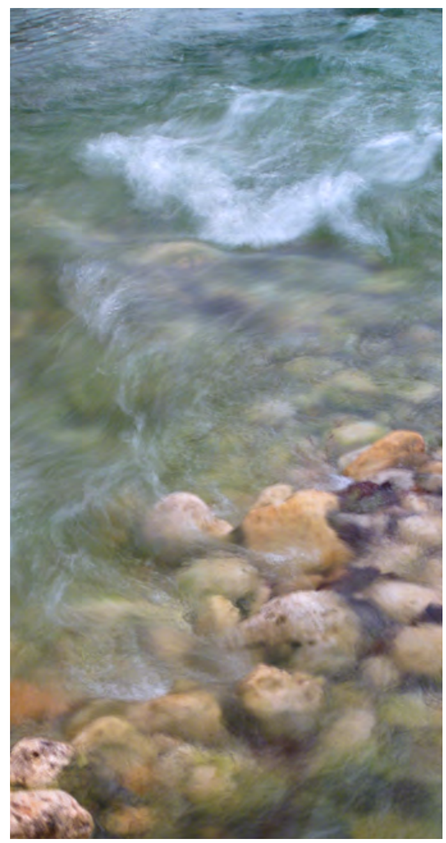

Texas Water Development Board
Groundwater Management Report 19-01

Groundwater Conditions in the Cross Timbers Aquifer

September 2019

by Natalie Ballew, GIT
Lawrence N. French, P.G.

Texas Water Development Board

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Groundwater Conditions in the Cross Timbers Aquifer

by

Natalie Ballew, GIT

Lawrence N. French, P.G.

September 2019

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The contents of this report (including figures and tables) document the work of the following licensed Texas geoscientists:

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Date: September 20, 2019 by

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Special thanks to:

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1. Summary

The Cross Timbers Aquifer is a minor aquifer consisting of four Paleozoic-age water-bearing formations in north central Texas (Figure 1-1). This evaluation assesses the general hydrogeology of and water use from this aquifer. A minor aquifer produces minor amounts of water over large areas or major amounts of water over small areas. The Cross Timbers Aquifer was designated a minor aquifer by the Texas Water Development Board (TWDB) in 2017. There are currently 22 minor aquifers in Texas.

Groundwater resources in north central Texas have attracted increased interest in recent years due to the scarcity of surface water supplies in times of drought and the increased oil and gas exploration and production that requires large amounts of water. Historically, there have been several locally-applied names for these formations, including the “Paleozoic aquifers.” Cross Timbers Aquifer is the name adopted by the TWDB based on results of a public survey.

1.1 Study Area

- The outcrop area of the Cross Timbers Aquifer covers nearly 11,800 square miles extending from the Red River southward to the Colorado River (Figure 1-1). The formations cover all or part of 31 counties.
- The study area includes six groundwater conservation districts in three groundwater management areas and five regional water planning areas.
- Towns with populations greater than 5,000 include Wichita Falls, Abilene, Mineral Wells, Breckenridge, Brownwood, and Graham.

1.2 Geology and aquifer properties

- The geologic formations of the Cross Timbers Aquifer primarily consist of limestone, shale, and sandstone. These rocks occur in layers and lenses, reflecting riverine and deltaic depositional environments.
- Formations in most of the study area are exposed at the land surface (outcrop areas) and generally dip to the west. The formations in the northern portion of the study area dip to the north and east, particularly where these formations are covered by the younger Trinity Aquifer formations.
- Groundwater in the Cross Timbers Aquifer occurs under mostly water-table (or unconfined) conditions and is typically discontinuous within isolated sandstone layers. Overall, groundwater resides in a shallow flow system that is susceptible to water level changes due to variable recharge and discharge.
- The geometry and aquifer properties of water-bearing strata vary widely and contribute to variability in well yields.
- Groundwater quality ranges from fresh to brackish.

1.3 Groundwater use

- About 75 percent of the wells in the Cross Timbers Aquifer are domestic wells and about 20 percent are stock wells. Fifty-one public supply wells obtain their water from the aquifer.
- Pumping from formations classified as "Other Aquifer"—groundwater formations that are not major or minor aquifers—over the past decade in the study area is most likely from the Cross Timbers Aquifer.

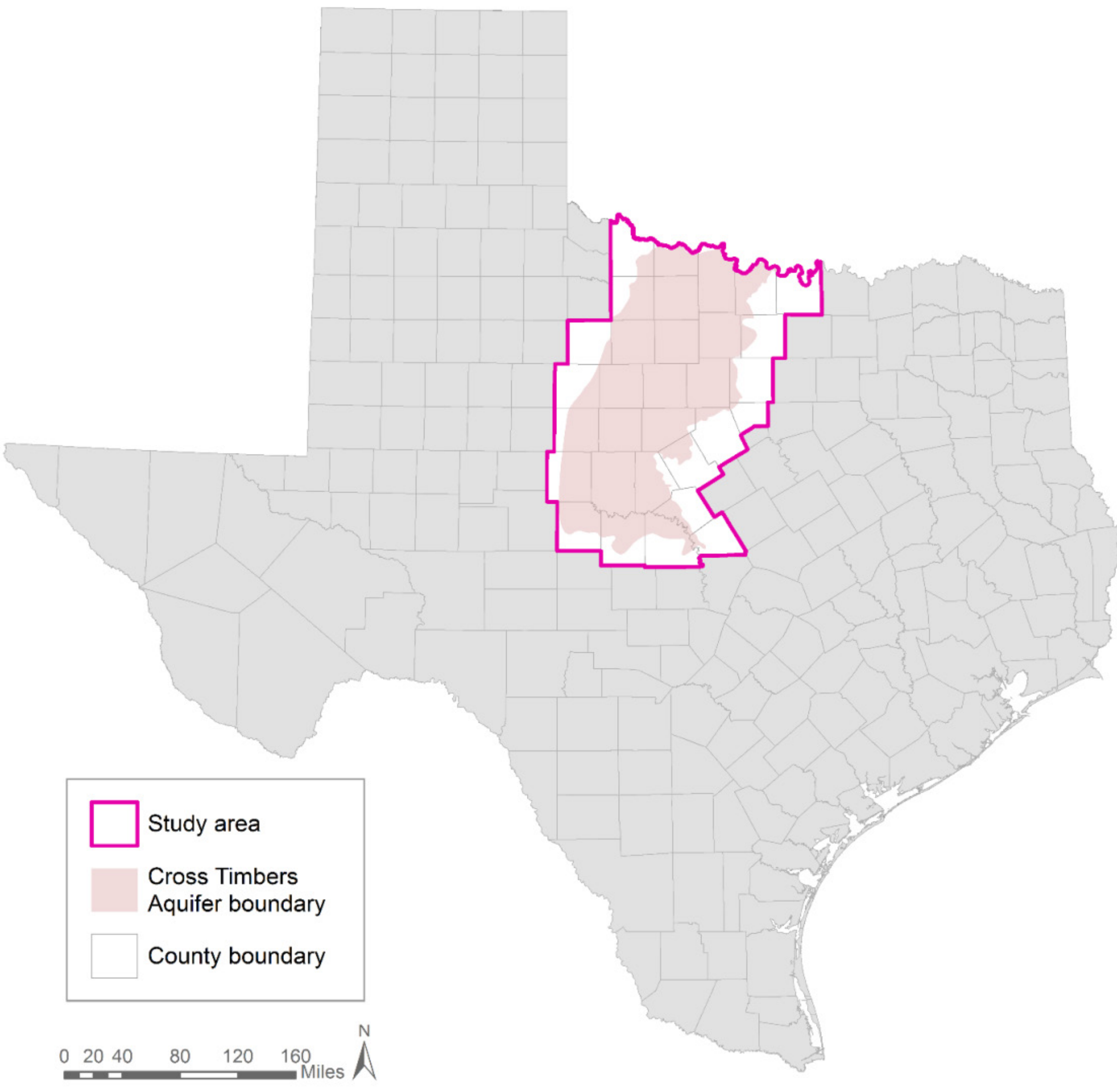

Figure 1-1. Study area in north central Texas.

2. Introduction

The original intent of this report was to provide supporting evidence to designate the Paleozoic water-bearing formations in north central Texas as an official minor aquifer. Supporting evidence for such a designation includes an assessment of general hydrogeology and water use from the geologic formations. These formations were designated as an official minor aquifer by the TWDB in December 2017 Figure 1-1 shows the extent of the Cross Timbers Aquifer boundary and the study area of this report.The aquifer consists of four Paleozoic-age water-bearing geologic groups including, from oldest to youngest, the Strawn (Middle Pennsylvanian), Canyon (Upper Pennsylvanian), Cisco (Upper Pennsylvanian), and Wichita (Lower Permian) groups.

2.1 Aquifer name

Cross Timbers Aquifer is the name adopted by the TWDB to describe the Paleozoic-age formations that are a source of groundwater in north central Texas. Although several local names have been used for these formations, the most common term has been “Paleozoic aquifers”. However, the term “Paleozoic aquifers” does not comply with current U.S. Geological Survey practice (U.S. Geological Survey, 1991), which discourages naming aquifers using references to geologic time. Multiple aquifers may have the same geologic age, and in Texas there are several aquifers that could be described as “Paleozoic”. Therefore, the TWDB identified several possible aquifer names that referenced rock-stratigraphic names or geographic names, as recommended by the U.S. Geological Survey Aquifer-Nomenclature Guidelines (U.S. Geological Survey, 1991). The TWDB emailed a survey listing possible aquifer names to groundwater conservation districts in the study area and distributed the survey via TWDB social media (Twitter and Facebook). The name “Cross Timbers Aquifer” was the most popular name (Figure 2-1).

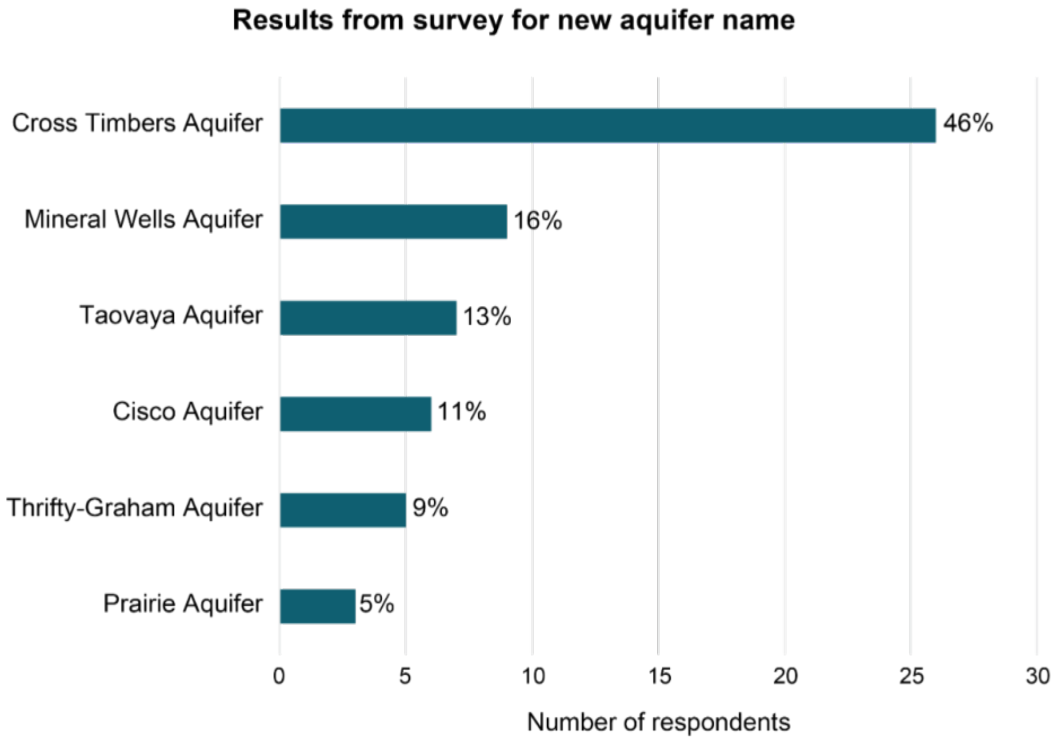

Figure 2-1. Survey results reflecting public input in 2017 on the new aquifer name.

2.2 Major and minor aquifer designations in Texas

An aquifer is a geologic formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs. This definition summarizes the concepts advanced by the U.S. Geological Survey and groundwater scientists (Meinzer, 1923; Theis, 1940; and Lohman and others, 1972).

The TWDB considers several factors to designate an aquifer as a major or minor aquifer. These factors include the land area of the aquifer and the quantity of water supplied by an aquifer. Aquifers are designated after review of relevant hydrogeologic studies and groundwater production data. The TWDB periodically adds a new aquifer or updates aquifer boundaries when new groundwater data become available.

In 1949, the Texas Legislature passed House Bill 162 authorizing the State Board of Water Engineers to designate groundwater basins and subdivisions. In 1961, the TWDB presented the first state water plan, which identified 15 principal aquifers tabulated by river basin. Between 1957 and 1962, the TWDB collaborated on groundwater studies with the U.S. Geological Survey, resulting in the designation of 7 major and 9 minor aquifers in the 1968 State Water Plan. In 1991, the TWDB documented the criteria on how the 9 major and 20 minor aquifer boundaries were updated. These criteria categorized aquifers as major or minor based on the quantity of water supplied by each in 1985 and on their areal extent (Ashworth and Flores, 1991). The TWDB defines a minor aquifer as having large quantities of water in small areas or relatively small quantities of water in large areas (Ashworth and Flores, 1991). Updated aquifer boundaries, which were included in the 1990 State Water Plan, stemmed from newly completed geologic mapping covering the entire state coupled with more recent groundwater studies. Revisions to aquifer maps reflected improved water quality data that resulted in extending the downdip boundaries to 3,000 milligrams per liter of total dissolved solids in most aquifers. The criteria for identifying the downdip limits of aquifer boundaries are variable—for example, the criteria range from 1,000 to more than 3,000 milligrams per liter of total dissolved solids and no limit, such as in the Pecos Valley Aquifer. More recently, in the 2002 State Water Plan, the TWDB designated the Yegua-Jackson Aquifer as a minor aquifer.

3. Study area

The Cross Timbers Aquifer covers nearly 11,800 square miles in north central Texas (Figure 1-1). The outcrop area of the Paleozoic formations of the aquifer extend from the Red River southward to the Colorado River, covering 31 counties: Archer, Baylor, Brown, Callahan, Clay, Coleman, Comanche, Concho, Cooke, Eastland, Erath, Haskell, Hood, Jack, Jones, Lampasas, McCulloch, Mills, Montague, Palo Pinto, Parker, Runnels, San Saba, Shackelford, Stephens, Taylor, Throckmorton, Wichita, Wilbarger, Wise, and Young. Cities with populations greater than 5,000 overlying the aquifer include Wichita Falls, Abilene, Mineral Wells, Breckenridge, Brownwood, and Graham.

The TWDB defined the boundaries of the Cross Timbers Aquifer based on water quality and water level data in the TWDB Groundwater Database. The eastern aquifer boundary generally reflects the mapped formation outcrop boundary. However, there are a few wells in the TWDB Groundwater Database that extend east of the outcrop area without water quality data or water level measurements but that are included within the aquifer boundary. The western edge of the boundary, in the downdip portion of the aquifer, is based on estimated groundwater quality conditions, recognizing that there are few wells and limited water quality data in this area. The current boundary is an estimation of the aquifer extent and may be refined with additional data.

Figure 3-1 shows groundwater conservation districts that overlap the study area and the aquifer boundary. The aquifer boundary extends into the following groundwater conservation districts: Hickory Underground Water Conservation District No. 1, Lipan-Kickapoo Water Conservation District, Middle Trinity Groundwater Conservation District, Rolling Plains Groundwater Conservation District, Saratoga Underground Water Conservation District, Upper Trinity Groundwater Conservation District, and North Texas Groundwater Conservation District. The Cross Timbers Aquifer is in groundwater management areas 6, 7, and 8 (Figure 3-2) and in regional water planning groups B, C, F, G, and K (Figure 3-3).

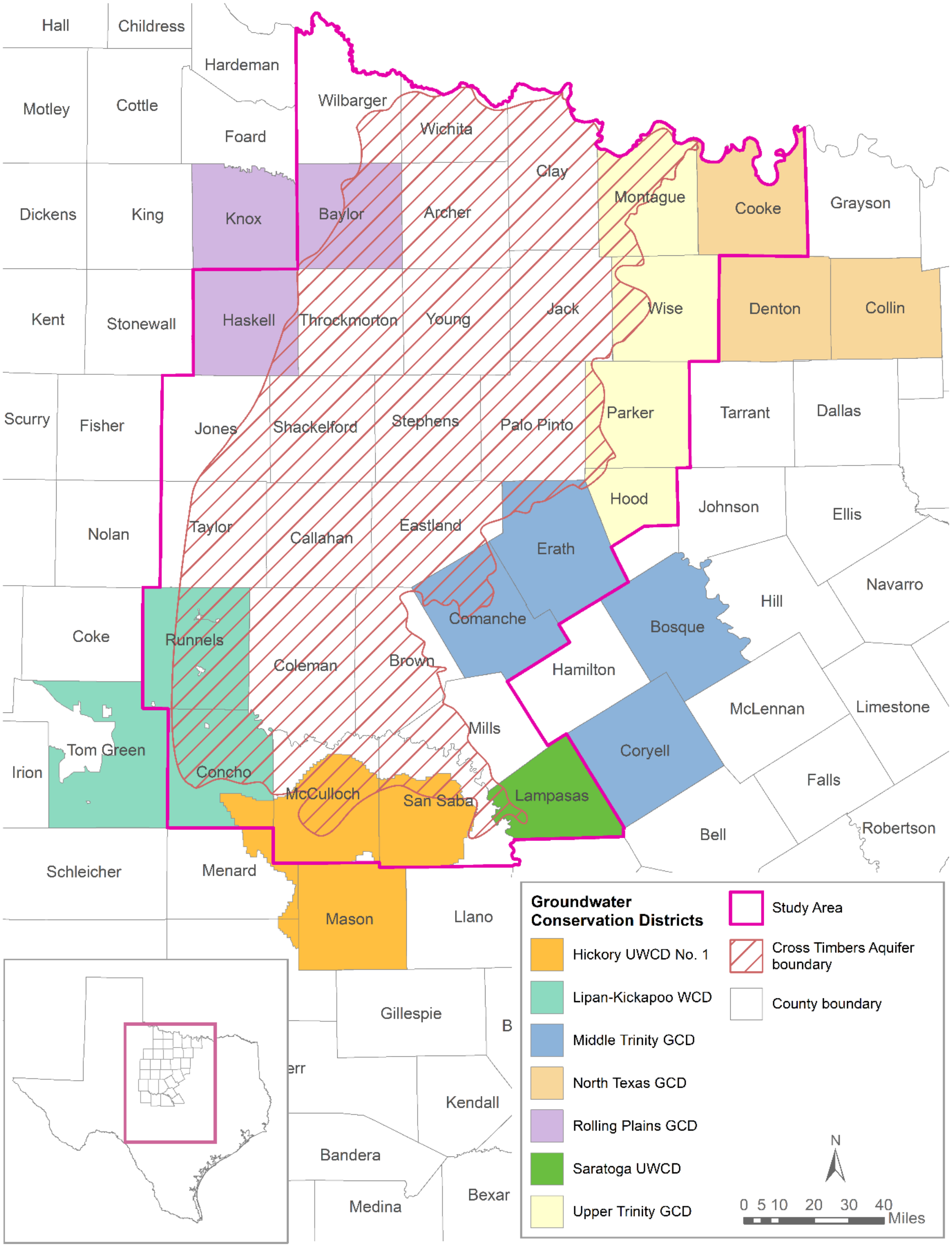

Figure 3-1. Groundwater conservation districts in the study area.

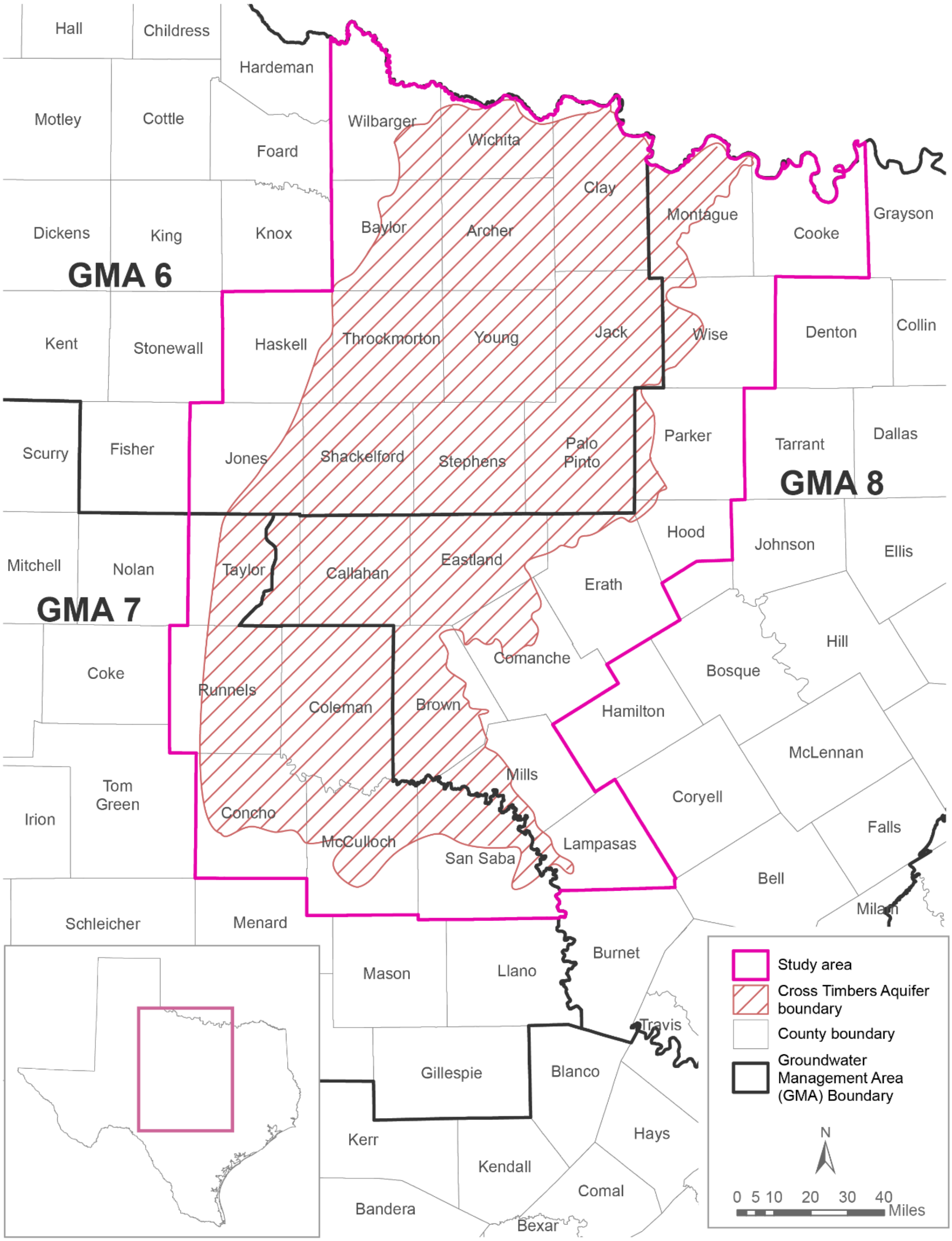

Figure 3-2. Groundwater management areas in the study area.

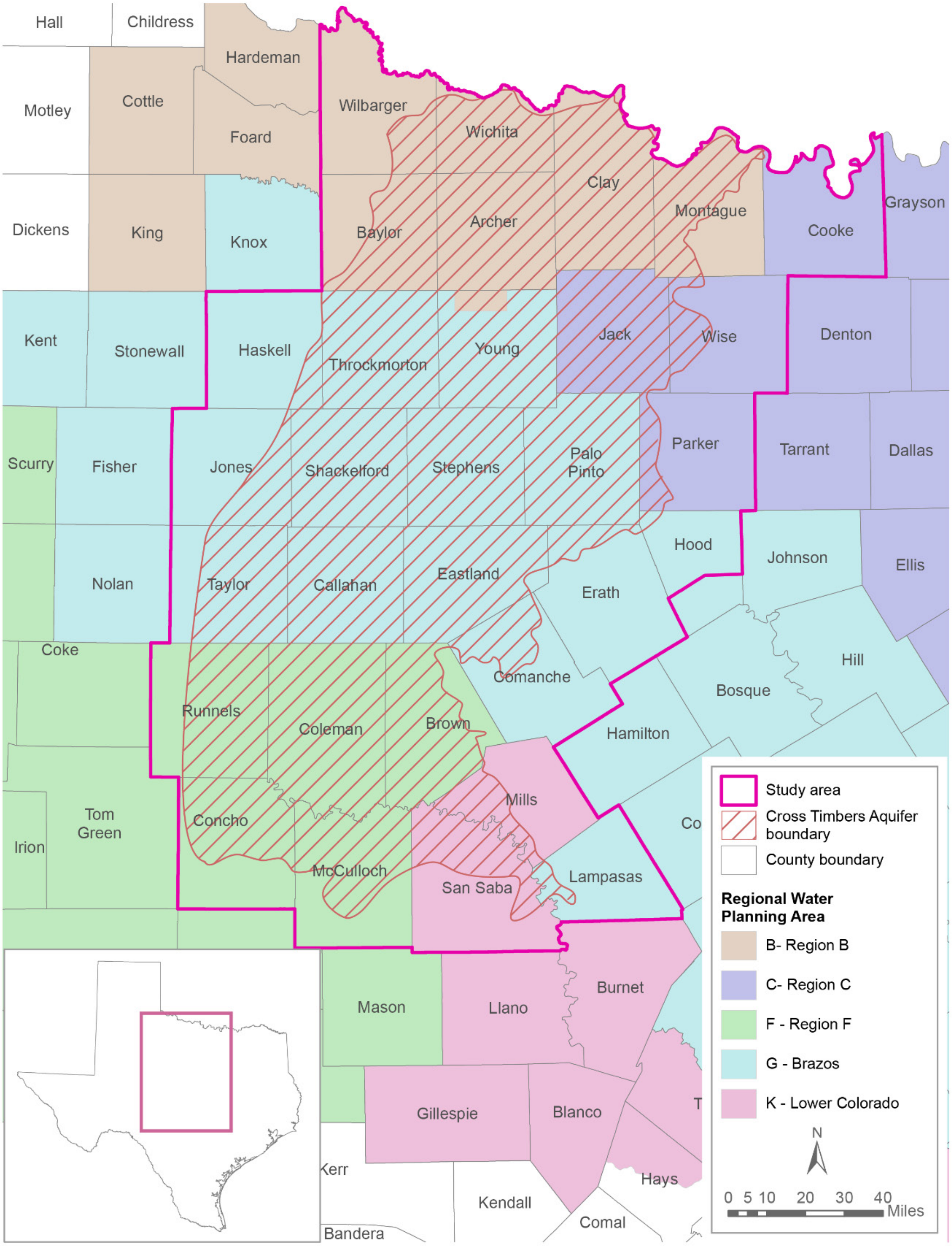

Figure 3-3. Regional water planning areas in the study area.

4. Previous investigations

Investigations of Paleozoic formations in north central Texas began as early as 1845. The initial geologic investigations prompted further inquiries about the water resources and hydrogeology in the region.

4.1 Geology

In December 1845, German-based Mainzer Adelsverein (Society for the Protection of German Immigrants in Texas) sent paleontologist Dr. Ferdinand von Roemer to Texas to develop a report on the natural environment German immigrants could expect to find. The Berlin Academy of Sciences supported this investigation of the geological resources in the area roughly equivalent to the Hill Country and the Llano Uplift (Roemer, 1995). Benjamin Shumard, the Texas State Geologist, published additional details of Paleozoic strata in 1860 and 1861 (Bridge and Girty, 1936). Later, in the 1880s and 1890s, Cummins, Drake, and Tarr performed field work for the Texas Geological Survey to describe the coal seams in the north central Texas area in the Brazos and Colorado valleys. In 1890, Cummins named and described the formations we currently use to describe the Paleozoic rock units in the study area, while Drake subdivided the units further in 1892 (Plummer and Moore, 1921). Beginning in 1901, the U.S. Geological Survey began studying and reporting on the structural and stratigraphic details of the Pennsylvanian formations in the study area and beyond. In 1973, Brown, Cleaves, and Erxleben compiled a guidebook that provides a regional profile of Pennsylvanian-age depositional systems in north Central Texas, summarizing structural interpretations of the Strawn, Canyon, and Cisco groups.

4.2 Hydrogeology

As early as 1913, the U.S. Geological Survey reported on water resources in the Strawn, Canyon, Cisco, and Wichita groups, citing many springs and shallow wells. This study indicated high mineral content in much of the groundwater, with lower mineral content in the shallow groundwater near the outcrop of sandstone beds in the Canyon and Cisco groups (Gordon, 1913).

In 1947, the Texas State Board of Water Engineers reported that the Pennsylvanian and Permian formations were not significant sources of public water supply in the study area, although the cities of Bryson, Jacksboro, Mercury, and Nocona obtained small quantities of water from Pennsylvanian-age sands (Sundstrom, Broadhurst, and Dwyer, 1947). Broadhurst and Follett (1944) reported that the City of Nocona had several wells in Paleozoic formations that yielded small quantities of water that increased in mineral content with increasing depth. The TWDB groundwater database records indicate that the City of Mercury is the only town from the Broadhurst and Follett (1944) report that currently has a public supply well in the Cross Timbers Aquifer.

From the 1960s to the 1980s, the TWDB assessed groundwater occurrence on a county-by-county basis, including the Paleozoic formations and a general inventory of groundwater wells and water quality. Most of these studies indicate that the water-bearing Paleozoic formations have low permeability and intermittent occurrence of groundwater (Bayha, 1964; Morris, 1964; Bayha, 1967; Morris, 1967; Thompson, 1967; Preston, 1969; Preston, 1970; Preston, 1978; Price, 1978; Price, 1979; Price, Walker, and Sieh, 1983; and Nordstrom, 1988).

In 1992, the TWDB evaluated regional groundwater resources in north central Texas (Duffin and Beynon, 1992). The study reported that Paleozoic aquifers commonly serve as a sole source of fresh to moderately saline groundwater, with many wells completed in these formations serving as a primary local water supply.

In 1991 and 1997, the Texas Natural Resources Conservation Commission (now the Texas Commission on Environmental Quality) studied these Paleozoic formations for consideration as a priority groundwater management area. A priority groundwater management area is expected to experience critical groundwater problems within 50 years, such as water shortages, land subsidence resulting from groundwater withdrawal, or groundwater contamination. The studies concluded that although there were some concerns about water quality, the groundwater supplies were sufficient, and the study area should not be designated as a priority groundwater management area (TNRCC, 1999).

In 2011 and 2012, the Bureau of Economic Geology compiled baseline data, developed a conceptual and numerical flow model, and evaluated the feasibility of groundwater production from the Paleozoic formations to address the exploration and production of natural gas in the Barnett Shale (Nicot and others, 2011; Nicot and others, 2012). The flow model suggests that additional groundwater development is possible, though groundwater development proposals would need to be supported by local hydrologic investigations.

In 2013, Nicot and others estimated the hydraulic conductivity and recharge characteristics of the formations in the eastern portion of the Cross Timbers Aquifer. This study indicated that water-bearing formations are primarily sandstones that are spatially discontinuous, but that groundwater can also be found in fractures in limestones. The groundwater flow system is shallow, mostly unconfined, and discontinuous. Groundwater generally discharges to local streams. The median hydraulic conductivity for the four Paleozoic formations was estimated to be about 0.6 feet per day. Recharge from precipitation is estimated to be between 0.05 to 0.15 inches per year, corresponding to 0.3 percent of annual mean precipitation, with an average distributed recharge of 0.1 inches per year (Nicot and others, 2013).

In 2014, INTERA, Inc. recalibrated the groundwater flow model developed by the Bureau of Economic Geology for use by the Upper Trinity Groundwater Conservation District (the District). This recalibrated model included updates to geologic structure, an evaluation of cross-formational flow from the overlying Trinity Aquifer, a reassessment of recharge rates, a reevaluation of hydraulic properties, and an extension of the model area north of the Red River into Oklahoma. The median hydraulic conductivity was recalculated to be 1.3 feet per day in the District and 1.2 feet per day in counties outside of the District (Oliver and Kelley, 2014). This study used a baseflow separation analysis to estimate recharge, resulting in a recharge distribution range of 0.08 to 0.18 inches per year (Oliver and Kelley, 2014). The studies from

2011 to 2014 only include a portion of the northern part of the study area delineated in this report.

5. Geologic and hydrogeologic setting

This section combines the information presented in previous investigations with data from the TWDB Groundwater Database.

5.1 Regional description

The Cross Timbers Aquifer includes, from oldest to youngest, the Strawn, Canyon, Cisco-Bowie (Cisco), and Wichita-Albany (Wichita) groups. The Cross Timbers Aquifer primarily consists of limestones, shales, and sandstones. Figure 5-1 presents the general stratigraphy of the aquifer and summarizes stratigraphic charts from all the documents reviewed for this report. With respect to geologic age, the Strawn Group is Middle Pennsylvanian, the Canyon and Cisco groups are Upper Pennsylvanian, and the Wichita Group is Lower Permian. Figure 5-2 is a generalized geologic map that shows the outcrop extent of the Paleozoic formations from the Geologic Atlas of Texas (BEG, 1972; BEG, 1986; BEG 1987; BEG; 1991).

The geologic history of the region has been thoroughly studied, mostly to help understand the occurrence and distribution of oil and gas deposits in north central Texas. The Paleozoic formations were deposited in various near-shore and off-shore environments in the Fort Worth Basin. These rocks formed as a result of episodes of sediment influx, primarily mudstones and sandstones, from marginal deltas. Deposits interfinger with accumulated limestone that formed during times of reduced sediment influx. The relative thickness and continuity of these sediments were influenced by the rates of erosion from uplifted areas generally to the east and north of the Fort Worth Basin.

Figure 5-3 shows two generalized cross-sections in the study area from Nicot and others (2013). Cross-section (a) transects the middle of the study area from east to west, while cross-section (b) transects only the eastern portion of the study area from north to south. The principal structural features that formed the depositional context of the aquifer include the Fort Worth Basin, the Bend Arch, the Red River Uplift, and the Eastern Midland Shelf (Duffin and Beynon, 1992). The formations generally dip to the west except in the northern portion of the aquifer where formations dip to the north due to the structural features of the Bend Arch and Fort Worth Basin.

The Cross Timbers Aquifer is bordered by the Trinity Aquifer to the east and other Paleozoic formations to the west (Figure 5-4). Portions of the Quaternary-age Seymour Aquifer overlay the Cross Timbers Aquifer in the north and west. The Edwards-Trinity (Plateau) Aquifer and Lipan Aquifer border the southwestern corner of the Cross Timbers Aquifer. The southeastern portion of the Cross Timbers Aquifer overlays the Llano Uplift Aquifer System.

Groundwater in the Cross Timbers Aquifer is mostly unconfined and discontinuous with a shallow flow system. Figure 5-5 shows a composite of contoured groundwater level elevations across the study area from Nicot and others (2013). Groundwater level elevations are highest in the southwestern portion of the area, decreasing toward the northeast. However, this trend is not uniform; there are multiple areas of relatively high or low groundwater elevations that may be attributed to surface topography or groundwater pumping. The dominant groundwater flow direction is along the formation strike direction (rather than downdip) to the north or northeast. Nicot and others (2013) note that groundwater typically becomes brackish with increasing depth.

Recharge rates to the Cross Timbers Aquifer appear to correspond to precipitation rates, with the lowest in the southwestern part of the study area, increasing generally to the east. Nicot and others (2013) estimated recharge as about 0.1 inches per year based on the occurrence of chloride in groundwater. Oliver and Kelley (2014) estimated the recharge distribution to range from 0.08 to 0.18 inches per year. Groundwater from the Cross Timbers Aquifer discharges primarily to surface water, with streams in the region generally quantified as mostly gaining (Nicot and others, 2013).

Era	System	Group	Approximate maximum thickness (feet)	Formation	Rock characteristics	Water-bearing properties
Paleozoic	Permian	Wichita	1,400	Lueders	Thin limestones, sandstone lenses, and shale. Some siltstone and coal beds reported in some areas	small quantities of fresh to slightly saline water
				Clyde		
				Belle Plains		
				Petrolia		
				Admiral		
				Putnam		
				Moran		
				Archer City		
				Pueblo		
	Pennsylvanian	Cisco	1,400	Markley	Lenticular sandstone, thin limestone, shale, siltstone	small quantities of fresh to slightly saline water
				Harpersville		
				Thrifty		
				Graham		
		Canyon	2,000	Home Creek	Sandstone, shale, limestone	small quantities of fresh to slightly saline water
				Colony Creek		
				Ranger		
				Placid		
				Winchell		
				Wolf Mountain		
				Posideon		
				Caddo Creek		
				Brad		
				Graford		
				Palo Pinto		
		Strawn	2,600	Mineral Wells	Shale with interbedded sandstone deposits, thin limestone, shale, and siltstone	small quantities of slightly to moderately saline water
				Brazos River		

Figure 5-1. General stratigraphy of the Cross Timbers Aquifer (modified from Bahya, 1964; Walker, 1967; Preston, 1969; Preston, 1970; Preston, 1978; Nordstrom 1988; Duffin and Beynon, 1992; and UTGCD, 2015).

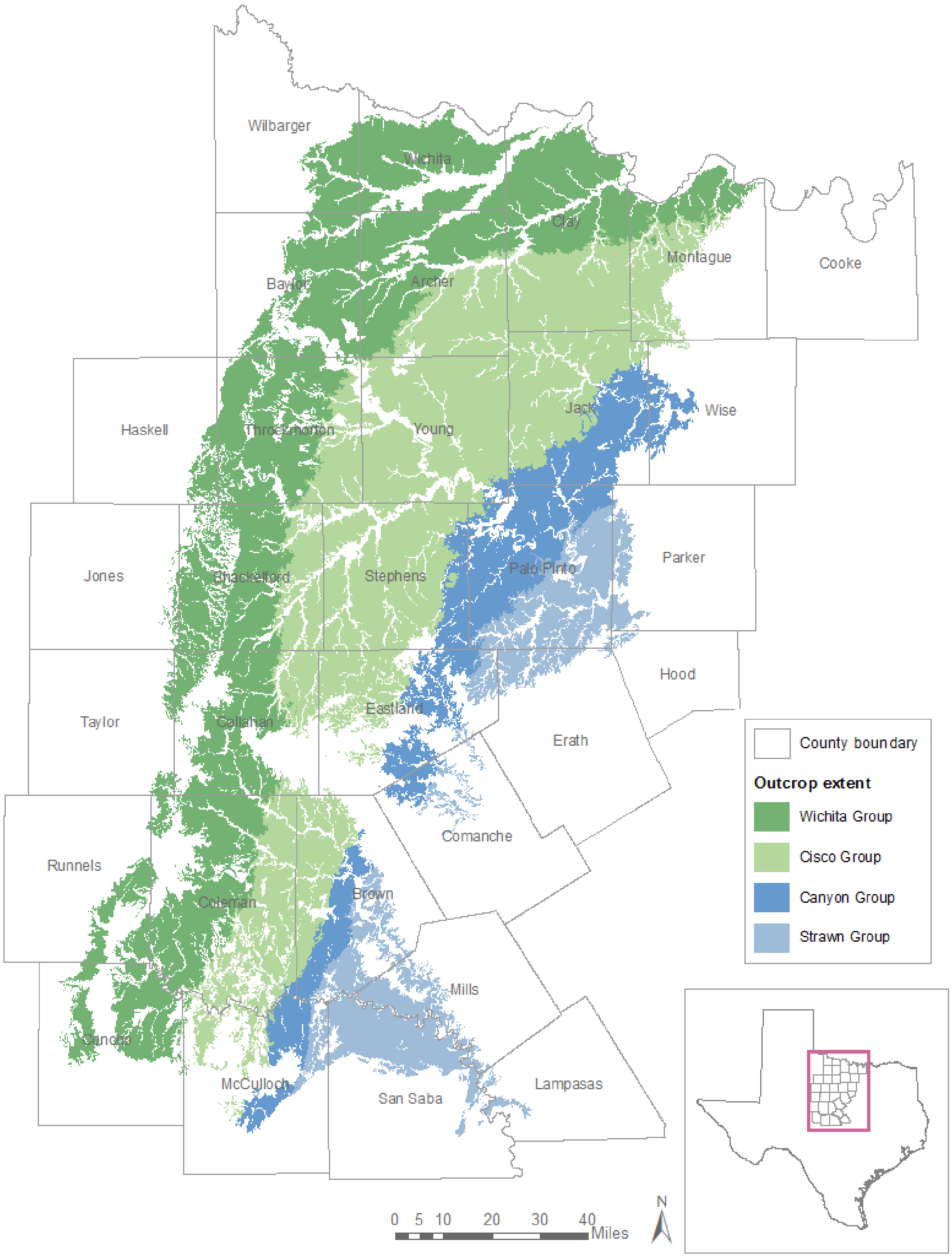

Figure 5-2. Generalized geologic map of the Strawn, Canyon, Cisco, and Wichita groups (data from BEG, 1972; BEG, 1986; BEG 1987; and BEG, 1991).

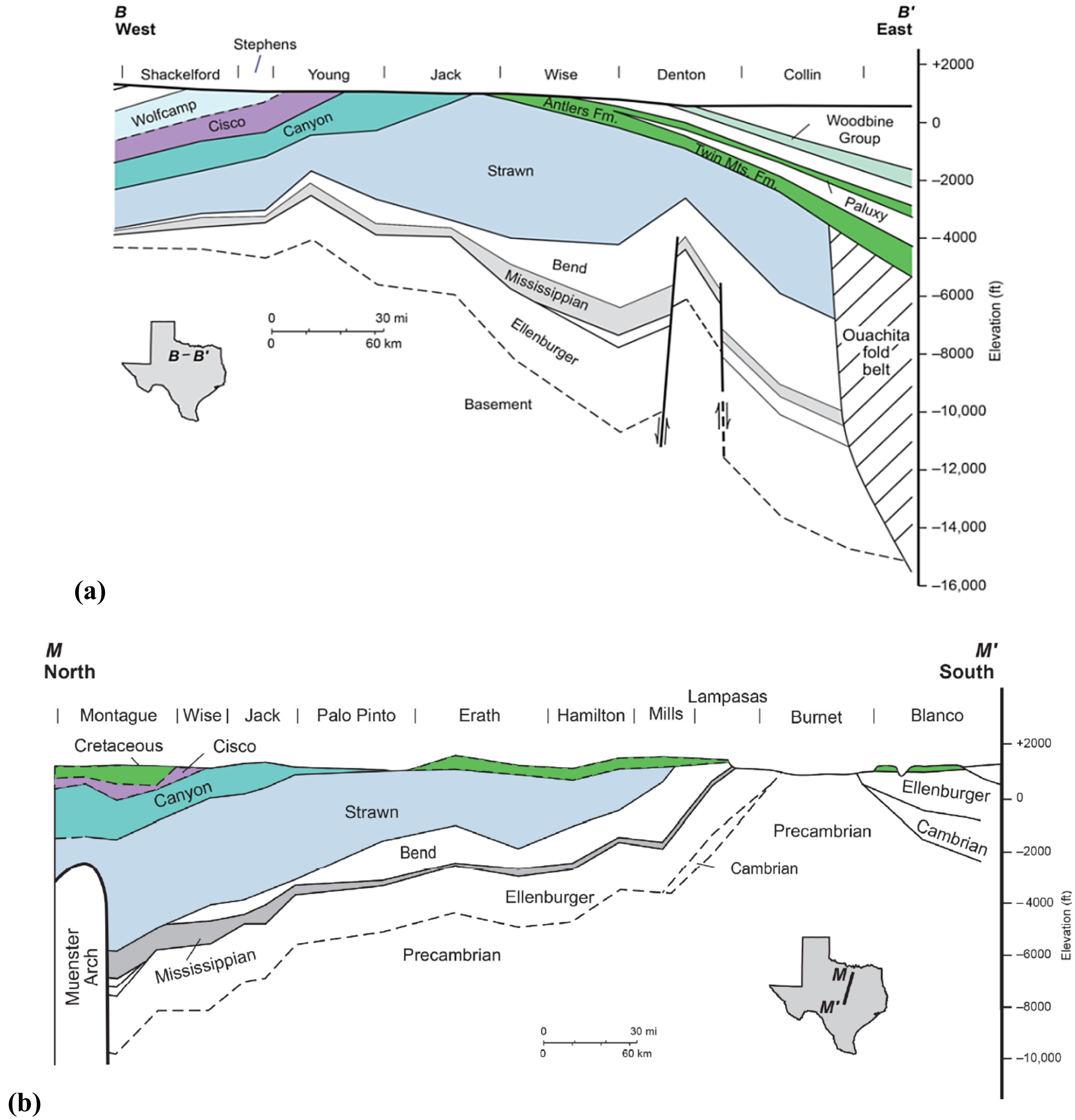

Figure 5-3. **Generalized west to east (a) and north to south (b) cross-sections of the Wichita (labeled as "Wolfcamp" in [a]), Cisco, Canyon, and Strawn group formations (Nicot and others, 2013).**

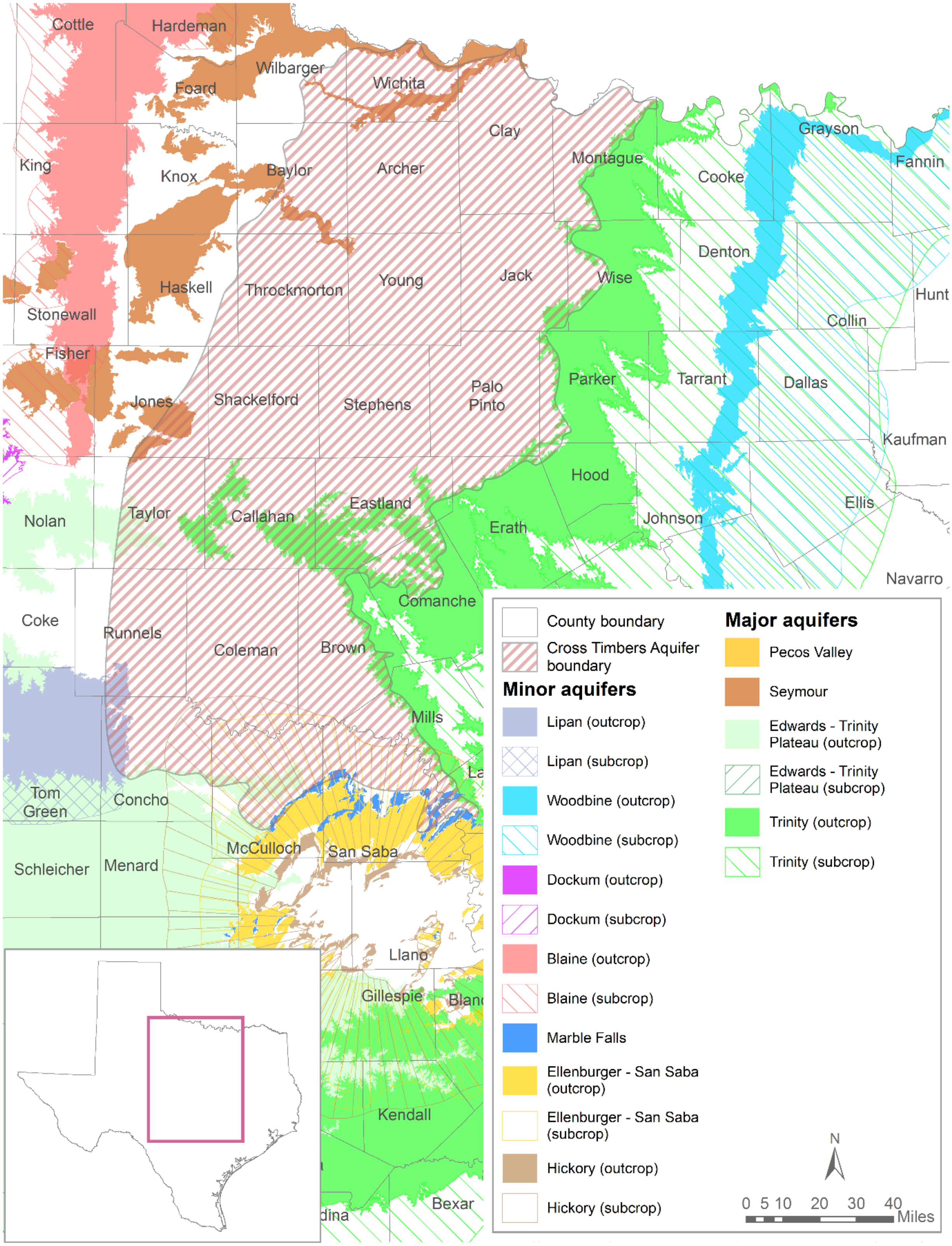

Figure 5-4. **Major and minor aquifers in relation to the Cross Timbers Aquifer.**

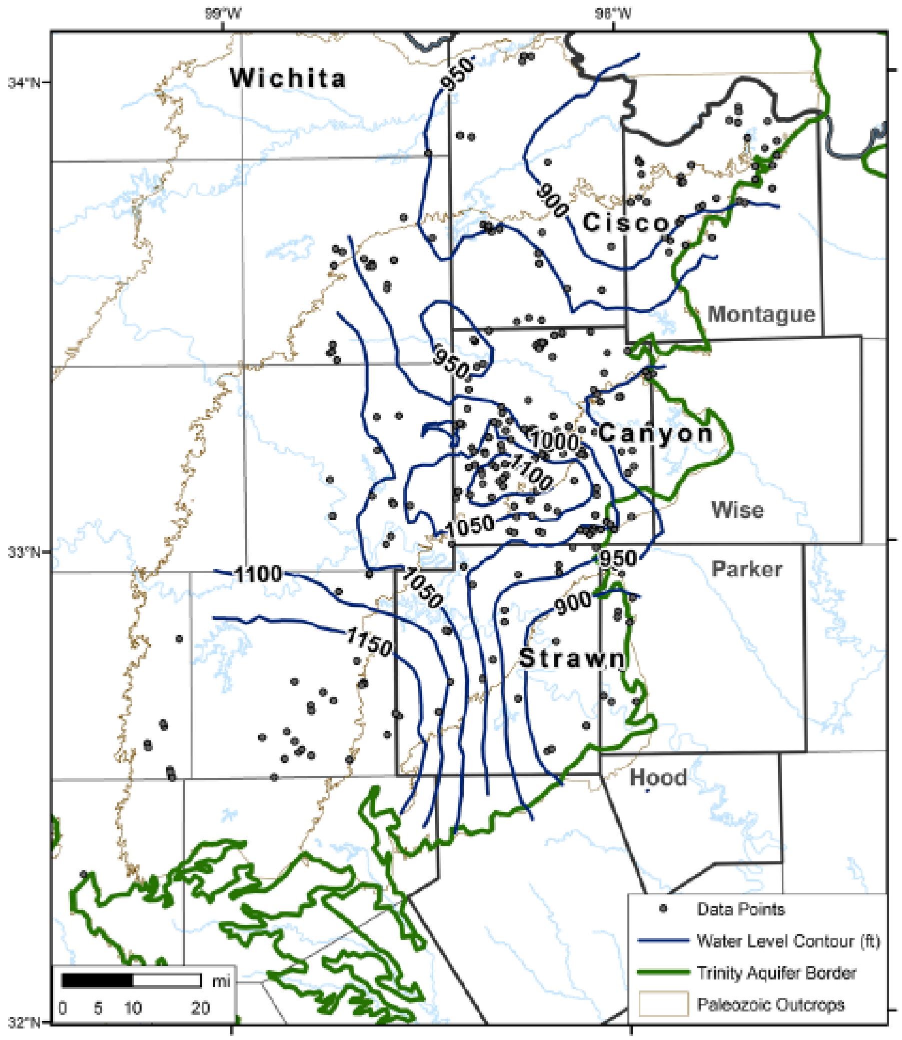

Figure 5-5. **Generalized groundwater-level elevation contours of the northern portion of the Cross Timbers Aquifer (Nicot and others, 2013).**

5.2 Formation descriptions and groundwater conditions

Various TWDB county-level groundwater studies and other investigations associated with the groundwater model development by the Bureau of Economic Geology and INTERA, Inc. have summarized the features of the Paleozoic formations that compose the Cross Timbers Aquifer. The region has a complex stratigraphy such that some previous investigations have used different criteria in assigning geological formations to geological groups. For this study we have assigned formations in this study to groups based on the USGS data standard for the identification of aquifer names and geological units (USGS, 1985). Geologic logs and other data from wells screened in the various geologic units in the TWDB Groundwater Database are coded as lower Permian-Wolfcampian, middle Pennsylvanian, and upper Pennsylvanian. These data are discussed and grouped according to the USGS data standard.

Table 5-1 shows summarized information from the TWDB Groundwater Database for each hydrogeological group in the Cross Timbers Aquifer. Information used in this report does not include wells classified as “Plugged/Destroyed” or “Unused”.

Table 5-1. TWDB Groundwater Database well data in the Cross Timbers Aquifer (excluding wells screened in multiple formations).

Group (age)	Maximum well depth (feet)	Average well depth (feet)	Median well depth (feet)	Range of reported well yields
Strawn (middle Pennsylvanian)	3,180	174	120	1.5 to 189 gallons per minute Most yield less than 45 gallons per minute
Canyon (middle Pennsylvanian)	4,644	193	160	2 to 57 gallons per minute Most yield less than 20 gallons per minute
Cisco (upper Pennsylvanian)	4,250	176	136	2 to 100 gallons per minute Most yield less than 35 gallons per minute
Wichita (lower Permian)	4,800	174	90	1 to 148 gallons per minute Most yield less than 35 gallons per minute

The TWDB, along with cooperators such as groundwater conservation districts and the U.S. Geological Survey, annually measures groundwater levels in groundwater wells in all 254 counties in Texas. Water quality samples are collected statewide within a four-year cycle and, when funding is available, analyzed for major cations and anions along with some isotopes and radionuclides. All data collected are available on the TWDB website at: www.twdb.texas.gov/groundwater/data/gwdbrpt.asp. While there are numerous wells in the Cross Timbers Aquifer, only a handful of these wells have both water level and water quality data. In the following sections, water levels are reported for wells that have seven or more measurements and/or have measurements that reflect a broad time period.

5.2.1 Strawn Group

The Strawn Group is the oldest of the Cross Timbers Aquifer and crops out in a northeastward-trending belt in parts of Parker, Palo Pinto, Eastland, and Erath counties. The Strawn Group consists of approximately 3,000 feet of shale, limestone, and sandstone, with conglomerate and thin beds of coal. These beds dip generally northwest at about 75 feet per mile. Water-bearing units consist primarily of sandstone and conglomerate, which receive recharge by precipitation in the outcrop area. The Brazos River Conglomerate Member of the Garner Formation (Table 5-2) is the source of the famous Mineral Wells “crazy water” that is sold commercially. Nicot and others (2013) suggest cross-formational flow may be occurring between the overlying Trinity

Aquifer and the Strawn Group based on lower salinity in the Strawn Group compared to other groups of the Cross Timbers Aquifer.

Table 5-10 lists the Strawn Group formations and the number of completed wells listed in the TWDB Groundwater Database. Well depths range from 6 to 3,180 feet with an average depth of 174 feet and a median depth of 120 feet. Reported well yields range from 1.5 to 189 gallons per minute but are typically less than 45 gallons per minute. Hydrographs of two wells in the Strawn Group with long monitoring records are listed in Table 5-3 and shown in Figure 5-6. These hydrographs show stable water level trends with some variability over the monitoring period.

Table 5-2 Strawn Group wells in the TWDB groundwater database.

Aquifer code	Aquifer name	Number of wells
324BZRVL	Brazos River Conglomerate Member, Lower Part of Garner Formation	3
324BZRVU	Brazos River Conglomerate Member, Upper Part of Garner Formation	5
324MLWL	Mineral Wells Formation	43
324MWBR	Mineral Wells and Brazos River Formations	2
324STRN	Strawn Group	154
320PSLV	Pennsylvanian System (Canyon/Strawn)	2
218TWMW	Twin Mountains and Mineral Wells Formations	1

Table 5-3 Water level ranges for selected wells (Figure 5-6) in the Strawn Group.

Group	State Well Number	Water level range	Years recorded
Strawn	3131502	3 to 8	1978 through 1993
Strawn	3151907	42 to 48	1971 through 1995

Note: Water level ranges are in feet below land surface.

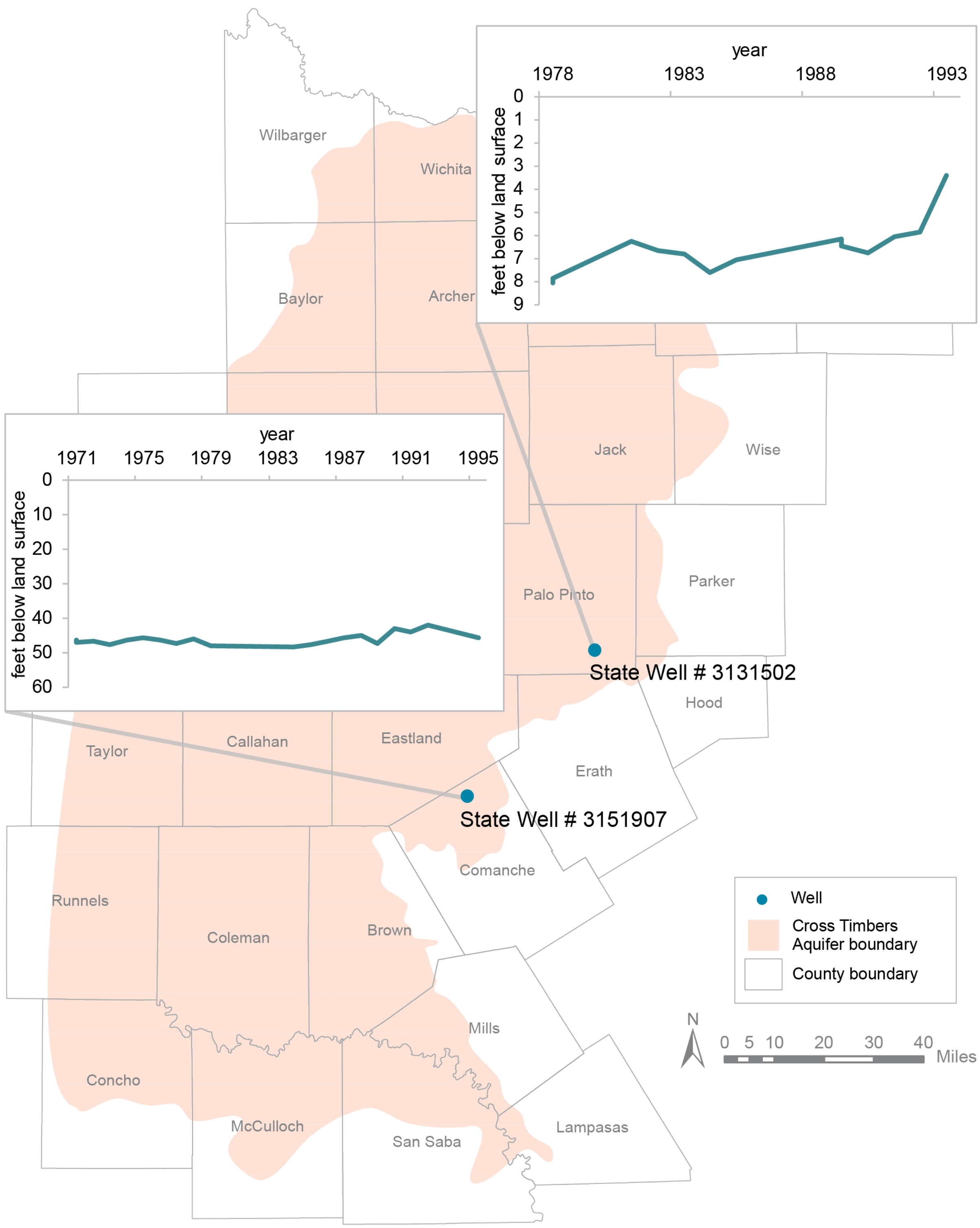

Figure 5-6 Hydrographs of selected wells in the Strawn Group.

5.2.2 *Canyon Group*

The Canyon Group crops out west of the Strawn Group in a northeastward-trending belt in parts of Comanche, Eastland, Stephens, Palo Pinto, Young, and Jack counties. The Canyon Group rocks consists of about 1,000 feet of massive to thin-bedded limestone, interbedded with shale, thin sandstone, and some conglomerate. The beds dip to the northwest at about 75 feet per mile. Groundwater occurs primarily in fractured limestone, localized sandstone lenses, and in shale in some locations. While the Canyon Group is largely massive limestone, karst features have not generally developed because there is limited surface exposure of the limestone (Nicot and others, 2013).

Table 5-4 shows the Canyon Group formations and the number of completed wells listed in the TWDB Groundwater Database. Well depths in the Canyon Group range from 7 to 4,644 feet with an average depth of 193 and a median depth of 160 feet. Reported well yields show variability within the Canyon Group, ranging from 2 to 57 gallons per minute. Many wells yield less than 20 gallons per minute. Hydrographs of four selected wells with long monitoring records are listed in Table 5-5 and shown in Figure 5-7. These hydrographs show stable water level trends with some variability over the monitoring period.

Table 5-4 Canyon Group wells in the TWDB Groundwater Database.

Aquifer code	Aquifer name	Number of wells
321CCPS	Colony Creek and Placid Shales	8
321CCRP	Colony Creek Shale, Ranger Limestone and Placid Shale	1
321CLCK	Colony Creek Shale	149
321CNYN	Canyon Group	188
321HMCK	Home Creek Limestone	10
321PLCD	Placid Shale	53
321PLPN	Palo Pinto Limestone	49
321PLPT	Palo Pinto Formation	4
321PSWM	Placid Shale and Wolf Mountain Formation	1
321RNGR	Ranger Limestone	1
321WFMP	Wolf Mountain and Posideon Shales	3
321WLFM	Wolf Mountain Shale	24
321WMPP	Wolf Mountain Shale, Posideon Shale and Palo Pinto Limestone	1
321WNCL	Winchell Limestone	5
321CNCS	Canyon and Cisco Groups (Cisco/Canyon)	2
320PSLV	Pennsylvanian System (Canyon/Strawn)	2
218TGHC	Trinity Sand, Graham Formation and Home Creek Limestone (Cisco/Canyon)	3
110AVCY	Alluvium and Canyon Group	2

Table 5-5 Water level ranges for selected wells (Figure 5-7) in the Canyon Group.

Group	State Well Number	Water level range	Years recorded
Canyon	2055221	113 to 146	1981 through 1993
Canyon	2063402	64 to 74	1976 through 1989
Canyon	2064809	32 to 54	1976 through 1993
Canyon	3114202	16 to 22	1974 through 1993

Note: Water level ranges are in feet below land surface.

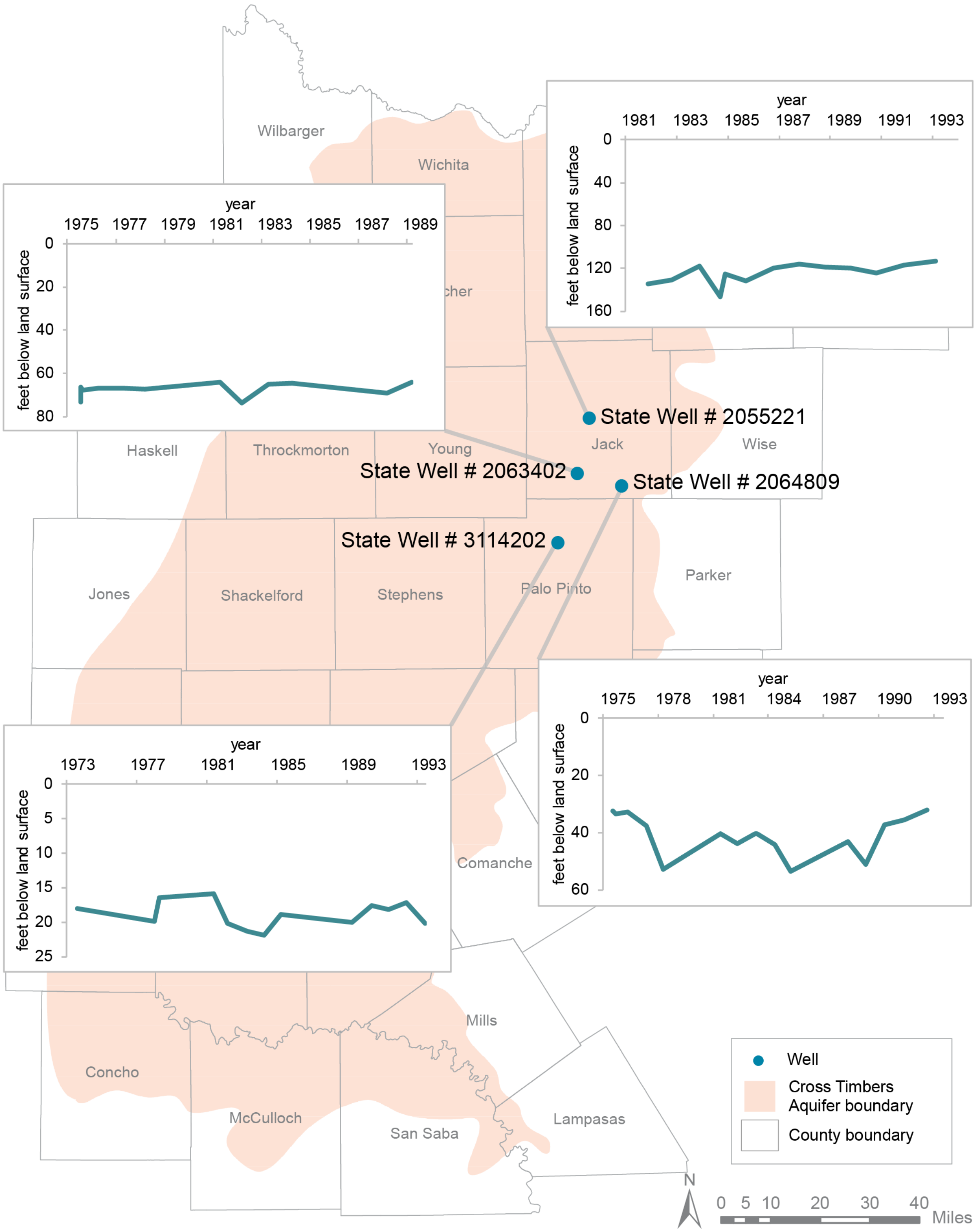

Figure 5-7 **Hydrographs of selected wells in the Canyon Group.**

5.2.3 Cisco Group

The Cisco Group crops out in parts of Callahan, Eastland, Stephens, Shackelford, Throckmorton, Young, Jack, and Archer counties. The rocks form a northeastward-trending belt consisting of approximately 1,200 feet of shale, siltstone, sandstone, limestone, conglomerate, and some coal. In terms of groundwater yield, this group is one of the most productive of the Pennsylvanian rocks due to the occurrence of relatively thick, water-bearing sandstone beds.

Table 5-6 shows the number of completed wells identified as screened in formations of the Cisco Group and listed in the TWDB Groundwater Database. Well depths in the Cisco Group range from 5 to 4,250 feet with an average depth of 176 and a median depth of 136 feet. Reported well yields range from 2 to 100 gallons per minute, with many yielding less than 35 gallons per minute. Hydrographs of eight selected wells that have long monitoring records are listed in Table 5-7 and shown in Figure 5-8. These hydrographs show stable water level trends with some variability over the monitoring period.

Table 5-6 Cisco Group wells in the TWDB Groundwater Database.

Aquifer code	Aquifer name	Number of wells
321CSCO	Cisco Group	597
321GRHM	Graham Formation	227
321HPVL	Harpersville Formation	55
321MARK	Markley Formation	3
321TFGM	Thrifty and Graham formations	13
321TRFT	Thrifty Formation	277
321AVIS	Avis Sandstone	12
321GZCK	Gonzales Creek Member	15
321CNCS	Canyon and Cisco Groups (Cisco/Canyon)	2
318WCCC	Wichita and Cisco Groups (Wichita/Cisco)	11
218TGHC	Trinity Sand, Graham Formation and Home Creek Limestone (Cisco/Canyon)	3
218TRGM	Trinity Sand and Graham Formation	1

Table 5-7 Water level ranges for selected wells (Figure 5-8) in the Cisco Group.

Group	State Well Number	Water level range	Years recorded
Cisco	2038403	51 to 59	1976 through 1993
Cisco	2039506	54 to 65	1976 through 1993
Cisco	2041903	17 to 25	1962 through 1992
Cisco	2054401	72 to 82	1962 through 1989
Cisco	3103804	48 to 54	1982 through 1990
Cisco	3118201	6 to 11	1978 through 1992
Cisco	3125302	7 to 12	1962 through 1990
Cisco	4223101	14 to 25	1964 through 2011

Note: Water level ranges are in feet below land surface.

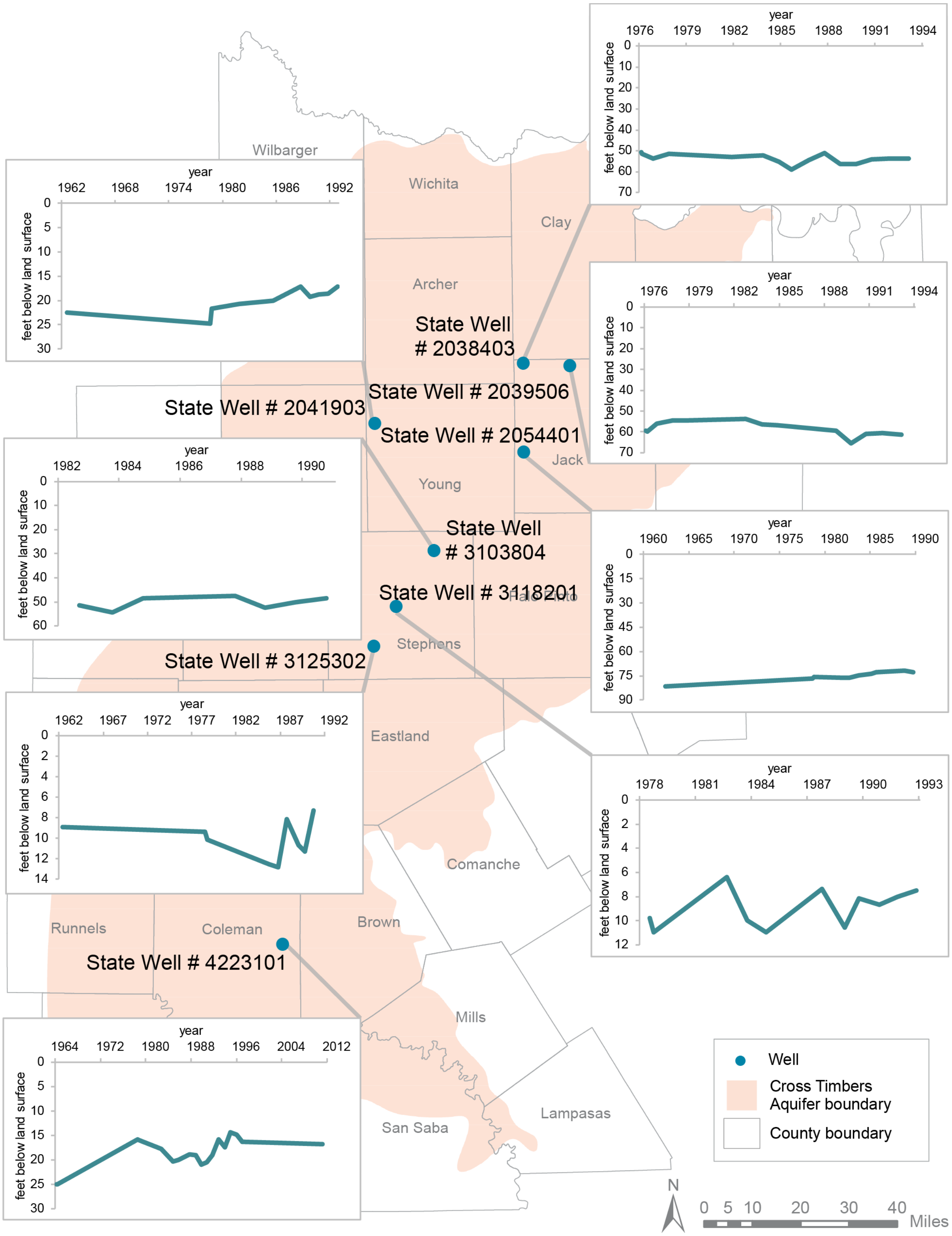

Figure 5-8 Hydrographs of selected wells in the Cisco Group.

5.2.4 *Wichita Group*

The Wichita Group is the youngest of the Cross Timbers Aquifer formations. The Wichita Group rocks were deposited in the Early Permian time and consist of limestone, shale, sandstone, mudstone, conglomerate, and some coal beds. The Wichita Group crops out in a north-south trending belt with a thickness of approximately 1,800 feet. Water-bearing formations include thin beds of limestone and fine-grained sandstone, though there are some massive saturated limestone beds near the top of the group. The Seymour Aquifer may contribute some cross-formational flow to the underlying Clear Fork and Wichita groups, though the amount is likely small due to the low permeability of the rocks in these groups (Ewing and others, 2004).

Table 5-8 shows the Wichita Group formations and the number of completed wells listed in the TWDB Groundwater Database. Well depths in the Wichita Group range from 6 to 4,800 feet with an average depth of 174 feet and a median depth of 90 feet. Reported well yields range from 1 to 148 gallons per minute, with many reported yielding less than 35 gallons per minute. Hydrographs of nine wells that have long monitoring records are listed in Table 5-9 and shown in Figure 5-9. These hydrographs show stable water level trends with some variability over the monitoring period.

Table 5-8 Wichita Group wells coded in the TWDB groundwater database.

Aquifer code	Aquifer name	Number of wells
318ADML	Admiral Formation	1
319ARCT	Archer City Formation	8
318BLPL	Belle Plains Formation	9
319CMJC	Coleman Junction Limestone Member of Putnam Formation	4
318LDRS	Lueders Limestone	98
319MORN	Moran Formation	10
318PTRL	Petrolia Formation	2
319PUBL	Pueblo Formation	58
319PTNM	Putnam Formation	8
318WCCC	Wichita and Cisco Groups (Wichita/Cisco)	11
318WCHT	Wichita Formation or Group	568
319WFMP	Wolfcamp Formation	44

Table 5-9 Water level ranges for selected wells (Figure 5-9) in the Wichita Group.

Group	State Well Number	Water level range	Years recorded
Wichita	2021707	22 to 41	1963 through 2016
Wichita	2145303	12 to 26	1967 through 1992
Wichita	3004702	8 to 11	1967 through 1992
Wichita	3012901	0 to 8	1966 through 1992
Wichita	3021201	13 to 14	1967 through 1989
Wichita	3063401	1 to 15	1964 through 1997
Wichita	4217602	26 to 43	2003 through 2009
Wichita	4228101	39 to 86	1960 through 2011
Wichita	4234601	22 to 54	1974 through 1997

Note: Water level ranges are in feet below land surface.

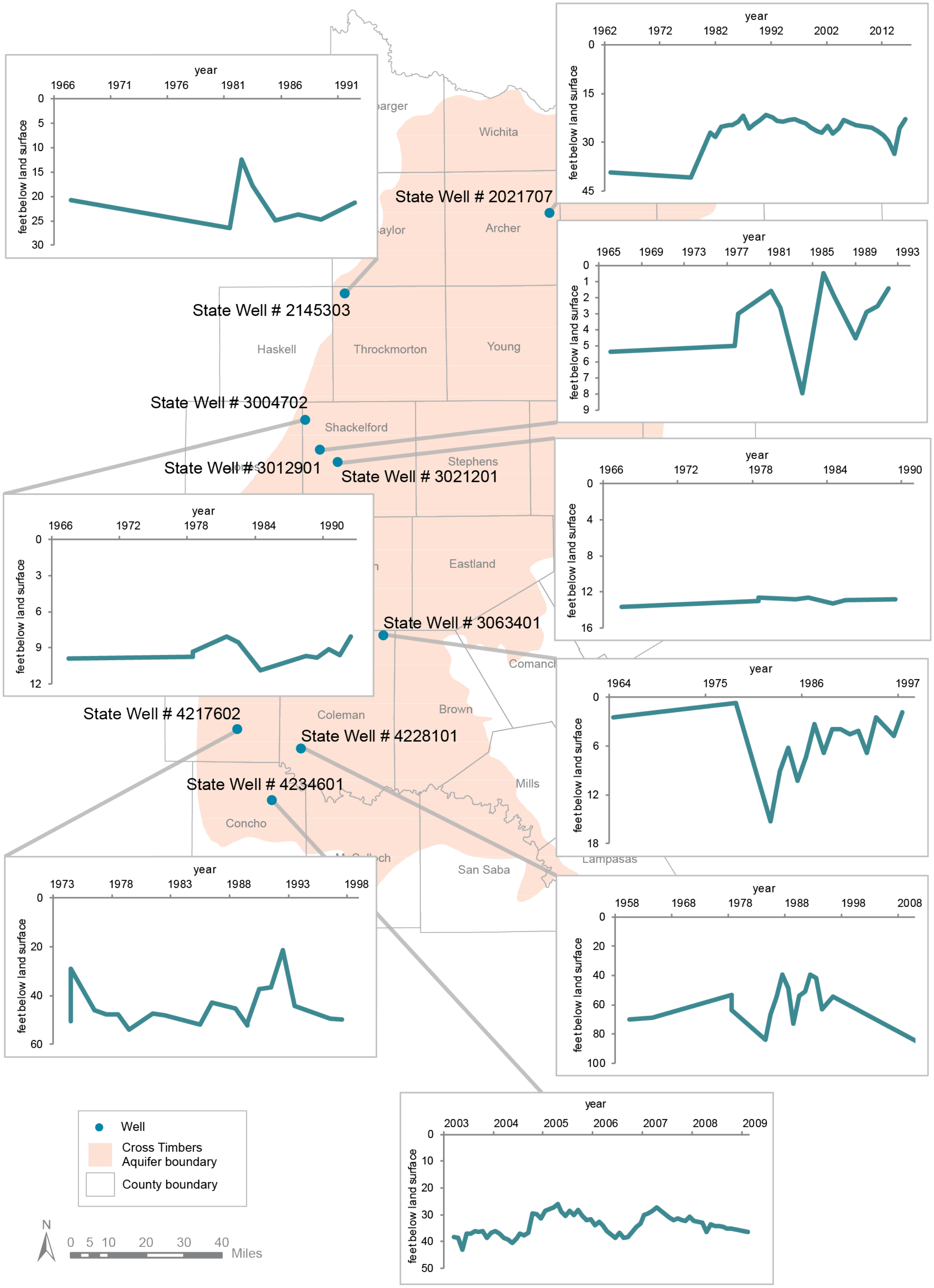

Figure 5-9 **Hydrographs of selected wells in the Wichita Group.**

5.2.5 Unknown aquifer classifications

When an aquifer cannot be determined based on well construction records or driller's logs, wells in the TWDB Groundwater Database are coded as "UNKNOWN". There are 17 "UNKNOWN" wells in the study area in Haskell, Montague, Wilbarger, and San Saba counties. These wells are probably completed in the Cross Timbers Aquifer. Based on location and well depths, the other "UNKNOWN" wells in the study area are probably screened in the Seymour Aquifer.

5.2.6 Springs

Brune (1975) documented three springs originating in the Cross Timbers Aquifer. These springs are:

1. Buffalo Springs in Clay County from the Cisco Group limestone and sandstone (currently reported as dry),
2. Barrel Springs in Montague County from the Wichita Group sandstone (reported to be dry as of 1967), and
3. China Springs in Wichita County from the Wichita Group limestone and sandstone (reported to have a discharge of 0.23 and 0.24 cubic feet per second and slightly brackish water).

Although springflow from shallower aquifers often decreases or ceases due to increased groundwater pumping, these documented springs help in characterizing the nature of the hydrogeologic regime. Brune (2002) also identified and described additional springs based on historical accounts from early Texas settlers, descendants' memories, and archeological evidence. Table 5-10 summarizes available information on the location and characteristics of the 287 historical springs in the study area (spring locations not included).

Table 5-10. Summary of historic, perennial, and existing springflow information in study area by county* (information modified from Brune, 2002; locations of springs not included).

County	Number of springs identified	Field notes
Archer	15	Mostly issuing at the base of the sandstone formations, from Permian sandstones.
Baylor	18	Flow is from primarily the Quaternary Seymour formation, with some small, mostly saline springs issuing from Permian sandstones, the Clear Fork and Wichita formations.
Clay	22	An area used for many thousands of years for water, primarily from Permian sandstones and Quaternary sand terraces along larger rivers. Native tribes such as the Taovayas (Wichitas) irrigated with spring water in this area.
Cooke	17	Flow is primarily from Upper and Lower Cretaceous rocks.
Hood	7	Flow is primarily from the Cretaceous Trinity Glen Rose and Paluxy formations.
Jack	21	Flow is primarily from the Pennsylvanian Cisco and Permian Wolfcampian formations.
Lampasas	12	Flow is primarily from the Pennsylvanian Marble Falls limestone. Native tribes such as the Tonkawas held the springs in great reverence, and prehistoric peoples also made extensive use of the springs.
Parker	20	Flow is primarily from the Cretaceous Trinity Paluxy formation. Native tribes such as the Wichitas used them as home sites, and prehistoric peoples also made extensive use of the springs.
Wichita	16	Flow is primarily from the Quaternary terrace deposits and some Permian sandstones. Native tribes such as the Wichitas used them for agriculture and prehistoric peoples also made extensive use of the springs.
Wilbarger	99	Flow is primarily from the Quaternary terrace deposits, Pliocene Seymour gravels, most very small and not described. Native tribes such as the Wichitas used them for agriculture and prehistoric peoples also made extensive use of the springs.
Wise	16	Flow is primarily from the Cretaceous sands, Antlers and Paluxy formations. Native tribes such as the Wichitas used them for agriculture and prehistoric peoples also made extensive use of the springs.
Young	24	Flow is primarily from the Pennsylvanian Cisco and Permian formations. Native tribes such as the Wichitas used them for agriculture and prehistoric peoples also made extensive use of the springs.

*The following counties in the study area were not addressed in Brune (2002): Brown, Callahan, Coleman, Comanche, Concho, Eastland, Erath, Haskell, Jones, McCulloch, Mills, Montague, Palo Pinto, Runnels, San Saba, Shackelford, Stephens, Taylor, and Throckmorton.

6. Groundwater quality

Groundwater is classified into five salinity classes based on total dissolved solids concentrations: fresh (0 to 999 milligrams per liter), slightly saline (1,000 to 2,999 milligrams per liter, moderately saline (3,000 to 9,999 milligrams per liter), and saline (greater than 10,000 milligrams per liter) (Winslow and Kister, 1956). Slightly saline, moderately saline, and saline groundwater is considered brackish.

Groundwater quality in the Cross Timbers Aquifer ranges from fresh to brackish. The available data indicate that water quality is highly variable within and between individual formations of the aquifer. Groundwater samples analyzed from most wells are fresh or slightly saline, with total dissolved solids concentrations less than 3,000 milligrams per liter. Median water quality samples indicate total dissolved solids concentrations of 839 milligrams per liter. Figure 6-1 shows the number of water quality samples in each group that indicate fresh, slightly saline, moderately saline, or saline water. Sample analyses from all formations in the Cross Timbers Aquifer indicate mostly fresh to slightly saline water quality. The Cisco Group has the most sampled data for total dissolved solids.

Nicot and others (2013) evaluated chloride concentrations in groundwater samples for regional water quality trends and recharge rates. The study revealed that the average chloride concentration in the Cross Timbers Aquifer is twice as much as that in the Trinity Aquifer. Chloride concentrations also increase from the younger to older groups in the Cross Timbers Aquifer, with a slight reversal of the trend in the Strawn Group. Figure 6-2 illustrates the distribution of groundwater samples and the approximate concentrations of chloride in a portion of the study area. Nicot notes that hot spots of high chloride concentrations are likely influenced by surface contamination or halite dissolution. Nicot concluded from the chloride concentrations in the Strawn Group that cross-formational flow may be occurring from the underlying Trinity Aquifer to the Strawn Group in the eastern part of the study area since the average chloride concentration in the Trinity Aquifer os less than the average chloride concentration in the Cross Timbers Aquifer.

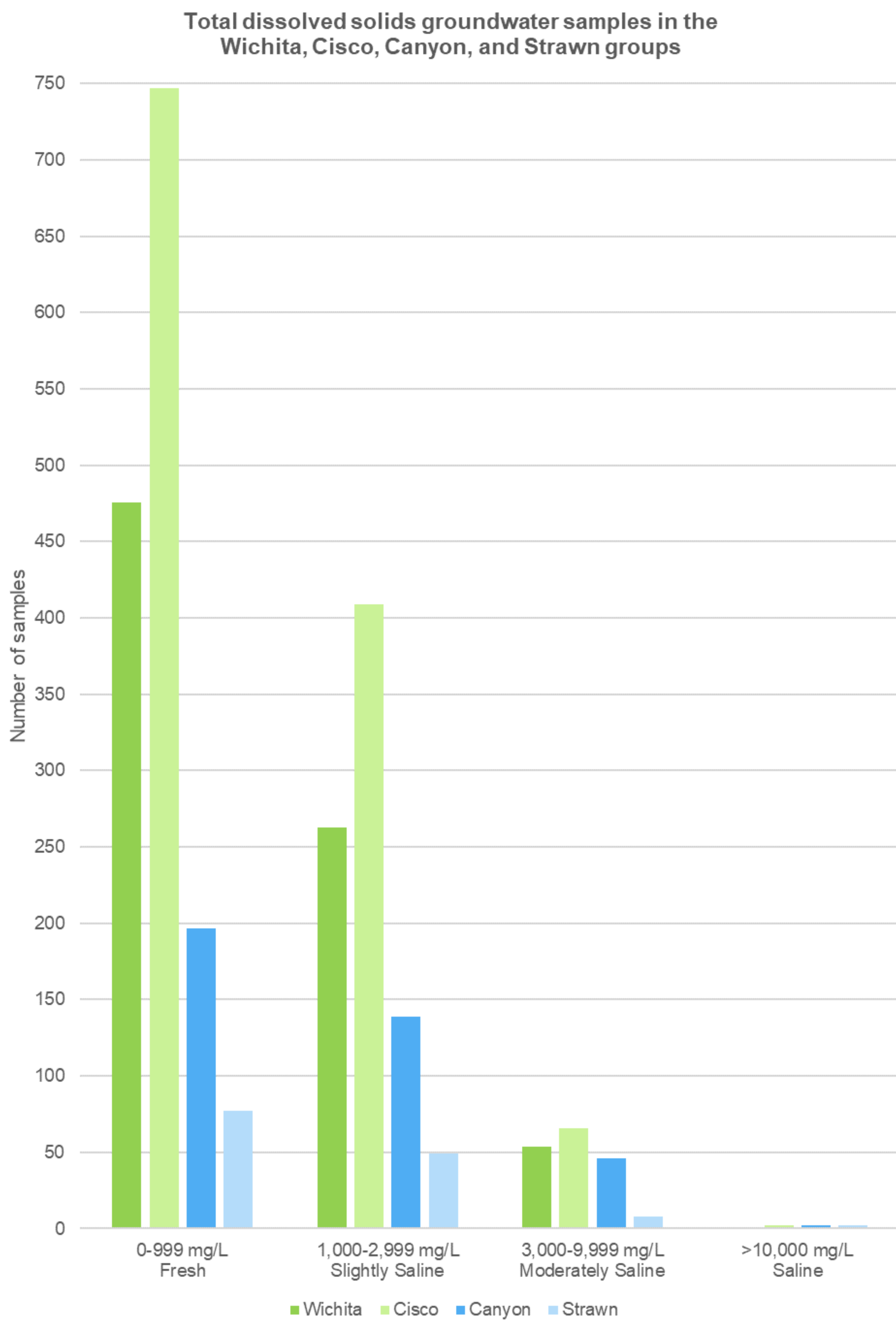

Figure 6-1. **Number of samples of total dissolved solids concentrations from the TWDB Groundwater Database in the Cross Timbers Aquifer.**

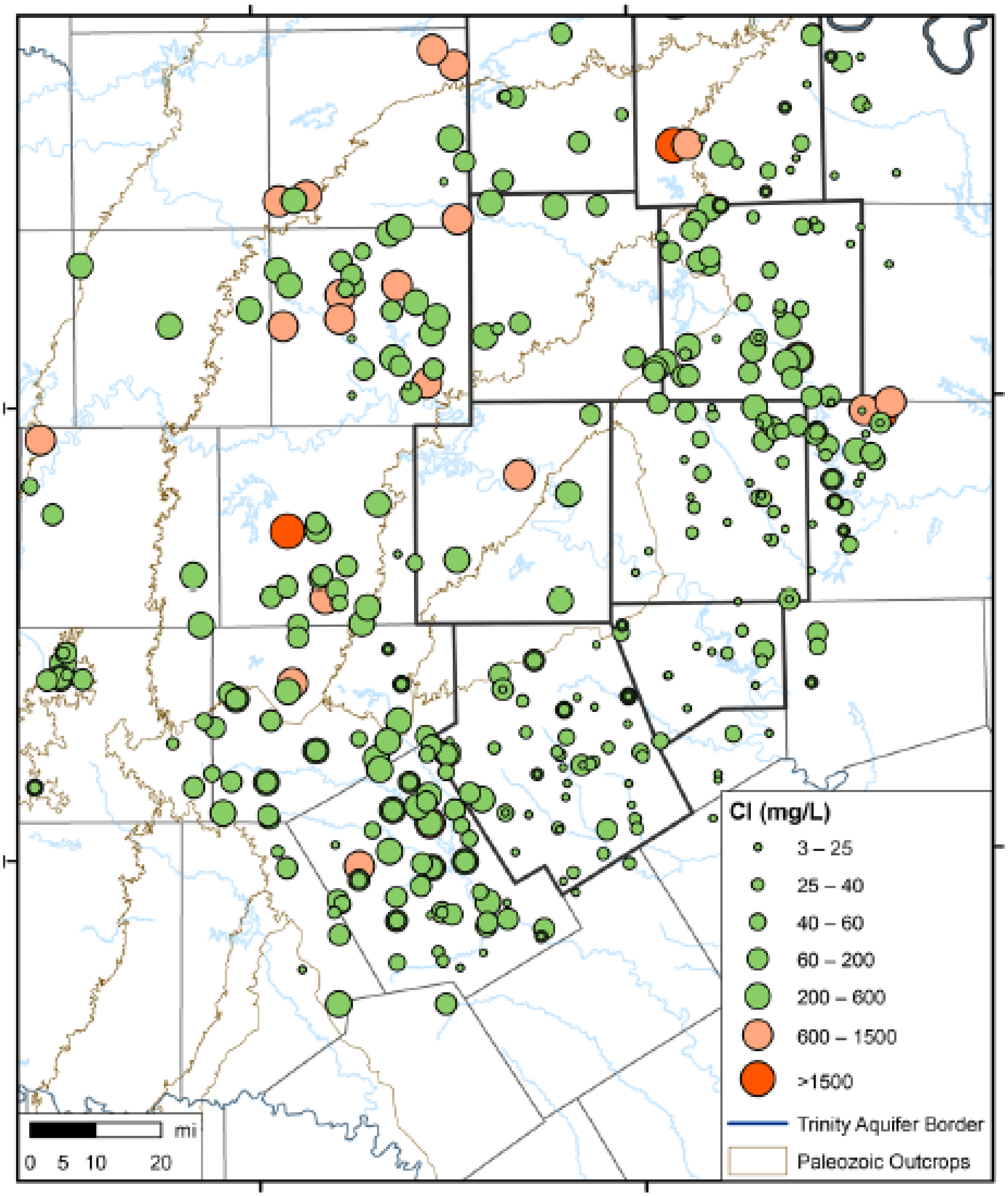

Figure 6-2. Spatial distribution of groundwater chloride concentrations in a portion of the Cross Timbers Aquifer (from Nicot and others, 2013).

7. Groundwater use

The TWDB Groundwater Database has 3,575 wells classified with aquifer codes that indicate the wells are completed in the Wichita, Cisco, Canyon, or Strawn groups. Excluding the unused and plugged or destroyed wells, there are 2,831 wells. Figure 7-1 shows the location of these wells recorded in the TWDB Groundwater Database.

Table 7-1 shows the percentage of Cross Timber Aquifer wells out of all wells in the study area by county. This table also includes the number of wells in which the aquifer is coded as "UNKNOWN". In the counties where the formations outcrop, only 22 percent of all wells (excluding unused and plugged or destroyed wells) are in the Cross Timbers Aquifer. While low as a percentage, the amount is significant because some of the counties have no wells in the Cross Timbers Aquifer, but many wells in other aquifers. If these counties were excluded from the calculation, the percentage would be much higher.

About 70 percent of wells in the study area are domestic, 20 percent are stock, 3 percent are industrial, 2 percent are public supply, 2 percent are irrigation, and the rest are institutional, de-watering, commercial, bottling, and aquaculture (Figure 7-2). The industrial wells generally have a higher well yield. While domestic wells are most common in the Cross Timbers Aquifer, there are 52 public supply wells in the aquifer. Table 7-2 lists public supply wells in the Cross Timbers Aquifer and associated well information from the TWDB Groundwater Database.

Based on data from the TWDB Water Use Survey for counties in the study area, from 2010 to 2016, which included a period of drought in the state, about 43 percent of water use was groundwater. The percentage of use from groundwater increased from about 37 percent in 1984 to 47 percent in 2016, with an average of 38 percent. Figure 7-3 shows total surface water and groundwater use from 1984 to 2016. Groundwater use includes use from all aquifers in the study area.

Groundwater pumpage for local aquifers that are not official TWDB aquifers is reported as "Other Aquifer", which currently includes the Cross Timbers Aquifer and other water-bearing formations. In the study area counties with wells in the Cross Timbers Aquifer, groundwater pumpage from "Other Aquifer" from 1984 to 2016 varied from 9,546 acre-feet (1995) to 25,024 acre-feet (2012), with an average of 14,716 acre-feet (Figure 7-4). Between 2010 and 2016, during which there was a drought in the region, average groundwater pumpage from "Other Aquifer" was 21,346 acre-feet. The lack of specificity and using the general term "Other Aquifer" prevents knowing how much groundwater is pumped from the Cross Timbers Aquifer. Regardless, a significant portion of groundwater pumpage from "Other Aquifer" likely originates from the Cross Timbers Aquifer because it is the primary water-bearing group of formations in the area.

Based on the large number of domestic wells in many counties in the study area, the Cross Timbers Aquifer appears to be an important local water source. Most of the study area includes counties that are not within the jurisdiction of a groundwater conservation district, although there are seven districts in the study area (see Figure 3-1). Five of the districts, the Middle Trinity Groundwater Conservation District, Rolling Plains Groundwater Conservation District, Lipan-Kickapoo Water Conservation District, Hickory Underground Water Conservation District No. 1, and Saratoga Underground Water Conservation District, may manage groundwater withdrawals from the Cross Timbers Aquifer but have not yet labeled them as such. There are no Cross Timbers Aquifer wells in the North Texas Groundwater Conservation District; only a very small portion of the aquifer boundary extends into this district. The Upper Trinity Groundwater Conservation District currently recognizes the Cross Timbers Aquifer as the "Paleozoic" formations and as a usable groundwater source, specifically in the northern and western portions of Montague County, west central Wise County, and western Parker County (UTGCD, 2015).

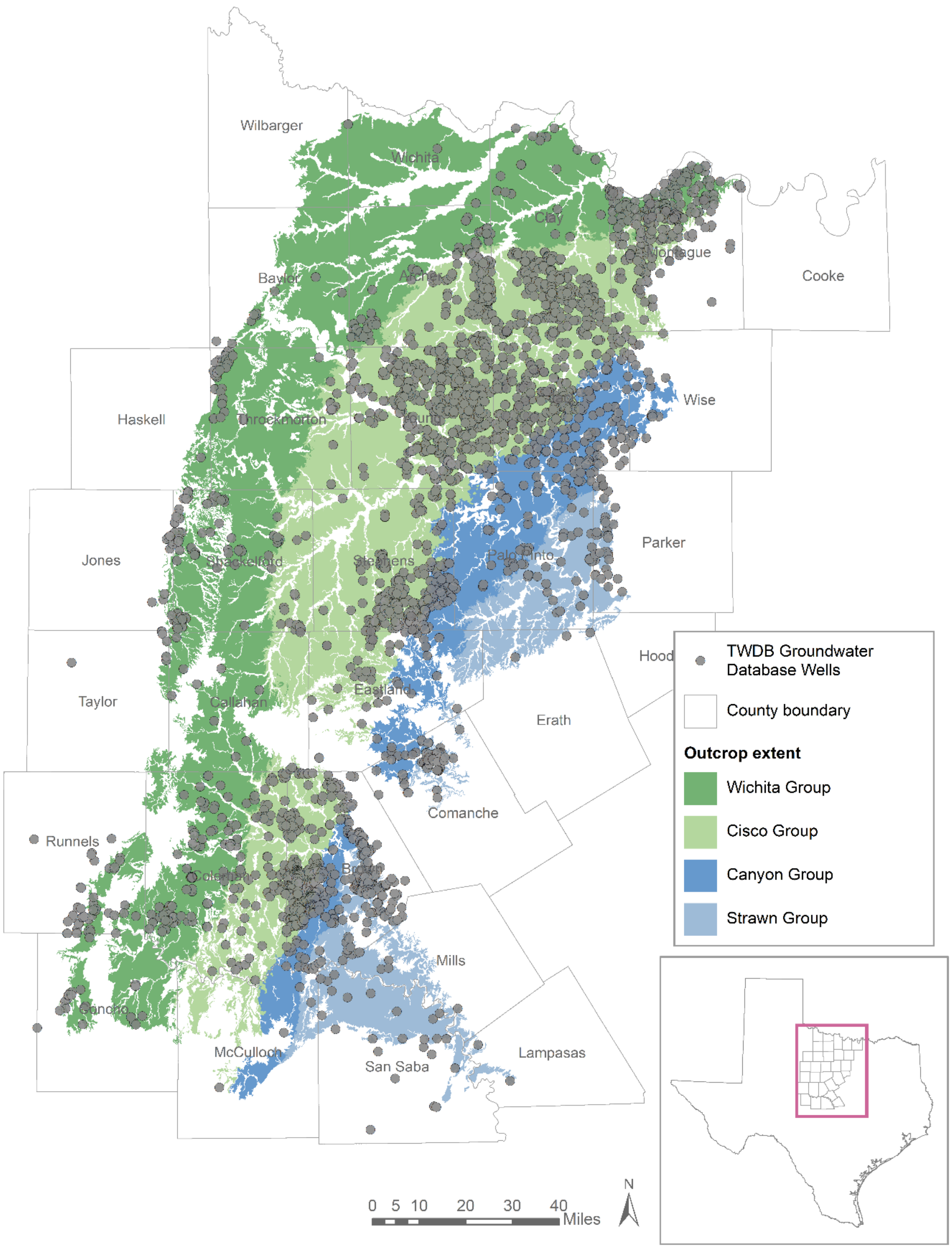

Figure 7-1. **Wells in the TWDB groundwater database completed in the Wichita, Cisco, Canyon, or Strawn groups.**

Table 7-1. Percentage of wells that are known to be completed in the Strawn, Canyon, Cisco, and Wichita groups by county in the study area.*

County	Percent of wells in Cross Timbers Aquifer	Number of wells in Cross Timbers Aquifer	Number of Unknown Wells	Total number of wells
Archer	100	199	0	199
Young	98	406	0	413
Jack	98	363	0	370
Palo Pinto	94	58	0	62
Stephens	90	234	0	261
Clay	83	268	0	323
Shackelford	78	56	0	72
Montague	67	333	2	503
Coleman	45	175	0	490
Throckmorton	43	36	0	83
Brown	29	395	0	1,347
Wise	16	33	0	209
Runnels	14	44	0	315
Comanche	7	72	0	1,025
Concho	7	22	0	306
Parker	6	33	0	570
San Saba	6	12	13	391
Eastland	5	40	0	807
Mills	4	3	0	70
Callahan	3	12	0	425
Baylor	2	6	0	385
Wichita	2	3	0	146
Jones	1	13	0	880
McCulloch	1	4	0	397
Erath	1	3	0	457
Taylor	1	3	0	367
Lampasas	1	2	0	147
Haskell	0.2	1	1	845
Wilbarger	0.1	0	1	748
Cooke	0	0	0	149
Hood	0	0	0	271
Total in study area	**22**	**2,829**	**17**	**13,033**

*This table also includes the number of wells in which the aquifer is coded as “UNKNOWN” but are likely in the Cross Timbers Aquifer, but excludes wells classified as “Plugged/Destroyed” or “Unused”.

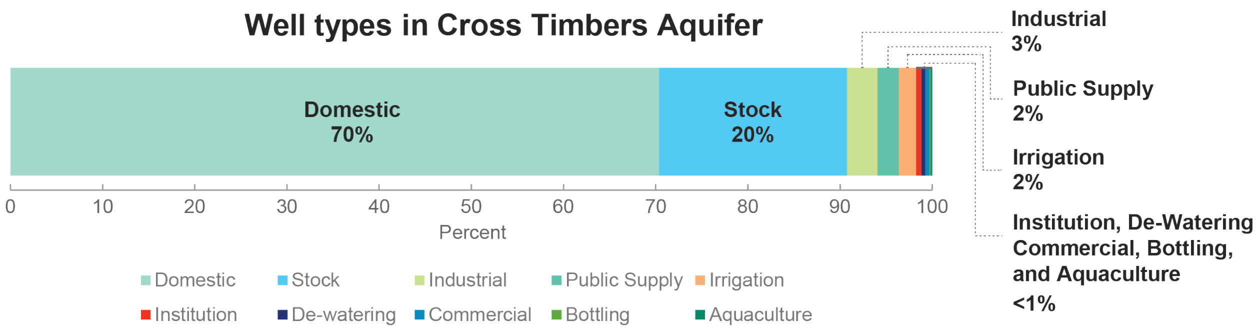

Figure 7-2. Well types distinguished by water use in the Cross Timbers Aquifer.

Table 7-2. Public supply wells in the Cross Timbers Aquifer. *

Owner	County	Remarks about well	Group
City of Mercury	McCulloch	Well D-3 in TBWE B-6017.	Strawn
City of Whitt Well No.1 City of Whitt Well No.2 (2 wells)	Parker	Cemented from 380 ft. to surface. Casing gun-perforated. / Cemented from 380 ft. to surface. Casing perforated. Pump set at 400 ft. Reported yield 15 gpm.	Strawn
Bay Landing (11 wells)	Wise	Owner's #1 well. Reported yield 18 GPM in 1984. Cemented from 0 to 70 feet. Gravel packed from 70 to 147 feet. / Owner's #2 well. Reported yield 18 GPM in 1984. Cemented from 0 to 70 feet. Gravel packed from 70 to 146 feet. / Owner's #3 well. Reported yield 25 GPM in 1984. Cemented from 0 to 40 feet. Gravel packed from 40 to 147 feet. / Owner's #4 well. Reported yield 12 GPM I 1984. Cemented from 0 to 30 fee. Gravel packed from 117 to 147 feet. / Owner's #5 well. Reported yield 20 GPM in 1984. Cemented from 0 to 40 feet. Gravel packed from 107 to 147 feet. / Owner's #6 well. Reported yield 20 GPM in 1984. Cemented from 0 to 40 feet. Gravel packed from 40 to 147 feet. / Owner's #7 well. Reported yield 24 GPM in 1984. Cemented from 0 to 60 feet. Gravel packed from 60 to 147 feet. / Owner's #8 well. Reported yield 12 GPM in 1984. Cemented from 0 to 50 feet. Gravel packed from 50 to 147 feet. / Owner's #9 well. Reported yield 26 GPM in 1984.	Canyon

Owner	County	Remarks about well	Group
		Cemented from 0 to 60 feet. Gravel packed from 60 to 147 feet. / Owner's #10 well. Reported yield 18 GPM. Cemented from 0 to 60 feet. Gravel packed from 60 to 147 feet. / Owner's #11 well. Reported yield 14 GPM in 1984. Cemented from 0 to 60 feet. Gravel packed from 60 to 147 feet. /	
City of Graford	Palo Pinto	Casing gun perforated, interval not reported.	Canyon
City of Perrin (4 wells)	Jack	Old well, reportedly completed from 220 to 230 feet. Well originally flowed. / Old well. Deepened in 1951. Originally flowed. / Well originally flowed. / No remarks	Canyon
Jack County Generating Facility (Well #2) / Jack County Generating Facility (Well #3) (2 wells)	Jack	Gravel packed from 35 to 120 ft. Estimated yield 40 GPM. Pump set at 105 feet. Cemented from 0 to 35 feet. / Reported yield 20 GPM with 55 feet drawdown after pumping 1 hour in 2004. Specific capacity 0.36 GPM/ft. Pumping level 100 feet. Cemented from 0 to 35 feet. Gravel packed from 35 to 120 feet.	Canyon
Lake Brownwood Christian Retreat	Brown	Cemented from 0 to 18 feet.	Canyon
Morton Valley School	Eastland	No remarks	Canyon
Blue Grove WSC Well #2 (West) / Blue Grove WSC Well #3 (Middle) / Blue Grove WSC Well #4 (East) / Blue Grove WSC Well #5 (South) (4 wells)	Clay	Cemented from 0 to 20 feet. / Owners well #3 (Middle). PWS ID #0390014C. Well is gravel packed. / Cemented from 0 to 15 feet. / Reported yield 9 GPM when drilled. Cemented from 0 to 40 feet. Gravel packed from 30 to 150 feet.	Cisco
City of Bellevue Well #1 / City of Bellevue Well #2 (2 wells)	Clay	Reported yield 70 GPM when drilled. Cemented from 0 to 300 feet. Gravel packed from 300 to 412 feet. Replaces well 20-24-901. / Well used on demand.	Cisco
City of Jean	Young	No remarks	Cisco
City of Saint Jo Well No.5 / City of Saint Jo Well No.6	Montague	Cemented from 565 ft. to surface. Gun-perforated. PWS# G1690006E UTGCD #1917 pump reported to be at -447 ft in 2010. / PWS# G1690006F UTGCD# 1918	Cisco
Ft. Belknap Park	Young	No remarks	Cisco
L.A. Berend	Archer	Supplies water for high school. Data from U. S. Geological Survey.	Cisco
Lone Star Gas	Jack	Old oil plugged back and converted to a water well	Cisco
Loving Water-Supply Corp. (2 wells)	Young	Owner's north well. / Owner's south well.	Cisco

Owner	County	Remarks about well	Group
Willie McDonald	Eastland	Reported yield 30 GPM	Cisco/Wichita
Gold-Burg Independent School District / Gold-Burg ISD Well #1 (2 wells)	Montague	Supplies water to school. / UTGCD #2554 reported yield of 80 gpm with 120 ft drawdown after 3hrs PWS# G1690014B	Wichita
Nocona Hills WSC Well No.1 / Nocona Hills WSC Well No.2 / Nocona Hills WSC Well No.3 / Nocona Hills WSC Well #4 (Rivercrest) (4 wells)	Montague	Cemented from 252 to 312 ft. PWS# G1690009A, UTGCD #2832 pump set at 252ft in 2010. / PWS# G1690009B, UTGCD #2833 pump set at 214ft in 2010. / PWS# G1690009C, UTGCD #2834 / Stand-by well.	Wichita
Prairie Valley High School	Montague	No remarks	Wichita
Red River Authority Ringold (Well #1-A)	Montague	Well 1-A. Flowed on 6/2/03. Reported yield 50 GPM with 357 feet drawdown after pumping 38 hours in 2003. Specific capacity 0.14 GPM/ft. PWS ID #1690005C. TR# 21391.	Wichita

*This table includes remarks as noted in the TWDB Groundwater Database.

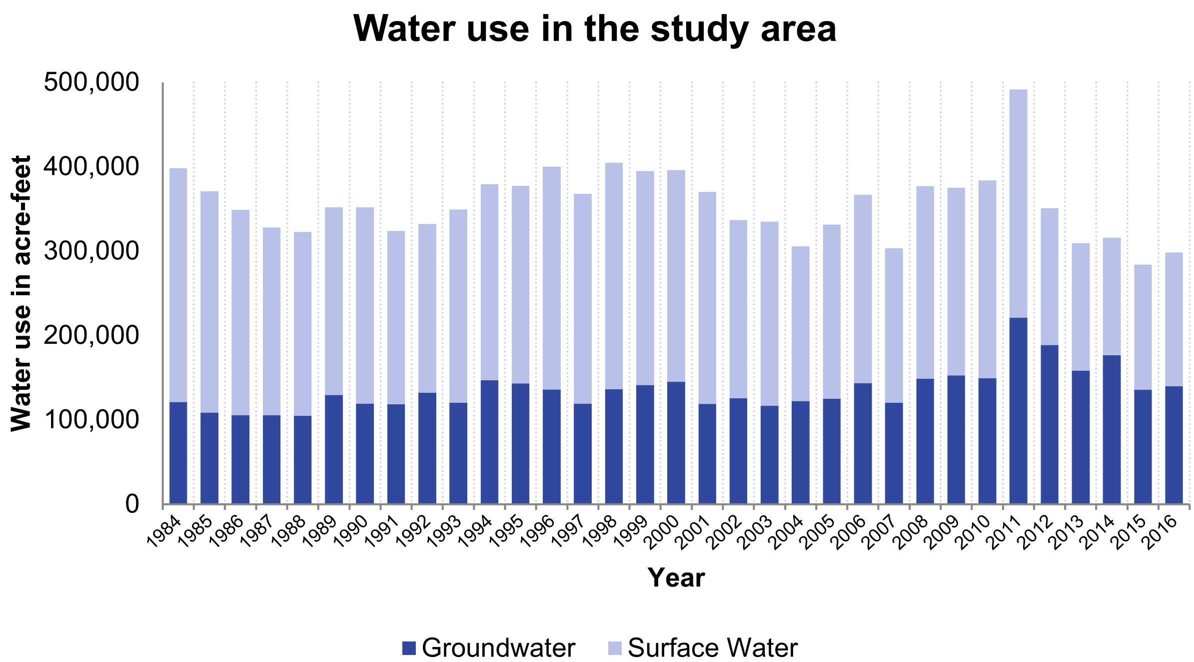

Figure 7-3. **Surface water and groundwater use in the study area from 1984 to 2016. Data from the TWDB Water Use Survey.**

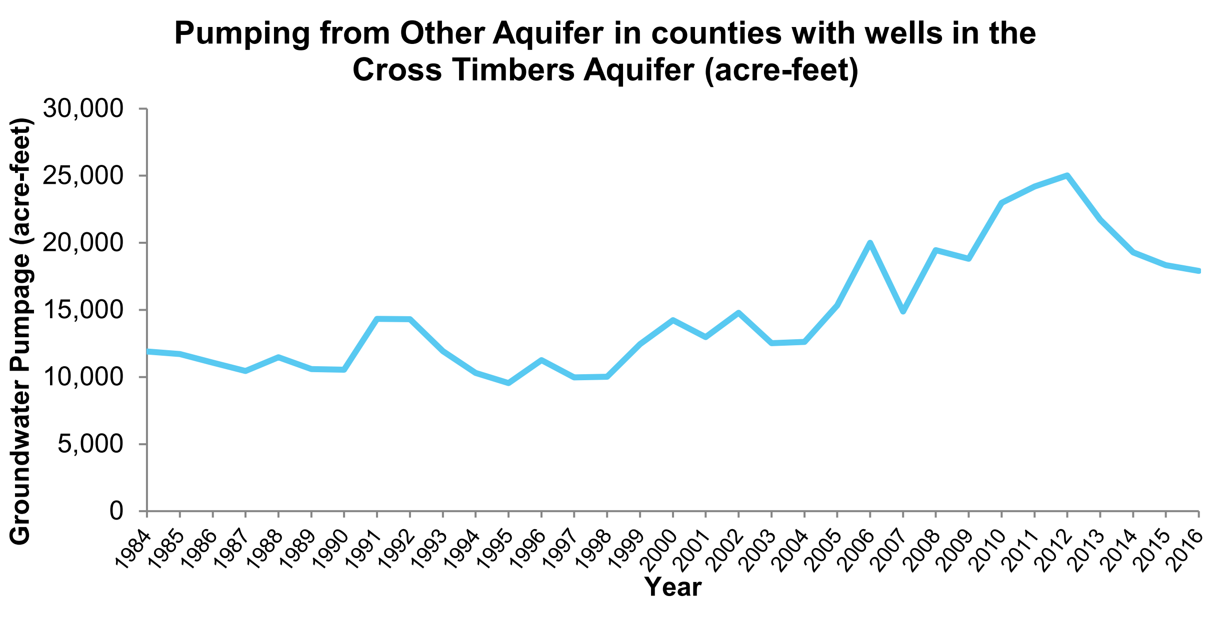

Figure 7-4. **Pumping in acre-feet from "Other Aquifer" in counties with wells in the Cross Timbers Aquifer from 1984 to 2016 (TWDB Water Use Survey).**

7.1 Regional water plans

In the 2016 regional water plans, regional planning groups B, C, F, and G (shown in Figure 3-3) list “Other Aquifer” as an existing supply, and planning groups F and G have developed water management strategies called “Other Aquifer Development” (TWDB, 2016). While the aquifers may not be specifically identified, the fact that “Other Aquifer” is a significant supply and the source of several water management strategies signals the importance of evaluating the formations labeled as “Other Aquifer.”

The 2016 Region B Regional Water Plan states that groundwater in Region B primarily comes from the Seymour and Blaine aquifers but also includes groundwater availability from “Other Aquifer.” Aquifers identified as “Other Aquifer” by the TWDB are locally important water supplies in Archer, Clay, Cottle, Montague, Wichita, and Wilbarger counties, and Region B explicitly groups the Paleozoic units into “Other Aquifer.” Region B determined groundwater availability from “Other Aquifer” based on historical use (Briggs & Matthews, Inc. and others, 2015).

Regions C, F, and G specify “Other Aquifer” as a water supply in counties in the study area, though they do not expressly define this supply as from the Paleozoic formations that compose the Cross Timbers Aquifer. Each of these regions includes groundwater availability from “Other Aquifer” in their regional water plans. Recommended water management strategies in the counties in regions F and G that are also in the study area are primarily to develop “Other Aquifer” for mining use (Freese and Nichols, Inc. and LBG-Guyton Associates, Inc., 2015; HDR Engineering Inc. and Freese and Nichols, Inc., 2015). Region C does not have any recommended water management strategies with “Other Aquifer” as a water source.

8. Comparison to other minor aquifers

The TWDB uses two criteria—areal extent of an aquifer and the amount of water that an aquifer supplies—to designate an aquifer as a major or minor aquifer. Figure 5-4 shows the location and extent of the Cross Timbers Aquifer relative to other major and minor aquifers in the region. The areal extent of the Cross Timbers Aquifer, which covers all or part of 31 counties, is larger than that of most minor aquifers in Texas.

As previously discussed, we consider groundwater pumpage from "Other Aquifer" in counties with wells in the Paleozoic formations to represent pumping from the Cross Timbers Aquifer. This groundwater pumpage averages 22,637 acre-feet from 2010 to 2016, which includes multiple years of drought in the region. By comparison, average pumping amounts reported from other minor aquifers during this period range from 266 acre-feet (Marathon Aquifer) to 137,965 acre-feet (Brazos River Alluvium Aquifer). Figure 8-1 shows this amount compared to average annual pumpage from other minor aquifers from 2010 to 2016. Median annual groundwater pumpage from all minor aquifers during this period is about 18,000 acre-feet. The minor aquifers' surface areas were divided by average pumpage from 2010 to 2015 to compare these two amounts among all aquifers and determine the acre-feet pumped per square mile of aquifer extent (Figure 8-2). Based on these data and comparisons, the groundwater pumpage and areal extent of the Cross Timbers Aquifer fall within the range of other minor aquifers in the state.

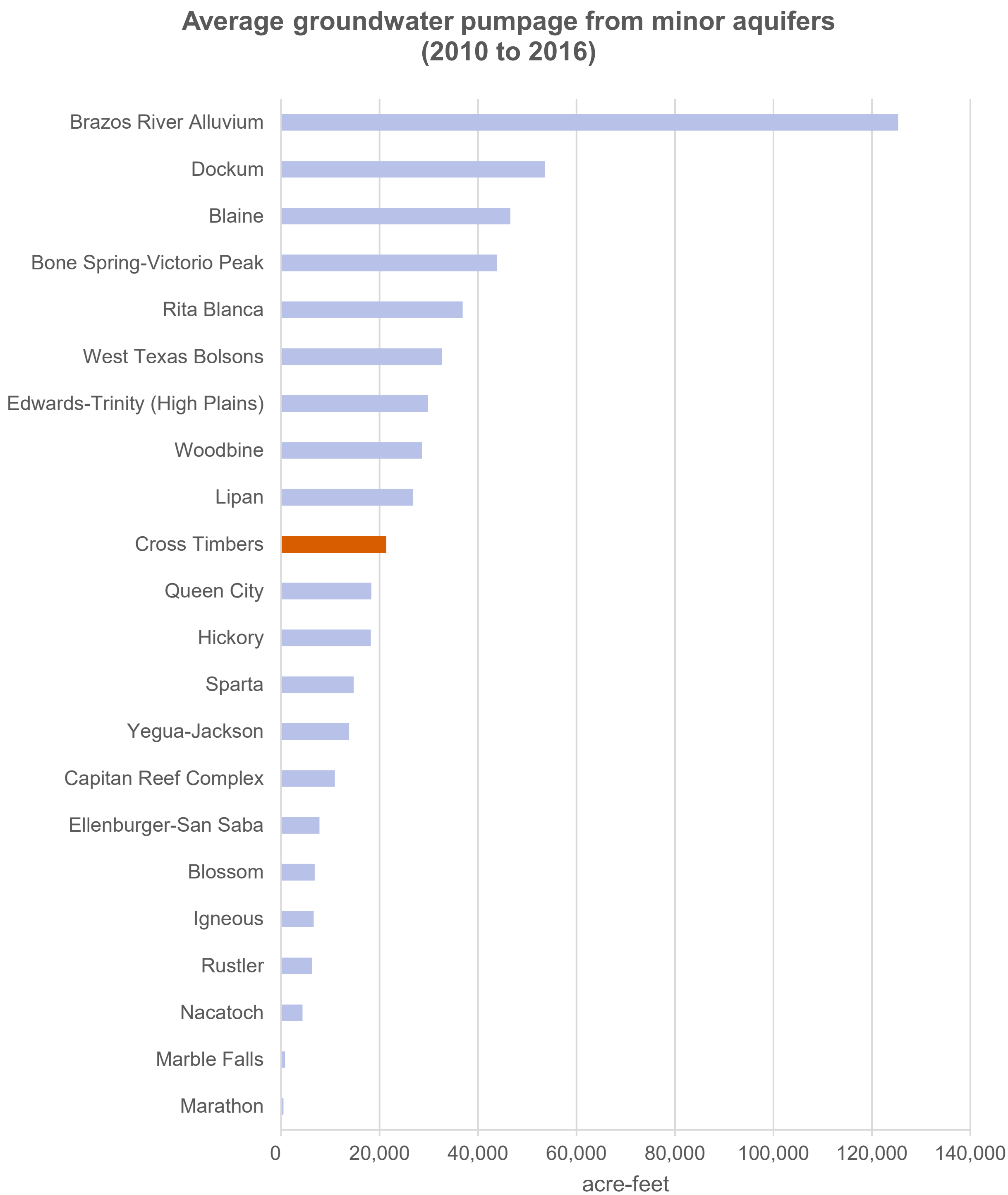

Figure 8-1. Groundwater pumpage from minor aquifers presented as an average from 2010 to 2016). Highlighted in orange is the pumpage from “Other Aquifer” in counties with wells in the Cross Timbers Aquifer.

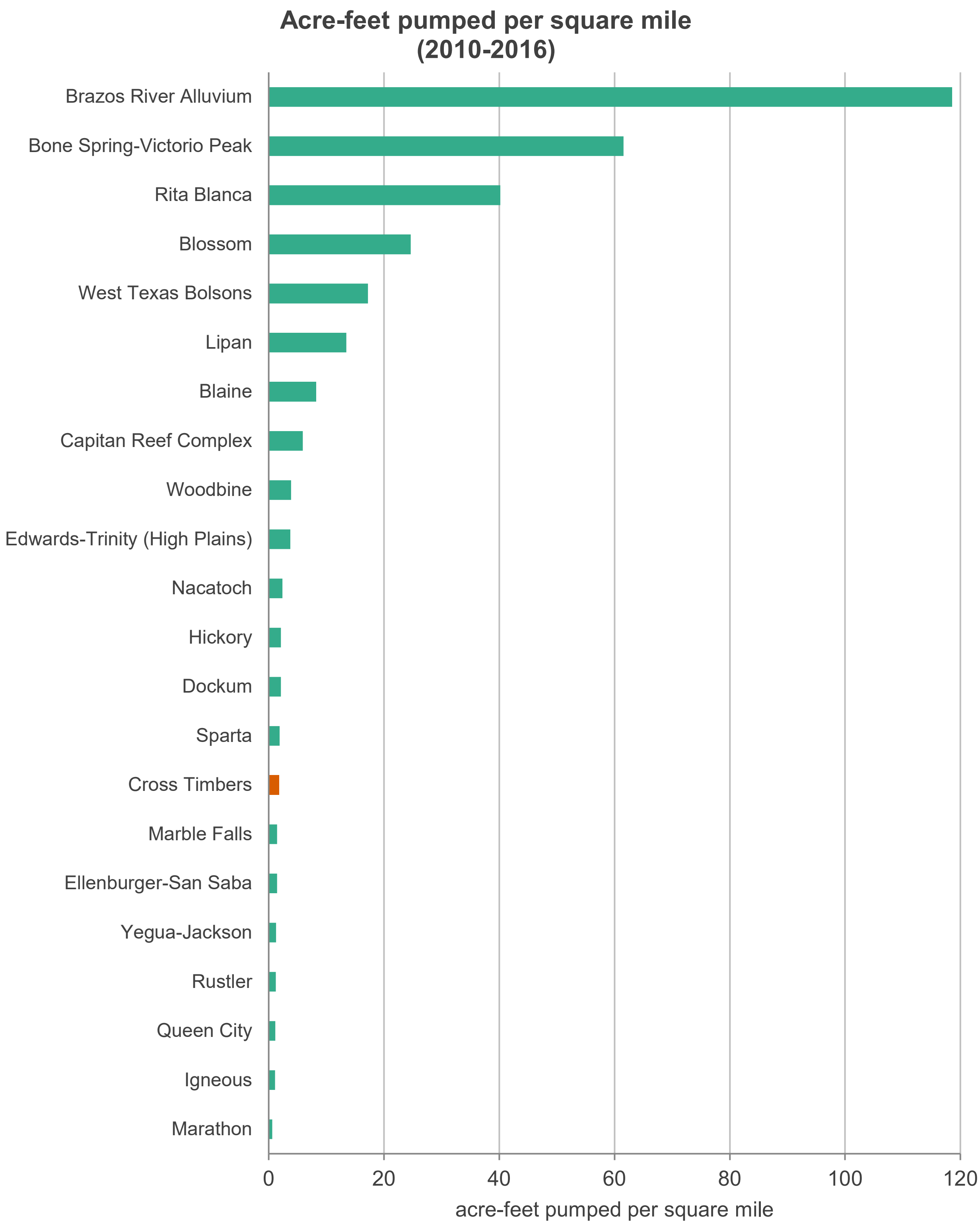

Figure 8-2. **Acre-feet pumped per square mile of aquifer area (outcrop and subsurface). Highlighted in orange is the value from "Other Aquifer" in counties with wells in the Cross Timbers Aquifer.**

9. Conclusions

The Cross Timbers Aquifer includes multiple Paleozoic geological formations that extend across much of north central Texas. Water-bearing units in these formations are primarily sandstone and limestone layers. Yields from water-bearing units vary across the region and the occurrence of groundwater is considered inconsistent in both availability and quality. Documented water levels in the aquifer are generally stable over time, with most water levels within 100 feet below land surface. Water quality is generally fresh to slightly saline. The Cross Timbers Aquifer supplies water primarily for domestic and stock uses, though industrial and public supply wells that also obtain water from these formations.

The original intent of this report was to provide supporting evidence to designate the Paleozoic water-bearing formations in north central Texas as an official minor aquifer. Supporting evidence for such a designation includes an assessment of general hydrogeology and water use from the geologic formations. The Cross Timbers Aquifer was designated as an official minor aquifer in December 2017.

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