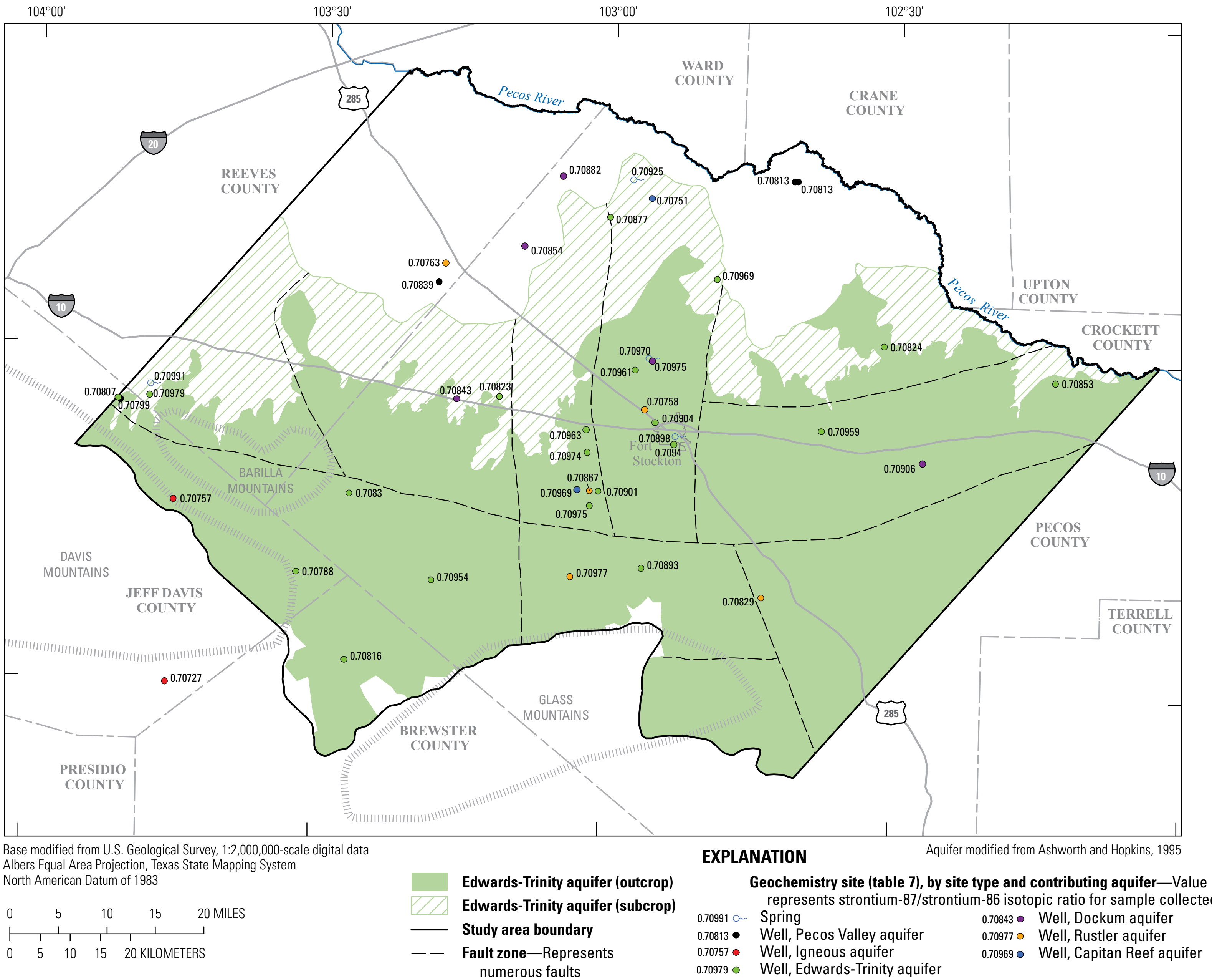


Figure 26. Strontium-87/strontium-86 isotopic ratios for samples collected from groundwater and spring sites in the Pecos County region study area, Texas.

of nitrate and nitrite) that are higher than the prevailing background concentration might result in agricultural or municipal areas as a result of input from livestock manure, septic systems, municipal treatment systems, or fertilizers. National background concentrations of nitrate in groundwater have been estimated to be 1.0 mg/L (Dubrovsky and others, 2010). Land-cover data obtained from the National Land Cover Dataset (NLCD) 2006 (Fry and others, 2011) show the distribution of land cover in the study area (fig. 27). Because of the small amount of developed areas and the presence of agricultural areas (shown as cultivated crops), the combined concentrations of nitrate and nitrite (NO_3+NO_2) were used to evaluate the potential presence of excess nutrients from irrigation, specifically cultivated crops, in the groundwater system.

Eight groundwater samples from the Igneous, Edwards-Trinity, and Dockum aquifers and two spring samples were analyzed for organic compounds, specifically pesticides and herbicides (table 7). Atrazine, a widely used herbicide, was detected in one sample collected from the Edwards-Trinity aquifer (site Q26) and one spring (site Q4). CIAT (deethylatrazine), an atrazine degradate, was detected in samples from three wells completed in the Edwards-Trinity aquifer (sites Q18, Q24, and Q26) and two springs (sites Q4 and Q6). The four deethylatrazine detections were qualified as estimated ("E") by the USGS National Water Quality Laboratory under laboratory reporting conventions used during the study period (Zaugg and others, 1995); a remark code of "E" indicates that a compound was identified at an estimated concentration, but concentration could not be accurately quantified. As explained in Oden and others (2011, p. 9), a constituent concentration is considered estimated by the laboratory when results are greater than the long-term method detection level and less than the laboratory reporting level. Deethylatrazine is permanently coded "E" because of poor laboratory recoveries. Sites with detectable concentrations (fig. 20) are in the Leon-Belding and Fort Stockton areas (fig. 1).

NO_3+NO_2 concentrations (as N) ranged from not detected (< 0.02) to 6.67 mg/L. Concentrations greater than 1 mg/L (table 7) were measured in samples collected from two wells completed in the Pecos Valley aquifer (sites Q27 and Q43). Concentrations of NO_3+NO_2 in samples collected from the two wells completed in the Igneous aquifer (sites Q7 and Q15) were less than 1 mg/L. NO_3+NO_2 concentrations were greater than 1 mg/L in 8 out of 20 samples collected from wells completed in the Edwards-Trinity aquifer. These sites include Q18, Q24, and Q26, which were also sites for which the samples contained detectable atrazine or deethylatrazine. NO_3+NO_2 concentrations were greater than 1 mg/L in three of the five samples collected from wells completed in the Dockum aquifer (sites Q21, Q39, and Q44) (fig. 20). NO_3+NO_2 concentrations were greater than 1 mg/L in only one of the five samples collected from wells completed in the Rustler aquifer (site Q10) and in none of the samples collected from wells completed in the Capitan Reef aquifer. NO_3+NO_2 concentrations were greater than 1 mg/L in samples collected from Santa Rosa, Comanche, and Diamond Y springs (sites Q2, Q4, and Q6, respectively). It is possible that the elevated NO_3+NO_2 concentrations measured in samples collected from Santa Rosa and Diamond Y springs (2.95 and 6.67 mg/L, respectively) reflect groundwater discharge, but it is also possible that edge-of-field surface runoff from land adjacent to the pools that occur where each spring discharges is the source of the elevated concentrations. Additionally, NO_3+NO_2 concentrations might also be affected by processes within the aquifers. While most groundwater samples were oxic (table 7), denitrification might be influencing NO_3+NO_2 concentrations in samples with low (less than 0.5 mg/L) dissolved oxygen concentrations.

Geochemical Endmembers

Geochemical endmembers in the groundwater system were selected based on variations in geochemical composition in order to qualitatively evaluate groundwater-flow paths and mixing processes. Selected endmembers were: (1) regional groundwater flow in the Edwards-Trinity aquifer that originated as recharge northwest of the study area and enters the study area near the western corner, (2) recharge entering the groundwater system along the southern boundary of the study area from the Barilla and Davis Mountains, (3) recharge entering the groundwater system at the southern study-area boundary from the Glass Mountains, and (4) regional groundwater flow in the Edwards-Trinity aquifer east of the Monument Draw trough. Although not denoted for the purposes of this report as geochemical endmembers, groundwater from the Dockum and Rustler aquifers likely mix with and affect groundwater compositions of the Edwards-Trinity aquifer.

The composition of the sample collected from site Q30 (fig. 20, tables 7 and 8), which is a well completed in the Edwards-Trinity aquifer in the western corner of the study area, was used to represent endmember 1: regional groundwater flow in the Edwards-Trinity aquifer entering the study area from the northwest. Endmember 1 was a Na-Ca-Cl-SO_4 type water; specific conductance was 2,710 µS/cm; SO_4 concentration was 498 mg/L; Cl concentration was 473 mg/L; $\delta^{18}O$ and δD values were -8.34 and -57.7 per mil, respectively; $^{87}Sr/^{86}Sr$ ratio was 0.70979; tritium concentration was 0.25 TU; no organic compounds were detected; and NO_3+NO_2 concentration was 0.135 mg/L. In summary, endmember 1 represents relatively mineralized, old water that likely recharged northwest of the study area under different climatic conditions and is flowing through the Edwards-Trinity aquifer along regional groundwater-flow paths.

Recharge along the southern boundary of the study area occurs as runoff from the mountains and moves vertically downward through underlying rocks and into the gravels along the slopes of the mountains (fig. 2) (Armstrong and McMillion, 1961; Small and Ozuna, 1993; Bochici, 1997; Uliana and Sharp, 2001; Uliana and others, 2007). There are

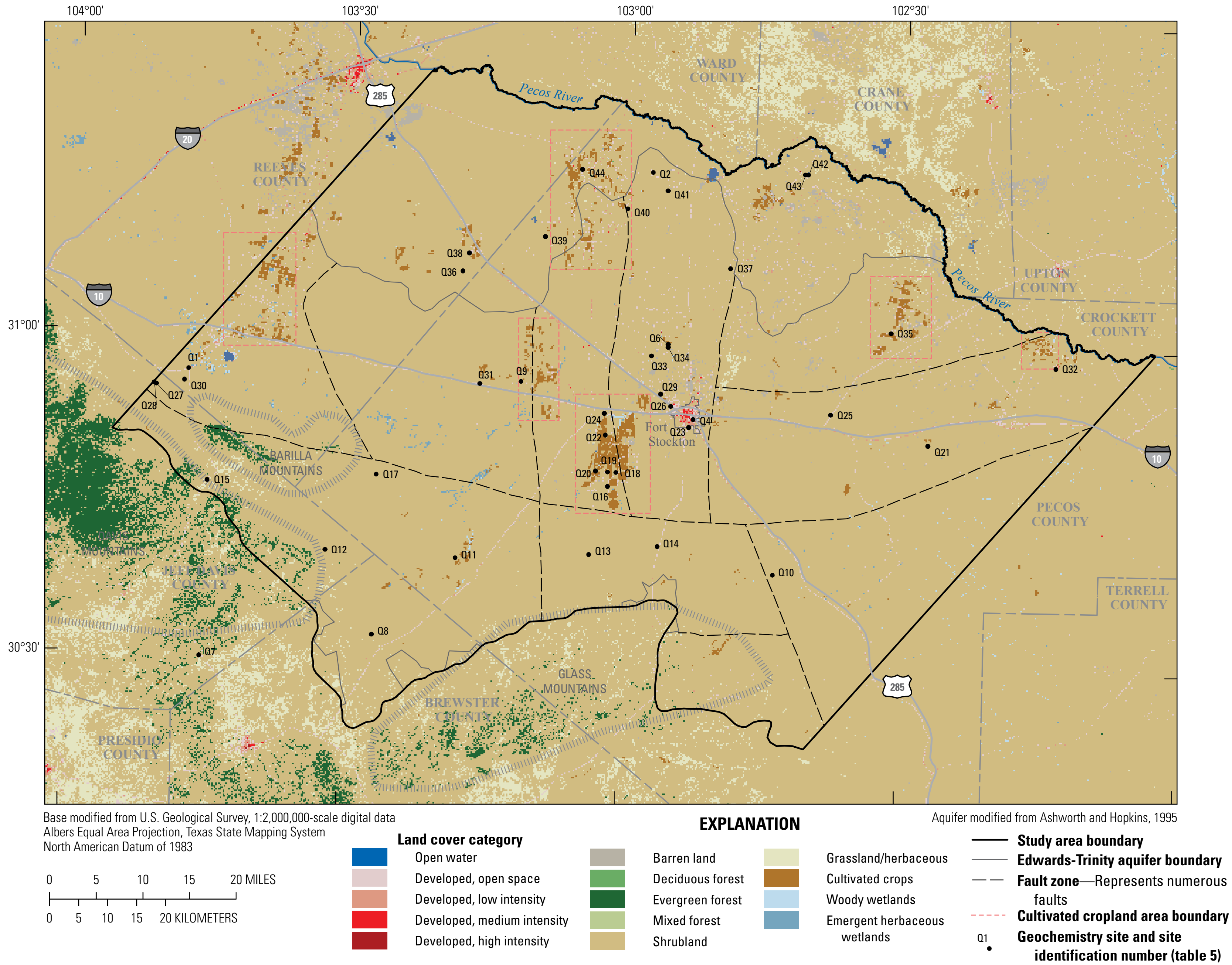


Figure 27. National Land Cover Database 2006 land-cover categories in the Pecos County region study area, Texas.

two distinct mountain-recharge endmembers because the Barilla and Davis Mountains are primarily igneous rocks composed of silicate minerals (endmember 2) and the Glass Mountains are sedimentary rocks composed primarily of carbonate minerals (endmember 3). Water-rock interaction with these different rock types results in different recharge compositions. The composition of the sample collected from site Q7 (fig. 20, tables 7 and 8), which is a well completed in the Igneous aquifer southwest of the study area, was used to represent endmember 2. Endmember 2 was a Ca-Na-HCO_3 type water; specific conductance was 408 µS/cm; SO_4 concentration was 12.9 mg/L; Cl concentration was 8.39 mg/L; $\delta^{18}O$ and δD values were -6.23 and -41.6 per mil, respectively; $^{87}Sr/^{86}Sr$ ratio was 0.70727, which was the lowest value measured in this study; the tritium concentration was 1.2 TU; organic compounds were not analyzed; and NO_3+NO_2 concentration was 0.632 mg/L. Si concentrations (table 7) also provided insight into this endmember. Si concentrations would likely be higher in groundwater interacting with igneous rocks of the Barilla and Davis Mountains. Relatively higher Si concentrations for samples collected from the Igneous aquifer and wells completed in proximity to the Barilla and Davis Mountains are consistent with this hypothesis. The Si concentration at site Q7 was 43.6 mg/L. In summary, endmember 2 represents relatively dilute, recent recharge with a relatively high concentration of Si and a low $^{87}Sr/^{86}Sr$ value that are indicative of interaction with low $^{87}Sr/^{86}Sr$ igneous rocks. Finally, the composition of endmember 2 is consistent with values reported by Uliana and others (2007) for samples collected in the Barilla and Davis Mountains, which were represented by their endmember B.

The composition of the sample collected from site Q8 (fig. 20 and table 7), which is a well completed in the Edwards-Trinity aquifer near the southwest boundary of the study area, was used to represent endmember 3; that is, recharge from the Glass Mountains. Endmember 3 was a type Na-HCO_3 water; specific conductance was 587 µS/cm; SO_4 concentration was 56.0 mg/L; Cl concentrations was 15.9 mg/L; $\delta^{18}O$ was -7.16 per mil and δD was -49.0 per mil, (predominantly young water); $^{87}Sr/^{86}Sr$ was 0.70816; environmental tracers and organic compounds were not analyzed; and NO_3+NO_2 was not detected. The Si concentration was 14.3 mg/L, which is lower than the Si concentration of endmember 2 as well as the average value of 21.6 mg/L for Edwards-Trinity aquifer water. From the geochemical assessment, endmember 3 represents relatively dilute, recent recharge with a composition indicative of interaction with carbonate rocks.

The composition of the sample collected from site Q25 (fig. 20, tables 7 and 8), which is a well completed in the Edwards-Trinity aquifer in the eastern part of the study area, was used to represent endmember 4; that is, regional groundwater flow in the Edwards-Trinity aquifer east of the Monument Draw trough. Endmember 4 was a type Na-Ca-Mg-SO_4-Cl-HCO_3 water; specific conductance was 1,520 µS/cm; SO_4 concentration was 277 mg/L; Cl concentration was 203 mg/L; $\delta^{18}O$ was -7.47 per mil and δD was -49.6 per mil; $^{87}Sr/^{86}Sr$ ratio was 0.70959; tritium concentration was 0.09 TU; and organic compounds and NO_3+NO_2 were not detected. Endmember 4 represents relatively mineralized water that is likely a mixture of recharge under current and different climatic conditions and is flowing through the Edwards-Trinity aquifer along regional groundwater-flow paths.

Groundwater-Flow System

Geochemical and groundwater-level data were used in context with the hydrogeologic framework to assess regional groundwater-flow paths, recharge sources, and groundwater mixing and discharge in the study area. Pearson and others (2012) detail the methods used for collection, analysis, and quality control of the groundwater-level data used in this report. The geochemical characteristics and endmembers were used to qualitatively evaluate the mixing of waters from different sources and the flow-path evolution of the chemical characteristics of aquifer water. Groundwater-level data were used to create potentiometric-surface maps of the Edwards-Trinity aquifer, assess regional groundwater gradients, and compute vertical gradients between the Edwards-Trinity and underlying aquifers. Structural features such as bed orientation and thickness, mountains, troughs, and faults play a substantial role in the distribution of recharge, local and regional groundwater-flow paths, spring discharge, and aquifer interaction.

Groundwater-level altitudes and geologic data for the study area were compiled from NWIS (U.S. Geological Survey, 2011), the TWDB Groundwater Database (Texas Water Development Board, 2011), and Middle Pecos Groundwater Conservation District (Paul Weatherby, Middle Pecos Groundwater Conservation District, written commun., 2011). A set of three criteria were used to determine which wells were completed in the Edwards-Trinity aquifer. Wells were considered completed in the Edwards-Trinity aquifer if:

1. the total depth was deeper than the top of the Cretaceous-age rocks,
2. the top of openings (screen, slots, open hole) in the well had a depth deeper than the top of the Cretaceous-age rocks, and
3. the total depth of the well was less than 50 ft below the base of the Cretaceous-age rocks.

If there were no opening or total-depth data associated with a well, the agency-assigned geologic data were used to identify the aquifer in which the well was screened so that groundwater-level measurements could be related to the specific aquifer in which the well was completed. Wells completed in multiple aquifers were not used in the groundwater-level analysis. All groundwater-level data collected from the Edwards-Trinity aquifer were separated into two seasons (summer and winter) for predevelopment years (before 1950) and for each year from 1950 to 2011. The summer season was defined as the months from May through October, and the winter season was defined as the months from November through April. These seasons were chosen as 6-month periods that coincide roughly with the start and the end of the agricultural irrigation season. The winter-season measurements were used for groundwater-flow analysis because groundwater-level data collected during these months are less affected by irrigation pumping. Figure 28 shows a potentiometric-surface map using the average of the groundwater-level data collected at each well completed in the Edwards-Trinity aquifer for the winter months during 1980–2010 (table 9 at end of report). The potentiometric-surface grid was generated using minimum curvature interpolation techniques. Geosoft, Inc. (2012) describes the minimum-curvature methods used for grid generation.

Regional Groundwater Flow

Groundwater-level altitudes in the Edwards-Trinity aquifer generally decrease from southwest to northeast and regional groundwater flow is from the south and southwest to the north and northeast in the study area (fig. 28). The highest groundwater-level altitudes (more than 3,300 ft) were measured near the southwestern boundary of the study area. Some of the lowest groundwater-level altitudes (about 2,400 ft) were measured in the down-dip extent of the Edwards-Trinity aquifer in the Monument Draw trough; a few groundwater altitudes of less than 2,300 ft were measured near the eastern part of the study area.

Two groundwater divides were observed in the study area from the potentiometric surface of the Edwards-Trinity aquifer (fig. 28). A groundwater divide begins where the boundaries of Jeff Davis, Brewster, and Pecos Counties come together, then extends generally northwest to the Reeves-Pecos County boundary. Groundwater west of this divide flows from the Barilla and Davis Mountains to the down-dip sections of the Edwards-Trinity along the northwestern study-area boundary into the Pecos trough (fig. 2). Groundwater east of this divide flows along the western margin of the Monument Draw trough. The other groundwater divide trends along the center of Monument Draw trough and is potentially related to the upwelling of water from deeper units. Groundwater west of the divide predominantly flows from the Glass Mountains to the down-dip section of Monument Draw trough, and groundwater east of the divide flows from the Glass Mountains into the down-dip section of Monument Draw trough and the eastern part of the study area. Because the potentiometric-surface map was developed using the average of the groundwater-level data collected in winter months, the locations of the divides likely vary during the irrigation season when groundwater pumping increases.

Recharge

Integrated results of this and previous studies indicate the Edwards-Trinity aquifer is recharged by: (1) regional groundwater flow in the Edwards-Trinity aquifer entering the study area from the northwest; (2) runoff from the Barilla, Davis, and Glass Mountains that percolates through underlying rocks and into the gravels along the slopes of the mountains; (3) return flow from irrigation; and (4) upwelling from deeper aquifers. These sources of recharge were qualitatively evaluated for this report and are consistent with previously reported sources (Armstrong and McMillion, 1961; Hiss, 1976; Small and Ozuna, 1993; Boghici, 1997; Uliana and Sharp, 2001; Uliana and others, 2007; Daniel B. Stephens and Associates, 2010). Neither the absolute nor the relative recharge proportion from each potential source was estimated. Also, although a component of the groundwater appears to have recharged under conditions similar to the recent, local climate, the only samples collected from the Edwards-Trinity aquifer that likely recharged during about the past 60 years (post-bomb) were collected from wells in mountain recharge areas and in areas receiving agricultural return flow. These results are consistent with local climate data because substantial, recent recharge is unlikely given the discrepancy between an average annual rainfall of 14 inches (National Weather Service, 2011) and annual potential evapotranspiration rates of as much as 109 inches (Boghici, 1997).

Regional groundwater flow in the Edwards-Trinity aquifer that originated as recharge northwest of the study area enters the study area near the western boundary (fig. 28). This regional groundwater-flow path was previously documented by Uliana and Sharp (2001) and Uliana and others (2007). The potentiometric surface shows that the groundwater-level altitudes are highest in the western part of the study area (fig. 28), and regional groundwater flow is generally towards the north. The groundwater divide near the Pecos-Reeves County boundary likely limits the connection of this regional flow path with the rest of the study area. The groundwater composition is consistent with older (Pleistocene) mineralized groundwater with high $^{87}Sr/^{86}Sr$ values (site Q30; endmember 1).

Recharge to the Edwards-Trinity aquifer along the southern boundary of the study area occurs from the Barilla, Davis, and Glass Mountains (fig. 28) (Armstrong and McMillion, 1961; Small and Ozuna, 1993; Boghici, 1997; Uliana and Sharp, 2001; Uliana and others, 2007). The geochemical composition of this relatively dilute, recent recharge is characterized by low specific conductance and stable isotope values similar to local rainfall. Although the hydrochemical facies for recharge endmembers from the Barilla and Davis Mountains (site Q7; endmember 2) and the Glass Mountains (site Q8; endmember 3) are similar ($Ca\text{-}Na\text{-}HCO_3$ and $Na\text{-}HCO_3$, respectively) and low $^{87}Sr/^{86}Sr$ values (0.70727 and 0.70816, respectively) are consistent

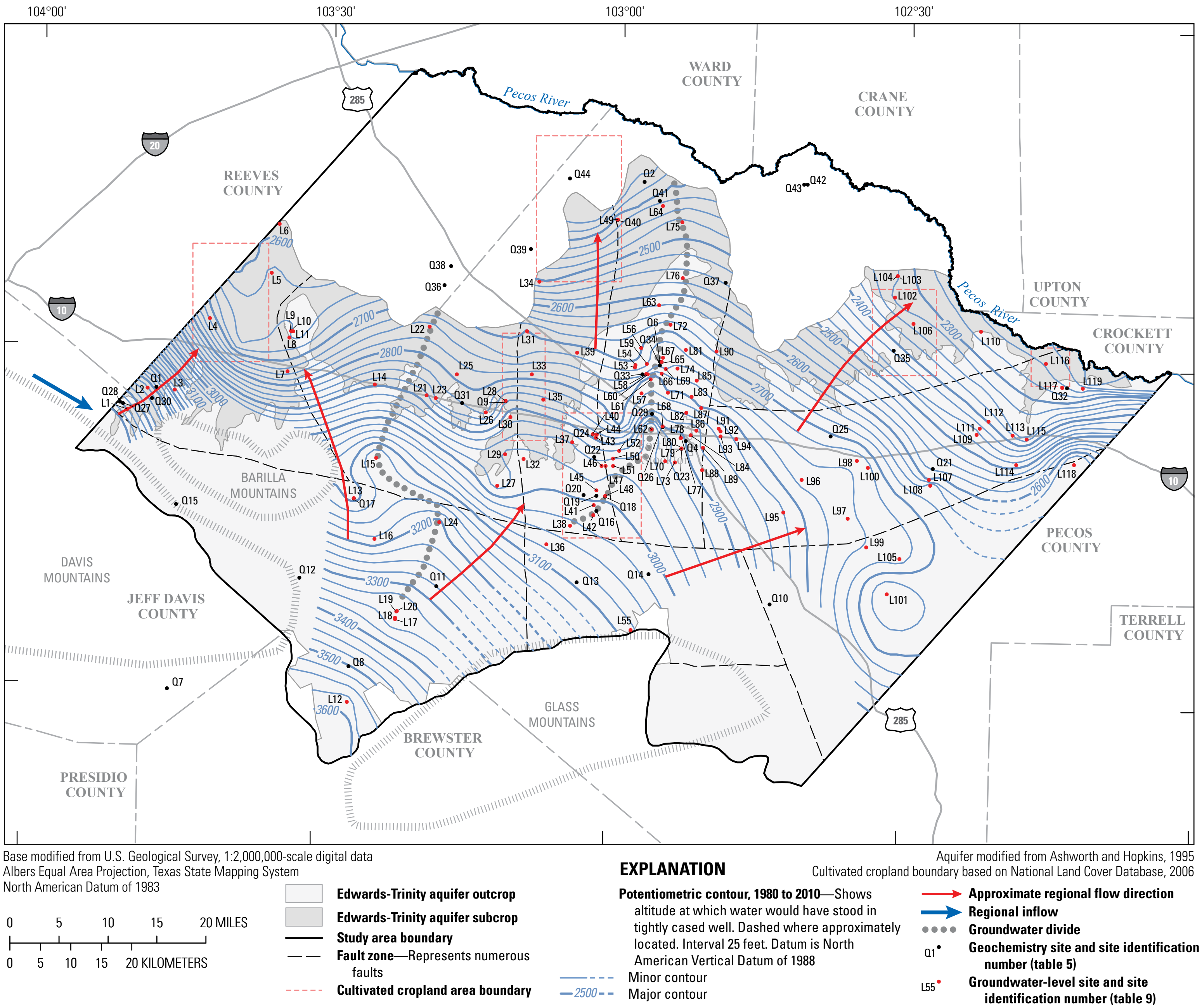


Figure 28. Potentiometric-surface map of the Edwards-Trinity aquifer developed using the average of the winter (November through April) groundwater-level data collected at each site for 1980–2010 in the Pecos County region study area, Texas.

with interaction with igneous rocks or carbonate rocks and not with siliciclastic rocks with high $^{87}Sr/^{86}Sr$ values, Si concentrations (43.6 and 14.3 mg/L) indicate these waters are likely from different sources. The composition of the Igneous aquifer sample from site Q15, the Pecos Valley aquifer sample collected from site Q27, and the Edwards-Trinity aquifer sample collected from site Q28 (fig. 28, tables 7 and 8) are similar to that of the Igneous aquifer recharge endmember 2 (high stable isotope values, low $^{87}Sr/^{86}Sr$ values, and high Si concentrations) and are west of the inferred groundwater divide. The high Si concentration and low $^{87}Sr/^{86}Sr$ values in groundwater samples from these wells are likely influenced by interaction with igneous rocks of the Barilla and Davis Mountains.

The results of this study indicate that return flows from irrigation likely contribute recharge to the Edwards-Trinity aquifer in agricultural areas (figs. 27 and 28). Detections of organic compounds (atrazine and its degradate deethylatrazine) and elevated NO_3+NO_2 in the Leon-Belding and down-gradient parts of the Edwards-Trinity aquifer, as well as near other agricultural areas, are consistent with a component of recharge from agricultural return flow (figs. 27 and 28, table 7). Generally, detections of organic compounds and elevated NO_3+NO_2 concentrations were measured in the shallowest aquifer units. For example, organic compounds and elevated NO_3+NO_2 concentrations were measured in the Edwards-Trinity aquifer in the Leon-Belding and downgradient areas but not in the underlying Rustler and Capitan Reef aquifers.

Upwelling of groundwater from deeper aquifers to the Edwards-Trinity aquifer has been previously documented (Hiss, 1976; Small and Ozuna, 1993; Barker and others, 1994). Upwelling is likely the result of groundwater flow from underlying aquifers along fault zones (Ashworth, 1990; Boghici, 1997) or, as hypothesized by Small and Ozuna (1993), it may occur in areas where a Triassic shale unit that separates the Trinity Group of the Edwards-Trinity aquifer from underlying units is absent. Upwelling groundwater contributes higher concentrations of salinity, including higher SO_4 and Cl concentrations, to overlying units as a result of extensive interaction with Permian-age evaporite deposits. Faulted zones (figs. 2, 17, 18, and 28) in the Leon-Belding and Fort Stockton areas (fig. 1) are some areas where upwelling is likely occurring. The high-salinity water collected from the Edwards-Trinity aquifer (sites Q16, Q18, Q22, Q23, Q24, and Q26; specific conductance from 2,040 to 3,820 µS/cm) (fig. 28, table 7) and Comanche Springs (site Q4; specific conductance 3,570 µS/cm), which discharges from the Edwards-Trinity aquifer, is compositionally similar to the high-salinity water collected from the underlying Rustler and Capitan Reef aquifers (sites Q19, Q20, and Q29; specific conductance 2,290 to 3,980 µS/cm). Groundwater-level data for the other aquifers in the groundwater system were limited. However, groundwater-level altitudes collected by the TWDB in 2001 from two wells completed in the Edwards-Trinity aquifer and in 2002 from two wells completed in the Rustler aquifer were used to evaluate vertical gradients in the Leon-Belding area (fig. 2) (Edwards-Trinity site numbers L48 and L45 [fig. 28, table 9]; and TWDB Rustler site numbers 5216609 [site Q19; fig. 28, table 5] and 5216608 [less than 0.5 miles northeast of L57]; Texas Water Development Board, 2011). Groundwater altitudes of 3,060 and 3,076 ft in the Rustler wells (measured Jan. 2, 2002, at sites 5216609 and 5216608, respectively) and 2,955 (measured May 9, 2001, at site L48) and 2,977 ft (measured April 2, 2001, at site L45) in the Edwards-Trinity wells show an upward gradient from the Rustler to the Edwards-Trinity aquifer of about 83 to 121 ft, which is consistent with the geochemical results and a historical upward gradient reported by Small and Ozuna (1993).

Geochemical Mixing and Discharge

Results of this study are consistent with previous studies of the region and indicate that groundwater generally flows north into the down-dip extent of the Edwards-Trinity aquifer or northeast out of the study area (fig. 28) (Barker and others, 1994; Anaya and Jones, 2009). Groundwater naturally discharges from the aquifer from springs, into overlying or underlying units at the down-dip extent of the aquifer, or to the Pecos River (Barker and others, 1994; Anaya and Jones, 2009). The four springs sampled in the study area (table 5) are likely connected to groundwater discharge along fault zones (figs. 17–18 and 28).

Regional groundwater flow entering the study area from the northwest naturally discharges from springs or turns northward to flow into the Pecos trough where it discharges into the Pecos Valley or Dockum aquifers at the down-dip extent of the Edwards-Trinity aquifer (Barker and others, 1994). The composition of samples collected from San Solomon Spring (site Q1; fig. 28, tables 7 and 8), which discharge from the Edwards-Trinity aquifer, are similar to those of the regional groundwater flow characterized by endmember 1 (site Q30). Previous studies indicate there are also local influences on San Solomon Spring (LaFave and Sharp, 1987; Sharp and others, 1999; Uliana and others, 2007).

Recharge from the Barilla and Davis Mountains also flows toward the Pecos trough and is thought to naturally discharge to other aquifers in the groundwater system (Barker and others, 1994). The Si concentrations in Edwards-Trinity aquifer samples from sites Q12 and Q17 (21.1 and 26.7 mg/L, respectively), which are intermediate between the mountain recharge endmembers 2 and 3 concentrations of 43.6 mg/L and 14.3 mg/L, indicated there might be mixing of recharge from the Barilla and Davis Mountains with recharge that has interacted with igneous rocks to a lesser degree than the igneous signature of endmember 2. The potentiometric-surface map (fig. 28) shows that recharge from the Glass Mountains primarily flows to the Monument Draw trough (fig. 2) and to the east. The Si concentration in the sample collected from site Q11 (28.4 mg/L) indicated that there could be some mixing of recharge from the Glass Mountains and groundwater that has been in contact with silicate-rich igneous or siliciclastic rocks. The relatively high $^{87}Sr/^{86}Sr$ value (0.70954) in the sample collected from site Q11, however, was more consistent with a siliciclastic source than igneous rocks of the Barilla and Davis Mountains.

Groundwater flow in the Edwards-Trinity aquifer in the Monument Draw trough originated as recharge in the Glass Mountains, agricultural return flow, or upwelling groundwater from lower units. Groundwater generally flows north and northeast in the Monument Draw trough and naturally discharges from springs or to other aquifers in the groundwater system (Barker and others, 1994). Based on low stable isotope ratios, groundwater in the Edwards-Trinity, Rustler, and Capitan Reef aquifers in the Monument Draw trough probably originated as recharge during the wetter, cooler climates of the Pleistocene. Recent recharge to the Edwards-Trinity aquifer near the Glass Mountains in the Monument Draw trough area is hydrologically possible, but low stable isotope values of groundwater from site Q14 of $\delta^{18}O$ -7.89 per mil and δD -55.0 per mil (fig. 28, table 7) and undetected ^{3}H (table 8) indicate the Edwards-Trinity aquifer water in this area is predominantly old. Similarly, high specific conductance, SO_4 concentrations, and Cl concentrations, and similar $\delta^{18}O$, δD, and $^{87}Sr/^{86}Sr$ values in groundwater samples collected from wells completed in the Monument Draw trough roughly south of Interstate Highway 10 (I-10) (fig. 28, tables 7 and 8) support earlier findings that groundwater from the Capitan Reef aquifer is mixing with groundwater flowing through Permian-age evaporite deposits in the Rustler aquifer (Small and Ozuna, 1993). Groundwater discharge from Comanche Springs (Q4) has a similar composition to groundwater samples collected from wells in this area (fig. 28, tables 7 and 8), including the detection of organic compounds and elevated NO_3+NO_2 concentrations that were measured in samples from upgradient Edwards-Trinity aquifer sites. This compositional similarity, along with the absence of flow at the springs caused by the lowering of the water table from pumping during the irrigation season (Small and Ozuna, 1993), confirms the connection between the springs, upgradient Edwards-Trinity groundwater, and return flow from the Leon-Belding area.

Except in isolated areas, a clear connection between the Edwards-Trinity aquifer and the underlying Rustler is not apparent in the Monument Draw trough north of I-10 (figs. 3 and 4). Upwelling in this area might be inhibited by the shale and siltstone confining units in the Lower Dockum Group (table 1; Barker and others, 1994), or these wells might not intersect faults or other structural features that act as preferential vertical flow paths. Samples collected from sites Q33 and Q40 (fig. 28, table 7), which are wells completed in the Edwards-Trinity aquifer where it overlies, or is near the edge of, the estimated extent of the Dockum aquifer, have somewhat different compositions than groundwater from samples collected from wells in the Monument Draw trough roughly south of I-10. However, samples from the well at site Q37 and Diamond Y and Santa Rosa Springs (sites Q6 and Q2) (fig. 28, tables 7 and 8), both of which discharge from the Edwards-Trinity aquifer, are compositionally similar to wells in the Monument Draw trough south of I-10. Site Q37 is on the eastern side of Monument Draw trough, completed in a portion of the Edwards-Trinity aquifer that is likely not underlain by the Dockum aquifer; Diamond Y Spring are east of the estimated extent of the Dockum aquifer; and Santa Rosa Springs appear to be the result of a localized upwelling that is not affected by the presence of the Dockum aquifer. Diamond Y and Santa Rosa Springs are within fault zones (figs. 17–18 and 28) (Baumgardner and others, 1982; Veni, 1991; Boghici, 1997) that create preferential flow paths for lower aquifers to discharge to the surface. Finally, groundwater likely discharges from the down-dip extent of the Edwards-Trinity aquifer in the Monument Draw trough to overlying or underlying aquifer units (Barker and others, 1994).

Groundwater in the eastern part of the study area likely originates in the Glass Mountains, generally flows northeast, and flows out of the study area to the east or naturally discharges from springs to other aquifers in the groundwater system or to the Pecos River. Groundwater in the eastern part of the study area has little compositional similarity to the groundwater samples collected in the Monument Draw trough area. The composition of groundwater collected from Edwards-Trinity aquifer site Q25 (endmember 4) (fig. 28, tables 7 and 8) is representative of regional groundwater flow in the Edwards-Trinity aquifer east of the Monument Draw trough. This endmember and the groundwater collected from the Edwards-Trinity aquifer site Q32 are more compositionally similar in terms of salinity to the groundwater collected from Edwards-Trinity aquifer sites Q8 and Q11, which are west of the Monument Draw trough near the Glass Mountains, than to groundwater samples collected in the Monument Draw trough area even though the regional gradient appears to move groundwater through the trough into the east. Conversely, the $^{87}Sr/^{86}Sr$ and stable isotope values of groundwater collected from sites Q25 and Q32 are different. The $^{87}Sr/^{86}Sr$ value of groundwater collected from site Q25 was 0.70959 and $\delta^{18}O$ was -7.47 per mil, which are similar to values measured in groundwater samples collected in the Monument Draw trough area and are consistent with a mixture of young and old groundwater interacting with siliciclastic rocks. The $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values in groundwater collected from site Q32 were 0.70853 and -6.75 per mil, respectively, which were more similar to the values measured in groundwater collected from site Q35 (0.70824 and -7.24) than site Q25 and are consistent with relatively young water interacting with Cretaceous-age carbonate rocks. Conversely, the groundwater collected from sites Q32 and Q35 are compositionally dissimilar in every other way. These compositional inconsistencies support the theory that there are localized influences on groundwater chemistry and regional groundwater flow.

Summary

The U.S. Geological Survey (USGS), in cooperation with the Middle Pecos Groundwater Conservation District, Pecos County, City of Fort Stockton, Brewster County, and Pecos County Water Control and Improvement District No. 1, conducted a comprehensive, integrated analysis of available hydrogeologic data in order to develop a conceptual model of the Edwards-Trinity and related aquifers in the Pecos County region study area in west Texas. The conceptual model of the hydrogeologic framework, geochemistry, and groundwater-flow system in the 4,700 square-mile study area was developed in an effort to better understand the groundwater system and establish a scientific foundation for resource-management decisions. Development of the conceptual model is the second phase of a three-phase groundwater-availability study being conducted in the Pecos County region by the USGS and the cooperators. The first phase was to collect groundwater, surface-water, geochemical, geophysical, and geologic data in the study area and develop a geodatabase of historical and collected data. Data compiled in the first phase of the study were used in this report to develop the conceptual model. The third phase of the study involves a numerical groundwater-flow model of the Edwards-Trinity aquifer in order to simulate groundwater conditions based on various groundwater-withdrawal scenarios.

Analysis of well, geophysical, geochemical, and hydrologic data contributed to the development of the conceptual model. Lithologic information obtained from well reports and geophysical data were used to describe the hydrostratigraphy and structural features of the groundwater system and aquifer-test data were used to estimate aquifer hydraulic properties. Geochemical data were used to evaluate groundwater-flow paths, water-rock interaction, aquifer interaction, and the mixing of water from different sources. Groundwater-level data also were used to evaluate aquifer interaction as well as to develop a potentiometric-surface map, delineate regional groundwater divides, and describe regional groundwater-flow paths.

Subsurface data were obtained from well reports; natural gamma, electric, and electromagnetic induction borehole geophysical logs; and audio-magnetotelluric soundings. The subsurface data were analyzed in order to map the top and base of the Edwards-Trinity aquifer, the top of the Trinity Group of the Edwards-Trinity aquifer, and the lateral and vertical relations of overlying and underlying aquifers where they occur in order to develop the hydrostratigraphy of the study area and evaluate structural features.

The thickness of the Edwards-Trinity aquifer in the study area was calculated as the difference in altitudes between the top and the base of the Edwards-Trinity aquifer. About 50 percent of the aquifer was between 234 and 362 ft thick with a minimum of about 5 ft and maximum of about 797 ft. Some of the thinnest sections of the Edwards-Trinity aquifer were in the eastern part of the study area, near the northwestern slope of the Glass Mountains, and near the northeastern slope of the Davis Mountains. Some of the thickest sections of the Edwards-Trinity aquifer were in the Pecos, Monument Draw, and Belding-Coyanosa trough areas.

Normal-fault zones were delineated based on interpretations of cross sections of the top and base surfaces of the Edwards-Trinity aquifer units. Faults appear to have formed as growth and collapse features as sediments were deposited along the margins of more resistant rocks and structures, such as the Glass Mountains, and as overlying sediments collapsed into the voids created by the dissolution of Permian-age evaporite deposits. Fault zones delineate domains in the hydrogeologic framework that generally align with previously identified structural features such as the Pecos and Monument Draw troughs.

Transmissivity values calculated and estimated from historical aquifer-test data ranged from 1,500 to 1,216,000 gallons per day per foot. The highest transmissivity values were measured in the Monument Draw trough area, which is also one of the thickest parts of the Edwards-Trinity aquifer and is in a faulted area. The lowest values were measured in the eastern part of the study, near some of the thinnest parts of the aquifer. Hydraulic conductivity values generally showed the same trends as the transmissivity values.

Analysis of the geochemical samples provided insight into the chemical characteristics of water from different sources and different aquifers. Chemical characteristics of water from different sources were used to qualitatively evaluate aquifer interaction, groundwater-flow paths, water-rock interaction, and mixing of water from different sources and to identify likely source waters and geochemical endmembers. Useful geochemical properties included specific conductance, hydrochemical facies, sulfate and chloride concentrations, silica concentrations, oxygen and hydrogen stable isotopes, strontium isotopes, environmental tracers, and concentrations of organic compounds and nutrients. The qualitative geochemical analysis did not include a quantitative evaluation of residence times in the aquifer nor did it include geochemical flow-path modeling of the groundwater system.

Geochemical and isotopic results indicate groundwater in the system likely is dominated by mineralized, regional groundwater flow that probably recharged during the cooler, wetter climates of the Pleistocene with variable contributions of recent, local recharge. The mixing of water from multiple sources combined with water-rock interaction with various rock types, including siliciclastic, carbonate, evaporite, and igneous rocks, contributed to a groundwater chemistry that was complex between and within aquifer units.

Four endmembers were identified to use as part of the qualitative groundwater-flow and mixing analysis. The endmembers represented: (1) mineralized groundwater that likely recharged northwest of the study area during the Pleistocene and is flowing through the Edwards-Trinity aquifer along regional groundwater-flow paths; (2) dilute, recent recharge from the Barilla and Davis Mountains with a composition indicative of interaction with igneous rocks; (3) dilute, recent recharge from the Glass Mountains with a composition indicative of interaction with carbonate rocks; and (4) mineralized water that is likely a mixture of recharge

under recent and Pleistocene climatic conditions and is flowing through the Edwards-Trinity aquifer along regional groundwater-flow paths east of the Monument Draw trough.

Groundwater-level and geochemical data were used in context with the hydrogeologic framework to assess regional groundwater-flow paths, recharge sources, and groundwater mixing and discharge in the study area. The geochemical characteristics and endmembers were used to qualitatively evaluate the mixing of water from different sources and the flow-path evolution of the chemical characteristics of aquifer water. Historical and current groundwater-level data were used to create a potentiometric-surface map of the Edwards-Trinity aquifer, assess regional groundwater gradients, and compute vertical gradients between the Edwards-Trinity and underlying aquifers. Structural features such as bed orientation and thickness, mountains, troughs, and faults play a substantial role in the distribution of recharge, local and regional groundwater-flow paths, spring discharge, and aquifer interaction.

Groundwater-level altitudes used to generate the potentiometric-surface map of the Edwards-Trinity aquifer ranged from about 2,300 to about 3,300 ft and generally decreased from southwest to northeast. Regional groundwater flow is from areas of recharge in the south and southwest to the north and northeast. Four principal sources of recharge to the Edwards-Trinity aquifer were identified: (1) regional groundwater flow in the Edwards-Trinity aquifer that originated as recharge northwest of the study area and enters the study area near the western corner; (2) runoff from the Barilla, Davis, and Glass Mountains that percolates through underlying rocks and into the gravels along the slopes of the mountains; (3) return flow from irrigation; and (4) upwelling from deeper aquifers. Although some of the groundwater appears to have recharged under conditions similar to the current climate, the only samples collected from the Edwards-Trinity aquifer that likely recharged during the last 60 years (post-bomb) were collected from wells in mountain recharge areas and in areas receiving agricultural return flow.

Groundwater generally flows north into the down-dip extent of the Edwards-Trinity aquifer or east out of the study area. Regional groundwater flow entering the study area from the northwest naturally discharges from springs or turns northward to flow into the Pecos trough where it discharges into the Pecos Valley or Dockum aquifers at the down-dip extent of the Edwards-Trinity aquifer. Recharge from the Barilla and Davis Mountains also predominantly flows toward the Pecos trough and most likely naturally discharges to other aquifers in the groundwater system. Groundwater flow in the Edwards-Trinity aquifer in the Monument Draw trough originated as recharge in the Glass Mountains, agricultural return flow, or upwelling groundwater from lower units. Edwards-Trinity aquifer water generally flows north and northeast in the Monument Draw trough and naturally discharges from springs or to other aquifers in the groundwater system at the down-dip extent. Groundwater in the eastern part of the study area likely originated in the Glass Mountains, generally flows northeast, and flows out of the study area to the east or naturally discharges from springs to other aquifers in the groundwater system at the down-dip extent or to the Pecos River.

References Cited

Anaya, Roberto, and Jones, Ian, 2009, Groundwater availability model for the Edwards-Trinity (Plateau) and Pecos Valley aquifers of Texas: Texas Water Development Board Report 373, 103 p.

Armstrong, C.A., and McMillion, L.G., 1961, Geology and ground-water resources of Pecos County, Texas: Texas Board of Water Engineers Bulletin 6106, 536 p.

Ashworth, J.B., 1990, Evaluation of ground-water resources in parts of Loving, Pecos, Reeves, Ward, and Winkler Counties, Texas: Texas Water Development Board Report 317, 51 p.

Ashworth, J.B., and Hopkins, Janie, 1995, Aquifers of Texas: Texas Water Development Board Report 345, 69 p.

Banner, J.L., 2004, Radiogenic isotopes–Systematics and applications to earth surface processes and chemical stratigraphy: Earth Science Reviews, v. 65, p. 141–194.

Banner, J.L., and Kaufman, Jonathan, 1994, The isotopic record of ocean chemistry and diagenesis preserved in nonluminescent brachiopods from Mississippian carbonate rocks, Illinois and Missouri: Geological Society of America Bulletin, v. 106, p. 1074–1082.

Banner, J.L., Musgrove, MaryLynn, and Capo, R.C., 1994, Tracing groundwater evolution in a limestone aquifer using Sr isotopes—Effects of multiple sources of dissolved ions and mineral-solution reactions: Geology, v. 22, p. 687–690.

Barker, R.A., and Ardis, A.F., 1992, Configuration of the base of the Edwards-Trinity aquifer and hydrogeology of the underlying pre-Cretaceous rocks, west-central Texas: U.S. Geological Survey Water-Resources Investigations Report 91–4071, 25 p., 1 pl.

Barker, R.A., and Ardis, A.F., 1996, Hydrogeological framework of the Edwards-Trinity aquifer system, west-central Texas: U.S. Geological Survey Professional Paper 1421–B, p. B1–B61.

Barker, R.A., Bush, P.W., and Baker, E.T., Jr., 1994, Geologic history and hydrogeologic setting of the Edwards-Trinity aquifer system, west-central Texas: U.S. Geological Survey Water-Resources Investigations Report 94–4039, 48 p.

Baumgardner, R.W., Jr., Hoadley, A.D., and Goldstein, A.G., 1982, Formation of the Wink Sink, a salt dissolution and collapse feature, Winkler County, Texas: Bureau of Economic Geology Report of Investigations no. 114, 38 p.

Bradley, R.G., and Kalaswad, Sanjeev, 2003, The groundwater resources of the Dockum aquifer in Texas: Texas Water Development Board Report 359, 73 p.

Brand, J.P., and DeFord, R.K., 1958, Comanchean stratigraphy of Kent quadrangle, Trans-Pecos, Texas: Austin, Tex., University of Texas Bulletin 1753, p. 67–172.

Brookins, D.G., 1988, Seawater 87Sr/86Sr for the Late Permian Delaware Basin evaporites (New Mexico, U.S.A): Chemical Geology, v. 69, p. 209–214.

Boghici, Radu, 1997, Hydrogeological investigations at Diamond Y Springs and surrounding area, Pecos County, Texas: The University of Texas, M.A. thesis, 132 p.

Burke, W.H., Dennison, R.E., Hetherington, E.A., Koepnick, R.B., Nelson, H.F., Otto, J.B., 1982, Variation of seawater 87Sr/86Sr throughout Phanerozoic time: Geology, v. 10, p. 516–519.

Cameron, K.L., Parker, D.F., and Sampson, D.E., 1996, Testing crustal melting models for the origin of flood rhyolites—A Nd-Pb-Sr isotopic study of the Tertiary Davis Mountains volcanic field, west Texas: Journal of Geophysical Research, v. 101, p. 20407–20422.

Casciotti, K.L., Sigman, D.M., Hastings, M.G., Böhlke, J.K., and Hilkert, A., 2002, Measurement of the oxygen isotopic composition of nitrate in seawater and freshwater using the denitrifier method: Analytical Chemistry, v. 74, p. 4905–4912.

Clark, I.D., and Fritz, Peter, 1997, Environmental isotopes in hydrogeology: Boca Raton, Fla., Lewis Publishers, 328 p.

Cooper, H.H., Jr., and Jacob, C.E., 1946, A generalized graphical method for evaluating formation constants and summarizing well-field history: American Geophysical Union Transactions, v. 27, no. 4, p. 526–534.

Craig, Harmon, 1961, Isotopic variations in meteoric waters: Science, v. 133, p. 1702–1703.

Daniel B. Stephens and Associates, 2010, City of Fort Stockton groundwater availability analysis—Evaluation of pumping on city wells: Prepared for the City of Fort Stockton, 79 p.

Denison, R.E., Kirkland, D.W., Evans, Robert, 1998, Using strontium isotopes to determine the age and origin of gypsum and anhydrite beds: Journal of Geology, v. 106, p. 1–17.

Driscoll, F.G., 1986, Groundwater and wells: Johnson Filtration Systems, 1089 p.

Dubrovsky, N.M., Burow, K.R., Clark, G.M., Gronberg, J.M., Hamilton P.A., Hitt, K.J., Mueller, D.K., Munn, M.D., Nolan, B.T., Puckett, L.J., Rupert, M.G., Short, T.M., Spahr, N.E., Sprague, L.A., and Wilber, W.G., 2010, The quality of our Nation's waters—Nutrients in the Nation's streams and groundwater, 1992–2004: U.S. Geological Survey Circular 1350, 174 p.

Faure, Gunter, 1986, Principles of isotope geology: New York, Wiley, 589 p.

Fenneman, N.M., and Johnson, D.W., 1946, Physical divisions of the United States: U.S. Geological Survey, 1 sheet, scale 1:7,000,000.

Ferris, J.G., Knowles, D.B., Brown, R.H., and Stallman, R.W., 1962, Theory of aquifer tests: U.S. Geological Survey Water-Supply Paper 1536–E, 105 p.

Fetter, C.W., 1988, Applied hydrogeology: New York, Macmillan, 592 p.

Freese and Nichols, LBG-Guyton, 2010, 2011 Region F water plan: Prepared for Region F Water Planning Group, 500 p.

Fry, J.A., Xian, George, Jin, Suming, Dewitz, J.A., Homer, C.G., Yang, Limin, Barnes, C.A., Herold, N.D., and Wickham, J.D., 2011, Completion of the 2006 National Land Cover Database for the conterminous United States: Photogrammetric Engineering and Remote Sensing, v. 77, no. 9, p. 858–864.

George, P.G., Mace, R.E., and Petrossian, Rima, 2011, Aquifers of Texas: Texas Water Development Board Report 380, 172 p.

Geosoft, Inc., 2012, Technical workshop—Topics in gridding: accessed January 18, 2012, at http://geosoft.com/media/uploads/resources/technical-papers/topicsingriddingworkshop.pdf.

Hem, J.D., 1992, Study and interpretation of chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Herald, F.A., ed., 1957, Occurrence of oil and gas in west Texas: University of Texas Bureau of Economic Geology, 442 p., 3 pls.

Hiss, W.L., 1976, Stratigraphy and ground-water hydrology of the Capitan aquifer, southeastern New Mexico and western Texas: University of Colorado, Ph.D. dissertation, 501 p.

International Atomic Energy Agency, 2011, Global networks of isotopes in precipitation: accessed March 31, 2011, at http://www-naweb.iaea.org/napc/ih/IHS_resources_gnip.html.

INTERRA Incorporated, 2011, Draft conceptual model report for the Rustler aquifer: Prepared for the Texas Water Development Board, 252 p.

Keller, G.V., and Frischknecht, F.C., 1966, Electrical methods in geophysical prospecting (1st ed.): Oxford, Pergamon Press, 519 p.

Keys, W.S., 1990, Borehole geophysics applied to ground-water investigations: Techniques of Water-Resources Investigations of the U.S. Geological Survey, chap. E2, 150 p.

Keys, W.S., 1997, A practical guide to borehole geophysics in environmental investigations: CRC-Lewis Publishers, 176 p.

LBG-Guyton, 2003, Brackish groundwater manual for Texas regional water planning groups: Prepared for the Texas Water Development Board, 188 p.

LaFave, J.I., and Sharp, J.M., 1987, Origins of groundwater discharging at the springs of Balmorhea: West Texas Geological Society Bulletin, v. 26, p. 5–14.

Langman, J.B., and Ellis, A.S., 2010, A multi-isotope (δD, δ18O, 87Sr/86Sr, and δ11B) approach for identifying saltwater intrusion and resolving groundwater evolution along the Western Caprock Escarpment of the Southern High Plains, New Mexico: Applied Geochemistry, v. 25, p. 159–174.

Lucas, L.L., and Unterweger, M.P., 2000, Comprehensive review and critical evaluation of the half-life of tritium: Journal of Research of the National Institute of Standards and Technology, v. 105, no. 4, p. 541–549.

Lucius, J.E., Langer, W.H., and Ellefsen, K.J., 2007, An introduction to using surface geophysics to characterize sand and gravel deposits: U.S. Geological Survey Circular 1310, 33 p.

Meyer, J.E., Wise, M.R., and Kalaswad, Sanjeev, 2011, Pecos Valley aquifer, west Texas—Structure and brackish groundwater: Texas Water Development Board Brackish Resources Aquifer Characterization System (BRACS), 92 p.

Meyers, B.N., 1969, Compilation of results of aquifer tests in Texas: Texas Water Development Board Report 98 (part 1 and 2), 534 p.

Musgrove, MaryLynn, and Banner, J.L., 1993, Regional groundwater mixing and the origin of saline fluids—Midcontinent, United States: Science, v. 259, p. 1877–1882.

Musgrove, MaryLynn, Fahlquist, Lynne, Houston, N.A., Lindgren, R.J., and Ging, P.B., 2009, Geochemical evolution processes and water-quality observations based on results of the National Water-Quality Assessment Program in the San Antonio segment of the Edwards aquifer, 1996–2006: U.S. Geological Survey Scientific Investigations Report 2010–5129, 93 p.

National Atmospheric Deposition Program (IR-7)/National Trends Network, 1997, Annual report: Fort Collins, Colo., NADP/NTN Coordination Office, Natural Resource Ecology Laboratory, Colorado State University, p. 103.

National Weather Service, 2011, Fort Stockton cooperative precipitation, normals 1970–2000, precipitation 1940–2012: accessed June 13, 2012, at http://www.srh.weather.gov/maf/?n=cli_maf_coop_annprecip_fort_stockton.

Neuendorf, K.K.E., Mehl, J.P., Jr., and Jackson, J.A., eds., 2005, Glossary of geology (5th ed.): Alexandria, Va., American Geological Institute, 779 p.

Oden, J.H., Brown, D.W., and Oden, T.D., 2011, Groundwater quality of the gulf coast aquifer system, Houston, Texas, 2010: U.S. Geological Survey Data Series 598, 64 p.

Pearson, D.K., Bumgarner, J.R., Houston, N.A., Stanton, G.P., Teeple, A.P. and Thomas, J.V., 2012, Data collection and compilation for a geodatabase of groundwater, surface-water, water-quality, geophysical, and geologic data, Pecos County region, Texas, 1930–2011: U.S. Geological Survey Data Series 678, 67 p.

Phillips, F.M., and Castro, M.C., 2003, Groundwater dating and residence-time measurements, *in* Drever, J.I., ed., 2005, Surface and ground water, weathering, and soils—Treatise on geochemistry: Boston, Elsevier, p. 451–497.

Piper, A.M., 1953, A graphic procedure in the geochemical interpretation of water analysis: U.S. Geological Survey Ground Water Note No. 12, 14 p.

Railroad Commission of Texas, 2010, Geophysical log database: accessed September 30, 2011, at http://rrcsearch.neubus.com/esd-rrc/#results.

Rees, R.A., and Buckner, Wayne, 1980, Occurrence and quality of ground water in the Edwards-Trinity (Plateau) aquifer, in the Trans-Pecos region: Texas Water Development Board Report 255, 40 p.

Ritzema, H.P., 1994, Determining the saturated hydraulic conductivity, chap. 12 *of* Ritzema, H.P., ed., Drainage principles and applications (2d ed.): Wageningen, The Netherlands, International Institute for Land Reclamation and Improvement, 40 p.

Rose, P.R., 1972, Edwards Group, surface and subsurface central Texas: Austin, Tex., University of Texas, Bureau of Economic Geology Report of Investigations 74, 198 p.

Schlosser, Peter, Stute, Martin, Dörr, Helmut, Sonntag, Christian, and Münnich, K.O., 1988, Tritium/^{3}He dating of shallow groundwater: Earth and Planetary Science Letters, v. 89, p. 353–362.

Schlosser, Peter, Stute, Martin, Sonntag, Christian, and Münnich, K.O., 1989, Tritiogenic ^{3}He in shallow groundwater: Earth and Planetary Science Letters, v. 94, p. 245–256.

Sharp, J.M., Uliana, M.M., and Boghici, Radu, 1999, Fracture controls on regional groundwater flow in a semiarid environment and implications for long-term maintenance of spring flows, *in* Water 99 Joint Congress—Institution of Engineers, 25th Hydrology & Water Resources Symposium, Brisbane, Australia, July 6–8, 1999: Institution of Engineers, v. 2, p. 1212–1217.

Sharp, J.R., 2001, Regional groundwater flow systems in Trans-Pecos, Texas, *in* Mace, R.E., Mullican, W.F., III, Angle, E.S., eds., Aquifers of west Texas: Texas Water Development Board Report 356, p. 41–55.

Small, T.A., and Ozuna, G.B., 1993, Ground-water conditions in Pecos County, Texas, 1987: U.S. Geological Survey Water-Resources Investigations Report 92–4190, 68 p.

Smith, C.I., and Brown, J.B., 1983, Introduction to road log Cretaceous stratigraphy: West Texas Geological Society Field Trip Guidebook, no. 83–77, p. 1–4.

Smith, C.I., and Brown, J.B., and Lozo, F.E., 2000, Regional stratigraphic cross sections, Commanche Cretaceous (Fredericksburg-Washita Division), Edwards and Stockton Plateaus, West Texas—Interpretation of sedimentary Facies, depositional cycles, and tectonics: Austin, Tex., The University of Texas, Bureau of Economic Geology, 39 p.

Solomon, D.K., and Cook, P.G., 1999, ^{3}H and ^{3}He, *in* Cook, Peter, and Herczeg, Andres, eds., Environmental tracers in subsurface hydrology: New York, Kluwer Academic Publishers, p. 397–424.

Texas Parks and Wildlife Department, 2012, Comanche Springs Pupfish (*Cyprinodon elegans*): accessed May 10, 2012, at http://www.tpwd.state.tx.us/huntwild/wild/species/comanchespringspupfish/.

Texas Water Development Board, 1972, A survey of the subsurface saline water of Texas: Texas Water Development Board Report 157, 113 p.

Texas Water Development Board, 2005, Diminished spring flows in the San Solomon Springs system, Trans-Pecos, Texas: Report to the Texas Parks and Wildlife Department, 121 p.

Texas Water Development Board, 2011, Groundwater database reports: accessed December 19, 2011, at http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWDatabaseReports/GWdatabaserpt.asp.

Thatcher, L.L., Janzer, V.J., and Edwards, K.W., 1977, Methods for determination of radioactive substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A5, 95 p.

Theis, C.V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: American Geophysical Union Transactions, 16th annual meeting, p. 519–524.

Thiem, Gunther, 1906, Hydrologische methoden [Hydrologic methods]: Leipzig, Germany, J.M. Gebhardt, 56 p.

Thornhill Group, Inc., 2008, Edwards-Trinity aquifer study—Leon-Belding area: Prepared for Clayton Williams Farms, Inc., 80 p.

Thornhill Group, Inc., 2009, Results of pumping tests—Williams Farms Pecos County, Texas: Prepared for Fort Stockton Holdings, L.P., 257 p.

Uliana, M.M., Banner, J.L., and Sharp, J.M., 2007, Regional groundwater flow paths in Trans-Pecos, Texas inferred from oxygen, hydrogen, and strontium isotopes: Journal of Hydrology, v. 334, p. 334–346.

Uliana, M.M., and Sharp, J.M., 2001, Tracing regional flow paths to major springs in Trans-Pecos, Texas using geochemical data and geochemical models: Chemical Geology, v. 179, p. 53–72.

University Lands, 2011, Well library: accessed July 1, 2011, at http://www.utlands.utsystem.edu/techdata.aspx.

U.S. Geological Survey, 2011, National Water Information System (NWISWeb) data: accessed December 19, 2011, at http://waterdata.usgs.gov/tx/nwis/nwis.

Veni, George, 1991, Delineation and preliminary hydrogeologic investigations of the Diamond Y Spring, Pecos County, Texas: Report to the Nature Conservancy of Texas, 110 p.

Wenzel, L. K., 1942, Methods for determining permeability of water-bearing materials, with special reference to discharging-well methods, *with a section* on Direct laboratory methods and bibliography on permeability and laminar flow, by V.C. Fishel: U.S. Geological Survey Water-Supply Paper 887, 192 p.

Wermund, E.G., 1996, Physiographic map of Texas: Bureau of Economic Geology Map SM0005.

Zaugg, S.D., Sandstrom, M.W., Smith, S.G., and Fehlberg, K.M., 1995, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of pesticides in water by C-18 solid-phase extraction and capillary-column gas chromatography/mass spectrometry with selected-ion monitoring: U.S. Geological Survey Open-File Report 95–181, 60 p.

Zohdy, A.A.R., Eaton, G.P., and Mabey, D.R., 1974, Application of surface geophysics to ground-water investigations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 2, chap. D1.

Table 1. Hydrostratigraphic section in the Pecos County region study area, Texas (modified from Brand and DeFord, 1958; Rose, 1972; Rees and Buckner, 1980; Smith and Brown, 1983; and Ashworth and Hopkins, 1995).

[Water-yielding properties: yields (gallons per minute) - small less than 50, moderate 50 to 500, large is more than 500; classification of water dissolved-solids concentration (milligrams per liter) - fresh less than 1,000, slightly saline 1,000 to 3,000, moderately saline 3,000 to 10,000.]

<table>
<tr><th>Era</th><th>Period</th><th colspan="2">Series or group</th><th colspan="5">Stratigraphic unit</th><th colspan="4">Approximate maximum thickness (feet)</th></tr>
<tr><td rowspan="2">Cenozoic</td><td>Quaternary and Tertiary</td><td colspan="2"></td><td colspan="5">Alluvium</td><td colspan="4">1,150</td></tr>
<tr><td>Tertiary</td><td colspan="2"></td><td colspan="5">Volcanic Rocks, Undivided</td><td colspan="4">1,000+</td></tr>
<tr><td rowspan="12">Mesozoic</td><td rowspan="10">Cretaceous</td><td rowspan="2">Gulfian Series</td><td rowspan="2">Terlingua Group</td><td colspan="5" rowspan="2">Boquillas Formation</td><td colspan="4">250</td></tr>
<tr><td colspan="2">Western Pecos County</td><td colspan="2">Eastern Pecos County</td></tr>
<tr><td rowspan="8">Comanchean Series</td><td rowspan="4">Washita Group</td><td colspan="3">Western Pecos County</td><td colspan="2">Eastern Pecos County</td><td colspan="2" rowspan="2">100</td><td colspan="2" rowspan="2">200</td></tr>
<tr><td rowspan="4">Sixshooter Group</td><td colspan="4">Buda Limestone</td></tr>
<tr><td colspan="2">Boracho Formation</td><td rowspan="3">Edwards Group</td><td>Fort Lancaster Formation</td><td colspan="2" rowspan="2">410</td><td colspan="2" rowspan="2">350</td></tr>
<tr><td colspan="2">University Mesa Marl</td><td>Burt Ranch Member</td></tr>
<tr><td>Fredericksburg Group</td><td colspan="2">Finlay Formation</td><td>Fort Terrett Formation</td><td colspan="2">165</td><td colspan="2">200</td></tr>
<tr><td rowspan="3">Trinity Group</td><td colspan="2" rowspan="3">Trinity Sands</td><td colspan="3">Maxon Sands</td><td colspan="4">300</td></tr>
<tr><td colspan="3">Glen Rose Formation</td><td colspan="4">200+</td></tr>
<tr><td colspan="3">“Basal” Sand</td><td colspan="4">100</td></tr>
<tr><td rowspan="2">Triassic</td><td colspan="2" rowspan="2">Dockum Group</td><td colspan="5">Middle</td><td colspan="4">600</td></tr>
<tr><td colspan="5">Lower</td><td colspan="4">70</td></tr>
<tr><td rowspan="9">Paleozoic</td><td rowspan="8">Permian</td><td colspan="2" rowspan="5">Ochoan Series</td><td colspan="5"></td><td colspan="4">600</td></tr>
<tr><td colspan="2">Southern Pecos County</td><td colspan="3">Northern Pecos County</td><td colspan="2">Southern Pecos County</td><td colspan="2">Northern Pecos County</td></tr>
<tr><td colspan="2" rowspan="3">Tessey Limestone</td><td colspan="3">Rustler Formation</td><td colspan="2" rowspan="3">1,050</td><td colspan="2">450</td></tr>
<tr><td colspan="3">Salado Formation</td><td colspan="2">2,200</td></tr>
<tr><td colspan="3">Castile Formation</td><td colspan="2">2,300</td></tr>
<tr><td rowspan="2">Guadalupian Series</td><td rowspan="2">Whitehorse Group</td><td colspan="2">Gilliam Limestone</td><td colspan="2">Capitan Limestone</td><td>Guadalupian Formations; undivided</td><td>870</td><td colspan="2">1,650</td><td>1,900</td></tr>
<tr><td colspan="5">Lower Guadalupian Formations; undivided</td><td colspan="4">2,000</td></tr>
<tr><td colspan="2"></td><td colspan="5">Lower Permian Formations; undivided</td><td colspan="4">10,000</td></tr>
<tr><td>Pennsylvanian</td><td colspan="2"></td><td colspan="5">Pennsylvanian Formations; undivided</td><td colspan="4">6,000</td></tr>
</table>

Table 1. Hydrostratigraphic section in the Pecos County region study area, Texas (modified from Brand and DeFord, 1958; Rose, 1972; Rees and Buckner, 1980; Smith and Brown, 1983; and Ashworth and Hopkins, 1995).—Continued

[Water-yielding properties: yields (gallons per minute) - small less than 50, moderate 50 to 500, large is more than 500; classification of water dissolved-solids concentration (milligrams per liter) - fresh less than 1,000, slightly saline 1,000 to 3,000, moderately saline 3,000 to 10,000.]

<table>
<tr><th colspan="3">Character of rocks</th><th colspan="2">Regional water yielding properties</th><th>Major and minor aquifers (figs. 3 and 4)</th></tr>
<tr><td colspan="3">Unconsolidated silt, sand, gravel, clay, boulders, caliche, gypsum, and conglomerate</td><td colspan="2">Yields range from small to large quantities of fresh to moderately saline water</td><td>Pecos Valley</td></tr>
<tr><td colspan="3">Lavas, pyroclastic tuffs, volcanic ash, tuff breccias, fragmental breccias, agglomerates; few thin beds of conglomerates, sandstones, and freshwater limestones</td><td colspan="2">Yields small quantities of freshwater</td><td>Igneous</td></tr>
<tr><td colspan="3">Brown to red flaggy limestone interbedded with shale</td><td colspan="2">Not known to yield water</td><td></td></tr>
<tr><td colspan="3">Soft nodular limestone, marl, and thin-bedded hard granular limesone</td><td colspan="2">Does not yield water in most of the study area; however, may yield small quantities in Reeves County</td><td rowspan="5">Edwards-Trinity</td></tr>
<tr><td colspan="3">Hard massive limestone, thin-bedded limestone, and soft nodular limestone with some clay</td><td colspan="2">Yields small quantities of water</td></tr>
<tr><td colspan="3">Soft nodular limestone, marl, and hard massive ledge-forming limestone</td><td colspan="2">Yields small quantities of water</td></tr>
<tr><td colspan="3">Massive ledge-forming limestone and soft nodular limestone</td><td colspan="2">Yields small quantities of fresh to moderately saline water</td></tr>
<tr><td colspan="3">Crossbedded, fine- to coarse-grained, poorly to well-cemented quartz sand with some silt, shale, and limestone</td><td colspan="2">Yields small to moderate quantities of fresh to slightly saline water</td></tr>
<tr><td colspan="3">Reddish-brown to gray coarse-grained sandstone</td><td colspan="2">Yields small to moderate quantities of fresh to slightly saline water</td><td>Dockum</td></tr>
<tr><td colspan="3">Red shale and siltstone</td><td colspan="2">Not known to yield water</td><td rowspan="3"></td></tr>
<tr><td colspan="3">Sand, shale, gypsum, and anhydrite</td><td colspan="2">Not known to yield water</td></tr>
<tr><td colspan="2">Southern Pecos County</td><td>Northern Pecos County</td><td>Southern Pecos County</td><td>Northern Pecos County</td></tr>
<tr><td colspan="2" rowspan="3">Limestone and dolomite</td><td>Red shale, sandstone, anhydrite, dolomite, limestone, conglomerate, and halite</td><td rowspan="3">Not known to yield water</td><td>Yields small to large quantities of slightly to moderately saline water</td><td>Rustler</td></tr>
<tr><td>Mostly halite, with anhydrite and some dolomite</td><td>Not known to yield water</td><td rowspan="2"></td></tr>
<tr><td>Mostly calcareous anhydrite, with halite and associated salts and some limestone</td><td>Not known to yield water</td></tr>
<tr><td>Limestone, dolomite, and sandstone</td><td>Limestone, dolomite, and reef talus</td><td>Dolomite, limestone, anhydrite, shale, and sandstone</td><td>Yields freshwater to a few wells in the Glass Moutains</td><td>Yields moderate to large quantities of moderately saline water</td><td>Capitan Reef</td></tr>
<tr><td colspan="3">Dolomite, dolomitic limestone, limestone, and siliceous shale</td><td colspan="2">Yields small to large quantities of moderately saline water</td><td rowspan="3"></td></tr>
<tr><td colspan="3">Shale, siliceous shale, limestone, dolomitic limestone, sandstone, and basal conglomerate</td><td colspan="2">Yields small quantities of water</td></tr>
<tr><td colspan="3">Limestone, sand, sandstone, shale chert, and conglomerate</td><td colspan="2">Yields small quantities of water</td></tr>
</table>

Table 2. Sites contributing well reports, borehole geophysical logs, and surface geophysical soundings used to determine the lithologies, hydrostratigraphic units, and tops and bases of the hydrostratigraphic units in the Pecos County region study area, Texas.

[--, not used]

Site identifier (fig. 7)	Latitude (decimal degrees)	Longitude (decimal degrees)	Land surface altitude (feet)	Altitude of the top of the Edwards-Trinity aquifer (feet)	Altitude of the top of the Trinity Group (feet)	Altitude of the base of the Edwards-Trinity aquifer (feet)
302122102504501	30.35600	102.35600	3,113	3,091	3,046	2,957
302630102503801	30.44176	102.84396	4,354	4,234	4,234	3,982
303503102303601	30.58421	102.51007	3,413	3,228	3,228	2,903
303824102285001	30.64000	102.48052	3,264	3,129	3,129	2,974
303852102432901	30.64790	102.72471	3,548	3,398	3,328	2,998
303948103205801	30.66344	103.34970	3,545	3,483	3,450	3,350
304134102312601	30.69279	102.52399	3,170	3,153	3,035	2,902
304153103090501	30.69796	103.15140	3,384	3,285	3,167	2,992
304210102443201	30.70269	102.74228	3,480	3,380	3,220	3,071
304551102361201	30.76448	102.60387	2,929	2,929	2,849	2,766
304622102312401	30.77304	102.52379	3,333	3,257	3,119	3,033
304711103003301	30.78642	103.00932	3,239	3,196	3,078	2,939
304715103263501	30.78740	103.44343	3,447	--	3,152	2,987
304728102304401	30.79098	102.51216	3,067	3,067	3,017	2,817
305042102595601	30.84509	102.99899	3,088	3,076	2,958	--
305055103110801	30.84864	103.18567	3,121	3,093	2,871	2,761
305548103161401	30.93771	103.26958	3,037	3,017	2,797	2,597
305604102581301	30.93455	102.97030	2,907	--	--	2,605
305627103071901	30.94075	103.12200	2,991	--	2,695	2,263
305706102095501	30.95175	102.16536	2,981	2,981	2,741	2,471
305740103110901	30.96120	103.18608	2,979	2,949	2,879	2,779
305835102134701	31.01156	102.25855	2,302	2,162	2,044	1,894
310041102152901	30.97650	102.22977	2,370	2,340	2,296	2,225
BRACS-0101	31.04111	103.38472	2,903	2,803	--	2,753
BRACS-0109	30.97583	103.73055	3,181	2,902	2,595	2,402
BRACS-0111	31.22222	102.93222	2,530	2,517	--	2,212
BRACS-0113	31.00083	103.09472	2,943	2,878	--	--
BRACS-0135	31.20805	102.93778	2,549	2,534	--	--
BRACS-0138	30.95333	102.83305	2,832	2,652	--	2,363
BRACS-0157	31.24750	102.91972	2,500	2,492	--	2,080
BRACS-0160	31.23889	102.91944	2,509	2,501	--	2,082
BRACS-0192	31.06472	103.40722	2,884	2,804	--	2,624
BRACS-0198	31.03972	102.81583	2,685	2,664	--	2,355
BRACS-0209	30.96167	103.33000	3,040	2,965	--	2,682
BRACS-0210	30.94611	103.41000	3,161	3,156	--	2,780
BRACS-0299	31.04944	102.35222	2,333	2,298	2,264	2,218
BRACS-0308	30.93000	103.46000	3,145	3,095	--	2,724
BRACS-0328	30.91333	103.17722	3,039	3,004	--	2,647
BRACS-0341	31.14444	102.56722	2,388	2,364	--	2,199
BRACS-0519	31.20830	103.07636	2,653	2,023	2,003	1,593
BRACS-0520	31.21101	103.05238	2,634	2,086	2,044	1,619
BRACS-0521	31.17668	103.02671	2,660	2,150	2,150	1,749
BRACS-0522	31.04934	103.02272	2,778	2,616	2,498	2,313
BRACS-0523	31.00094	103.09373	2,944	2,876	2,614	2,494
BRACS-0524	30.96626	103.20461	2,963	2,813	2,813	2,663
BRACS-0525	31.19085	102.83513	2,472	2,437	--	2,107

Table 2. Sites contributing well reports, borehole geophysical logs, and surface geophysical soundings used to determine the lithologies, hydrostratigraphic units, and tops and bases of the hydrostratigraphic units in the Pecos County region study area, Texas.—Continued

[--, not used]

Site identifier (fig. 7)	Latitude (decimal degrees)	Longitude (decimal degrees)	Land surface altitude (feet)	Altitude of the top of the Edwards-Trinity aquifer (feet)	Altitude of the top of the Trinity Group (feet)	Altitude of the base of the Edwards-Trinity aquifer (feet)
BRACS-0526	30.99283	102.21311	2,304	2,054	2,039	1,844
BRACS-0542	31.10201	102.55492	2,395	2,355	2,293	2,175
BRACS-0544	30.98961	102.26984	2,338	2,176	2,058	1,938
BRACS-0627	31.02472	102.84555	2,870	2,870	--	2,489
BRACS-0633	31.21417	103.02917	2,617	2,252	--	1,742
BRACS-0730	30.93423	102.93300	2,925	2,845	2,845	2,695
BRACS-0731	30.94153	102.94986	2,903	2,813	2,813	2,663
BRACS-0732	31.22609	102.83262	2,442	2,402	2,402	2,183
BRACS-0733	30.94907	103.03827	3,035	3,035	2,965	2,615
BRACS-0734	30.96357	103.00668	2,958	2,848	2,748	2,568
BRACS-0735	31.22850	102.85153	2,454	2,354	2,354	2,154
BRACS-0736	31.15706	102.94037	2,582	2,547	2,252	2,097
BRACS-0737	31.04779	103.01047	2,777	2,677	2,617	2,437
BRACS-0738	31.24765	102.86736	2,457	2,422	2,422	2,197
BRACS-0739	30.98453	103.05897	2,920	2,810	2,710	2,535
BRACS-0741	30.80259	102.99008	3,193	3,143	3,023	2,833
BRACS-0744	31.19169	102.88496	2,519	2,469	2,369	2,147
BRACS-0746	31.01443	102.84010	2,851	2,826	2,661	2,401
BRACS-0747	31.19244	102.93365	2,550	2,500	--	--
BRACS-0749	30.82914	102.95679	3,104	3,044	2,989	--
BRACS-0753	31.20135	102.94071	2,559	2,509	2,374	2,246
BRACS-0755	31.13003	102.89910	2,610	2,540	2,480	2,280
BRACS-0757	30.80957	102.94955	3,187	3,047	--	--
BRACS-0762	31.25080	102.84100	2,430	2,335	2,335	2,140
BRACS-0764	30.91562	103.00171	2,990	--	--	2,545
BRACS-0766	31.00553	102.94862	2,799	2,564	--	--
BRACS-0768	30.80934	102.93241	3,206	3,106	3,076	2,936
BRACS-0769	30.84665	102.94038	3,068	3,048	3,048	2,843
BRACS-0770	31.12670	102.94008	2,624	2,589	2,414	2,154
BRACS-0771	31.08683	102.91504	2,711	2,711	2,601	2,451
BRACS-0772	31.09040	102.92793	2,681	2,681	2,578	2,428
BRACS-0773	30.74136	102.93528	3,551	3,551	3,451	3,266
BRACS-0777	31.03613	102.93529	2,818	2,818	2,668	2,538
BRACS-0780	30.85778	102.93244	3,057	3,007	--	--
BRACS-0782	30.97206	102.89709	2,864	2,864	2,784	2,642
BRACS-0783	30.75097	103.14153	3,534	3,534	3,534	3,206
BRACS-0934	30.97444	103.27250	2,974	2,829	--	2,548
BRACS-0935	30.93805	103.25944	3,030	3,002	--	2,620
BRACS-0937	30.97417	103.64028	3,001	2,418	--	--
BRACS-0943	31.01306	103.52000	2,950	2,844	2,844	2,570
BRACS-0944	31.05306	103.46139	2,921	2,776	--	2,597
BRACS-0963	31.07917	103.62333	2,894	2,304	--	1,955
BRACS-0974	30.97194	102.17528	2,383	2,383	--	2,021
BRACS-0990	30.99667	102.37555	2,487	2,487	--	--
BRACS-1028	31.06139	103.62000	2,911	2,326	--	1,986
BRACS-1192	31.03447	103.47014	2,954	2,764	2,764	2,714

Table 2. Sites contributing well reports, borehole geophysical logs, and surface geophysical soundings used to determine the lithologies, hydrostratigraphic units, and tops and bases of the hydrostratigraphic units in the Pecos County region study area, Texas.—Continued

[--, not used]

Site identifier (fig. 7)	Latitude (decimal degrees)	Longitude (decimal degrees)	Land surface altitude (feet)	Altitude of the top of the Edwards-Trinity aquifer (feet)	Altitude of the top of the Trinity Group (feet)	Altitude of the base of the Edwards-Trinity aquifer (feet)
BRACS-1201	31.15030	103.03856	2,706	2,311	2,311	1,880
BRACS-1203	31.18958	102.87461	2,512	2,477	2,457	2,155
BRACS-1212	31.13737	102.51653	2,391	2,315	--	2,161
BRACS-1213	31.07577	102.45276	2,333	2,303	2,283	2,103
BRACS-1214	31.07524	102.36937	2,289	2,239	2,239	2,069
BRACS-1345	31.01694	103.69972	3,084	2,564	2,334	2,184
BRACS-1346	31.04028	103.58972	2,882	2,697	2,662	2,402
BRACS-1347	31.01917	103.51778	2,945	--	--	2,625
BRACS-1354	30.96944	103.55333	2,967	--	2,484	2,334
BRACS-1355	30.97722	103.52889	2,980	2,980	--	--
BRACS-1478	30.95732	103.36377	3,066	3,066	--	2,721
BRACS-1479	30.99617	103.28807	2,955	2,902	--	2,655
BRACS-1481	31.14586	103.00910	2,682	2,332	--	1,946
BRACS-1482	31.09035	103.03724	2,780	2,450	--	--
BRACS-1521	31.02076	103.52570	2,936	--	--	2,606
BRACS-1522	30.93780	103.31012	3,075	3,025	--	2,699
BRACS-1523	30.93539	103.26028	3,036	3,022	--	2,635
BRACS-1525	30.86167	103.42722	3,306	3,306	--	2,962
BRACS-1527	30.96861	103.39271	3,044	3,016	--	2,734
BRACS-1530	31.00844	103.37838	2,945	2,945	--	2,796
BRACS-1532	30.97841	103.53645	2,972	2,954	--	--
BRACS-1533	30.94464	103.57559	3,010	2,775	--	2,233
BRACS-1538	30.90699	103.57838	3,138	2,963	--	2,456
BRACS-1540	31.02707	103.55891	2,896	2,896	--	2,583
BRACS-1541	31.05026	103.60564	2,895	2,415	--	2,092
BRACS-1568	31.00827	103.20741	2,903	2,573	--	2,320
BRACS-1586	30.93806	103.18667	3,016	3,016	--	2,739
BRACS-1625	31.05021	102.36771	2,366	2,256	2,251	2,116
BRACS-1626	30.95847	102.90540	2,870	2,810	--	2,605
BRACS-1627	31.00020	103.12570	2,917	2,867	2,715	2,603
BRACS-1628	30.98685	103.23485	2,923	2,733	--	2,459
BRACS-1629	30.93716	103.12898	2,993	2,903	--	--
BRACS-1630	30.95826	103.13609	2,974	2,894	--	2,349
BRACS-1639	30.91583	103.09555	3,038	2,943	--	2,394
BRACS-1641	31.03361	102.39000	2,394	2,319	--	2,099
BRACS-1642	31.04389	102.39694	2,368	2,318	2,238	2,095
BRACS-1647	31.12785	102.52808	2,386	2,325	--	2,164
BRACS-1648	31.10293	102.58501	2,464	2,464	--	2,283
BRACS-1650	31.00373	102.53770	2,536	2,471	--	2,106
BRACS-1651	31.02515	102.51900	2,453	2,363	--	2,062
BRACS-1652	30.99661	102.54653	2,570	2,505	--	2,160
BRACS-1654	31.09593	102.94353	2,652	2,572	--	2,332
BRACS-1655	30.96800	102.65588	2,726	2,726	--	2,567
BRACS-1658	30.96743	102.57421	2,711	2,691	--	2,491
BRACS-1659	31.04967	102.48284	2,371	2,286	--	2,065
BRACS-1660	31.09867	102.44283	2,327	2,274	--	2,075

Table 2. Sites contributing well reports, borehole geophysical logs, and surface geophysical soundings used to determine the lithologies, hydrostratigraphic units, and tops and bases of the hydrostratigraphic units in the Pecos County region study area, Texas.—Continued

[--, not used]

Site identifier (fig. 7)	Latitude (decimal degrees)	Longitude (decimal degrees)	Land surface altitude (feet)	Altitude of the top of the Edwards-Trinity aquifer (feet)	Altitude of the top of the Trinity Group (feet)	Altitude of the base of the Edwards-Trinity aquifer (feet)
BRACS-1667	30.96458	102.28388	2,375	2,235	--	1,893
BRACS-1669	30.98912	102.31238	2,486	2,476	2,326	2,221
BRACS-1681	31.06475	103.52950	2,876	2,876	2,651	2,456
BRACS-1704	30.99439	103.67245	3,049	2,611	2,124	2,083
BRACS-1705	30.98096	103.68008	3,065	2,567	--	1,935
BRACS-1981	30.83688	102.69043	2,951	2,829	2,711	2,561
BRACS-1982	31.11386	102.53687	2,410	2,380	--	2,209
BRACS-1984	30.93423	103.41634	3,317	3,317	--	2,895
BRACS-1985	31.19859	102.95412	2,581	2,561	2,561	2,315
BRACS-1986	31.24079	102.97340	2,563	2,508	2,508	2,333
BRACS-1992	30.80612	102.65878	3,004	3,004	2,784	2,544
BRACS-1997	31.13050	102.85201	2,589	2,519	2,419	2,199
BRACS-1998	30.77326	103.51899	3,765	3,715	3,505	3,345
BRACS-2002	30.98461	103.21682	2,926	2,866	2,786	2,586
BRACS-2004	30.75005	103.33497	3,433	3,433	3,158	3,043
BRACS-2008	30.83654	103.45462	3,461	3,461	3,461	3,053
BRACS-2010	30.86716	103.27643	3,343	3,343	3,343	2,913
BRACS-2011	31.05707	102.40528	2,345	2,223	2,105	1,985
BRACS-2012	30.88377	103.23200	3,174	3,174	3,084	2,934
BRACS-2015	30.73693	103.17870	3,613	3,613	3,373	3,213
BRACS-2017	31.04011	102.43908	2,407	--	--	2,097
BRACS-2019	31.03129	102.26479	2,291	2,021	1,961	1,841
BRACS-2020	31.22852	103.07432	2,630	2,032	2,032	1,600
BRACS-2026	30.96192	103.45549	3,085	2,995	2,995	2,875
BRACS-2033	31.02639	103.38380	2,925	2,813	2,813	2,740
BRACS-2037	30.98931	103.50246	3,005	2,953	2,835	2,665
BRACS-2145	30.82604	103.17534	3,216	3,164	3,046	2,966
BRACS-2147	31.06344	102.45971	2,341	2,211	2,211	2,041
BRACS-2150	30.70695	103.25022	3,380	3,365	3,345	3,200
BRACS-2151	30.81561	102.51381	3,245	--	--	2,705
BRACS-2153	31.10459	102.96820	2,651	2,621	2,571	2,461
BRACS-2154	30.97626	102.94308	2,854	2,854	2,754	2,614
BRACS-2161	30.83718	102.51338	2,805	2,805	2,755	2,580
BRACS-2169	31.04222	102.43322	2,411	2,361	2,361	--
BRACS-2182	30.84668	103.01816	3,094	3,049	--	--
BRACS-2186	30.89022	102.56684	3,033	2,763	2,763	2,583
BRACS-2192	31.03419	102.96265	2,805	2,805	2,730	2,580
BRACS-2194	30.87545	102.59659	2,918	2,918	2,748	2,628
BRACS-2203	30.93063	103.35175	3,119	3,112	2,994	2,844
BRACS-2204	30.80490	103.53533	4,052	3,682	3,542	3,390
BRACS-2206	30.86788	102.57487	2,869	2,749	2,749	2,529
BRACS-2207	31.07271	102.36447	2,291	2,201	2,161	2,051
BRACS-2208	30.80653	102.76004	3,040	--	--	2,715
BRACS-2210	31.17944	103.04391	2,663	2,143	--	1,673
BRACS-2211	30.82964	102.77051	3,118	3,118	2,868	2,713
BRACS-2212	30.80104	102.75377	3,053	2,993	--	--

Table 2. Sites contributing well reports, borehole geophysical logs, and surface geophysical soundings used to determine the lithologies, hydrostratigraphic units, and tops and bases of the hydrostratigraphic units in the Pecos County region study area, Texas.—Continued

[--, not used]

Site identifier (fig. 7)	Latitude (decimal degrees)	Longitude (decimal degrees)	Land surface altitude (feet)	Altitude of the top of the Edwards-Trinity aquifer (feet)	Altitude of the top of the Trinity Group (feet)	Altitude of the base of the Edwards-Trinity aquifer (feet)
BRACS-2222	30.76278	103.06633	3,312	3,042	--	2,812
BRACS-2225	30.99741	102.96687	2,832	2,832	2,736	2,502
BRACS-2226	30.73992	103.06305	3,415	3,395	3,285	3,145
BRACS-2230	30.73716	103.08348	3,330	3,190	--	2,980
BRACS-2237	30.92991	102.63428	3,113	3,113	--	2,961
BRACS-2240	30.78615	103.46353	3,566	3,466	3,286	3,126
BRACS-2247	30.64390	103.25482	3,480	3,480	3,480	3,325
BRACS-2252	31.23881	103.07869	2,619	2,049	1,964	1,554
BRACS-2255	31.00500	102.21113	2,280	2,060	2,040	1,810
BRACS-2258	30.71379	103.28194	3,335	3,305	3,185	3,090
BRACS-2263	30.81347	102.82316	3,155	3,155	--	2,855
BRACS-2264	31.06550	102.40337	2,331	2,226	2,226	1,966
BRACS-2265	31.07118	102.41585	2,353	2,248	2,248	1,998
BRACS-2268	30.76702	103.11723	3,451	3,451	3,321	3,096
BRACS-2295	30.99133	102.67243	2,636	--	2,436	--
BRACS-2313	31.12583	102.89809	2,617	2,583	2,457	2,317
BRACS-2452	30.87898	102.47309	2,716	2,716	2,556	2,406
BRACS-2453	30.93657	102.58736	2,934	2,744	2,714	2,629
BRACS-2454	30.96603	102.59072	2,807	2,807	2,687	2,597
BRACS-2513	31.18653	102.97079	2,607	2,347	--	2,107
BRACS-2659	30.93602	103.67832	3,204	--	--	2,354
BRACS-2660	30.93044	103.57864	3,047	2,837	2,837	2,292
BRACS-2661	30.97555	103.53611	2,980	2,951	--	2,434
BRACS-2663	30.97917	103.55417	2,952	2,946	--	2,410
BRACS-2664	30.96880	103.51518	3,045	3,045	2,825	2,655
BRACS-2665	30.96689	103.64024	3,018	--	2,426	2,028
BRACS-2666	30.98029	103.57663	2,943	--	2,313	2,085
BRACS-2668	30.93604	103.74402	3,319	2,419	2,169	1,969
BRACS-2669	30.92550	103.79484	3,406	2,956	2,956	2,446
BRACS-2670	30.94163	103.66829	3,144	2,786	--	--
BRACS-2744	30.96465	102.28367	2,375	2,255	1,965	--
BRACS-2904	30.94875	103.55675	2,998	2,836	--	2,271
BRACS-2909	30.99887	103.16815	2,926	2,840	--	--
BRACS-2910	31.07580	103.08670	2,810	2,320	--	--
BRACS-2911	31.08418	103.03573	2,779	2,422	--	1,919
BRACS-2912	31.11792	103.11281	2,763	2,313	--	1,903
BRACS-2913	31.14389	103.08611	2,715	2,048	--	1,720
BRACS-2923	30.99842	103.64334	2,991	2,361	--	1,925
BRACS-2924	30.98840	103.62820	2,980	2,385	--	1,969
BRACS-2926	30.99106	103.64371	2,998	2,455	--	--
BRACS-2942	31.15243	103.01463	2,684	2,346	--	1,955
BRACS-2943	31.22802	102.96004	2,554	2,534	--	2,314
BRACS-2945	31.20861	102.99417	2,602	2,327	--	2,072
BRACS-2946	31.20940	102.95644	2,564	--	--	--
BRACS-3264	30.98361	103.44205	3,033	2,963	--	2,837
DBSA-036	30.81761	103.27782	3,252	3,213	2,928	2,857

Table 2. Sites contributing well reports, borehole geophysical logs, and surface geophysical soundings used to determine the lithologies, hydrostratigraphic units, and tops and bases of the hydrostratigraphic units in the Pecos County region study area, Texas.—Continued

[--, not used]

Site identifier (fig. 7)	Latitude (decimal degrees)	Longitude (decimal degrees)	Land surface altitude (feet)	Altitude of the top of the Edwards-Trinity aquifer (feet)	Altitude of the top of the Trinity Group (feet)	Altitude of the base of the Edwards-Trinity aquifer (feet)
DBSA-039	30.75100	103.16760	3,495	3,494	3,293	3,138
DBSA-040	30.84284	103.02623	3,100	3,045	2,915	2,790
DBSA-041	30.85833	103.02736	3,076	3,042	--	2,614
DBSA-043	30.75471	103.06810	3,345	3,078	--	2,852
DBSA-044	30.76306	103.00694	3,272	3,242	3,043	2,714
DBSA-045	30.70377	103.24315	3,409	3,400	--	3,206
DBSA-046	30.70718	103.25866	3,353	3,344	--	3,170
DBSA-047	30.67946	103.21452	3,453	3,442	--	3,163
DBSA-049	30.83185	103.19955	3,146	3,071	2,891	2,793
DBSA-051	30.74283	103.07800	3,334	--	--	3,058
DBSA-052	30.74267	103.08117	3,320	3,151	--	--
DBSA-053	30.74524	103.00021	3,296	3,296	2,976	2,796
DBSA-054	30.68197	103.12469	3,490	3,190	3,090	2,715
DBSA-055	30.94478	102.94840	2,892	--	--	2,686
DBSA-056	30.94498	102.93862	2,892	2,842	2,842	2,695
DBSA-057	30.92335	102.93428	2,968	2,963	2,748	2,698
DBSA-058	30.86957	103.00247	3,041	--	2,729	--
DBSA-059	30.86610	103.04056	3,062	3,012	2,462	2,312
DBSA-061	30.83043	102.95392	3,101	3,051	--	2,866
DBSA-062	30.87479	102.90796	3,055	3,017	--	2,625
DBSA-063	30.85412	102.90950	3,049	3,024	2,829	2,695
DBSA-064	30.80139	102.99889	3,196	3,169	3,118	2,859
DBSA-065	30.85642	102.90196	3,033	2,998	2,848	2,661
DBSA-066	30.81876	102.88520	3,130	3,120	2,914	2,881
DBSA-067	30.75770	102.90531	3,442	3,442	--	3,133
DBSA-068	30.74312	102.91567	3,634	3,634	3,448	3,311
DBSA-070	30.66601	102.90874	3,466	3,431	3,246	2,955
DBSA-071	30.85766	102.97734	3,054	3,030	--	2,707
DBSA-073	30.62451	103.14530	3,690	3,640	--	3,249
DBSA-074	30.63910	103.06406	3,749	3,679	3,509	3,179
DBSA-075	30.59485	103.02183	3,843	3,808	3,798	3,748
DBSA-076	30.58608	103.12334	3,958	3,913	3,691	3,616
DBSA-077	30.60114	102.97080	3,738	3,678	--	3,518
DBSA-078	30.64638	102.96949	3,644	3,575	3,355	3,150
DBSA-079	30.64589	102.88489	3,549	3,494	3,277	3,164
DBSA-080	30.61599	102.86091	3,700	3,685	2,960	2,890
DBSA-081	30.79969	103.03890	3,181	--	--	2,762
DBSA-082	30.81505	103.02453	3,160	3,110	2,793	2,650
DBSA-083	30.79855	103.01440	3,202	3,131	--	2,804
DBSA-084	30.76344	103.04282	3,309	3,279	3,279	2,950
DBSA-085	30.74792	103.05654	3,543	3,353	3,123	3,078
DBSA-086	30.72105	103.15928	3,487	3,487	--	3,235
DBSA-087	30.69572	103.02660	3,486	3,331	2,795	2,590
DBSA-088	30.67661	103.02219	3,534	3,455	2,837	2,657
DBSA-089	30.66518	103.04358	3,602	3,602	3,178	3,107
DBSA-090	30.81608	102.96619	3,154	3,089	2,964	2,677

Table 2. Sites contributing well reports, borehole geophysical logs, and surface geophysical soundings used to determine the lithologies, hydrostratigraphic units, and tops and bases of the hydrostratigraphic units in the Pecos County region study area, Texas.—Continued

[--, not used]

Site identifier (fig. 7)	Latitude (decimal degrees)	Longitude (decimal degrees)	Land surface altitude (feet)	Altitude of the top of the Edwards-Trinity aquifer (feet)	Altitude of the top of the Trinity Group (feet)	Altitude of the base of the Edwards-Trinity aquifer (feet)
DBSA-091	30.77362	102.94773	3,398	3,388	3,198	2,962
DBSA-092	30.69928	102.97718	3,479	3,479	3,094	2,706
DBSA-093	30.67625	102.95187	3,504	3,483	3,074	2,745
DBSA-094	30.69013	102.91888	3,396	3,201	2,809	2,636
DBSA-095	30.69090	102.83673	3,309	3,257	2,772	2,646
DBSA-096	30.66216	102.83509	3,409	3,239	2,939	2,774
DBSA-097	30.96886	103.14349	2,967	2,890	--	2,462
DBSA-098	30.97212	103.13810	2,964	2,906	--	2,483
DBSA-099	30.95497	103.13222	2,972	2,876	2,500	2,334
DBSA-100	30.92149	103.11474	3,008	2,918	--	2,338
DBSA-101	30.92557	103.15312	3,015	2,985	--	2,536
DBSA-102	30.88752	103.14824	3,078	3,002	2,603	2,565
DBSA-103	30.88246	103.13142	3,075	3,005	2,625	2,535
DBSA-104	30.87376	103.04722	3,045	2,975	2,466	2,335
DBSA-105	30.88916	103.08508	3,062	2,977	2,762	2,542
DBSA-107	30.96245	102.88053	2,879	2,795	2,683	2,557
DBSA-108	30.90077	102.98753	2,979	2,929	2,699	2,509
DBSA-109	30.90050	102.89341	2,980	2,900	--	2,610
DBSA-110	30.91598	102.85998	2,919	2,859	2,751	2,630
DBSA-111	30.88715	103.02782	3,006	2,981	--	2,484
DBSA-112	30.86597	103.00654	3,048	--	2,822	--
DBSA-113	30.98443	103.02628	3,034	3,034	2,654	2,537
DBSA-114	30.91735	103.00551	2,999	2,999	--	2,554
DBSA-115	30.84964	103.03246	3,090	3,040	2,842	2,707
DBSA-116	30.83180	103.02364	3,124	3,054	2,944	2,829
DBSA-117	30.88136	102.87716	2,941	2,941	2,681	2,625
DBSA-118	30.85433	102.88516	3,002	2,982	2,897	2,685
DBSA-119	30.86818	102.92472	3,086	3,086	2,806	2,704
DBSA-120	30.85843	102.99702	3,062	3,012	2,782	2,659
DBSA-121	30.84515	102.99178	3,083	3,058	--	2,797
DBSA-124	30.91430	103.03516	3,206	3,206	2,996	2,486
DBSA-125	30.89546	103.02813	3,046	3,046	2,736	2,576
DBSA-126	30.85354	103.05756	3,095	3,040	2,940	2,530
DBSA-127	30.88081	103.01438	3,008	2,988	2,827	2,559
DBSA-128	30.87188	103.00596	3,039	2,979	--	2,578
DBSA-130	30.86300	103.02164	3,064	2,990	--	2,559
DBSA-131	30.86755	103.03802	3,061	2,987	--	--
DBSA-132	30.84495	103.01109	3,096	--	2,872	--
DBSA-133	30.78701	103.05560	3,205	3,187	--	2,869
DBSA-134	30.78707	103.05347	3,206	3,176	--	2,855
DBSA-136	30.88515	102.79960	2,973	2,943	2,788	2,493
DBSA-137	30.80919	102.96216	3,183	3,113	3,006	2,773
DBSA-138	30.96679	102.85950	2,862	2,792	--	2,517
DBSA-139	30.90253	102.87825	2,961	--	2,683	2,586
DBSA-140	30.90572	102.93458	3,081	3,081	2,760	2,641
DBSA-141	30.89308	102.93134	3,122	--	--	2,594

Table 2. Sites contributing well reports, borehole geophysical logs, and surface geophysical soundings used to determine the lithologies, hydrostratigraphic units, and tops and bases of the hydrostratigraphic units in the Pecos County region study area, Texas.—Continued

[--, not used]

Site identifier (fig. 7)	Latitude (decimal degrees)	Longitude (decimal degrees)	Land surface altitude (feet)	Altitude of the top of the Edwards-Trinity aquifer (feet)	Altitude of the top of the Trinity Group (feet)	Altitude of the base of the Edwards-Trinity aquifer (feet)
DBSA-142	30.88351	102.92979	3,142	2,997	2,718	2,524
DBSA-143	30.88857	102.89481	3,004	2,939	2,718	2,591
DBSA-144	30.89213	102.88336	2,980	2,966	2,720	2,632
DBSA-145	30.90148	102.85575	2,921	2,886	2,813	2,646
DBSA-146	30.91087	102.82786	2,897	2,867	2,737	2,551
DBSA-147	30.88935	102.83192	2,971	2,811	2,561	2,461
DBSA-148	30.86527	102.88777	2,984	2,964	2,874	2,584
DBSA-149	30.86559	102.88877	2,989	2,971	--	2,593
DBSA-150	30.91333	103.17722	3,039	3,004	--	2,647
DBSA-151	30.68389	103.45111	3,722	3,672	3,292	3,122
DBSA-152	30.70000	103.41444	3,604	3,514	--	3,099
DBSA-153	30.72667	103.33333	3,376	3,376	--	3,060
DBSA-154	30.72722	103.33389	3,371	3,371	--	3,053
DBSA-155	30.72750	103.33500	3,368	3,368	--	3,047
DBSA-156	30.65444	103.35472	3,567	3,483	--	3,323
DBSA-157	30.63556	103.30806	3,442	3,433	--	3,282
DBSA-158	30.63194	103.16306	3,640	3,625	--	3,264
DBSA-161	30.57083	103.20500	3,927	3,908	3,766	3,671
DBSA-163	30.97472	102.89028	2,873	2,859	--	2,626
DBSA-164	30.95361	102.87889	2,877	2,860	2,753	2,627
DBSA-165	30.95806	102.89611	2,882	2,792	2,697	2,577
DBSA-166	30.87639	102.98972	3,030	2,950	2,830	2,556
DBSA-167	30.89806	102.93194	3,103	3,103	2,778	2,611
DBSA-168	30.88472	102.90972	3,061	3,019	--	2,615
DBSA-169	30.87667	102.89028	3,000	2,920	2,800	2,556
DBSA-171	30.90500	102.89111	2,968	2,890	--	2,585
DBSA-172	30.96194	102.84889	2,830	2,760	2,751	2,478
DBSA-173	30.90611	102.83806	2,914	2,784	2,744	2,495
DBSA-174	30.87278	102.90667	3,051	2,993	--	2,606
DBSA-175	30.77306	102.90194	3,340	3,328	--	3,043
DBSA-176	30.85667	102.77806	3,053	3,053	--	2,666
DBSA-177	30.84517	102.99220	3,083	3,062	--	2,803
DBSA-178	30.84512	102.99756	3,088	3,067	--	--
DBSA-179	30.83006	102.97460	3,100	3,025	2,884	2,735
DBSA-181	31.02009	103.26006	2,897	2,617	2,517	2,412
DBSA-182	31.00726	103.32115	2,952	2,837	2,667	2,507
DBSA-183	31.06246	103.31201	2,863	2,733	2,578	2,418
DBSA-184	30.98268	103.32626	3,004	2,794	2,674	2,554
DBSA-188	30.80170	103.03060	3,188	3,133	2,768	--
DBSA-189	30.80810	103.04360	3,159	2,967	2,697	2,583
DBSA-190	30.78920	103.02780	3,219	3,169	--	2,837
DBSA-191	30.78780	103.02670	3,223	3,158	--	2,829
DBSA-193	30.78833	103.00167	3,250	3,170	--	2,874
DBSA-197	30.74310	103.21396	3,433	3,433	--	3,091
DBSA-199	30.72045	103.16864	3,578	3,578	3,483	3,326
DBSA-200	30.71839	103.16225	3,493	3,493	--	3,259

Table 2. Sites contributing well reports, borehole geophysical logs, and surface geophysical soundings used to determine the lithologies, hydrostratigraphic units, and tops and bases of the hydrostratigraphic units in the Pecos County region study area, Texas.—Continued

[--, not used]

Site identifier (fig. 7)	Latitude (decimal degrees)	Longitude (decimal degrees)	Land surface altitude (feet)	Altitude of the top of the Edwards-Trinity aquifer (feet)	Altitude of the top of the Trinity Group (feet)	Altitude of the base of the Edwards-Trinity aquifer (feet)
DBSA-201	30.71925	103.16655	3,540	3,540	--	3,305
DBSA-203	30.75199	102.97328	3,400	3,360	3,211	2,870
DBSA-204	30.64366	103.16820	3,588	3,518	--	3,159
DBSA-205	30.69429	103.06752	3,538	3,538	3,181	2,814
DBSA-208	30.77372	102.94765	3,395	3,385	3,195	2,955
DBSA-210	30.71609	103.16714	3,510	3,510	3,434	--
DBSA-211	30.72922	103.11029	3,322	3,237	--	2,922
DBSA-212	30.65791	103.09612	3,715	3,715	3,487	3,030
DBSA-214	30.70229	103.06421	3,536	3,536	3,098	2,843
DBSA-216	30.73513	103.18741	3,574	3,574	3,452	3,189
DBSA-217	30.72077	103.20475	3,601	3,601	--	3,237
DBSA-218	30.79551	102.96050	3,244	3,104	2,969	2,774
DBSA-220	30.70713	103.19519	3,591	3,591	3,301	3,181
DBSA-223	30.88088	103.40379	3,301	3,301	--	3,076
DBSA-224	30.77515	103.42563	3,590	3,590	3,412	3,271
DBSA-228	30.98683	103.23491	2,923	2,734	--	2,460
DBSA-229	30.89575	103.12843	3,056	3,042	2,620	2,551
DBSA-230	31.02881	102.90003	2,731	2,706	2,706	2,453
DBSA-231	31.04620	102.89913	2,782	2,782	2,782	2,517
DBSA-251	30.90939	102.87435	2,944	--	2,729	--
DBSA-255	30.91918	102.86270	2,918	2,838	2,763	2,623
DBSA-256	30.91525	102.85698	2,919	2,859	2,779	2,626
DBSA-257	30.88119	102.85087	2,993	2,903	2,823	2,707
DBSA-258	30.88677	102.86808	2,929	--	2,759	--
DBSA-259	30.88166	102.84805	2,996	2,906	2,806	--
DBSA-260	30.88135	102.84943	2,994	2,904	2,827	2,706
DBSA-261	30.88140	102.85122	2,992	2,902	--	2,707
DBSA-265	30.90828	102.87469	2,947	--	2,732	--
DBSA-310	31.09256	103.04454	2,784	--	2,103	--
DBSA-311	31.08878	103.09438	2,787	2,512	2,274	--
DBSA-312	31.05870	102.80656	2,624	2,581	2,521	2,337
DBSA-313	30.91173	103.00093	2,995	2,945	2,715	2,525
DBSA-314	30.93779	103.43380	3,326	3,326	3,036	2,916
DBSA-315	30.93127	103.40476	3,261	3,261	2,941	2,821
DBSA-316	30.87068	103.26405	3,336	3,336	2,956	2,876
DBSA-318	30.85440	103.01811	3,074	--	2,834	--
DBSA-320	30.81678	102.81948	3,164	3,164	--	--
DBSA-322	30.81955	102.65095	2,970	2,970	--	2,537
DBSA-324	31.01231	103.33244	2,944	--	2,804	2,684
DBSA-325	30.99298	103.30716	2,975	2,925	2,825	2,705
DBSA-326	30.98358	103.28544	2,970	2,886	2,777	2,642
DBSA-327	31.01290	103.26838	2,913	2,803	2,623	2,533
DBSA-328	31.02781	103.25969	2,886	2,626	2,516	2,416
DBSA-329	31.03164	103.24734	2,870	2,590	2,390	2,290
DBSA-330	30.77244	102.85862	3,281	3,231	3,063	2,931
DBSA-331	30.77541	102.80033	3,118	3,048	2,893	2,677

Table 2. Sites contributing well reports, borehole geophysical logs, and surface geophysical soundings used to determine the lithologies, hydrostratigraphic units, and tops and bases of the hydrostratigraphic units in the Pecos County region study area, Texas.—Continued

[--, not used]

Site identifier (fig. 7)	Latitude (decimal degrees)	Longitude (decimal degrees)	Land surface altitude (feet)	Altitude of the top of the Edwards-Trinity aquifer (feet)	Altitude of the top of the Trinity Group (feet)	Altitude of the base of the Edwards-Trinity aquifer (feet)
DBSA-333	30.79551	102.77492	3,070	3,050	2,822	2,670
DBSA-334	30.85935	103.47376	3,421	3,421	2,961	2,896
DBSA-335	30.99862	103.16741	2,925	--	2,564	2,425
RRC-4237130439	30.90436	102.92809	3,081	--	--	2,631
RRC-4237130512	30.96859	102.25849	2,377	2,377	2,307	2,157
RRC-4237130938	30.67648	103.05709	3,520	--	3,250	3,120
RRC-4237134760	30.86302	102.93169	3,059	--	--	2,694
RRC-4237134898	30.90304	102.32704	2,527	2,492	--	2,297
RRC-4237134909	30.89240	102.31876	2,648	2,628	2,553	--
RRC-4237135042	30.88697	102.31262	2,571	--	2,441	2,301
RRC-4237136582	30.99401	102.41091	2,560	2,508	2,390	2,240
RRC-4237136860	30.53832	102.91787	4,056	3,964	3,846	3,666
RRC-4237137144	30.81913	102.39868	3,233	3,113	3,103	2,898
RRC-4237137145D1	30.97233	102.99202	2,905	2,853	2,735	2,585
RRC-4237137149	30.79113	102.36360	3,244	2,979	2,844	2,684
RRC-4237137184	30.98321	102.95896	2,827	--	--	2,377
RRC-4237137192	30.81190	102.42367	2,866	2,866	2,606	2,451
RRC-4237137193	31.21404	102.93741	2,541	--	2,321	2,171
RRC-4237137219	31.08091	102.78678	2,564	2,392	--	2,104
RRC-4237137222	30.95380	102.41601	2,936	2,736	2,736	2,332
RRC-4237137226H1	31.02169	102.94414	2,821	2,769	2,651	2,501
RRC-4237137249	30.83260	102.46539	2,740	2,740	2,710	2,560
RRC-4237137308	31.02083	102.92737	2,854	--	2,524	2,424
RRC-4237137343	31.00069	102.91066	2,792	2,792	2,682	2,532
RRC-4237137344	31.00180	102.93251	2,806	2,736	2,691	2,506
RRC-4237137345	30.98513	102.91801	2,813	2,813	2,703	2,553
RRC-4237137346	30.98643	102.92052	2,815	2,815	2,705	2,555
RRC-4237137348	30.98543	102.94906	2,838	2,696	2,578	2,388
RRC-4237137404	30.44705	102.91642	4,391	4,306	--	4,111
RRC-4237137420	31.18497	103.01739	2,641	2,371	2,361	--
RRC-4237137425	30.43616	102.80653	4,203	4,161	4,043	3,823
RRC-4237137432	30.94433	102.40882	2,631	2,631	2,631	2,331
RRC-4237137440	31.20530	103.07624	2,656	2,026	2,026	1,636
RRC-4237137476	31.00547	102.93700	2,806	--	2,696	--
RRC-4237137512	30.47826	102.80501	4,088	3,774	3,683	3,605
RRC-4237137513	30.97139	102.46972	2,633	2,633	2,443	2,273
RRC-4237137521	31.22954	102.95019	2,547	2,547	2,447	--
RRC-4237137546	31.08070	102.78273	2,560	--	--	2,090
RRC-4237137549	30.79703	102.48402	2,986	2,986	2,926	2,694
RRC-4237137552	30.80645	102.49553	2,983	2,921	--	2,613
RRC-4237137563	30.77833	102.47648	3,350	3,350	3,100	2,940
RRC-4237137659	31.05036	102.78674	2,615	2,450	2,335	2,180
RRC-4237137690	31.18991	102.83923	2,475	2,440	--	2,145
RRC-4237137769	30.97606	102.47663	2,574	2,542	2,424	2,274
RRC-4237137896	30.93913	102.97209	2,899	2,837	2,719	--
RRC-4237137898	30.92596	102.92080	2,957	2,860	2,742	2,592

Table 2. Sites contributing well reports, borehole geophysical logs, and surface geophysical soundings used to determine the lithologies, hydrostratigraphic units, and tops and bases of the hydrostratigraphic units in the Pecos County region study area, Texas.—Continued

[--, not used]

Site identifier (fig. 7)	Latitude (decimal degrees)	Longitude (decimal degrees)	Land surface altitude (feet)	Altitude of the top of the Edwards-Trinity aquifer (feet)	Altitude of the top of the Trinity Group (feet)	Altitude of the base of the Edwards-Trinity aquifer (feet)
RRC-4237137899	30.95065	102.95198	2,884	2,844	2,844	2,674
RRC-4237137943	31.19705	103.00962	2,623	2,316	2,198	1,993
RRC-4237137947	31.04948	102.67692	2,550	2,435	2,435	2,285
RRC-4237138229	30.97959	102.89657	2,861	--	--	2,623
RRC-4237138416	30.87378	102.48960	2,678	2,496	2,378	2,228
RRC-4237138566	30.99109	102.39304	2,559	--	--	2,154
RRC-4237138567	31.00559	102.39790	2,543	2,447	--	2,163
RRC-4237138635	31.00456	102.39528	2,520	2,428	--	--
RRC-4237138636	30.99320	102.39055	2,540	--	--	2,170
USGS-AMT01	30.57745	103.28333	3,649	3,492	--	3,266
USGS-AMT02	30.51932	103.30687	3,794	3,499	3,422	3,289
USGS-AMT03	30.71023	103.52157	3,725	3,485	3,314	3,157
USGS-AMT04	30.88350	103.38389	3,278	2,986	--	2,884
USGS-AMT05	30.80659	103.48194	3,646	3,364	--	3,200
USGS-AMT06	30.60335	102.78842	3,536	3,280	--	2,706
USGS-AMT09	31.06002	103.13731	2,841	2,707	2,677	2,582
USGS-AMT10	30.94134	102.55057	2,888	2,623	--	2,409
USGS-AMT13	30.86516	103.82792	3,659	3,560	3,553	3,409
UTL-4237100408	30.85729	102.33328	2,702	2,602	2,562	2,352
UTL-4237100624	30.91815	102.37499	2,491	2,476	2,476	2,261
UTL-4237100629	30.88577	102.30522	2,562	--	2,482	2,302
UTL-4237100632	30.91466	102.40170	2,564	2,564	2,564	2,430
UTL-4237100760	30.91809	102.21097	2,963	--	2,707	2,558
UTL-4237101084	30.96110	102.21109	2,495	2,495	2,375	2,225
UTL-4237101169	30.89871	102.32453	2,593	--	2,483	--
UTL-4237101303	30.90291	102.43366	2,682	2,682	2,572	2,472
UTL-4237101376	31.00633	102.70556	2,627	2,480	2,377	2,307
UTL-4237101391	30.91191	102.41052	2,613	2,613	2,613	2,455
UTL-4237102196	30.93593	102.42189	2,626	2,626	2,596	2,446
UTL-4237104143	30.89737	102.67229	3,002	2,980	2,862	2,782
UTL-4237104725	30.93361	102.65531	3,113	3,093	3,093	2,943
UTL-4237110713	30.92267	102.63851	3,088	3,088	3,088	2,935
UTL-4237110836	30.83082	102.57477	2,808	2,808	--	2,568
UTL-4237111117	30.92991	102.63428	3,113	3,113	3,113	2,961
UTL-4237111280	30.91496	102.67222	2,939	2,929	--	2,756
UTL-4237111415	30.94856	102.62639	2,787	2,787	2,787	2,617
UTL-4237130857	30.80820	102.59066	2,857	2,857	2,832	2,675
UTL-4237132468	30.83847	102.65610	2,937	2,937	2,804	2,497
UTL-4237132640	30.86691	102.64927	2,858	2,728	2,668	2,468
UTL-4237132819	30.94366	102.35298	2,504	2,504	2,454	2,274
UTL-4237133557	30.77395	102.66017	3,104	2,944	2,769	2,594
UTL-4237133677	30.85197	102.65775	2,880	2,808	2,650	2,480
UTL-4237134344	30.86660	102.69992	3,075	2,804	2,804	2,582
UTL-4237134536	30.88957	102.70809	2,899	2,789	2,724	2,619
UTL-4237135055	30.88176	102.70735	2,906	2,786	2,711	2,604
UTL-4237136157	30.99542	102.69718	2,646	2,516	2,471	2,356

Table 3. Location of geophysical soundings and the nearby borehole geophysical log the sounding was compared to in the Pecos County region study area, Texas.

[TDEM, time-domain electromagnetic sounding; AMT, audio-magnetotelluric sounding; USGS, U.S. Geological Survey]

Sounding identifier	Latitude (decimal degrees)	Longitude (decimal degrees)	USGS station number for borehole log comparison	Latitude (decimal degrees)	Longitude (decimal degrees)
TDEM1	30.85286	102.89278	310221102534201	30.85286	102.89278
TDEM2	30.84514	102.99889	305042102595601	30.84509	102.99899
TDEM3	30.78642	103.00917	304711103003301	30.78642	103.00932
TDEM4	30.64000	102.48028	303824102285001	30.64000	102.48052
AMT07	30.64030	102.47209	303824102285001	30.64000	102.48052
AMT08	30.44190	102.84390	302630102503801	30.44176	102.84396
AMT11	30.77301	102.52359	304622102312401	30.77304	102.52379
AMT12	31.13473	103.29427	310806103171901	31.13502	103.28796

Table 4. Compiled transmissivity values using data from aquifer tests conducted at wells completed in the Edwards-Trinity aquifer in or near the Pecos County region study area, Texas.

[Trans., transmissivity; [(gal/d)/ft], gallons per day per foot; [(gal/d)/ft²], gallons per day per square foot; --, not available; JMF, Jacob modified formula; TNEF, Theis nonequilibrium formula; TRF, Theis recovery formula; DF, Driscoll's formula; USGS, U.S. Geological Survey; TWDB, Texas Water Development Board]

Site identifier (fig. 19)	TWDB well number	Source site name	Year of data collection	Latitude (decimal degrees)	Longitude (decimal degrees)	Trans. [(gal/d)/ft]	Aquifer thickness (feet)	Hydraulic conductivity [(gal/d)/ft²]	Log of Trans. value	Method	Source
T1	--	M-3	2009	30.76829	103.02616	1,078,000	1,202	8,900	13.891	JMF	Thornhill Group, Inc., 2009
T2	--	M-9	2009	30.77201	103.02618	726,000	1,201	6,050	13.685	JMF	Thornhill Group, Inc., 2009
T3	--	CITY No. 5	2009	30.77221	103.03584	755,000	2,202	3,400	13.891	JMF	Thornhill Group, Inc., 2009
T4	--	S-4	2009	30.82763	103.04356	363,000	3,402	1,060	14.737	JMF	Thornhill Group, Inc., 2009
T5	--	S-3	2009	30.82737	103.04354	389,000	3,301	1,200	14.166	JMF	Thornhill Group, Inc., 2009
T6	--	S-10	2009	30.83067	103.02697	1,017,000	1,902	5,300	13.832	JMF	Thornhill Group, Inc., 2009
T7	--	S-32	2009	30.85885	103.03509	637,000	3,602	1,800	12.934	JMF	Thornhill Group, Inc., 2009
T8	--	S-26	2009	30.85883	103.03722	842,000	3,602	2,300	13.696	JMF	Thornhill Group, Inc., 2009
T9	--	C-B2	2009	30.89105	103.03141	1,070,000	2,802	3,821	13.883	JMF	Thornhill Group, Inc., 2009
T10	--	C-3	2009	30.89123	103.03452	1,216,000	2,702	4,500	14.011	JMF	Thornhill Group, Inc., 2009
T11	--	S-33	2007	30.91737	102.61213	96,000	--	--	11.472	JMF	Thornhill Group, Inc., 2008
T13	--	--	1957	30.88750	102.89194	18,100	2,803	65	9.804	TNEF	Meyers, 1969, p. 408
T14	--	--	1957	30.89250	102.90222	7,000	1,603	44	8.854	TRF	Meyers, 1969, p. 408
T15	--	--	1957	30.96944	102.88167	4,580	2,103	22	8.429	TNEF	Meyers, 1969, p. 411
T16	--	--	1957	30.95611	102.88556	5,640	2,203	26	8.638	JMF	Meyers, 1969, p. 411
T17	--	--	1957	30.96778	102.88472	2,800	1,203	23	7.937	TRF	Meyers, 1969, p. 412
T18	--	--	1957	30.96667	102.89444	7,150	1,803	40	8.875	TNEF	Meyers, 1969, p. 412
T19	--	--	1959	31.02028	103.55000	8,260	203	413	9.019	JMF	Meyers, 1969, p. 427
T20	--	Fritz	2011	30.78740	103.44340	13,713	4,103	33	9.526	DF	USGS
T26	4561604	--	1969	31.05110	102.37780	7,800	1,603	49	8.962	DF	TWDB, 2011
T27	4561605	--	1969	31.05360	102.37690	4,350	1,503	29	8.378	DF	TWDB, 2011
T28	4561608	--	1969	31.05060	102.38360	4,350	1,703	26	8.378	DF	TWDB, 2011
T29	4561610	--	1969	31.04390	102.39690	3,300	1,603	21	8.102	DF	TWDB, 2011
T30	4561901	--	1968	31.03360	102.39000	1,800	1,803	10	7.496	DF	TWDB, 2011
T31	4561902	--	1968	31.03000	102.38940	2,850	1,703	17	7.955	DF	TWDB, 2011
T32	4561903	--	1968	31.02810	102.38670	4,350	1,703	26	8.378	DF	TWDB, 2011
T33	4561904	--	1968	31.02690	102.38830	4,650	1,703	27	8.445	DF	TWDB, 2011
T34	4561905	--	1968	31.02440	102.38940	2,700	1,703	16	7.901	DF	TWDB, 2011
T35	5216302	--	2007	30.85190	103.02560	73,500	2,603	283	11.205	DF	TWDB, 2011
T36	5216308	--	2007	30.84500	103.03440	192,000	2,403	800	12.165	DF	TWDB, 2011
T37	5216309	--	2007	30.86390	103.03250	609,000	5,303	1,149	13.320	DF	TWDB, 2011
T38	5216603	--	2007	30.83060	103.02610	265,500	2,203	1,207	12.489	DF	TWDB, 2011
T39	5216618	--	2007	30.83030	103.03030	436,500	2,503	1,746	12.987	DF	TWDB, 2011
T40	5216619	--	2007	30.79310	103.00610	87,000	1,203	725	11.374	DF	TWDB, 2011
T41	5305301	--	2001	30.99670	102.37560	6,600	1,703	39	8.795	DF	TWDB, 2011
T42	5305903	--	1973	30.89500	102.37690	9,375	1,003	94	9.146	DF	TWDB, 2011
T45	5313203	--	2000	30.83860	102.44970	1,920	503	38	7.560	DF	TWDB, 2011
T46	5313209	--	1999	30.84470	102.45560	1,500	603	25	7.313	DF	TWDB, 2011

[1]Unknown well completion depth; assumed 400 ft below land surface for site T2 and assumed 500 ft below land surface for site T5.

[2]Thickness from Thornhill Group, Inc., 2009 report.

[3]Thickness approximated from water level and interpreted base of aquifer (rounded to nearest 10 ft).

Table 5. Data-collection sites providing data for the geochemical analysis in the Pecos County region study area, Texas.

[USGS, U.S. Geological Survey; --, not applicable; ET, Edwards-Trinity; PC QW, Pecos County water quality]

Site identifier (fig. 20)	USGS station name	State well number	USGS station number	Latitude (decimal degrees)	Longitude (decimal degrees)	Site type	Contributing aquifer
Q1	San Solomon Spring	--	08427500	30.94292	103.78824	Spring	--
Q2	Santa Rosa Spring	--	08437000	31.26743	102.95828	Spring	--
Q4	Comanche Springs	--	08444500	30.88628	102.87495	Spring	--
Q6	Diamond Y Spring	--	08446600	31.00190	102.92358	Spring	--
Q27	PS-52-02-404	PS-52-02-404	305502103504101	30.91737	103.84518	Well	Pecos Valley
Q36	WD-46-62-201	WD-46-62-201	310625103175201	31.10685	103.29777	Well	Pecos Valley
Q42	US-45-43-807	US-45-43-807	311602102400601	31.26942	102.67609	Well	Pecos Valley
Q43	US-45-43-8xx (PA 1)	US-45-43-8xx	311602102400901	31.26934	102.68214	Well	Pecos Valley
Q15	PS-52-11-702	PS-52-11-702	304605103444601	30.77100	103.74800	Well	Igneous
Q7	PS-52-34-303	--	302955103451101	30.49860	103.75300	Well	Igneous
Q11	US-52-22-8xx (Farm Well 3)	US-52-22-8xx	303941103175001	30.66139	103.29720	Well	Edwards-Trinity
Q12	PS-52-20-601	PS-52-20-601	304006103315601	30.66827	103.53216	Well	Edwards-Trinity
Q14	US-53-17-501	US-53-17-501	304117102560101	30.68806	102.93361	Well	Edwards-Trinity
Q16	US-52-16-910	US-52-16-910	304646103013401	30.77931	103.02615	Well	Edwards-Trinity
Q17	US-52-13-801	US-52-13-801	304715103263501	30.78740	103.44343	Well	Edwards-Trinity
Q18	US-52-16-611	US-52-16-611	304802103003901	30.80088	103.01110	Well	Edwards-Trinity
Q22	US-52-16-3xx (S-21)	US-52-16-3xx	305132103015701	30.85899	103.03244	Well	Edwards-Trinity
Q23	US-53-09-306	US-53-09-306	305140102521101	30.87393	102.88229	Well	Edwards-Trinity
Q24	US-52-08-909	US-52-08-909	305331103020501	30.89210	103.03516	Well	Edwards-Trinity
Q25	US-53-03-9xx	US-53-03-9xx	305354102373501	30.89825	102.62647	Well	Edwards-Trinity
Q26	US-53-01-907	US-53-01-907	305419102545301	30.90560	102.91610	Well	Edwards-Trinity
Q28	PS-52-02-4xx (Balmorhea)	PS-52-02-4xx	305509103510101	30.91911	103.85027	Well	Edwards-Trinity
Q30	WD-52-02-507	WD-52-02-507	305531103474201	30.92539	103.79511	Well	Edwards-Trinity
Q32	US-53-07-105	US-53-07-105	305836102131701	30.97667	102.22139	Well	Edwards-Trinity
Q33	US-53-01-210	US-53-01-210	305859102571001	30.98293	102.95271	Well	Edwards-Trinity
Q35	US-45-60-903	US-45-60-903	310136102311601	31.02670	102.52102	Well	Edwards-Trinity
Q37	US-45-58-2xx	US-45-58-2xx	310718102484801	31.12162	102.81354	Well	Edwards-Trinity
Q40	US-46-56-309	US-46-56-309	311235103000901	31.20974	103.00262	Well	Edwards-Trinity
Q8	BK-52-29-8xx (Brewster County ET Well)	BK-52-29-8xx	303222103263701	30.53950	103.44346	Well	Edwards-Trinity
Q9	US-52-07-502	US-52-07-502	303342103064001	30.93779	103.18711	Well	Edwards-Trinity
Q21	US-53-13-208	US-53-13-208	305112102265901	30.85341	102.44965	Well	Dockum
Q31	US-52-06-603	US-52-06-603	305559103154101	30.93305	103.26194	Well	Dockum
Q34	US-53-01-208	US-53-01-208	305949102552301	30.99718	102.92291	Well	Dockum
Q39	US-46-55-9xx (Weatherby Ranch)	US-46-55-9xx	310949103090401	31.16341	103.15103	Well	Dockum
Q44	US-46-48-701	US-46-48-701	311610103050901	31.26959	103.08683	Well	Dockum
Q10	US-53-19-7xx (PC QW)	US-53-19-7xx	303852102432902	30.64799	102.72470	Well	Rustler
Q13	US-52-24-501	US-52-24-501	304020103025202	30.67295	103.05601	Well	Rustler
Q19	US-52-16-609	US-52-16-609	304805103013301	30.80129	103.02618	Well	Rustler
Q29	US-53-01-5xx (Apache 3)	US-53-01-5xx	305529102560601	30.92470	102.93490	Well	Rustler
Q38	WD-46-54-901	WD-46-54-901	310806103171901	31.13502	103.28796	Well	Rustler
Q20	US-52-16-504	US-52-16-504	304807103025301	30.80241	103.04844	Well	Capitan Reef
Q41	US-45-49-203	US-45-49-203	311422102555101	31.23974	102.93097	Well	Capitan Reef

Table 6. Contributing-aquifer revisions for groundwater wells providing data for the geochemical analysis based on the comparison of well production depths with the hydrostratigraphy of hydrogeologic framework for the Pecos County region study area, Texas.

[USGS, U.S. Geological Survey]

Site identifier (fig. 20)	USGS station number	Previously identified contributing aquifer (Pearson and others, 2012)	Updated contributing aquifer
Q12	304006103315601	Igneous	Edwards-Trinity
Q30	305531103474201	Cretaceous Undivided	Edwards-Trinity
Q40	311235103000901	Pecos Valley	Edwards-Trinity
Q21	305112102265901	Edwards-Trinity	Dockum
Q31	305559103154101	Edwards-Trinity	Dockum
Q34	305949102552301	Edwards-Trinity	Dockum
Q39	310949103090401	Edwards-Trinity	Dockum
Q10	303852102432902	Edwards-Trinity	Rustler
Q13	304020103025202	Edwards-Trinity	Rustler

Table 7. Summary of selected physical properties and constituents measured in groundwater and spring water samples and hydrochemical facies, Pecos County region study area, Texas.

[USGS, U.S. Geological Survey; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; $\delta^{18}O$, delta oxygen-18; δD, delta deuterium; $^{87}Sr/^{86}Sr$, strontium-87/strontium-86; CIAT, Deethylatrazine; Na, sodium; Ca, calcium; Mg, magnesium; Cl, chloride; SO_4, sulfate; HCO_3, bicarbonate; --, not available; E, estimated; <, nondetection less than laboratory reporting level]

Site identifier (fig. 20)	USGS station number	Site type	Contributing aquifer	Sample date	Sample start time	Specific conductance, water, unfiltered (µS/cm)	Calcium, water, filtered (mg/L)	Magnesium, water, filtered (mg/L)	Sodium, water, filtered (mg/L)	Potassium, water, filtered (mg/L)	Bicarbonate, water, filtered, inflection-point titration method (incremental titration method), field (mg/L)
Q1	08427500	Spring	--	8/18/2010	11:00	2,430	143	54.0	291	14.3	239
Q2	08437000	Spring	--	1/25/2011	14:00	6,100	462	180	696	21.6	283
Q4	08444500	Spring	--	1/25/2011	10:00	3,570	276	119	362	12.0	259
Q6	08446600	Spring	--	8/8/2010	13:00	6,730	504	249	837	26.2	395
Q27	305502103504101	Well	Pecos Valley	8/15/2010	19:00	362	58.6	4.79	11.6	2.96	204
Q36	310625103175201	Well	Pecos Valley	9/2/2010	15:00	783	76.0	17.0	68.3	4.79	232
Q42	311602102400601	Well	Pecos Valley	8/17/2010	18:00	1,250	695	352	2,010	19.1	315
Q43	311602102400901	Well	Pecos Valley	8/17/2010	21:00	1,690	856	384	2,700	36.3	190
Q15	304605103444601	Well	Igneous	6/22/2011	14:00	331	45.4	5.93	16.7	3.60	182
Q7	302955103451101	Well	Igneous	9/2/2010	11:00	408	54.0	6.92	22.2	3.15	225
Q11	303941103175001	Well	Edwards-Trinity	8/25/2010	10:00	1,390	100	27.7	145	8.26	251
Q12	304006103315601	Well	Edwards-Trinity	6/23/2011	11:00	1,310	27.0	4.38	265	7.43	409
Q14	304117102560101	Well	Edwards-Trinity	8/25/2010	16:00	2,520	265	44.4	233	11.6	277
Q16	304646103013401	Well	Edwards-Trinity	8/16/2010	14:00	2,040	138	48.4	227	11.5	280
Q17	304715103263501	Well	Edwards-Trinity	8/28/2010	14:00	680	84.8	14.1	40.9	4.75	273
Q18	304802103003901	Well	Edwards-Trinity	8/20/2010	10:00	2,640	206	60.8	260	11.0	263
Q22	305132103015701	Well	Edwards-Trinity	8/16/2010	11:00	3,070	197	75.9	335	13.3	287
Q23	305140102521101	Well	Edwards-Trinity	8/10/2010	17:00	3,150	257	91.1	309	18.3	288
Q24	305331103020501	Well	Edwards-Trinity	8/17/2010	10:00	3,820	278	109	421	15.2	286
Q25	305354102373501	Well	Edwards-Trinity	6/21/2011	10:00	1,520	114	46.6	138	11.5	269
Q26	305419102545301	Well	Edwards-Trinity	8/6/2010	13:00	3,240	259	108	298	13.4	280
Q28	305509103510101	Well	Edwards-Trinity	9/1/2010	16:00	273	50.5	4.43	10.5	2.80	177
Q30	305531103474201	Well	Edwards-Trinity	6/22/2011	11:00	2,710	157	60.3	331	15.1	260
Q32	305836102131701	Well	Edwards-Trinity	8/13/2010	11:00	1,610	126	51.7	133	5.49	290
Q33	305859102571001	Well	Edwards-Trinity	8/5/2010	13:00	1,570	120	40.4	137	11.4	243
Q35	310136102311601	Well	Edwards-Trinity	8/26/2010	15:00	4,730	515	113	449	11.2	237
Q37	310718102484801	Well	Edwards-Trinity	8/27/2010	15:00	7,260	462	225	876	35.9	275
Q40	311235103000901	Well	Edwards-Trinity	8/11/2010	9:00	1,530	138	38.8	126	9.514	204
Q8	303222103263701	Well	Edwards-Trinity	9/2/2010	9:00	587	21.0	9.7	95.9	5.47	270
Q9	303342103064001	Well	Edwards-Trinity	8/27/2010	11:00	1,150	108	41.0	80.5	5.10	286
Q21	305112102265901	Well	Dockum	8/13/2010	15:00	3,200	255	98.6	328	11.6	270
Q31	305559103154101	Well	Dockum	8/6/2010	17:00	736	81.8	16.3	43.6	4.69	241
Q34	305949102552301	Well	Dockum	8/4/2010	12:00	2,080	146	49.1	202	13.0	256
Q39	310949103090401	Well	Dockum	8/31/2010	13:00	809	87.3	18.7	54.5	4.68	238
Q44	311610103050901	Well	Dockum	8/12/2010	12:00	1,560	149	33.5	126	7.38	201
Q10	303852102432902	Well	Rustler	8/10/2010	13:00	553	61.1	19.6	22.6	2.18	222
Q13	304020103025202	Well	Rustler	9/1/2010	10:00	2,050	135	45.0	226	11.1	281
Q19	304805103013301	Well	Rustler	8/19/2010	17:00	2,510	251	53.1	220	10.4	262
Q29	305529102560601	Well	Rustler	8/31/2010	17:00	3,980	589	213	177	17.3	244
Q38	310806103171901	Well	Rustler	8/29/2010	20:00	1,080	67.6	30.5	100	13.1	32.2
Q20	304807103025301	Well	Capitan Reef	8/19/2010	19:00	2,290	145	49.9	249	12.2	267
Q41	311422102555101	Well	Capitan Reef	8/11/2010	14:00	4,160	675	201	234	12.1	182

Table 7. Summary of selected physical properties and constituents measured in groundwater and spring water samples and hydrochemical facies, Pecos County region study area, Texas.—Continued

[USGS, U.S. Geological Survey; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; $\delta^{18}O$, delta oxygen-18; δD, delta deuterium; $^{87}Sr/^{86}Sr$, strontium-87/strontium-86; CIAT, Deethylatrazine; Na, sodium; Ca, calcium; Mg, magnesium; Cl, chloride; SO_4, sulfate; HCO_3, bicarbonate; --, not available; E, estimated; <, nondetection less than laboratory reporting level]

Site identifier (fig. 20)	Sulfate, water, filtered (mg/L)	Chloride, water, filtered (mg/L)	Silica, water, filtered (mg/L as silicon dioxide)	Nitrate plus Nitrite, water, filtered (mg/L)	Dissolved oxygen (mg/L)	Hydrochemical facies	$\delta^{18}O$ (per mil) (fig. 23)	δD (per mil)	$^{87}Sr/^{86}Sr$ (fig. 25)	Strontium, water, filtered (µg/L)	Atrazine (µg/L)	CIAT (µg/L)
Q1	437	431	24.6	0.788	3.47	Na-Ca-Cl-SO_4	-8.30	-58.1	0.70991	2,340	--	--
Q2	1,550	1,180	32.8	2.95	4.19	Na-Ca-Mg-Cl-SO_4	-6.56	-47.0	0.70925	9,060	--	--
Q4	987	565	22.8	5.74	2.10	Na-Ca-Mg-SO_4-Cl	-7.45	-50.5	0.70898	6,230	0.0064	E0.0141
Q6	1,890	1,220	35.4	6.67	6.35	Na-Ca-Mg-SO_4-Cl	-6.83	-49.5	0.70970	8,970	<0.007	E0.0213
Q27	11.8	7.16	53.5	1.22	6.14	Ca-HCO_3	-6.84	-46.3	0.70799	240	--	--
Q36	115	70.4	33.8	0.964	5.83	Ca-Na-HCO_3-SO_4-Cl	-6.85	-46.2	0.70839	1,300	--	--
Q42	2,600	3,930	25.8	<0.04	1.02	Na-Ca-Cl-SO_4	-4.86	-39.9	0.70813	12,300	--	--
Q43	3,020	4,770	22.6	2.10	2.73	Na-Ca-Cl-SO_4	-2.21	-26.0	0.70813	15,000	--	--
Q15	16.0	8.81	43.4	0.184	7.96	Ca-Na-HCO_3	-6.12	-44.6	0.70757	257	<0.008	<0.006
Q7	12.9	8.39	43.6	0.632	4.44	Ca-Na-HCO_3	-6.23	-41.6	0.70727	198	--	--
Q11	222	195	28.4	0.207	0.216	Na-Ca-Cl-SO_4-HCO_3	-7.29	-50.1	0.70954	1,730	--	--
Q12	271	58.6	21.1	<0.02	0.280	Na-HCO_3-SO_4	-7.47	-50.2	0.70788	1,030	<0.008	<0.006
Q14	661	340	20.8	<0.04	0.306	Ca-Na-SO_4-Cl	-7.89	-55.0	0.70893	3,610	--	--
Q16	341	317	20.2	0.309	0.897	Na-Ca-Cl-SO_4-HCO_3	-7.82	-54.1	0.70975	2,140	--	--
Q17	57.7	50.8	26.7	0.832	1.28	Ca-Na-HCO_3	-6.97	-45.6	0.70830	754	--	--
Q18	546	438	19.9	3.53	E1.171	Na-Ca-Cl-SO_4	-7.70	-54.2	0.70901	4,170	<0.007	E0.0065
Q22	578	556	22.7	1.58	0.921	Na-Ca-Cl-SO_4	-7.78	-53.9	0.70974	3,710	--	--
Q23	807	502	22.8	4.51	2.97	Na-Ca-Mg-SO_4-Cl	-7.18	-47.5	0.70940	7,320	--	--
Q24	908	758	23.3	1.61	1.17	Na-Ca-Mg-Cl-SO_4	-7.47	-52.3	0.70963	5,330	<0.007	E0.0075
Q25	277	203	10.6	<0.02	0.770	Na-Ca-Mg-SO_4-Cl-HCO_3	-7.47	-49.6	0.70959	2,370	<0.008	<0.006
Q26	883	470	19.7	4.04	1.43	Na-Ca-Mg-SO_4-Cl	-7.06	-48.8	0.70904	5,300	0.017	E0.013
Q28	12.2	5.16	52.0	1.18	4.48	Ca-HCO_3	-6.72	-45.3	0.70807	215	--	--
Q30	498	473	20.8	0.135	0.450	Na-Ca-Cl-SO_4	-8.34	-57.7	0.70979	2,720	<0.008	<0.006
Q32	217	240	18.3	1.81	6.32	Ca-Na-Mg-Cl-HCO_3-SO_4	-6.75	-44.5	0.70853	2,150	--	--
Q33	238	247	10.4	<0.04	0.180	Ca-Na-Mg-Cl-SO_4-HCO_3	-7.50	-50.6	0.70961	2,250	--	--
Q35	1,510	783	12.2	<0.04	0.447	Ca-Na-SO_4-Cl	-7.24	-50.7	0.70824	8,790	--	--
Q37	2,010	1,370	28.3	0.391	2.99	Na-Ca-Mg-SO_4-Cl	-6.85	-48.6	0.70969	10,300	--	--
Q40	376	180	13.0	<0.04	E0.230	Ca-Na-SO_4-Cl-HCO_3	-7.33	-50.0	0.70877	3,080	--	--
Q8	56.0	15.9	14.3	<0.04	0.149	Na-HCO_3	-7.16	-49.0	0.70816	575	--	--
Q9	276	55.9	25.5	5.74	3.93	Ca-Na-Mg-SO_4-HCO_3	-6.42	-44.6	0.70823	257	--	--
Q21	586	675	16.2	5.63	4.45	Na-Ca-Mg-Cl-SO_4	-7.14	-48.1	0.70906	4,040	--	--
Q31	91.8	58.2	14.4	<0.04	0.140	Ca-Na-HCO_3-SO_4-Cl	-6.87	-46.3	0.70843	1,000	--	--
Q34	335	331	11.1	<0.04	0.140	Na-Ca-Cl-SO_4-HCO_3	-7.81	-53.0	0.70975	2,610	--	--
Q39	119	68.1	26.3	1.09	7.32	Ca-Na-HCO_3-SO_4-Cl	-6.81	-47.2	0.70854	1,350	--	--
Q44	346	195	30.9	2.43	4.41	Ca-Na-SO_4-Cl-HCO_3	-7.21	-48.5	0.70882	2,800	<0.007	<0.014
Q10	52.5	23.5	14.0	2.19	4.03	Ca-Mg-HCO_3	-6.66	-45.1	0.70829	772	--	--
Q13	357	323	19.6	<0.04	0.0740	Na-Ca-Cl-SO_4-HCO_3	-7.84	-53.3	0.70977	2,200	--	--
Q19	704	332	18.7	<0.04	E0.170	Ca-Na-SO_4-Cl	-7.89	-53.2	0.70867	3,190	--	--
Q29	2,270	179	14.0	<0.04	6.57	Ca-Mg-SO_4	-7.61	-52.7	0.70758	10,000	--	--
Q38	354	110	0.479	<0.04	0.129	Na-Ca-Mg-SO_4-Cl	-6.83	-47.6	0.70763	3,390	--	--
Q20	421	370	21.0	<0.04	E 0.252	Na-Ca-Cl-SO_4	-7.92	-54.9	0.70969	2,650	--	--
Q41	2,320	354	13.9	<0.04	1.25	Ca-Mg-SO_4	-7.74	-52.8	0.70751	10,200	--	--

Table 8. Tritium concentrations and helium-4 screen interpretations for groundwater samples collected in the Pecos County region study area, Texas.

[USGS, U.S. Geological Survey; pCi/L, picocuries per liter; TU, tritium units (3.22 pCi/L = 1 TU); --, not available; ssLc, sample specific critical level; R, radiochemical nondetect]

Site identifier (fig. 20)	USGS station number	Site type	Contributing aquifer	Sample date	Sample start time	Tritium, water, unfiltered (pCi/L)	Tritium, water, unfiltered (TU)	ssLc	Analysis date	Preliminary assessment of viability of age information, based on helium-4 measurement[1]
Q2	08437000	Spring	--	1/25/2011	14:00	1.8	0.55	0.31	4/19/2011	--
Q4	08444500	Spring	--	1/25/2011	10:00	6.5	2.0	0.56	4/19/2011	Dateable
Q6	08446600	Spring	--	8/8/2010	13:00	1.9	0.59	0.43	2/7/2011	--
Q27	305502103504101	Well	Pecos Valley	8/15/2010	19:00	3.5	1.1	0.40	2/7/2011	Dateable
Q36	310625103175201	Well	Pecos Valley	9/2/2010	15:00	R0.26	--	0.37	1/31/2011	--
Q43	311602102400901	Well	Pecos Valley	8/17/2010	21:00	4.2	1.3	0.41	1/31/2011	Dateable
Q15	304605103444601	Well	Igneous	6/22/2011	14:00	9.9	3.1	0.54	12/1/2011	Dateable
Q7	302955103451101	Well	Igneous	9/2/2010	11:00	3.8	1.2	0.39	1/31/2011	Dateable
Q11	303941103175001	Well	Edwards-Trinity	8/25/2010	10:00	0.34	0.11	0.36	1/31/2011	--
Q12	304006103315601	Well	Edwards-Trinity	6/23/2011	11:00	0.94	0.29	0.25	12/1/2011	--
Q14	304117102560101	Well	Edwards-Trinity	8/25/2010	16:00	R0.17	--	0.35	1/31/2011	--
Q17	304715103263501	Well	Edwards-Trinity	8/28/2010	14:00	3.7	1.1	0.43	1/31/2011	Dateable
Q18	304802103003901	Well	Edwards-Trinity	8/20/2010	10:00	R0.0	--	0.36	1/31/2011	--
Q23	305140102521101	Well	Edwards-Trinity	8/10/2010	17:00	4.3	1.3	0.40	2/7/2011	Dateable
Q24	305331103020501	Well	Edwards-Trinity	8/17/2010	10:00	1.3	0.40	0.36	2/7/2011	--
Q25	305354102373501	Well	Edwards-Trinity	6/21/2011	10:00	0.29	0.090	0.25	12/1/2011	--
Q26	305419102545301	Well	Edwards-Trinity	8/6/2010	13:00	2.7	0.85	0.42	2/7/2011	--
Q28	305509103510101	Well	Edwards-Trinity	9/1/2010	16:00	6.7	2.1	0.44	1/31/2011	Dateable
Q30	305531103474201	Well	Edwards-Trinity	6/22/2011	11:00	0.80	0.25	0.25	12/1/2011	--
Q9	303342103064001	Well	Edwards-Trinity	8/27/2010	11:00	0.13	0.040	0.35	1/31/2011	--
Q31	305559103154101	Well	Dockum	8/6/2010	17:00	R0.0	--	0.37	2/7/2011	--
Q44	311610103050901	Well	Dockum	8/12/2010	12:00	0.44	0.14	0.41	2/7/2011	--
Q10	303852102432902	Well	Rustler	8/10/2010	13:00	0.070	0.022	0.39	2/7/2011	--

[1]Dateable refers to the potential for obtaining valid groundwater age information based on preliminary results.

Table 9. Average winter (November through April) groundwater-level data used for the 1980–2010 compiled potentiometric-surface map of the Edwards-Trinity aquifer in the Pecos County region study area, Texas.

[TWDB, Texas Water Development Board]

Site identifier (fig. 28)	TWDB well number	Source station number	Latitude (decimal degrees)	Longitude (decimal degrees)	Groundwater-level altitude data from 1980 to 2010				
					Number of water-level measurements for the site	Minimum water level (feet)	Maximum water level (feet)	Average water level (feet) (value used to generate water-level contour map fig. 28)	Data collection period
L1	5202704	5202704	30.90750	103.83694	1	3,454.23	3,454.23	3,454.23	1990
L2	5202511	5202511	30.94056	103.80361	2	3,323.25	3,326.25	3,324.75	1997–2001
L3	5202608	5202608	30.93861	103.75694	1	3,275.93	3,275.93	3,275.93	1997
L4	4659508	4659508	31.04583	103.70055	21	2,701.74	2,728.82	2,715.83	1988–2009
L5	4660101	4660101	31.11611	103.59639	19	2,594.25	2,651.02	2,629.25	1988–2006
L6	4652404	4652404	31.18833	103.58555	27	2,585.41	2,609.59	2,594.46	1980–2009
L7	5204210	5204210	30.97139	103.56389	2	2,721.15	2,732.85	2,727.00	1988–89
L8	4660807	4660807	31.02111	103.56250	16	2,625.34	2,661.67	2,650.11	1988–2004
L9	4660808	4660808	31.03111	103.56000	1	2,622.24	2,622.24	2,622.24	1988
L10	4660809	4660809	31.03083	103.55889	1	2,718.52	2,718.52	2,718.52	1988
L11	4660810	4660810	31.03028	103.55611	1	2,625.51	2,625.51	2,625.51	1988
L12	5237202	5237202	30.48555	103.44389	2	3,581.81	3,583.15	3,582.48	2002
L13	5213801	5213801	30.78740	103.44343	3	3,072.20	3,085.76	3,076.87	2006–10
L14	5205601	5205601	30.95611	103.41278	1	2,890.04	2,890.04	2,890.04	1987
L15	5213303	5213303	30.84778	103.40639	1	3,153.07	3,153.07	3,153.07	1987
L16	5221301	5221301	30.72805	103.40583	7	3,163.77	3,182.09	3,173.12	2002–8
L17	5230104	5230104	30.61055	103.36611	1	3,315.82	3,315.82	3,315.82	1987
L18	5230105	5230105	30.61222	103.36583	6	3,318.53	3,323.90	3,319.55	1984–92
L19	5230107	303717103214801	30.62144	103.36383	2	3,343.44	3,381.83	3,362.63	2006–10
L20	5230108	303718103214601	30.62182	103.36324	2	3,342.75	3,344.78	3,343.77	2006–10
L21	5206501	5206501	30.94167	103.32361	29	2,870.84	2,886.68	2,879.09	1980–2009
L22	4662801	310238103191701	31.04401	103.32139	151	2,753.34	2,755.31	2,754.33	2008–10
L23	5206504	5206504	30.93861	103.30750	1	2,843.31	2,843.31	2,843.31	1999
L24	5214801	5214801	30.75555	103.29500	1	3,201.43	3,201.43	3,201.43	1987
L25	5206303	5206303	30.97444	103.27250	1	2,748.55	2,748.55	2,748.55	1987
L26	5207401	5207401	30.91944	103.22055	1	2,809.52	2,809.52	2,809.52	1987
L27	5215501	5215501	30.81167	103.19722	1	2,956.76	2,956.76	2,956.76	1987
L28	5207502	303342103064001	30.93779	103.18711	1	2,869.84	2,869.84	2,869.84	2006
L29	5215201	5215201	30.85861	103.18500	1	2,979.84	2,979.84	2,979.84	1987
L30	5207801	5207801	30.91417	103.17833	1	2,913.58	2,913.58	2,913.58	1987
L31	4663902	4663902	31.04056	103.15389	15	2,692.49	2,703.99	2,699.75	1984–2001
L32	5215301	5215301	30.85250	103.15333	1	2,984.91	2,984.91	2,984.91	1987
L33	5207302	5207302	30.97780	103.14330	95	2,659.73	2,808.75	2,770.35	1984–2008
L34	4663302	310652103080601	31.11444	103.13500	1	2,499.90	2,499.90	2,499.90	1983
L35	5208402	5208402	30.94075	103.12200	1	2,813.57	2,813.57	2,813.57	2010
L36	5224102	5224102	30.72722	103.10972	1	3,064.50	3,064.50	3,064.50	1987
L37	5208801	5208801	30.87861	103.07083	27	2,885.60	2,973.93	2,945.57	1982–2009
L38	5216801	5216801	30.75556	103.07000	1	3,081.22	3,081.22	3,081.22	1988
L39	4664801	310039103035701	31.01095	103.06624	1	2,713.43	2,713.43	2,713.43	1984
L40	5208909	5208909	30.89210	103.03516	1	2,946.59	2,946.59	2,946.59	1988

Table 9. Average winter (November through April) groundwater-level data used for the 1980–2010 compiled potentiometric-surface map of the Edwards-Trinity aquifer in the Pecos County region study area, Texas.—Continued

[TWDB, Texas Water Development Board]

Site identi-fier (fig. 28)	TWDB well number	Source station number	Latitude (decimal degrees)	Longitude (decimal degrees)	Groundwater-level altitude data from 1980 to 2010: Number of water-level measure-ments for the site	Minimum water level (feet)	Maximum water level (feet)	Average water level (feet) (value used to generate water-level contour map fig. 28)	Data collection period
L41	5216907	5216907	30.78694	103.03083	1	3,003.25	3,003.25	3,003.25	1987
L42	53027	53027	30.77210	103.03080	1	2,993.26	2,993.26	2,993.26	2009
L43	5208905	5208905	30.88694	103.02972	1	2,942.07	2,942.07	2,942.07	1988
L44	5208906	5208906	30.89167	103.02889	1	2,945.58	2,945.58	2,945.58	1988
L45	5216605	5216605	30.80861	103.02694	2	2,970.33	2,977.41	2,973.87	1988–2001
L46	5216304	5216304	30.84528	103.01861	1	2,978.68	2,978.68	2,978.68	1988
L47	5216303	5216303	30.84556	103.01194	7	2,852.62	3,050.52	2,956.78	1980–89
L48	5216611	304802103003901	30.80088	103.01110	4	2,955.01	3,008.01	2,980.00	1988–2001
L49	4656309	311235103000901	31.20974	103.00262	182	2,405.23	2,415.07	2,410.37	2007–10
L50	5309101	5309101	30.85667	102.99972	1	2,924.91	2,924.91	2,924.91	1988
L51	5309105	5309105	30.84528	102.99917	22	2,944.41	2,983.42	2,967.17	1980–2008
L52	5309102	5309102	30.86833	102.98944	1	2,943.88	2,943.88	2,943.88	1988
L53	5301102	5301102	30.99222	102.96583	1	2,706.66	2,706.66	2,706.66	1993
L54	5301101	5301101	30.99556	102.96528	1	2,701.78	2,701.78	2,701.78	1993
L55	5325101	5325101	30.60417	102.96167	1	3,079.44	3,079.44	3,079.44	1987
L56	4557805	4557805	31.02083	102.95611	1	2,698.51	2,698.51	2,698.51	1993
L57	5301503	5301503	30.95426	102.95382	1	2,832.38	2,832.38	2,832.38	2010
L58	5301206	5301206	30.98305	102.94611	1	2,740.54	2,740.54	2,740.54	1993
L59	5301204	5301204	30.99778	102.94583	1	2,717.87	2,717.87	2,717.87	1993
L60	5301205	5301205	30.98222	102.94417	1	2,745.46	2,745.46	2,745.46	1993
L61	5301207	5301207	30.97444	102.93805	1	2,823.21	2,823.21	2,823.21	1993
L62	530105	530105	30.90111	102.93500	2	2,994.25	3,003.25	2,998.75	2006–8
L63	4557201	4557201	31.08417	102.92750	1	2,616.78	2,616.78	2,616.78	1987
L64	4549201	4549201	31.23139	102.92500	1	2,464.48	2,464.48	2,464.48	1984
L65	4557807	310002102551100	31.00071	102.92016	1	2,743.36	2,743.36	2,743.36	1987
L66	5301202	5301202	30.98389	102.92000	3	2,767.04	2,776.37	2,773.00	1991–93
L67	4557802	4557802	31.00778	102.91833	1	2,774.30	2,774.30	2,774.30	1993
L68	5301907	305419102545301	30.90560	102.91610	1	2,884.39	2,884.39	2,884.39	1981
L69	5301305	5301305	30.99056	102.91333	1	2,741.86	2,741.86	2,741.86	1993
L70	530103	530103	30.85472	102.90970	2	2,918.51	2,936.43	2,927.47	2006
L71	5301607	5301607	30.95583	102.90861	1	2,799.53	2,799.53	2,799.53	1993
L72	4557603	4557603	31.05667	102.90722	30	2,667.82	2,681.03	2,679.82	2007–9
L73	5309301	305110102533401	30.85286	102.89278	31	2,888.48	2,936.40	2,913.94	1980–2010
L74	5301304	5301304	30.99194	102.89250	1	2,751.44	2,751.44	2,751.44	1993
L75	4549301	4549301	31.20861	102.89139	24	2,472.26	2,481.34	2,477.28	1980–2005
L76	4549902	4549902	31.12555	102.88805	1	2,546.64	2,546.64	2,546.64	2004
L77	5301902	5301902	30.88972	102.88417	27	2,847.64	2,929.56	2,913.08	1980–2009
L78	5301908	5301908	30.88952	102.88397	1	2,903.70	2,903.70	2,903.70	2010
L79	530102	530102	30.87389	102.88250	2	2,901.83	2,928.13	2,914.98	2006–8
L80	5309306	5309306	30.87389	102.88222	1	2,891.41	2,891.41	2,891.41	2007

Table 9. Average winter (November through April) groundwater-level data used for the 1980–2010 compiled potentiometric-surface map of the Edwards-Trinity aquifer in the Pecos County region study area, Texas.—Continued

[TWDB, Texas Water Development Board]

Site identifier (fig. 28)	TWDB well number	Source station number	Latitude (decimal degrees)	Longitude (decimal degrees)	Groundwater-level altitude data from 1980 to 2010				
					Number of water-level measurements for the site	Minimum water level (feet)	Maximum water level (feet)	Average water level (feet) (value used to generate water-level contour map fig. 28)	Data collection period
L81	4557904	4557904	31.02000	102.87944	1	2,712.33	2,712.33	2,712.33	1993
L82	5301608	5301608	30.92694	102.87611	3	2,837.03	2,844.20	2,841.06	2006–8
L83	530201	530201	30.95111	102.86750	3	2,790.19	2,814.42	2,806.06	2006–8
L84	5302705	5302705	30.89389	102.86722	21	2,848.92	2,899.06	2,876.55	1983–2007
L85	5302102	5302102	30.97528	102.85944	11	2,744.10	2,774.99	2,766.63	1982–97
L86	5302710	305404102512701	30.90120	102.85770	56	2,864.80	2,895.68	2,876.53	2007–9
L87	5302403	305603102505901	30.93435	102.85013	3	2,789.68	2,803.68	2,796.83	1983–87
L88	5310103	5310103	30.84278	102.84639	1	2,890.53	2,890.53	2,890.53	1987
L89	5302708	305234102504301	30.87618	102.84521	29	2,832.81	2,890.13	2,869.55	1980–2010
L90	4558802	4558802	31.01889	102.82611	1	2,663.29	2,663.29	2,663.29	1987
L91	5302804	5302804	30.90500	102.81917	2	2,833.83	2,844.21	2,839.02	1999–2004
L92	5302802	5302802	30.90111	102.81583	9	2,830.43	2,846.33	2,840.14	1984–95
L93	5302803	5302803	30.89333	102.81555	1	2,823.93	2,823.93	2,823.93	1987
L94	520201	520201	30.89000	102.78860	1	2,814.12	2,814.12	2,814.12	2006
L95	521002	521002	30.78360	102.70500	3	2,825.52	2,826.35	2,825.91	2004–7
L96	5311501	5311501	30.83167	102.67444	1	2,762.29	2,762.29	2,762.29	1987
L97	521001	521001	30.77639	102.59420	2	2,753.47	2,753.47	2,753.47	2006–7
L98	5312205	5312205	30.86222	102.58000	1	2,742.53	2,742.53	2,742.53	1987
L99	5320201	5320201	30.73417	102.56111	1	2,749.16	2,749.16	2,749.16	1987
L100	5312203	5312203	30.85250	102.56083	3	2,726.72	2,735.76	2,729.99	1980–90
L101	5320901	5320901	30.66555	102.52389	1	2,642.44	2,642.44	2,642.44	1987
L102	4560303	4560303	31.10444	102.52083	1	2,317.40	2,317.40	2,317.40	1993
L103	4552901	4552901	31.13639	102.51778	1	2,331.01	2,331.01	2,331.01	1987
L104	45529	310810102310200	31.13626	102.51764	1	2,327.57	2,327.57	2,327.57	1987
L105	5320302	5320302	30.71861	102.50361	1	2,742.07	2,742.07	2,742.07	1987
L106	4561404	4561404	31.06611	102.48805	1	2,302.49	2,302.49	2,302.49	2002
L107	5313201	5313201	30.83611	102.45611	1	2,584.94	2,584.94	2,584.94	1987
L108	5313501	5313501	30.82805	102.45333	1	2,649.81	2,649.81	2,649.81	1987
L109	5306703	305415102222801	30.90460	102.37514	1	2,456.44	2,456.44	2,456.44	1987
L110	456101	456101	31.05667	102.37170	3	2,259.35	2,261.15	2,260.29	2006–07
L111	5306704	5306704	30.91389	102.37028	1	2,428.56	2,428.56	2,428.56	1987
L112	5306401	5306401	30.92444	102.35583	1	2,397.39	2,397.39	2,397.39	1987
L113	5306803	5306803	30.90458	102.31327	1	2,371.37	2,371.37	2,371.37	2010
L114	5314201	5314201	30.86139	102.30667	1	2,474.97	2,474.97	2,474.97	1987
L115	5306901	305357102172001	30.89923	102.28912	189	2,348.83	2,351.25	2,349.43	2007–10
L116	4562901	310041102152901	31.01156	102.25855	28	2,240.29	2,252.56	2,247.17	1980–2010
L117	5307106	5307106	30.97650	102.22977	1	2,229.27	2,229.27	2,229.27	2010
L118	5315201	5315201	30.86306	102.20667	1	2,678.63	2,678.63	2,678.63	1987
L119	530704	530704	30.97583	102.19440	3	2,201.58	2,222.86	2,215.27	2006–9

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