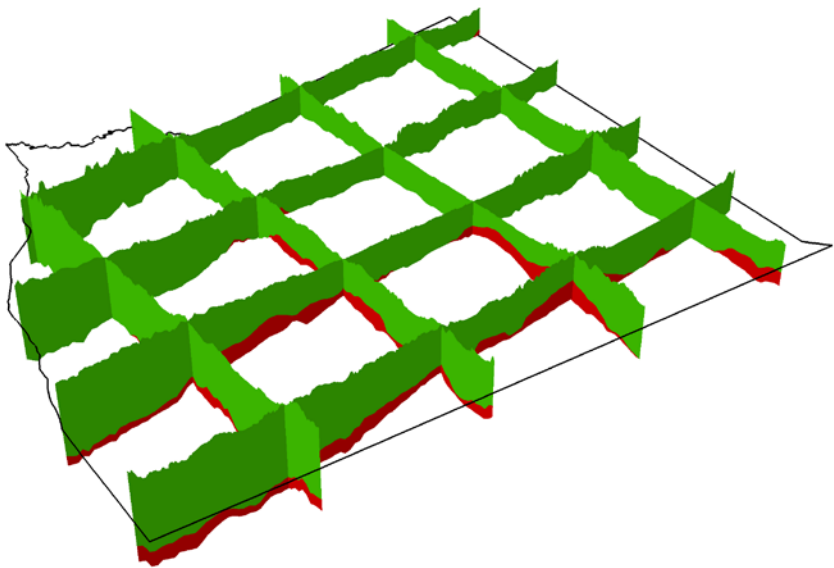


Wilcox Structure, Water Levels, and Water Quality in Panola County Groundwater Conservation District

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Panola County Groundwater Conservation District

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Wilcox Structure, Water Levels, and Water Quality in Panola County Groundwater Conservation District

Introduction

This report was developed for Panola County Groundwater Conservation District (PCGCD) to provide information on the geology and hydrogeology of the groundwater resources in Panola County. PCGCD, which is coextensive with Panola County in East Texas, contains the Carrizo-Wilcox Aquifer, a major aquifer as defined by the Texas Water Development Board (TWDB, 2012). In general, this means that the aquifer is capable of providing relatively large amounts of water over a large area. A minor aquifer, by comparison, is defined as one capable of providing either a small amount of water over a large area or a large amount of water over a small area. TWDB does not recognize any other major or minor aquifers in the district.

There is considerable literature related to the Carrizo-Wilcox Aquifer which the reader can reference including Kaiser (1990), Xue and Galloway (1995), Fryar and others (2003), Kelley and others (2004), George (2009), Deeds and others (2009), Boghici (2009), and George and others (2011). A brief summary of some of the general information relevant to the district is provided as context for the analyses later in the report.

The Carrizo-Wilcox Aquifer, which extends from the Texas-Mexico border along the Rio Grande River in South Texas to the Texas-Louisiana border in East Texas, can vary significantly in character depending on location (Figure 1). It is Eocene in age consisting primarily of unconsolidated sands and clays deposited between 56.5 and 60 million years before the present (George, 2009). In many areas of the state, the Wilcox formation within the aquifer is divided into upper, middle, and lower units. In central Texas these are known as the Hooper, Simsboro, and Calvert Bluff formations, respectively (Deeds and others, 2009). The Middle Wilcox is the primary unit exposed at land surface in Panola County, though some areas are overlain by the Upper Wilcox, Carrizo sand, and younger alluvial deposits along rivers and streams (George, 2009). The presence and extent of the Lower Wilcox unit below the Middle Wilcox is limited, but discussed in more detail in the next section.

As can be seen throughout the district, lignite coal is present in many areas of the Wilcox formation. Lignite is a low-grade coal commonly used for power generation. In the portion of the Wilcox near the surface, the lignite is relatively discontinuous whereas large continuous seams can be found deep at the base of the Wilcox in Panola and Shelby counties (Kaiser, 1990).

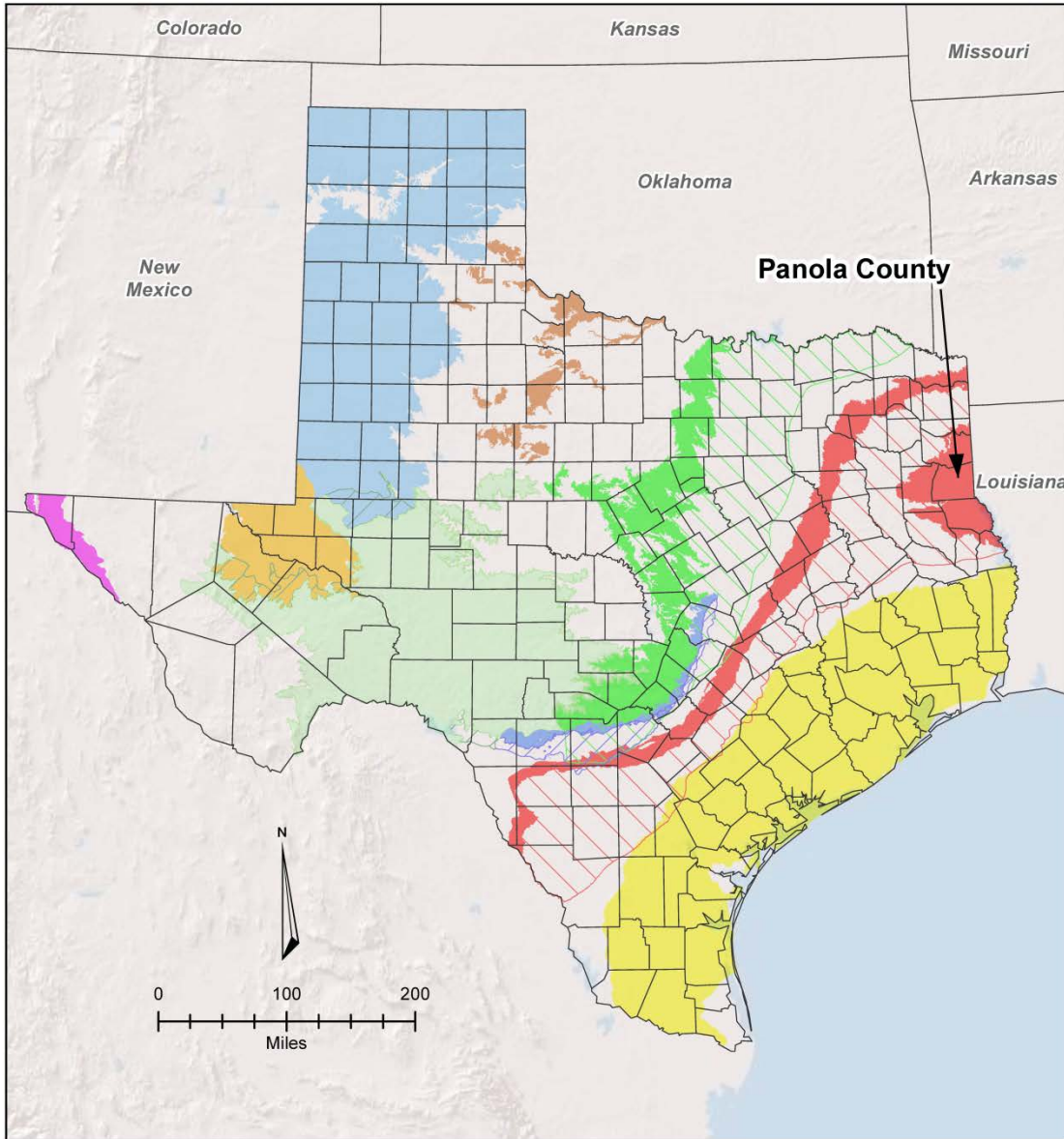
Irrigation and municipal supply account for approximately 90 percent of the groundwater use of the Carrizo-Wilcox Aquifer in Texas (George and others, 2011). In Panola County, between 1980 and 2008 the TWDB estimates that pumping from the Carrizo-Wilcox has varied between approximately 3,000 and

**Wilcox Structure, Water Levels, and Water Quality
in Panola County Groundwater Conservation District**

6,000 acre-feet per year, with approximately half of that attributable to municipal supply and the rest a combination of manufacturing, mining, livestock, and oil and gas activities. However, the districts' estimates of the amount and distribution of groundwater use may differ significantly.

The analyses presented here focus on PCGCD (Figure 2 and Plate 1) and include an evaluation of the structure and usable quality water of the Wilcox formation in the district, an assessment of water levels and trends, and an overview and evaluation of the major constituents of water quality.

**Wilcox Structure, Water Levels, and Water Quality
in Panola County Groundwater Conservation District**



**Major Aquifers
of Texas**

(Source: TWDB)

Prepared for Panola
County Groundwater
Conservation District

January 22, 2013

Legend

- | | |
|----------------------------|-------------------------------------|
| Texas Counties/US States | Ogallala |
| Pecos Valley | Edwards - Trinity Plateau (outcrop) |
| Seymour | Edwards - Trinity Plateau (subcrop) |
| Gulf Coast | Edwards BFZ (outcrop) |
| Carrizo - Wilcox (outcrop) | Edwards BFZ (subcrop) |
| Carrizo - Wilcox (subcrop) | Trinity (outcrop) |
| Hueco - Mesilla Bolson | Trinity (subcrop) |



Figure 1. Major Aquifers of Texas.

Wilcox Structure, Water Levels, and Water Quality in Panola County Groundwater Conservation District

Wilcox Structure and Usable Quality Water

Since the Wilcox is the primary aquifer unit in PCGCD, we developed a detailed surface for the elevation of its base. Existing surfaces for the base of the Wilcox (for example, Kaiser, 1990; Fryar and others, 2003) are of a much coarser resolution because the studies were of a regional scale.

To develop the surface, we used picks from geophysical logs for over 3,000 oil and gas wells available through the Texas Railroad Commission. The Railroad Commission interprets the “usable quality water” to define areas that must be protected when casing oil or gas wells. The base of usable quality water generally corresponds to water of a total dissolved solids concentration of greater than 3,000 milligrams per liter (mg/L). However, the picks are based on geophysical log signatures and do not include water quality analyses. It is important to note that though some areas may be below the base of “usable quality water,” the water may have some current uses or serve as a broader water source in the future if treated.

We cross-checked the picks for the base of the Wilcox and the base of usable quality water by the Railroad Commission against several geophysical logs to ensure the picks were reasonable for use in this study. An example of one of these logs, Q-28, is shown in Figure 3. Shown are a spontaneous potential log (the left track) and a resistivity log (the right track). The base of the Wilcox picked by the Railroad Commission is at the base of the inverted “Christmas tree” signature, which represents the transition of the Wilcox into the underlying Midway formation. Lithologically, this is a transition from a predominantly sandy unit into a fine-grained muddy/shale unit. The inverted Christmas tree feature was documented in Kaiser (1990) as the base of the Wilcox and the Railroad Commission picks are consistent with this interpretation. Additionally, the net sand thickness in this well of approximately 100 feet reasonably matches the net sand distribution reported in Kaiser (1990).

In Q-28, the Railroad Commission picked the base of usable quality water at 150 feet below ground surface at the base of a sandy unit with a high resistivity response (see Figure 3). The resistivity response for the two lower sandy zones beginning at depths of approximately 210 feet and 300 feet, however, indicates that the water in these zones is less “resistive” to the flow of an electrical current. We interpret that the water in the formation here is of a lower quality since it is the dissolved salts in the water that allow electrical current to flow. The pick of the base of usable quality water above these areas is, therefore, reasonable.

The base of the Wilcox formation in the district is shown in Figure 4 and Plate 2. In order to show the density of wells used to develop the surface, the locations of the control points are also shown in Plate

Wilcox Structure, Water Levels, and Water Quality in Panola County Groundwater Conservation District

2. The Wilcox base is highest in the northeastern portion of the county at elevations up to 50 feet above sea level. It dips to the south and west between approximately 13 and 17 feet per mile to elevations of 500 to 600 feet below sea level along the western border with Rusk County. While most areas of the Carrizo-Wilcox in Texas dip to the southeast, this structure is due to Panola County's location in the Sabine Uplift – an area of East Texas and Northwestern Louisiana where uplift occurred before and during deposition of the Wilcox (George, 2009).

To better illustrate the trends in the Wilcox in PCGCD, we developed a series of eight cross-sections oriented both North-South and East-West. These are shown in figures 5 through 12 and on Plate 3. In each cross-section, the thickness of Wilcox sediments (and younger alluvial sediments overlying the Wilcox where present) is shown as the difference between land surface and the base of the Wilcox. Wilcox sediments are 250 to 350 feet thick in northeastern portion of the district, thickening to over 800 feet to the west toward Rusk County. This trend can be seen in each of the East-West oriented cross-sections (Figures 5 through 8). The North-South oriented sections, figures 9 through 12, show some thickening to the south as well, but not to the same extent.

In each of the cross-sections, areas of the Wilcox that are below the base of usable quality water as defined by the Railroad Commission are shown in red. While the majority of the Wilcox is considered to contain usable quality water throughout the district, some areas, especially in the south-central portion of the district, contain significant sections below the base of usable quality water. This can be most clearly seen in Figure 13 in which the cross-sections are shown three-dimensionally as a Fence Diagram.

In the cross-sections, there is no differentiation between individual units of the Wilcox, where present. However, as described in Kaiser (1990) and Fryar and others (2003), the Lower Wilcox exists in some areas of southern and central Panola County. There may be interest by the district, therefore, in delineating the individual units of the Wilcox for management purposes. Since this conceptual framework for the aquifer was also implemented into the groundwater availability model maintained by TWDB (Fryar and others, 2003; Kelley and others, 2004), the current modeled available groundwater for the district – an estimate of the amount of groundwater available for pumping consistent with the “desired future conditions” adopted by Groundwater Management Area 11 – is reported by TWDB separately for the Carrizo, Upper Wilcox, Middle Wilcox, and Lower Wilcox units (Jones and others, 2012).

We sought to evaluate both the need and potential for delineating the boundary between the lower and middle Wilcox units in the district. Kaiser (1990) describes the upper/middle Wilcox units in the area as

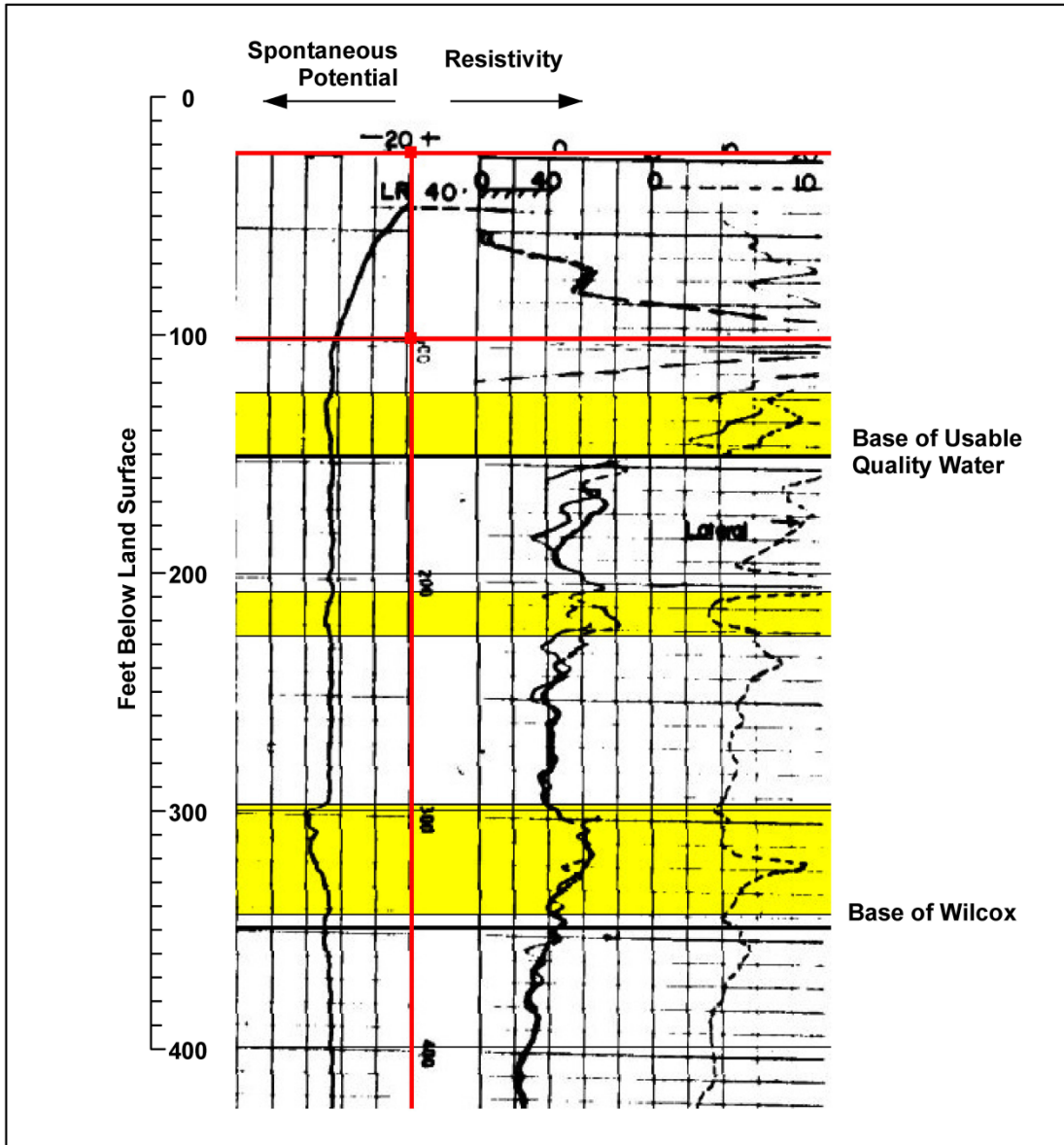
Wilcox Structure, Water Levels, and Water Quality in Panola County Groundwater Conservation District

having blocky sands (especially the Middle Wilcox/Simsboro equivalent) with some log patterns indicating upward coarsening (the inverted “Christmas tree”). The Lower Wilcox, which is relatively thin, is limited to the central-southern portions of the district and exhibits upward-coarsening sequences without the blocky sands.

In our investigation of several geophysical logs available through the Bureau of Economic Geology, the boundary between the Middle and Lower Wilcox units was not clearly identifiable. Given sufficient time and resources to acquire and interpret a relatively high density of logs in the county, we are confident the horizontal and vertical extent of the Lower Wilcox can be successfully defined. However, an important consideration relative to the need for delineating the Lower Wilcox is how (or if) the district would manage the unit differently from the Middle Wilcox. This includes considerations such as whether the two units are hydrologically separated or connected, whether the quality of water differs significantly between the units, and how each are used.

The Lower Wilcox reported in Kaiser (1990) is similar in extent and thickness to the portion of the Wilcox below the base of usable quality water defined by the Railroad Commission (Figure 13). While not universally true, such as in the northern portion of the county shown in cross-section A-A' (Figure 5) where the base of usable quality water is equivalent to the base of the Wilcox, this indicates that the quality of water between the units may be significantly different. This may be due to a regional hydrologic separation between the units or simply indicate that water-level gradients do not allow for significant mixing of the groundwater. The “base of usable quality water” delineation is inherently coarse, however, and not the only information available on water quality, which will be discussed in more detail later in this report. Though outside the scope of this study, other important factors such as production patterns and well screen locations may also influence whether a more detailed characterization of the Lower Wilcox is necessary.

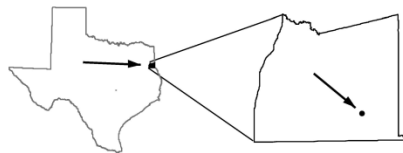
**Wilcox Structure, Water Levels, and Water Quality
in Panola County Groundwater Conservation District**



**Example
Geophysical Log
Q-28**

Prepared for Panola
County Groundwater
Conservation District

January 22, 2013



Panola County

Well Location

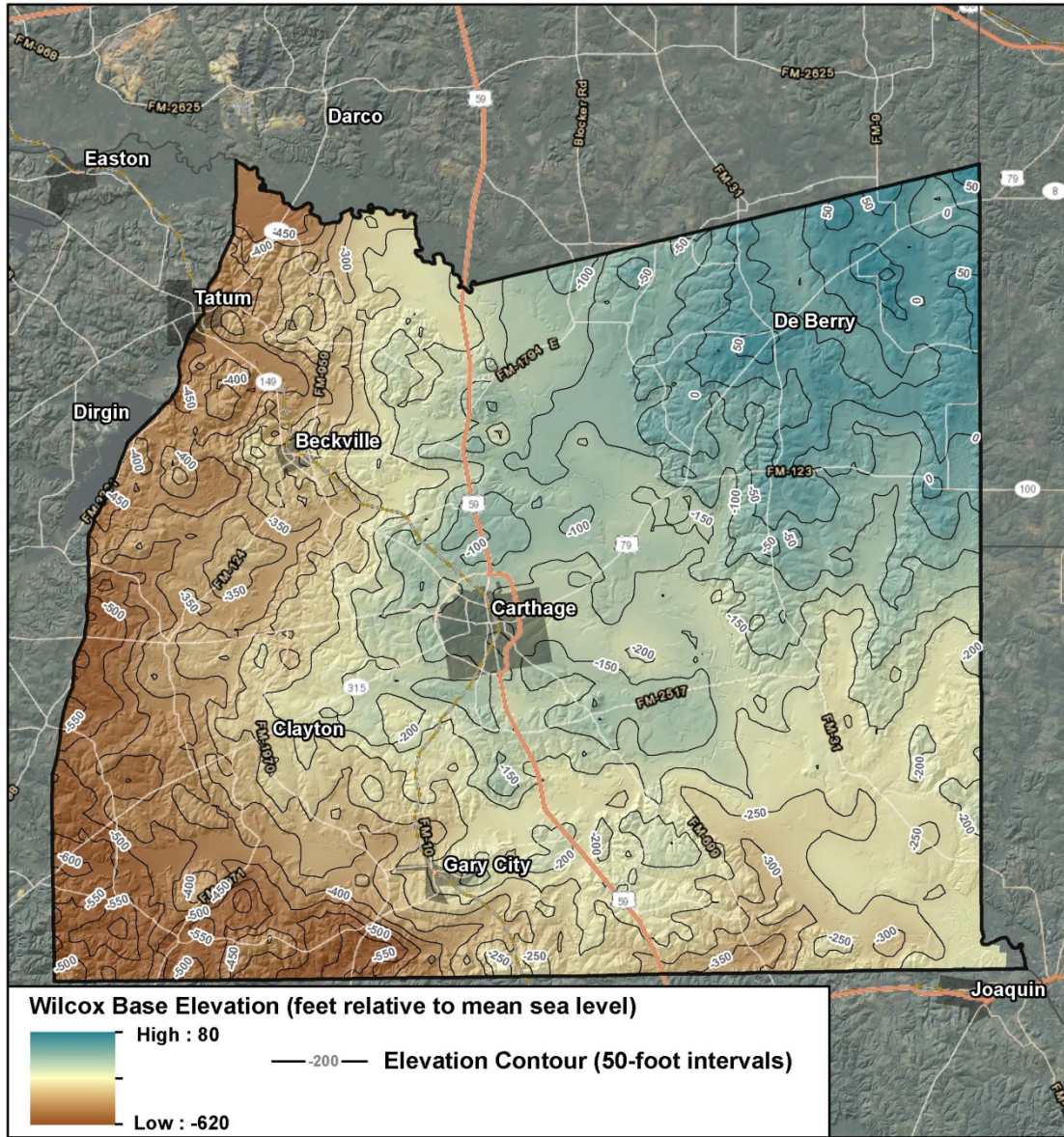
Legend

 Interpreted Sand Units



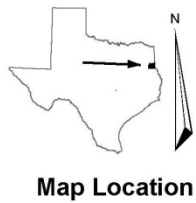
Figure 3. Example Geophysical Log.

**Wilcox Structure, Water Levels, and Water Quality
in Panola County Groundwater Conservation District**



Wilcox Base Elevation

Prepared for Panola County Groundwater Conservation District
 January 22, 2013



Legend

- Panola County
- Counties/Parishes
- Texas Cities

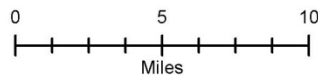


Figure 4. Wilcox Base Elevation in feet above mean sea level.

Wilcox Structure, Water Levels, and Water Quality in Panola County Groundwater Conservation District

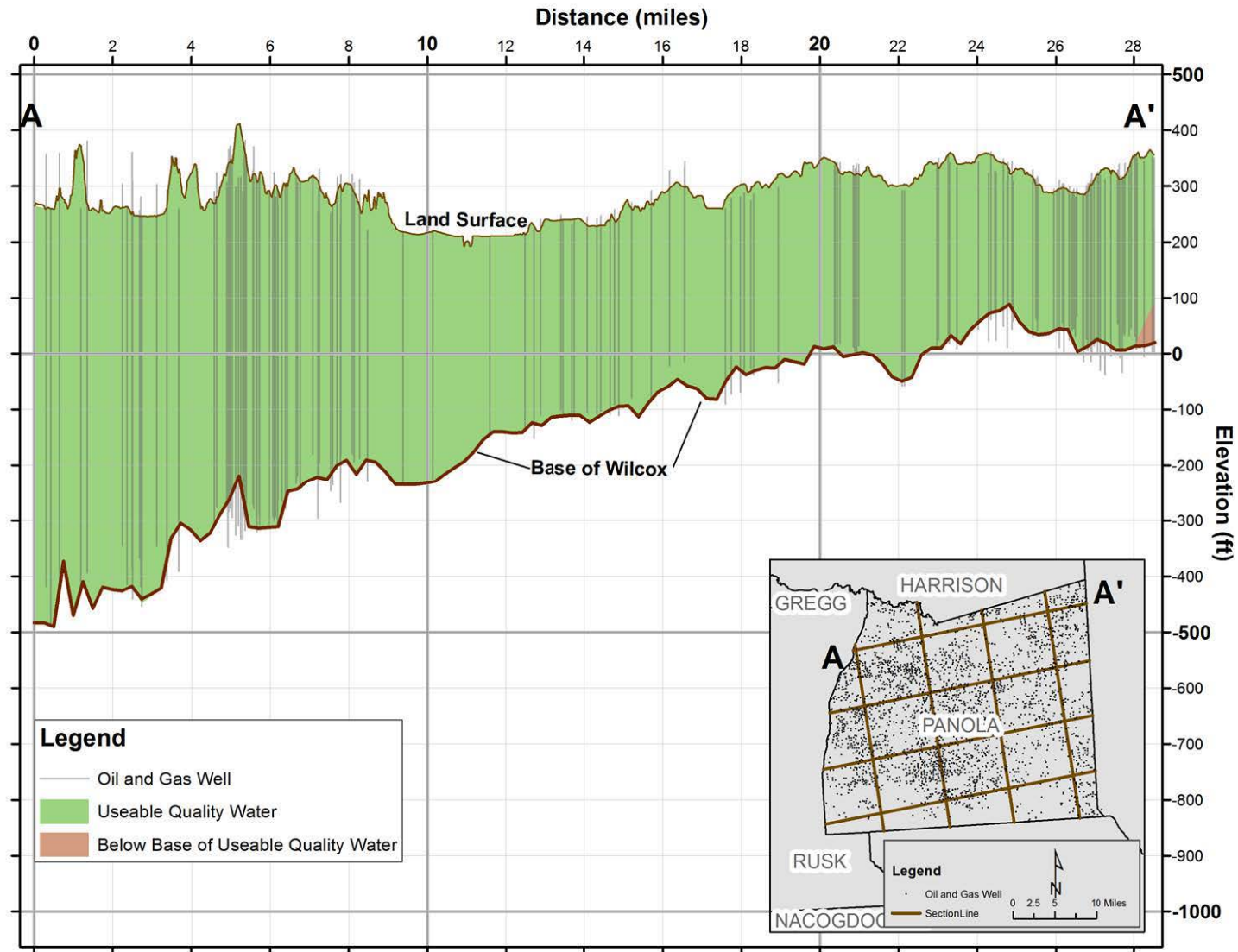


Figure 5. Cross Section A – A'.

**Wilcox Structure, Water Levels, and Water Quality
in Panola County Groundwater Conservation District**

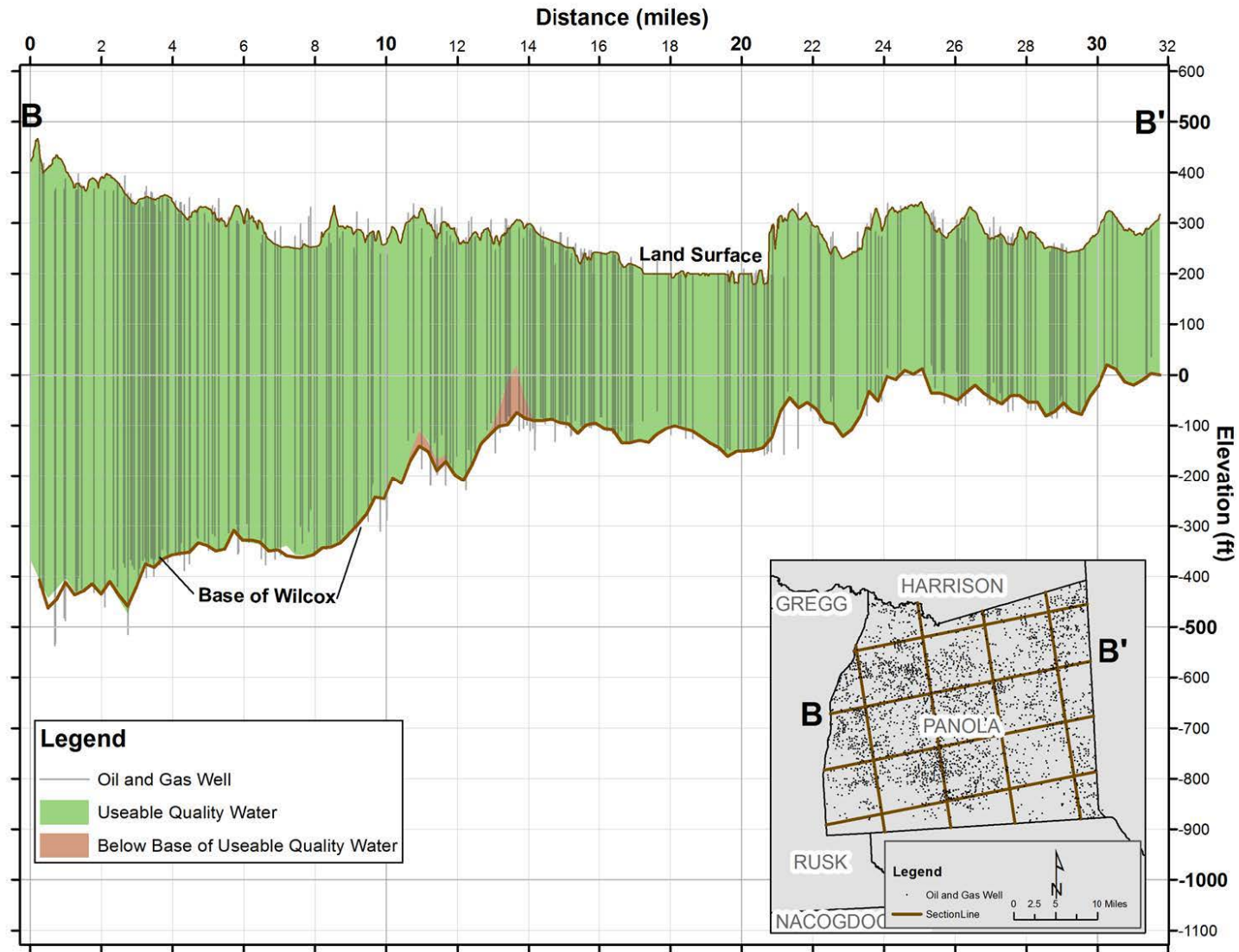


Figure 6. Cross-Section B – B’.

Wilcox Structure, Water Levels, and Water Quality in Panola County Groundwater Conservation District

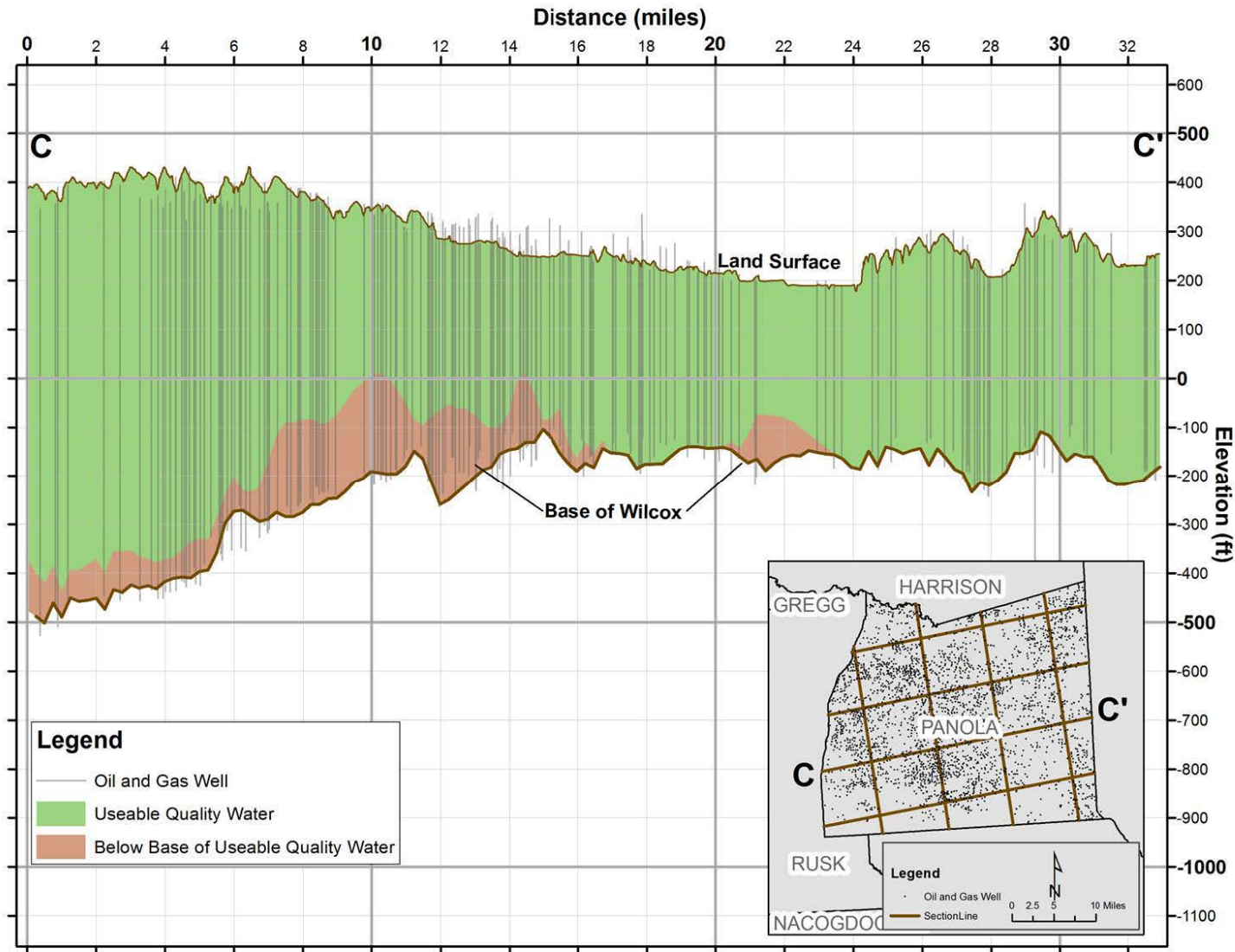


Figure 7. Cross-Section C – C’.

Wilcox Structure, Water Levels, and Water Quality in Panola County Groundwater Conservation District

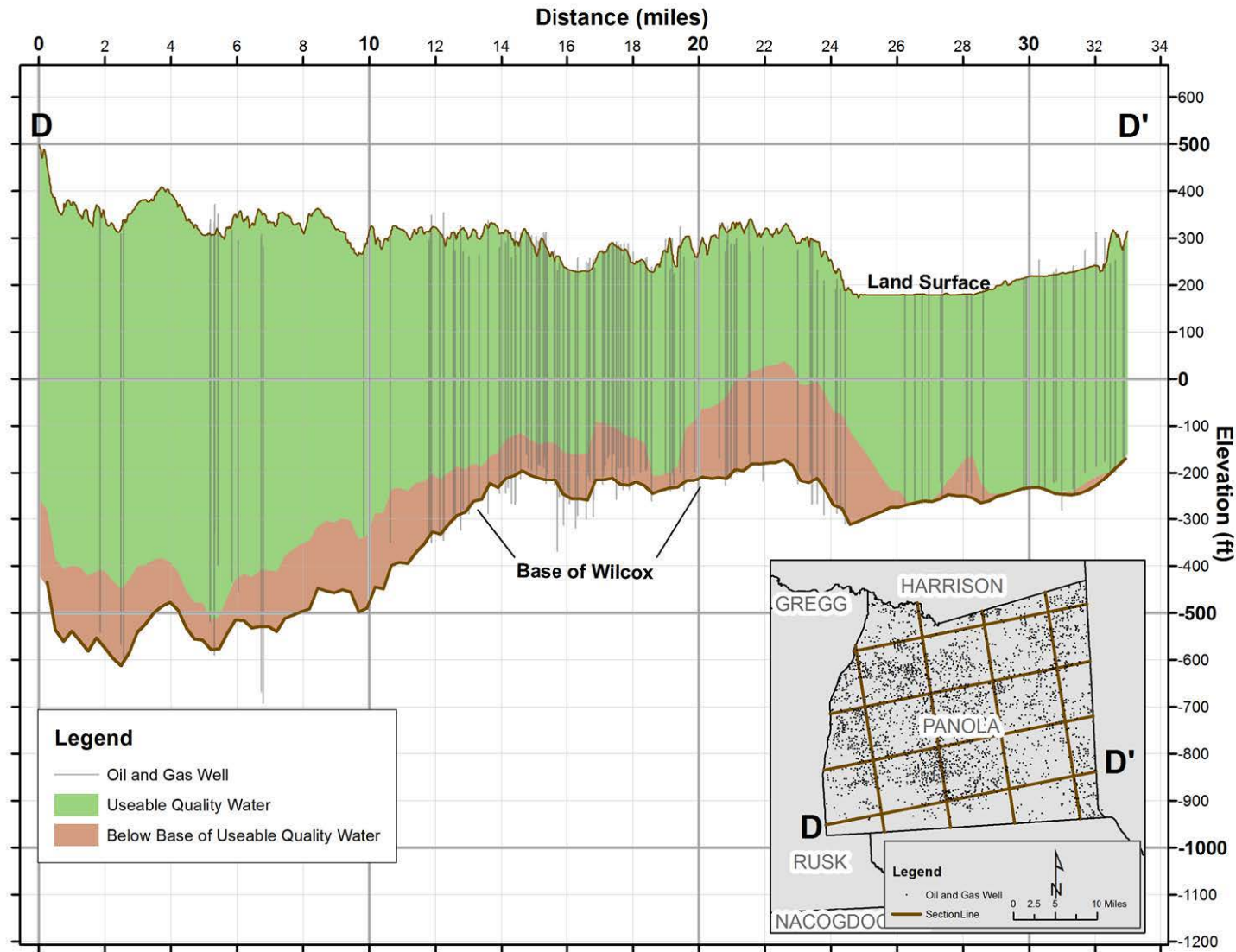


Figure 8. Cross-Section D – D'.

Wilcox Structure, Water Levels, and Water Quality in Panola County Groundwater Conservation District

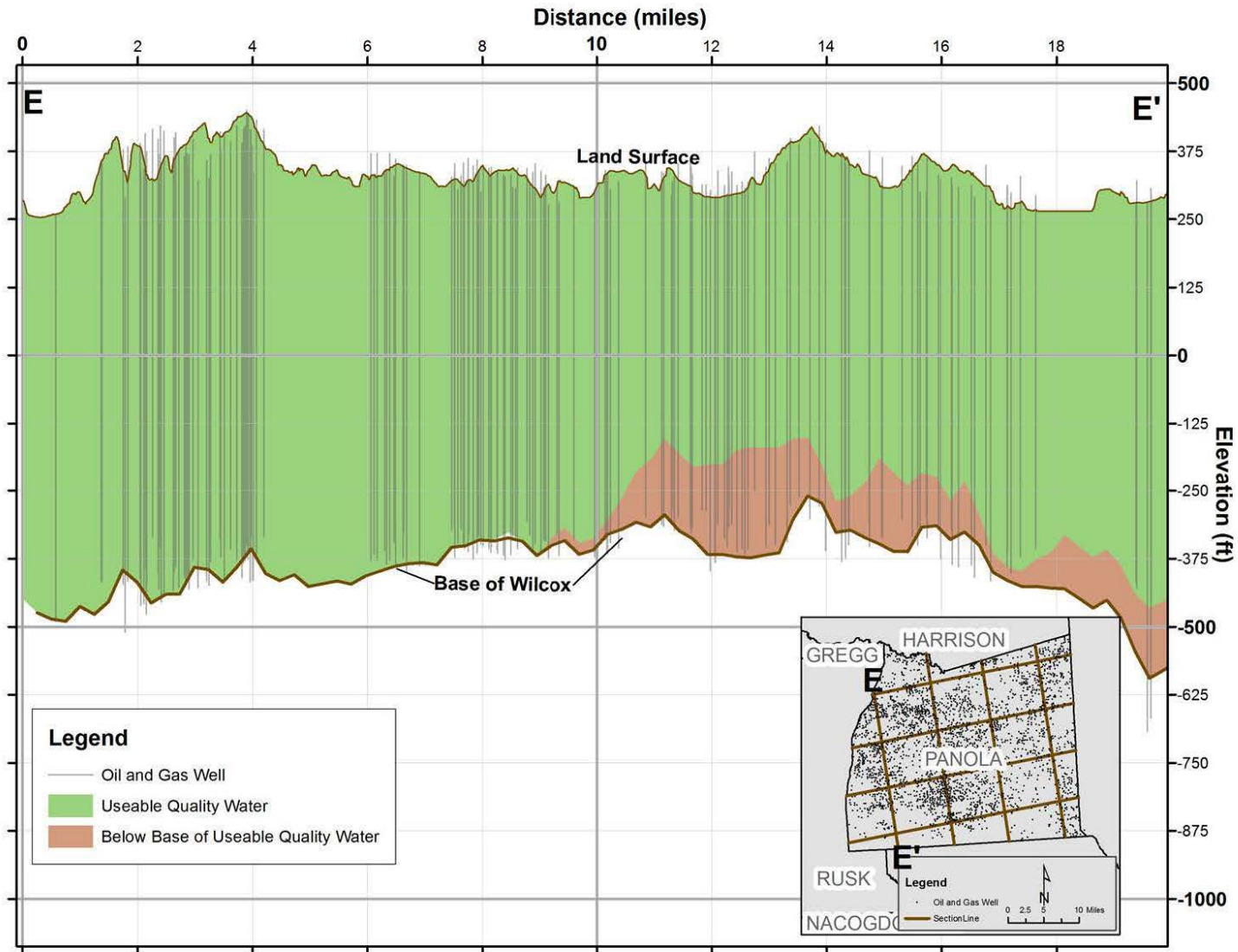


Figure 9. Cross-Section E – E’.

Wilcox Structure, Water Levels, and Water Quality in Panola County Groundwater Conservation District

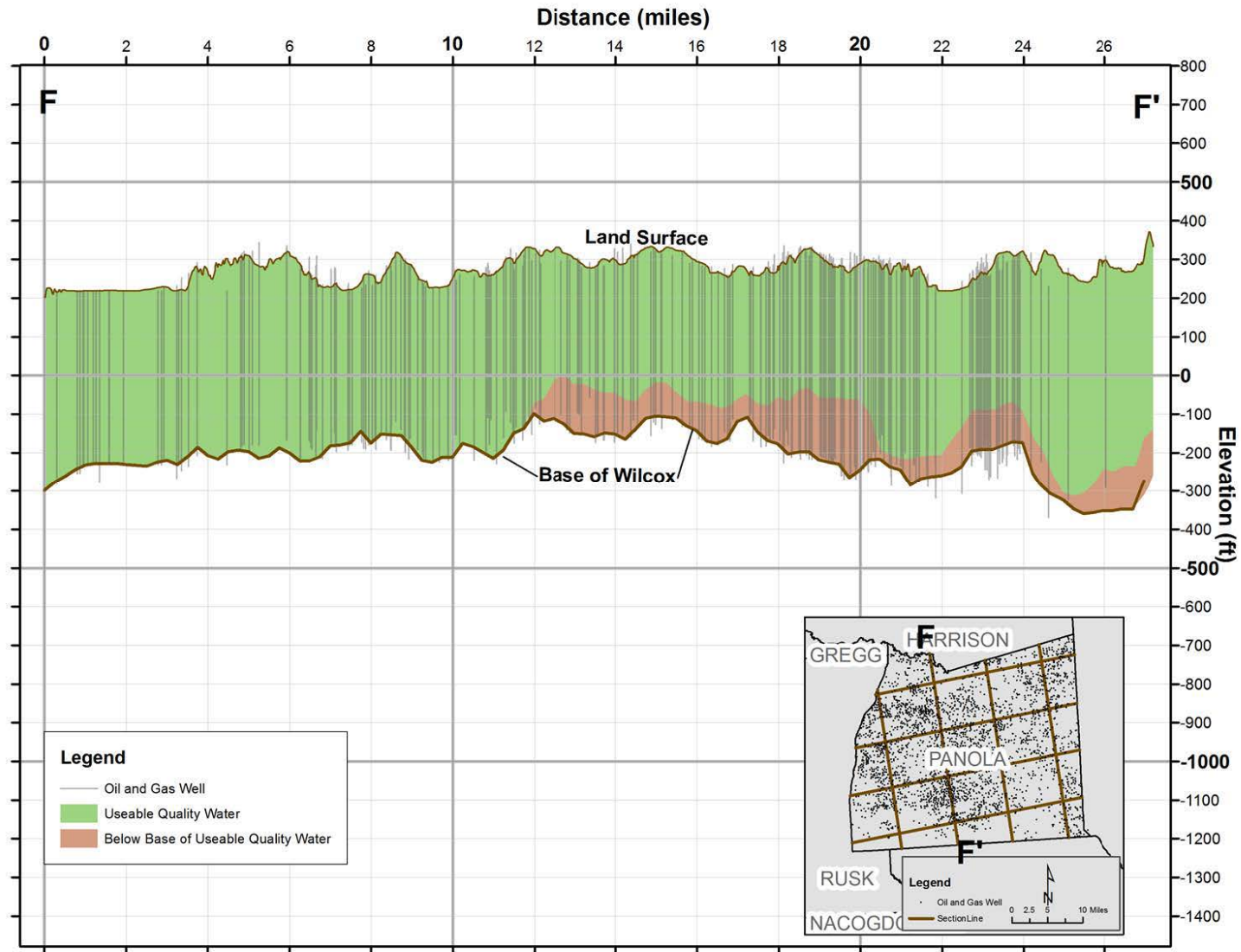


Figure 10. Cross-Section F – F'.

Wilcox Structure, Water Levels, and Water Quality in Panola County Groundwater Conservation District

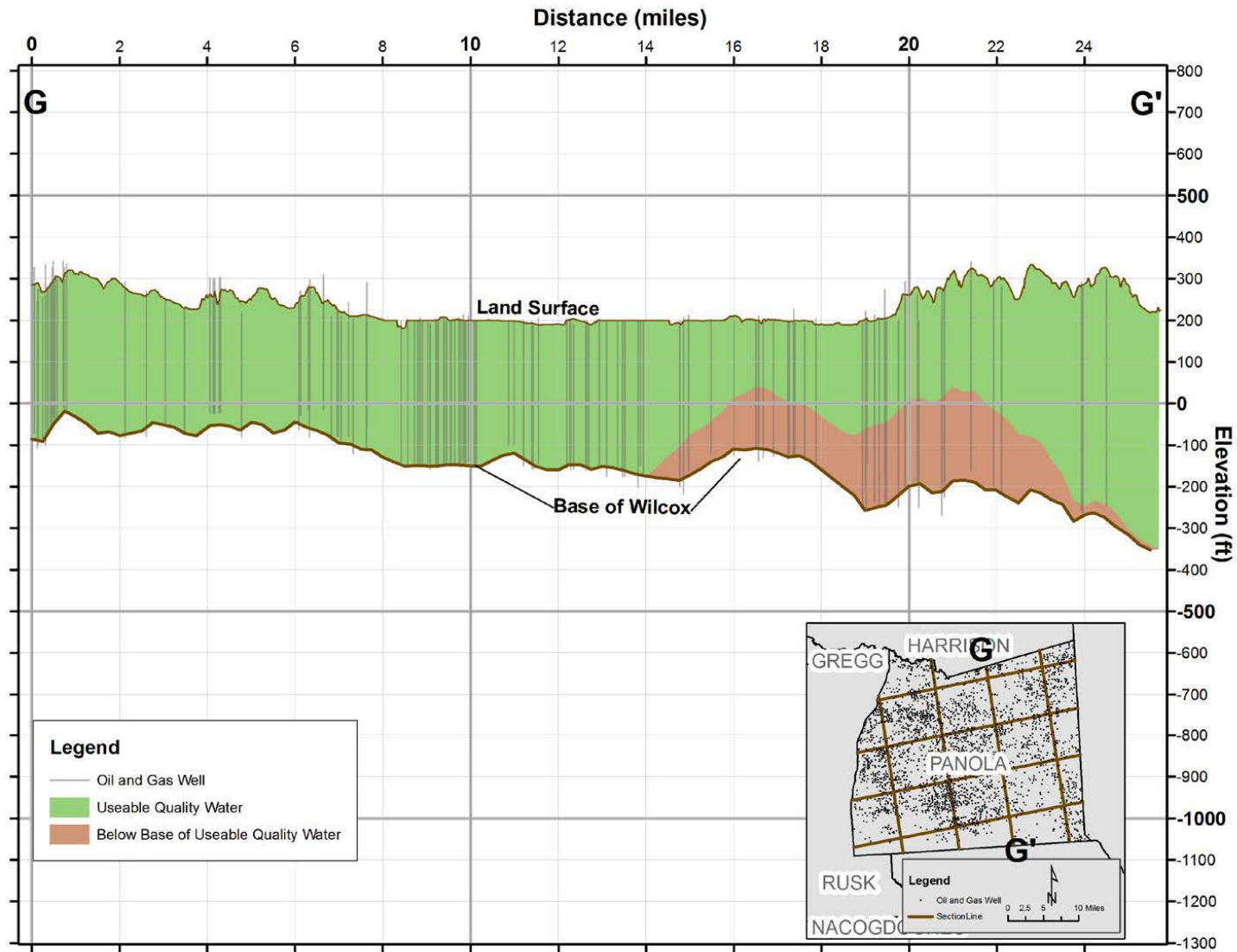


Figure 11. Cross-Section G – G'.

**Wilcox Structure, Water Levels, and Water Quality
in Panola County Groundwater Conservation District**

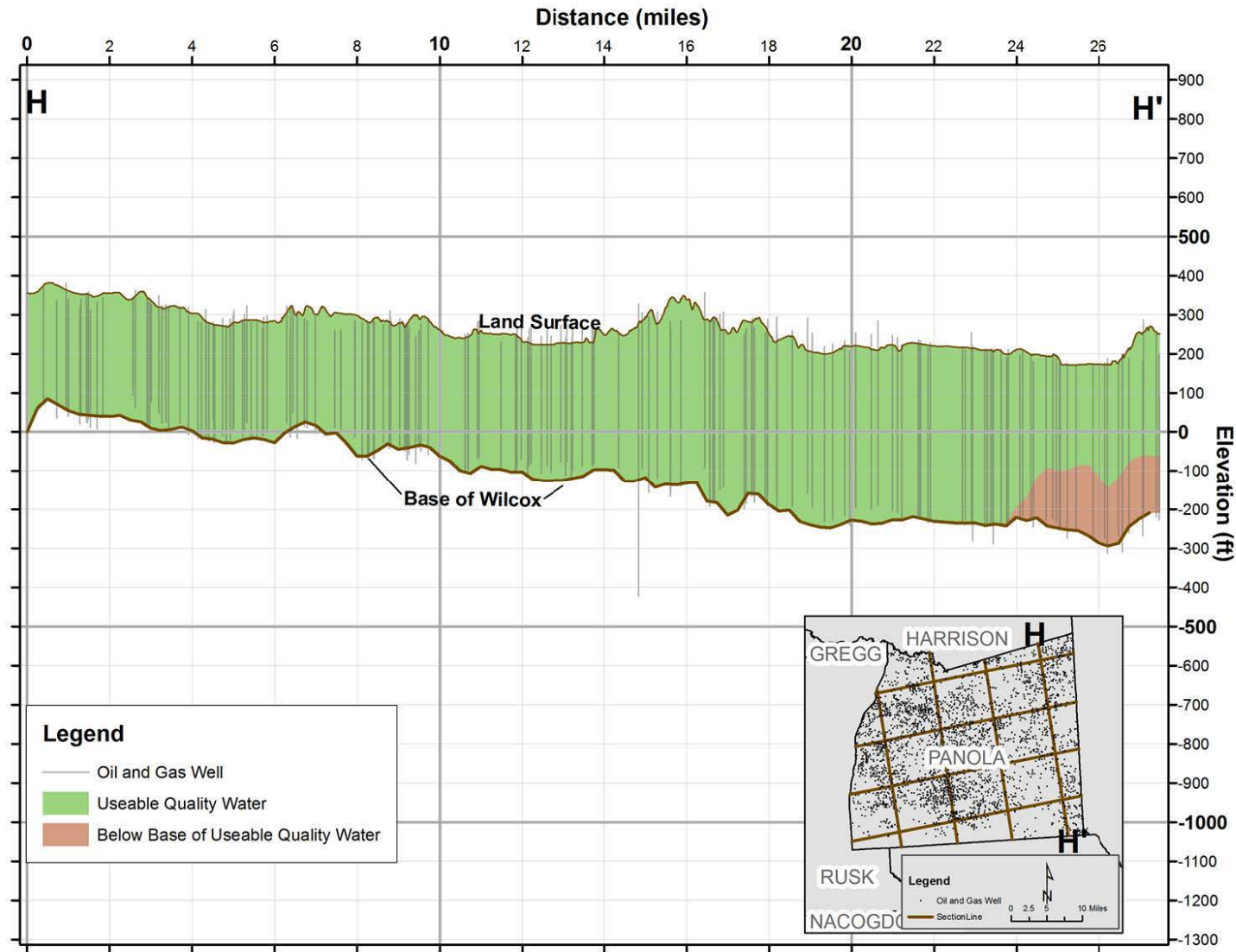
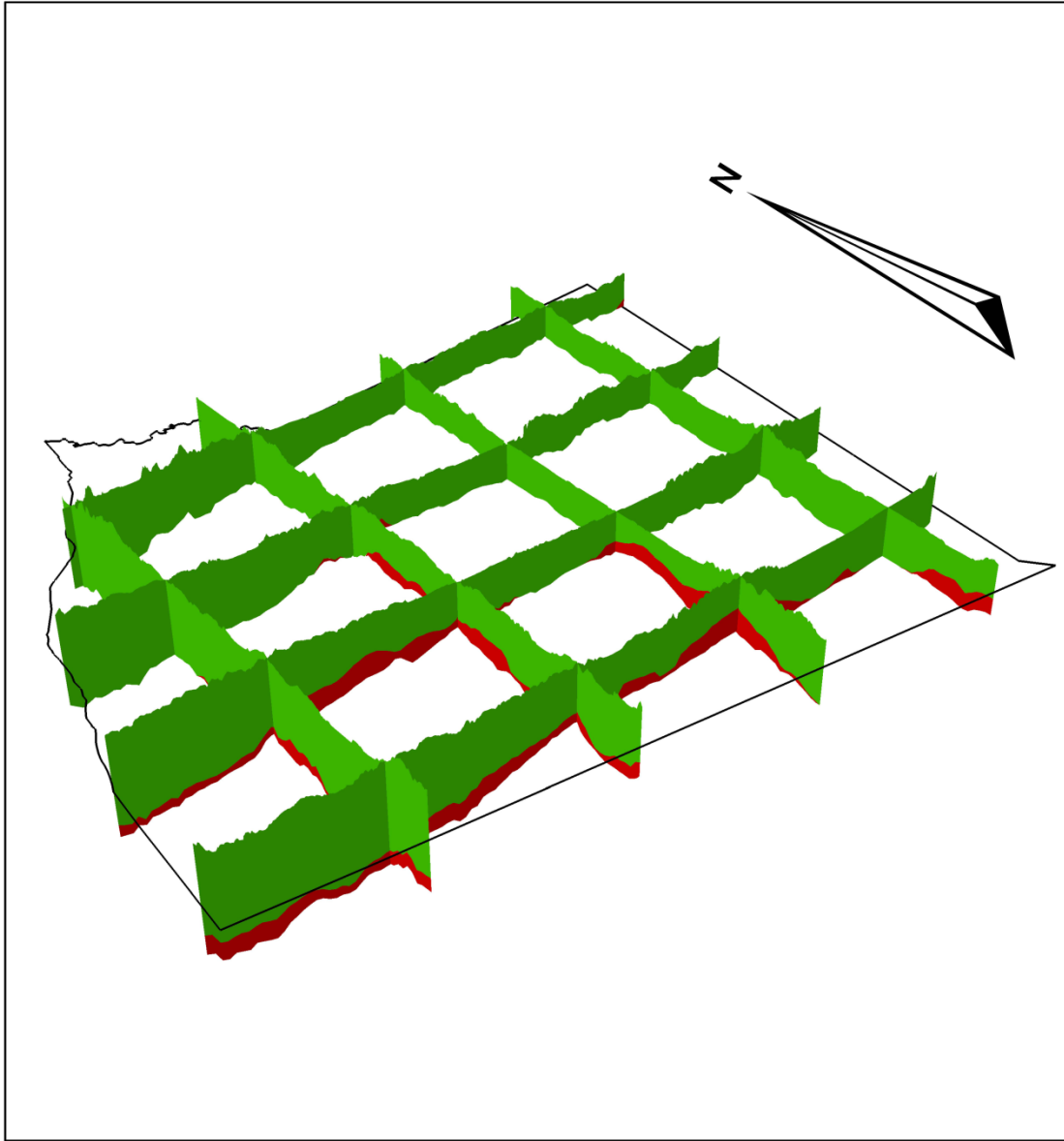


Figure 12. Cross-Section H – H'.

**Wilcox Structure, Water Levels, and Water Quality
in Panola County Groundwater Conservation District**



Fence Diagram

Prepared for Panola
County Groundwater
Conservation District

January 22, 2013



Map Location

Legend

- Wilcox Above Base of Usable Quality Water
- Wilcox Below Base of Usable Quality Water
- Panola County

Note: 25x Vertical Exaggeration



Figure 13. Fence Diagram showing the Wilcox unit with the base of usable quality water.

Wilcox Structure, Water Levels, and Water Quality in Panola County Groundwater Conservation District

Water Levels and Trends

Water levels in wells are generally the most common type of data available for aquifers. Water levels and their changes through time can indicate the direction of groundwater flow, recharge and discharge locations, and potential impacts to the aquifer from pumping or other sources. The current desired future condition for the aquifers in Groundwater Management Area 11, of which Panola County Groundwater Conservation District is a member, is based on average water level changes through time. We first developed an initial assessment of “current” water levels in the district for potential use in measuring conformance with the desired future condition and to highlight areas that may be in need of additional water-level monitoring.

The first water level measurements used to develop the surface were acquired from the TWDB Groundwater Database for Panola and the surrounding counties (TWDB, 2012b). Only measurements that met certain criteria for inclusion in the dataset were accepted. These criteria include:

- Was the most recent water level measurement available for the well denoted in the TWDB records as “publishable”, which indicates a certain threshold of reliability of the measurement.
- Did not include remarks indicating the measurement may not be representative of the aquifer such as recent pumping in the well or known pumping occurring nearby.
- Categorized as being in the Carrizo-Wilcox Aquifer
- Measurement taken after January 1, 2010 during the winter months between November and March to minimize impacts of seasonal changes due to factors such as increased production during the summer months.

Ninety-nine wells from the TWDB Groundwater Database met the above criteria, with only 17 falling within PCGCD, which is insufficient to develop a reasonable water level surface. In addition to providing supplementary records for wells in the TWDB Groundwater Database, PCGCD also provided records for over 400 water level measurements in the district between 2010 and 2012. Based on discussions with district staff, we removed measurements taken using sonic meters due to potential inaccuracies. Additionally, we removed several records with only qualitative water level information such as “artesian” or “dry well.” We did not, however, filter results by season in order to maintain a sufficient number of wells for water level surface development. The PCGCD dataset provided an additional 302 water level measurements for this analysis.

Wilcox Structure, Water Levels, and Water Quality in Panola County Groundwater Conservation District

The locations of wells in the district from the TWDB Groundwater Database, the PCGCD water level database, and the TWDB Submitted Drillers Reports Database (TWDB, 2012c) are shown in Figure 14 and are symbolized by well type (public supply, industrial, other, and unknown). Wells included in the TWDB Submitted Drillers Reports database were not used for the water level surface development due to lack of information on the method of quality of measurements. The Submitted Drillers Reports Database wells also do not contain information on well type. Therefore the majority of wells shown in Figure 14 are classified as “unknown.” The wells in Figure 14 represent the initial set of all reported wells in the three databases prior to filtering to develop the water level surface.

In addition to water level measurements in wells, an important component of the aquifer flow system impacting water levels is the interaction of the aquifer with surface water features such as perennial rivers, reservoirs, and springs. In areas with relatively large amounts of precipitation such as East Texas, aquifers typically discharge to rivers. This provides baseflow – the component of river flow that is not due to a recent precipitation event.

To incorporate the impact of interaction of the aquifer with surface water features and ensure that the water level surface is realistic, we defined both the locations and representative elevations of the features in and surrounding the district. For reservoirs and springs, the locations were defined using the National Hydrography Dataset (NHD; U.S. Geological Survey, 2012b). While rivers and streams are also included in NHD, we performed a flow accumulation analysis on the 1/3 arc-second digital elevation model available in the U.S. Geological Survey National Elevation Dataset to define the locations of rivers and streams to ensure a continuous stream network and consistent threshold for perennial versus intermittent streams.

The locations and elevations of the surface water features were merged with the well water level data and interpolated (using ordinary kriging) to produce the water level surface for the district. This surface is shown in Figure 15 and Plate 4. In addition, Plate 4 shows the locations of the water well control points used to develop the surface. In general, water level elevations (and by extension, groundwater flows) trend toward the Sabine River, with the highest elevations (about 350 feet above sea level) in the extreme northeast and southwest areas of PCGCD. The groundwater elevations near the Sabine River are commonly 180 to 200 feet above sea level. This equates to average water level gradients of approximately 10 to 12 feet per mile with some significant local variability.

While the water level surface shown in Figure 15 represents a snapshot of the aquifer using data from the last 2 years, water levels can change significantly through time. We developed hydrographs of those

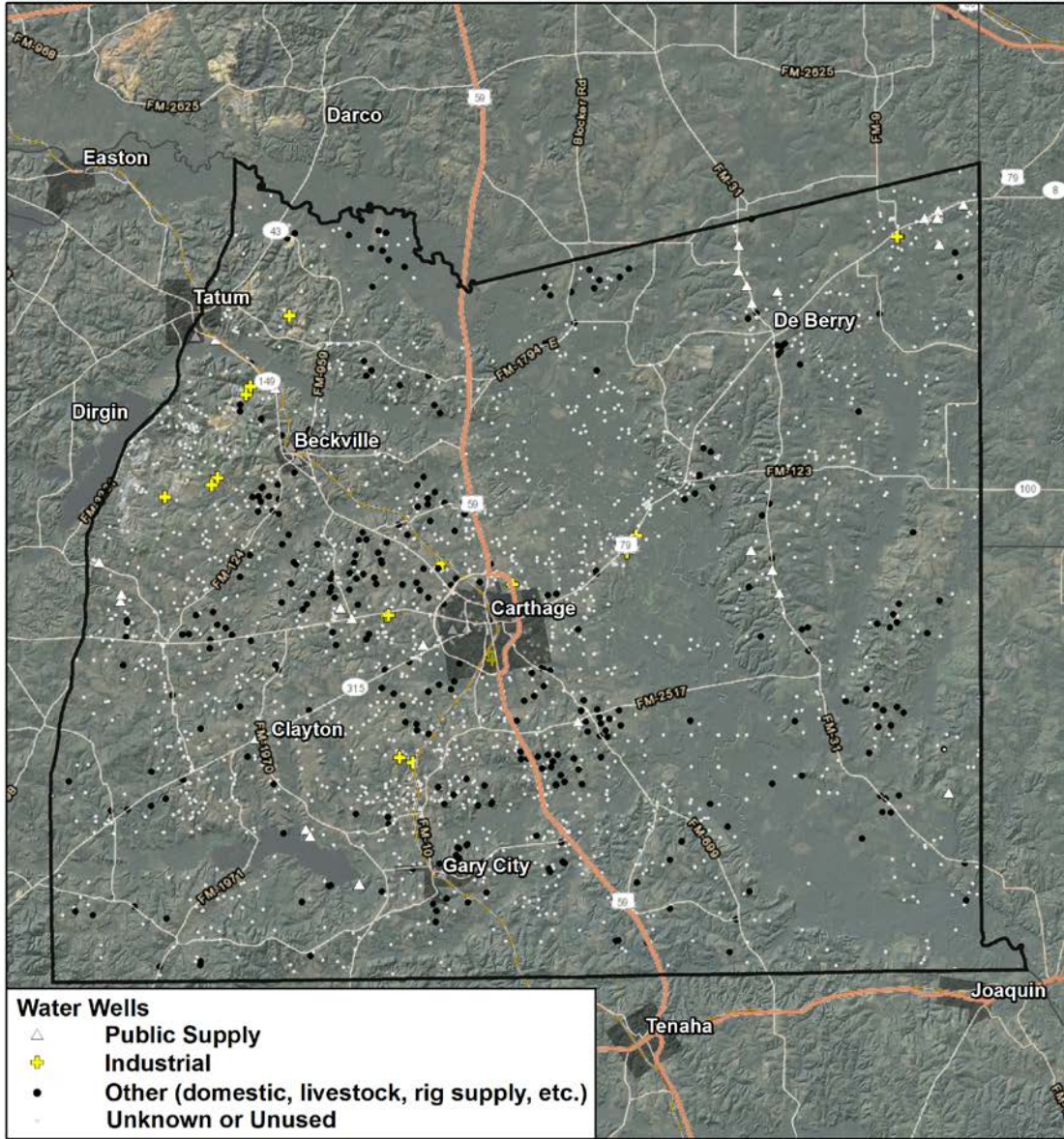
Wilcox Structure, Water Levels, and Water Quality in Panola County Groundwater Conservation District

wells with several water level measurements to show how water levels in the aquifer have changed between 1960 and 2012 (Plate 5). The wells shown in Plate 5 include the 17 wells in the county with water level measurements after 2010 described above along with 6 additional wells that had a series of recorded water levels prior to 2007. Wells in the PCGCD water level database were not included due to an insufficient period of record.

The water level trends shown in Plate 5 are not consistent throughout the district. In the southwest portion of the county, water levels are generally steady (well 3708201) or steadily declining (well 3560502). Near the Sabine River, most wells show relatively steady water levels over the period, which may be due to the Sabine River interacting with the aquifer and buffering potential water level responses. There are fewer water wells along the Sabine River, so this may also simply indicate fewer stresses on the aquifer in this area. One exception to this is well 3554601, which has relatively steady water levels between the 1970s and early 2000s before rising abruptly by 25 to 30 feet.

In the northeast and northwest areas of the county, water levels are considerably more variable, possibly due to the impact of nearby pumping (for example, wells 3552301 and 3547503). While steps were taken to remove water level measurements that TWDB noted as influenced by pumping, it is likely that many of these hydrographs are still impacted. With a greater number of public supply and industrial wells in these areas, it is more difficult to isolate the static condition of the aquifer from the impacts of nearby, potentially heavily producing wells.

**Wilcox Structure, Water Levels, and Water Quality
in Panola County Groundwater Conservation District**



Water Wells

Prepared for Panola
 County Groundwater
 Conservation District
 January 22, 2013



Legend

- ◻ Panola County
- ◻ Counties/Parishes
- ◻ Carthage Texas Cities

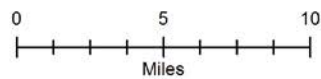
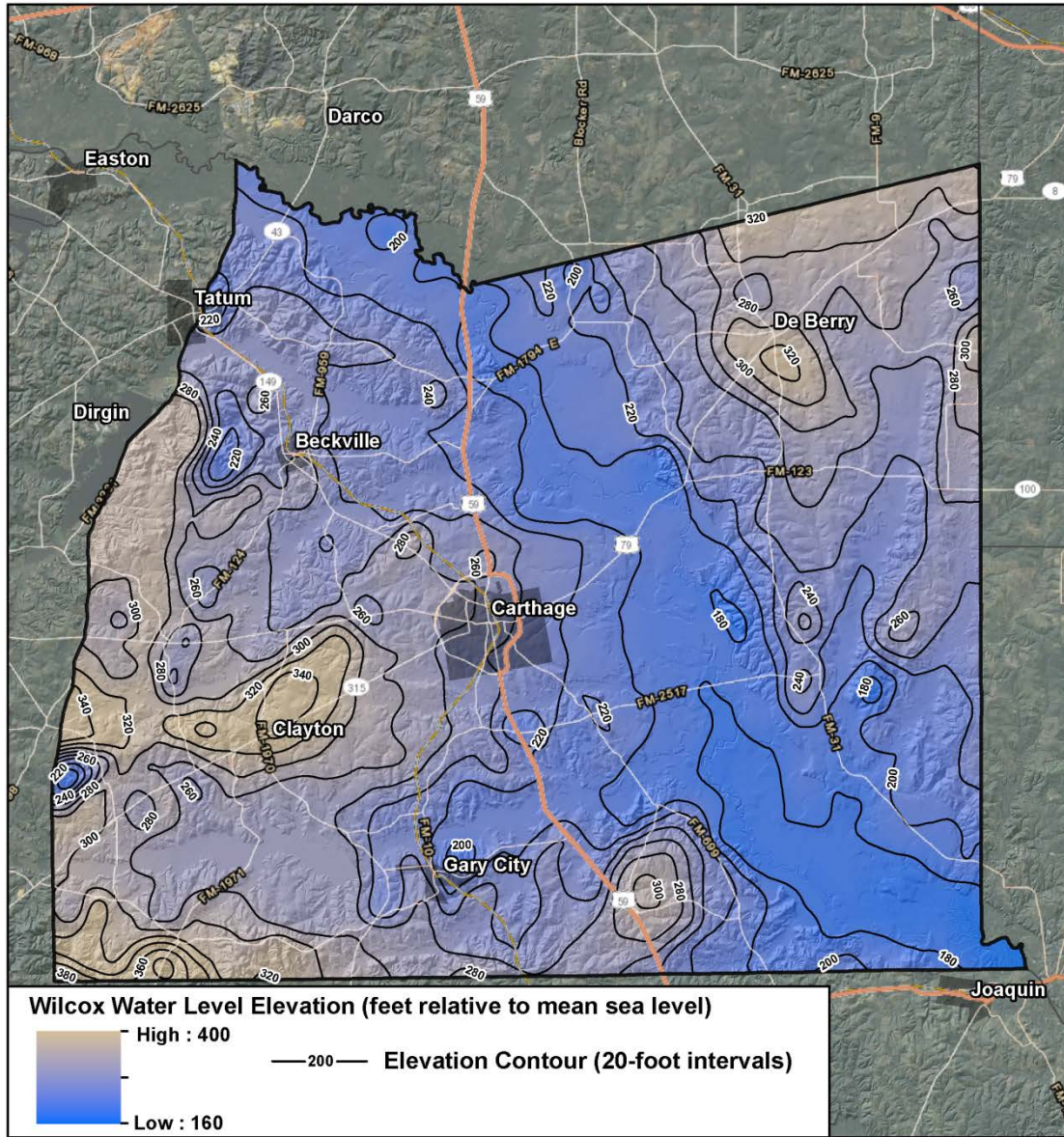


Figure 14. PCGCD well locations.

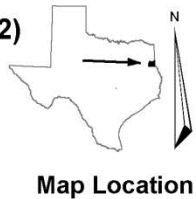
**Wilcox Structure, Water Levels, and Water Quality
in Panola County Groundwater Conservation District**



**Wilcox Water Level
Elevation (2010 - 2012)**

Prepared for Panola
County Groundwater
Conservation District

January 22, 2013



Legend

- Panola County
- Counties/Parishes
- Texas Cities



Figure 15. Wilcox water level elevation using measurements between 2010 and 2012.

Wilcox Structure, Water Levels, and Water Quality in Panola County Groundwater Conservation District

Baseline Water Quality Analysis

The physical and chemical characteristics of groundwater, known as its water quality, are important properties that can influence its usability for many purposes. Water quality analyses can take many different forms, but often include temperature, pH, electrical conductivity, and concentrations of eight common dissolved ions (sodium – Na⁺, potassium – K⁺, magnesium – Mg²⁺, calcium – Ca²⁺, chloride – Cl⁻, bicarbonate – HCO₃⁻, sulfate – SO₄²⁻, and nitrate – NO₃⁻). In addition, the total dissolved solids (TDS) concentration, the most common indicator of water quality, is the total amount of organic and inorganic substances dissolved into the water and is often used to indicate whether water is fresh, brackish, or saline.

Water quality can be impacted by many different factors including the rate of recharge to the aquifer, the production of groundwater from the aquifer, the physical composition of the aquifer sediments, and potentially contamination from the surface or from neighboring geologic formations. We have focused our analysis on the eight major individual dissolved constituents of the water in the Wilcox in Panola County and the total dissolved solids.

As described in previous studies of the aquifer in general (for example, George, 2009; Fryar and others, 2003; Kelley and others, 2004) and its water quality specifically (Boghici, 2009), the Carrizo-Wilcox Aquifer is generally fresh (TDS < 1,000 mg/L), but does contain areas of brackish quality water (TDS generally between 1,000 and 10,000 mg/L). This is true in PCGCD as well. As discussed in the section on Usable Quality Water above, there are portions near the base of the Wilcox below the base of “usable quality water” as defined by the Railroad Commission. This water, however, may still be used for some purposes as-is or potentially be treated in the future to serve as new water source.

To investigate the TDS and dissolved ions, we gathered the most recent water quality analyses available in the TWDB Groundwater Database for the district. TDS concentrations are shown in Figure 16. East of the Sabine River and near the City of Carthage, the water is generally very fresh with concentrations below 500 milligrams per liter (mg/L) in most wells and many below 250 mg/L. In the northwest portion of the district toward the City of Tatum and in the south central portion near Gary City, the water quality diminishes, with TDS concentrations up to and exceeding 1,000 mg/L. Though only the most recent water quality analysis is shown for each well, records are available for several historical analyses for many of these wells. We inspected these prior analyses, but did not identify any wells with temporal trends (specifically degradation) in TDS concentration. This includes well 3544601 with 16 water quality

Wilcox Structure, Water Levels, and Water Quality in Panola County Groundwater Conservation District

analyses between 1938 and 1986 in which the TDS fluctuated between 690 and 980 mg/L throughout the period.

The TDS, chloride, and sulfate concentrations for these wells have been posted on Plate 6 to allow a more direct and quantitative comparison of the individual concentrations. Since the TDS concentration is comparable (though not equal due to the minor constituents such as silica and iron) to the sum of the 8 major dissolved ions, one can infer that chloride is a minor to secondary constituent of groundwater in the district and sulfate, with a few exceptions, is only a minor constituent.

A quick way to visualize the TDS and the major dissolved ions is through the use of Stiff diagrams. Stiff diagrams are a graphical representation of the major dissolved ions in which the positively charged cations (Na^+ , K^+ , Ca^{2+} , and Mg^{2+}) plot to the left of the vertical axis and the negatively charged anions (Cl^- , HCO_3^- , CO_3^{2-} , and SO_4^{2-}) plot to the right (Appelo and Postma, 2005). The concentrations are also converted to milliequivalents per liter from milligrams per liter to reflect a charge balance on each side of the diagram. The Stiff diagrams for wells in PCGCD are shown in Plate 7 and were generated using the GeoStiff tool described in Boghici and Boghici (2001).

As shown in Plate 7, groundwater in the district is predominantly sodium-bicarbonate in composition with chloride as a common secondary anion. This is consistent with the composition of much of the Carrizo-Wilcox (Boghici, 2009). While the amount of dissolved solids varies considerably, with noticeably higher levels in the south and northwest, the shape of the Stiff diagrams is largely consistent.

As mentioned above, this analysis is not exhaustive for all aspects of water quality. Rather, it is an assessment of the major dissolved ions characterizing the aquifer for which data is commonly available. Though less often included in analyses, water quality can also be significantly influenced by more minor constituents (for example, iron, silica, nitrates, and fluoride), trace elements (for example, arsenic and mercury), or dissolved gases (for example, methane). Point-source contamination from surficial or underground sources can have severe local impacts to water quality as well, though these are best characterized through site-specific studies.

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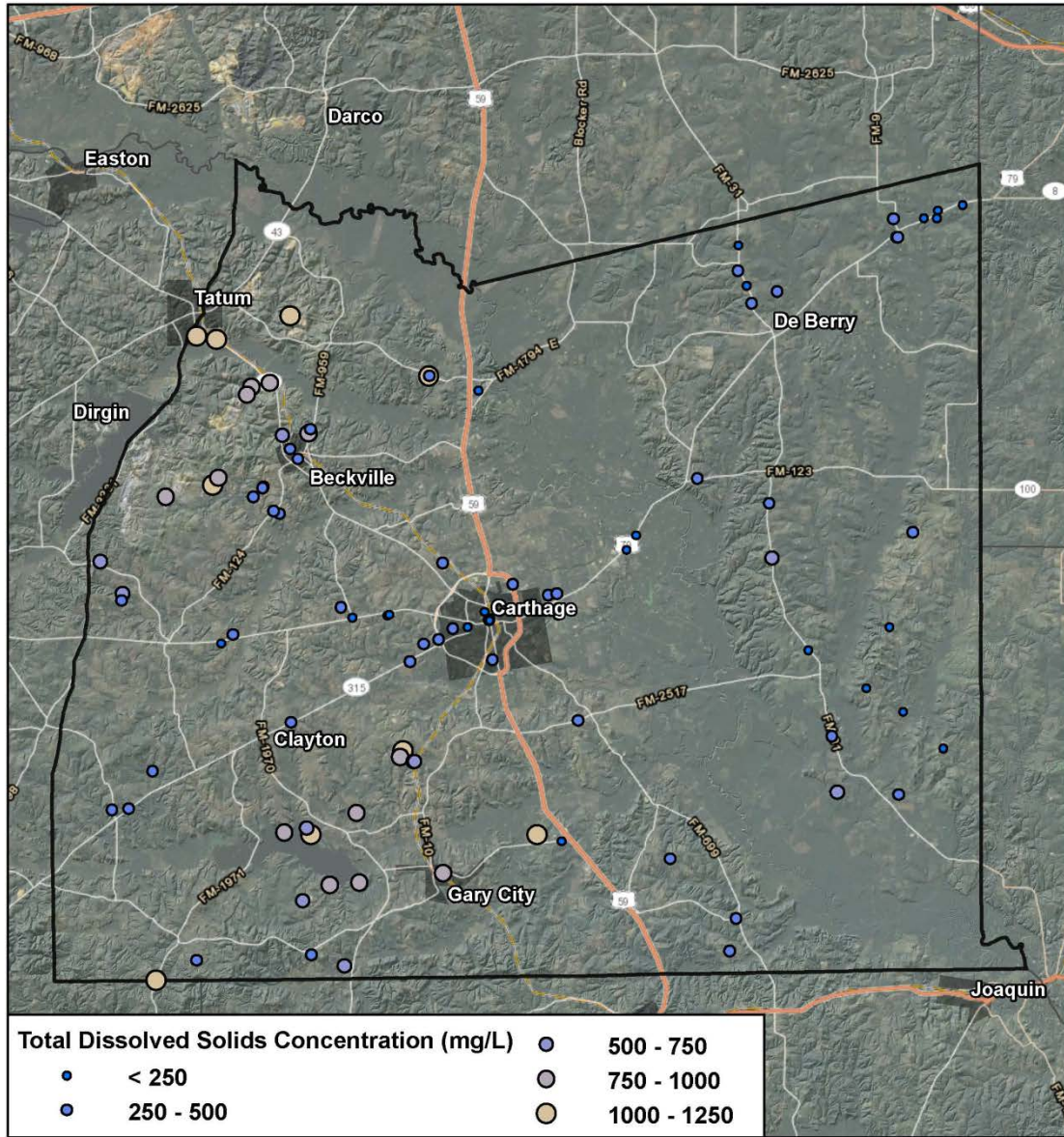


Figure 16. Total dissolved solids concentration for wells in the Wilcox.

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