Queen City and Sparta Aquifers, Atascosa and McMullen Counties, Texas: Structure and Brackish Groundwater

Technical Note 14-01

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The Sparta Formation along State Highway 39, Leon County, Texas

Table of Contents

List of Figures

List of Tables

1. Executive summary

Estimated at more than 2.7 billion acre-feet, brackish groundwater (water with total dissolved solids concentration of 1,000 to 10,000 milligrams per liter) constitutes an important desalination water supply option in Texas. A lack of detailed information on hydrogeological characteristics of the brackish portions of Texas Water Development Board (TWDB) designated aquifers is a challenging issue, however, and a potential hindrance to more widespread implementation of desalination.

In 2009, the TWDB established the Brackish Resources Aquifer Characterization System (BRACS) program to map and characterize brackish groundwater in the state and facilitate the planning of desalination projects. The goals of the program are to map and characterize brackish groundwater in all of the major and minor aquifers, develop techniques of data analysis, and build a database management system that could be used in future brackish aquifer mapping projects and other geologic studies.

The Queen City and Sparta aquifers underlie an area of about 2,379 square miles in South Texas. The project area for these aquifers is Atascosa and McMullen counties, which includes portions of Regional Water Planning Areas L and N as well as Groundwater Management Areas 13 and 16. While the two aquifers account for only a small amount of the total groundwater use in the project area, the increased oil and gas activity in the region may lead to greater use.

Hundreds of water well and geophysical well logs were collected, analyzed, and interpreted to map the geologic units and establish stratigraphic relationships. Water chemistry, water level, and aquifer test data were gathered from various sources to characterize the groundwater in each aquifer and assess the hydraulic properties of each aquifer.

The subsurface interval studied extends from the top of the Sparta Formation to the bottom of the underlying Queen City Formation. The Sparta Formation constitutes the Sparta Aquifer and the Queen City Formation comprises the Queen City Aquifer. These formations consist of approximately 2,000 feet of Eocene fluvio-deltaic and marine sediments that are part of a gulfward thickening wedge of sediments deposited within the Gulf of Mexico basin.

The Sparta Formation contains approximately 5,470,000 acre-feet of brackish groundwater in storage in Atascosa County and about 3,410,000 acre-feet of brackish groundwater in storage in McMullen County within the project area. The entire project area has about 8,880,000 acre-feet of brackish groundwater in storage within the Sparta Formation. It also has approximately 994,000 acre-feet of very saline water in storage within the project area.

The Queen City Formation contains approximately 18,480,000 acre-feet of brackish groundwater in storage in Atascosa County and about 30,900,000 acre-feet of brackish groundwater in storage in McMullen County within the project area. The Queen City Formation has approximately 49,380,000 acre-feet of brackish groundwater in storage in the entire project area. It also has approximately 21,100,000 acre-feet of fresh water and 4,700,000 acre-feet of very saline water in storage within the project area.

Brackish groundwater occurs within the outcrop areas of the Sparta and Queen City formations in the project area.

2. Introduction

Estimated at more than 2.7 billion acre-feet (LBG-Guyton, 2003), brackish groundwater constitutes an important desalination water supply option in Texas. However, the more widespread implementation of desalination is being hindered by the lack of detailed information (especially parameters pertinent to desalination) on the brackish sections of TWDB-designated aquifers.

The TWDB classifies water salinity in terms of total dissolved solids and groups it into five categories: fresh (0–999 milligrams per liter); slightly saline (1,000–2,999 milligrams per liter); moderately saline (3,000–9,999 milligrams per liter); very saline (10,000–35,000 milligrams per liter); and brine (> 35,000 milligrams per liter) (Winslow and Kister, 1956). The term brackish water includes slightly to moderately saline waters (1,000–9,999 milligrams per liter of total dissolved solids) (LBG-Guyton, 2003).

While a 2003 TWDB-funded study (LBG-Guyton, 2003) helped lay the foundation for estimating brackish groundwater volumes in the state, the study was by design regional in scope, limited in areal extent, and narrow in its assessment of groundwater quality. To improve on the 2003 study, TWDB requested and received funding from the 81st Texas Legislature, 2009, to implement the Brackish Resources Aquifer Characterization System program to more thoroughly map and characterize the brackish aquifers.

The project area extends from the northern edge of the Queen City outcrop in Atascosa County into McMullen County (Figure 2-1). The primary goals of the project included

- mapping the top and bottom depths and thicknesses of the Queen City and Sparta formations,
- mapping the sand content of the formations,
- mapping the distribution of total dissolved solids in the two formations,
- mapping the distribution of key chemical parameters of interest to desalination,
- estimating the volume of brackish water in the two formations, and
- providing publicly available project data and information.

The Queen City and Sparta formations extend from south central Texas into east Texas and are designated as minor aquifers by TWDB (George and others, 2011). The aquifers are used primarily for livestock and domestic purposes, with significant municipal and industrial use only in northeast Texas (George and others, 2011). In recent years, oil and gas extraction activity in the Eagle Ford Shale area in South Texas has increased the level of interest in these aquifers as potential sources of water for hydraulic fracturing.

We used spontaneous potential, gamma ray, and resistivity geophysical well logs, water well data, and water quality data from several different sources to map and characterize the Queen City and Sparta formations. Salinity gradients in the aquifer could not be determined due to the lack of discrete water quality analyses from different depth intervals.

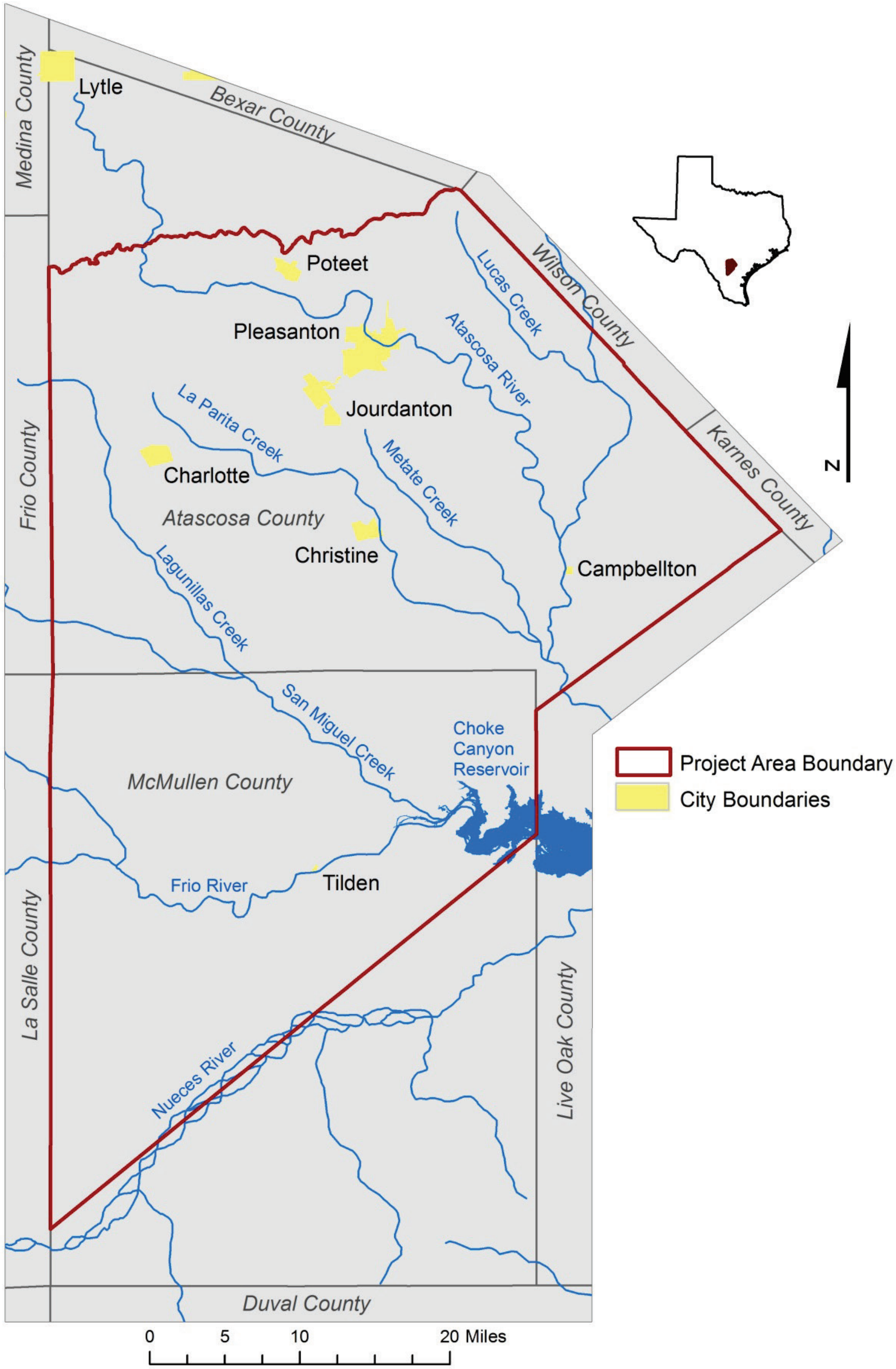


Figure 2-1. Project area in Atascosa and McMullen counties, South Texas.

3. Project area

A brief description of the project area including its location, topography, climate, and geologic history follows.

3.1 Location, topography, and climate

The project area in Atascosa and McMullen counties of South Texas covers about 1,712 square miles (Figure 2-1). It is mostly rural, with a population (2010 estimate) of about 45,618.

Oil and gas extraction is a leading industry in the project area. In 2012, more than 15 million barrels of oil were produced in the two counties as was more than 49 million cubic feet of natural gas (Railroad Commission of Texas, 2013). Lignite and sand are some of the other natural resources mined in the project area.

The project area is included in Regional Water Planning Areas L and N (Figure 3-1). Atascosa County lies within the boundaries of the Evergreen Underground Water Conservation District and McMullen County within the McMullen Groundwater Conservation District (Figure 3-2).

Physiographically, the project area lies within the Western Gulf Coastal Plain section of the Coastal Plain province (Thornbury, 1965). The Coastal Plain province is a gently sloping plain characterized by wide valleys, terraces along rivers, nearly flat divides of the upland areas, and low linear bands of northeast-southwest trending sandstones ridges that roughly parallel the coastline of the Gulf of Mexico. Elevations in the project area range from about 150 feet above sea level in the east to about 800 feet in Atascosa County in the west.

The project area has a subtropical, subhumid climate characterized by hot summers and dry winters (Larkin and Bomar, 1983). Average annual temperature is about 70 degrees Fahrenheit (Larkin and Bomar, 1983). Average annual rainfall in the project area is about 24 inches in the south and about 28 inches in the north (Larkin and Bomar, 1983). Mean lake surface evaporation rates range from about 63 inches per year in Atascosa County to about 67 inches per year in McMullen County (Larkin and Bomar, 1983).

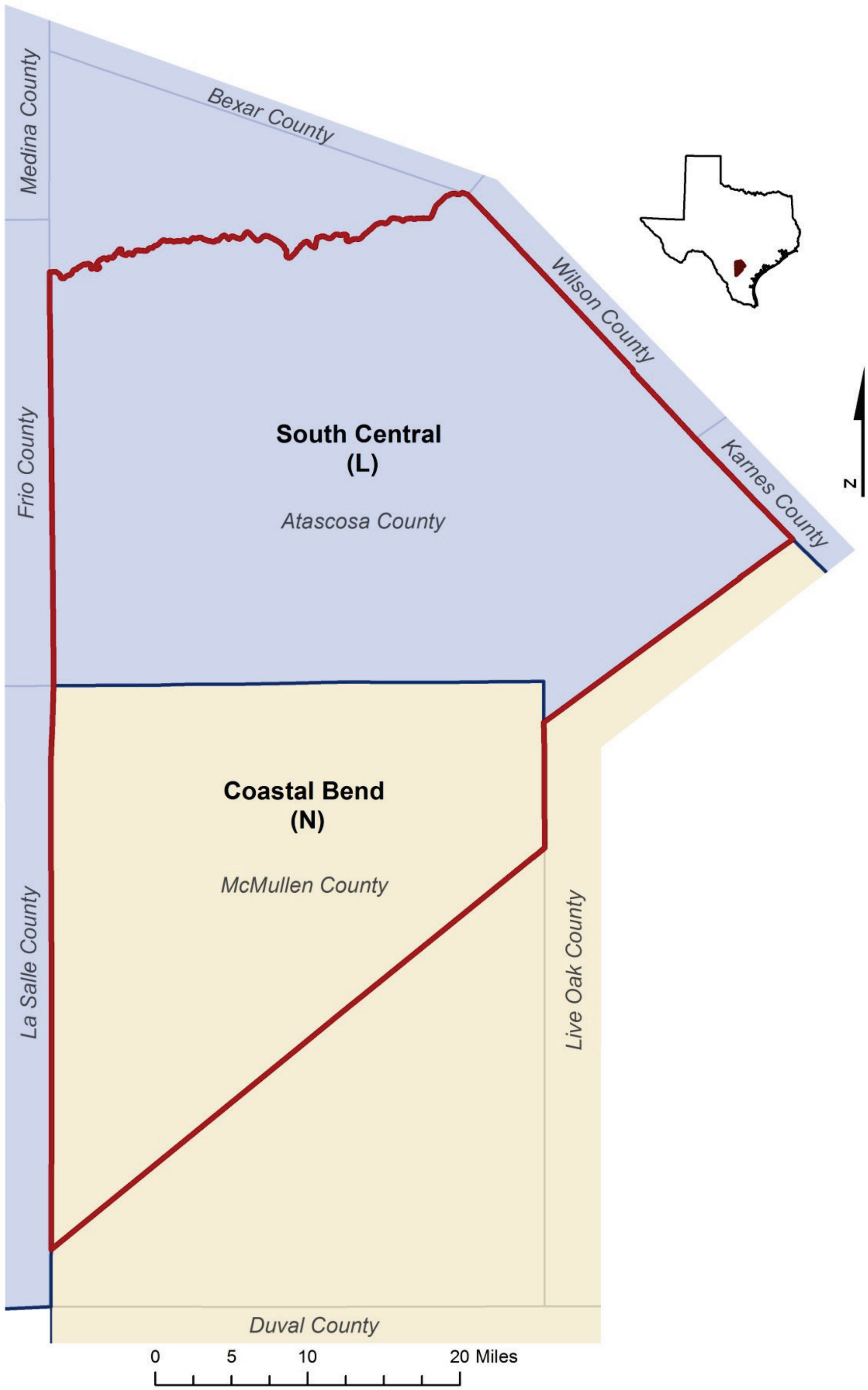


Figure 3-1. **Regional water planning areas in the project area. The project area boundary is shown in red.**

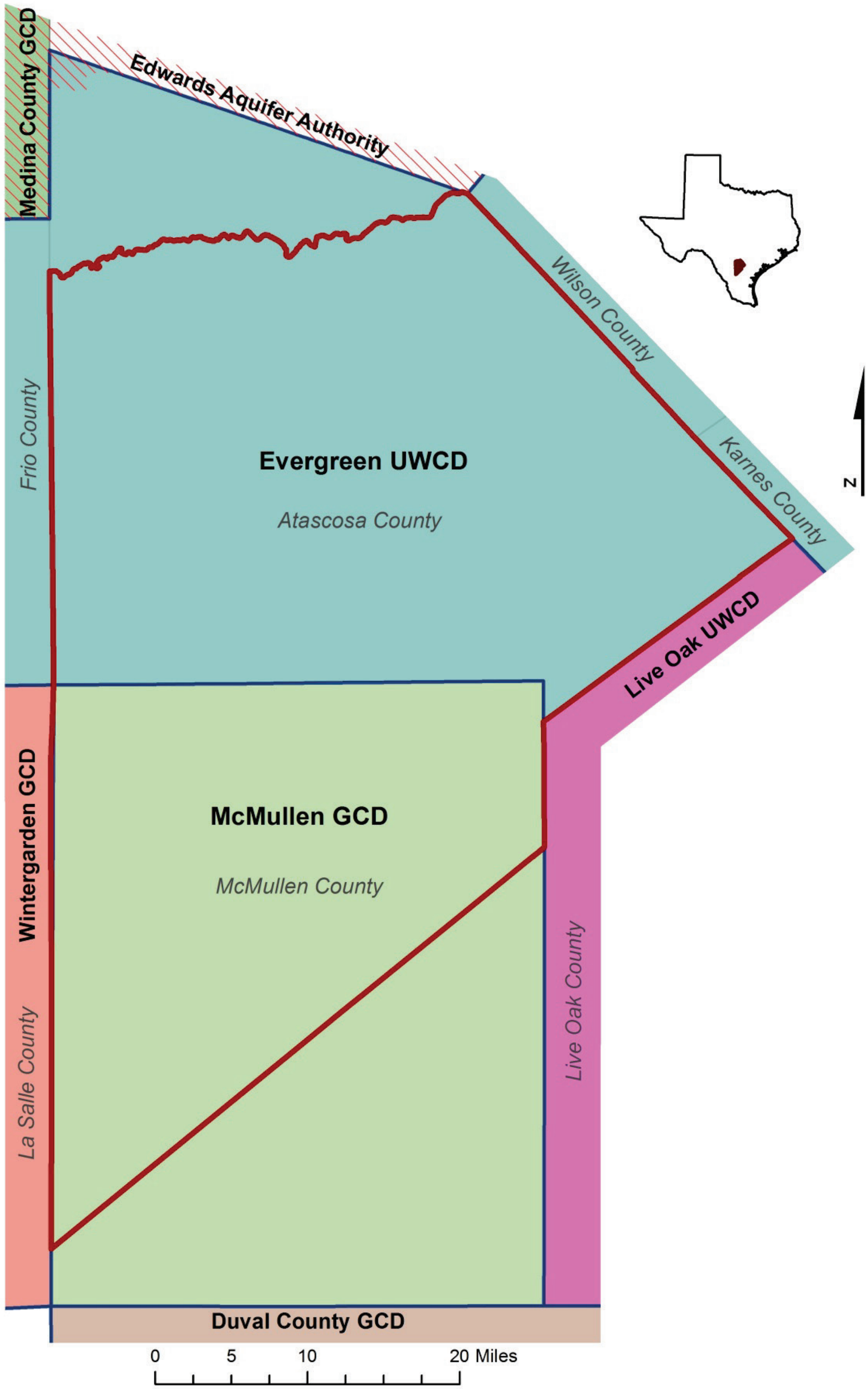


Figure 3-2. **Groundwater conservation districts in the project area. The project area boundary is shown in red. GCD = groundwater conservation district; UWCD = underground water conservation district.**

3.2 Geology

The general stratigraphy of the sediments in the project area is presented in Table 3-1. The columns of this table represent regions with different stratigraphic intervals that have been assigned a number to facilitate the aquifer determination process for project wells; regions 1 through 3 are located outside of the project area and are not shown.

Table 3-1. Stratigraphic relationships within the project area; region numbers are used in the aquifer determination process for project wells.

Geologic Epoch	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9	Region 10	Region 11
Oligocene								Gulf Coast Formations
							Frio	Frio
Eocene						Jackson	Jackson	Jackson
					Yegua	Yegua	Yegua	Yegua
				Cook Mountain	Cook Mountain	Cook Mountain	Cook Mountain	Cook Mountain
			Sparta	Sparta	Sparta	Sparta	Sparta	Sparta
		Weches	Weches	Weches	Weches	Weches	Weches	Weches
	Queen City	Queen City	Queen City	Queen City	Queen City	Queen City	Queen City	Queen City
	Reklaw	Reklaw	Reklaw	Reklaw	Reklaw	Reklaw	Reklaw	Reklaw
	Carrizo	Carrizo	Carrizo	Carrizo	Carrizo	Carrizo	Carrizo	Carrizo
Paleocene	Wilcox	Wilcox	Wilcox	Wilcox	Wilcox	Wilcox	Wilcox	Wilcox
	Midway	Midway	Midway	Midway	Midway	Midway	Midway	Midway

Notes: Aquifer formations shown in yellow. Confining formations shown in green.

The Sparta and Queen City formations are part of the Claiborne Group of Middle Eocene age and were deposited from about 41 to 47 million years ago (Galloway and others, 2000). The Sparta and Queen City formations are components of the Tertiary sequence of successive siliclastic wedge shaped layers that filled the Gulf of Mexico basin during this time (Ricoy and Brown, 1977; Guevara and Garcia, 1972). Sparta deposition did not, however, significantly prograde the northwestern Gulf of Mexico continental margin of Texas and the outer continental shelf, slope, and deep basin did not receive much sediment supply during this time (Galloway and others, 2000). By contrast, Queen City deposition was concentrated in the northwest Gulf of Mexico continental margin, near the present day Rio Grande River, and prograded the margin up to 20 miles in some places (Galloway and others, 2000).

The Sparta Formation has been referred to as the Sparta Sand (BEG, 1974, 1976) and constitutes the Sparta Aquifer (George and others, 2011). It is primarily composed of sand, silt, and clay of fluvial and deltaic origins deposited conformably on the older Weches Formation. The Cook Mountain Formation conformably overlies the Sparta Formation. Within the project area, the Sparta Formation represents a high-destructive wave dominated delta system composed of fluvial sediments that are contemporaneously reworked by marine processes because sediment input is dominated by marine wave and current energy (Ricoy and Brown, 1977). The Sparta Formation outcrop in South Texas consists of coastal barriers and associated lagoonal facies and coastal barrier, lagoon, and prodelta shelf facies in the subsurface. This wave-dominated delta system is present from Atascosa and Live Oak counties southward to the Rio Grande and into northern Mexico. Eocene analogs occur in the South Texas Wilcox Group, Yegua, and Queen City formations (Ricoy and Brown, 1977).

The Queen City Formation has been referred to as the Queen City Sand (BEG, 1974, 1976) and constitutes the Queen City Aquifer (George and others, 2011). It is composed primarily of sand, silt, and clay of fluvial and deltaic origins with relatively minor amounts of lignite. The Queen City Formation was deposited conformably on the older Reklaw Formation. The Weches Formation disconformably overlies the Queen City Formation. The Queen City Formation was deposited as part of a high-destructive, wave-dominated delta system (Guevara and Garcia, 1972). The upper Queen City and Weches formations transition into the El Pico Clay to the west of the project area (Kelly and others, 2009).

Sellards and others (1932) described the Queen City Formation sediments as about 70 percent sand, 22 percent silt and clay, 5 percent glauconite, 1 percent lignite, and 1 percent bentonite with the sand being medium to very fine-grained and mostly light gray. They described the Sparta Formation as about 70 percent sand, 25 percent clay, 3 percent glauconite, 1 percent limonite, and 1 percent lignite. The Sparta Formation sand tends to be unconsolidated, gray or brown in color, and medium to very fine grained (Sellards and others, 1932).

The project area is within the Rio Grande Embayment (Figure 3-3). The basinward extent of the Lower Cretaceous carbonate platforms within the project area are represented by the Sligo and Stuart City reef trends (Figure 3-3). These reefs developed at the continental shelf margin (Ewing, 1991). The Stuart City reef trend is younger than and developed landward of the Sligo reef trend. The Charlotte-Jourdanton and Karnes fault zones are part of a normal fault zone at or near the limit of Jurassic Louann Salt deposition (Jackson and others, 2003). Subsequent salt movement created the extensional fault system, with strata generally northwest of the faults locked in place and the strata overlying the salt detached and moved generally to the southeast (Jackson and others, 2003). We extracted the surface expression of these faults from the digital geologic atlas, a Geographic Information System (GIS) dataset derived from surficial geology maps created by the Bureau of Economic Geology (BEG 1974; BEG, 1976) (Figure 3-3). Syndepositional normal (growth) fault systems, such as the Wilcox Fault Zone, are present south of the project area (Ewing, 1991).

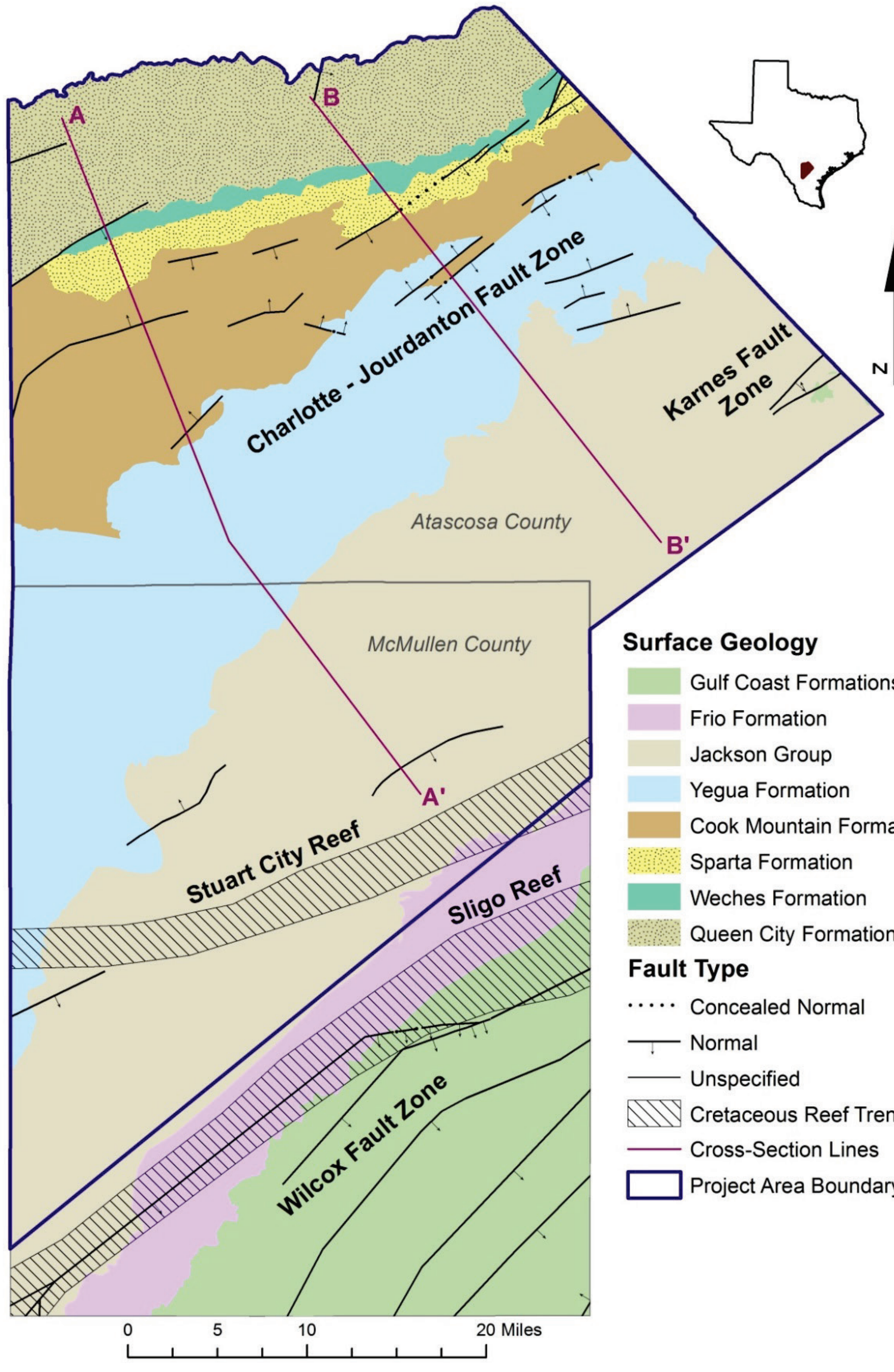


Figure 3-3. **General geology of and geologic structures in the project area. Map created from the digital geologic atlas maps that were developed by the Bureau of Economic Geology (BEG 1974, 1976), Hamlin (1988), and Ewing (1991). For clarity, Quaternary alluvium and terrace deposits are not shown.**

We placed the southern boundary of the project area in McMullen County updip of the Wilcox Fault Zone (Figure 3-3). The extreme structural complexity in this fault zone and the significant depth (more than 3,000 feet) to the top of Sparta makes the area an unlikely target for brackish groundwater development.

3.3 Summary of water demands and supplies in the project area

The Queen City and Sparta formations are a secondary source of water in the project area and primarily provide water for domestic and livestock supply. Usable quality water is commonly found within the outcrop and for a few miles downdip and in some areas may occur at depths of 1,500 feet.

The Sparta Formation provides less than one percent of total groundwater used in regional water planning areas L and N, whereas the Queen City Formation provides approximately 2 to 3 percent of total groundwater used in Regional Water Planning Area L and about 1 to 2 percent in Regional Water Planning Area N (Regional Water Planning Group L, 2010; Regional Water Planning Group N, 2010).

While Atascosa County in Regional Water Planning Area L is expected to face municipal, steam-electric, and irrigation water shortages during the 50-year planning period, the recommended water management strategies do not include use of the Queen City or Sparta formations to provide additional water (Regional Water Planning Group L, 2010). McMullen County in Regional Water Planning Area N is not projected to face water shortages over the 50-year planning period.

4. Previous investigations

Although not major aquifers, the Queen City and Sparta aquifers have nevertheless received a fair amount of scientific attention because of their large areal extent and potential to provide groundwater. Harris (1965) and Alexander and others (1964) provide a history of the early geologic and groundwater investigations conducted in the project area.

Deussen and Dole (1916) wrote one of the first reports on the groundwater resources of McMullen County. Their report contains records of 28 water wells drilled between 1893 and 1914 and the chemical analyses of 15 water samples collected in 1913 and 1914 within McMullen County. Lonsdale (1935) described groundwater development that occurred in Atascosa County between 1900 and 1930. The report contains records of 184 wells and chemical analyses of 22 water samples within Atascosa County. Swartz (1954) compiled records of water-level measurements in Atascosa and adjoining Frio counties for the 1929 to 1954 time period and Stearman (1960) from 1955 to 1960. Sundstrom and Follett (1950) investigated the groundwater resources of Atascosa County.

Kelley and others (2004) developed a groundwater availability model for the Queen City and Sparta aquifers to predict groundwater availability over a 50-year planning period. The model was based on current projections of groundwater demands during drought-of-record conditions.

Kelley and others (2009) describe the hydrogeologic characteristics of the Queen City and Sparta formations in Texas. The study also reviewed the recharge-discharge mechanisms in the two formations and their significance in and relation to future aquifer development.

Sellards and others (1932) provide a regional account of the geological formations in the project area. Garcia-Solorzano (1972) and Ricoy (1976) mapped the depositional environments of the Queen City and Sparta formations within Texas, respectively. Guevara and Garcia (1972) described the depositional systems and the oil and gas reservoirs in the Queen City Formation of Texas. Ricoy and Brown (1977) described the depositional systems and the oil and gas reservoirs of the Sparta Formation within Texas.

The chemical quality of groundwater in the Queen City and Sparta formations is an important part of this project. Biri (1997) reported on the sampling results between 1993 and 1995 for five Sparta wells in Atascosa County. Brown (1997) reported on water quality samples taken between 1990 to 1994 from the Queen City Formation from nine wells in Atascosa County and one well in McMullen County.

5. Data collection and analysis

One of the primary objectives of the project was to gather available well-control data from existing water well reports, geophysical well logs, water chemistry samples, and aquifer tests. This information augmented existing well information contained in the TWDB Groundwater Database. No single agency has complete information on all water, oil, or gas wells in Texas. Therefore, a number of existing collections that contain publicly available paper and digital information had to be evaluated. Because many of the datasets and analysis features did not fit into the existing TWDB Groundwater Database structure, we loaded information into the BRACS Database. Each well added to the BRACS Database shows the source of the information and all applicable well identification numbers.

Another equally important objective was to make the information and datasets gathered for the project readily available to the public. Thus, all of the information is non-confidential. Project information includes raw data such as water well reports and digital geophysical well logs; processed data such as lithology, simplified lithologic descriptions, stratigraphic picks, water chemistry; and interpreted results in the form of GIS datasets.

We appended information from 1,653 wells located within Atascosa, McMullen, and adjacent counties to the BRACS Database. Of this total, 1,457 wells are located within the project area with the remainder (196 wells) located outside the project area. The latter wells were necessary to accurately map the formations near the project area boundary (Figure 5-1). The number of project wells represents only a fraction of all wells completed in the project area because information from many other wells is either unavailable, incomplete, limited in scope, of poor quality, confidential, or does not meet project requirements.

The location of every well that we obtained from other agency datasets was not verified unless a problem was apparent, such as a mismatch in the geology. When locations had to be verified or when digital locations were not available, we used the Original Texas Land Survey GIS data from the Railroad Commission of Texas as a base map to plot the wells using the legal descriptions of locations provided on geophysical well log headers to determine the latitude and longitude coordinates and elevation. Users of the data need to be aware that well locations may need to be verified.

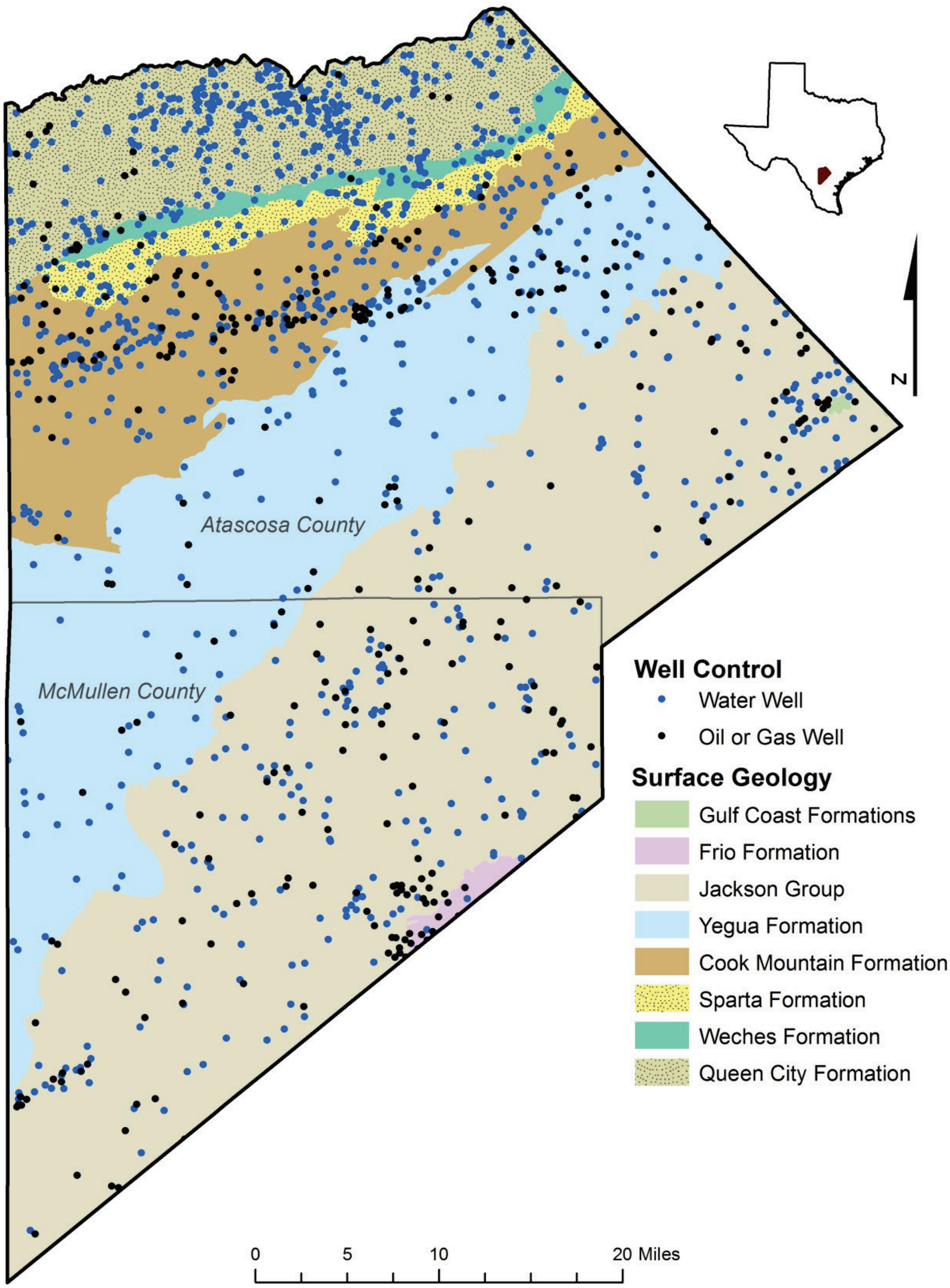


Figure 5-1. **Distribution of wells available for use in the project (total 1,457). Sources of information are the TWDB BRACS Database, TWDB Groundwater Database, BEG 1974, and BEG 1976.**

The following sources of well data were used in this project: Bureau of Economic Geology Geophysical Log Facility; Texas Department of Licensing and Regulation digital water well reports; Railroad Commission of Texas paper and digital geophysical well logs; TWDB Groundwater Database; and paper well reports, paper geophysical well log collection, groundwater availability model studies, and written reports. Each well in the BRACS Database contains a source reference for the information.

We made a decision to include some, but not all, of the wells contained in the TWDB Groundwater Database and Texas Department of Licensing and Regulation Submitted Driller's Report Database within BRACS. These wells contained information essential to understanding the geology of the region. These two databases are updated frequently, so in the future more information will be available from these sources in addition to the BRACS Database.

Based on information from the Railroad Commission of Texas Oil and Gas Well Database, the project area has approximately 7,300 oil and gas wells and about 69 Class II injection wells (Figure 5-2). Two publicly available collections of geophysical well logs that could supplement the dataset include those at the Groundwater Advisory Unit of the Railroad Commission of Texas and the Geophysical Log Facility at the Bureau of Economic Geology.

The data sets we developed for this project include original well data, ArcGIS® GIS files, the BRACS Database in Microsoft® Access® 2010 format, the BRACS Database Dictionary (Meyer, 2012), and project report. These deliverables are available on the TWDB website. At the time of writing this report, the BRACS statewide geophysical log collection of more than 38,000 geophysical well logs is not available online but can be obtained by contacting TWDB.

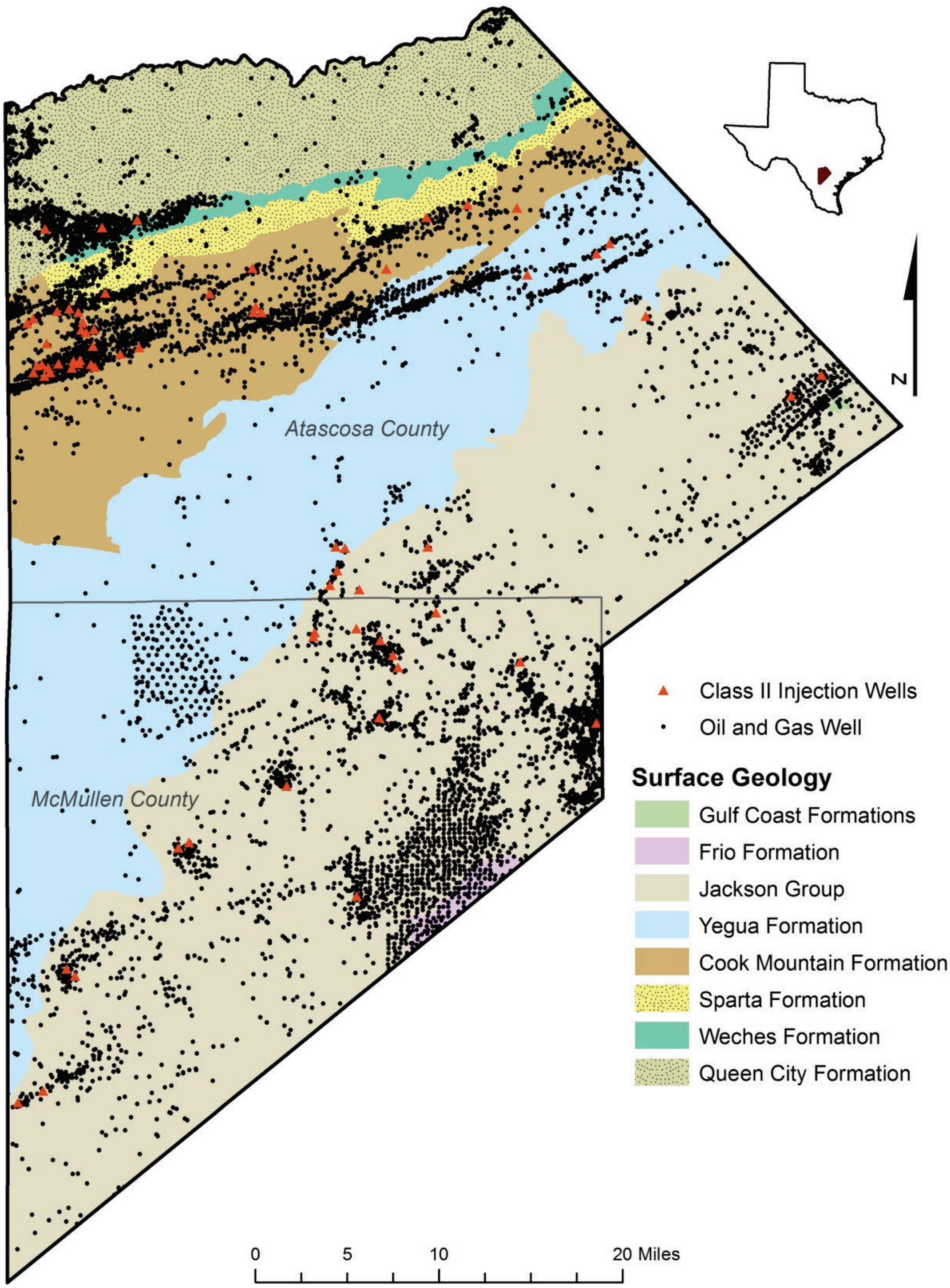


Figure 5-2. Oil and gas production wells (about 7,300) and Class II injection wells (about 69) in the project area. Source of information is the Railroad Commission of Texas.

6. Hydrogeologic setting

The hydrogeologic setting of an area is described by the structural, lithologic, geochemical, and hydrologic properties that characterize a geological formation's capacity to store and transmit groundwater. The Queen City and Sparta formations hydrogeologic setting is provided next.

6.1 Aquifer determination

We employed a technique to consistently assign a correct aquifer to wells drilled in the project area so information from these wells, specifically hydraulic properties, lithology, and water quality, could be meaningfully compared and extrapolated across the entire project area. We developed a hydrostratigraphic framework of the Queen City and Sparta formations for this project and used it to meet this objective. We assigned each well in the project area stratigraphic top and bottom depths and elevations based on the interpolated structural surfaces created for the Queen City and Sparta formations. Well screen information combined with formation top and bottom depths determined the aquifer(s) being used by the water well. If well screen information was not available, we used the total depth of the well or borehole to assign all aquifers from the surface to total depth.

We verified that the correct TWDB Groundwater Database aquifer codes had been assigned to project water wells. Wells appended to the BRACS Database from sources other than the TWDB Groundwater Database do not have aquifers assigned to them; our technique assigns this attribute. The aquifer determination technique facilitated the assignment of sand-bearing layers to specific formations, allowing us to tabulate and map the net sand and sand percent data for each aquifer.

Quality assurance steps helped ensure accuracy during the aquifer assignment process. These steps involved inspecting ranges of values (such as well depth or well screen depth), adding missing information, and correcting any mistakes. We examined aquifer assignments spatially in GIS to evaluate their validity as a final quality assurance review.

Aquifer assignments for wells with multiple screens required manual verification. Oil and gas wells in the database do not have an aquifer assigned to them. Additional information on the aquifer determination process is available in Meyer and others (2012).

6.2 Sparta and Queen City simulated hydraulic heads

Simulated hydraulic heads for 1999 from the Sparta and Queen City transient calibrated groundwater availability models are provided in figures 6-1 and 6-2. The last year used in the calibration period for most of the groundwater availability models was 1999. The models are calibrated so that the error between the highest and lowest simulated heads in the model versus the measured water levels in target wells is less than 10 percent. Additional information on the Sparta and Queen City groundwater availability models can be found in Kelly and others (2004).

Simulated hydraulic heads were calculated within the TWDB-designated aquifer boundaries. In order to support this project, we extrapolated the hydraulic head values to the project boundaries based on the observed hydraulic gradients (figures 6-1 and 6-2). We resampled the 1-mile grid cells of the simulated values to the project 250-foot grid cell size. Hydraulic head is used in the groundwater volume calculations and represents the water level in a well.

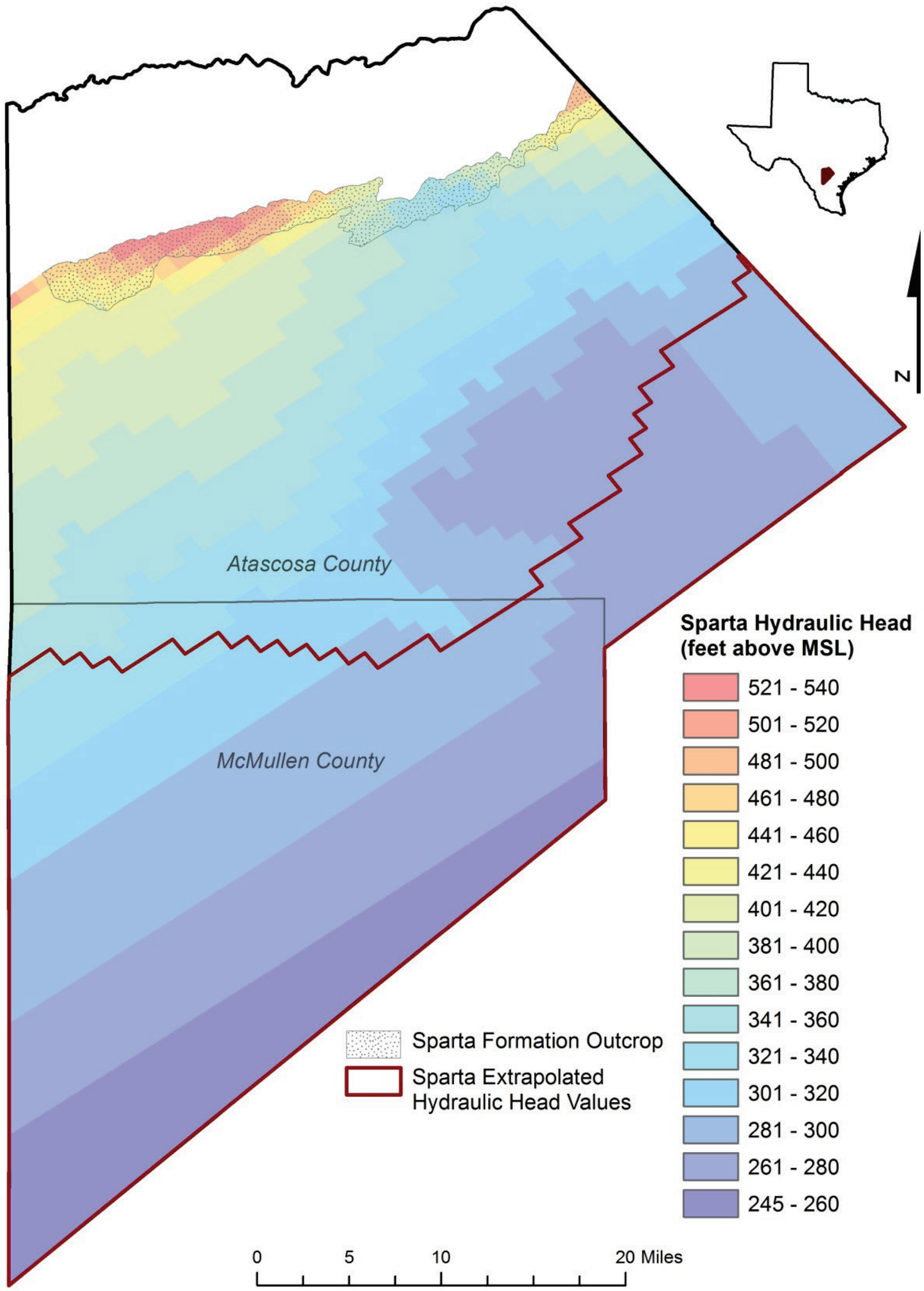


Figure 6-1. **Sparta Formation simulated hydraulic head values from the groundwater availability model with extrapolated values extending to the project area boundary. MSL = mean sea level**

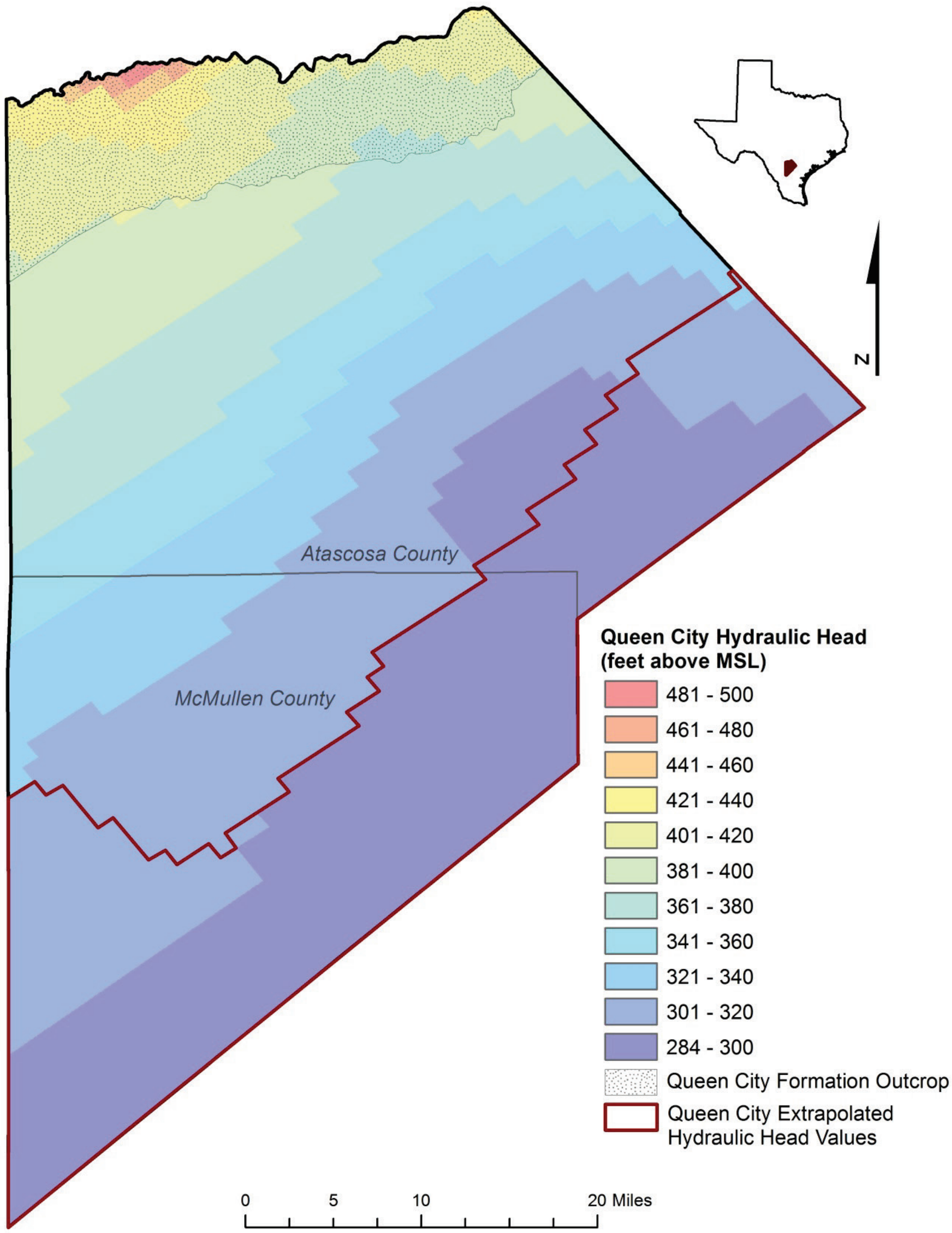


Figure 6-2. Queen City Formation simulated hydraulic head values from the groundwater availability model with extrapolated values extending to the project area boundary. MSL = mean sea level

Overall, the simulated heads in each formation display a southeast gradient that reflects regional groundwater flow towards the southeast. The Sparta simulated hydraulic head elevations vary from 533 feet above mean sea level in the outcrop area to an estimated 245 feet above mean sea level at the southern project boundary. The Queen City simulated hydraulic head elevations range from 496 feet above mean sea level in the outcrop area to an estimated 284 feet above mean sea level at the southern project boundary.

The simulated hydraulic head maps for each formation display relatively lower hydraulic head values in eastern Atascosa County (figures 6-1 and 6-2). One likely reason is the Atascosa River in this part of the county, which would tend to cause hydraulic gradient contours to bend upstream due to relatively lower groundwater levels along the river. Another likely reason for the simulated hydraulic head variations in eastern Atascosa County is the pumping stress placed on the Queen City Formation in the vicinity of the cities of Pleasanton and Christine (Kelly and others, 2004).

6.3 Hydraulic properties

The hydraulic properties of a formation refer to characteristics that allow water to flow through and be released from the aquifer. Hydraulic properties include transmissivity, hydraulic conductivity, specific capacity, drawdown, pumping rate (well yield), and storativity (specific yield and confined storativity). Lithology, cementation, fracturing, structural framework, and juxtaposition of adjacent formations all influence the flow of water within and between formations.

We appended hydraulic properties for 67 wells completed in the Queen City and Sparta formations to the BRACS Database Aquifer Test Information Table. Values from wells consist of transmissivity (1 value), hydraulic conductivity (1 value), specific capacity (28 values), and well yield (67 values). Information on hydraulic properties from wells completed in the Sparta or Queen City formations within the project area is limited (Table 6-1).

The sources of aquifer test information include TWDB aquifer test spreadsheet and the remarks table in the TWDB Groundwater Database, published reports (Alexander and White, 1966; Myers, 1969; Sundstrom and Follett, 1950), and Texas Department of Licensing and Regulation Submitted Driller’s Reports Database. Additional information is available in TWDB paper well reports.

Average yields of Sparta wells are 123 gallons per minute, and average yields of Queen City wells are 345 gallons per minute. Some wells produce as much as 200 and 1,700 gallons per minute from the Sparta and Queen City formations, respectively.

Specific yield data for wells located within the project area were not available. LBG-Guyton (2003) used a specific yield value of 0.1 and a confined storativity value of 0.0005 to calculate brackish groundwater volumes for the Queen City and Sparta formations in the project area and we used these values for this project. This confined storativity value is very close to the estimated mean value of 0.00052 presented by Ryder and Ardis (1991) for the Sparta and Queen City formations combined. Johnson (1967) reported that a specific yield of 0.1 is the minimum value of the fine sand range. This specific yield value is assumed valid for the project area given the occurrence of fine sand in both formations (Sellards and others, 1932; Lonsdale 1935; Payne, 1968) and that specific yield will likely decrease with depth due to a reduction in porosity from compaction and diagenesis.

Table 6-1. Hydraulic properties of the Sparta and Queen City formations.

Hydraulic Property	Sparta Formation	Queen City Formation
Transmissivity		
Number of values	0	1
Low	--	14,300 gpd/ft
High	--	14,300 gpd/ft
Average	--	14,300 gpd/ft
Hydraulic Conductivity		
Number of values	0	1
Low	--	893 ft/day
High	--	893 ft/day
Average	--	893 ft/day
Storativity		
Number of values	0	0
Low	--	--
High	--	--
Average	--	--
Specific Capacity		
Number of values	3	25
Low	1.6 gpm/ft	0.2 gpm/ft
High	6.4 gpm/ft	25 gpm/ft
Average	4.1 gpm/ft	6.9 gpm/ft
Well Yield		
Number of values	7	60
Low	80 gpm	15 gpm
High	200 gpm	1,700 gpm
Average	123 gpm	345gpm

Notes: Sources of data are the TWDB Groundwater Database and aquifer test information, Alexander and White (1966), Myers (1969), Sundstrom and Follett (1950), and the Texas Department of Licensing and Regulation Submitted Driller's Reports Database. gpd/ft = gallons per day per foot of drawdown; gpm/ft = gallons per minute per foot of drawdown; gpm = gallons per minute; ft/day = feet per day.

6.4 Stratigraphic surfaces

We used water well records and geophysical well logs to define the stratigraphic top and bottom of a geologic formation. We revised stratigraphic interpretations several times during an iterative process of correlating logs and refining stratigraphic interpretations.

The BRACS Database Well Geology Table contains the top and bottom depths of the Queen City, Weches, and Sparta formations. We added the names of each formation from the bottom of the Queen City to ground surface to this table, although the top and bottom depths of overlying units were left blank. A value of “>”in this table denotes partial penetration of the formation where a water well did not reach the stratigraphic base of a formation. The partial depth information is useful for preparing contour maps.

Published reports covering the project area provided formation descriptions, maps, and cross-sections: Lonsdale (1935), Harris (1965), Alexander and White (1966), Eargle (1968), Payne (1968), Garcia-Solorzano (1972), Guevara and Garcia (1972), Ricoy (1976), Ricoy and Brown (1977), Ewing (1991), Kelley and others (2004). We loaded geologic cross-section well points and lines into GIS and used to evaluate stratigraphic interpretations performed on project wells. The published reports also served as a reference for the interpretation, composition, thickness, and areal distribution of the geological units.

We compared the geophysical well log stratigraphic interpretations of this project with the interpretations in referenced reports (figures 6-3 through 6-6). These figures provide a direct way of comparing the differences between the stratigraphic interpretations used in these works.

We compare the Sparta Formation and the top of the Queen City Formation stratigraphic interpretations used for this project to that used by Ricoy (1976), Garcia-Solorzano (1972), and Alexander and White (1966) (Figure 6-3). We compare Queen City Formation bottom stratigraphic interpretations on the same geophysical well log (Figure 6-4). The Sparta and Queen City formation well log depths shown for Alexander and White (1966) are approximate due to the scale at which the geophysical well log cross-sections are presented in their report and the absence of depth values.

Sparta Formation stratigraphic interpretations for this project are similar to Ricoy (1976) for the majority of wells with variations present in some wells (Figure 6-3). Alexander and White (1966) had a much more restrictive interpretation of the Sparta Formation than this project and Ricoy (1976) (Figure 6-3). The project Queen City Formation top agrees with the interpretation of Alexander and White (1966) (Figure 6-3). The top of the Queen City Formation interpreted by Garcia-Solorzano (1972) extends into the bottom portion of the Sparta Formation, omitting the Weches Formation (Figure 6-3).

The bottom of the Queen City Formation interpreted by Garcia-Solorzano (1972) extends through the clay-rich Reklaw Formation almost to the top of the Carrizo Formation at about 3,720 feet below ground surface (Figure 6-4). Conversely, Alexander and White (1966) consistently placed the bottom of the Queen City Formation above the Queen City-Reklaw contact as identified on geophysical well logs for this project.

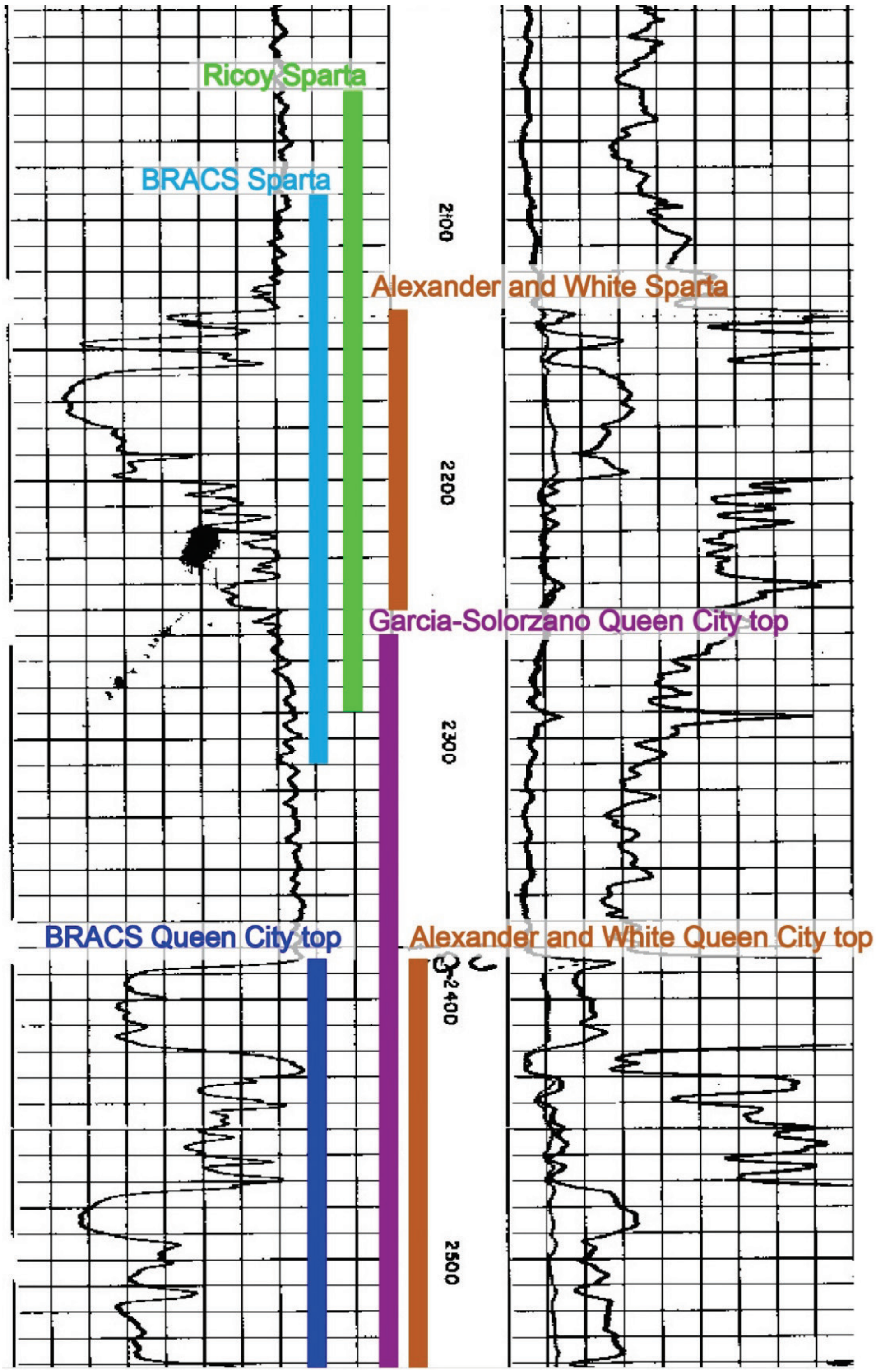


Figure 6-3. **Comparison of Sparta Formation and Queen City Formation top stratigraphic interpretations. Shown are the interpretations of BRACS, Ricoy (1976), Garcia-Solorzano (1972), and Alexander and White (1966). Spontaneous potential tool is shown in the left track and short, normal, and amplified resistivity tools are in the right track. Well log is BRACS well number 13417 and is located at the circle in Figure 6-7. BRACS = Brackish Resources Aquifer Characterization System**

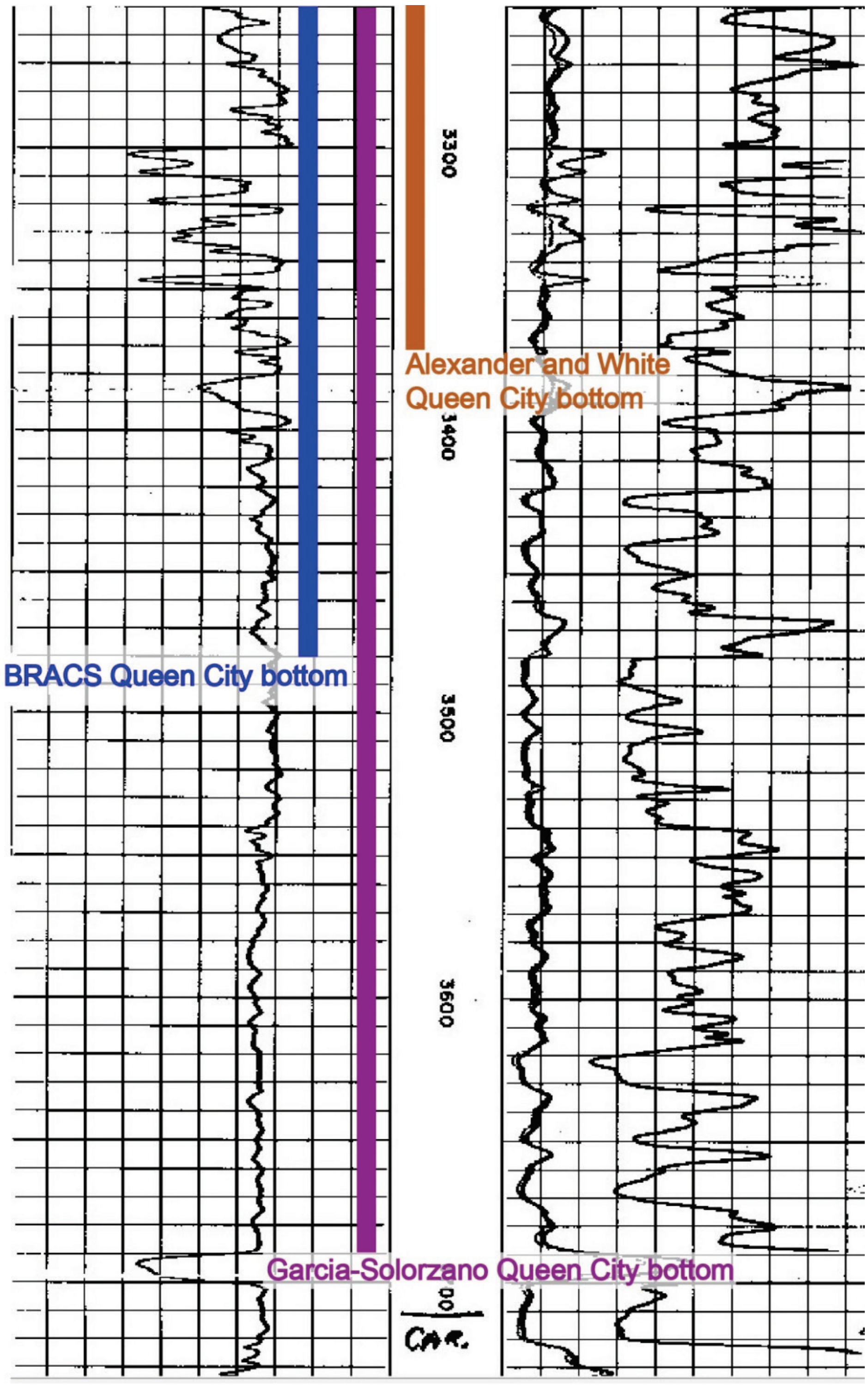


Figure 6-4. **Comparison of Queen City Formation bottom stratigraphic interpretations. Shown are the interpretations of BRACS, Garcia-Solorzano (1972), and Alexander and White (1966). Spontaneous potential tool is shown in the left track and short, normal, and amplified resistivity tools are in the right track. Well log is BRACS well number 13417 and is located at the circle in Figure 6-7. BRACS = Brackish Resources Aquifer Characterization System**

We compare the Sparta Formation and the top of the Queen City Formation stratigraphic interpretations used for this project to that used by Kelley and others (2004) and Harris (1965) (Figure 6-5). The Sparta and Queen City formations well log depths shown for Harris (1965) are approximate due to the scale at which the geophysical well log cross-sections are presented in the report and the absence of depth values. We compare Queen City Formation bottom stratigraphic interpretations on the same geophysical well log (Figure 6-6).

The Sparta Formation thickness delineated for this project is less than that mapped for the groundwater availability model, which extends the top of the Sparta Formation into the clay layers of the Cook Mountain Formation (Kelley and others, 2004). Conversely, the Sparta Formation thickness is greater than that mapped by Harris (1965) who did not include thin, sandy layers near the top of the formation (Figure 6-5). The top of the Queen City Formation identified for this project coincides with that of Harris (1965) but not with Kelly and others (2004) who place the top within the Weches Formation (Figure 6-5).

We positioned the Queen City Formation bottom above the one chosen for the groundwater availability model (Figure 6-6). The Queen City Formation bottom of Harris (1965) was consistently shallower than the stratigraphic interpretation for this project.

We created a database table of wells with formation top and bottom depths and elevations within Microsoft® Access® and corrected for kelly bushing heights because well log depths are commonly referenced to it. We exported this table to ArcGIS® and projected into depth and elevation point shapefiles for each formation. We combined formation depth point shapefiles with manual contour line vertex points to prepare formation raster surfaces using ArcGIS® Spatial Analyst® tools. We interpolated the Sparta and Queen City stratigraphic surfaces using the Spline with Barriers tool using a 250-foot raster grid cell size. This cell size provided stratigraphic and structural detail in areas with denser well control and around faulted areas. The Spline with Barriers interpolation tool can account for abrupt changes in formation depths caused by faulting by recognizing the fault as an interpolation barrier and independently generating values on each side of it.

We prepared each initial formation raster surface using manual contour lines and the depth point shapefile. We converted the contour lines to vertex points and combined them with the well point depth values to create a new formation depth point shapefile. We generated the initial formation raster surface with the new formation depth point shapefile using the Spline with Barriers tool. We then added manual contour lines to areas where the interpolation failed to generate a geologically plausible surface to prepare subsequent formation raster surfaces. We compared the final formation raster surface with well point depths and evaluated it for geologic accuracy. We compared each formation top raster surface with the digital elevation model surface to ensure that it did not extend above this surface near the outcrop and we also compared each formation bottom raster surface with the top raster surface to verify it did not intersect this surface; we made corrections as necessary. The final step was to assign each formation depth value obtained from stratigraphic interpretation to the grid cell containing the well.

Some areas, such as near the eastern edge of the project area in the vicinity of the Sparta outcrop, lacked adequate well control to properly characterize faults.

We developed formation top depth and bottom depth raster surfaces in units of feet below ground surface. We produced the formation thickness raster by subtracting the bottom depth raster surface from the top depth raster surface.

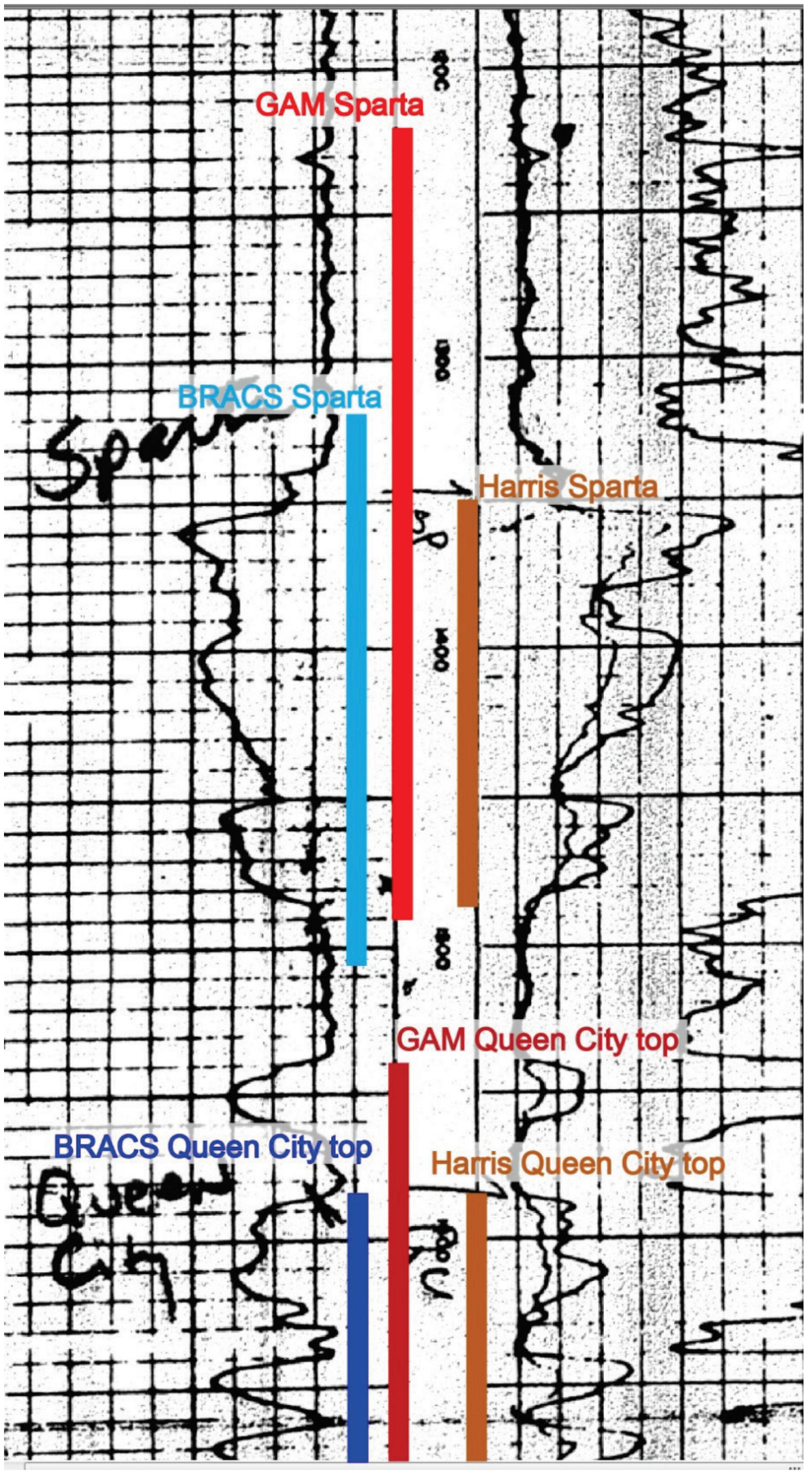


Figure 6-5. Comparison of Sparta Formation and Queen City Formation top stratigraphic interpretations. Shown are the interpretations of BRACS, Kelly and others (2004), and Harris (1965). Spontaneous potential tool is shown in the left track and short, normal, and amplified resistivity tools are in the right track. Well log is BRACS well number 13499 and is located at the square in Figure 6-7. The handwritten formation names in the image are on the paper log. BRACS = Brackish Resources Aquifer Characterization System; GAM = groundwater availability model.

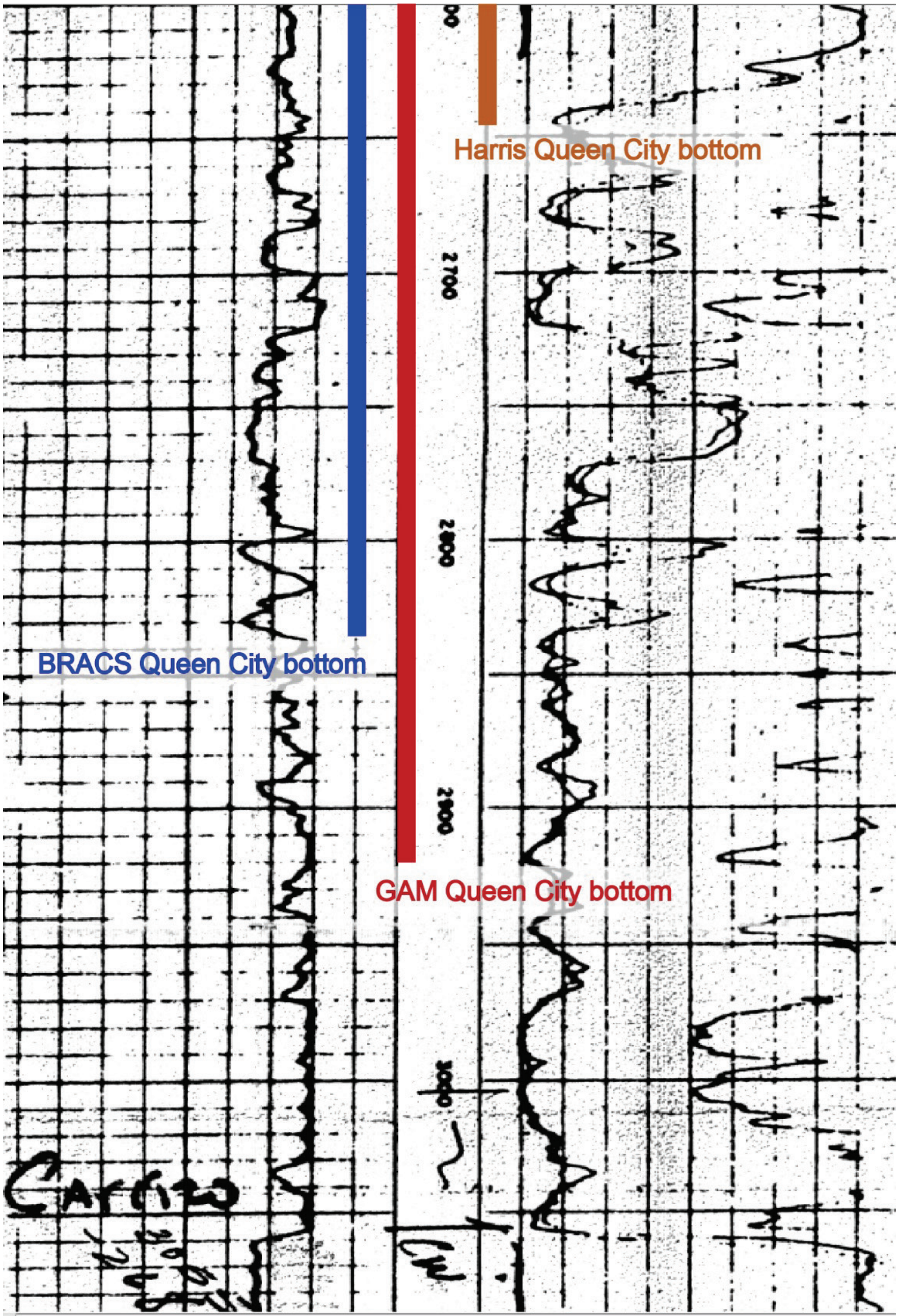


Figure 6-6. **Comparison of Queen City Formation bottom stratigraphic interpretations. Shown are the interpretations of BRACS, Kelly and others (2004), and Harris (1965). Spontaneous potential tool is shown in the left track and short, normal, and amplified resistivity tools are in the right track. Well log is BRACS well number 13499 and is located at the square in Figure 6-7. The handwritten formation name in the image is on the paper log. BRACS = Brackish Resources Aquifer Characterization System; GAM = groundwater availability model.**

We generated formation top and bottom elevation raster surfaces by subtracting the formation depth raster surfaces from the digital elevation model. We clipped the U.S. Geological Survey 30-meter digital elevation model to the project area and resampled it to a 250-foot cell size. All elevation surfaces are in units of feet above mean sea level. We compared each formation elevation raster surface with the digital elevation model to ensure the raster surface did not extend above the ground surface and corrected it as necessary.

We based all formation raster surfaces primarily on geophysical well log interpretation. Water well driller's lithology descriptions provided several data points in the outcrop areas where available geophysical well logs could not be recorded in the shallow cased borehole. We did not apply additional information such as core samples or paleontology data to stratigraphic correlation for this project.

6.4.1 *Sparta Formation top stratigraphic surface and thickness map*

The Sparta Formation can be differentiated from adjacent formations using diagnostic geophysical well log features representing the onset of Sparta progradation over transgressive shelf muds of the Weches Formation and subsequent marine transgression and deposition of Cook Mountain Formation shelf muds (Ricoy and Brown, 1977). The top and bottom of the Sparta Formation are represented by a discernible minimum response on spontaneous potential and resistivity tools and a clay response on gamma ray tools (figures 6-3 and 6-5).

Stratigraphic well control for the Sparta Formation top depth raster surface consisted of 164 well logs (Figure 6-7). We interpreted a total of 165 wells logs to define the bottom of the Sparta Formation. The regional dip of the Sparta Formation is to the southeast at approximately 100 feet per mile but local variability exists within the project area.

Differences in the magnitude of dip can be seen between eastern and western Atascosa County. The dip angle is greater in the eastern portion of the county near the outcrop area (Figure 6-7). In western Atascosa County, the Sparta Formation dips less steeply possibly because it is less affected by faulting. The depth to the top of the Sparta Formation rapidly increases to the southeast in McMullen County.

The thickness of the Sparta Formation ranges from 2 feet in the outcrop area to over 300 feet downdip towards the Gulf of Mexico (Figure 6-8). Areas with anomalous thicknesses are evident in the Sparta Formation thickness map due to a combination of structural complexity related to faulting, sparse well control in some areas, and interpolation artifacts (Figure 6-8). These features have less than a 20 foot difference from surrounding values with the majority exhibiting a 5 to 10 foot differential. Some of the formation thickness variability occurs in fault zones where displacements create areas of reduced formation thickness. The elongated, anomalously thick area of the Sparta Formation extending through central Atascosa County may be due to sparse well control and interpolation artifacts as are the relatively thicker sections in McMullen County.

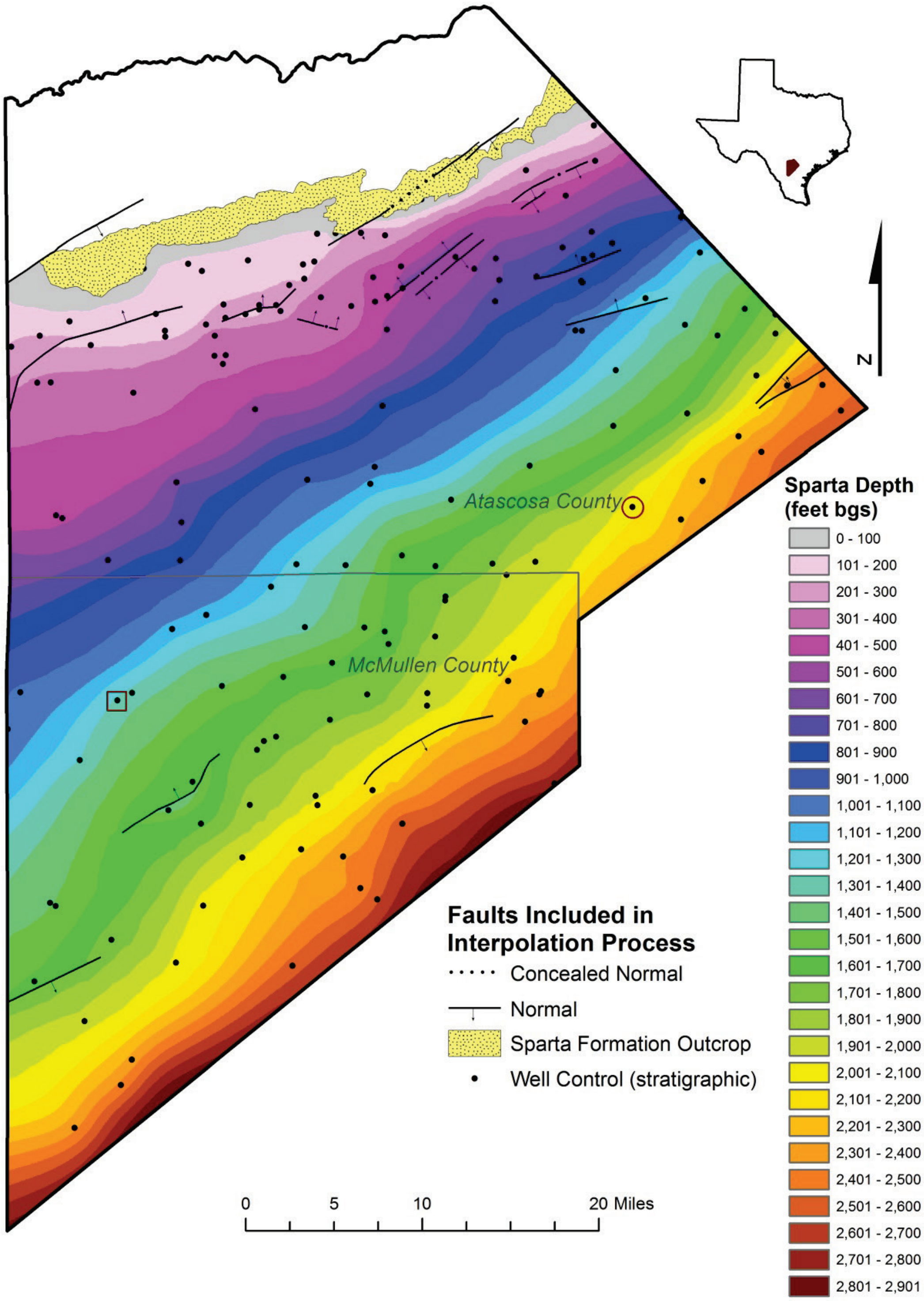


Figure 6-7. **Top depth raster surface of the Sparta Formation in the project area prepared using 164 wells. Circle indicates location of well log shown in figures 6-3 and 6-4. Square denotes location of well log shown in figures 6-5 and 6-6. Fault information is from BEG (1974), BEG (1976), Hamlin (1988), and Ewing (1991). Outcrop area is from BEG (1974) and BEG (1976). bgs = below ground surface**

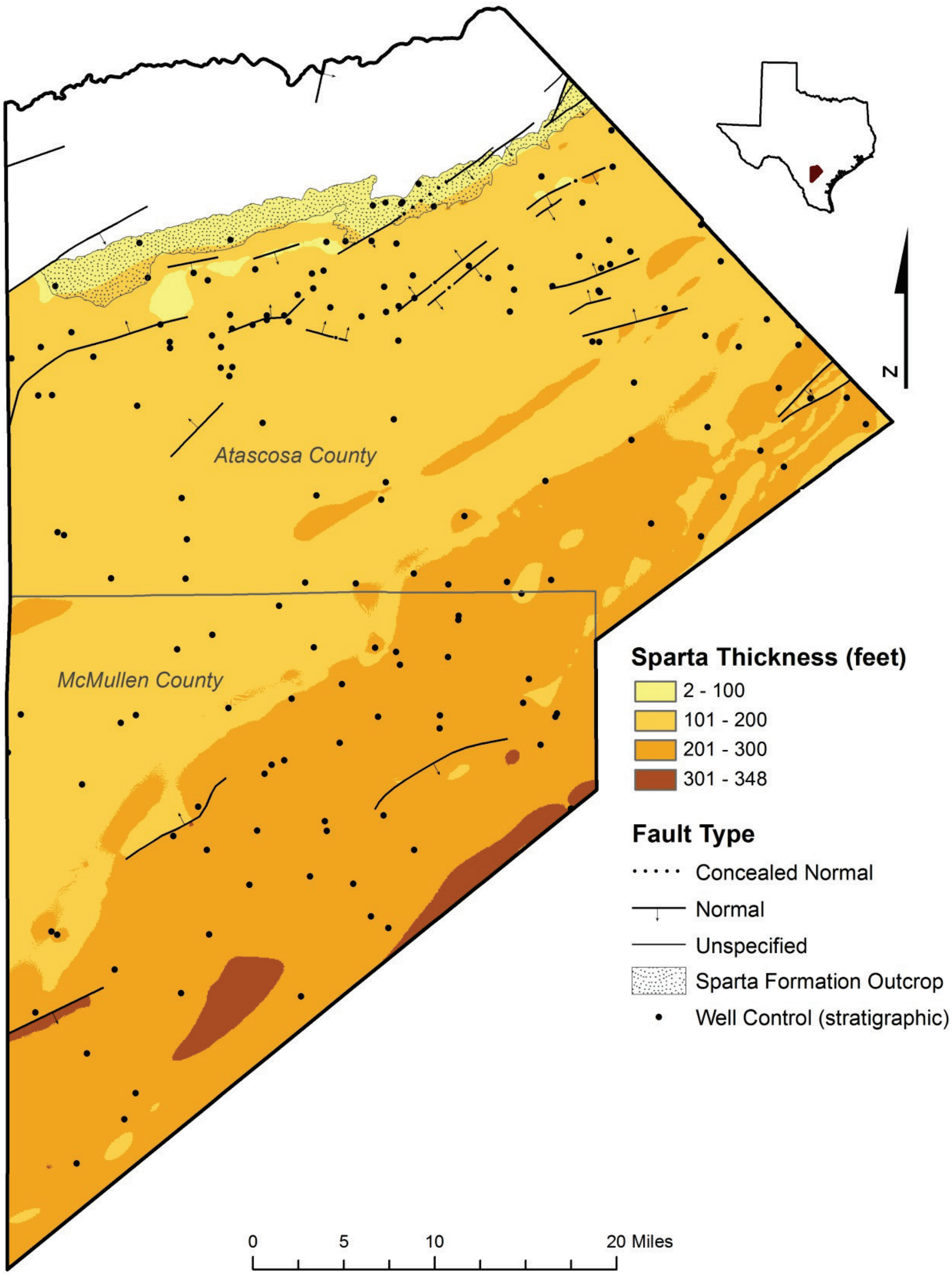


Figure 6-8. **Thickness between the top depth and bottom depth raster surfaces of the Sparta Formation in the project area.**

6.4.2 *Queen City Formation top stratigraphic surface and thickness map*

We differentiated the top of the Queen City Formation from the overlying clay-rich Weches Formation using geophysical well logs based on the first presence of sand. We identified the bottom of the Queen City Formation by selecting the base of the first coarsening upward sediment package that overlies the underlying, clay-rich Reklaw Formation.

The bottom of the Queen City Formation is more difficult to identify than the top of the formation because the lower portions of the Queen City Formation are more clay-rich than the sandier deposits in the upper section. Sandier layers in the basal part of the Queen City Formation are sometimes thinner than those in the upper part, causing the contact with the underlying Reklaw to appear somewhat gradational.

Stratigraphic well control for the Queen City Formation top depth raster surface consisted of 186 well logs (Figure 6-9). We interpreted 192 well logs to define the bottom of the formation.

The Queen City Formation top depth increases six-fold in eastern Atascosa County near the outcrop area (Figure 6-9). The formation dips more gently in western Atascosa County before steepening eastward to the south.

The thickness of the Queen City Formation increases from 3 feet in the outcrop area to over 1,400 feet in southwestern McMullen County (Figure 6-10).

Like the Sparta Formation thickness map, the Queen City Formation thickness map also exhibits anomalous thickness values due to a combination of structural complexity related to faulting, sparse well control in some areas, and interpolation artifacts. These are most prominent in eastern Atascosa County around the Charlotte-Jourdanton Fault Zone and the Karnes Fault Zone. The majority of these thickness variations are less than 10 feet and all are less than 20 feet compared to surrounding areas.

After we prepared the final Queen City Formation bottom surface and thickness map, additional well control added in northeastern Atascosa County within the Queen City outcrop area indicated that the bottom of the Queen City Formation is deeper than the final interpolated bottom surface. The BRACS Database has updated stratigraphic information on this area.

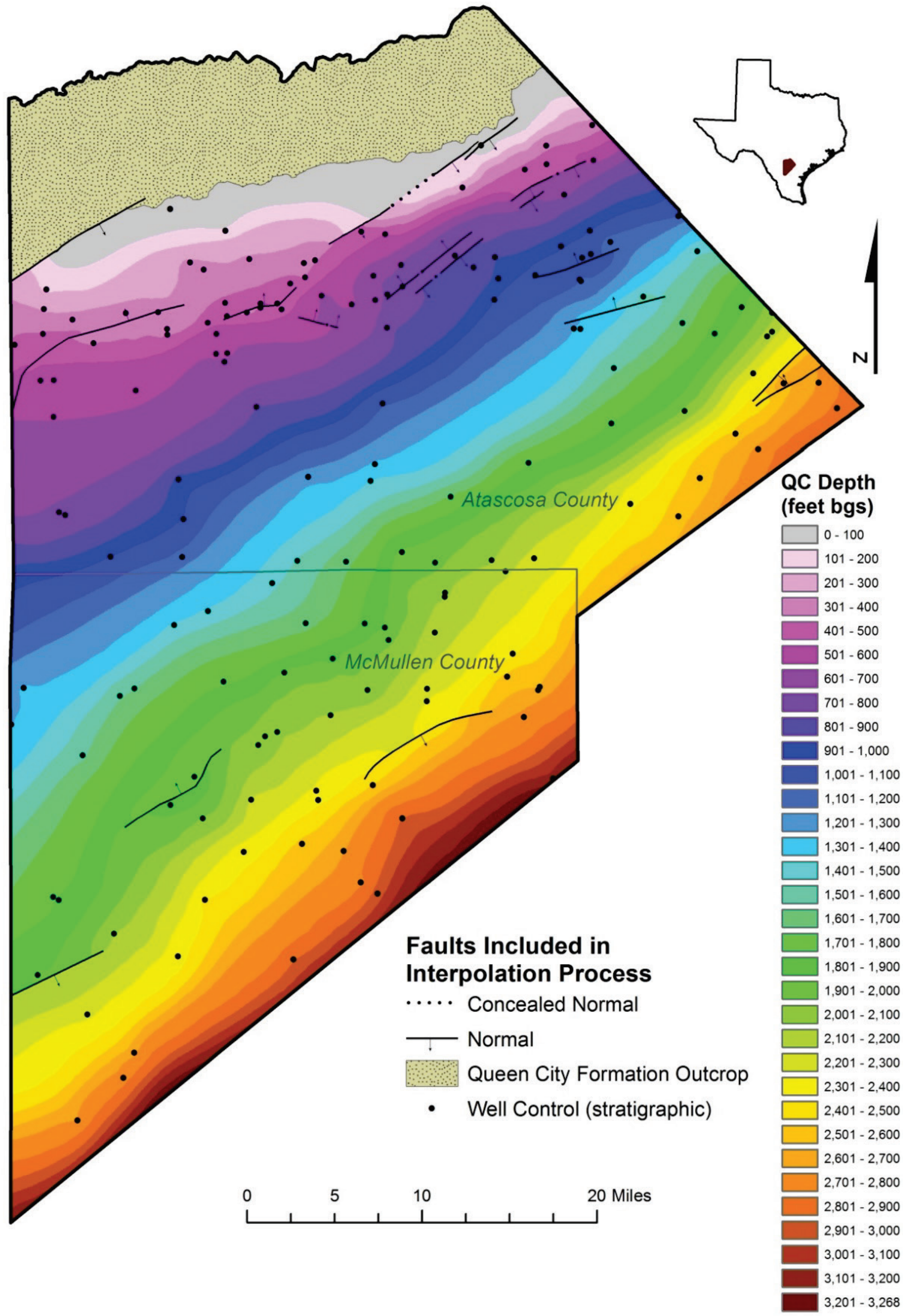


Figure 6-9. **Top depth raster surface of the Queen City Formation in the project area prepared using 186 wells. Fault information is from BEG (1974), BEG (1976), Hamlin (1988), and Ewing (1991). Outcrop area is from BEG (1974) and BEG (1976). QC = Queen City Formation; bgs = below ground surface.**

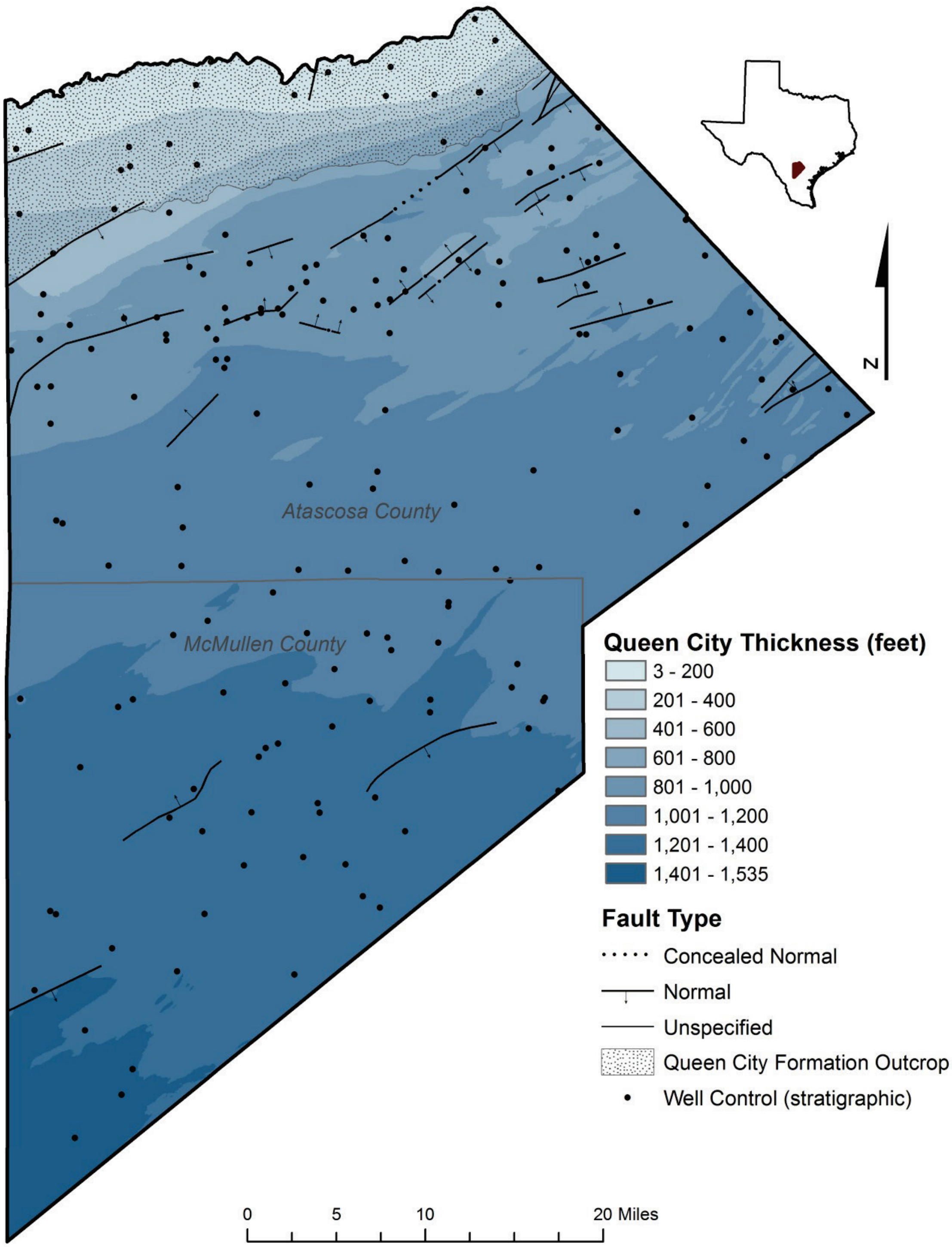


Figure 6-10. Thickness between the top depth and bottom depth raster surfaces of the Queen City Formation in the project area.

6.4.3 *Geologic cross-sections*

We show the stratigraphic surfaces developed for the project in two geologic cross-sections (figures 6-11 and 6-12). The locations of the cross-section lines can be viewed in Figure 3-3. The cross-sections only display faults included in the interpolation process.

6.5 Lithologic descriptions

The well geology table in the BRACS Database contains water well driller's formation descriptions written on State of Texas Water Well Reports. We appended these records to the table either manually or by digitally parsing a Texas Department of Licensing and Regulation digital water well report. This database table stores information such as top and bottom depths, thickness of each unique lithologic unit, the driller's description of the lithologic unit, and the source of the information.

We used a database method to convert driller's formation descriptions into a simplified lithologic description framework because many well drillers do not use accurate and consistent geological terms. The numerous variations of formation descriptions found on water well reports are related to the corresponding simplified lithologic description in a database lookup table. The simplified lithologic description terms are based on mineralogy and grain size.

The term "No Record" in the geology table indicates a depth interval where a water well report or geophysical well log does not have information due to the presence of well casing. The term "Geology not processed – Log image cut off" in the geology table indicates a missing depth interval because the log is incomplete. The term "Geology Not Described, But Available on Log" in the geology table signifies the portion of a geophysical log still available for lithologic interpretation. Tracking missing information with these terms is a requirement for subsequent evaluation of net sand and sand percent.

The simplified lithologic names represent either one predominant type of material (for example, sand), or a mixture of two (for example, sand with clay). The creation of the database table relating lithologic name to simplified lithologic name presented challenges and also necessitated some simplifications. We converted formation descriptions that contained more than two terms as part of a mixture (for example, sand, clay, and limestone) to only the first two terms or the two most important terms based on percentage if provided by the driller.

The geophysical well log analysis consisted of a technique that categorized simplified lithology into four groups: sand (100 percent sand), clay (0 percent sand), sand with clay (65 percent sand), and clay with sand (35 percent sand). We derived simplified lithologic descriptions from a total of 194 wells in the project area, which includes both water wells and oil/gas wells with gamma ray, spontaneous potential, or resistivity logs. Gamma ray logs are useful for differentiating between sand and clay sequences and we used them in conjunction with the deep resistivity log to identify lithology. Combining gamma ray and deep resistivity information to interpret different lithologies in the Queen City Formation was especially important due to the presence of glauconitic sands. Glauconitic layers produce an elevated gamma ray signal due to the presence of potassium-40. A glauconitic sandy layer can therefore appear similar to a clay-rich layer on the gamma ray log but will still exhibit a relatively higher resistivity than a clay-rich layer.

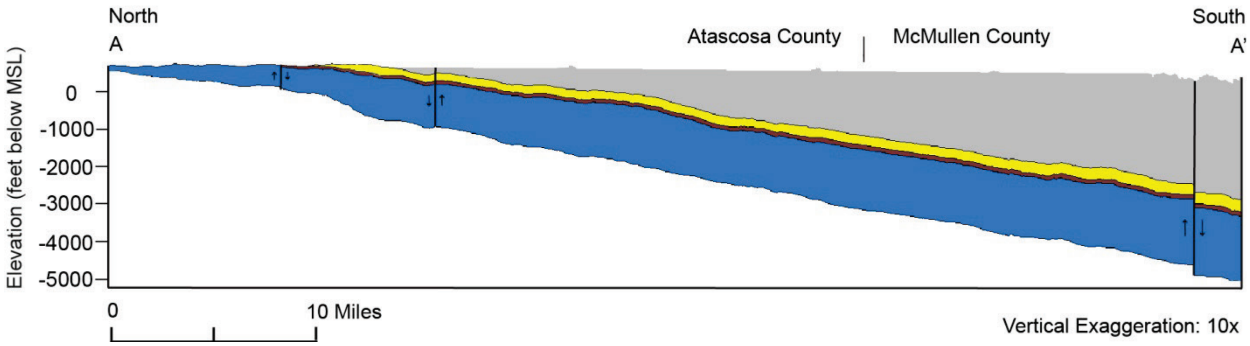


Figure 6-11. **Cross-section A–A' in Atascosa and McMullen counties. Figure 3-3 shows the location of this cross-section. MSL = mean sea level**

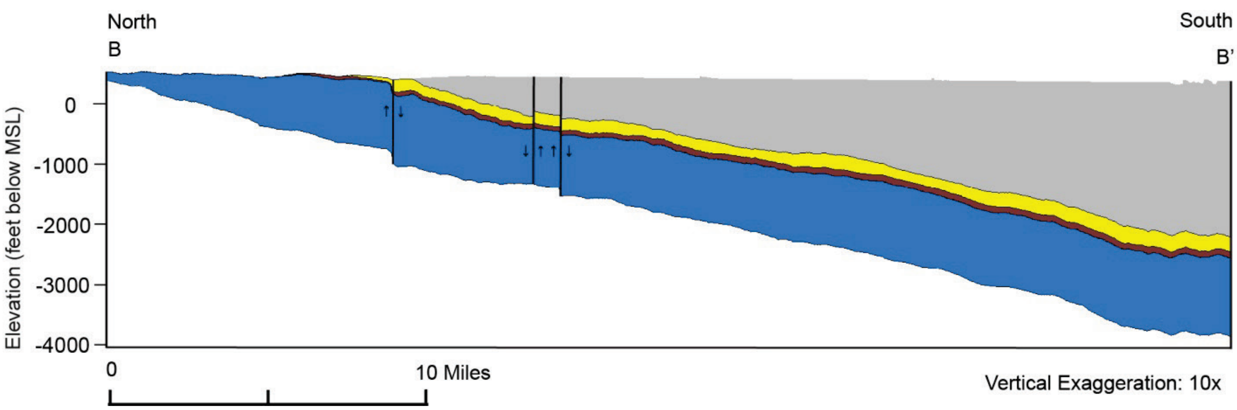
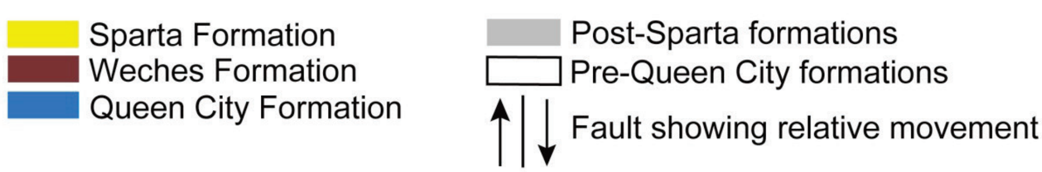


Figure 6-12. **Cross-section B–B' in Atascosa County. Figure 3-3 shows the location of this cross-section. MSL = mean sea level**



We applied simplified lithologic descriptions from ground surface to total depth of the hole for water wells. We applied simplified lithologic descriptions derived from geophysical well logs to the entire Sparta, Weches, and Queen City formations and limited adjacent strata above and below this interval.

6.6 **Net sand analysis**

We generated net sand and sand percent values for wells penetrating the Sparta, Weches, and Queen City formations from the simplified lithologic descriptions obtained from geophysical well logs and water well driller descriptions. The database table listing all simplified lithologic names contains a field for sand percent. We chose values of 0, 35, 50, 65, or 100 based on the presence of sand or coarser material. For example, we applied a value of 50 to a lithologic unit containing a mixture of sand and clay. If a well only partially penetrated a formation, we calculated a net sand value, but not the sand percent. We used this table in subsequent database queries to process well records.

Because database queries must address lithologic units that are not completely contained within one formation (the unit may straddle the formation top, bottom, or both), we wrote specific queries to evaluate each of these scenarios and to assign the correct thickness of a lithologic unit to the correct formation. We loaded these queries into Microsoft® Visual Basic for Applications® and linked to a form to systematically process the information. We performed a separate query to assemble the information into a table for export into GIS for spatial display.

We created two Microsoft® Access® database tables containing net sand information for the project area; one table contains individual records for each layer with sand and the other table with one record per well and is a summary of net sand and sand percent for each formation encountered. These tables can be exported into GIS for display and analysis. The two database tables can also be queried in a number of ways to develop custom approaches to analysis. Sand content maps can be generated from the information gained from queries of the net sand data that show the number of sand layers greater than a certain thickness in each well, for example.

We used a total of 85 simplified lithologic description well records that spanned the entire formation thickness to generate the Sparta Formation net sand and sand percent maps (figures 6-13 and 6-14). We created the Queen City Formation net sand and sand percent maps using 86 simplified lithologic description well records that spanned the entire formation thickness (figures 6-15 and 6-16). We removed many simplified lithologic description well records derived from water well driller's descriptions from the analysis for each formation due to obvious inaccuracies of sand content.

We created each net sand and sand percent raster map using the same approach as the formation raster surfaces, except that the Spatial Analyst® Topo-to-Raster tool interpolated the sand content.

The Sparta Formation net sand and sand percent maps (figures 6-13 and 6-14) are similar showing the thickest sand deposits in central Atascosa County and northwestern McMullen County along a northeast-southwest axis. Net sand thickness reaches a maximum of 145 feet in this area. Sand content decreases steadily downdip towards the project boundary in McMullen County. The Sparta Formation sand maps are similar to the net sand distribution and dispersal patterns determined by Ricoy and Brown (1977). For example, the high sand percentages observed near the central portion of the outcrop correspond to an area where Ricoy and

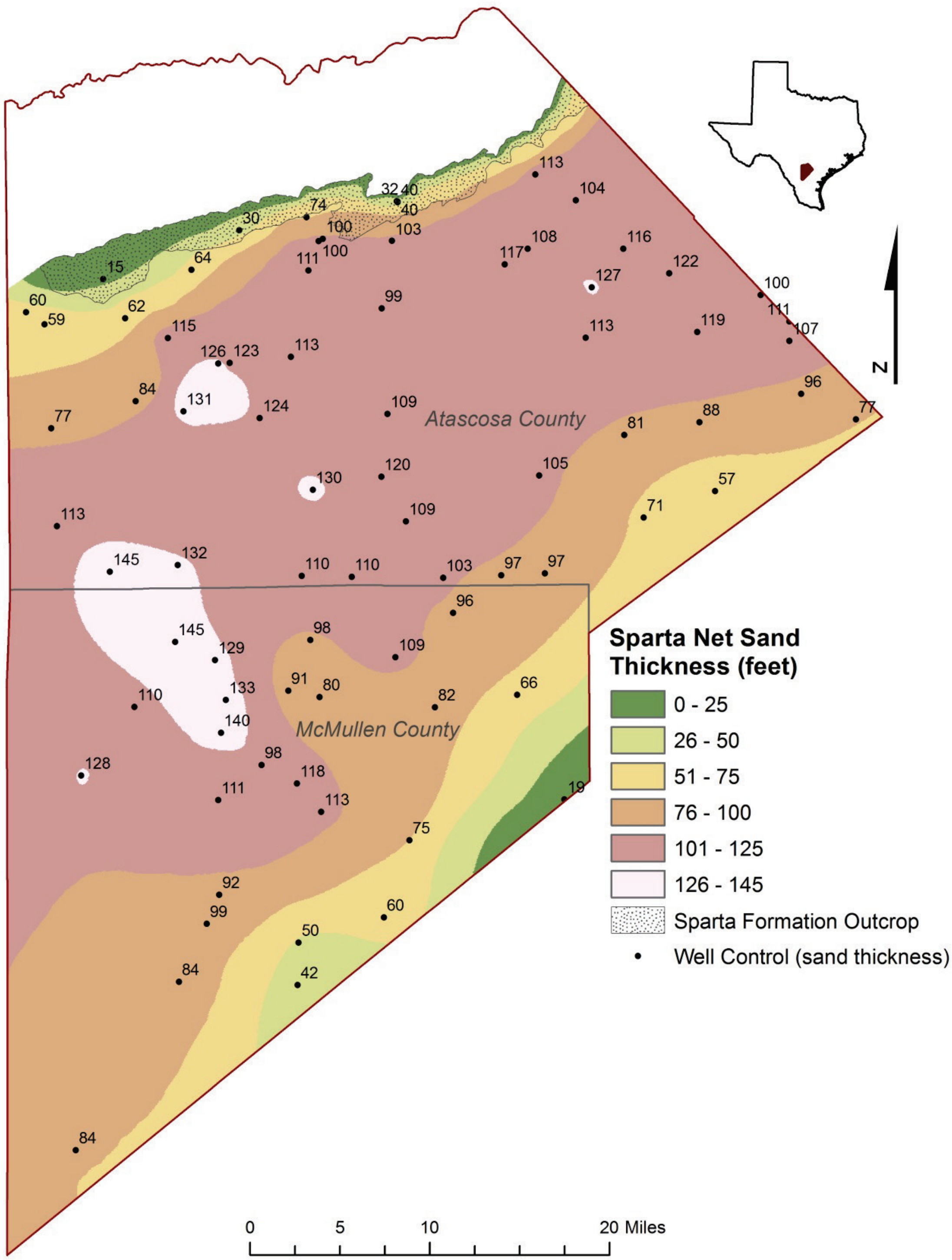


Figure 6-13. Net sand thickness map of the Sparta Formation in the project area prepared using 85 wells.

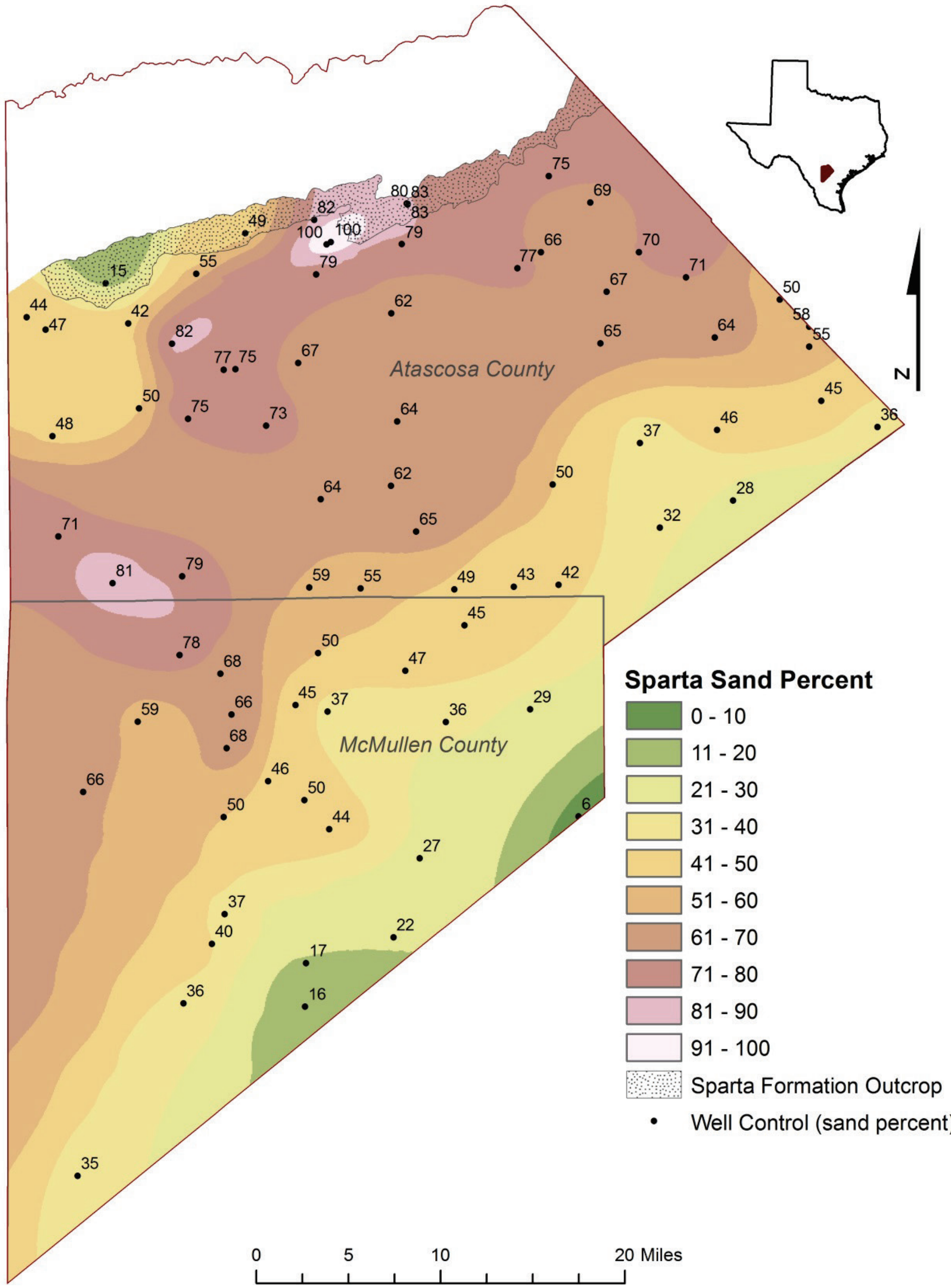


Figure 6-14. Sand percent map of the Sparta Formation in the project area prepared using 85 wells.

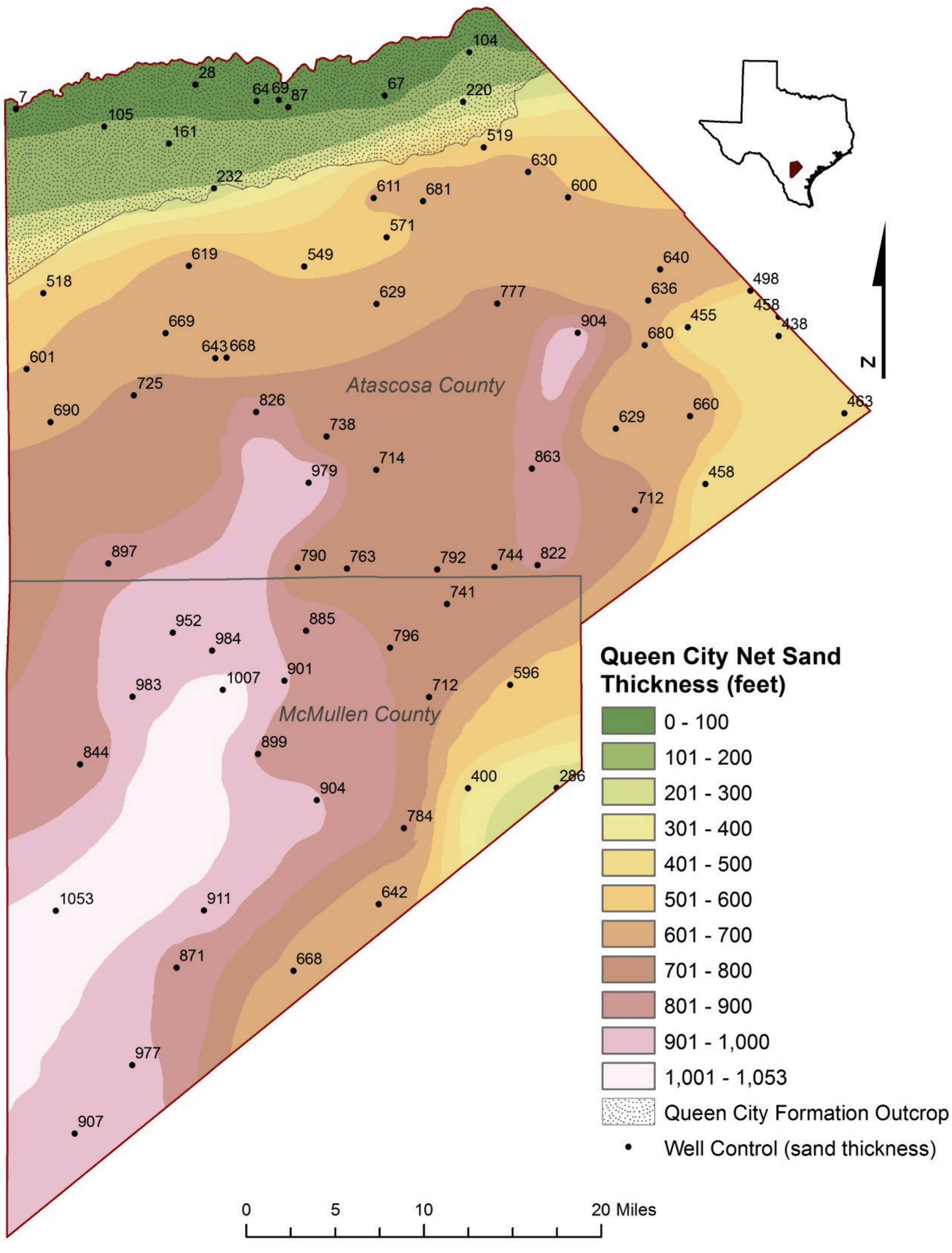


Figure 6-15. Net sand thickness map of the Queen City Formation in the project area prepared using 86 wells.

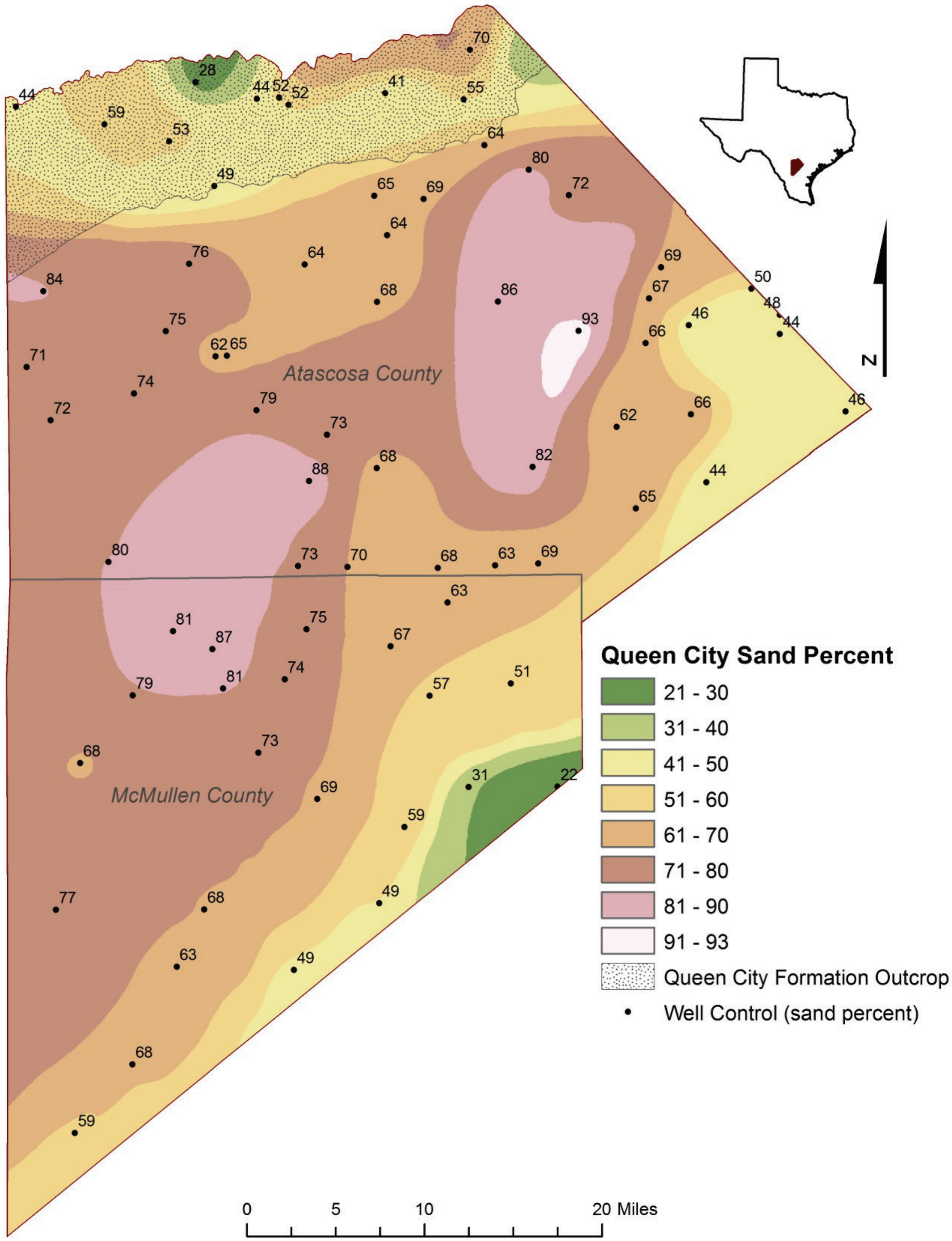


Figure 6-16. Sand percent map of the Queen City Formation in the project area prepared using 86 wells.

Brown (1977) had interpreted a fluvial sand input source. Sand values in the Sparta outcrop must be interpreted with caution because of missing section due to erosion.

The Queen City Formation net sand and sand percent maps (figures 6-15 and 6-16) illustrate sand dispersal trends. The net sand content of the Queen City Formation generally increases to the southwest across the project area as the formation thickens. Net sand values in excess of 1,000 feet are present in western McMullen County. Almost the entire western edge of the project area exhibits a Queen City Formation sand percent above 70 percent. Two areas with Queen City Formation sand percentages above 80 percent are present in the eastern and central portion of the project area with one well in the eastern section displaying a sand percentage above 90 percent. These results are similar to the findings presented by Guevara and Garcia (1972) where the Queen City Formation thickens to the west and southwest of the project area.

6.7 **Water quality data**

Groundwater quality in an aquifer can vary greatly due to factors such as mineral composition and diagenesis of formation materials, formation sand architecture and interconnectedness, recharge rates, spatial distribution and chemical composition of recharge waters, geochemical processes, spatial distribution of natural and man-made discharge rates, groundwater residence time, cross formational flow, and groundwater flow paths and velocity.

We added data from 835 groundwater chemistry samples collected from 376 wells that were completed in any aquifer in the project area to the BRACS Database; 829 analyses from wells listed in the two main tables in the TWDB Groundwater Database and 6 analyses from published reports (Alexander and White, 1966; Marquardt and Rodriguez, 1977; Sundstrom and Follet, 1950). A total of 6 Sparta wells and 29 Queen City wells had 79 groundwater chemistry sample results. We assigned these aquifers to the wells based on screen intervals relative to the stratigraphic surfaces mapped during the project (Section 6.1, Aquifer Determination). We provide a summary of the range of groundwater quality sample results (tables 6-2 and 6-3).

We appended all records to one master table in the BRACS Database to facilitate the creation of a water quality GIS shapefile, which is provided as part of this project's GIS deliverables. The table shows the source of each record along with all applicable well identification numbers.

Sparta Formation groundwater quality results show that the total dissolved solids concentration is between 1,743 and 2,424 milligrams per liter with an average of 2,160 milligrams per liter. Total dissolved solids concentration remained stable in a Sparta well (BRACS well 42643) that was sampled three times: 2,136, 2,156, and 2,151 milligrams per liter in 1994, 1998, and 2002, respectively. Silica concentration in the Sparta Formation ranged from 13 to 15 milligrams per liter. Iron concentration varied from 0.3 to 2.2 milligrams per liter. Sulfate concentration is between 500 and 996 milligrams per liter. Chloride concentrations ranged from 226 to 550 milligrams per liter.

Concentration maps of selected groundwater constituents help to illustrate their spatial distribution in the Sparta Formation (figures 6-17 through 6-20). Silica and chloride concentrations are relatively consistent across all of the samples. Iron and sulfate concentrations exhibit relatively more variability with the northernmost well having the highest level of both constituents at 2.2 milligrams per liter and 996 milligrams per liter, respectively.

Table 6-2. Water quality in the Sparta Formation.

Parameter	Minimum	Maximum	Mean
Silica, dissolved (mg/L)	13	15	13.4
Calcium, dissolved (mg/L)	8.32	133	55.1
Magnesium, dissolved (mg/L)	4.57	119	39.4
Sodium, dissolved (mg/L)	333	733	633.4
Potassium, dissolved (mg/L)	6	21	10.5
Strontium, dissolved (mg/L)	0.84	3.55	1.5
Carbonate (mg/L)	0	9.6	1.8
Bicarbonate (mg/L)	173.29	471.05	335.43
Sulfate, dissolved (mg/L)	500	996	730
Chloride, dissolved (mg/L)	266	550	493
Fluoride, dissolved (mg/L)	0.2	0.64	0.38
Nitrate nitrogen, dissolved (mg/L)	0.04	3.8	1.2
pH (standard units)	7.1	8.8	8.0
Total dissolved solids (mg/L)	1,743	2,424	2,160
Alkalinity, phenolphthalein	0	8	1.5
Alkalinity, total	144.26	386	277.9
Hardness, total	40	821	300.3
Sodium, percent	53	97	81.7
Sodium adsorption ratio	5.8	50.56	28.1
Residual sodium carbonate	0	6.75	3.0
Specific conductance (µmhos/cm @ 25 °C)	2,310	4,004	3,342
Iron, dissolved (mg/L)	0.3	2.2	1.3
Manganese, dissolved (mg/L)	NA	NA	NA

Notes: Source of data is the TWDB Groundwater Database. mg/L = milligrams per liter; µg/L = micrograms per liter; µmhos/cm = micromhos per centimeter; °C = degree Celsius; NA = not available.

Table 6-3. **Water quality in the Queen City Formation.**

Parameter	Minimum	Maximum	Mean
Silica, dissolved (mg/L)	14	35	18.2
Calcium, dissolved (mg/L)	1	263	46.7
Magnesium, dissolved (mg/L)	0.2	156	20.4
Sodium, dissolved (mg/L)	28	672	210.9
Potassium, dissolved (mg/L)	0.4	26.6	8.0
Strontium, dissolved (mg/L)	0.12	10.6	2.5
Carbonate (mg/L)	0	36	2.7
Bicarbonate (mg/L)	189.06	740	373.64
Sulfate, dissolved (mg/L)	1	1360	144
Chloride, dissolved (mg/L)	34	805	153
Fluoride, dissolved (mg/L)	0.08	1.7	0.54
Nitrate nitrogen, dissolved (mg/L)	0	2	0.3
pH (standard units)	6.74	8.7	7.9
Total dissolved solids (mg/L)	284	2,704	776
Alkalinity, phenolphthalein	0	30	2.3
Alkalinity, total	154.92	639.73	310.7
Hardness, total	6	1310	201.0
Sodium, percent	25	99	75.2
Sodium adsorption ratio	0.9	94.63	16.8
Residual sodium carbonate	0	12.6	4.2
Specific conductance (µmhos/cm @ 25 C)	793	3,900	1,257
Iron, dissolved (mg/L)	0.04	3.5	0.38
Manganese, dissolved (mg/L)	0	0.11	0.11

Notes: Source of data is the TWDB Groundwater Database. mg/L = milligrams per liter; µg/L = micrograms per liter; µmhos/cm = micromhos per centimeter; °C = degree Celsius.

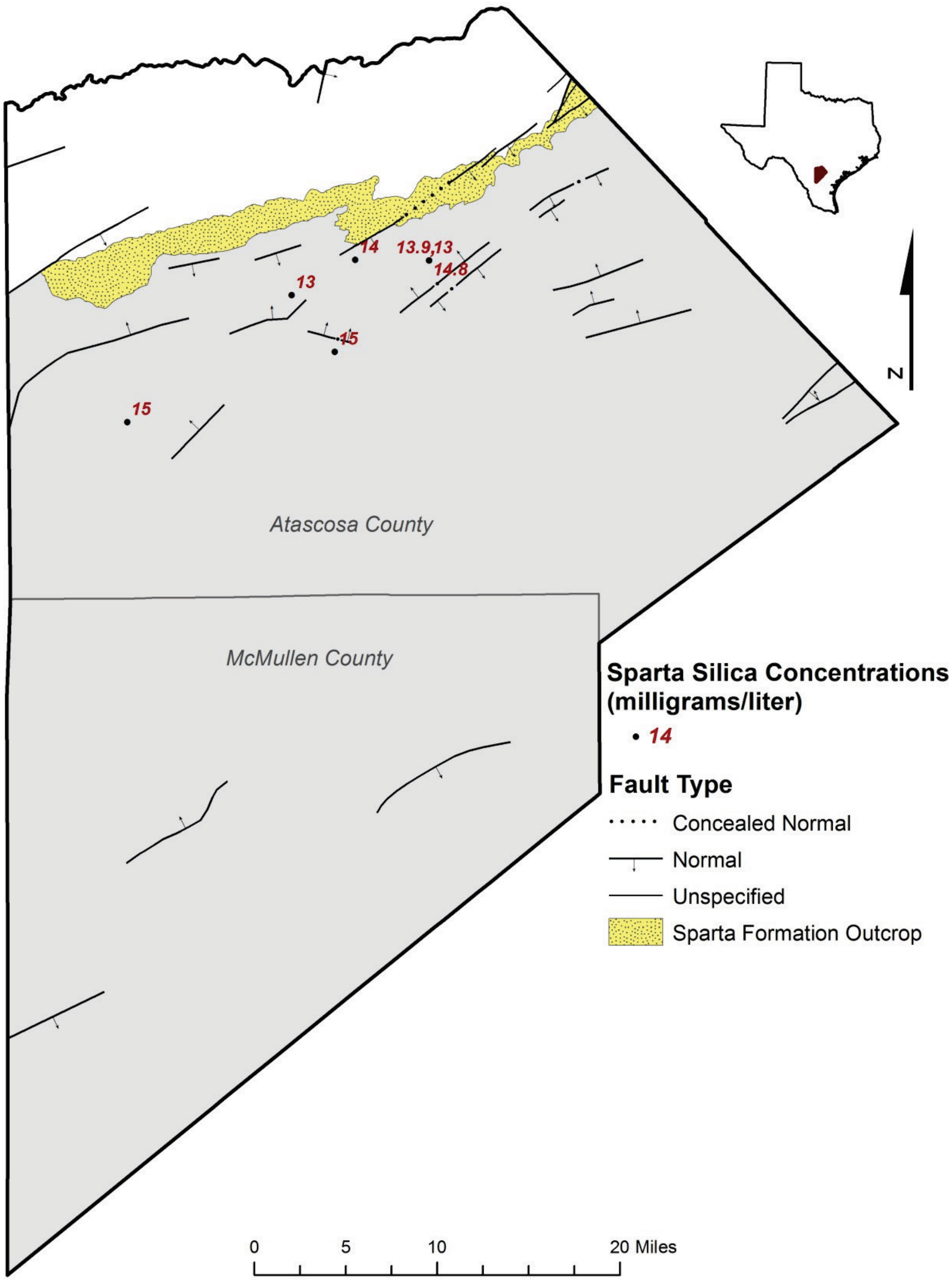


Figure 6-17. **Sparta silica concentrations. The values of 13.9, 13, and 14.8 milligrams per liter are from the same well.**

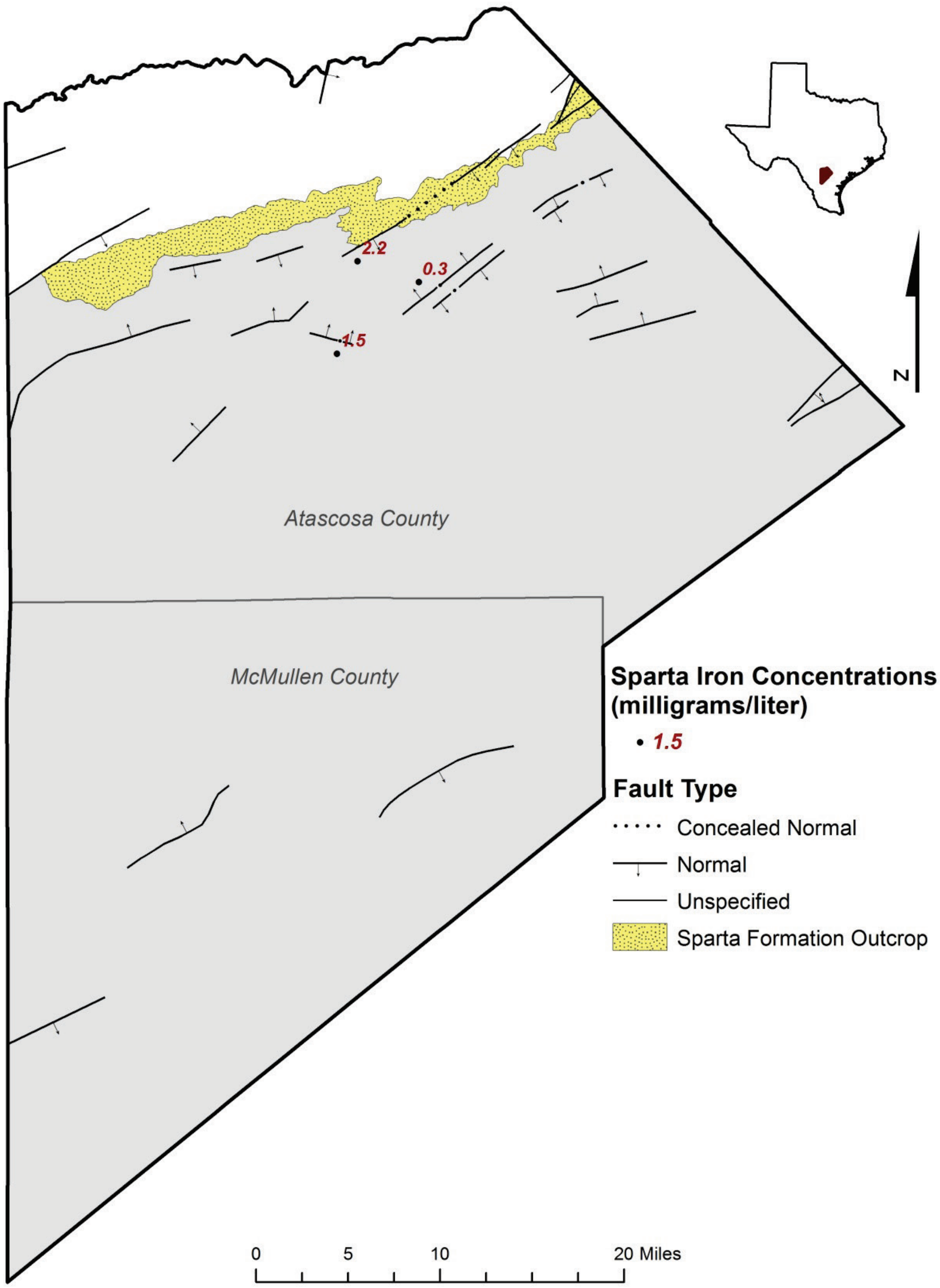


Figure 6-18. Sparta iron concentrations.

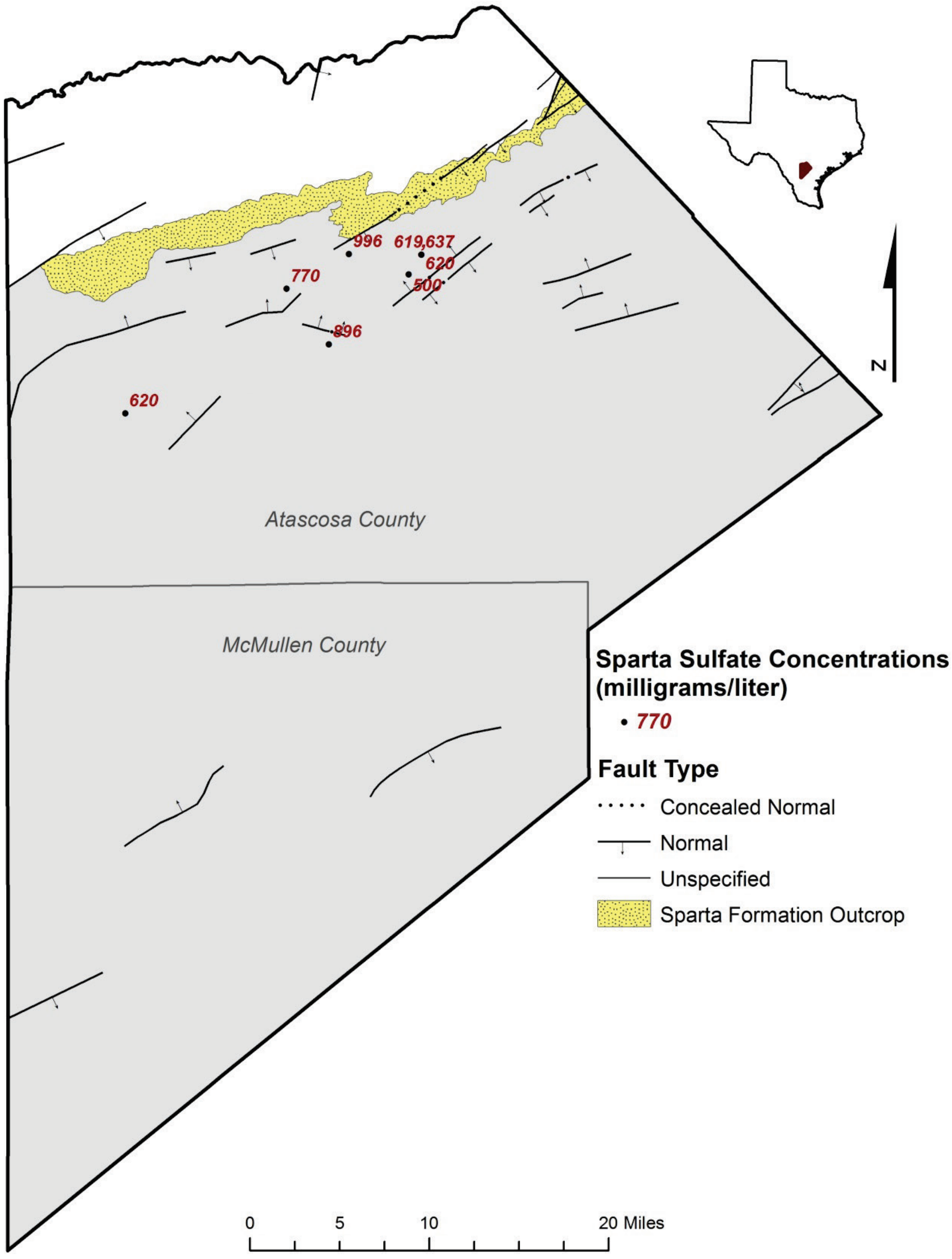


Figure 6-19. **Sparta sulfate concentrations. The values of 619, 637, and 620 milligrams per liter are from the same well.**

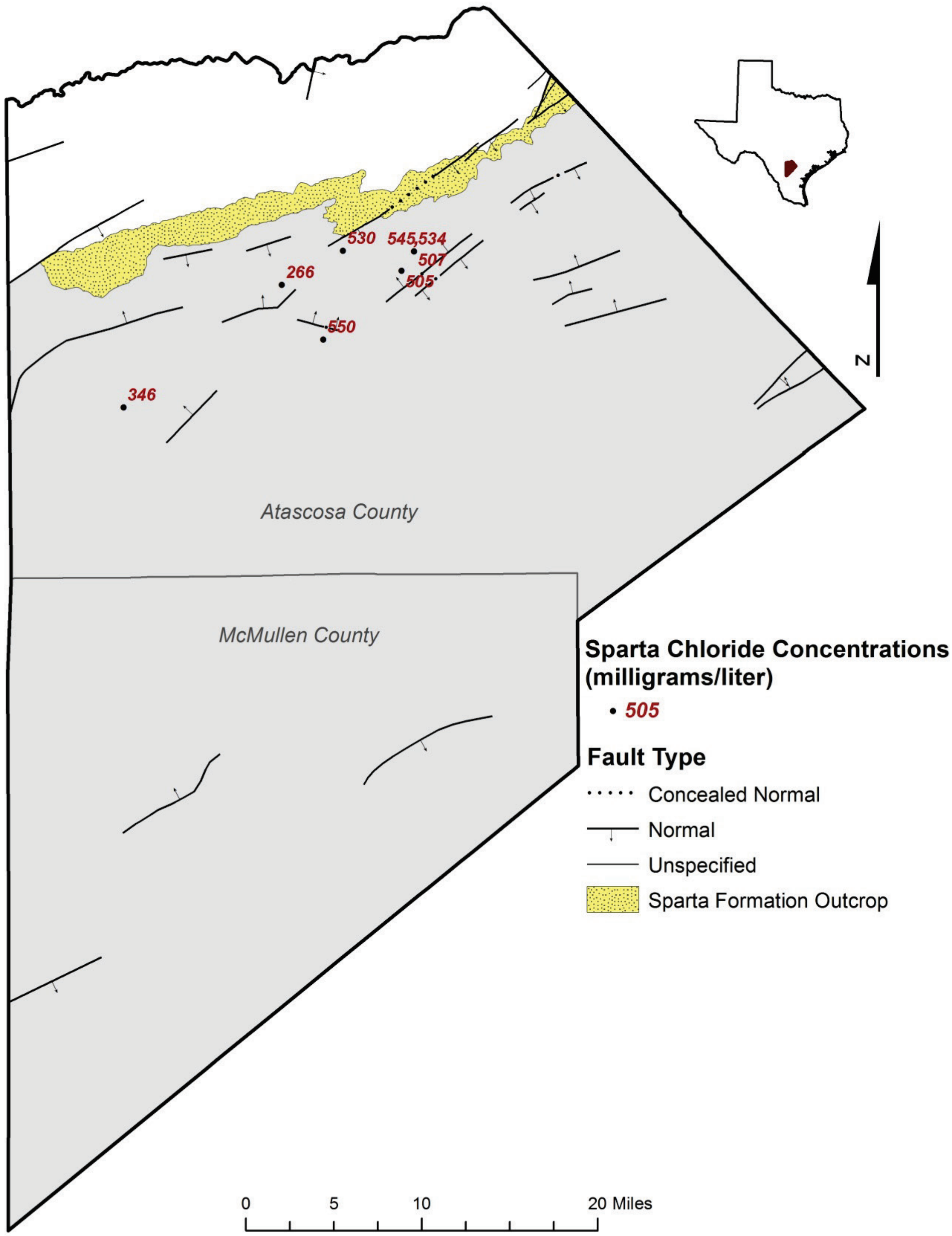


Figure 6-20. Sparta chloride concentrations. The values of 545, 534, and 507 milligrams per liter are from the same well.

An assessment of groundwater quality in the Queen City Formation from 71 samples indicates total dissolved solids concentration ranged from 284 to 2,704 milligrams per liter with an average of 776 milligrams per liter. Total dissolved solids concentration remained relatively stable over time, several decades in some cases, in wells that were sampled more than once. Chloride concentration ranged from 34 to 805 milligrams per liter. Silica concentration is between 14 and 35 milligrams per liter. Iron concentration in the Queen City Formation ranged from 0.04 to 3.5 milligrams per liter. Sulfate concentration ranged from 1 to 1,360 milligrams per liter.

Concentration maps of selected groundwater constituents help to illustrate their spatial distribution in the Queen City Formation (figures 6-21 through 6-24). We show only the most recent silica sample results on the concentration map. Groundwater constituent levels within the Queen City Formation exhibit some degree of variability, with silica showing the least amount of variability and sulfate the most. The highest silica, iron, and chloride concentrations are found in the outcrop area at 35 milligrams per liter, 3.5 milligrams per liter and 805 milligrams per liter, respectively.

We observed elevated iron, sulfate, and chloride concentrations, when compared to surrounding sample results, in BRACS well 13282 located on the upthrown side of a fault in central Atascosa County (Label A in figures 6-22 through 6-24). The iron, sulfate, and chloride concentrations in this well are 1.19 milligrams per liter, 1,360 milligrams per liter, and 302 milligrams per liter, respectively. This sulfate level of 1,360 milligrams per liter is also the highest observed sulfate level in the project area by an order of magnitude. The silica level in this well is similar to those observed elsewhere in the Queen City Formation.

Total dissolved solids concentrations from water quality data are in the brackish range for the Sparta Formation wells (Figure 6-25). We show only the most recent water quality sample result on the map. It is possible that the Sparta Formation outcrop area contains fresh groundwater. Moderately saline groundwater with total dissolved solids concentration of 4,839 milligrams per liter and 3,276 milligrams per liter occurs relatively close to the outcrop area on the downdip side of the Charlotte-Jourdanton Fault Zone in eastern Atascosa County (Label A in Figure 6-25). The prevalence of brackish groundwater could be the result of several factors, including compartmentalization of the flow system within the Sparta Formation due to faulting. Geologic units offset at faults within the relatively thin Sparta Formation (~150 feet total thickness near the outcrop) could restrict the amount of recharge to the formation and increase groundwater residence time. Payne (1968) noted that strandline sand packages in the Sparta Formation which are oriented approximately parallel to strike have relatively higher total dissolved solids concentrations due to lower rates of groundwater movement along strike.

Total dissolved solids concentrations from water quality data are in the fresh and brackish ranges for the Queen City Formation wells (Figure 6-26). We show only the most recent water quality sample result on the map. The Queen City Formation exhibits regions of brackish total dissolved solids concentrations in and around the outcrop area. Fresh groundwater appears to be more prevalent in this area as compared to the Sparta Formation.

Richter and Kreitler (1991) provided a summary of sources of groundwater salinity in the United States that outlines the mechanisms and water chemistry of each source. They identify seven major sources of groundwater salinization: natural saline groundwater, halite solution, sea water intrusion, oil-field brine, agricultural effluent, saline seep, and road salting.

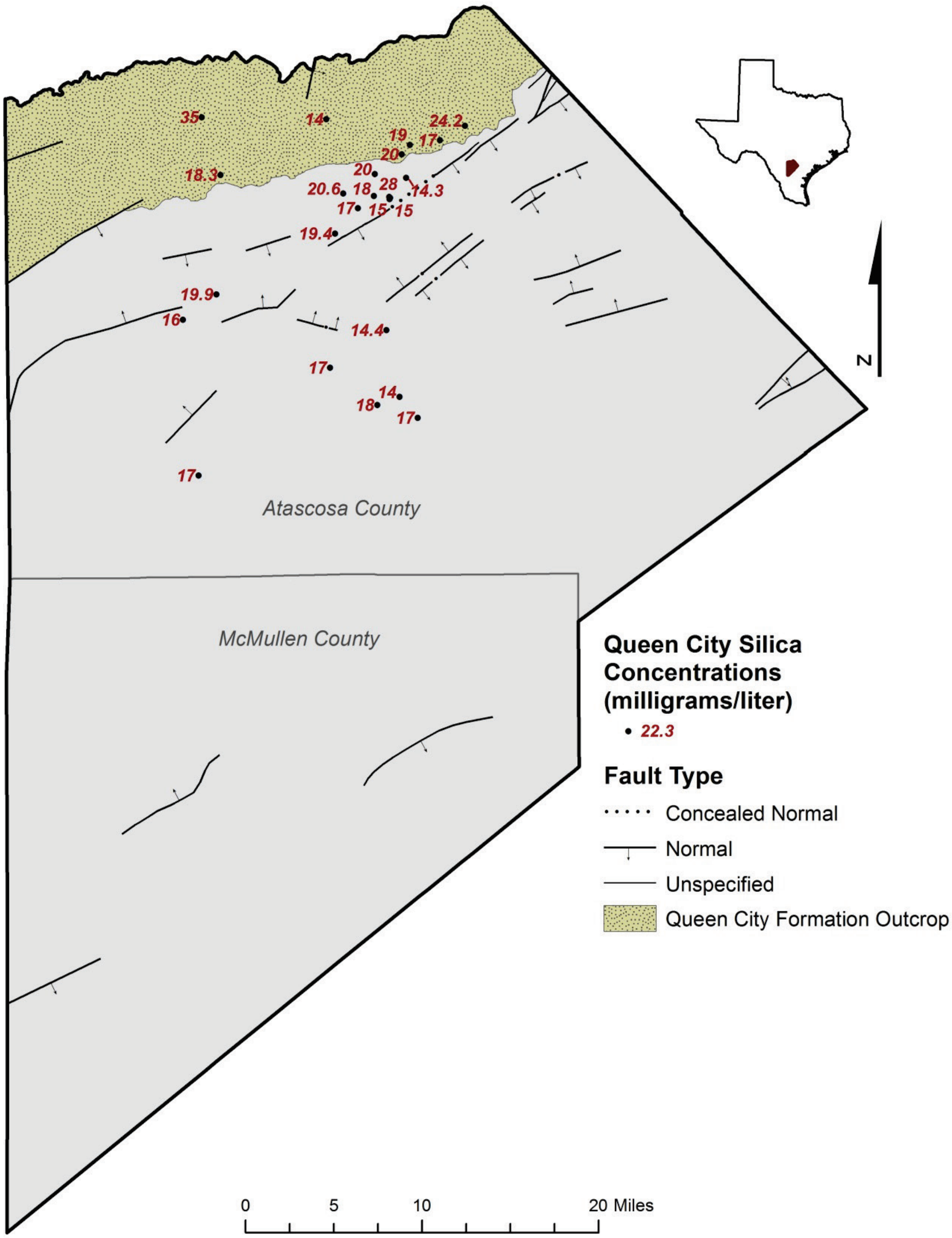


Figure 6-21. **Queen City silica concentrations.**

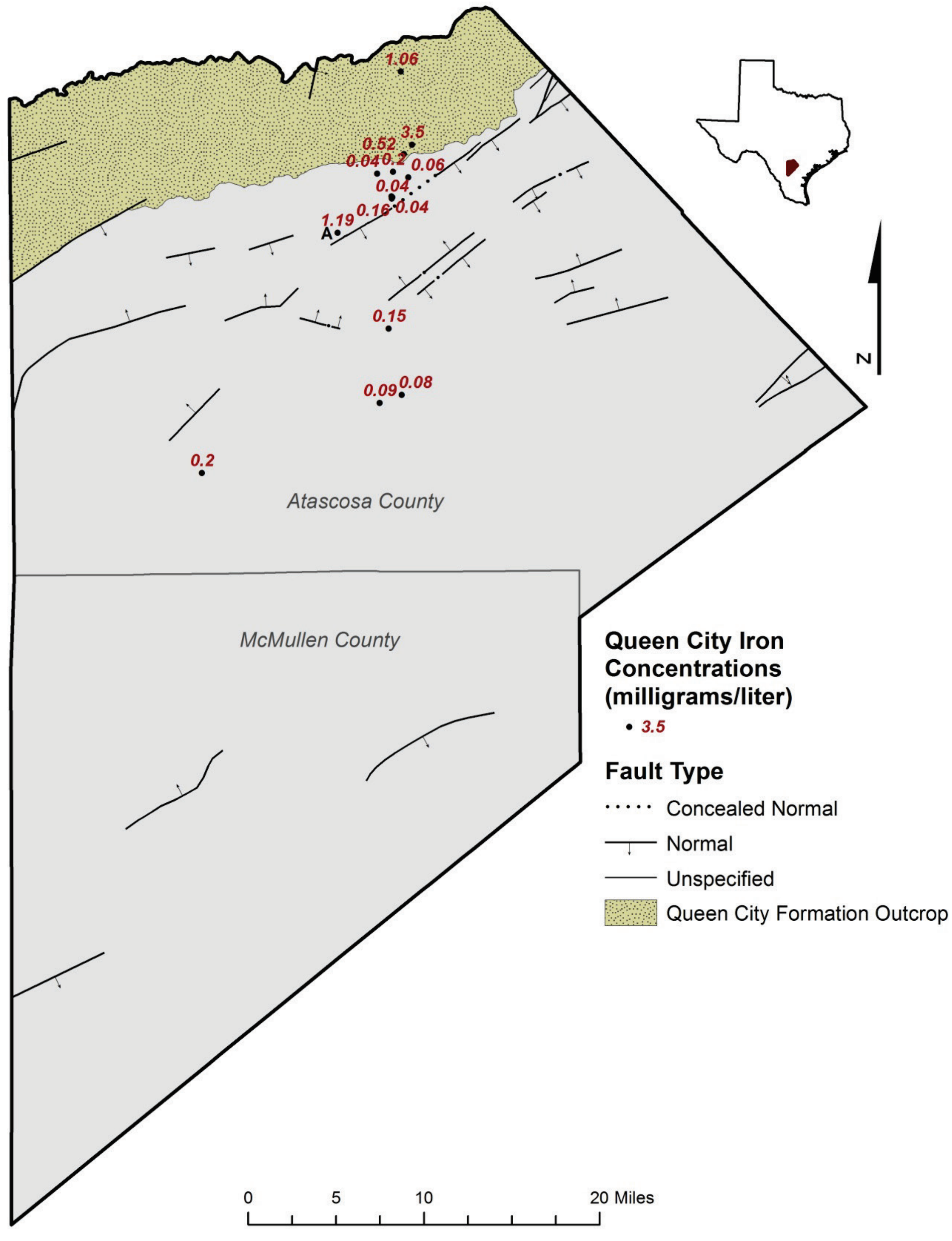


Figure 6-22. Queen City iron concentrations. Reference point A is discussed in the text.

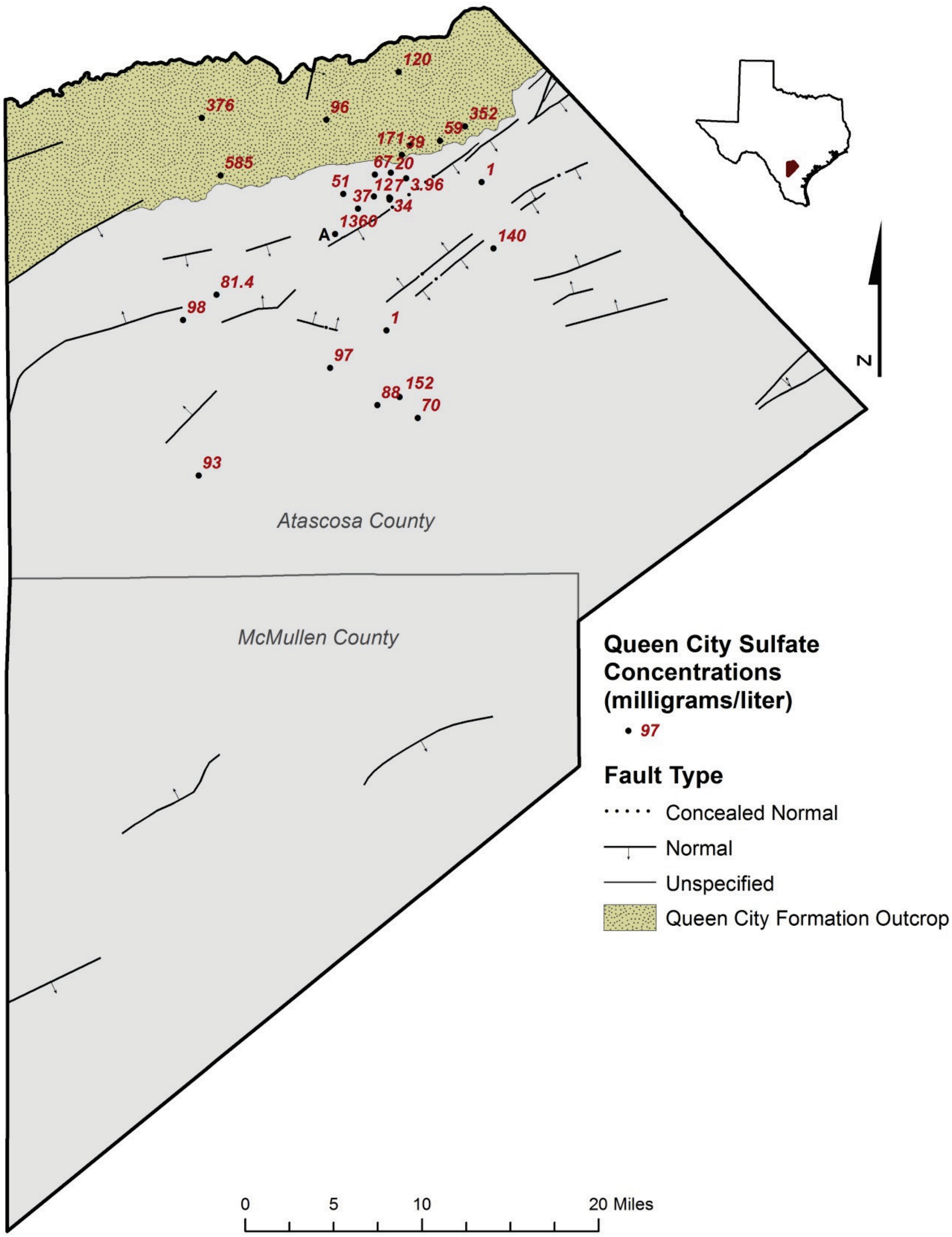


Figure 6-23. Queen City sulfate concentrations. Reference point A is discussed in the text.

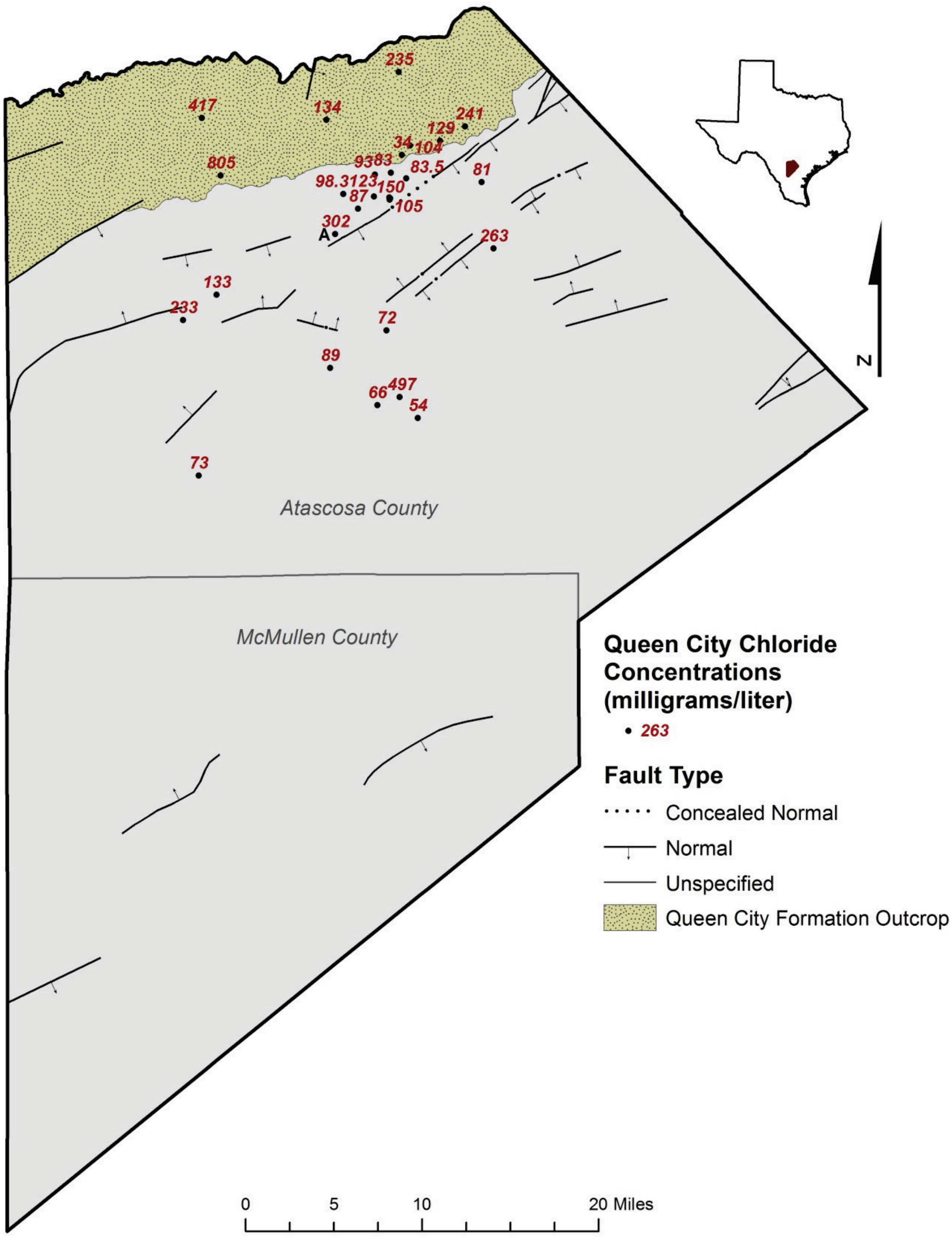


Figure 6-24. Queen City chloride concentrations. Reference point A is discussed in the text.

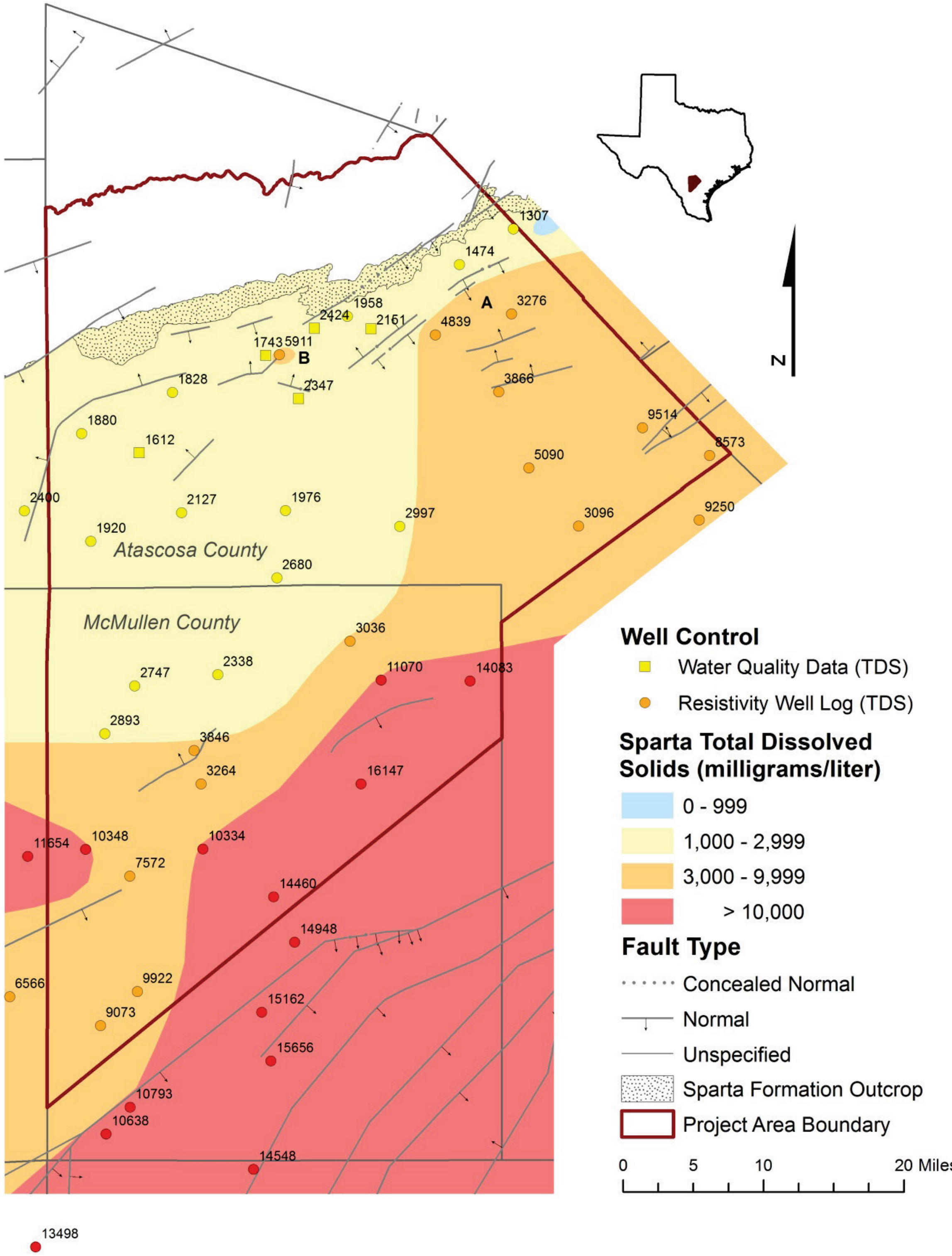


Figure 6-25. **Distribution of total dissolved solids in the Sparta Formation. Map prepared using water quality samples from 5 water wells and geophysical well log analyses from 33 wells. Reference points A and B are discussed in the text. TDS = total dissolved solids**

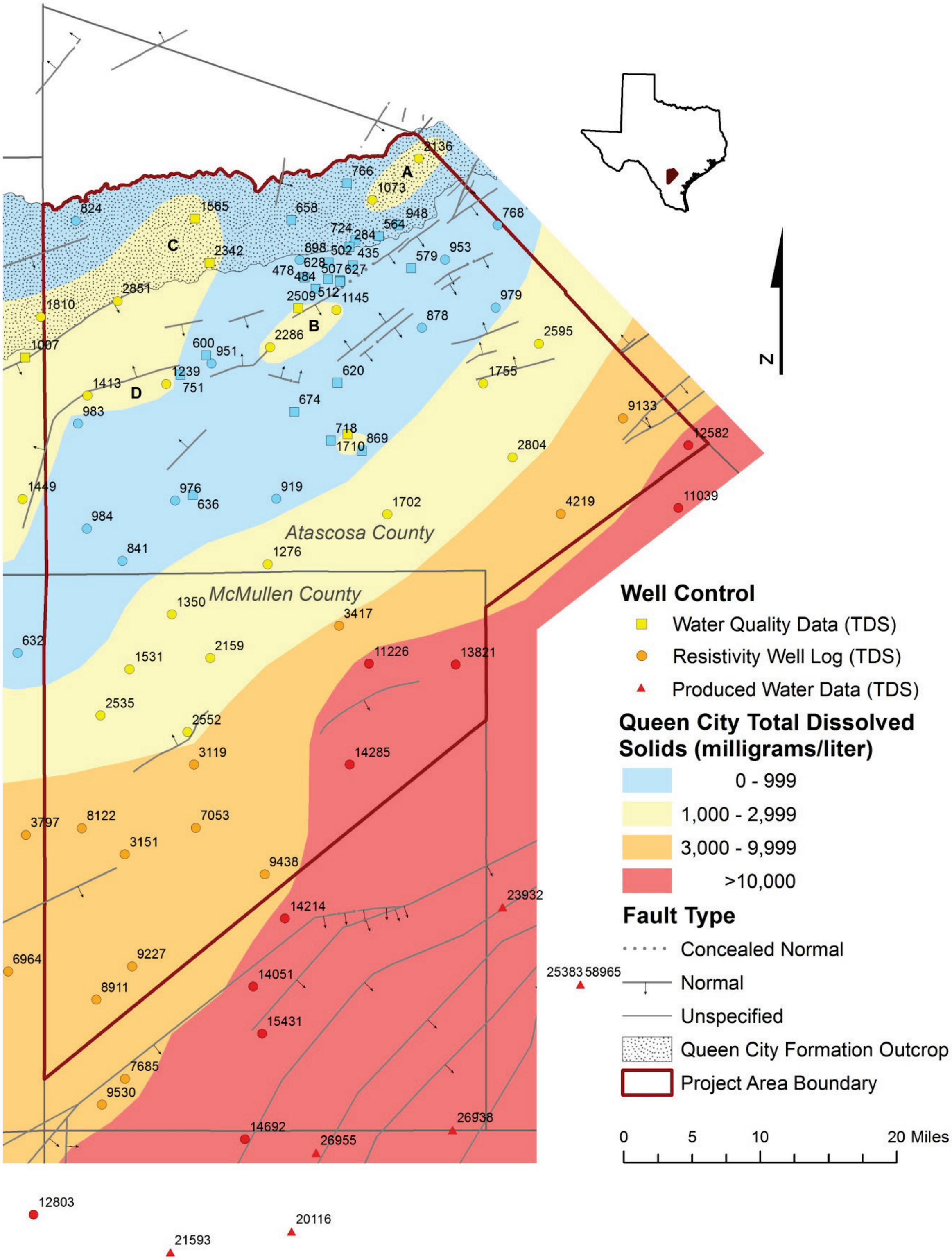


Figure 6-26. **Distribution of total dissolved solids in the Queen City Formation. Map prepared using water quality samples from 24 water wells, 6 produced water samples from oil/gas wells, and geophysical well log analyses from 42 wells. Reference points A, B, C, and D are discussed in the text. TDS = total dissolved solids**

The most likely sources of salinity in the project area include naturally occurring saline groundwater, oil-field brine, and agricultural effluent. Halite solution and saline seeps are not likely sources due to the geologic setting of the project area. The project area location also precludes both sea water intrusion and road salting as possible salinity sources.

The Sparta Formation total dissolved solids map displays a brackish (moderately saline) area (Label B in Figure 6-25) where resistivity log analysis indicated an interpreted total dissolved solids estimate of 5,911 milligrams per liter (BRACS well 11042). The Queen City Formation total dissolved solids map displays a brackish (slightly saline) area in the same location (Label B in Figure 6-26). Resistivity log analysis of BRACS well 11042, BRACS well 11134, and three water quality samples from BRACS well 13282 indicate a larger area of slightly saline groundwater in this region. The water quality data BRACS well 13282 has higher levels of calcium, magnesium, sodium, potassium, iron, sulfate, and chloride. BRACS well 13282 has a nitrate concentration of 0.21 milligrams per liter. Nitrate is the most significant parameter that differentiates agricultural effluent salinization from other sources (Richter and Kreitler, 1991).

Brackish (slightly saline) groundwater is found in the Queen City outcrop in two areas (labels A and C in Figure 6-26), one in eastern and one in western Atascosa County. Resistivity log analysis on BRACS wells 11098 and 11109 indicate interpreted total dissolved solids estimates of 2,136 milligrams per liter and 1,073 milligrams per liter, respectively (Label A). Resistivity log analysis on BRACS wells 11036, 11060, and 13459 provide interpreted total dissolved solids estimates of 2,851 milligrams per liter, 1,239 milligrams per liter, and 1,413 milligrams per liter, respectively (Label C). Brackish groundwater within the Queen City outcrop area is further delineated by water quality samples from BRACS well 13251 and state well number 7803312 that indicate total dissolved solids concentrations of 1,565 milligrams per liter and 2,342 milligrams per liter, respectively (Label C).

Nitrate concentration is low (0.27 milligrams per liter in BRACS well 13251) or below detection limit in the Queen City groundwater quality samples collected in the outcrop area. This suggests that irrigation effluent is not the source of the salinity in this area (Richter and Kreitler, 1991).

The graben in the Charlotte-Jourdanton Fault Zone appears to influence the southern extent of brackish groundwater in western Atascosa County (Label D in Figure 6-26). Fresh groundwater is indicated south and east of this area based on water well samples and a number of resistivity well log interpretations.

Both the Sparta and Queen City total dissolved solids maps generally show increasing salinity with depth. Groundwater salinity naturally increases with depth because chemical reactions with aquifer material, residence time, and mixing of different waters also increase (Richter and Kreitler, 1991).

7. Resistivity analysis of geophysical well logs

Geophysical well logs are produced from tools that are lowered into a well bore with a wireline and retrieved back to the ground surface at a specific rate. Combinations of different tools can be assembled in standard "packages" to measure specific formation, fluid, borehole, casing, and cement properties. Tools are selected based on a number of factors including cased or uncased boreholes, and the composition of the well bore (air or drilling muds). The tools have progressively improved since they were first applied to oil field investigations in the 1930s. The geophysical well logs collected for this project were produced between 1935 and 2010.

Interpretation of logs that were produced over such a long time span and presumably with varying designs and accuracies presents challenges. Obviously, some of the older logs simply could not be used in all aspects of the project. The digital image quality of some of logs also presented challenges. Oil field wells are generally logged after a section of surface casing is installed. With the exception of the gamma ray tool, the section of the wellbore containing surface casing cannot be logged. It thus limits the amount of information that can be collected from ground surface to the top of the casing, which can be several hundred or thousand feet.

We evaluated geophysical well logs capable of recording shallow and deep resistivity within a formation to determine if these tools could provide an interpreted total dissolved solids concentration. We evaluated two methods that are described in detail by Estepp (1998) to estimate total dissolved solids for this project: Modified Alger-Harrison and Rwa Minimum. This task was not a comprehensive evaluation of each method which is an ongoing research task at the TWDB. Each method attempts to approximate a highly complex geologic system, often with incomplete information, using log parameters and correction factors that were designed to address oilfield rather than groundwater environments.

Despite these shortcomings, geophysical well logs are routinely used to derive an interpreted total dissolved solid value for groundwater. While the results obtained from these methods can be used to generalize total dissolved solids in the project area, they cannot provide an exact total dissolved solids value. Accurate total dissolved solids concentration using these methods can be determined only with a properly designed test well drilling, logging, and formation sample and chemical analysis program that determines each variable used in the formulas.

The formation resistivity is determined by reading a deep resistivity geophysical tool in a thick layer of shale-free sand that is not affected by hydrocarbons. The measured formation resistivity is the result of several parameters: resistivity of the formation minerals, resistivity of formation water and its composition, porosity and tortuosity, cementation of sediment grains, sediment grain size, and surface conductance on mineral grains (Alger, 1966). The objective is to determine formation water resistivity from formation resistivity. Obtaining some of these parameters is not possible with information from a geophysical well log. Lab experiments indicating parameter variance under different conditions have shown that this is complex (Alger, 1966). To solve the calculations, some of the parameters are estimated based on similar geologic conditions.

We used two logging tools for deep resistivity measurements: the induction log and the resistivity log. We evaluated the formation invaded zone, potentially impacted by drilling mud filtrate, using shallow resistivity tools such as the shallow focused log or 16” normal resistivity. Porosity logging tools were not available in the project area within the evaluated depth zones.

We used a value of 30 percent porosity to evaluate the Sparta and Queen City formations north of the Atascosa-McMullen county line; south of the county line we used a value of 25 percent porosity for the Rwa Minimum Total Dissolved Solids Method. To gain additional ct (total dissolved solids divided by specific conductance) relationships, we evaluated the Carrizo Formation north of the Atascosa-McMullen county line using a value of 30 percent porosity; south of the county line we used a value of 20 percent porosity for the Rwa Minimum Total Dissolved Solids Method.

The Modified Alger-Harrison and the Rwa Minimum Total Dissolved Solids methods are two quantitative methods of interpreting total dissolved solids from geophysical well log resistivity

(Estepp, 1998). We applied these methods to 56 wells in the project area for the Sparta, Queen City, and Carrizo formations. We performed one hundred and thirty-eight analyses, two of which used the Modified Alger-Harrison Method and the remainder used the Rwa Minimum Method.

Selected wells each had a geophysical well log with the appropriate tool types and complete log header information. The wells were proximal to water wells for which the following parameters were available: total dissolved solids concentration, ct value, and the ratios of sulfate divided by total dissolved solids and bicarbonate divided by total dissolved solids. We used Carrizo water quality data in areas where Sparta and Queen City water quality was not available.

We appended the log parameters to the BRACS Database using a multi-table relational form with the calculations for interpreted total dissolved solids written in Visual Basic for Applications® and assigned to form command buttons. Interpreted total dissolved solids is the value generated using geophysical well log parameters, log correction factors, formation factors, and aquifer ct value as input parameters. In this project, we obtained the log parameters from the geophysical well log, determined the ct value from nearby water wells in either the Sparta, Queen City, or Carrizo formations, and acquired the cementation factor (m), which is dimensionless, from the equation $m = 1.75 + ([\text{depth formation in feet} - 1{,}500] / 10{,}000)$ (Estepp, 2010) as well as values provided for various lithologies in Estepp (2010).

We plotted results from the interpreted total dissolved solids evaluation against resistivity values measured in the different formations (Figure 7-1). The term interpreted total dissolved solids should not be confused with total dissolved solids measured in a water quality sample.

The use of these geophysical well log interpretation methods permitted interpretation of the extent of brackish groundwater zones for the Sparta and Queen City formations in the project area (figures 6-25 and 6-26). This was necessary since available water quality data for Sparta and Queen City formations is limited to updip areas near the recharge zone. We obtained produced water (water produced from oil and gas wells) data from the U.S. Geological Survey (2002) and we evaluated six Queen City wells located outside of the project area as downdip well control in the saline zone.

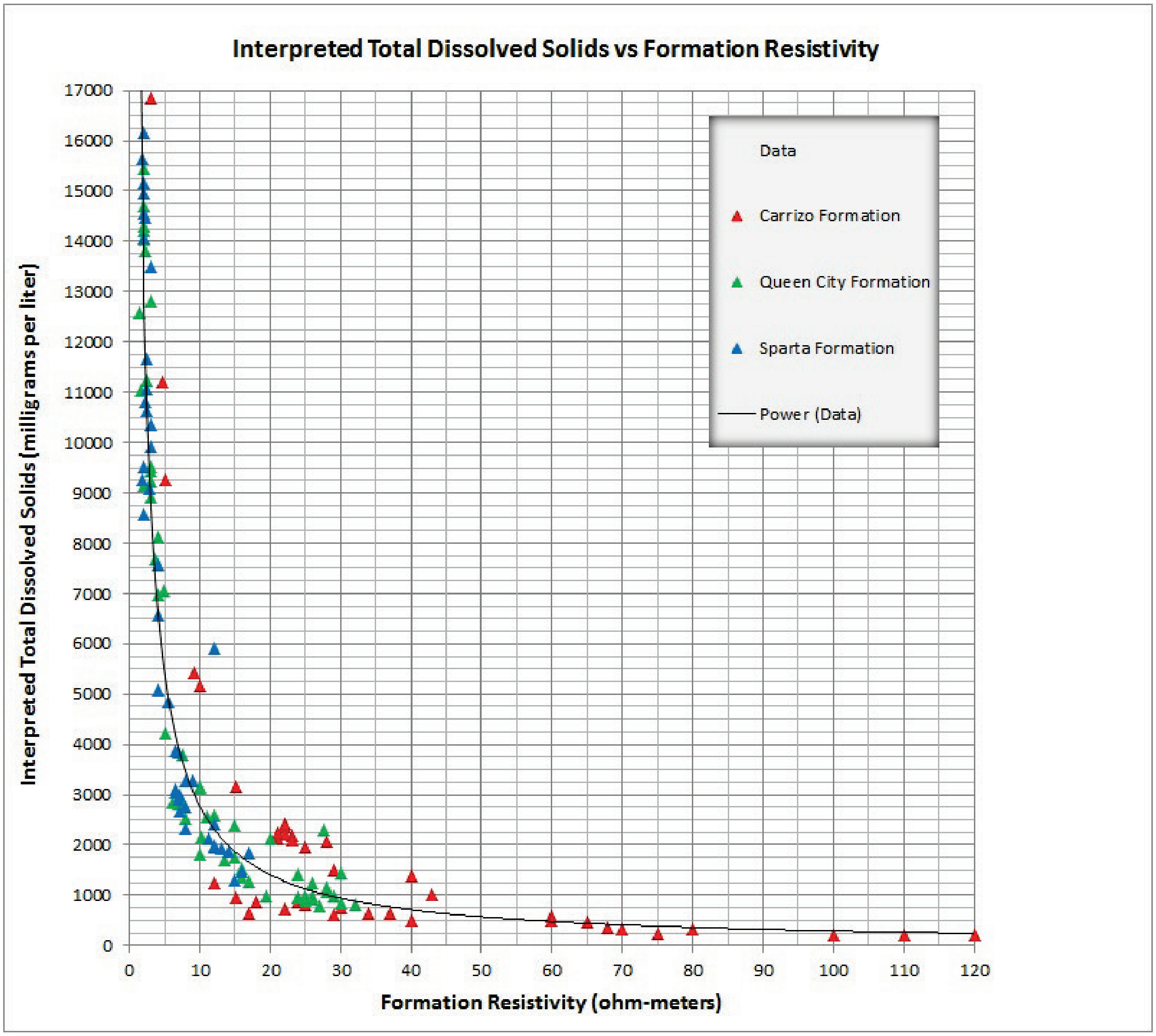


Figure 7-1. **Plot of interpreted total dissolved solids concentrations versus formation resistivity in the Queen City, Sparta, and Carrizo formations. Graph produced from 138 analyses on 56 geophysical well logs.**

7.1 Brackish groundwater volume estimates

The TWDB categorizes water salinity based on total dissolved solids concentrations: fresh (0–999 milligrams per liter); slightly saline (1,000–2,999 milligrams per liter); moderately saline (3,000–9,999 milligrams per liter); very saline (10,000–35,000 milligrams per liter); and brine (>35,000 milligrams per liter) (Winslow and Kister, 1956). The term brackish water includes slightly to moderately saline waters (1,000–9,999 milligrams per liter of total dissolved solids) (LBG-Guyton, 2003).

We mapped brackish groundwater in the Sparta and Queen City formations according to TWDB's classification system with the exception that we grouped all water with total dissolved solids concentrations greater than 10,000 milligrams per liter into one category. This is consistent with the system used by LBG-Guyton (2003). We used total dissolved solids concentration data and resistivity well log analysis interpretation to create water quality zones corresponding to the brackish groundwater classification system for each formation (figures 6-25 and 6-26). The groundwater volume estimates did not include interpretation of vertical salinity differences within a formation.

We generally used a method similar to the one used in TWDB's Groundwater Availability Modeling studies (Jigmond and Wade, 2013) to estimate total storage volumes. The method used for estimating total storage in this project differs from that used by the Groundwater Availability Modeling Section in several ways. This project used formation net sand thicknesses rather than the entire formation thickness; project stratigraphic formation surfaces are different from those used for the groundwater availability model; the lateral mapped extent of each formation extends farther downdip than the official minor aquifer boundaries used in the groundwater availability model; this project calculates the water quality based on total dissolved solids concentration categories of fresh, brackish, and very saline whereas the groundwater availability models do not use this distinction.

The storage term for unconfined aquifers, or when dewatering the pore space of a confined aquifer, is known as specific yield. It is the volume of water that is released from aquifer storage per unit surface area of aquifer per unit decline in water level. This volume is labeled as drained volume (V-drained) (Figure 7-2). Not all water in the saturated zone can be removed by drainage or pumping. Similarly, the storativity of a saturated confined aquifer is the volume of water that a confined aquifer releases from storage per unit surface area per unit decline in hydraulic head. This confined volume is labeled as V-confined (Figure 7-2). The confined volume is produced while the aquifer remains fully saturated and is the result of the expansion of groundwater and compaction of the aquifer matrix as the hydraulic pressure decreases in the aquifer due to pumping. Unconfined and confined storativity values are dimensionless numbers.

We used the Queen City and Sparta specific yield and storativity values of 0.10 and 0.0005, respectively, presented by LBG-Guyton (2003) for regional water planning areas L and N, to estimate the groundwater storage volumes.

For the Queen City and Sparta formations, we calculated the unconfined storage (unconfined drained volume) by multiplying together, on a grid cell by grid cell basis over the outcrop area only, the project grid cell area, the specific yield value, the saturated thickness, and sand percentage values. We obtained saturated thickness values from the modeled hydraulic head height above the formation bottom.

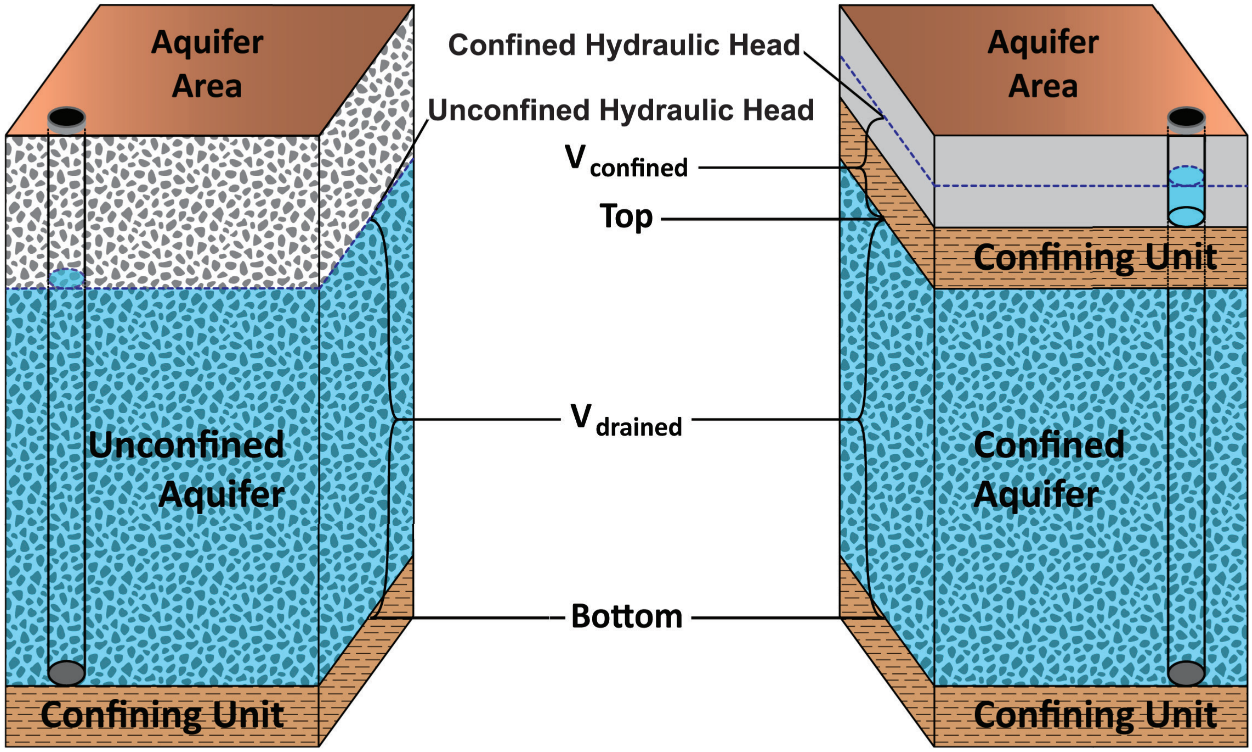


Figure 7-2. **Schematic drawing showing the unconfined and confined groundwater volumetric parameters. Figure from Jigmond and Wade (2013).**

Since we did not calculate the modeled hydraulic head position (water level) relative to the sand layers, we used sand percentage values in partially saturated areas. We used the formation thickness in place of saturated thickness in areas where hydraulic head elevations were above the project digital elevation model surface (artesian heads) in the outcrop area.

For the Queen City and Sparta formations, the confined storage calculation had two components: the confined volume and the drained volume (Figure 7-2). We calculated the confined volume in areas where the modeled hydraulic head values were above the formation top by multiplying together, on a grid cell by grid cell basis over the confined area, the project grid cell area, the confined storativity value, and the modeled hydraulic head height above the formation top. We calculated the drained volume by multiplying together, on a grid cell by grid cell basis over the confined area, the project grid cell area, the specific yield value, the saturated thickness, and either the sand percentage values if partially saturated or the net sand values if fully saturated.

Total storage is the sum of the unconfined storage and confined storage. We used the ArcGIS® Spatial Analyst® Zonal Statistics to Table tool to calculate the total storage volumes within each water quality zone. It achieves this by summing all of the volume estimates at each grid cell within each water quality zone.

The Sparta Formation brackish groundwater total storage estimates for Atascosa and McMullen counties are 5,470,000 acre-feet and 4,404,000, respectively (tables 7-1 and 7-2). The Queen City Formation brackish groundwater total storage estimates for Atascosa and McMullen counties are 37,960,000 acre-feet and 37,220,000, respectively (tables 7-3 and 7-4). All volumes are rounded to within 1 percent of the total.

Table 7-1. Total storage estimates in the Sparta Formation, Atascosa County, for each water classification. Total storage values are rounded to within 1 percent of the total.

Water classification (milligrams per liter of total dissolved solids)	**Total storage (acre-feet)**
Fresh water (0–999)	0
Brackish water	
(1,000–2,999)	3,320,000
(3,000–9,999)	2,150,000
Subtotal (1,000–9,999)	5,470,000
Very saline water (>10,000)	0
Total Sparta Formation Atascosa County	5,470,000

Table 7-2. Total storage estimates in the Sparta Formation within the project area in McMullen County for each water classification. Total storage values are rounded to within 1 percent of the total.

Water classification (milligrams per liter of total dissolved solids)	**Total storage (acre-feet)**
Fresh water (0–999)	0
Brackish water	
(1,000–2,999)	1,500,000
(3,000–9,999)	1,910,000
Subtotal (1,000–9,999)	3,410,000
Very saline water (>10,000)	994,000
Total Sparta Formation McMullen County	4,404,000

Table 7-3. Total storage estimates in the Queen City Formation, Atascosa County, for each water classification. Total storage values are rounded to within 1 percent of the total.

Water classification (milligrams per liter of total dissolved solids)	Total storage (acre-feet)
Fresh water (0–999)	19,300,000
Brackish water (1,000–2,999) (3,000–9,999) Subtotal (1,000–9,999)	 14,000,000 4,480,000 18,480,000
Very saline water (>10,000)	180,000
Total Queen City Formation Atascosa County	37,960,000

Table 7-4. Total storage estimates in the Queen City Formation within the project area in McMullen County for each water classification. Total storage values are rounded to within 1 percent of the total.

Water classification (milligrams per liter of total dissolved solids)	Total storage (acre-feet)
Fresh water (0–999)	1,800,000
Brackish water (1,000–2,999) (3,000–9,999) Subtotal (1,000–9,999)	 10,400,000 20,500,000 30,900,000
Very saline water (>10,000)	4,520,000
Total Queen City Formation McMullen County	37,220,000

8. Future work

The hydraulic heads in the Queen City and Sparta formations may be compared by examining the differences between them to evaluate the potential for vertical flow between the formations and its possible influence on groundwater quality. Information such as historical aerial photos could be obtained to investigate surface disposal of oil-field brine prior to the establishment of the statewide no-pit rule, especially in the Sparta and Queen City outcrop areas and around other areas with shallow brackish groundwater. Collecting additional Queen City and Sparta water well data and geophysical well logs in the project area will help future studies.

9. Conclusions

The total amount of brackish groundwater in storage in the Queen City and Sparta formations in the project area is estimated at approximately 58,260,000 acre-feet.

The Sparta Formation in the project area has about 8,880,000 acre-feet of brackish groundwater in storage: approximately 5,470,000 acre-feet in Atascosa County and about 3,410,000 acre-feet in McMullen County. It also has approximately 994,000 acre-feet of very saline water in storage within the project area.

The Queen City Formation in the project area contains approximately 49,380,000 acre-feet of brackish groundwater in storage: about 18,480,000 acre-feet in Atascosa County and about 30,900,000 acre-feet in McMullen County. The formation also has approximately 21,100,000 acre-feet of fresh water and 4,700,000 acre-feet of very saline water in storage within the project area.

Brackish groundwater occurs within the outcrop areas of the Sparta and Queen City formations in the project area.

10. Acknowledgments

I wish to thank Sanjeev Kalaswad and John E. Meyer for technical assistance and support throughout this project. A special thank-you is extended to Norman Gearhart and John Estepp, Railroad Commission of Texas, for allowing us access to the Commission's geophysical well log library. Finally, this work could not have been undertaken or completed without the generous support of Jorge A. Arroyo and Dr. Robert E. Mace.

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12. Appendix A

12.1 Project GIS datasets

Point files, polyline files, and polygon files are ArcGIS® shapefiles.

Raster files are ArcGIS® integer grid files with the exception of the groundwater storage raster files which are ArcGIS® floating point grid files. All raster files were snapped to the project snap grid.

All GIS files contain metadata describing content, data processing steps, and map projection parameters.

The well point correction column indicates if stratigraphic values were assigned to cell values at well sites after the formation surface was prepared. This step ensures that stratigraphic values in the database exactly match the values in GIS files.

Sparta Formation

File type	Shapefile	Raster file	Well point correction
Top depth	sp_t_d_pt	sp_td_sspb_i	Yes
Bottom depth	sp_b_d_pt	sp_bd_sspb_i	Yes
Top elevation	sp_t_e_pt	sp_t_e_i	
Bottom elevation	sp_b_e_pt	sp_b_e_i	
Thickness	sp_tk_pt	sp_tk_i	Yes
Sand percent	sparta_sand_content_pt	sp_ps_tr_i	
Net sand	sparta_sand_content_pt	sp_ns_tr_i	
Water quality zones	BRACS_WQ_Zones_SP		
Unconfined area		sp62500_i_otc	
Atascosa County confined area		sp62500cfnata	
McMullen County confined area		sp62500cfnmcm	
Atascosa County total groundwater storage		sp_vw_tot_ata	
McMullen County total groundwater storage		sp_vw_tot_mcm	

Notes: Each well record in the point files contains the stratigraphic log interpretation values. The project grid cell area is 62,500 square feet (250 feet x 250 feet).

Weches Formation

File type	Raster file	Well point correction
Top depth	w_t_d_i	Yes
Bottom depth	w_b_d_i	Yes
Top elevation	w_t_e_i	
Bottom elevation	w_b_e_i	

Queen City Formation

File type	Shapefile	Raster file	Well point correction
Top depth	qc_t_d_pt	qc_td_sspb_i	Yes
Bottom depth	qc_b_d_pt	qc_bd_sspb_i	Yes
Top elevation	qc_t_e_pt	qc_t_e_i	
Bottom elevation	qc_b_e_pt	qc_b_e_i	
Thickness	qc_tk_pt	qc_tk_i	Yes
Sand percent	queen_city_sand_content_pt	qc_ps_tr_i	
Net sand	queen_city_sand_content_pt	qc_ns_tr_i	
Water quality zones	BRACS_WQ_Zones_QC		
Unconfined area		qc62500_i_otc	
Atascosa County confined area		qc62500cfnata	
McMullen County confined area		qc62500cfnmcm	
Atascosa County total groundwater Storage		qc_vw_tot_ata	
McMullen County total groundwater Storage		qc_vw_tot_mcm	

Notes: Each well record in the point files contains the stratigraphic log interpretation values. The project grid cell area is 62,500 square feet (250 feet x 250 feet).

Support files

File Type	Shapefile	Description
Project elevation	dem_i_250	Project elevation model clipped from a statewide digital elevation model and resampled from a 30-meter grid cell to a 250-foot grid cell
Snap grid	qc_sp_snap250	Snap grid for the project with a 250-foot cell size
Project boundary	QC_Sp_project_area	Project boundary, polygon, used as mask file
Aquifer regions	sTx_PaleoceneEocene_AD	Outlines regions with different stratigraphic relationships of Paleocene and Eocene age strata in South Texas
Aquifer determination	BRACS_AD_QC-Sp	Well records with the aquifer assignment
Geologic structure	Tx_Structural_Geol_Surface_QC-Sp_interpolation_edit	Removed faults in areas of sparse well control from polyline file Tx_Structural_Geol_Surface.shp before implementing the interpolation algorithm Spline with Barriers
Groundwater quality	BRACS_WQ_QC-Sp	Well records with groundwater quality data
Aquifer test information	BRACS_AT_QC-Sp	Well records with aquifer test data
Hydraulic head	sp_hh_i qc_hh_i	Sparta Aquifer modeled water level grid Queen City Aquifer modeled water level grid
Cross-sections	BRACS_QC-Sp_X-section_lines	Project cross-section line locations
Geophysical logs	BRACS_GL_Analysis	Wells with analyzed geophysical logs
Mapped geological features	CretaceousReefTrends	Mapped Cretaceous reef trends in the project area