Identification of Potential Brackish Groundwater Production Areas – Rustler Aquifer

TWDB Contract Number 1600011949

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1 Executive summary

Groundwater is a major source of water in Texas, providing about 60 percent of the water used in the state. To better formulate water management strategies, planners and decision makers need reliable estimates of available fresh, brackish, and saline groundwater. House Bill 30, passed by the 84th Texas Legislative Session, requires the Texas Water Development Board (TWDB or "the Board") to identify and designate brackish groundwater production zones in the aquifers of the state. Specifically, the legislation directs the Board to conduct studies on four aquifers and report the results of the studies to the legislature by December 31, 2016. Studies and reports on the remaining aquifers are to be completed by December 31, 2022. To meet this requirement, the TWDB let contracts to conduct studies of brackish groundwater in six Texas aquifers. The Rustler Aquifer was one of the aquifers selected for study in House Bill 30. This report documents the Rustler Aquifer study.

The Rustler Aquifer is a TWDB designated minor aquifer in the state of Texas and underlies parts of Brewster, Culberson. Jeff Davis, Loving, Pecos, Reeves and Ward counties and defines the area of this study. The objective of this study is to characterize the quantity and quality of groundwater within the Rustler Aquifer and to evaluate potential brackish production zones that can be used by the TWDB to make recommendations to the legislature on designation of brackish production zones. House Bill 30 provides direction to TWDB to identify and designate local or regional brackish groundwater production zones in areas of the state with moderate to high availability and productivity of brackish groundwater that can be developed to reduce the use of fresh groundwater.

It is important to note that TWDB designates brackish groundwater production zones. The purpose of this study is to provide the information necessary for the TWDB to designate brackish groundwater production zones for the Rustler Aquifer. To meet these objectives, we have collected and analyzed data to better define aquifer structure and transmissive units of the Rustler Aquifer, and water quality. Hydraulic calculations have been performed to provide guidance regarding the production potential of the aquifer in potential production areas and the nature of impacts to protected users and freshwater within the aquifer. This information has been integrated to evaluate potential production areas for consideration by the Board for formal designation as brackish groundwater production zones.

A detailed stratigraphic analysis was performed, which focused on refining the Rustler Formation stratigraphy into its five member units and eight informal submember units. Adding an additional 346 new geophysical logs to previous research performed by the TWDB, a total of 589 geophysical logs have been analyzed, making approximately 5,000 stratigraphic picks to gain further insight into the specific depositional and post depositional regime of the Rustler Formation and how this knowledge relates to the Rustler Aquifer.

A rigorous search for Rustler Aquifer groundwater quality data was performed as part of this study, including outreach to stakeholders in the aquifer area. To augment observed water quality data, we used state-of-the art petrophysical analysis techniques to analyze geophysical logs for both porosity and water quality. Calculations of Rustler Aquifer water quality (total dissolved solids) using geophysical logs provided the additional data needed to better define the groundwater salinity zones within the Rustler Aquifer.

The groundwater quality defined by total dissolved solids concentration was discretized based on groundwater salinity zones corresponding to; fresh water with total dissolved solids concentration less than 1,000 milligrams per liter, slightly saline groundwater defined as groundwater with total dissolved solids concentration between 1,000 to 3,000 milligrams per liter, moderately saline groundwater with total dissolved solids concentration between 3,000 and 10,000 milligrams per liter and very saline groundwater with total dissolved solids concentration between 10,000 to 35,000 milligrams per liter. Based upon mapping of salinity zones, INTERA calculated the volume of groundwater in place for the entire Rustler Formation which included up to three transmissive units of the Rustler Aquifer where they were discernable. In some areas of the Rustler Aquifer individual members were not discernable due to collapse and or dissolution. The Rustler Aquifer contains approximately 18,538,000 acre-feet of groundwater. Of the approximate 18 million acre-feet of groundwater, 88,000 acre-feet is fresh groundwater, 10,172,000 acre-feet is slightly saline groundwater, 7,905,000 acre-feet is moderately saline and 373,000 acre-feet is very saline. Due to unpredictable and generally low production rates within the Rustler Aquifer, the vast majority of the groundwater volume in the Rustler Aquifer would likely be uneconomical to produce.

The final part of the analysis defines potential production areas. In total, we evaluated five potential production areas. We used the Rustler Aquifer Groundwater Availability Model to estimate productivity of each potential production area and to evaluate potential impacts to freshwater resources and water use categories protected in House Bill 30. The ranking of potential brackish production areas on a productivity basis would be the following: potential brackish production zone 5; potential brackish production zone 4; potential brackish production zone 3; potential brackish production zone 1; and potential brackish production zone 2. The TWDB staff will take the results from this study and consider recommending potential production areas to be designated to brackish groundwater production zones by the Board.

Study deliverables include a study report, Geographic Information System map files, all data compiled in a BRACS Database format, and water well and geophysical well log files. In addition, codes used to calculate volumes, interpolated structural surface and model simulations to calculate production rates and potential impacts within potential production areas have been documented and delivered to the TWDB.

2 Introduction

The Rustler Aquifer is a TWDB designated minor aquifer in the state of Texas and underlies parts of Brewster, Culberson. Jeff Davis, Loving, Pecos, Reeves and Ward counties (Figure 2-1). The aquifer is designated as minor because it provides small quantities of water to a relatively small number of users. However, where it is the only source of water, the Rustler is a critical water resource to local users. The TWDB defines the boundaries of the Rustler Aquifer as the extent of groundwater with less than 5,000 milligrams per liter total dissolved solids.

The objective of this study is to characterize the quantity and quality of groundwater within the Rustler Aquifer and to evaluate potential production areas that can be used by TWDB staff to recommend brackish groundwater production zones. From there the Executive Administrator will make recommendations and the Board will designate the brackish groundwater production zones for the Rustler Aquifer. House Bill 30 provides direction to TWDB to identify and designate local or regional brackish groundwater production zones in areas of the state with moderate to high availability and productivity of brackish groundwater that can be used to reduce the use of fresh groundwater. Table 2-1 defines the criteria set forth in House Bill 30 to be used for designation of brackish groundwater production zones.

The TWDB designates brackish groundwater production zones. The purpose of this study is to provide the information necessary for the TWDB to designate brackish groundwater production zones for the Rustler Aquifer. To meet these objectives, INTERA and our team mates; Dr. Dennis Powers, Drs. Carlos Torres-Verdin and Jack Sharp from the University of Texas, the Bureau of Economic Geology Subsurface Library, DrillingInfo and WellGreen, LLC. collected and analyzed data to better define aquifer structure and transmissive units of the Rustler Aquifer, and water quality. Hydraulic calculations have been performed to provide guidance regarding the production potential of the Rustler Aquifer in potential production areas and the nature of impacts to protected users and freshwater within the aquifer. A summary of our approach will follow.

The Rustler Aquifer, which is wholly comprised of the Rustler Formation, is a complex assemblage of lithologies ranging from dolomite to limestone to anhydrite to halite to siltstone. In addition to a complex range of lithologies, post-depositional processes such as cementation, collapse, faulting, etc., have further complicated the ability to systematically define the Rustler Formation and differentiate its member units and its informal submember units (Figure 2-2 from Powers, 2008). In order to better understand the Rustler Formation as it relates to the Rustler Aquifer, INTERA performed a detailed stratigraphic analysis, initially focused on refining the Rustler Formation stratigraphy into its various member units and informal submember units (Figure 2-2). Adding 346 additional new geophysical logs to those available from Ewing and others (2012) and Meyer (2012), we analyzed 589 geophysical logs making approximately 5,000 stratigraphic picks providing insight into the specific depositional and post depositional regime of the Rustler Formation as it relates to the Rustler Aquifer. The hydrostructural zonation proposed in Ewing and others (2012), and results of the detailed hydrostratigraphic analysis performed in this study, was the framework used in this study to evaluate the hydrogeology of the Rustler Aquifer

While a significant emphasis of this project is on the acquisition and interpretation of geophysical logs for structure, stratigraphy and water quality, actual water quality samples from the Rustler Aquifer represent the most important dataset available. In support of this, a search for water chemistry samples from water wells (or recompleted oil and gas wells) that are producing from the Rustler Aquifer was performed. Large quantities of data were evaluated, and extreme care was taken to assure that the information that was being assigned to the Rustler Aquifer is an accurate portrayal of the Rustler water chemistry. The search for this data involved evaluating multiple online state databases, relevant publications, and inquiries to public and private Rustler Aquifer users. After the data were gathered, they were further evaluated to understand the data as they relate to the distribution of water quality. The data was also evaluated to better understand the relationship between the speciation of ions in Rustler Aquifer water and how it relates to resistivity from geophysical logs run in oil and gas wells.

From the beginning of this project, the INTERA team knew that, due to the complexity of the Rustler Formation geology and log availability, standard techniques used in the calculation of water quality from resistivity logs would not suffice in the Rustler Aquifer. This study used state-of-the art petrophysical analysis techniques to analyze geophysical logs for both porosity and water quality. Geophysical logs of much higher quality than surrounding logs were identified with respect to log type and signature quality. These well logs were designated as “key wells” and were used in combination with sensitivity analysis to better understand the sensitivities of geophysical logs in the Rustler Formation to the diverse range in petrophysical parameters found in the southern Delaware Basin (see Figure 2.2.1 in Ewing and others 2012 for map of Delaware Basin with respect to entire Permian Basin). The sensitivity modeling provided tremendous insights into log sensitivities in the project area, and these sensitivities subsequently guided the approaches taken to calculate petrophysical parameters for the Rustler wells.

In combination with the sensitivity analysis, the key wells were analyzed to determine porosity from neutron, sonic and resistivity logs and water quality (total dissolved solids in milligrams per liter), from resistivity logs. Prior to this work, traditional calculations of water quality were performed using methods such as the R_{wa} Minimum (Estepp, 2010) which is based on the Archie (1942) water saturation equation. As a result of this study, an approach to calculating water quality specifically within the Rustler Aquifer of the southern Delaware Basin has been developed. For future work, this approach can be field checked using water quality samples and additional petrophysical calculations on quality geophysical logs.

Calculations of water quality provided the additional data needed to better define the groundwater salinity zones within the Rustler Aquifer. Given that the water chemistry of the Rustler Aquifer is fairly vertically homogeneous, plan view contours of water quality breaks were interpreted for the project area, and the Rustler Aquifer was discretized based on water quality zones defined by Winslow and Kister (1956). Winslow and Kister define groundwater with less than 1,000 milligrams per liter total dissolved solids as fresh, 1,000 to 3,000 milligrams per liter as slightly saline, 3,000 to 10,000 milligrams per liter as moderately saline, and 10,000 to 35,000 milligrams per liter as very saline groundwater. These groundwater salinity zones were used to define three dimensional distributions of brackish groundwater within the Rustler Aquifer, and a tool was developed to make calculation of brackish groundwater volumes by geographic location.

Based upon mapping of salinity zones, INTERA calculated the volume of groundwater in place for the three transmissive members of the Rustler Aquifer: (1) the Magenta Dolomite, (2) the Culebra Dolomite and (3) the limestones of the Los Medaños. In addition, the volume of groundwater in place of the Rustler Aquifer was also estimated in areas where the Rustler Aquifer is suspected to be collapsed and acting as one unit from top to bottom. The Rustler

Aquifer contains approximately 18,538,000 acre-feet of groundwater. Of the approximate 18 million acre-feet of groundwater, 88,000 acre-feet is fresh groundwater, 10,172,000 acre-feet is slightly saline groundwater, 7,905,000 acre-feet is moderately saline groundwater, and 373,000 acre-feet is very saline groundwater. It is important to note that a large percentage of this groundwater would not be economical to produce.

The final part of the analysis defines potential production areas. In total, five potential production zones were evaluated in this report. The Rustler Aquifer Groundwater Availability Model (Ewing and others, 2012) was used to estimate productivity of each potential production zone and to evaluate potential impacts to freshwater resources and water use categories protected in House Bill 30. The TWDB will take the results from this study and consider whether to designate brackish production zones based upon our potential production zones.

Table 2-1. House Bill 30 Criteria for designation of Brackish Production Zones.

Criteria Type	Criteria for Designation of a Brackish Groundwater Production Zone
Water Quality	Has an average total dissolved solids level of more than 1,000 milligrams per liter.
Hydraulic Isolation	Separated by hydrogeologic barriers sufficient to prevent significant impacts to water availability or water quality in the area of the same or other aquifers, subdivisions of aquifers, or geologic strata that have an average total dissolved solids level of 1,000 milligrams per liter or less at the time of designation of the zone.
Aquifer Use	Is not serving as a significant source of water supply for municipal, domestic, or agricultural purposes at the time of designation of the zone.
Aquifer Use	Is not in an area or geologic stratum that is designated or used for wastewater injection through the use of injection wells or disposal wells permitted under Texas Water Code, Title 2, Subtitle D, Chapter 27.
Regulatory Jurisdiction	Is not located in: an area of the Edwards Aquifer subject to the jurisdiction of the Edwards Aquifer Authority; the boundaries of the: (a) Barton Springs-Edwards Aquifer Conservation District; (b) Harris-Galveston Subsidence District; or (c) Fort Bend Subsidence District.

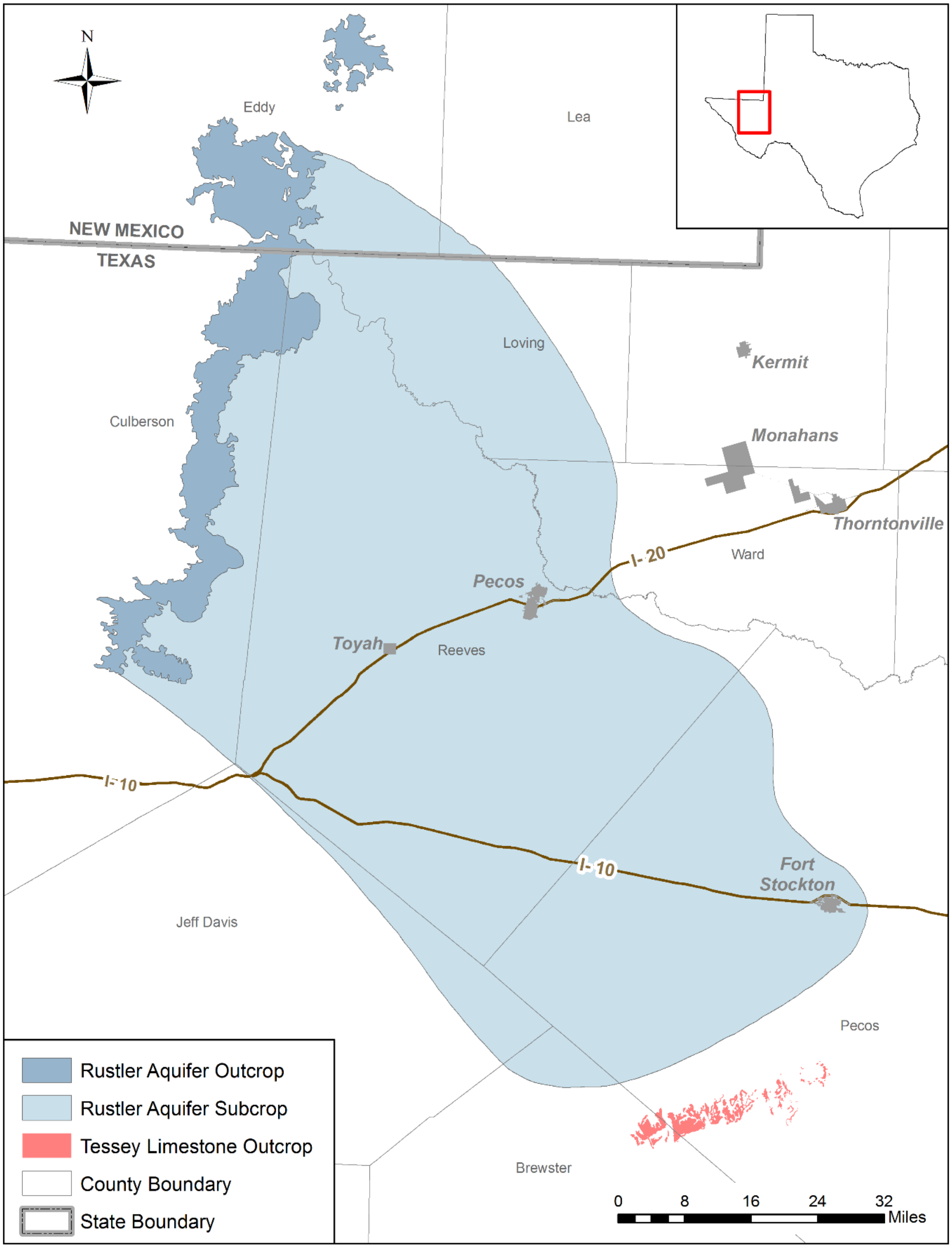

Figure 2-1. Project area base map.

Tessey Limestone outcrop shape file comes from USGS Texas Water Science Center and the Texas Natural Resource Information Center, 2004.

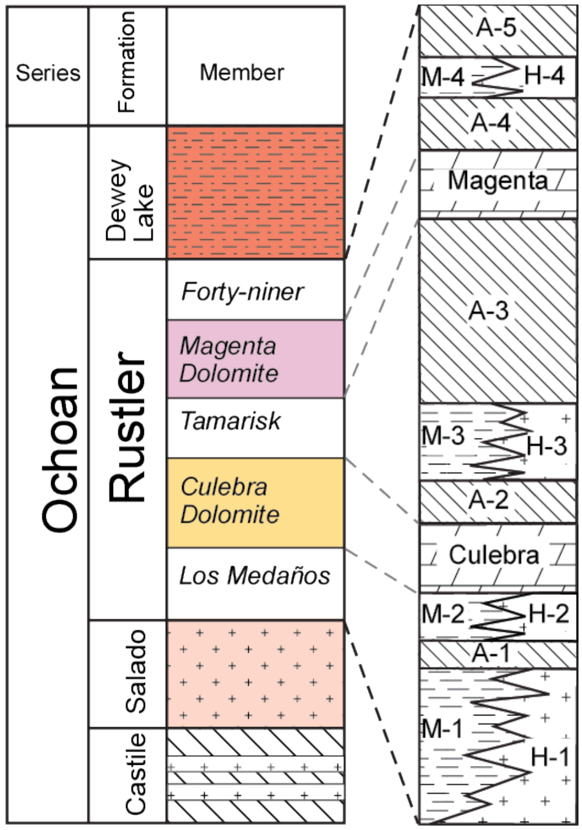

Figure 2-2. Stratigraphic section from Powers (2008) showing the Upper Permian Ochoan series stratigraphy in the Delaware Basin of West Texas and New Mexico.

Note: For the informal submember units, "A" stands for Anhydrite, "M" stands for Mud and "H" stands for Halite.

The Rustler Formation is subdivided into its member units and informal submember units. The Delaware Mountain Group occurs below the Castile in the majority of the project area. Lateral equivalent units, mainly the Capitan/Goat Seep Reefs and members of the Artesia Group, occur beneath the Castile Formation in the southeastern portions of the project area.

3 Project deliverables

This report contains information on: the project area; the hydrogeologic setting; groundwater salinity zones; information on previous investigations; a summary of data collection and analysis methods and results; aquifer hydraulic properties; sampled water quality data including dissolved minerals and radionuclides; the methodology for calculating groundwater volumes; the methodology for geophysical well log analysis; discussion on the modeling methodology and results for potential brackish groundwater production areas including a pumping analysis and results for 20- and 50-year periods; and recommendations for future improvements and study conclusions. In addition, figures generated for this report, the accompanying ArcGIS files (.mxds, shp and raster files) and both digital (Log ASCII Standard) and Tagged Image File Format (.tif) geophysical logs that were used in the analysis of structure, stratigraphy and water quality have been provided as part of the deliverables for this project. All of the associated metadata for the geophysical log analysis has been uploaded into a copy of the BRACS database using formats consistent with Meyer (2014). These, and files accompanying the groundwater model runs have been provided on a two terabyte hard drive to the TWDB.

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4 Project area

The project area encompasses portions of Brewster, Culberson, Jeff Davis, Loving, Pecos, Reeves and Ward counties and is coincident with the boundaries of the Rustler Aquifer as defined by the TWDB (George and others, 2011). The Rustler Aquifer exists in the outcrop and portions of the subcrop of the Rustler Formation in the Trans-Pecos area of West Texas. In Texas, the Rustler Formation outcrop exists in a relatively narrow band oriented approximately north-south and located slightly west of the Culberson-Reeves county line. The outcrop is located in Rustler Hills, from which the formation obtained its name. The location of the project area is shown in Figure 2-1, with the outcrop and downdip portions of the Rustler Aquifer in Texas as defined by the TWDB and presented in George and others, 2011. In addition, outcrops of the Tessey Limestone are also shown in Figure 2-1 because several investigators believe that the Tessey Limestone may act as surface recharge area similar to the Rustler Formation outcrop in Culberson County. The boundaries of the project area are restricted to the boundaries of the Rustler Aquifer only in Texas. In the development of the Groundwater Availability Model (Ewing and others, 2012), the spatial extent of the Rustler Aquifer was extended beyond the official TWDB boundaries into New Mexico, but these areas of the aquifer are not part of this project.

The project area intersects several groundwater regulatory jurisdictional boundaries, including groundwater conservation districts and underground water conservation districts, groundwater management areas and regional water planning groups. Groundwater conservation districts or underground water conservation districts in the project area include small portions of the Brewster County Groundwater Conservation District, the Jeff Davis County Underground Water Conservation District, portions of the Middle Pecos Groundwater Conservation District, and the Reeves County Groundwater Conservation District (Figure 4-1). The project area intersects portions of three groundwater management areas; Groundwater Management Areas 3, 4, and 7 (Figure 4-2). The project area intersects portions of the Far West Texas (E) Regional Water Planning Area and the Region F Regional Water Planning Area (Figure 4-3). The Rustler Aquifer does not exist within the boundaries of any River Authority. The Rustler Aquifer is contained wholly within the Rio Grande basin.

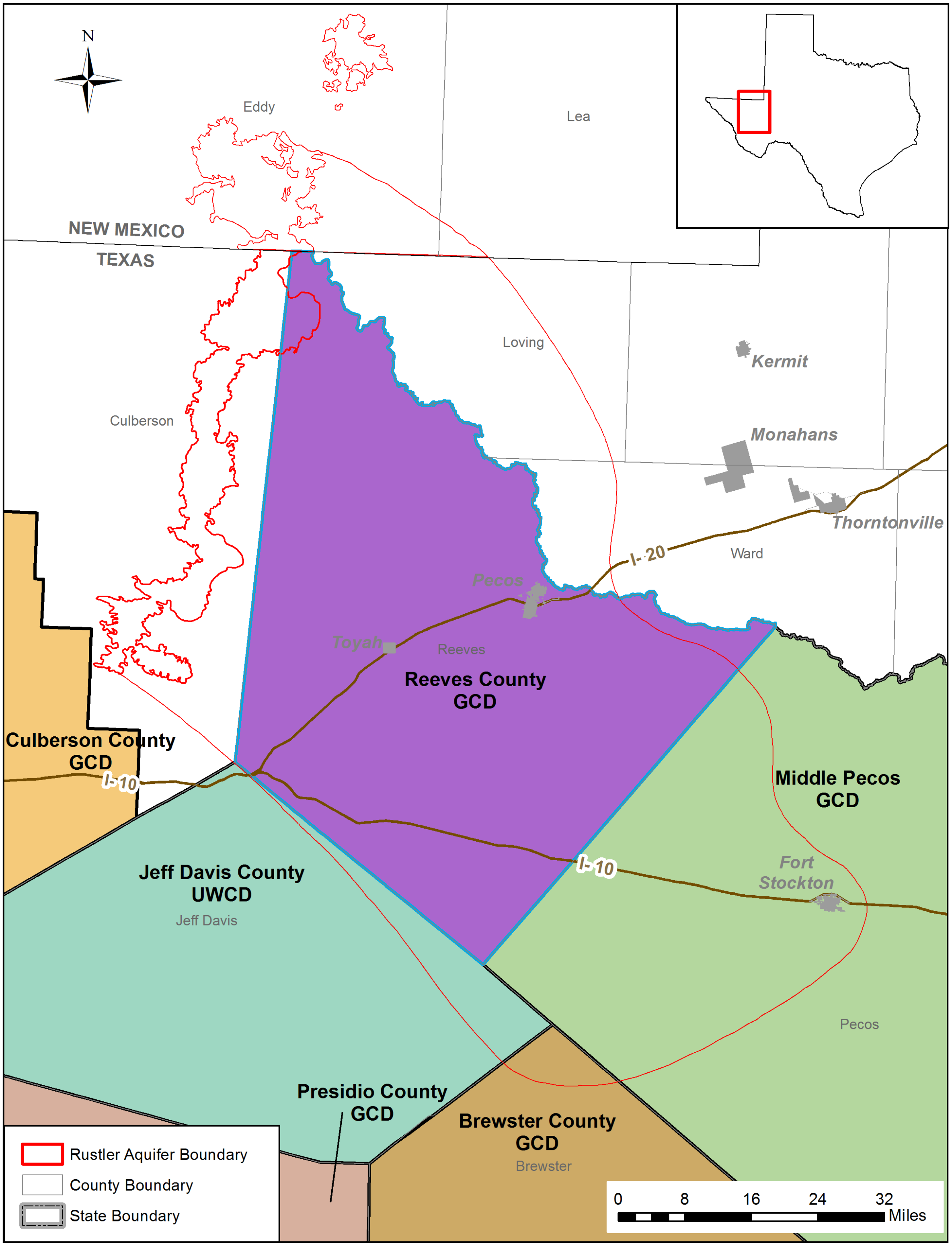

Figure 4-1. **Groundwater conservation and underground water conservation districts in the project area.**

Note: GCD=Groundwater Conservation District; UWCD=Underground Water Conservation District

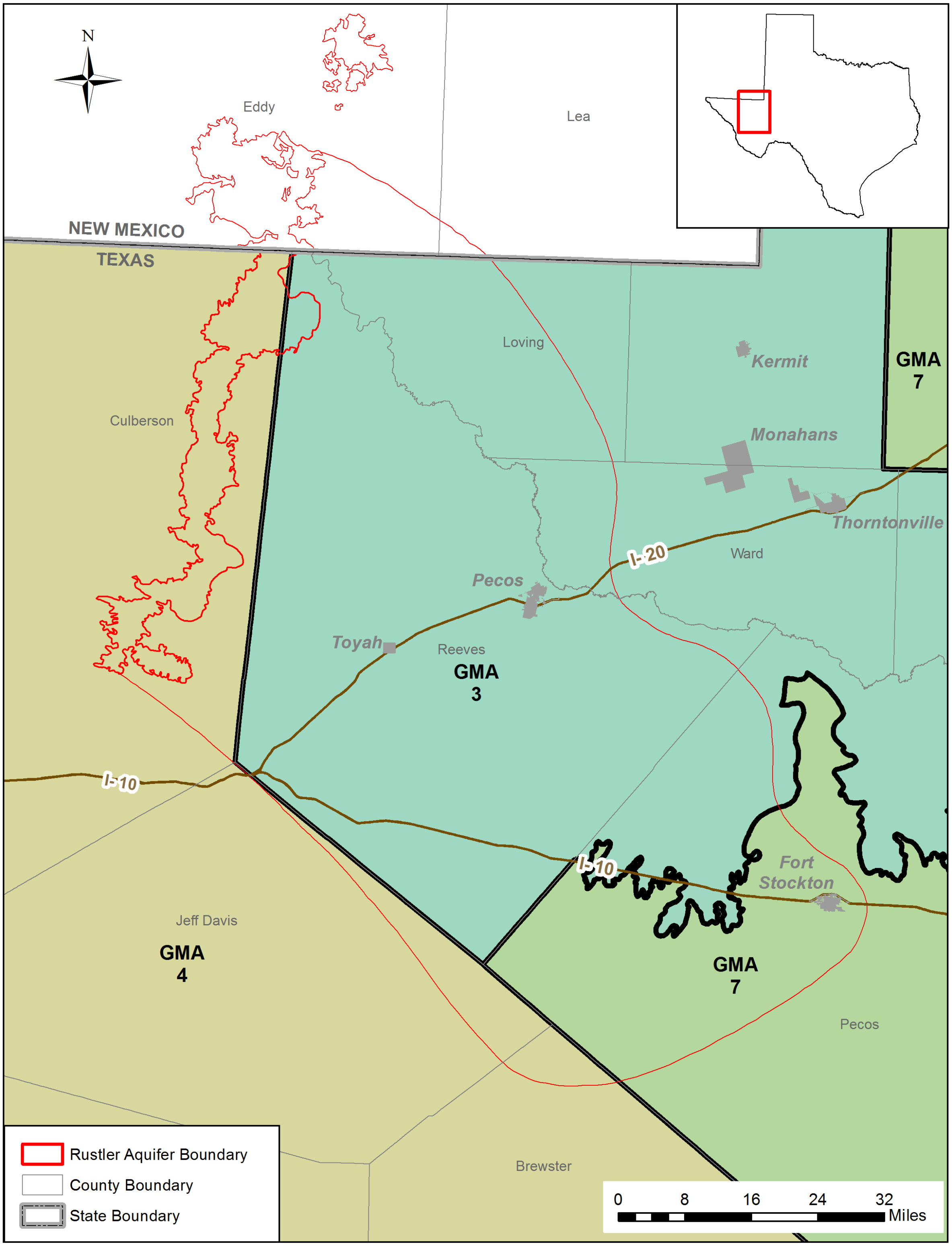

Figure 4-2. Groundwater management areas in the project area.

Note: GMA=Groundwater Management Area

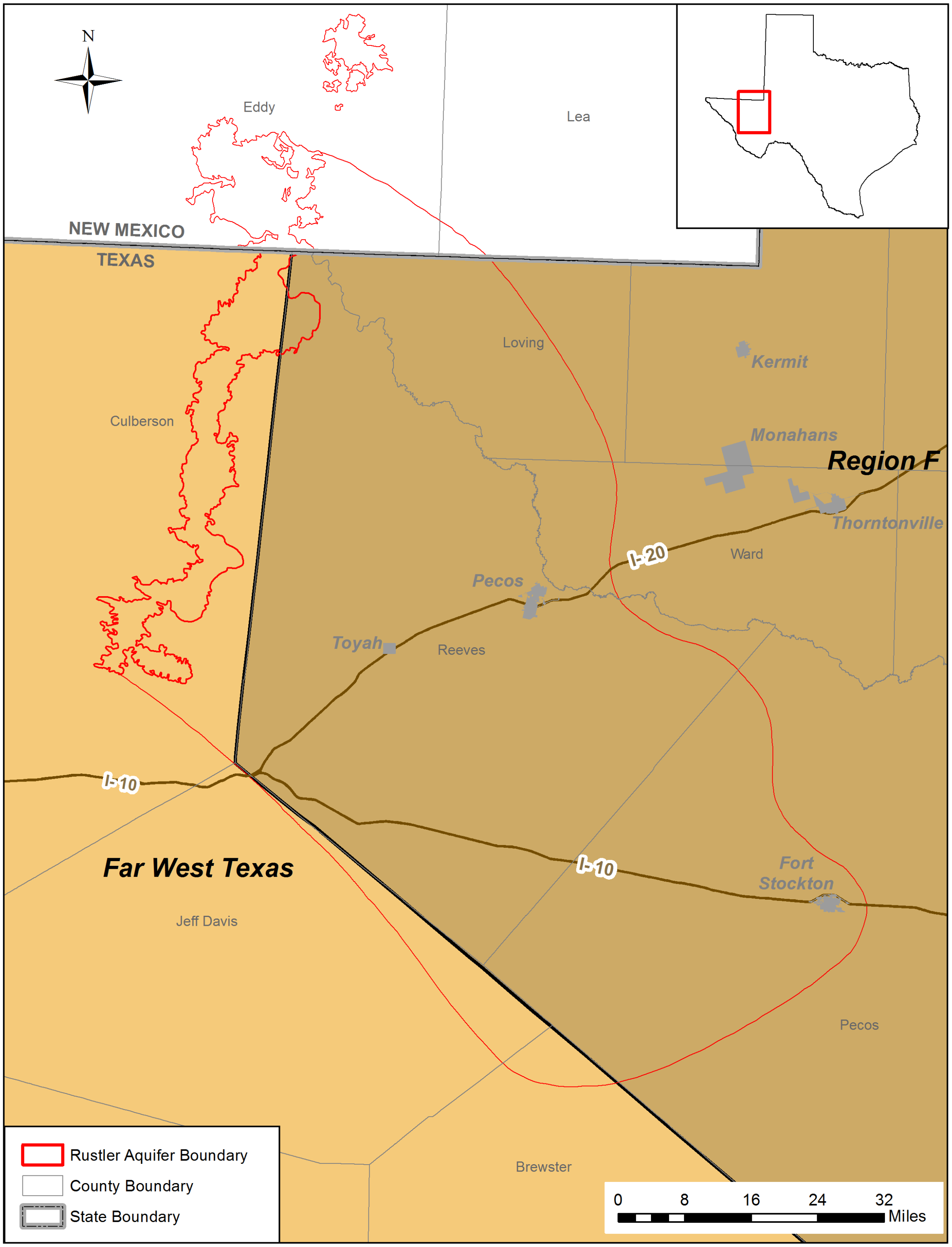

Figure 4-3. Regional water planning groups in the project area.

5 Hydrogeologic setting

5.1 Stratigraphy and structure of the Rustler Formation

The stratigraphy and structure of the top and base of the Rustler Formation was developed by Ewing and others (2012) in support of a Rustler Aquifer groundwater availability model. While these surfaces are an accurate regional model of the structure of the top and base of the Rustler, additional detail on the member units and informal submember units of the Rustler Formation was necessary for this study in order to understand the distribution of the main hydrostratigraphic units. In support of this, INTERA used geophysical logs run in oil and gas wells to build a more detailed geologic and lithologic model of the Rustler Formation, its member units and its informal submember units. Picks were made for each of the Member Unit and informal submember unit tops, shown in Figure 2-2.

Geological data comes chiefly from geophysical logs interpreted for this project or from prior projects (e.g., Rustler groundwater availability model – Ewing and others, 2012 or Meyer, 2012). Rustler outcrops exist in the western end of the aquifer footprint and locally along the Pecos River. In addition, if the Tessey Limestone is a lateral, or time, or both lateral and time equivalent unit to the Rustler Formation, there is also outcrop in the Glass Mountains to the south of Fort Stockton (Figure 2-1). Geologists (Lupton and Powers) undertaking the geological interpretation have also been responsible for numerous on-site geological evaluations of Rustler Aquifer water wells drilled within the aquifer footprint. The data for these wells are proprietary, but the experience gained helps guide the interpretation of the geology of the Rustler Formation.

An initial phase of this project involved creating a series of north-south and east-west cross-sections across the Rustler Aquifer footprint. These sections used the Tagged Image File Format (.tif) files for each of the geophysical logs, and interpretations of the structure and stratigraphy were made using primarily the gamma ray and porosity signatures. Where there was a spontaneous potential and resistivity log, stratigraphic inferences could be made by looking at the resistivity spikes and troughs relative to the anhydritic and silty submember units of the Rustler Formation.

Interpretations made by Dennis Powers prior to and including the Rustler groundwater availability model structure (Ewing and others, 2012) lead to the discretization of the Rustler Formation into structural subdomains. These subdomains reflect the structural complexity of the Pecos-Loving and Monument Draw Troughs and the intervening structural high between the two troughs (see Figure 3.0.1 of Ewing and others 2012 for reference). The subdomain approach to characterizing the Rustler Formation has been adopted with modification in this study. In addition, the distribution of the major water-bearing units (Magenta Dolomite, Culebra Dolomite and limestones of the Los Medaños Unit) will lead to a further discretization of the project area based upon stratigraphy, using the following criteria:

1. Zone 1 - Individual member units are not consistently distinguishable, and collapse due to karstification is suspected;

2. Zone 2 - All of the individual member units are consistently distinguishable, and the hydraulic potential of the zone is the combination of the Magenta Dolomite, Culebra Dolomite and limestones of the Los Medaños Unit;
3. Zone 3 - Member units above the Tamarisk are consistently eroded, and the hydraulic potential of the zone is the combination of the Culebra Dolomite and limestones of the Los Medaños Unit.

More about how the Rustler Aquifer will be discretized into hydrostructural subdomains (generally referred to as subdomains in this report) will be addressed in later portions of this section.

The geophysical log analysis program Petra® has the capability to display these cross-sections relative to a single stratigraphic horizon (stratigraphic mode), for example the top of Rustler Formation, or relative to mean sea level (structural mode). The stratigraphic and lithologic assessments were made primarily in the stratigraphic mode, using top of Rustler as the main reference horizon. Stratigraphic mode is the best for interpreting lateral differences in deposition, especially with a regionally extensive and continuous marker bed such as the A5, A4 or A3 anhydrites when they occur at the top of Rustler Formation, representing the distinctive boundary between the Dewey Lake and Rustler Formations. Structure mode displays the post-depositional changes in the geologic units and allows for the interpretation of fault location(s) and geometry. In stratigraphic mode, with the wells artificially placed one inch apart, it was immediately apparent that the Member and submember units of the Rustler Formation were laterally extensive and, where they were not laterally extensive, it was predictable and consistent.

5.1.1 Stratigraphy

Figure 5-1 shows two type logs in the northern and central portions of the Rustler Aquifer extent with stratigraphy and lithology identified. To determine general lateral continuity, each of the five member units of the Rustler Formation (Los Medaños, Culebra Dolomite, Tamarisk, Magenta Dolomite, and Forty-niner, from base to top) were distinguished where possible. Two stratigraphic cross-sections (P-P’ and P1-P1’) were prepared that illustrate the continuity and general differences from north to south and west to east within each of the Member and submember units of the Rustler Formation. The locations of these two cross-sections are shown in Figure 5-2 and the actual cross-sections are given in Figures 5-3 and 5-4. These sections were done with an enforced horizontal spacing of approximately one inch and were “hung” on the top of the Rustler Formation. Informal submember units of the Rustler Formation (Figure 2-2 and also Figure 2 in Powers, 2008) were identified, when possible, for greater detail and information about lateral changes that might help distinguish hydrologic regions. For example, in subdomain 4 and zone 3 (Figure 5-10), units above the Tamarisk Member, mainly the Magenta Dolomite, appeared to be consistently eroded away. Hence, the Rustler Aquifer in this area is comprised of the Culebra Dolomite and limestones of the Los Medaños Formation.

The Rustler-Dewey Lake transition is one of the most widely recognized contacts in the Permian Basin, both from geophysical logs and early work based on cuttings. Many geophysical logs are annotated by individual geologists or geophysicists to show “1st anhydrite” or “Rustler.” In general, there is no variance here from that history. Toward the southeastern margin of the project area, however, our work indicates that pre-Dewey Lake erosion has likely removed some of the uppermost Rustler Formation units. Some logs display low natural gamma intervals above the obvious top of Rustler contact, and these may represent partially dissolved remains of upper Rustler Formation sulfate. The signatures are not clear, and we have tended to place these as part of the basal Dewey Lake. Currently, no official standard exists in the southeastern margin of the aquifer area for how to assign the contact specifically. In those cases, we worked from the Los Medaños pick and tried to clearly identify the Member and sub member units until a logical Dewey Lake-Rustler transition could be picked. This process, along with building sections from west to east and north to south, gave rise to the thesis that the Magenta Dolomite had been eroded away in the eastern to southeastern portion of the project area and needed to be treated accordingly when interpolating the raster surfaces of the Member and submember units.

The Salado-Rustler transition is clear in the northern area and is not always clear to the south and around the margins of the project area. We have taken a more inclusive approach: a deeper, thicker interval displaying higher natural gamma is more likely to be included as Rustler Formation in some areas, whether it truly belongs to the Rustler Formation depositional system or might be an amalgamated upper Salado. Our experience indicates that the main potential water-bearing interval in the Los Medaños is carbonate and lies well above “extra” Rustler Formation that may be included here. This approach is slightly different than the one taken by Ewing and others (2012) and will result in a consistently lower pick for the Rustler-Salado contact and in turn a slightly thicker Rustler Formation.

Figure 5-1 displays differences between the northern end of the Rustler aquifer footprint and the central-south area. Informal units of the Rustler are clearly identified, and principal lithologies are shown for each informal unit, as well as the two formal members that are carbonates. This two-log cross-section also identifies differences in the Los Medaños Member between the carbonate water-bearing portions (central part of the aquifer footprint) and potentially equivalent zones to the north that appear to be halite or halite-cemented sand. The Los Medaños is known to include carbonates in the southern Delaware Basin (Eager, 1983) but not in the northern Delaware Basin in and around the Waste Isolation Pilot Plant site. The acoustic velocity of this interval in 30-025-08302 is the same as the halite in the upper Salado Formation in this well, leading us to believe that it is halite-cemented. Because of this lateral facies change, the northeastern end of the footprint has fewer zones in the Los Medaños interpreted as carbonate and, potentially, water-bearing. However, given the ambiguity of the limestone signal in this area on many of the logs, we assumed that the limestone of the Los Medaños was generally present in this area, but its water resource potential is considered to be greatly reduced by halite cementation as compared to areas of the aquifer to the south with less ambiguous log picks.

The geophysical log (42-389-00802) from south-central Reeves County is near areas where cuttings from a water well clearly identified carbonate (mainly limestone) in the Los Medaños. The log signature for this well served as a template for much of the interpreted carbonate zones in the Los Medaños. This carbonate signature tends to have a natural gamma higher than background, may overlie a thin low-gamma zone (sulfate?), and may increase natural gamma upward to another thin low-gamma zone. At the north end of the aquifer footprint, the Los Medaños displays a characteristic high natural gamma further down in the member that decreases upward. Within the aquifer footprint, a thin (20-30 feet) interval of low gamma shows acoustic velocity very consistent with either halite, or halite-cemented sandstone, for this interval.

To the extent possible, we interpreted these limestone signatures from the Los Medaños throughout the footprint of the Rustler Aquifer. These carbonates are not present in the northern Delaware Basin, to the north of the aquifer footprint, but they represent expanded hydrologic potential for the aquifer as a whole. Areas in the northern portion of the aquifer footprint should be treated with caution with respect to the presence of limestones of the Los Medaños due to the fact that it is suspected that this area represents the beginning of the transition from limestones in the south into an equivalent halite cemented sand in the north.

The Culebra Dolomite and Los Medaños on a reference geophysical log (42-389-00802 on Figure 5-1) from southern Reeves County have been interpreted based on experience from proprietary work in a similar area. The Culebra here is much thicker than in the northern Delaware Basin, and the signature from well 42-389-00802 has been used to interpret the Culebra where it appears to be thicker. Possible explanations are that the upper carbonate in this thicker unit is restricted to the Texas portion of the Delaware Basin, or that it is partially equivalent to the overlying sulfate bed (informally A-2) in the northern Delaware Basin.

Our experience across the Permian Basin also indicates that the Culebra was deposited after a widespread transgression (e.g., Holt and Powers, 1988; Powers and Holt, 1999), and the underlying mudstone/claystone provides an important marker in natural gamma logs beyond even the carbonate deposition (Powers, 2008). Likewise, the informal A-1 in the Los Medaños Member and A-3 (the upper sulfate of the Tamarisk Member) are very widespread, useful stratigraphic markers with good log signatures. Each of these beds represents a regional freshening of the paleo-depositional environment that contrasts with the paleo-depositional environment of underlying beds.

At the Waste Isolation Pilot Plant site, the Culebra is the most significant hydrologic unit in the northern Delaware Basin. Here, it is assumed to be significant, but data are too scant to assert its relative hydraulic properties as compared to the other Rustler members. From our field experience, the carbonate(s) of the Los Medaños are significant groundwater sources in the southern part of the basin and may exceed the Culebra in productivity. The Magenta can bear water locally elsewhere; although it is present in the southern Delaware Basin, its hydrologic potential there is practically unassessed to our knowledge. It is assumed to have some import, but our assessment is based primarily on the stratigraphic distribution of the Magenta, as opposed to knowledge of its hydraulic characteristics in the southern Delaware Basin.

For initial quality control on Rustler Formation stratigraphy and carbonate intervals, all of the geophysical logs were rechecked, especially with respect to details of the upper Rustler Formation around the boundary of the aquifer footprint. Erosion (or possibly some upper Rustler Formation solution) prior to Dewey Lake deposition apparently altered the upper Rustler Formation around much of the aquifer boundary. Petra® was used to create temporary short cross-sections (generally <12 logs), with common overlap with one or more wells where logs had previously been checked. In most cases, minor adjustments to the stratigraphic picks were needed to provide consistency. Assigned carbonate intervals in the Los Medaños from initial work were again examined for every well in short, commonly overlapping, cross-sections. As the transition area north of Pecos became more evident, some of these wells were revisited several times to increase confidence and consistency in the assignment (or removal) of interpreted carbonate zones. All picks, along with associated metadata, were tabulated in Appendix 19.5, provided as a GIS shape file and imported into the BRACS database.

5.1.2 Structure

As a result of previous work in the southern Delaware Basin, the INTERA team knew that the structural configuration of the Rustler Formation was going to introduce complexity into the characterization. With the main goal of identifying the stratigraphic continuity, or lack thereof, of the Member and submember units completed, the next task was to better understand how the structural distribution of these units had been altered by post-depositional processes, mainly dissolution related collapse. In general, the structure of the project area is dominated by the Pecos-Loving and Monument Draw Troughs (subdomains 9 and 4 respectively) and the structurally more stable areas flanking the troughs (subdomains 10, 8 and 7) (Figure 5-2).

Collapse and subsequent faulting in the area is attributed to dissolution of the Salado and Castile evaporites. To help distinguish these effects from tectonic events, the elevation of the Castile-Delaware Mountain Group contact has been picked on the majority of the wells (447 out of 589, see Appendix 19.5). Given a relatively quiet post-depositional structural environment, the top of the Delaware Mountain Group within the Rustler Formation footprint is relatively flat when compared to the Rustler Formation. One exception to this is in subdomain 5, where it appears that the faulting that upthrew the Glass Mountains also impacted the pre Ochoan rocks in the area. In areas where the Rustler Formation top has been significantly down-faulted, collapse in the Salado and/or Castile Formations is suspected to have occurred, and the overall thickness of those units, as determined from subtracting top of Salado Formation from top of Delaware Mountain Group, has thinned substantially when compared with areas where the Rustler Formation has not been downthrown.

After making all of the Rustler Member and submember unit picks, the stratigraphic cross-sections were then converted into structural cross-sections. It was immediately apparent that faulting and dissolution collapse affected the project area on both a local and regional scale. Large areas of the aquifer footprint display evidence of major elevation differences for various Rustler Formation member units. Localized dissolution induced fault graben structure can have throws in excess of 1,000 feet. To better relay these points, four structural cross-sections were created. The locations of the four cross-sections are shown in Figure 5-5 and the actual cross-sections are given in Figures 5-6 through 5-9. The geophysical logs are displayed at a common vertical scale and relative to sea level (equivalent to subsea depth commonly used in petroleum geology). In addition, the distance between each log baseline is scaled according to the distance between wells represented in the cross-section. The natural gamma is not normalized to account for hole diameter, open or cased hole, or other factors.

The Rustler Formation is the formation of interest, but the Dewey Lake Formation and some of the upper Salado Formation are also represented in the cross-sections. Contacts for the formal member units, as well as some informal submember units (Figure 2-2; see also Powers, 2008), are identified by name and/or number. The three most likely water-bearing intervals (Magenta Dolomite, Culebra Dolomite, and limestones of the Los Medaños) are colored blue-green with carbonate lithologic symbols.

Faults have been inferred along these cross-sections where the displacements are more significant across relatively short distances. Regarding structure, two things are of note: (1) with the exception of the area north of the Glass Mountains and south of Fort Stockton (Oates Field area), the top of the Delaware Mountain Group does not generally indicate faulting with such displacements; and (2) that the intervening soluble evaporites of the Salado and Castile have not been so thoroughly interpreted as to determine where solution and collapse may be concentrated. It was hypothesized that we would be able to use marker beds in the Salado, mainly the Vaca Triste sandstone, to better understand collapse but, these marker beds were not able to be consistently picked in the wells. An evaluation of each of the four structural cross-sections is provide below.

Cross-Section 0-0’

Cross-Section 0-0’ (Figure 5-6) runs the length of the project area from north to south, and it is a key cross-section into which east-west cross-sections are tied. The vertical scale on the cross-section is approximately 130 times the horizontal scale. The central two-thirds of the cross-section is bounded by interpreted faults and show the main properties of subdomain 9, the largest within the project area boundaries. These fault locations are generally consistent with hydrostructural domains proposed by Ewing and others (2012) and serve to represent the main bounding faults between subdomains 9 and 8 to the north and subdomain 5 to the south. The faulting between wells 10513 and 35149, and in turn subdomains 9 and 5, appears to be more severe the farther west one goes along the fault separating those two regions. It is possible that the geometry of this fault could result in a more consistent connection between the upthrown and downthrown portions of the Rustler Formation on the eastern side than on the western side.

At the northern end of the cross-section, the effects of erosion (removing upper Rustler Formation) and solution are apparent, and some of the logs are classified as “collapse.” As explained elsewhere, this designates areas where, in general, we interpret dissolution to have removed or damaged the stratigraphic relationships to the point that unit identifications are limited. The southern end of the cross-section also is classified this way, although we remain uncertain of the extent of facies changes and transition into the Tessey Limestone (Formation). Subdomain 9 has good internal consistency, all three potential water-bearing intervals are present, and it represents a significant target overall for exploitation of brackish water.

From the structural high at the north end, there is apparent dip to the south-southeast along the cross-section. One of the logs (00594) at the structural high presents interpretive difficulties, with an apparent greatly thickened Los Medaños. This log illustrates the decision to include more of the high-gamma zones in the Rustler Formation, although they may be amalgamated upper Salado Formation. Note that the adjacent log (31270) presented what appears to be a more distinctive basal Rustler Formation, and the Rustler-Salado contact was interpreted accordingly.

This cross-section also illustrates the relatively thin Magenta that characterizes much of the project area. In general, our experience suggests that it is unlikely to very productive over the project area, presumably due in large part to its thinness.

The Culebra, as interpreted here, is generally considerably thicker than is found in the northern Delaware Basin. Experience from wells nearby in Subdomain 7 reveal that the carbonate thickness is much greater, and this has directed interpretation of the geophysical logs. Some of the logs show a signature within the lower interpreted Culebra that is very similar to that in the northern Delaware Basin. We are unable to determine, on the basis of available information for this study, whether the Culebra is simply thicker to the south or if beds above the Culebra to the north have carbonate facies to the south. Here, we simply designate the entire carbonate interval as Culebra.

Of note, we were not able to find good log coverage between wells 31421 and 32331. Several nearby wells were hung between these two wells, but the wells were to the west and updip within the Pecos-Loving Trough. Adding these wells between 31421 and 32331 resulted in an artificial "upthrow" of the Rustler Formation, so they were removed and the area was appropriately labeled in the section.

Cross-Section 1-1'

Cross-section 1-1' (Figure 5-7) generally parallels 0-0', running from the north end of the project area to the south-southeast near Fort Stockton. It traverses several subdomains, with Subdomains 9, 7 and 4 mostly represented. The scaling and representation of logs and features is the same as for Cross-section 0-0 with the exception of the vertical scale which is approximately 90 times the horizontal scale.

In contrast with 0-0', Rustler Formation units are well represented across the section, with no area interpreted as "collapse". The major structural transitions representing the hydrostructural boundaries can be clearly seen on this section. However, the specific orientation of the cross-section serves to "smear" the faulting as the section transitions from subdomain 7 into subdomain 9. This, combined with the significant localized faulting/solution collapse (called breccia pipes by some researchers, Meyer, 2012 for example), accurately displays some of the significant structural elevation changes that can happen in this specific area. It is clear that the Pecos River and the occurrence of localized collapse in southwestern Loving and western Ward Counties are coincident. In general, sharp structural changes are evident and more significant along this cross-section, compared to 0-0'. More faulting (compared to 0-0') has been interpreted, and the northern end of the cross-section is more disrupted than is the southern end.

The southern end of Cross-section 1-1' in Subdomain 4 exhibits evidence that upper Rustler Formation units (A5 and M4) have been thinned or completely removed, likely by erosion before the Dewey Lake was deposited. The transition from Subdomain 7 to Subdomain 4 represents the transition from the stable platform in between the Pecos-Loving and Monument Draw Troughs into the Monument Draw Trough subdomain. However, unlike the Pecos Trough, the Monument Draw Trough has a clear plunge to the north that results in much subtler faulting south of Fort Stockton when compared to north of Fort Stockton.

Cross-Section A-A'

Cross-section A-A' (Figure 5-8) is a west-east cross-section, in the northern part of the project area, intersecting both 0-0' and 1-1'. The west end (A) starts in the Rustler Hills outcrop area; the eastern end (A') extends just outside the project area near Monahans, Texas. The scaling and representation of logs and features is the same as for Cross-section 0-0, with the exception of the vertical scaling, which is set at roughly 70 times the horizontal scale.

Cross-section A-A' displays all the complexities of importance in these cross-sections: numerous displacements interpreted as faults; difficult-to-interpret logs classified as "collapse"; erosion of the upper Rustler Formation; a complicated upper Salado-Rustler contact; and higher dip on the west (and north) with much reduced dip to the east (south).

As elsewhere, there is general correspondence between the hydrostructural subdomains and the continuity of log intervals as they cross these subdomains. Greater detail, with more logs, shows that the subdomains are more complicated than presented in the Rustler groundwater availability model (Ewing and others, 2012).

It is not clear that the displacements inferred in the cross-section will necessarily extend great distances and prevent hydrologic continuity. Nevertheless, the two lower potential water-bearing units (Culebra dolomite and limestones of the Los Medaños) are identifiable in most logs, with the exception of the limestones of the Los Medaños, which is intermittently present in wells 32272 through 31489. The limestones of the Los Medaños are represented with question marks in some of these wells because the geophysical signature of the limestone was difficult to interpret. The Magenta is thicker here in the north than in much of the south, and it may have more hydrologic potential than in the south.

Cross-Section B-B'

Cross-section B-B' (Figure 5-9) is oriented west to east and approximately parallels Interstate 10 through the southern end of the project area. It crosses Subdomains 9, 7, and 4. Cross-section B-B' intersects both 0-0' and 1-1'. The scaling and representation of logs and features is the same as for Cross-section A-A', including the vertical scaling which is set at roughly 100 times the horizontal scale.

B-B' presents a different structural pattern compared to the other three cross-sections. The western end, in Subdomain 9, is synformal. All members and informal units are interpreted as present and persistent. It is possible that the lower structural points offer greater hydrologic potential. A fault is interpreted that is the boundary between Subdomains 9 and 7 and represents complete displacement of the Rustler Formation.

Subdomain 7 is bounded by inferred faults, and the Rustler Formation is antiformal, with the eastern limb lower than the western. The uppermost Rustler Formation appears to be missing from the eastern limb of the antiform, but all potential water-bearing carbonates are present and appear continuous.

Subdomain 4 is mildly synformal, with a higher eastern limb. The principal characteristic of this part of the log cross-section is that the upper Rustler Formation has been removed, down to the upper Tamarisk (A-3) in some logs. This is similar to the southeastern end of 1-1'. The Culebra and carbonate of Los Medaños are persistent although they are both somewhat thinner than some of the central areas in the north to south cross-sections.

5.2 Relationship between stratigraphy, structure and hydrogeology

When comparing areas of significant faulting in the Rustler Formation with the structural subdomains developed by Ewing and others (2012), it is immediately apparent that the structural subdomains provide a means to account for the major faults within the project area. More localized minor structural features were noted but not incorporated into the interpolation of regional surfaces because they likely had minimal effect on the regional hydrochemistry or volumetrics of the Rustler Aquifer.

The distribution of the member units had direct implications on the hydrogeologic interpretations. In the majority of the project area, the A5 anhydrite of the Forty-niner Member is situated at the top of the Rustler Formation. The transition between the high gamma siltstone of the Dewey Lake Formation and the low gamma anhydrite of the Rustler Formation is what makes the characteristic signature of the Rustler-Dewey Lake contact. In the southeast portion of the aquifer extent, the top of the Rustler Formation transitions from A5 to A4. In these areas, the Rustler-Dewey Lake contact is still characteristic but, the A5 and M4 have been eroded. Even farther to the southeast, the top of the Rustler Formation is represented by the Tamarisk Member Unit (Subdomain 4 Zone 3 in Figure 5-10). Wells to the south and west that are marked as collapsed represent areas where the various member units of the Rustler Formation are more consistently unidentifiable and likely due to collapse. We hypothesize collapse for two main reasons: (1) field investigations of the Rustler Formation outcrop in the Rustler Hills and various other sites to the north clearly shows that the Rustler Formation is karstified, collapsed and has significant recharge features, and (2) in the southern portion of the aquifer, recharge is suspected from the Glass Mountains and would likely create a similar dissolution/recharge situation.

For purposes of classification in this report, we modified the structural (see Figure 4.2.10 of Ewing and others, 2012) and hydrostructural (see Figure 4.6.6 of Ewing and others, 2012) subdomains. We adopted the hydrostructural subdomain terminology. Hydrdostructural subdomains in this report (informally referred to as subdomains in this report) were developed using a combination of the structural subdomains proposed by Ewing and others (2012), along with stratigraphic boundaries that demarcate the transition zones between areas that have all three major water-bearing units (Zone 2), areas that only have the lower two major water-bearing units (Zone 3) and areas of suspected collapse (Zone 1) (Figure 5-10). Areas identified as collapse are in Zone 1 and occur in outcrop to the northwest, immediately down dip from outcrop in the southwest and in the south (Figure 5-10). In all three hydrostructural subdomains, collapse is likely related to recharge and dissolution of the underlying evaporites. For zones of collapse, the Rustler Aquifer is characterized by the entire Rustler Formation. Areas with an entire section of Rustler member units are designated as Zone 2. Zone 2 occupies the majority of the Rustler Aquifer extent and represent an area where we identified all three water-bearing units: Magenta Dolomite, Culebra Dolomite and limestones within the Los Medaños Unit. In Zone 2, the Rustler Aquifer is comprised of the three previously mentioned hydrostratigraphic units. Zone 3 represents an area where the top of Rustler is represented by the top of the

Tamarisk Member Unit (A3). In this area, it is suspected that the Magenta Dolomite has been extensively eroded, and any remaining portions of the unit are disconnected and do not represent a consistent, laterally connected resource. In Zone 3, the Rustler Aquifer is comprised of Culebra Dolomite and limestones of the Los Medaños Unit.

It must be re-emphasized that parsing the submember units into the stratigraphic zones is our attempt to simplify the extremely complex structural, stratigraphic and hydrogeologic environments represented by the Rustler Aquifer. While an area might be characterized as having all of the hydrostratigraphic units, there could be smaller portions of them where we were not able to find the units in all of the wells. Future local studies could result in a refinement of the characterization of a particular area.

5.3 Interpolation of structural surfaces

The interpolation of the structural picks was completed using ArcGIS v.10.2. This entire process, along with instructions on how to recreate the surfaces using ArcGIS v.10.2, is summarized in Appendix 19.1. The results of this process provided insights into the structure and thickness of the main transmissive units comprising the Rustler Aquifer. Main emphasis on the interpolation was to maintain consistency with the previous top of Rustler Formation/Aquifer surface create by Ewing and others (2012), maintain consistency with the thicknesses of the water-bearing units and maintain consistency with the structural picks made in Petra®.

To maintain consistency with the previous top of Rustler Formation/Aquifer surface from Ewing and others (2012), we sampled picks made as part of this study for the top of the Rustler Formation to the surface from Ewing and others (2012) and interpolated a residual surface from the difference between the previous surface and the new pick. This interpolated residual surface was then added to the surface created by Ewing and others (2012). Residuals tended to be the largest in areas where Ewing and others (2012) did not have a pick and a new pick was acquired as part of this study. In addition, a few wells very close to the fault boundaries appeared to be on the wrong side of the interpreted fault. While it would have been ideal to change the fault location, we instead decided to take that well out of the interpolation (documented in Appendix 19.1).

Figure 5-11 is a map of the interpolated elevation of the top of the Rustler Formation. As can be clearly seen from the map, faulting has had a significant influence on the top of the Rustler Formation. The transition between the Pecos-Loving Trough and the structurally elevated portion between the Pecos-Loving and Monument Draw Troughs represents a sharp fault with blocks downthrown to the west. From the outcrop into the Pecos-Loving Trough, the top of Rustler Formation dips much more gradually. While this surface is represented as one continuous surface, it is in reality a series of downthrown blocks to the east. Given the amount of effort involved in characterizing these fault blocks, it was considered acceptable to account for the dip of the Rustler Formation top in this area using a slope as opposed to individual fault blocks. The transition between hydrostructural subdomains 7 and 4 represents the transition into the Monument Draw Trough. As with the Pecos Trough, the top of Rustler could be more accurately represented with a series of downthrown blocks but, the level of effort made it prohibitive.

Figure 5-12 is a map of the depth to the top of the Rustler Formation. The Rustler Formation transitions from ground surface in outcrop in the northwest to depths around 2,000 to 2,500 feet in the Pecos-Loving and Monument Draw Troughs. Additionally, significant topographic relief exists in the south to southwestern portion of the project area. In this area, the Rustler Formation is anticipated to be 3,000 to 3,500 feet below ground surface. Large portions of the structurally elevated area between the Pecos-Loving and Monument Draw Trough display depths around 250 feet below ground surface.

Figure 5-13 is a map of the thickness of the Rustler Formation and was created by subtracting the interpolated structural elevations of the top of the Rustler Formation from the top of the Salado Formation. On average, the Rustler Formation is 450 feet thick and perturbations from this are likely associated with the structural pick for the top of the Salado Formation. In some areas, this pick was difficult due to the absence of a clear transition between the mudstones of the Los Medaños Unit and the halites of the Salado Formation. While this can serve to thicken the unit, it is not thought to significantly affect the volumetric calculations due to the discretization of the three major transmissive carbonates (zone 2) in the majority of the project area. In and immediately downdip from outcrop, the Rustler Formation is likely thicker than it was in Ewing and others (2012). In the southern portions of the project area, specifically in the collapse portion of subdomain 5 (Figure 5-10), a 100-foot thickness was imposed due to lack of data in the area.

Figure 5-14 is a map of the thickness of the Magenta Dolomite and was created by subtracting the interpolated structural elevations of the top of the Magenta Dolomite from the top of the Tamarisk Member Unit. This unit was consistently the thinnest of the three main transmissive units. In general, the Magenta Dolomite has an average thickness of 16 feet, with a maximum of 71 feet and a minimum of five feet. Given its relative thinness, the Magenta Dolomite is not considered a large potential resource.

Figure 5-15 is a map of the thickness of the Culebra Dolomite and was created by subtracting interpolated elevations for the top of the Culebra Dolomite from the interpolated elevations for the top of the Los Medaños Member Unit. The Culebra Dolomite has an average thickness of 65 feet, with a minimum of 17 and a maximum of 140 feet. Thicknesses generated by the subtraction of the two previously mentioned surfaces were constrained with the actual range in thickness values from the structural picks. The Culebra Dolomite represents the most identifiable carbonate of the three main transmissive water-bearing units. The base of the Culebra Dolomite, represented by the high gamma spike of the Los Medaños Member, served to punctuate the base of the unit throughout the Rustler Aquifer extent. Thicknesses of the Culebra over 100 feet generally only happen in a few areas and are thought to be localized phenomena.

Figure 5-16 is a thickness map of the limestones of the Los Medaños Unit. In general, one to two and sometimes three limestones comprised the bulk of the limestones within the Los Medaños Unit. For simplicity and the fact that any one limestone could not be consistently correlated, we decided to treat the limestones of the Los Medaños Unit as one hydrostratigraphic unit. The structural pick for the top of the highest limestone and the base of the lowest limestone were interpolated and subsequently subtracted from one another to acquire the thickness of the total unit. While this might create small amount of additional non-limestone thickness in the unit, it is inconsequential. On average, the limestones of the Los Medaños are 59 feet thick and range between 15 and 162 feet.

Hydrogeologically, in areas designated as collapse (Zone 1 in Figure 5-10) the Rustler Aquifer is comprised entirely by the Rustler Formation. In areas where there is a preserved thickness of the Magenta Dolomite, Culebra Dolomite and limestones of the Los Medaños Unit, the Rustler Aquifer is represented by the total thickness of the three units. In areas where the Magenta Dolomite is suspected to be eroded (Zone 3 in Figure 5-10), the Rustler Aquifer is represented by the combined thickness of the Culebra Dolomite and the limestones of the Los Medaños Unit (Zone 2 in Figure 5-10).

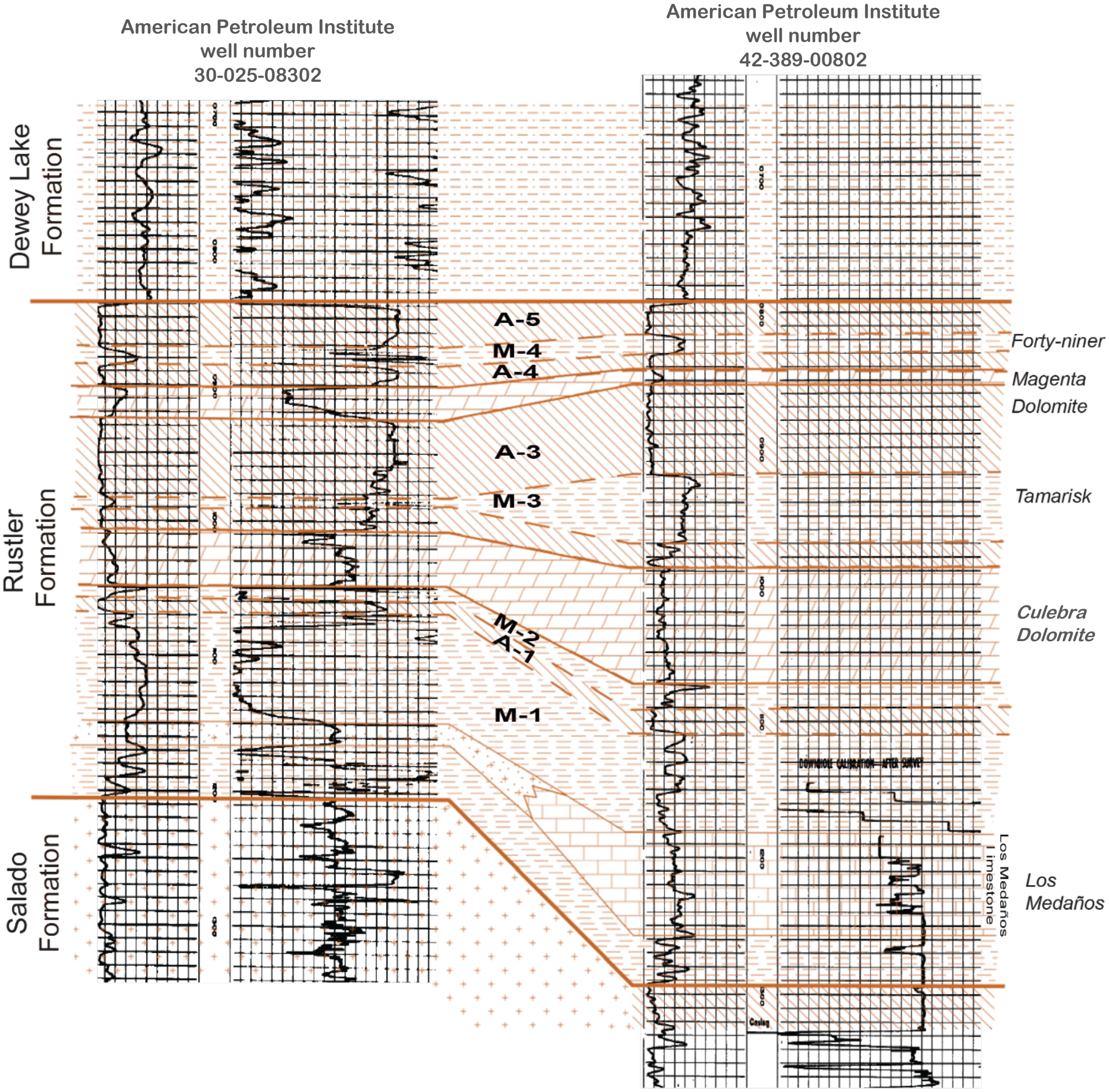

Figure 5-1. Two type logs form the northern and central portion of the Rustler Aquifer extent used to show how the specific geophysical log signatures relate to the Member and informal submember units of the Rustler Formation.

Note: For the informal submember units, "A" stands for Anhydrite, "M" stands for Mud and "H" stands for Halite.

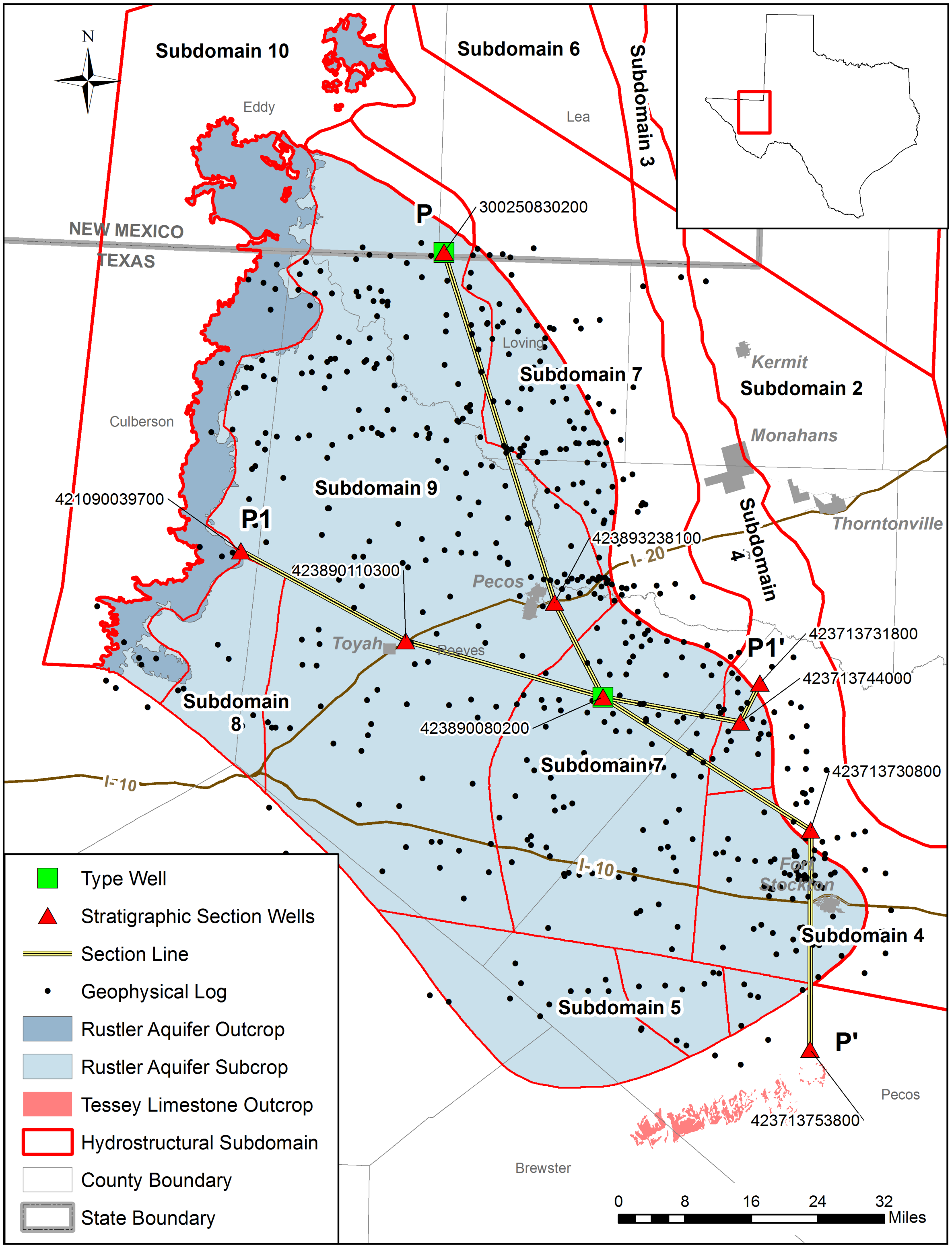

Figure 5-2. **Stratigraphic cross-sections and type wells used to guide stratigraphy and lithology interpretations.**

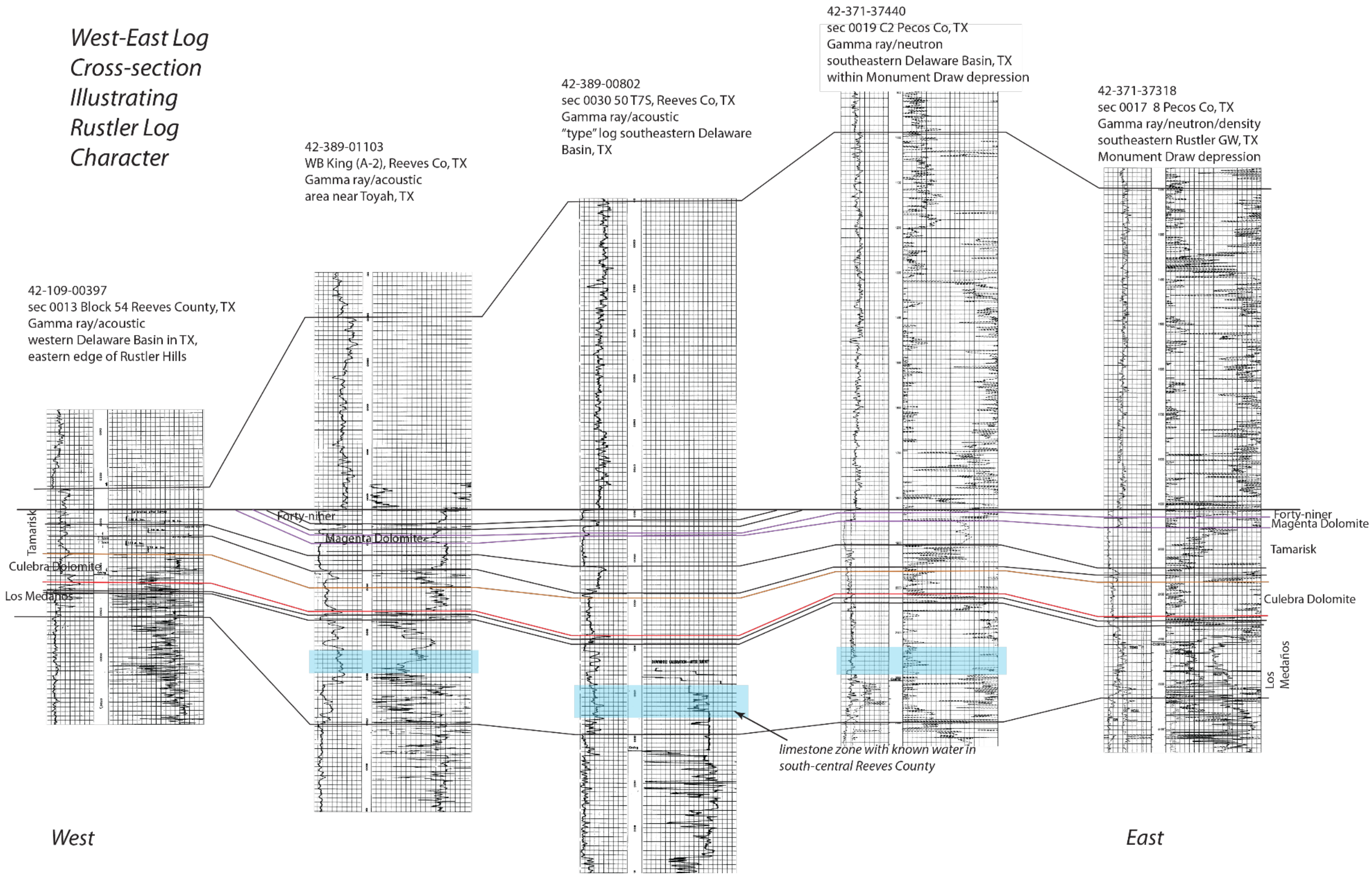

Figure 5-3. **West-east stratigraphic cross-section (P1-P1') through the Rustler Aquifer.**

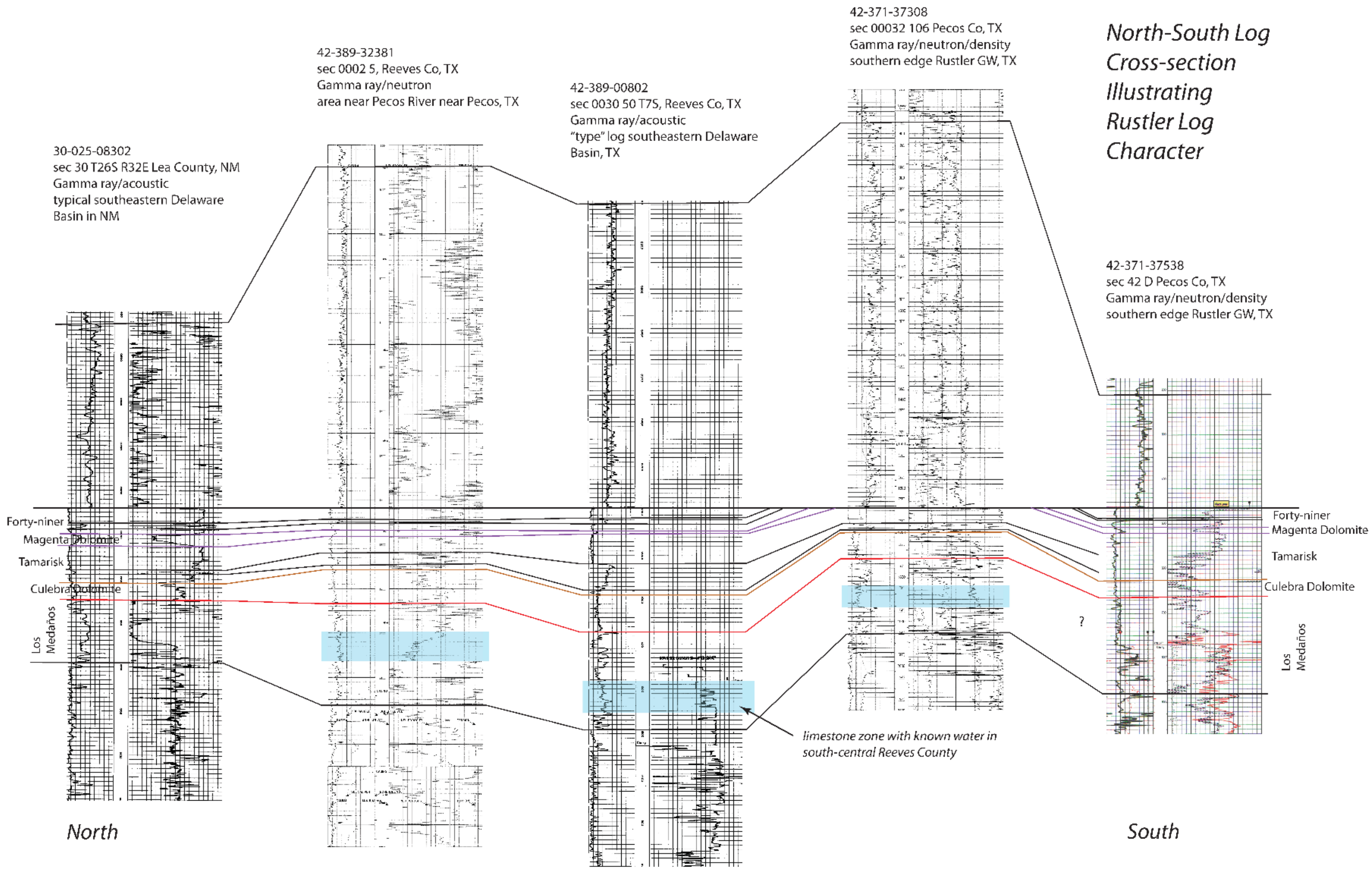

Figure 5-4. North-south stratigraphic cross-section (P-P') through the Rustler Aquifer.

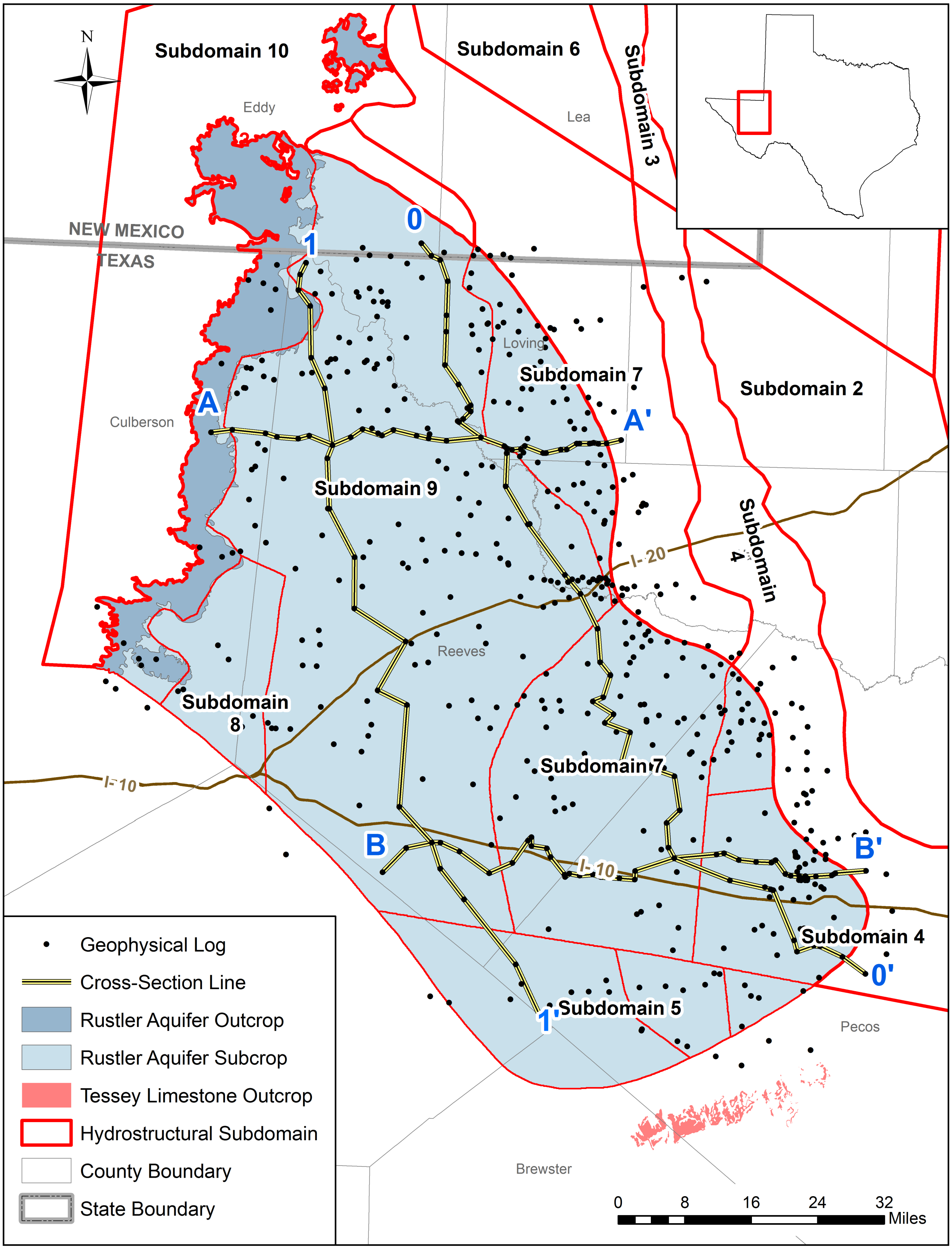

Figure 5-5. Plan view map with structural cross-section locations.

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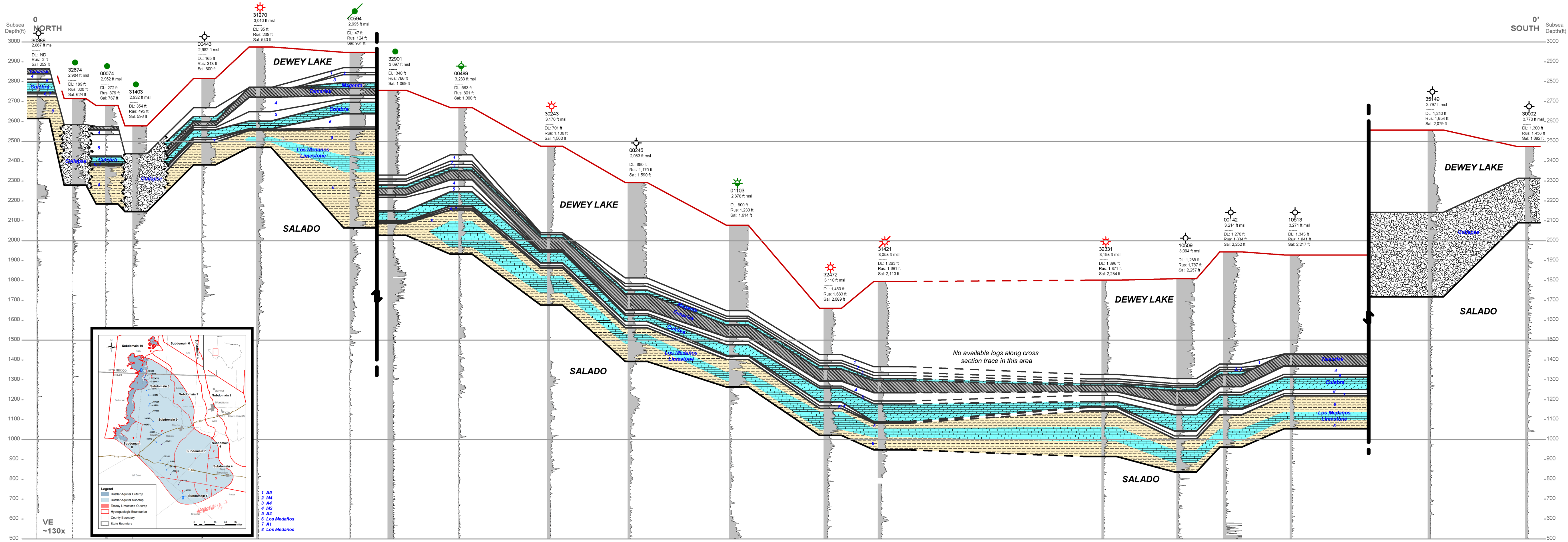

Figure 5-6. **Cross-section 0-0'.**

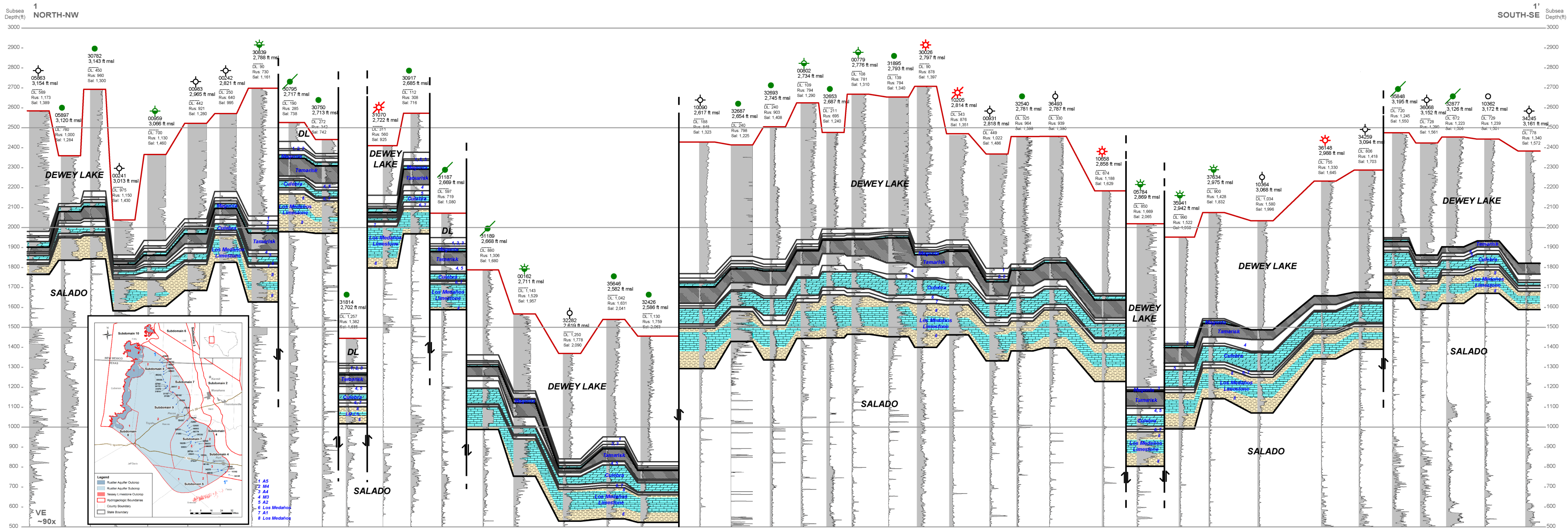

Figure 5-7. **Cross-section 1-1'.**

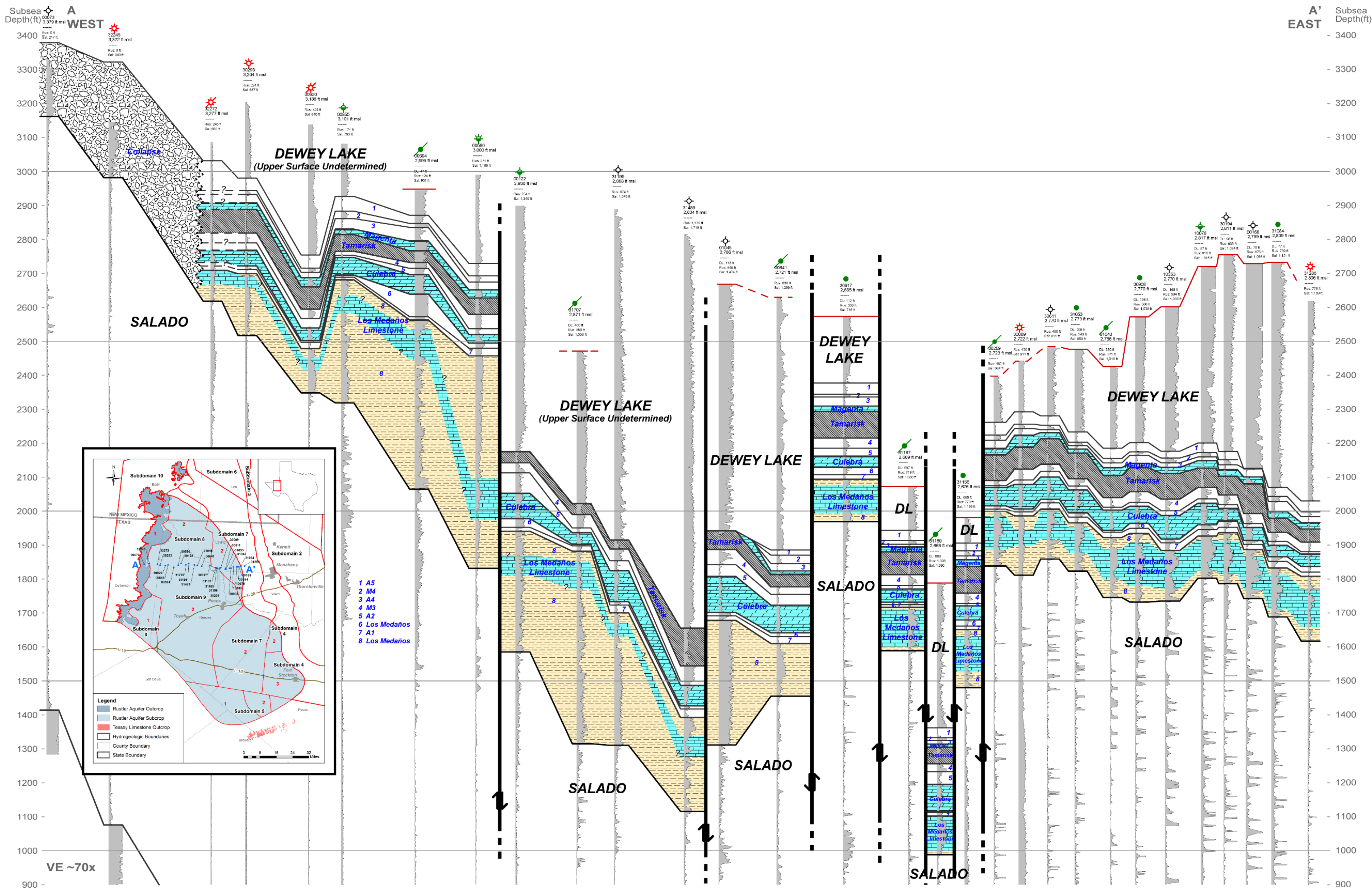

Figure 5-8. **Cross-section A-A'.**

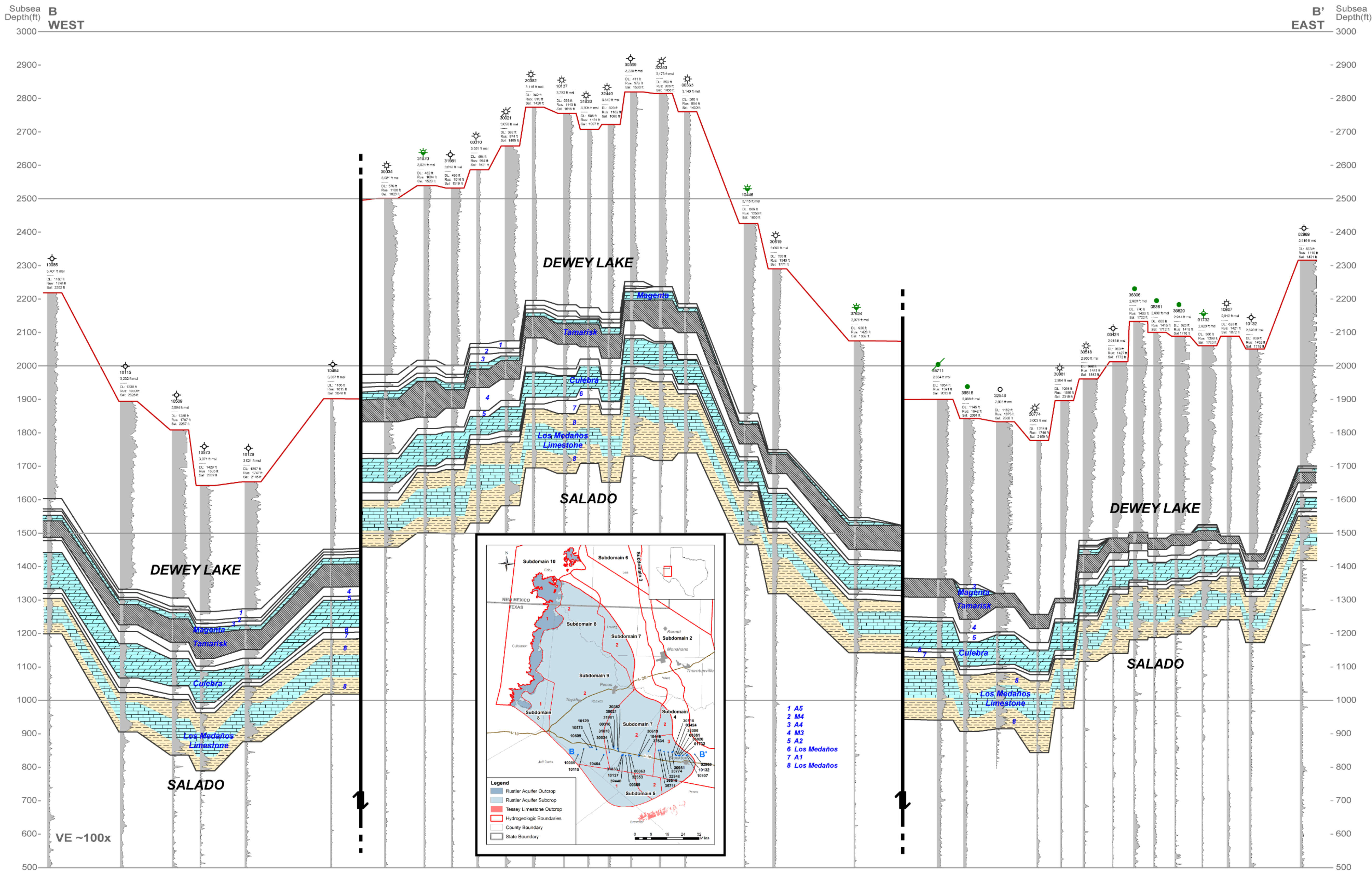

Figure 5-9. **Cross-section B-B'.**

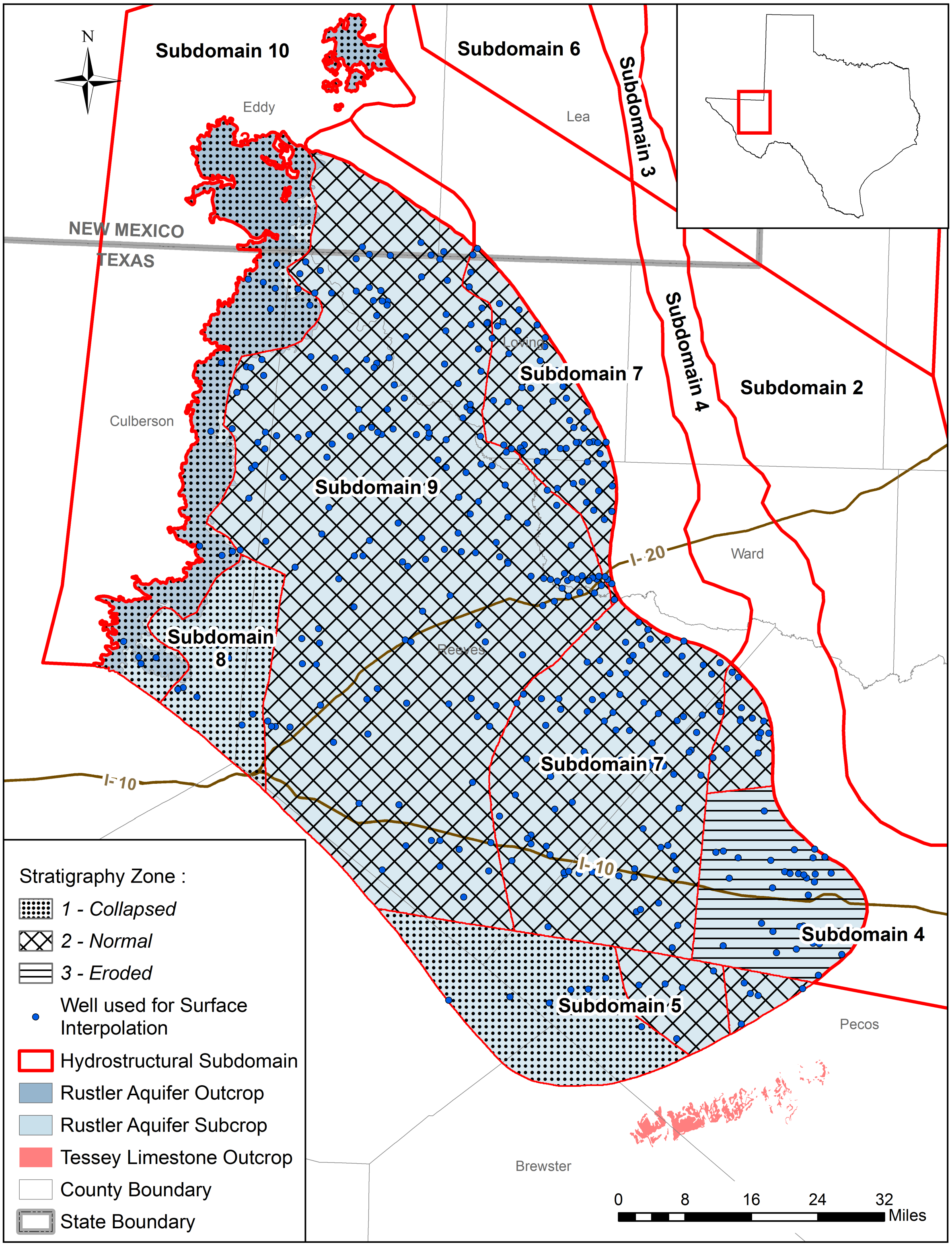

Figure 5-10. Figure showing distribution of structural and stratigraphic regions.

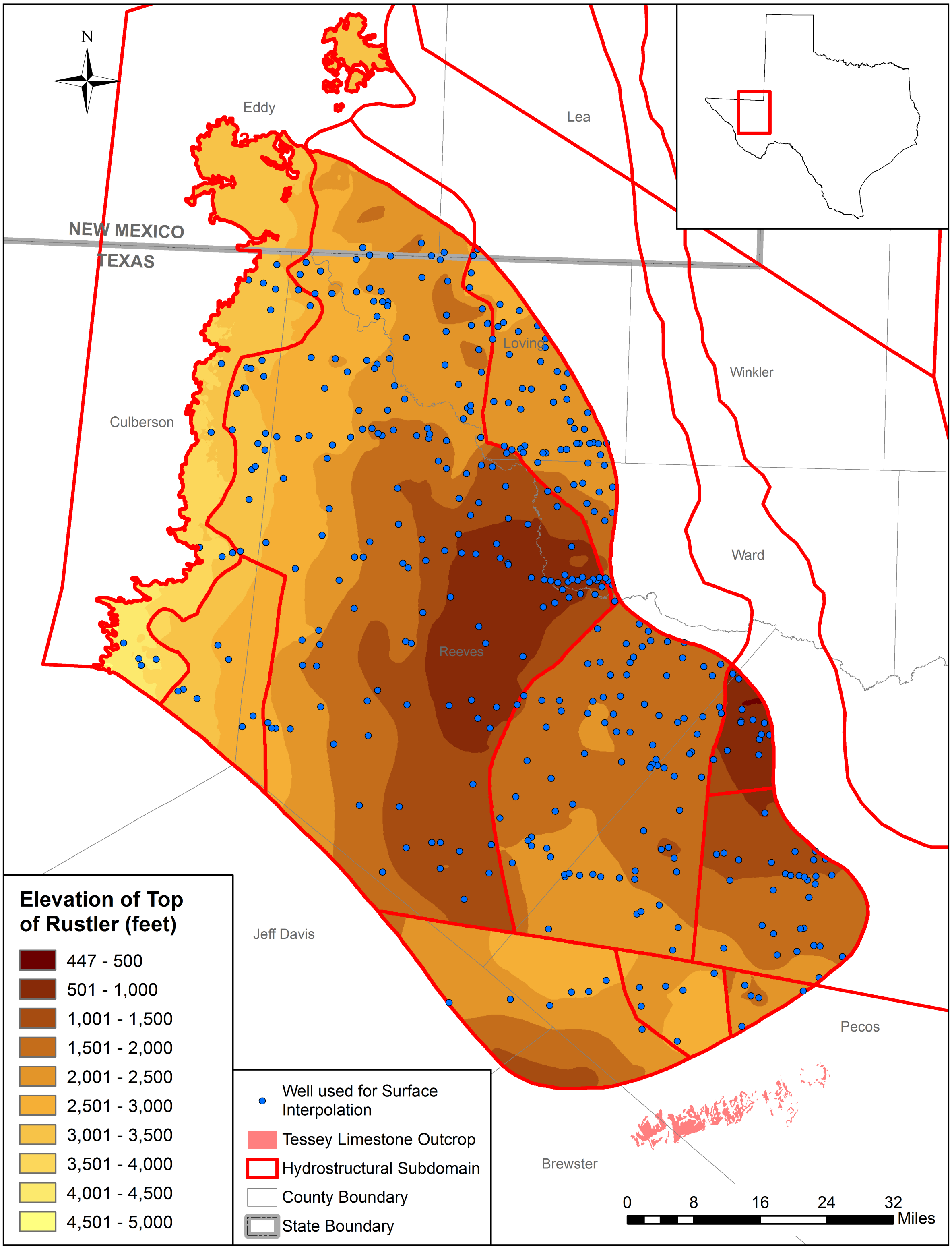

Figure 5-11. Interpolated elevation (in feet above mean sea level) of the top of the Rustler Formation.

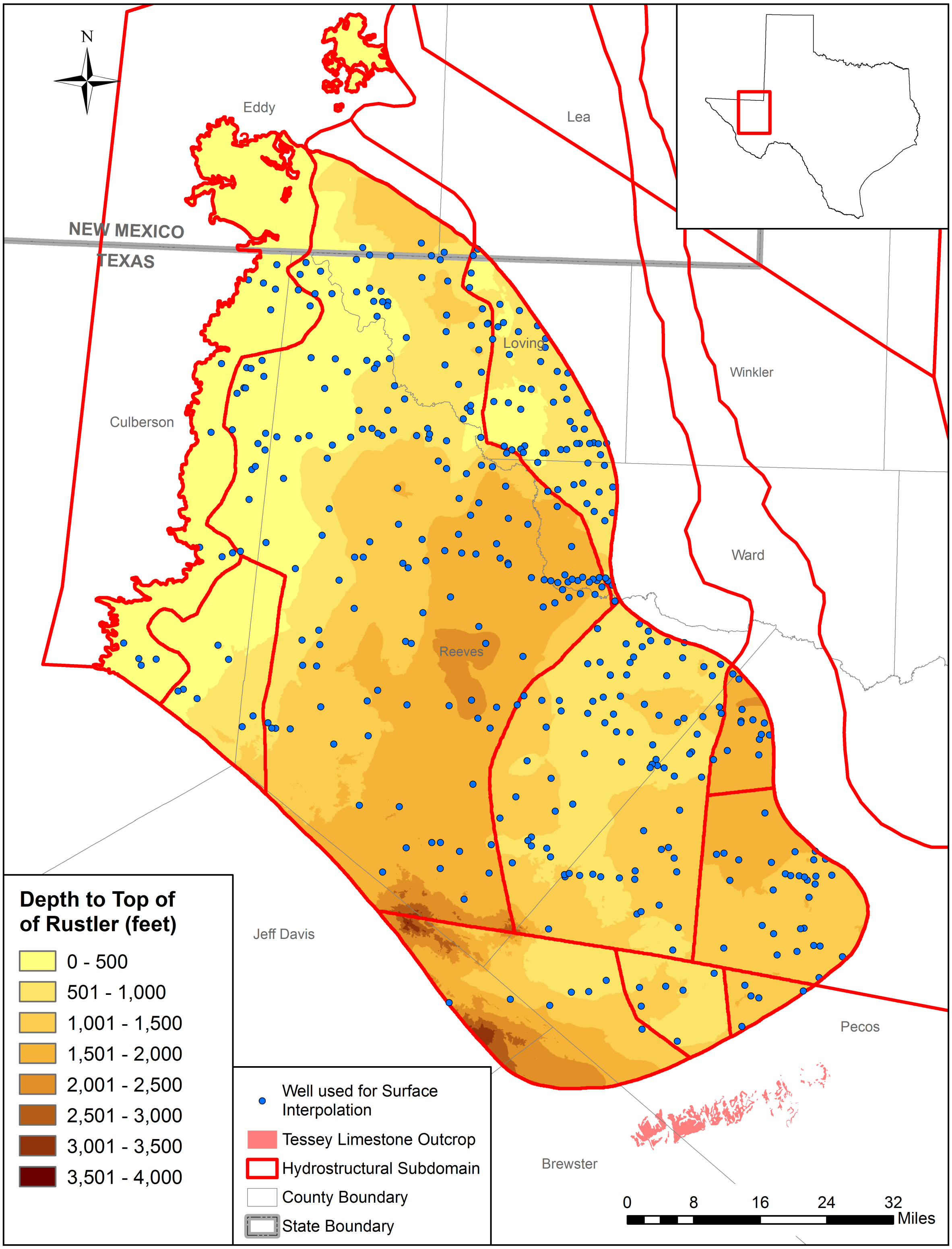

Figure 5-12. Interpolated depth (in feet below ground surface) to the top of the Rustler Formation.

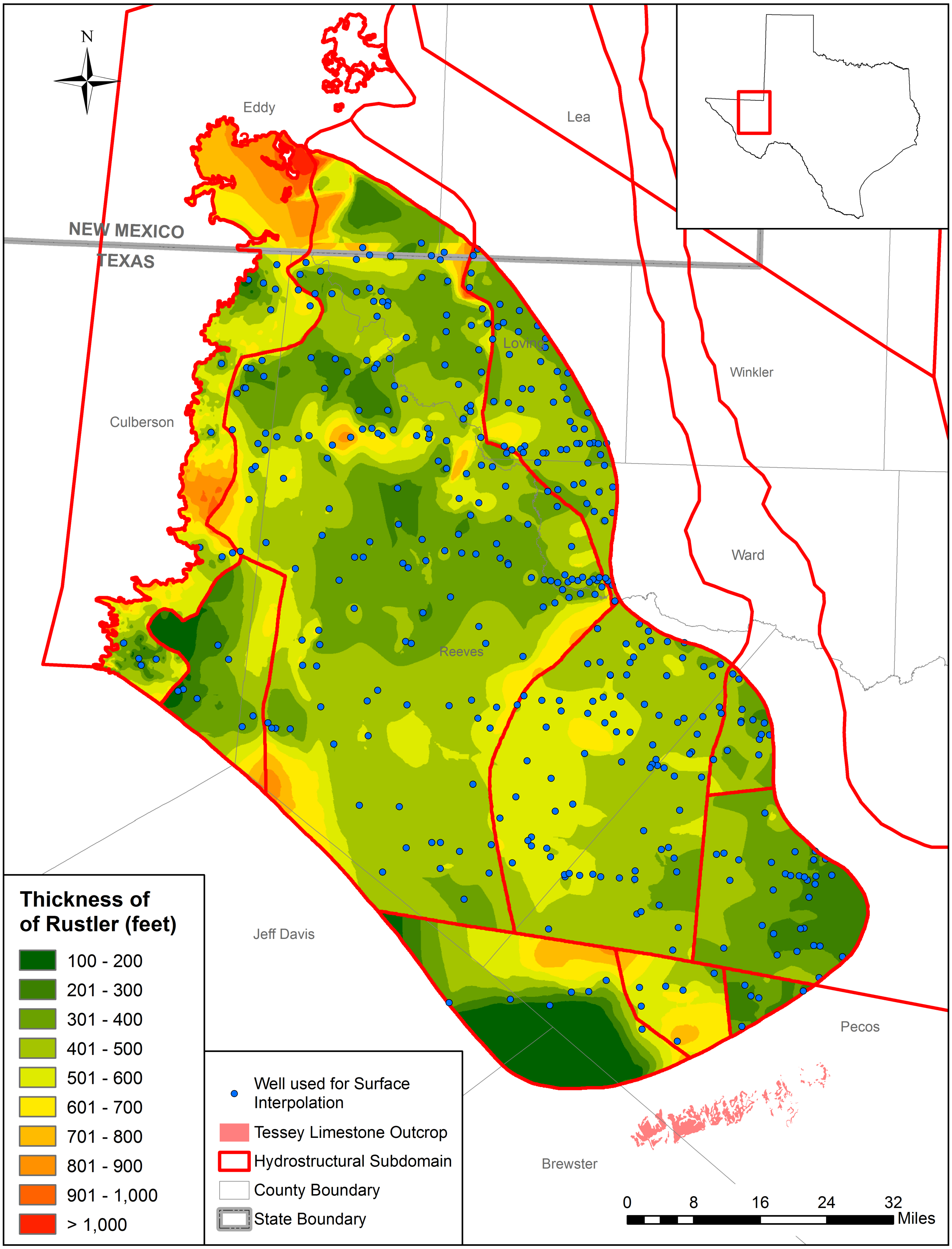

Figure 5-13. Interpolated thickness (in feet) of the Rustler Formation.

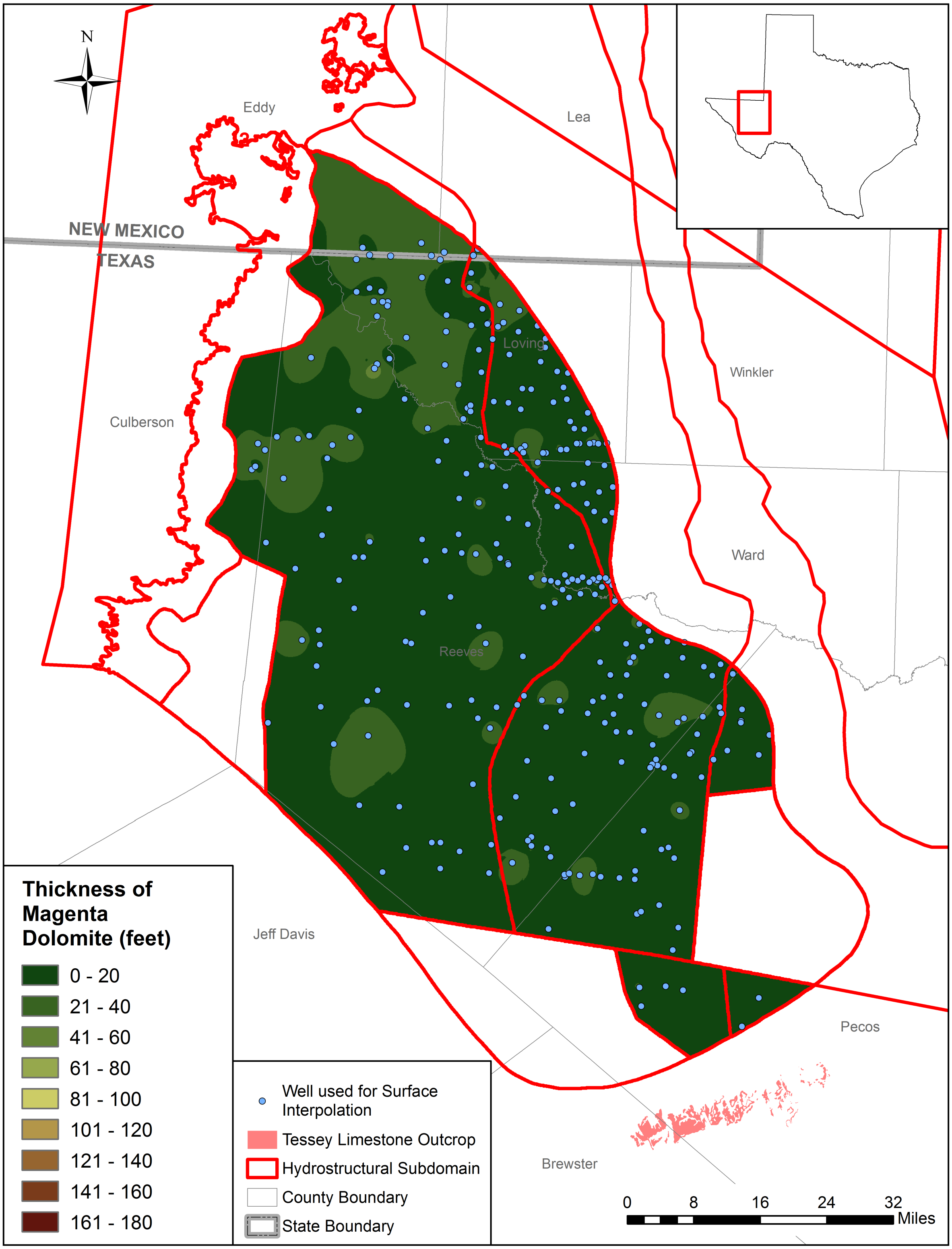

Figure 5-14. Interpolated thickness (in feet) of the Magenta Dolomite.

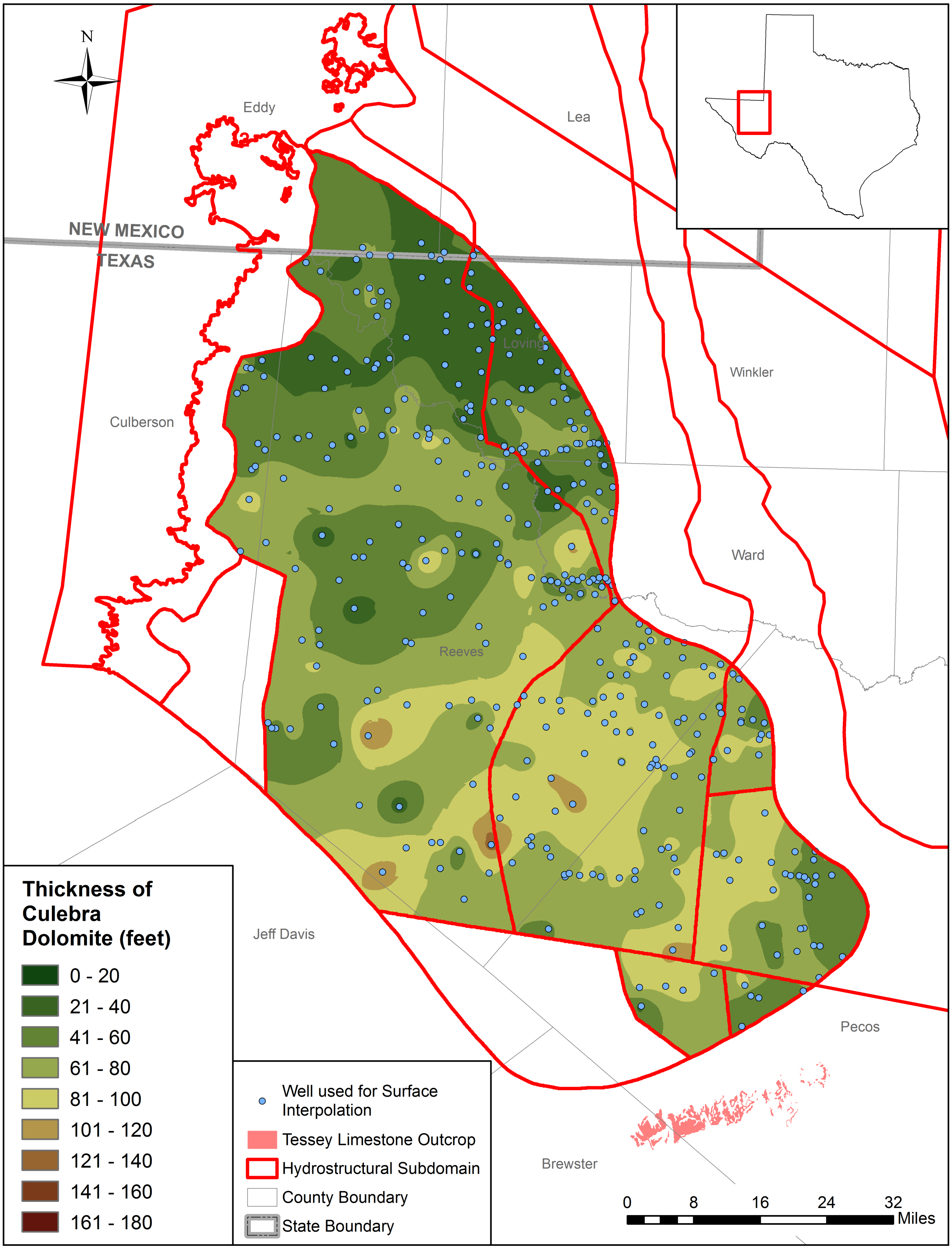

Figure 5-15. **Interpolated thickness (in feet) of the Culebra Dolomite.**

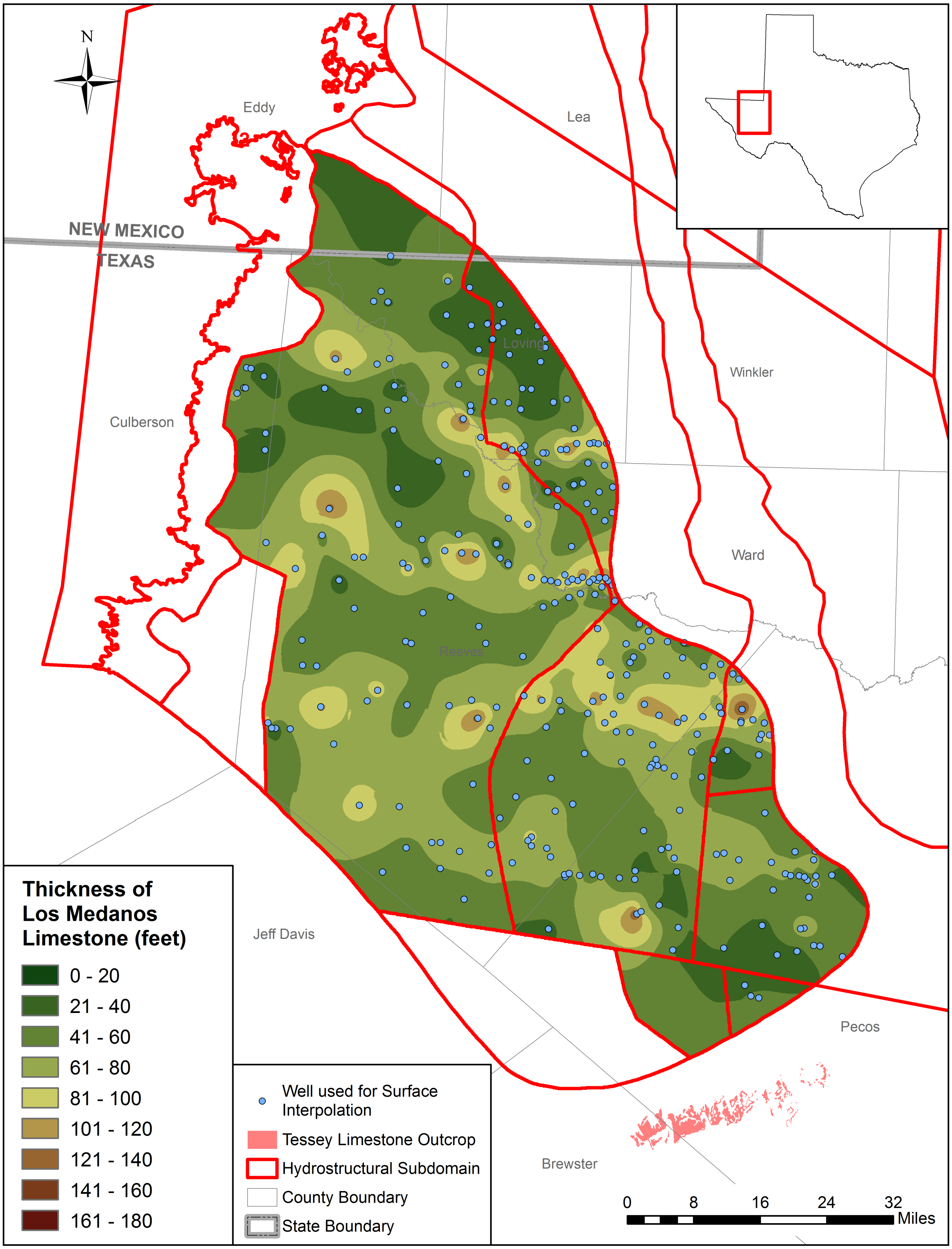

Figure 5-16. **Interpolated thickness (in feet) of the limestones of the Los Medaños Member Unit.**

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6 Groundwater salinity zones

Groundwater salinity zones were determined through a combination of:

- Structural and stratigraphic evaluation of the Rustler Formation in an attempt to delineate the specific hydrostratigraphic units that comprise the Rustler Aquifer (Section 5 and Appendix 19-1 and 19-5);
- Evaluation of sampled water quality from wells determined to be completed in the Rustler Aquifer (Section 10 and Appendices 19.3 – 19.4);
- Evaluation of high quality geophysical logs (referred to as key wells) using advanced petrophysical techniques (Section 13);
- Additional calculations using a technique developed from the analysis of the key wells in an attempt to infill areas in between the sampled water quality and key wells (Section 13).

Figure 6-1 is a map of the project area with total dissolved solids values from sampled water wells and springs posted with a white background, key well calculated total dissolved solids posted with a red background, and additional calculations of total dissolved solids posted with a green background. The posted total dissolved solids values represent an average value from the transmissive water-bearing units found at that location. An average was taken so that total dissolved solids sampled from water wells could be compared to calculated total dissolved solids values for the transmissive units using geophysical methods. Because the degree of resolution between a water-well sample and a geophysical log calculation are different, we had to integrate all data to the lowest degree of resolution, which is the Rustler Aquifer.

Initial calculations of total dissolved solids on key wells were made irrespective of the geographic location. Upon placing the well location on the map and posting the total dissolved solids value along with those from sampled water wells and springs, it was immediately apparent that this unbiased approach to calculating the total dissolved solids in the key wells produced a high level of consistency with the sampled values. Exceptions did occur, especially in the southwestern portion of the project area where the value of 20,372 milligrams per liter total dissolved solids occurs (Figure 6-1). However, the consistency between the two separate techniques is irrefutable, and their combination provides a much clearer understanding of the water quality distribution in the Rustler Aquifer. Further, in an attempt to infill some of the areas in between the sampled and calculated water quality, additional calculations of total dissolved solids were made using a less petrophysically rigorous technique that was adapted based upon what was learned from analyzing key geophysical wells.

After posting all of the sampled and calculated water quality values on a map of the Rustler Aquifer, it was immediately apparent that trends in water quality existed and could be defined. In support of this, contours of 1,000, 3,000 and 10,000 milligrams per liter total dissolved solids were defined. The contours were made to be consistent with Winslow and Kister (1956). Of note, the sampled water quality in the southwestern portion of the aquifer was the only occurrence of total dissolved solids less than or equal to 1,000 milligrams per liter. These contours are based on the data available to INTERA during the generation of this report. These contours, along with the tools used and provided to the Brackish Resource Aquifer Characterization System Program to evaluate the volumetrics of the salinity zones, are meant to be living tools that can be used to increase our knowledge of Rustler Aquifer water quality as more data become available.

Interpolated surfaces based on picks for the main hydrostratigraphic units that comprise the Rustler Aquifer were clipped to the water quality zones in an attempt to better understand the occurrence and distribution of the various water quality zones. (This section will refer to Rustler Aquifer subdomains, and the reader is referred to Figure 5-10 for their locations).

6.1 Slightly saline zones

The slightly saline zone consists of: the entire Rustler Formation in outcrop and hydrostructural subdomains 10, 8 and 5; the Magenta and Culebra Dolomites and limestones of the Los Medaños Unit in subdomains 9 and 7 and the northern portion of subdomain 4; and the Culebra Dolomite and limestones of the Los Medaños Unit in the southern portion of subdomain 4 (Figure 6-2; subdomains in Figure 5-10). The depth to the top of the slightly saline zone ranges from zero in outcrop where the zone reaches ground surface to 3,550 feet in the southern extent of subdomain 9 and the southwestern extent of subdomain 5 (Figure 6-2). Average depth to the top of the slightly saline zone is 1,115 feet below ground surface. Depth to the base of the slightly saline zone ranges between 95 feet in outcrop and 3,805 feet below ground surface in the southern extent of the Rustler Aquifer (Figure 6-3). Average depth to the base of the slightly saline zone is 1,465 feet below ground surface. The thickness of the slightly saline zone averages 247 feet and ranges between 80 feet in portions of subdomains 9, 7 and 4 to greater than 300 feet in portions of outcrop and subdomains 8 and 5 (Figure 6-4).

6.2 Moderately saline zones

The moderately saline zone consists of: the entire Rustler Formation in outcrop; the Magenta and Culebra Dolomites and limestones of the Los Medaños Unit in subdomains 9 and 7 and the northern portion of subdomain 4; and the Culebra Dolomite and limestones of the Los Medaños Unit in the southern portion of subdomain 4 (Figure 6-5; subdomains in Figure 5-10). The depth to the top of the moderately saline zone ranges from zero in outcrop where the zone reaches ground surface and 2,198 feet below ground surface in the Pecos-Loving Trough (Figure 6-5). Average depth to the top of the moderately saline zone is 1,180 feet below ground surface. Depth to the base of the moderately saline zone ranges from 296 feet below ground surface in outcrop to 2,537 feet below ground surface in the Pecos-Loving Trough (Figure 6-6). Average depth to the base of the moderately saline zone is 1,498 feet below ground surface. Thickness of the moderately saline zone averages 150 feet and ranges from 71 feet in areas of subdomains 9, 7 and 4 to 736 feet in the extreme eastern portions of the outcrop (Figure 6-7; subdomains in Figure 5-10).

6.3 Very saline zones

The very saline zone consists of the Magenta and Culebra Dolomites and limestones of the Los Medaños Unit in subdomains 9, and 7 (Figure 6-8; subdomains in Figure 5-10). Depth to the top of the very saline zone ranges from 213 feet to 1,269 feet below ground surface (Figure 6-8). Average depth to the top of the very saline zone is 815 feet below ground surface. Depth to the base of the very saline zone ranges between 713 and 1,518 feet below ground surface (Figure 6-9). Average depth to the base of the very saline zone is 1,114 feet below ground surface. Thickness of the very saline zone averages 93 feet and ranges between 64 and 122 feet. This zone is considered to have the least potential of the three salinity zones discussed.

6.4 Brine

The Rustler Aquifer extent was delineated by the Texas Water Development Board based on their understanding of the occurrence of a 5,000 milligram per liter total dissolved solids cutoff. While water quality within the Rustler Aquifer does exceed 5,000 milligrams per liter, it does not exceed 35,000 milligrams per liter, the cutoff for very saline groundwater.

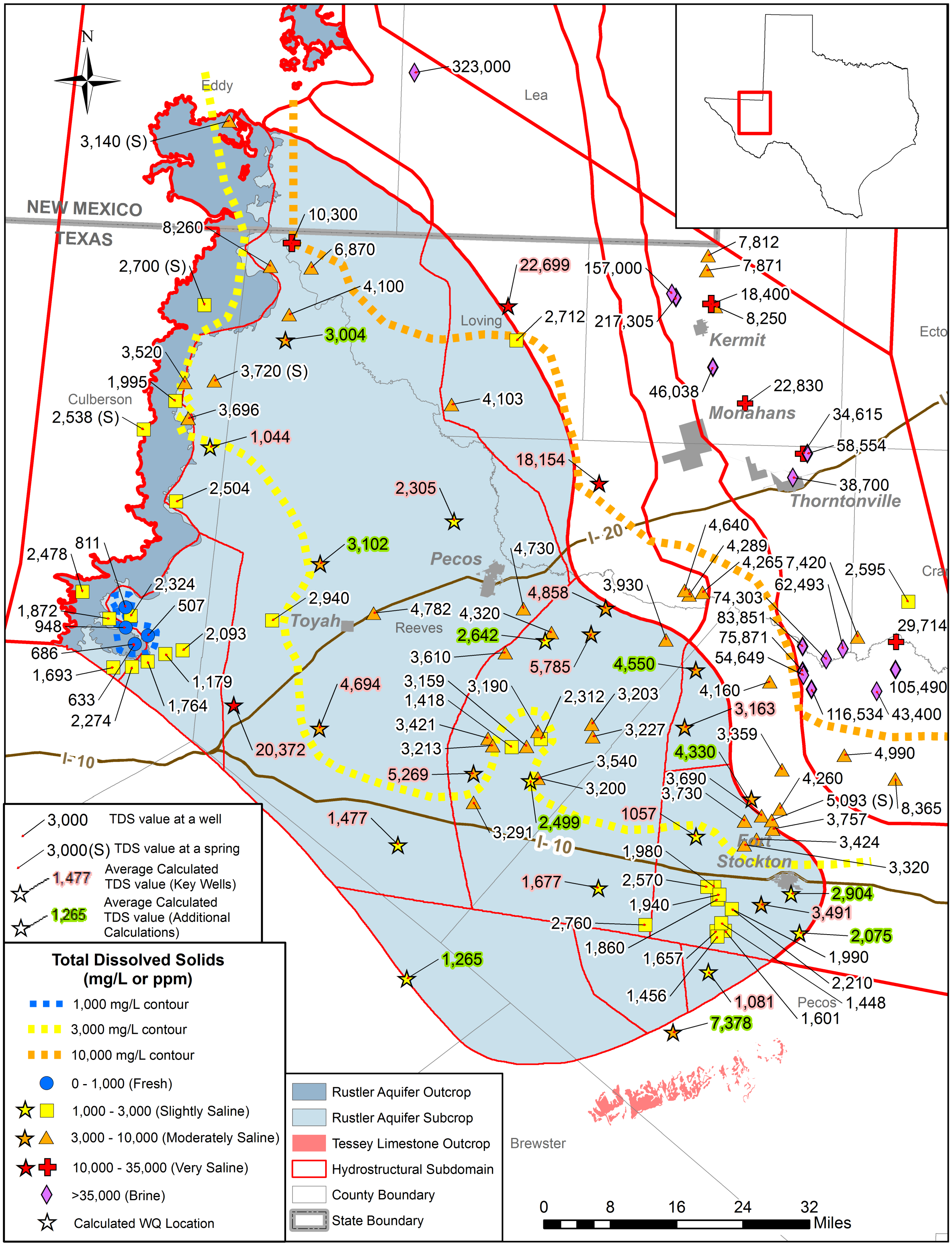

Figure 6-1. Map showing the distribution of sampled and calculated water quality values.

Note: TDS=total dissolved solids; mg/L=milligrams per liter; ppm=parts per million.

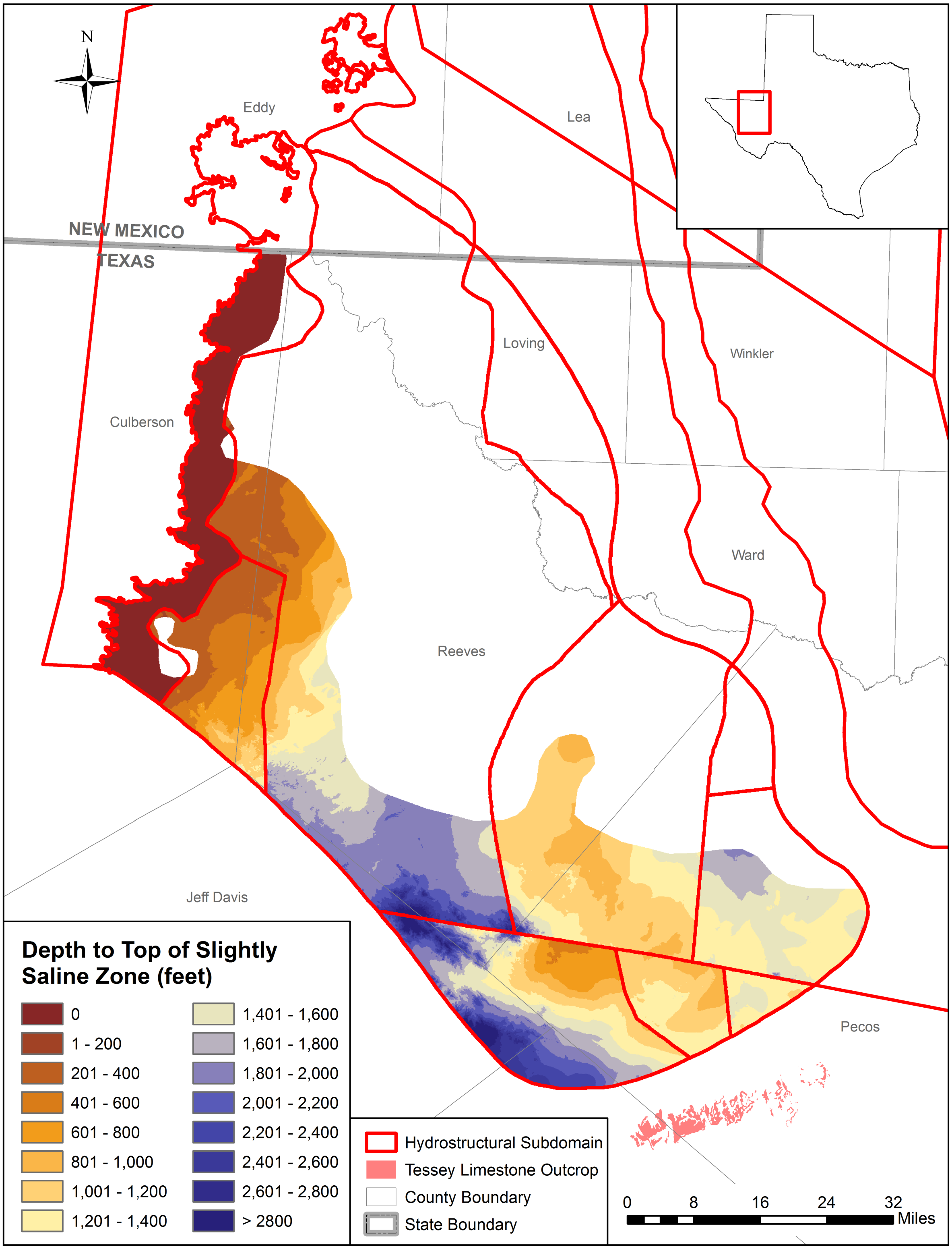

Figure 6-2. Depth to the top of the slightly saline zone.

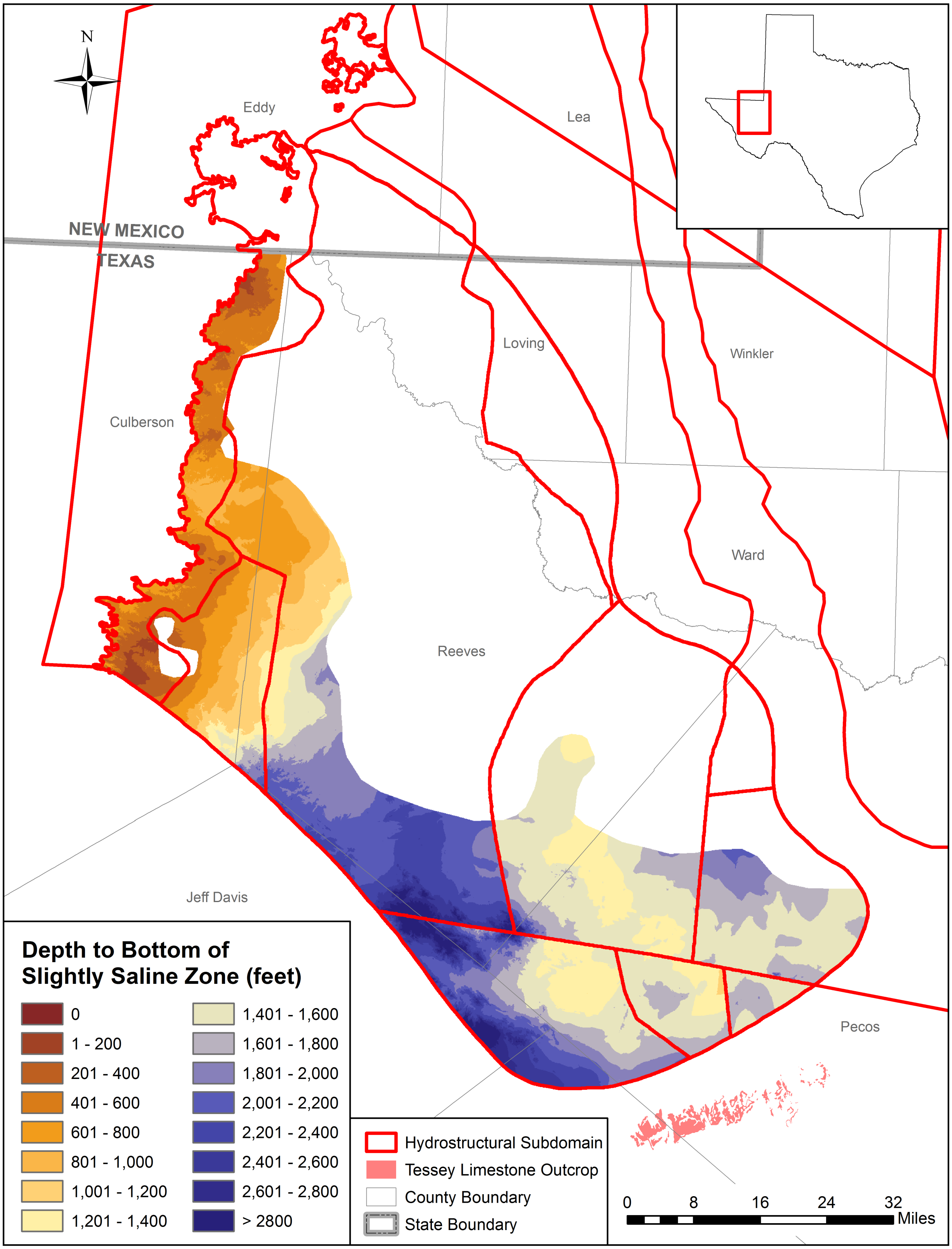

Figure 6-3. **Depth to the bottom of the slightly saline zone.**

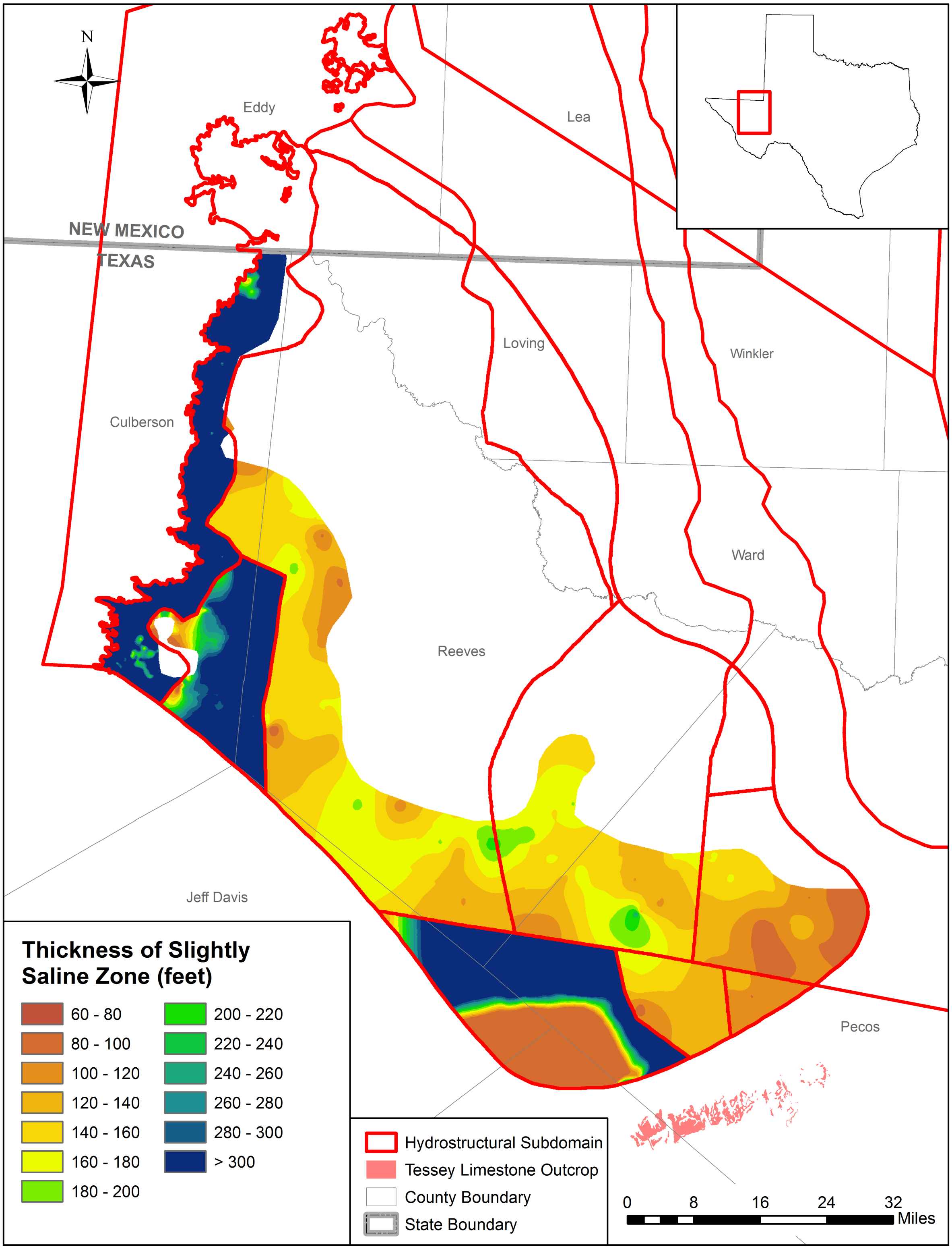

Figure 6-4. Thickness of the slightly saline zone.

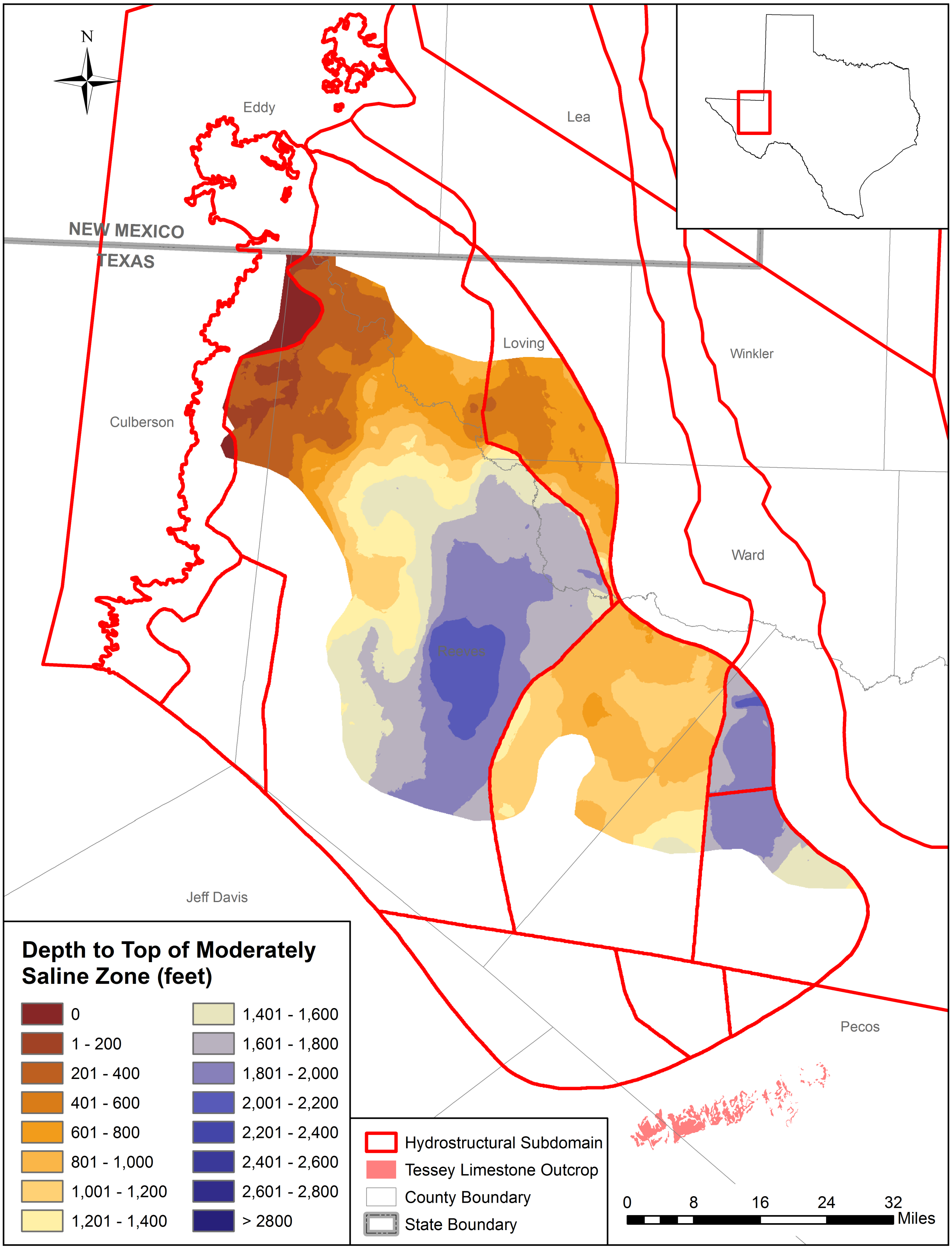

Figure 6-5. **Depth to the top of the moderately saline zone.**

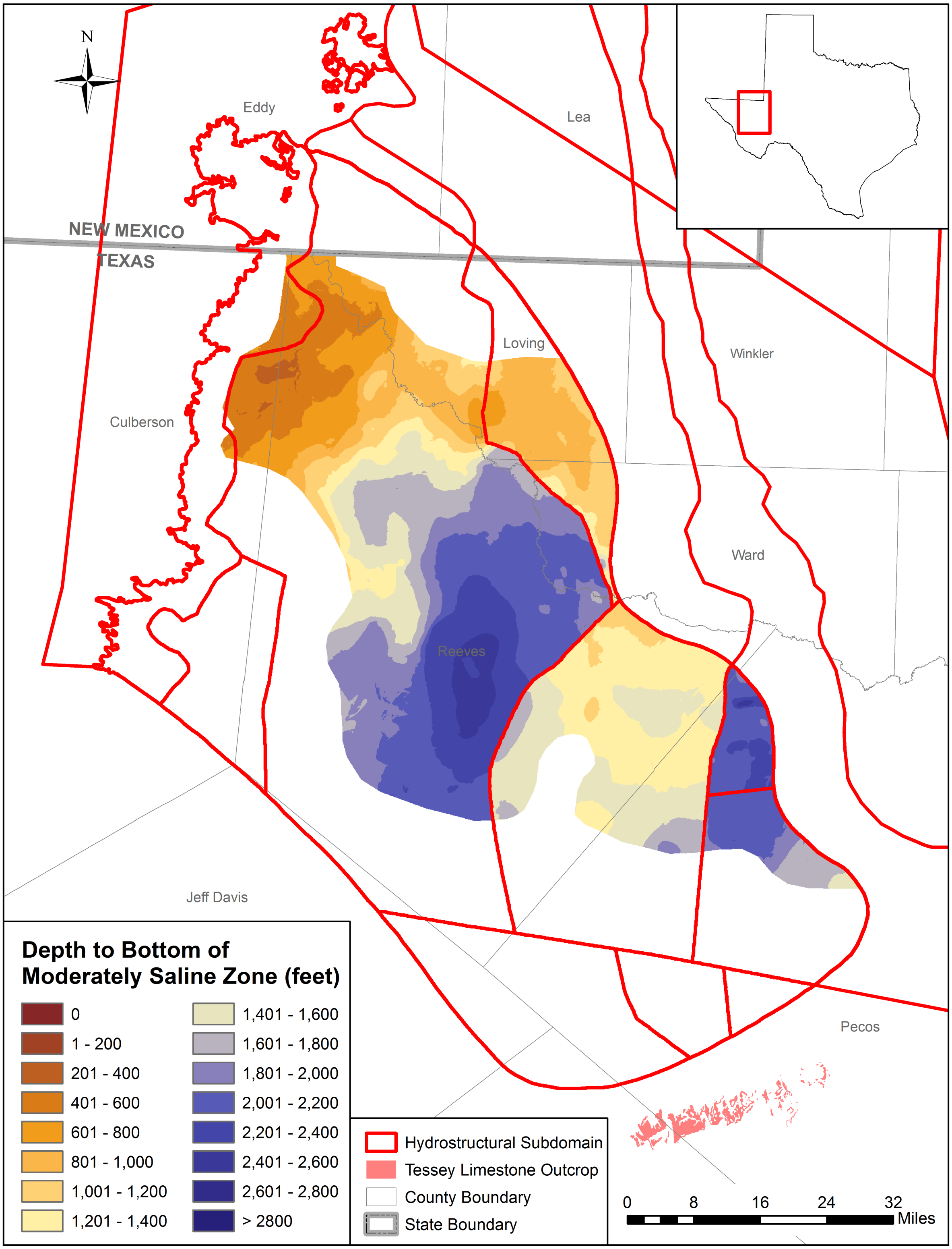

Figure 6-6. **Depth to the bottom of the moderately saline zone.**

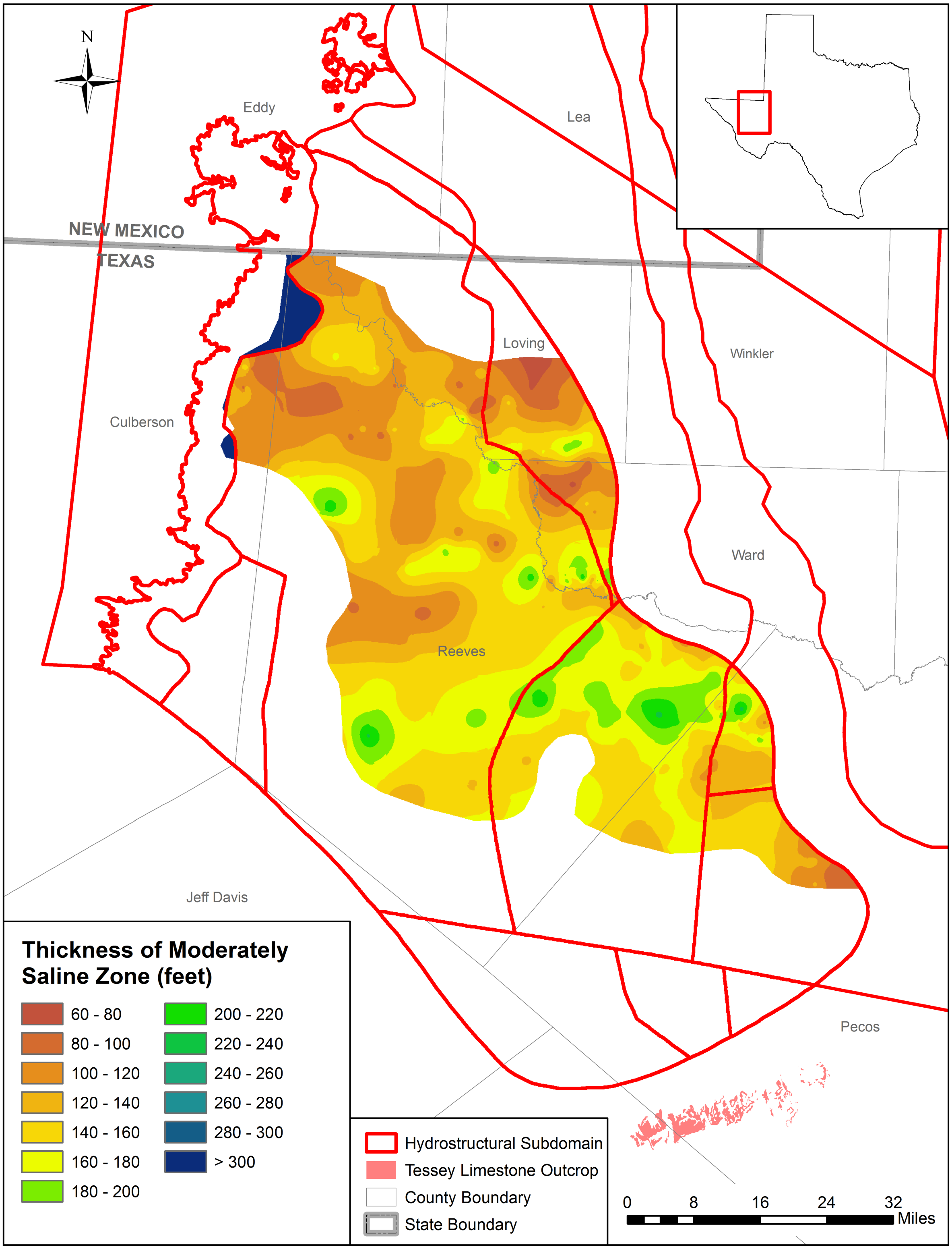

Figure 6-7. **Thickness of the moderately saline zone.**

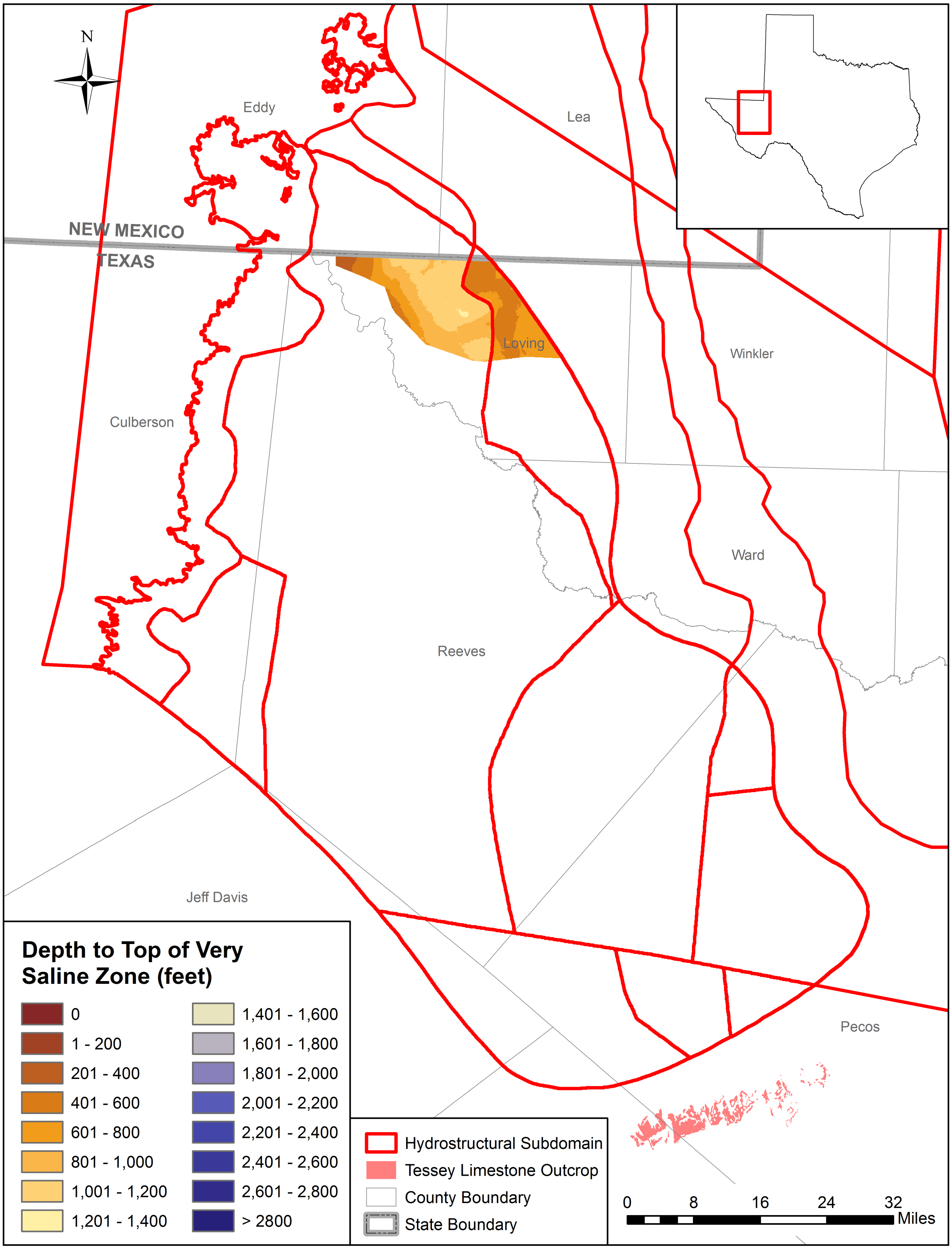

Figure 6-8. Depth to the top of the very saline zone.

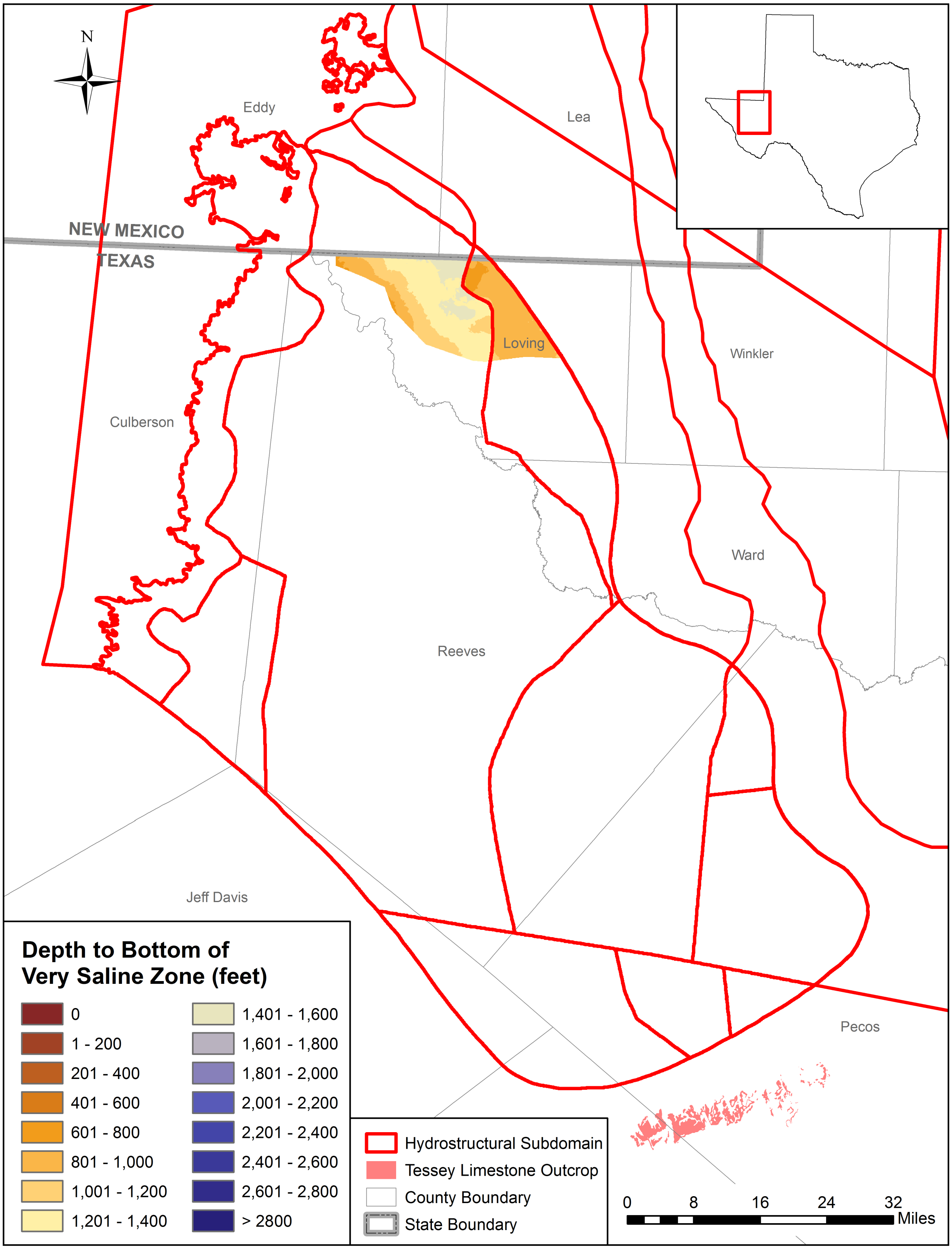

Figure 6-9. Depth to the top of the very saline zone.

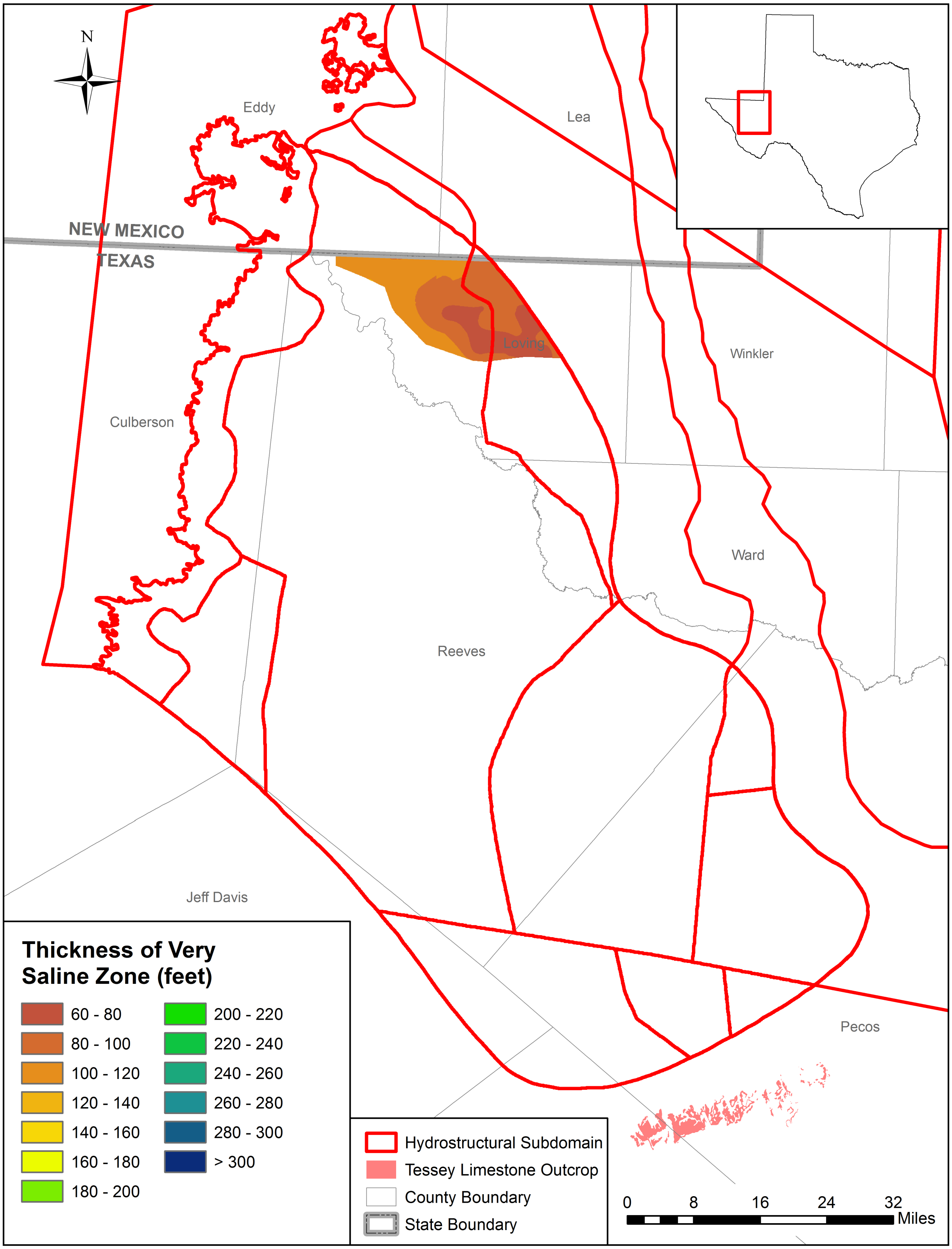

Figure 6-10. **Thickness of the very saline zone.**

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7 Previous investigations

INTERA documented a complete review of previous work in the Rustler Aquifer as part of the development of the Rustler Aquifer Groundwater Availability Model (Ewing and others, 2012). Much of the following is taken from Ewing and others (2012) and augmented with more recent studies where applicable.

The lithology of the Rustler Formation has been described by Richardson (1904), who named the formation from outcrops near Rustler Springs in the Rustler Hills of Culberson County. While some other early workers (Porch, 1917; Lang, 1935, 1937; Adams, 1944) described some aspects of the formation, it was Vine (1963) who clearly defined five members in the formation based on work in the northern Delaware Basin in support of Project Gnome. The structure of the top of the Rustler Formation in southeast New Mexico and West Texas was first comprehensively developed and described by Hiss (1976), following earlier work by Maley and Huffington (1953). Hill (1996) includes a discussion of the Rustler Formation in her work on the geology of the Delaware Basin, and Guadalupe, Apache, and Glass Mountains in New Mexico and West Texas. Hill (1996) describes the stratigraphy, hydrology (predominately from Waste Isolation Pilot Plant investigations), groundwater chemistry, and sulfur and potash resources of the Rustler Formation.

Investigations into the geologic and hydrogeologic nature of the Rustler Formation in southeastern New Mexico have provided a wealth of investigations on the stratigraphy (Powers and Holt, 2010), depositional environments, diagenesis and post-depositional alteration of the Rustler Formation and the underlying Salado Formation and the impact on hydraulic properties (e.g., Holt and Powers, 1988; Powers and others, 2003, 2006; Holt and others, 2005). Powers and Holt (2010) developed a detailed stratigraphic column of the Rustler Formation, dividing it into its formal Member units and several informal submember units (see Figure 2-2). While most of this work has been performed in New Mexico, the development of the Rustler Aquifer groundwater availability model confirmed that most Members and submembers of the Rustler Formation are regionally extensive and continuous to the north, east, and southeast beyond the Texas extent of the aquifer. Ewing and others (2012) developed a further understanding of the structure of the Rustler Aquifer and developed a system of hydrostructural domains that divide the aquifer into areas expected to be different hydrologically or structurally.

Several reports written by various past and present Texas state agencies responsible for water resources include a discussion of the Rustler Aquifer. The Rustler Aquifer is not the focus of any of these reports because it provides small amounts of groundwater compared to the primary aquifers discussed. A very brief description of the Rustler Aquifer is provided by Ashworth (1990) in his evaluation of groundwater resources in parts of Loving, Pecos, Reeves, Ward, and Winkler counties, Texas and in Reese (1987) in his record of wells, water levels, pumping, and chemical analyses from selected wells in parts of the Trans-Pecos region of Texas. A discussion of the quality of groundwater in the Rustler Aquifer is provided in Texas Water Commission (1989). A discussion of the Rustler Formation, including development of water supplies, water quality, and natural discharge to overlying formations, is provided by Armstrong and McMillion (1961) in their report on the geology and groundwater resources of Pecos County, Texas. They also provide a record of Rustler Formation wells in Pecos County, chemical analyses of several samples of groundwater in the Rustler Formation, and describe a fault system near the city of Belding. The Rustler Formation in Reeves County is described in Knowles and Lang (1947) and Ogilbee and others (1962). In addition to a discussion of the formation, records of wells completed into the Rustler Formation and analyses of groundwater samples collected from the formation are provided in these two reports. White (1971) provides a discussion of the Rustler Formation, including structural top, lithology, hydrology, hydraulic properties, water use, water quality, and records of wells, for Ward County, Texas. The Rustler Formation in Winkler County, Texas is briefly discussed in Garza and Wesselman (1959). They also include records for wells completed into the Rustler Formation and results of chemical analyses on groundwater from the Rustler Formation. Boghici and Van Broekhoven (2001) provide information on the regional geologic setting, structure, properties, potentiometric surface, recharge, discharge, water availability, and groundwater geochemistry of the Rustler Aquifer. Ewing and others (2012) provides a comprehensive study of the hydrogeology of the Rustler Aquifer.

United States Geological Survey reports by Hood and Kister (1962), Richey and others (1985), and Small and Ozuna (1993) also provide discussions of the Rustler Formation. In their report on saline water resources in New Mexico, Hood and Kister (1962) include a brief discussion of the Rustler Formation and include a listing of several saline water wells completed into the Rustler Formation. Richey and others (1985), in their report on the geohydrology of the Delaware Basin and vicinity in Texas and New Mexico, include a discussion of the structure, thickness, groundwater occurrence, groundwater use, recharge, discharge, aquifer test data, and water quality of the Rustler Formation. They also include water-level measurements in Rustler Formation wells and results of analyses of water sampled from selected wells completed into the Rustler Formation. A brief description of the Rustler Aquifer is provided by Small and Ozuna (1993) in their report on groundwater conditions in Pecos County, Texas, 1987. Brown (1998) provides an evaluation of the quality of groundwater in the Rustler Aquifer. He discusses the total dissolved solids concentration, major anion and cation concentrations, nutrient concentrations, and radioactivity of groundwater in the Rustler Aquifer based on the analysis of samples from 18 wells collected from 1990 to 1995. Brown (1998) also compares his results with those from earlier studies for concentrations of chloride, fluoride, sulfate, and total dissolved solids and for hardness. Most recently The United States Geological Survey has recently been studying the aquifers of the Pecos County Region (Baumgarner and others, 2012; Pearson and others, 2013; and Clark and others, 2014). Baumgarner and others (2012) developed a conceptual model of the hydrogeologic framework, geochemistry, and groundwater-flow system of the Edwards-Trinity and related aquifers in the Pecos County region. Pearson and others (2013) developed a geodatabase of groundwater and surface-water data, water-quality data, geophysical, and geologic data for the Pecos County Region.

A study of the hydrogeology and geochemistry of the aquifers in the Leon-Belding Area was completed by Thornhill Group (2008) and Harden and others (2011) to support new production permits for wells in the area under regulation by the Middle Pecos County Groundwater Conservation District. The study looked extensively at water quality but was largely focused on aquifers above the Rustler Aquifer.

Diamond Y Springs is the largest spring system remaining in Pecos County and provides aquatic habitat for endangered species. Diamond Y Springs is one of the largest and few remaining cienegas (desert wetlands) in West Texas. Veni (1991) performed an unpublished study for the Nature Conservancy of Texas on the delineation and hydrogeology of the Diamond Y Springs system located in Pecos County, Texas northwest of the city of Fort Stockton. Research of Boghici (1997) concluded that the groundwater from the Rustler Aquifer probably accounts for most of the discharge at Diamond Y Springs. Boghici (1997) performed an investigation into the source of water at the Diamond Y Springs system. His study combined water quality and isotopic data.

The research of Boghici (1997) referenced above is part of a large body of research that focused on the hydrogeology of the Trans-Pecos area of Texas performed by geology students studying under Dr. John Sharp at the University of Texas in Austin over the past 25 years (Nielson and Sharp, 1985; LaFave, 1987; Schuster, 1996; Boghici, 1997; Uliana, 2000). Like most studies in the area, the Rustler Aquifer was not the focus of any of these investigations, with the exception of Boghici (1997). The strength of all these studies is that they have done a good job of integrating geochemistry, geology, and hydrogeology to understand groundwater flow patterns in the region. Through this research, the hydrogeology, hydrochemical facies and origins of spring flow, and conceptualization of regional flow systems in the Trans Pecos area of Texas has been further developed. Synthesis of these studies are presented in Sharp (2001), Uliana and Sharp (2001), and Sharp and others (2003). Their conclusions regarding the Rustler Aquifer are specific to the origin of the Diamond Y Springs, which they conclude is sourced, at least in part, from groundwater in the Rustler Formation discharging through a deep-seated fault system. These studies also provide further conclusions that potential far-field regional flow systems occur within the Cretaceous, and potentially the Permian, carbonates from the Diablo Plateau-Apache Mountains and Wild Horse Flat area and extend into Reeves and possibly Pecos counties. Uliana (2000) and Uliana and Sharp (2001) document hydrochemical facies used in conjunction with geologic fault orientation information and hydraulic heads to conclude that a regional flow system may occur which parallels the Jeff Davis-Reeves county boundary through an extensive fault system comprised of the Stocks and Rounsaville Faults. Their work would suggest that flow could occur from the Apache Mountains through to the Toyah Basin in Reeves County and potentially as far as Pecos County. The water quality data developed in this project support that thesis. Sharp and others (2003) also propose a regional flow system in the Cretaceous limestones extending from the Glass Mountains to the south, north to Comanche Springs through what they refer to as the Belding-Coyanosa trough, which is similar to the southern end of Hiss' (1976) Belding-San Simon trough.

There have been several numerical models developed to simulate groundwater flow in the Culebra Dolomite member in the near vicinity of the Waste Isolation Pilot Plant site (D'Appolonia Consulting Engineers, 1981; Barr and others, 1983; Haug and others, 1987; LaVenue and others, 1990; Davies, 1989; United States Department of Energy, 1996, 2004, 2009). Several models were developed for the Waste Isolation Pilot Plant site that modeled the entire Rustler Formation (Corbet and Wallace, 1993; Corbet and Knupp, 1996; United States Department of Energy, 2009 and Corbet, 2000).

In Texas, Harden and others (2011) developed a groundwater model focused on the Edwards-Trinity (Plateau) Aquifer but which included the Rustler Aquifer as part of a Permian system model layer. Ewing and others (2012) developed the groundwater availability model for the Rustler Aquifer, which this study uses as a primary basis. The United States Geological Survey has recently developed a groundwater model of the Edwards-Trinity Aquifer but which also includes the Rustler Aquifer (Clark and others, 2014).

With the boom in fracking that occurred in the Delaware Basin from 2011 through late 2014, there has been significant interest in developing groundwater resources from the Rustler Aquifer, as well as other aquifers in the region. While this research and associated data would be beneficial for this study and future studies, this work is generally proprietary.

8 Data collection and analysis

Useful data for evaluating the geology of the Rustler Formation exists from: (1) previous investigations of the Rustler Formation hydrogeology documented in Section 7 of this report (for example Ewing and others, 2012; Holt and Powers, 1988, 2010; Powers, 2008); (2) the Brackish Resources Aquifer Characterization System Database and accompanying reports (e.g., Meyer and others, 2012) found online at the Texas Water Development Board (TWDB) website; and (3) the TWDB Groundwater Database and Submitted Driller's Reports database, also downloaded from the TWDB website. These sources were all reviewed in support of evaluating the brackish groundwater in the TWDB designated extent of the Rustler Aquifer. Results from the analysis of this data are provided in Appendices (19.3 and 19.4) and as shape files and relevant data is provided as part of the Brackish Resources Aquifer Characterization System database.

To develop a better understanding of the hydrostratigraphy of the Rustler Formation, geophysical logs were sought to provide additional information. The pre-requisites for such data are: (1) availability to the public, (2) the specific log suite, and (3) located to supplement existing geological information. INTERA began the investigation using logs and data from the Brackish Resources Aquifer Characterization System database, which included logs submitted as part of the Rustler Groundwater Availability Model (Ewing and others, 2012), and the IHS database. If the log was in the IHS database, the Subsurface Library and DrillingInfo were contacted to provide a public copy of the geophysical log. All of the geophysical logs, along with their metadata, are provided as a deliverable for this project. In addition, the metadata has been chronicled in a format consistent with entry into the Brackish Resources Aquifer Characterization System database.

After acquiring the geophysical logs, a subset of them were digitized for one of three reasons:

- Analyzed as part of the key geophysical well dataset;
- Analyzed as part of the additional water quality calculation dataset;
- Digitized specifically for the final cross-sections.

Raw Log ASCII Standard (.LAS) files for the original digitized curves on the geophysical logs along with derivative logs have been provided in a format consistent with the Brackish Resources Aquifer Characterization System database requirements.

The details regarding data sources and means of collection and analysis are described in the relevant sections of this report for all geologic, hydrogeologic and water quality data reviewed.

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9 Aquifer hydraulic properties

Aquifer hydraulic properties refer to the physical characteristics that govern flow of groundwater through the aquifer. There are many factors that impact aquifer hydraulic properties, such as aquifer structure, aquifer lithology, depositional environment, and the presence of fractures and faults. However, the primary hydraulic properties are horizontal and vertical hydraulic conductivity, transmissivity, and specific storage. These are defined below:

Hydraulic Conductivity – The measure of the ease with which groundwater can flow through an aquifer. Higher hydraulic conductivity indicates that the aquifer will allow more water movement under the same hydraulic gradient. Hydraulic conductivity has dimensions of length per unit time and typically is expressed in units of feet per day or gallons per day per square foot.

Transmissivity – This term is closely related to hydraulic conductivity and refers to the product of the hydraulic conductivity multiplied by the effective aquifer thickness. Transmissivity describes the ability of groundwater to flow through the entire thickness of an aquifer. As the thickness of the aquifer increases, the transmissivity increases for a given hydraulic conductivity. Transmissivity has dimensions of length squared per unit time and is typically expressed in units of square feet per day or gallons per day per foot.

Specific Storage – This term describes the volume of water a unit thickness of a confined aquifer will release when the water level in the aquifer is lowered. Specific storage has dimensions of inverse length.

Storativity – This term is closely related to specific storage and refers to the product of the specific storage times the effective aquifer thickness. Also referred to as the coefficient of storage, this term describes the volume of water a confined aquifer will release when the water level in an aquifer is lowered. Storativity is a dimensionless parameter.

Fault Hydraulic Conductance – This term is a measure of the ability for groundwater to flow across a fault and has dimensions of length squared per unit time. This term is the product of the fault zone hydraulic conductivity times a grid cell area divided by a length over which the fault zone exists.

MODFLOW calculates the area of a fault zone as the grid cell horizontal dimension normal to the fault times the aquifer (grid cell) thickness. Therefore, the variable input to MODFLOW is termed the fault hydraulic characteristic and is calculated by dividing the fault zone hydraulic conductivity by the length over which the fault zone exists. Fault hydraulic characteristic has dimensions of one over time (inverse time).

Horizontal hydraulic conductivity is generally determined from the interpretation of aquifer pump tests or specific capacity tests that provide an estimate of transmissivity. Horizontal hydraulic conductivity is typically derived from dividing transmissivity by some effective aquifer thickness thought to be contributing flow during the aquifer test. Storativity of aquifers is also determined from interpretation of pump tests or specific capacity tests that provide an estimate of transmissivity. Vertical hydraulic conductivity and fault hydraulic conductance are not easily measurable at the scale of a typical regional model grid and are typically considered scaled parameters fit during model calibration.

Ewing and others (2012) performed a review of the available hydraulic properties for the Rustler Aquifer and found that, in many areas of the model domain, hydraulic property estimates are lacking. The calibrated hydraulic properties for the Rustler Aquifer are provided in Table 9-1. Because horizontal hydraulic conductivity is perhaps the most important hydraulic parameter governing groundwater flow, INTERA has tabulated horizontal hydraulic conductivity statistics by potential production areas (defined in Section 14) in Table 9-2.

For horizontal hydraulic conductivity, Table 9-2 reports the minimum, maximum, geometric mean and median horizontal hydraulic conductivity. This property has a very large range in potential production areas 1 through 3 because of a depth dependent hydraulic conductivity model implemented in the calibrated groundwater availability model (see Ewing and others, 2012). For potential production areas 4 and 5, the depth decay model was not applied in the calibrated model, and horizontal hydraulic conductivity was limited to as high as five feet per day based upon considerations described in Ewing and others (2012). Figures 9-1 through 9-5 plot frequency histograms of horizontal hydraulic conductivity in potential production areas 1 through 5, respectively.

Vertical hydraulic conductivity in the calibrated Groundwater Availability Model was based upon a constant horizontal to vertical anisotropy ratio of 1,000. The calibrated model applied a constant specific storage of 1×10^{-6} 1/ft. Numerous faults with significant vertical displacement affect the structure of the Rustler Aquifer, dividing the aquifer, in some areas, into relatively isolated flow domains. The effect of these faults on the hydraulic properties of the Rustler Aquifer was implemented through the MODFLOW horizontal flow barrier package in the calibrated Rustler Groundwater Availability Model (Ewing and others, 2012). The horizontal flow barrier package was used to add horizontal resistance to flow between groups of neighboring grid cells on either side of a fault through a prescribed fault hydraulic characteristic. The parameterization of fault hydraulic characteristic was developed based upon a hierarchal approach. Faults were characterized into three groups based upon vertical displacement across the faults. Areas where the fault is completely disconnected, areas where the fault does not completely off lap the Rustler but offset is significant and areas where the off lap is a small percent of the total aquifer thickness.

Few publicly available studies on aquifer hydraulic properties have been performed since the review performed by Ewing and others (2012). INTERA requested data from the Middle Pecos Groundwater Conservation District, but specific aquifer tests for the Rustler Aquifer were not available. Oil and gas and other land owners and developers have performed several relevant studies since Ewing and others (2012), but they are not generally publicly available.

The United States Geological Survey performed the most recent and comprehensive study of the Rustler and younger aquifers in the Pecos County Region. Pearson and others (2012) developed a geodatabase of groundwater and surface-water quality, geophysical and geologic data. This data provided some of the basis for a conceptual model of the hydrogeologic framework, geochemistry, and groundwater-flow system of the Edwards-Trinity and related aquifers in the Pecos County region (Baumgarner and others, 2012). In 2014, the United States Geological Survey developed a groundwater flow model which included the Rustler Aquifer (Baumgarner and others, 2014). The calibrated parameters for the Rustler Aquifer from Clark and others (2014) model are summarized in Table 9-3.

Table 9-1. Rustler Aquifer Groundwater Availability Model Calibrated Hydraulic Parameters by potential production area (PPA).

PPA Number	Median Horizontal Hydraulic Conductivity (ft/day)*	Median Vertical Hydraulic Conductivity (ft/day)*	Specific Storage (1/ft)**	Fault Hydraulic Characteristic (1/day)***
1	0.01	1×10^{-5}	1 x 10-6	100, 1, 1×10^{-8}
2	0.24	2.4×10^{-4}	1×10^{-5}, 1×10^{-6}	1.0
3	0.23	2.3×10^{-4}	1 x 10-6	0.01, 1000
4	5.0	5×10^{-3}	1 x 10-6	100, 1, 1×10^{-8}
5	5.0	5×10^{-3}	1 x 10-6	0.01, 1000

* ft/day = feet per day
**1/ft = inverse feet
***1/day = inverse day

Table 9-2. Rustler Groundwater Availability Model calibrated horizontal hydraulic conductivity (in feet per day) statistics by potential production area.

Statistic	PPA-1	PPA-2	PPA-3	PPA-4	PPA-5
Minimum	0.01	0.01	0.01	0.01	3.00
Maximum	0.19	0.72	0.51	5.00	5.00
Geometric Mean	0.01	0.24	0.23	5.00	5.00
Median	0.02	0.16	0.21	4.94	4.94

Note: PPA stands for potential production area

Table 9-3. Calibrated parameters for the Rustler Aquifer (from Clark and others, 2014).

PPA* Number	Horizontal Hydraulic Conductivity (ft/day)**
Horizontal Hydraulic Conductivity (ft/day)**	100
Vertical Hydraulic Conductivity (ft/day)**	0.49
Specific Storage (1/ft)***	5×10^{-6}
Horizontal Flow Barrier Hydraulic Conductivity (ft/day)*	1×10^{-6}

* PPA = potential production area
** ft/day = feet per day
***1/ft = inverse feet

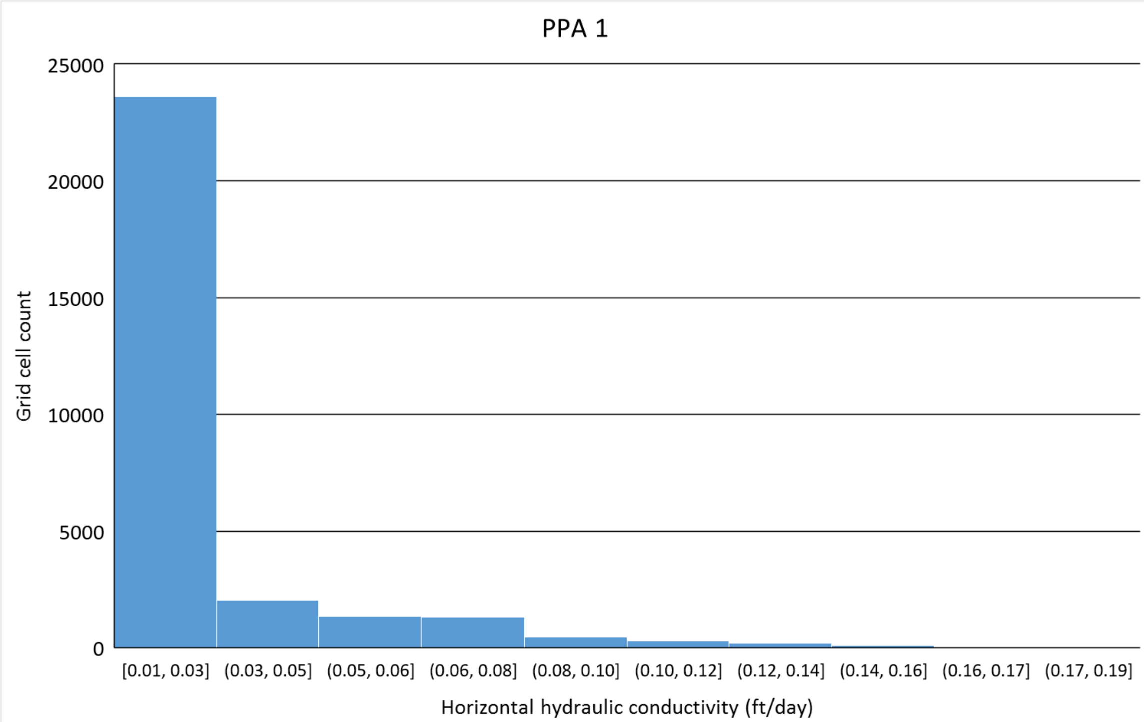

Figure 9-1. Rustler GAM calibrated horizontal hydraulic conductivity (feet per day) for PPA-1.

Note: PPA=potential production area; ft/day=feet per day.

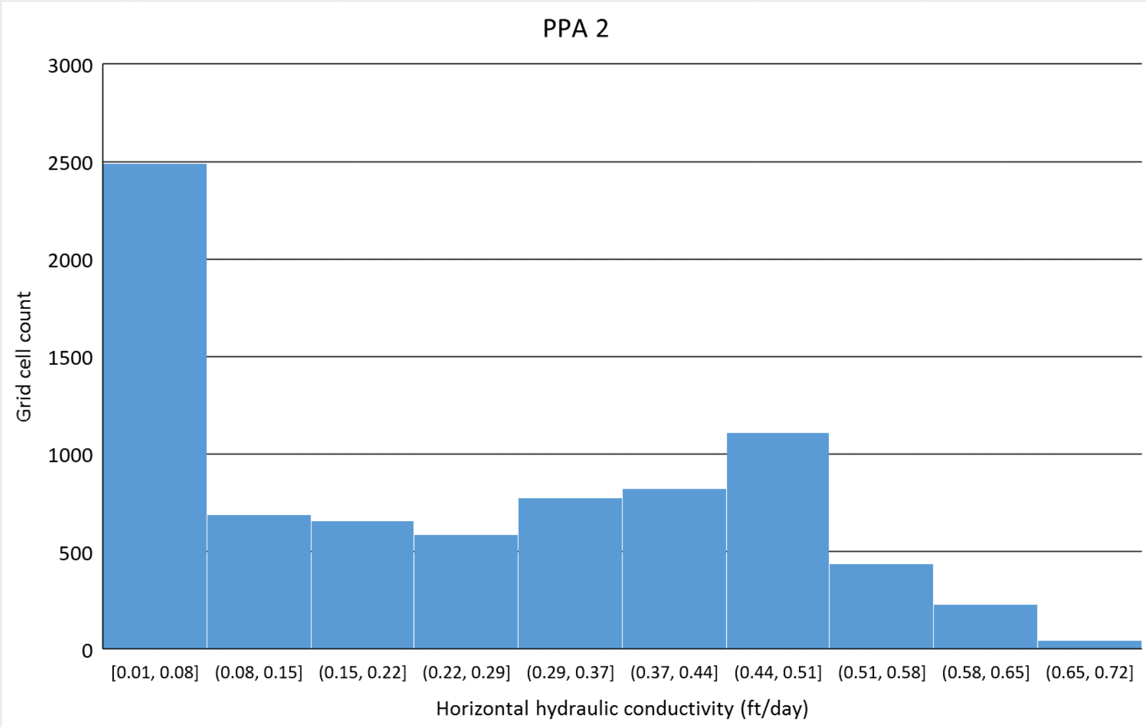

Figure 9-2. Rustler GAM calibrated horizontal hydraulic conductivity (feet per day) for PPA-2.

Note: PPA=potential production area; ft/day=feet per day.

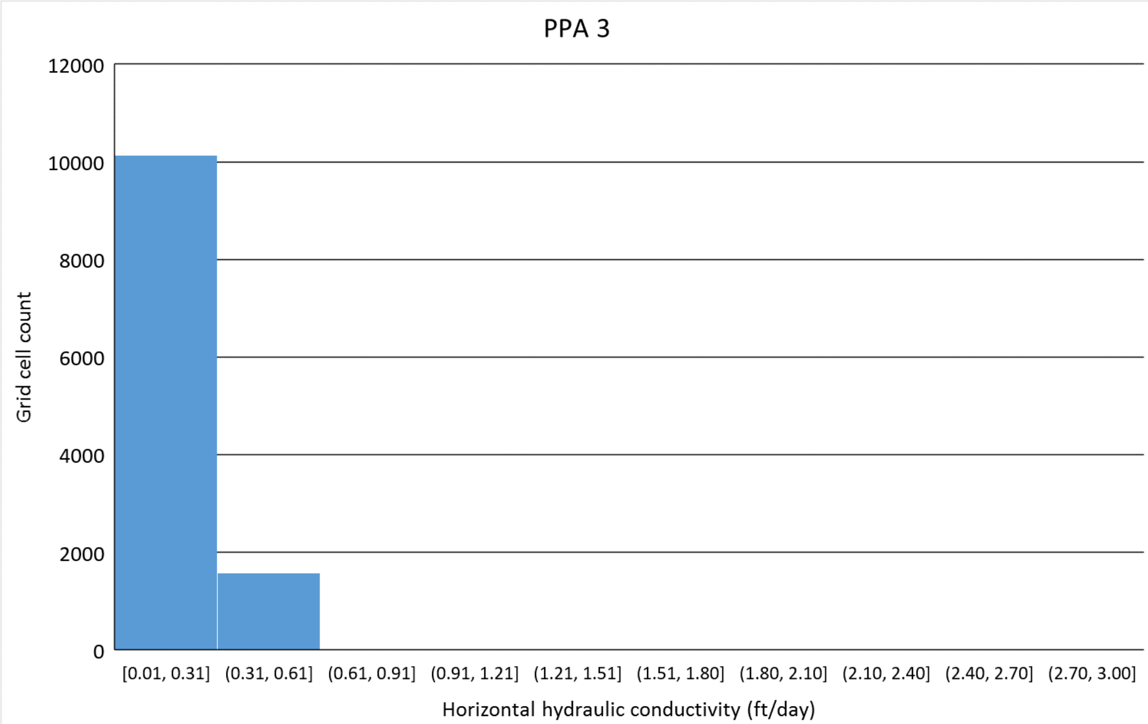

Figure 9-3. Rustler GAM calibrated horizontal hydraulic conductivity (feet per day) for PPA-3.

Note: PPA=potential production area; ft/day=feet per day.

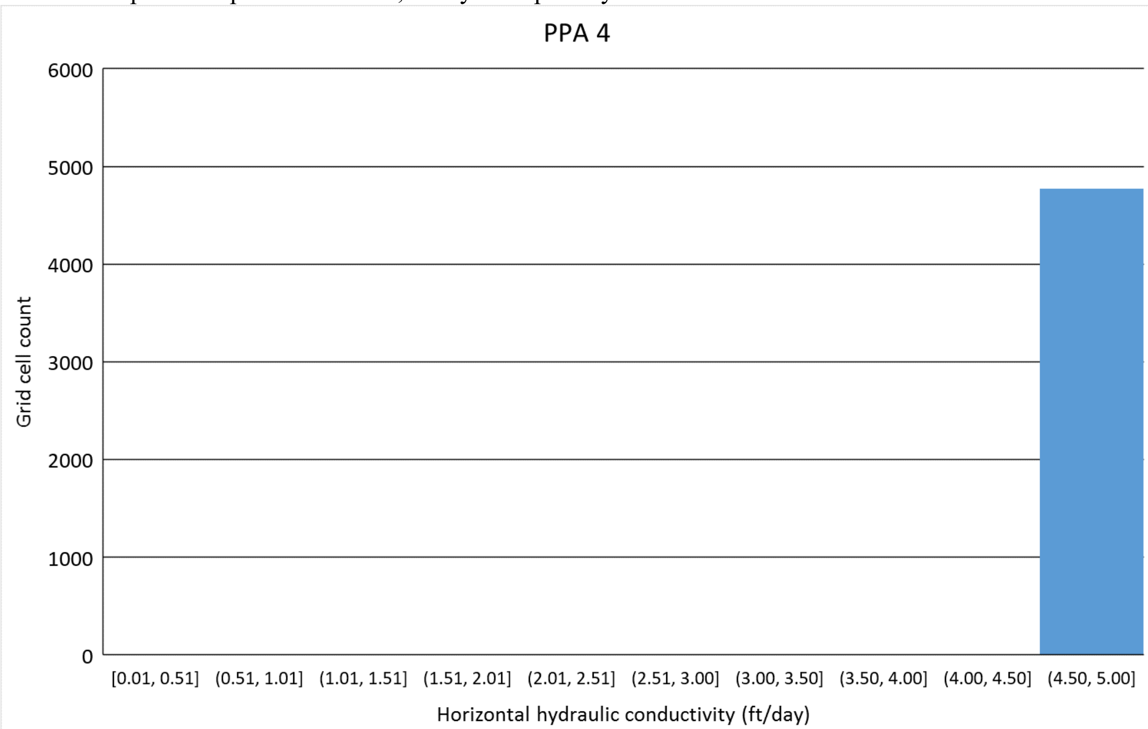

Figure 9-4. Rustler GAM calibrated horizontal hydraulic conductivity (feet per day) for PPA-4.

Note: PPA=potential production area; ft/day=feet per day.

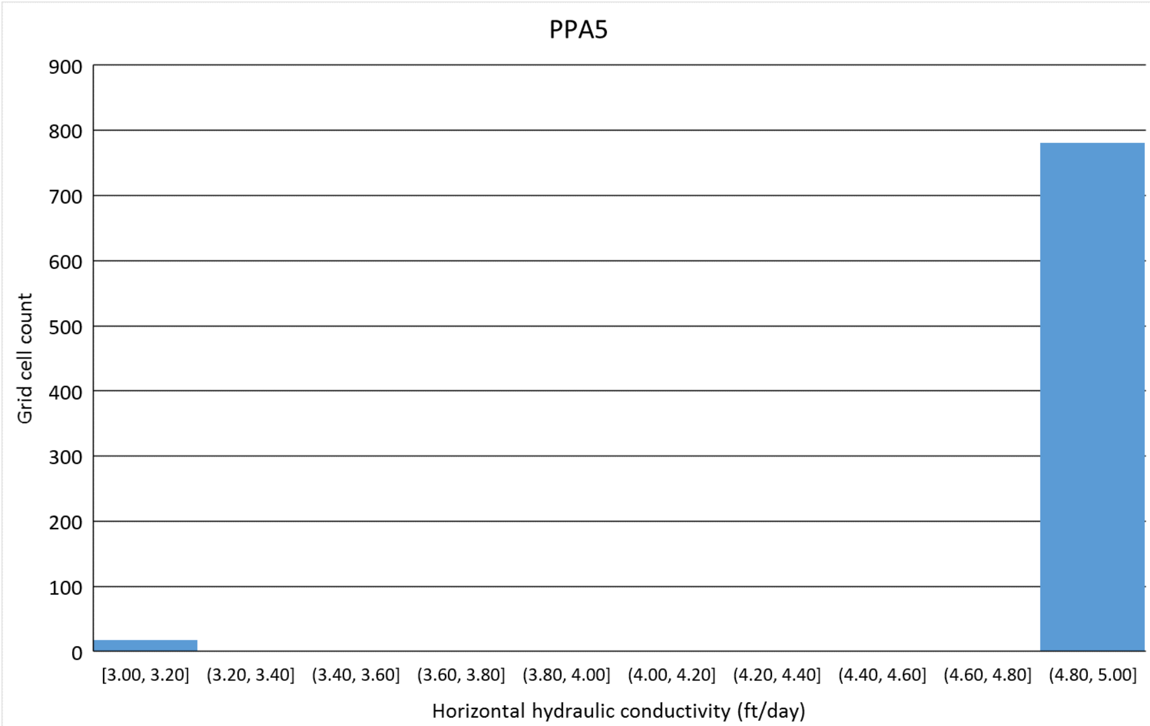

Figure 9-5. Rustler GAM calibrated horizontal hydraulic conductivity (feet per day) for PPA-5.

Note: PPA=potential production area; ft/day=feet per day.

10 Water quality data

This section presents a description of the observed water quality data and our process for analyzing that data to support salinity zone delineation and geophysical log interpretation (Section 13). Data on the water quality of the Rustler Aquifer were compiled by Ewing and others (2012) from the following sources: Texas Water Commission (1989); Small and Ozuna (1993); Boghici (1997); Brown (1998); Boghici and Van Broekhoven (2001); and TWDB (2012). These data were combined with data extracted from the TWDB Groundwater Database (Groundwater Database; 1/25/2016), the Brackish Resources Aquifer Characterization System database (2/10/2016), the United States Geological Survey Produced Waters Database (3/29/2016), and the United States Geological Survey Report Data Series 678 (Pearson and others, 2012). Additionally, INTERA evaluated 15 water resistivity samples from a 1982 Society of Professional Well Log Analysts publication (SPWLA, 1982). The majority of the Society of Professional Well Log Analysts samples were located outside of the project area and had highly contrasting calculated water quality values when compared to samples within the main flow system, which corresponds to the TWDB designated aquifer extent. The values inside the extent only had a resistivity of water (R_w) value, and it was not known if corrections had been made to the value. Given the limited ability to assure the quality of the Society of Professional Well Log Analysts data, INTERA decided that the dataset should not be integrated into the analysis. INTERA made data requests to various oil and gas operators in the Rustler Aquifer footprint, as well as the Middle Pecos Groundwater Conservation District. All operators contacted declined to share their data, or relayed that it had already been provided to the Brackish Resource Aquifer Characterization System Program at the TWDB for integration into their database. The Middle Pecos Groundwater Conservation District showed interest in sharing their data but were not able to compile it in time for this study.

In addition to the above mentioned water chemistry data, a query of the TWDB Groundwater Database identified all wells and springs with a minimum of total depth information lying within 10 miles of the Rustler Aquifer. These were evaluated against the TWDB structural surfaces for the top and base of the Rustler Aquifer (Ewing and others, 2012). Initially, there were 2,036 wells, of which 616 had screen information and 1,709 had total depth information. Of the 2,036 wells, 56 were shallow wells located in the Rustler Hills, where the Rustler Formation outcrops. Wells located in the Rustler Hills lacking depth information were assumed to be producing from the Rustler Aquifer due to the fact that a thick sequence of evaporites (Castile and possibly Salado Formations) underlie the Rustler Formation, negating any potential for deeper useable water. For the 616 wells with screen information, the structural top and base of the Rustler Aquifer was compared to the elevation of the top and base of the screened/open intervals of the water well. If there was no reported screen information, then the elevation of the base of the well (based on the total depth of the well) was compared to the top- and base-of-Rustler Aquifer surfaces. Any well with a total depth intersecting the Rustler Formation structural surfaces or lying within 100 feet of the top-of-Rustler surface were included for further evaluation, even if the well extended below the base of the Rustler Aquifer due to the possibility of the well having screen slots within the Rustler Aquifer. This resulted in 142 out of 2,036 Groundwater Database wells located within 10 miles of the TWDB Rustler Aquifer footprint potentially being screened to the Rustler Aquifer. Five additional Groundwater Database wells (four of which lie outside the TWDB Rustler Aquifer footprint) were added to this preliminary dataset based on their classification as a Rustler well within the United States Geological Survey National Water Inventory System database. Seven additional wells included in the water quality data for the Rustler Groundwater Availability Model (Ewing and others, 2012) lying to the east of the TWDB Rustler Aquifer footprint outside the initial search area described above were also added to the set of potential Rustler Aquifer wells, bringing the total number of potential Rustler Aquifer wells or springs from the Groundwater Database to 154.

Additional data were added for wells identified as being completed in the Rustler Aquifer in historic reports. A total of 32 potential Rustler Aquifer wells were identified from historic reports: two wells were indicated as Rustler Aquifer wells in Table 7 of Texas Board of Water Engineers Bulletin 5916 (Garza and Wesselman, 1959), 11 wells were indicated as Rustler Aquifer wells in Table 4 of Texas Board of Water Engineers Bulletin 6106 (Armstrong and McMillion, 1961), four wells were indicated as Rustler Aquifer wells (or having been sampled from the Rustler Aquifer prior to plugging back) in Table 6 of Texas Water Commission Bulletin 6214 (Ogilbee and others, 1962), and 13 wells and two springs were indicated as being completed in the Rustler Aquifer in Table 2 of Winslow and Kister (1956). Locations for these wells were digitized from maps included in the reports.

Well and water quality data were also collected from the United States Geological Survey National Water Inventory System database. For the United States Geological Survey data, only wells or springs with available water quality were considered. Based on the United States Geological Survey's well aquifer code and/or comparison of screened or open intervals with structural surfaces from the Rustler groundwater availability model (Ewing and others, 2012), 14 United States Geological Survey wells were identified as potential Rustler Aquifer wells. Four of these wells are located in New Mexico, and of the remaining 10 wells, only one could not be confidently tied to a well record already included from the TWDB's Groundwater Database. As discussed previously, five wells identified from the Groundwater Database were also identified in the United States Geological Survey National Water Inventory System search on the basis of being classified as a Rustler Aquifer well. In some cases, the United States Geological Survey National Water Inventory System database contained additional sampling events for these wells that were not included in the Groundwater Database, although the Groundwater Database generally had more extensive records of water quality data. As a result of the United States Geological Survey National Water Inventory System search, four additional wells and one spring were identified. The distribution of the wells with water quality data by type can be seen in Figure 10-1.

After the project initiation meeting, members of the Brackish Resource Aquifer Characterization System Program notified INTERA that the Brackish Resources Aquifer Characterization System database had been updated with water well completion and water chemistry data that could be relevant to the Rustler Aquifer. These 26 wells were identified from the Brackish Resources Aquifer Characterization System database and incorporated into the list of potential Rustler Aquifer wells.

In total, 217 wells or springs from these different data sources were flagged as potentially completed in the Rustler (Table 19-3). For each of these wells, the ground surface elevation was taken from the digital elevation model used in the Rustler Groundwater Availability Model (Ewing and others, 2012). This digital elevation model has been provided as part of the deliverables of this project. In cases where different coordinates for a well were reported by the

TWDB and the United States Geological Survey, the coordinates from the TWDB were used. INTERA evaluated the water well data using Petra® and looked at each well "in section." That is, each water well was projected onto a structural cross-section between geophysical logs that had, at minimum, identified the top and base of the Rustler Formation. For example, Figure 10-2 illustrates a water well completion for well 4652107, which was put in section between geophysical logs for wells 423893296500 and 423893035300. It is apparent that this well was drilled down to the lower portion of the Rustler Aquifer. Assuming that the well does not have any higher completions, water chemistry data for this well, if available, should be reflective of the Rustler Aquifer. This analysis was performed on 217 water wells with completion information. Sixteen water wells that did not pass this additional screening step but had the Rustler Aquifer code designation in the Groundwater Database, or were indicated as Rustler wells in their source report, were used in the analysis. Additionally, four springs designated as "Rustler" by the TWDB were retained for further analysis. Any water chemistry data that either had suspect remarks or had a reliability code (as designated by the TWDB Groundwater Database) of "1-Not indicative of aquifer quality" or "99-Reliability unknown or not available" were not incorporated into the initial water quality dataset.

10.1 Dissolved minerals

Table 19-4 summarizes the results of the water chemistry analysis. In the table, equivalent sodium chloride (NaCl) salinity (labeled TDS_{NaCl}) was calculated for each water quality sample using Schlumberger Chart Gen-4 (Schlumberger, 2009). Once the equivalent sodium chloride salinity was determined, the resistivity value of the water at 75 degrees Fahrenheit was solved for using Schlumberger Chart Gen-6 (Schlumberger, 2009). The purpose of this step is to facilitate the comparison of calculated water resistivity values between the sampled water quality and the calculated water resistivity from the geophysical logs. In the oil and gas industry, the majority of the water that is co-produced with oil or gas is dominated by sodium and chloride ions. The relationship between a sodium chloride-dominated water sample and its resistivity is fairly well understood through empirical methods. When other molecules, such as bicarbonate and sulfate, make up significant portions of the water sample, this relationship deviates from that of sodium chloride and needs to be accounted for (Alger, 1966).

This two-step analysis was performed on 133 water quality samples for 84 water wells that were determined to be producing from the Rustler Aquifer. An ionic balance calculation (see Collier, 1993b for example calculation) was performed and any water chemistry samples that exceeded the plus or minus 15 percent criterion were omitted from further analysis. While most references recommend a plus or minus 5 percent (again, see Collier, 1993a), data availability for the Rustler Aquifer was so sparse that the criteria were relaxed to bring on additional data. Subsequently, all of the total dissolved solids data that met the above criteria were plotted on a map of the project area (Figure 10-3). It is important to note that Figure 10-3 includes total dissolved solids contours based upon observed water quality (presented in this section) and on geophysical log analyses not presented in this section. Posted values in Figure 10-3 are all observed water quality data. Figure 10-3 also includes data from the United States Geological Survey produced waters database (Blondes and others, 2016). The data from the United States Geological Survey produced waters database was not specifically incorporated into our water quality dataset for a number of reasons including: 35% had a charge balance in excess of plus or minus 15%; inconsistencies in the sample depths; for the 65% that did not have a charge balance in excess of plus or minus 15 %, only two were below 10,000 milligrams per liter total dissolved solids; and the sample depth information was ambiguous or not reported. While the United States Geological Survey produced data were not specifically integrated into our database, the total dissolved solids values were plotted on the water quality maps because they provide additional data resolution in the higher total dissolved solids portions of the project area to the east of the Monument Draw Trough, outside the Rustler Aquifer boundary.

The majority of the samples within the Rustler Aquifer extent had reported total dissolved solids values below 10,000 milligrams per liter (Figure 10-3 and Appendix 19-4). Therefore, to keep the water chemistry analysis specifically relevant to the Rustler Aquifer extent, samples with values in excess of 10,000 milligrams per liter were omitted from subsequent water quality analysis. It is suspected that the relative increases in sodium and chloride values associated with the higher total dissolved solids values would artificially skew data within the Rustler Aquifer extent. Water quality analyses that met all criteria were distinguished in Appendix 19-4 as "Data Accepted." This resulted in 103 water chemistry analyses for 64 wells. For wells that had more than one water quality measurement, the median value is used unless otherwise specified in Appendix 19-4.

Figure 10-3 shows a base map of the project area with total dissolved solids (actual value for single samples and median for multiple samples unless otherwise specified in Appendix 19-4) displayed on water wells that have water chemistry information. Additionally, structural subdomains outside the aquifer boundary developed by Ewing and others (2012) are plotted to represent the boundaries of the major structure in the area. Upon initial investigation, it is apparent that subdomain 4 represents a water quality boundary that separates higher-total dissolved solids water to the east from lower-total dissolved solids water to the west, with the exception of the southern extent in the Fort Stockton area (See Figure 5-10 for hydrostructural zone numbers). Subdomain 4 represents a graben that overlies the Capitan Reef Complex and is an area where the Rustler Formation is completely disconnected (Ewing and others, 2012) from areas to the east of subdomain 4. Toward the south-southeast portion of subdomain 4, the structural throw is greatly reduced, and the Rustler Aquifer is likely still in hydraulic communication with updip portions of the unit to the west and northwest. In addition, it is also surmised that additional recharge is coming from the outcrop of the Tessey Limestone, and the recharging water is making it north towards the Fort Stockton area. Additional data would be needed to confirm the Tessey Limestone hypothesis.

Within the TWDB-designated extent of the Rustler Aquifer, the sampled water quality is less than 6,000 milligrams per liter, with two exceptions. The first exception is TWDB well 4613402 in central Loving County that has two sampled TDS values of 2,712 milligrams per liter and 89,716 milligrams per liter. INTERA suspects that the much higher value is due to contamination and does not reflect Rustler Formation water. The second exception is in the extreme northern portion of the project area around Red Bluff Reservoir. Three wells there have sample values of 6870, 8260 and 10300 milligrams per liter (Figure 10-3). Geophysical logs both within the Rustler Aquifer extent and to the north in Lea and Eddy Counties show a relative decrease in porosity from south to north. It is likely that structural events (downwarping, burial, and subsequent exhumation associated with the Pecos-Loving Trough) did not have as severe of an effect on the Rustler Formation towards the northern portion of the project area. We suspect that the complex structural history of the Rustler Formation within the Rustler Aquifer extent led to it becoming an aquifer. The Rustler Formation outside of the designated aquifer extent generally produces insignificant quantities of very brackish groundwater.

Evaluation of the sampled water chemistry data determined a speciation of predominantly calcium-chloride-sulfate (population 1), with minor amounts of calcium-magnesium-chloride-sulfate (population 2) (see Figure 10-4 for a Piper plot of water chemistry data). Spread in the two populations is primarily controlled by the relative percent of the anions comprised by the sulfate molecule in each water quality sample. Population 1 has sulfate values between 80 and 94 percent, and population 2 has sulfate values between 60 and 70 percent. With aquifers that have interbedded gypsums, sulfate content within the formation water increases down dip from the recharge area until the water is at saturation with respect to sulfate (Hem, 1985). It was anticipated that plotting the water quality data and parsing it into the two populations would have alluded to trends in distance from recharge areas or a better understanding of the flow path evolution. However, data plotted in the project area showed no real spatial correlation. This is likely due to the complex nature of the groundwater flow system within the Rustler Aquifer. A ESRI shape file of the data will be provided as a deliverable for this project in the hope that future researchers can use the data.

While the geographic distribution of the piper plot results did not allude to trends, the speciation of the water chemistry plays a critical component in the calculation of water quality from resistivity signatures. Sampled water chemistry data, including the speciation of the various ions and anions, were used to guide the calculations of water quality (calculated total dissolved solids in milligrams per liter) from resistivity logs. These values provide a range of expected total dissolved solids values and serve to constrain calculated water quality to values within that range. To go from resistivity derived water quality (salinity) to actual water quality (total dissolved solids), an understanding of how the two are related must be acquired so that the values can be converted back and forth. This process will be expanded upon in Section 13.

10.2 Water quality parameters of concern for desalination

Brackish groundwater is typically defined as water that contains between 1,000 milligrams per liter and 10,000 milligrams per liter of total dissolved solids. Significant areas of the Rustler Aquifer produce water with total dissolved solids in this range. To be classified as potable water according to the Texas Commission on Environmental Quality's primary and secondary drinking water standards, the brackish groundwater will need to be desalinated.

The predominant technology used for desalination of brackish groundwater in Texas is reverse osmosis. Reverse osmosis is a pressure-driven process that relies on semi-permeable membranes to separate dissolved salts from water. These membranes are subject to fouling and scaling, depending on the feed water quality and design and operation of the reverse osmosis system. Therefore, understanding the fouling and scaling potentials of a water are key considerations when developing a brackish groundwater supply.

Fouling is the accumulation of contaminants (particles, bacteria, colloidal material, etc.) on the membrane surface. Turbidity and silt density index values of the membrane feed water are typically used to characterize the water's fouling potential. Silt density index is described in American Society of Testing Materials D4189, and is based on the plugging rate of a standard

0.45-micrometer membrane filter. Most reverse osmosis membrane manufacturers limit the maximum silt density index value of the feed water to between one and five, depending on the water source. Turbidity can be measured using an in-line continuous or a hand-held nephelometer. The maximum limit for turbidity of the feed water is typically no greater than 0.1 nephelometric turbidity units. Coagulation, filtration, chloramination, and combinations thereof may be used as pretreatment for reverse osmosis systems to minimize fouling of the membranes.

Scaling occurs on the surface of a membrane when the concentration of a salt in the feed water exceeds its solubility limit. Common limiting salts for reverse osmosis systems include:

- Calcium Carbonate
- Calcium Sulfate
- Barium Sulfate
- Strontium Sulfate
- Silica (anionic form)
- Calcium Fluoride
- Calcium phosphate

Depending on the feed water quality and system recovery, acid, scale inhibitors (sometimes referred to as antiscalants), softening, or appropriate combinations thereof may be used to control scale formation and increase the operating recovery of the system.

The physical and chemical water quality parameters of concern for reverse osmosis systems and their respective Texas Commission on Environmental Quality primary and secondary standards are presented in Table 10-1. If a cell only has dash lines, there is not a standard set. In addition, a summary of potential regulatory- and membrane-related issues for each parameter is presented using the following categories:

- **Human health** - Water quality parameters that present risks to human health are regulated by the Texas Commission on Environmental Quality with Primary Drinking Water Standards. These are enforceable standards with maximum contaminant levels established to protect public health.
- **Aesthetic** - Aesthetic water quality parameters have the potential to cause objectionable taste, odor, and appearance. These parameters are not known to be a risk to human health. Secondary Drinking Water Standards were established by the United States Environmental Protection Agency as guidelines to manage the aesthetic quality of drinking water. In Texas, these standards are enforceable.
- **Membrane fouling and scaling** - Water quality parameters that have potential to cause mechanical damage, fouling, and scaling of membrane-based desalination technologies.
- **Special concentrate management** - In general, management or disposal of reverse osmosis concentrate that contains a majority of the parameters listed in Table 10-1 will be approved by the Texas Commission on Environmental Quality on a case-by-case basis. A major consideration for disposal is whether the reverse osmosis concentrate will deteriorate the water quality of the receiving water body. The presence of constituents, like combined radium, in high enough concentrations may require special regulatory considerations to manage the radioactive materials in the reverse osmosis concentrate.

The need and requirements for special concentrate management should be evaluated in early stages of reverse osmosis project development.

A summary of wells primarily from the Rustler Aquifer outcrop and subcrop with concentrations of water quality parameters that exceed threshold values based on Texas Commission on Environmental Quality Primary and Secondary Drinking Water Standards is presented in Table 10-2. The water quality and well information was extracted from the TWDB Groundwater Database. The most widespread regulated dissolved solids found in Rustler Aquifer water quality were chloride, sulfate, nitrate, and gross alpha. Some other water quality parameters that do not have maximum regulatory limits, such as alkalinity, calcium, silica, sodium, and strontium (not shown in Table 10-2), had elevated levels in some Rustler Aquifer wells and need to be considered for design and operation of a desalination system. Threshold values for these water quality parameters will depend on the water chemistry and reverse osmosis system design. Based upon available data, the water quality data within the boundaries of the Rustler Aquifer is not discriminant with regards to desalination treatment technologies. The radionuclide parameters gross alpha and combined radium could become an issue in waste concentrate and would have to be considered in the Rustler Aquifer. Two wells that stand out are State Well Numbers 4613402 and 5301203.

Table 10-1. Summary of physical and chemical water quality parameters of concern for reverse osmosis systems.

	Parameter	Potential Issue	TCEQ[a] Primary Drinking Water Standard (mg/L)[b]	TCEQ[a] Secondary Drinking Water Standard (mg/L)[b]
General and Physical Parameters	Alkalinity	Aesthetic, membrane fouling and scaling	---	---
	pH	Aesthetic	---	> 7 standard units
	Silt density index	Membrane fouling and scaling	---	---
	Temperature[c]	Aesthetic	---	---
	Total dissolved solids	Aesthetic	---	1,000
	Turbidity	Human health (indicator)[d], aesthetic, membrane fouling and scaling	treatment technique	---
Cations	Aluminum	Aesthetic, membrane fouling and scaling	---	0.05 to 0.2
	Ammonia	Human health (advisory)[e]	---	---
	Arsenic	Human health	0.01	---
	Barium	Human health, membrane fouling and scaling	2.0	---
	Calcium	Aesthetic, membrane fouling and scaling	---	---
	Iron	Aesthetic, membrane fouling and scaling	---	0.03
	Magnesium	Aesthetic	---	---
	Manganese	Aesthetic, membrane fouling and scaling	---	0.05
	Potassium	Aesthetic	---	---
	Sodium	Aesthetic	---	---
	Strontium	Membrane fouling and scaling	---	---

	Parameter	Potential Issue	TCEQ[a] Primary Drinking Water Standard (mg/L)[b]	TCEQ[a] Secondary Drinking Water Standard (mg/L)[b]
Anions	Bromide[f]		---	---
	Chloride	Aesthetic	---	300
	Fluoride	Human health, membrane fouling and scaling	4.0	2.0
	Nitrate	Human health	10	---
	Phosphate	Membrane fouling and scaling	---	---
	Silica	Membrane fouling and scaling	---	---
	Sulfate	Aesthetic, membrane fouling and scaling	---	300
Radionuclides	Gross Alpha	Human health, special concentrate management	15.0 pCi/L[g]	---
	Radium, Combined (Ra-226 and -228)	Human health, special concentrate management	5.0 pCi/L[g]	---
	Other			
	Boron	Human health (advisory)[h]	---	---
	Hydrogen sulfide	Aesthetic, membrane fouling and scaling	---	0.05

[a] TCEQ stands for Texas Commission on Environmental Quality

[b] mg/L stands for milligrams per liter

[c] Feed water temperatures greater than approximately 110 degrees Fahrenheit may cause failure of reverse osmosis membranes. In such cases, lowering feed water temperatures as part of the design of a reverse osmosis system will need to be addressed.

[d] Turbidity may be used as an indicator parameter for the presence of disease-causing organisms. To control turbidity in public water systems, the Texas Commission on Environmental Quality established a level of treatment process performance that must be followed, known as a treatment technique.

[e] The United States Environmental Protection Agency has established a non-enforceable lifetime health advisory for ammonia of 30 milligrams per liter. This is the concentration of ammonia in drinking water that is not expected to cause any adverse non-carcinogenic effects for a lifetime of exposure.

[f] The concentration of bromide should be considered during development of the groundwater supply. At microgram per liter levels, bromide may react with free chlorine (drinking water disinfectant) and organic carbon to form disinfection by-products, which are regulated by the Texas Commission on Environmental Quality. As an example, this may occur if a groundwater containing bromide is blended with a treated surface water.

[g] pCi/L stands for picoCuries per liter

[h] The United States Environmental Protection Agency has established a non-enforceable lifetime health advisory for boron of six milligrams per liter. This is the concentration of boron in drinking water that is not expected to cause any adverse non-carcinogenic effects for a lifetime of exposure.

Table 10-2. Summary of Wells with Water Parameters that Exceed Primary and Secondary Drinking Water Standards.

	Parameter	Threshold Value[a] (milligrams per liter)	Wells with Concentrations Above the Threshold Value (Well ID#)
General and Physical	pH	7 standard units	(pH values from these wells are below threshold value) 4660905, 4661103, 4661203, 4731901, 4746101, 5216608, 5216612, 5216613, 5301203
	Total dissolved solids	1,000	All but five wells (4654901, 4747403, 4747404, 4747701, 4747801) reported in the database had concentrations above the threshold value.
	Cations		
	Aluminum	0.2	4747901
	Manganese	0.05	4542703, 4549203, 4613402
Anions	Chloride	300	55950, 55953, 55954, 55959, 4549203, 4559501, 4620405, 4640701, 4640703, 4640801, 4643102, 4661206, 5216608, 5216609, 5216612, 5216613, 5301203, 24S.28E.27.4111 26S.29E.22.330, H-35, P-120, P-64, P-66, P-71, P-95
	Fluoride	4.0	4723602
	Nitrate (as N)	10	P-57, 4559501, 4723701, 4723701, 4746101, 4747701, 4747704, 4747801, 4754302, 4755104, 4755203
	Selenium	0.05	4549203
	Sulfate	300	All but two wells (4640701, 4747801) reported in the database had concentrations above the threshold value
Radionuclides	Gross Alpha	15.0 pCi/L[b]	4613402, 4640701, 4652901, 4653903, 4654901, 4654903, 4660905, 4661103, 4661203, 5215502, 5216608, 5216609, 5216612, 5216613, 5301203
	Radium, Combined (Ra-226 and -228)	5.0 pCi/L[b]	4613402, 5216609, 5216612, 5301203

[a] Threshold value based on Primary and Secondary Drinking Water Standards.

[b] pCi/L stands for picoCuries per liter

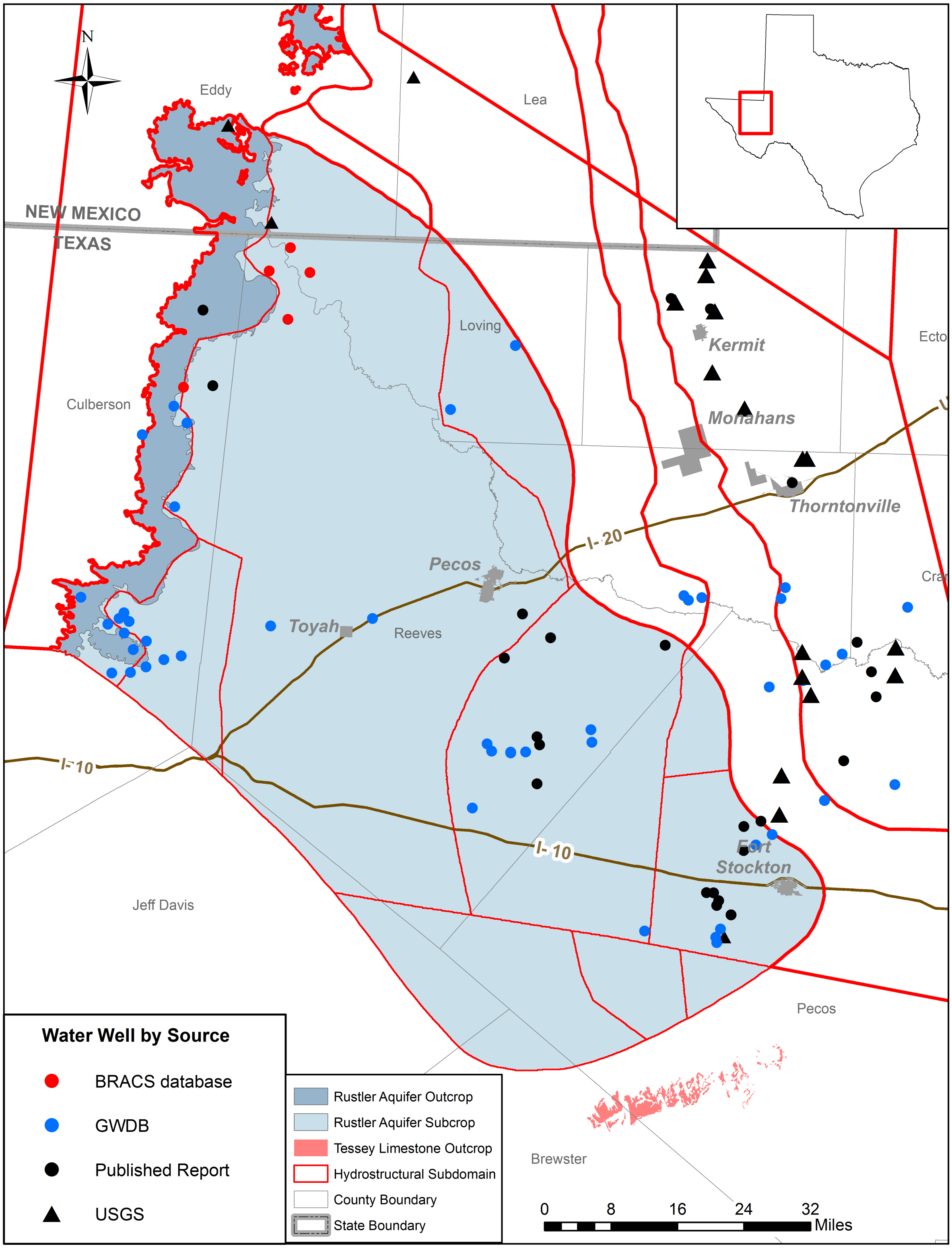

Figure 10-1. Distribution of water quality samples by source.

Note: BRACS= Brackish Resource Aquifer Characterization System; GWDB=groundwater database; USGS=United States Geological Survey

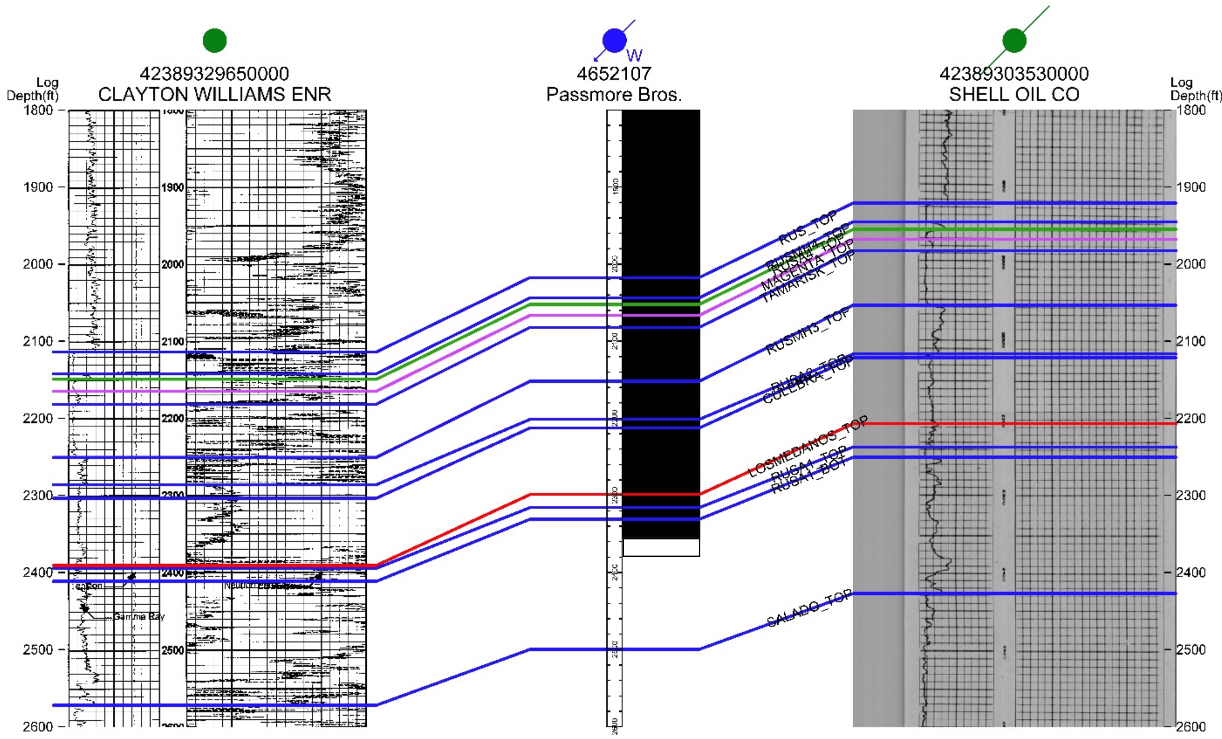

Figure 10-2. **Example of how wells were evaluated to determine if completion was in the Rustler Aquifer.**

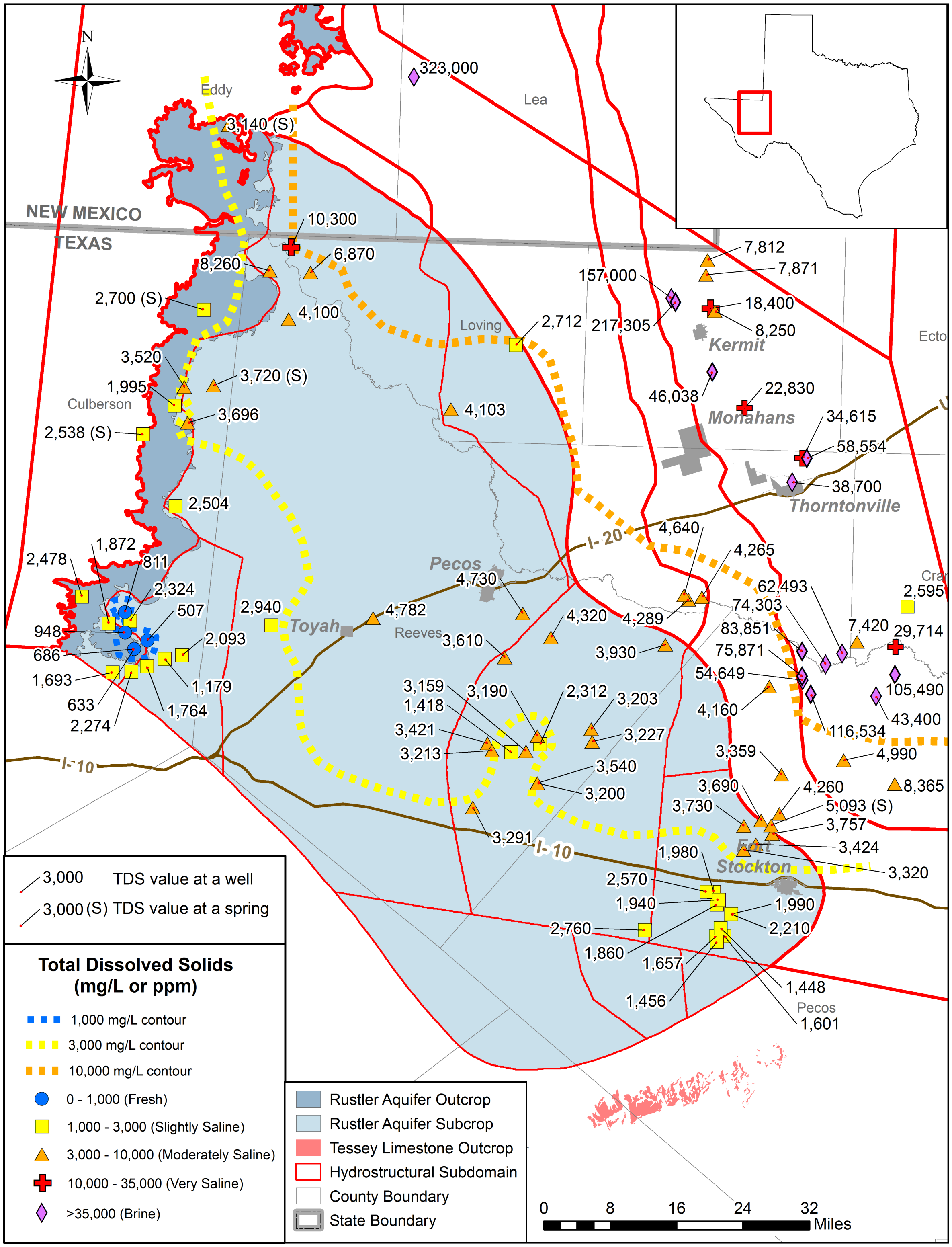

Figure 10-3. Sampled water quality values from wells determined to be producing from the Rustler Aquifer.

Note: TDS=total dissolved solids; mg/L=milligrams per liter; ppm=parts per million.

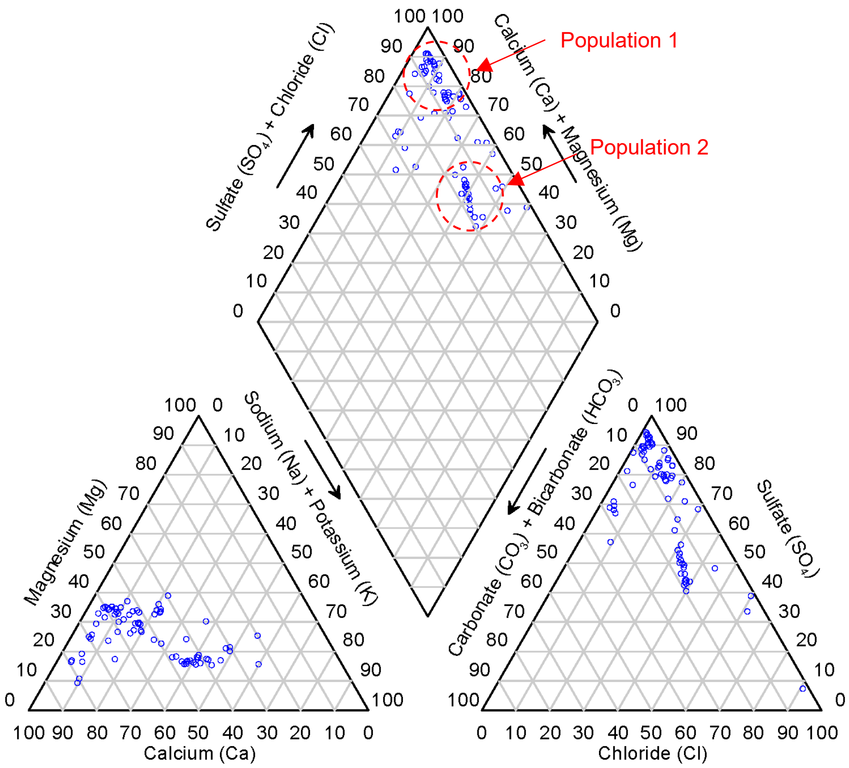

Figure 10-4. Piper plot of water chemistry analyses from wells producing from the Rustler Aquifer.

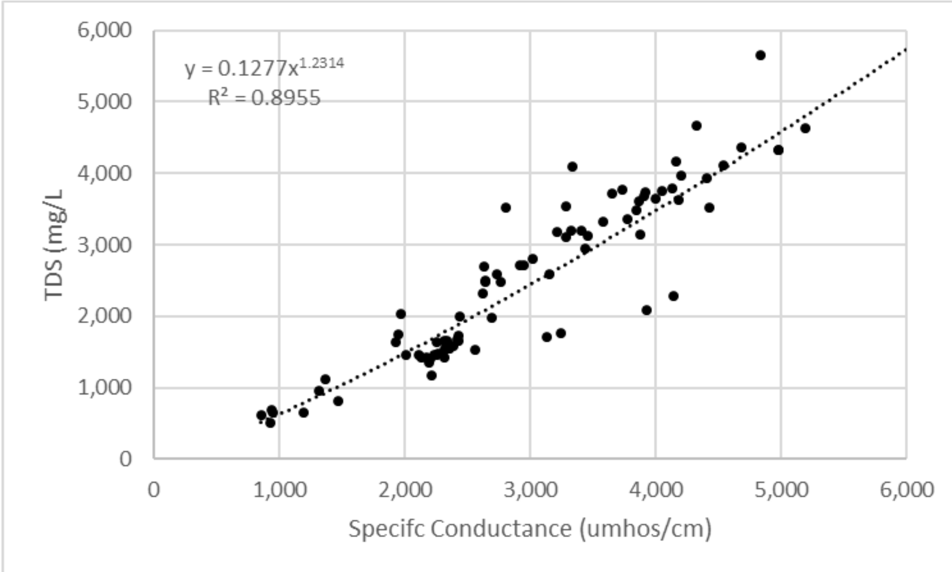

Figure 10-5. Relationship between TDS and specific conductance for the sampled water quality data in the Rustler Aquifer.

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11 Net sand analysis

The Rustler Aquifer is composed of a complex assemblage of lithologies ranging from dolomite to limestone to anhydrite to halite to siltstone. As discussed in Section 5 of this report, the transmissive water-bearing units of the Rustler Aquifer are the Magenta Dolomite, the Culebra Dolomite and the limestones of the Los Medaños Unit of the Rustler Formation. Therefore, no net sand analysis can be performed for this study. However, isopach maps of the dolomite and limestone units are provided and discussed in Section 5.

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12 Groundwater volume methodology

In this section, estimates of groundwater volumes are generated for different classifications of groundwater quality for the Rustler Aquifer based on the water salinity zones defined in Section 6. The salinity zones in the Rustler Aquifer have been developed based upon observed water quality data and analysis of geophysical logs presented (see Section 13). As has been discussed previously in this report, the three transmissive water producing members of the Rustler Aquifer are the Culebra Dolomite member, the Magenta Dolomite member, and the limestone portion of the Los Medaños Unit. For definition of groundwater salinity zones and potential production areas, we have defined one average water quality estimate for all three of the transmissive units within the Rustler Aquifer.

12.1 Mechanics of calculating groundwater volumes

Boghici and others (2014) provide a good overview of the calculation of the volume of groundwater in storage in an aquifer as part their calculation of Total Estimated Recoverable Storage for different aquifers in Groundwater Management Area 4. The approach used to calculate aquifer groundwater volumes is essentially the same as the process used by the TWDB to estimate Total Estimated Recoverable Storage, except we do not make the judgement as to what defines recoverable storage. Because there are three transmissive members of the Rustler Aquifer, we calculate groundwater storage for each of these members. This approach is different than was done for the Rustler Aquifer Total Estimated Recoverable Storage calculations for Groundwater Management Areas 3, 7 and 4 (Boghici and others 2014; Jones and others 2013a; Jones and others 2013b). In their calculations, they used the entire thickness of the Rustler Aquifer to calculate storage. Here, we limit storage calculations to the three mapped transmissive members, where we were able to map them and the entire thickness of the Rustler Formation where collapse is suspected.

The calculation of groundwater in storage will be performed based upon water quality classifications developed by the United States Geological Survey (Winslow and Kister, 1956) and presented in Table 12-1.

The method used by the TWDB to calculate groundwater volume is dependent on whether or not the aquifer is confined or unconfined. Before describing the mathematical equations that will be used to calculate the groundwater volumes, a general discussion of the confined and unconfined aquifer is presented to clarify the terminology used to describe the volume calculations.

12.1.1 Confined and unconfined aquifer

Figure 12-1 provides a schematic of a confined and unconfined aquifer from Boghici and others (2014). In the Rustler Aquifer, most of the aquifer extent as defined by the TWDB is confined, with an unconfined portion at the far western edge of the aquifer in Culberson County where the Rustler Aquifer outcrops. Many believe that the Rustler Aquifer also outcrops as a facies equivalent the Tessey Limestone in the Glass Mountains to the south of Fort Stockton (Ewing and others, 2012). However, this potential outcrop region is not considered in these calculations because it is outside of southeastern extent of the aquifer as defined by the TWDB. Figure 12-2 shows a schematic of a dipping aquifer that is unconfined up dip and is confined down dip.

For an unconfined aquifer, the total storage is equal to the volume of groundwater removed by pumping that makes the water level fall to the aquifer bottom. For a confined aquifer, the total storage contains two parts. The first part is groundwater released from the aquifer when the water level falls from above the top of the aquifer to the top of the aquifer. The reduction of hydraulic head (which can be couched as pressure) in the aquifer by pumping causes expansion of groundwater and deformation of aquifer solids. The aquifer is still fully saturated to this point. This portion of aquifer storage is referred to as the confined aquifer storage.

The second part of groundwater storage is sourced from actual dewatering of the aquifer as the water level in the aquifer falls below the top of the aquifer and ultimately to the bottom of the aquifer. This portion of aquifer storage is referred to as the unconfined aquifer storage. Given the same aquifer area and water level decline, the amount of water released from unconfined storage is much greater (orders of magnitude) than that released from confined storage. The difference is because of the physical nature of storage reduction occurring under confined versus unconfined conditions. In confined storage reduction, water is being supplied through groundwater expansion and aquifer volume reduction. In unconfined storage reduction, water is being supplied through dewatering of pore space. The parameters that quantify these physical differences are storativity of a confined aquifer and specific yield of an unconfined aquifer. Aquifer storativity typically ranges from 10^{-5} to 10^{-3} for most confined aquifers, while specific yield values typically range from 0.01 to 0.3 for most unconfined aquifers. The TWDB makes a distinction between the total volume of groundwater in unconfined aquifer storage versus that portion that is considered drainable. The equations for calculating the total groundwater volume are presented below:

For unconfined aquifers:

$$\text{Total Volume} = V_{drained} = \text{Area} * S_y * (\text{Water Level} - \text{Bottom}) \qquad \text{(Equation 12-1a)}$$

For confined aquifers:

$$\text{Total Volume} = V_{confined} + V_{drained} \qquad \text{(Equation 12-1b)}$$

- Volume for confined part

$$V_{confined} = \text{Area} * [S * (\text{Water level} - \text{Top})] \qquad \text{(Equation 12-2)}$$

Or

$$V_{confined} = \text{Area} * [S_s * (\text{Thickness}) * (\text{Water level} - \text{Top})] \qquad \text{(Equation 12-3)}$$

- Volume for unconfined part

$$V_{drained} = \text{Area} * [S_y * (\text{Thickness})] \qquad \text{(Equation 12-4)}$$

Where

$V_{drained}$ = storage volume due to water draining from the formation (acre-feet)
$V_{confined}$ = storage volume due to elastic properties of the aquifer and water (acre-feet)

Area	=	area of aquifer (acre)
Water Level	=	groundwater elevation (feet above mean sea level)
Top	=	elevation of aquifer top (feet above mean sea level)
Bottom	=	elevation of aquifer bottom (feet above mean sea level)
Thickness	=	thickness of aquifer (feet)
S_s	=	specific yield (no units)
S_y	=	specific storage (1/feet)
S	=	storativity or storage coefficient (no units)

12.1.2 Hydraulic and physical properties for the Rustler Aquifer

The equations for calculating groundwater volumes described above require specification of aquifer properties such as aquifer structure, thickness, water level and specific yield. These will be described below.

Structure and Thickness – For calculations for the Culebra Dolomite, the Magenta Dolomite and the Limestone Units of the Los Medaños Member, member unit thickness and elevation of their tops are based upon the work performed in this study and described in Section 5. For the outcrop regions, the base of the aquifer is taken from the Groundwater Availability Model (Ewing and others, 2012).

Rustler Aquifer Water Level – The water levels used to calculate the aquifer volumes are based upon the last year of calibration (end of 2008) from the Rustler Aquifer Groundwater Availability Model (Ewing and others, 2012). In areas of the aquifer which are not coincident with the Rustler Aquifer Groundwater Availability Model, the volume calculations are limited to unconfined drainable groundwater storage, thus not requiring a water level (after Boghici and others, 2014).

Specific Yield – The Groundwater Availability Model used a specific yield of 0.15 in the outcrop (Ewing and others, 2012). However, Boghici and others (2014) used a specific yield of 0.03. After consultation with TWDB, INTERA adopted the 0.03 value for calculations.

12.1.3 Process for calculating groundwater volumes based on water quality

The groundwater volume calculations for groundwater storage are implemented on a quarter-mile grid scale coincident with the Groundwater Availability Model Grid (Ewing and others, 2012) and consistent with TWDB Total Estimated Recoverable Storage calculations in process. Modifications are described below.

There are portions of the Rustler Aquifer in Brewster, Jeff Davis and Pecos counties that are not included in the Groundwater Availability Model area in Groundwater Management Area 4 and 7 (see Boghici and others, 2014; Jones and others, 2013; and Figure 14-8 of this report). We adopted the approach used in Boghici and others (2014) for estimating groundwater volumes in those areas. In those areas we only calculate an unconfined or drainable groundwater storage volume (Equation 12-1a above). Unlike Boghici and others (2014), we did not use a constant aquifer thickness but rather used the thickness for each transmissive member of the Rustler Aquifer as defined in this study and discussed in Section 5. We checked our calculations against the Total Estimated Recoverable Storage by defining the aquifer thickness as the top elevation minus the bottom elevation of the Rustler Aquifer. In our comparison we only had differences in Groundwater Management Area 4 and 7, which is where the differences in approach would make our estimates somewhat higher because of our assumption of using aquifer thickness in areas outside the model domain. In Groundwater Management Area 3, we were within rounding error.

Where present, both confined storage and unconfined drained storage are calculated for the three transmissive members of the Rustler Aquifer, the Culebra Dolomite, the Magenta Dolomite and the limestone units of the Los Medaños Member. Therefore, for the unconfined drained groundwater storage, we use equation 12-1a for each member present at that location. Likewise, we use Equation 12-3 for the confined groundwater storage. However, variable "Thickness" is calculated specifically for each transmissive member. Also, the variable "Top" is the top elevation of the uppermost transmissive member (i.e., the Culebra Dolomite or the Magenta Dolomite).

In the outcrop areas or areas designated as collapse areas the variable "Bottom" in Equation 12-1a is equal to the bottom of the Rustler Aquifer for estimation of the unconfined drainable aquifer storage. In confined designated collapse areas, the variable "Thickness" is the entire Rustler Aquifer thickness (from the Groundwater Availability Model) and the variable "Top" is the elevation of the top of the Rustler Aquifer (from the Groundwater Availability Model) for Equation 12-3.

The calculations were developed using a Python code. The complete detailed algorithm and equations implemented are described in detail in Appendix 19.6.

12.2 Calculated groundwater volumes

Table 12-2 provides the total calculated volume of groundwater in the Rustler Aquifer. The calculations are rounded to the nearest 1,000-acre foot per year. Table 12-2 provides the volume in the Collapse portion of the Rustler Aquifer (which includes the outcrop), the Magenta Dolomite, the Culebra Dolomite and the limestones of the Los Medaños. The total volume of groundwater calculated is 18,538,000 acre-feet of groundwater. Total groundwater in the Collapse (Zone 1) portion of the Rustler Aquifer, the Magenta Dolomite, the Culebra Dolomite and the limestones of the Los Medaños, is 5,832,000, 1,327,000, 6,019,000 and 5,361,000 acre-feet, respectively. The Magenta Dolomite has the smallest volume of the hydrologic units which is expected given that it is the thinnest of the mapped transmissive members (see Section 5). Percent of total groundwater in the Collapse (Zone 1) portion of the Rustler Aquifer, which includes the outcrop, is 31.5%. Percent of total groundwater in the Magenta Dolomite is 7.2%. Percent of total groundwater in the Culebra Dolomite is 32.5%. Percent of total groundwater in the Los Medaños Limestones is 28.9%. Table 12-2 also summarizes the volumes of groundwater by Rustler Aquifer Member and by salinity classification. The majority (54.9%) of the groundwater is moderately saline. Approximately 42.6% of the groundwater is slightly saline and 2 % is very saline. This leaves approximately 0.5 % as fresh groundwater.

Table 12.3 provides the volume of groundwater by aquifer unit and by salinity class for all the counties which intersect the boundaries of the Rustler Aquifer. Table 12-4 provides the volume of groundwater by aquifer unit and by salinity class for all the Groundwater Conservation or Underground Water Districts that intersect the boundaries of the Rustler Aquifer. Table 12-4 also summarizes groundwater not within the boundaries of a groundwater conservation district which equals approximately 21% of the total aquifer groundwater. Table 12-5 provides the volume of groundwater by aquifer unit and by salinity class for all the Groundwater Management Areas that intersect the Rustler Aquifer.

Table 12-1. **Groundwater classification based on the Criteria Establish by Winslow and Kister (1956).**

Water Classification Description	TDS Range (milligrams per liter)
Fresh	Less than 1,000
Slightly Saline	1,000 to 3,000
Moderately Saline	3,000 to 10,000
Very Saline	10,000 to 35,000

Table 12-2. **The volumes of fresh, moderately saline, slightly saline, very saline, and total groundwater volumes in the Rustler Aquifer.**

Aquifer Unit	Total Volume (Acre-feet)				
	Fresh	Slightly saline	Moderately saline	Very saline	Total
Collapse	88,000	5,531,000	213,000	0	5,832,000
Magenta	0	410,000	835,000	82,000	1,327,000
Culebra	0	2,387,000	3,493,000	140,000	6,019,000
Los Medaños	0	1,844,000	3,365,000	151,000	5,361,000
Rustler Aquifer	88,000	10,172,000	7,905,000	373,000	18,538,000

Table 12-3. The volumes of fresh, moderately saline, slightly saline, very saline, and total groundwater volumes in the Rustler Aquifer by County.

Aquifer Unit	Total Volume (Acre-feet)				
	Fresh	Slightly saline	Moderately saline	Very saline	Total
Brewster County					
Collapse	0	106,000	0	0	106,000
Magenta	0	0	0	0	0
Culebra	0	0	0	0	0
Los Medaños	0	0	0	0	0
Rustler Aquifer	0	106,000	0	0	106,000
Culberson County					
Collapse	88,000	2,026,000	79,000	0	2,194,000
Magenta	0	20,000	27,000	0	47,000
Culebra	0	80,000	71,000	0	151,000
Los Medaños	0	61,000	66,000	0	126,000
Rustler Aquifer	88,000	2,187,000	244,000	0	2,518,000
Jeff Davis County					
Collapse	0	661,000	0	0	661,000
Magenta	0	12,000	0	0	12,000
Culebra	0	61,000	0	0	61,000
Los Medaños	0	36,000	0	0	36,000
Rustler Aquifer	0	770,000	0	0	770,000
Loving County					
Collapse	0	0	0	0	0
Magenta	0	0	97,000	82,000	179,000
Culebra	0	0	244,000	140,000	384,000
Los Medaños	0	0	307,000	151,000	458,000
Rustler Aquifer	0	0	648,000	373,000	1,021,000
Pecos County					
Collapse	0	1,665,000	0	0	1,665,000
Magenta	0	128,000	69,000	0	198,000
Culebra	0	1,131,000	552,000	0	1,683,000
Los Medaños	0	776,000	458,000	0	1,234,000
Rustler Aquifer	0	3,701,000	1,079,000	0	4,780,000

Aquifer Unit	Total Volume (Acre-feet)				
	Fresh	Slightly saline	Moderately saline	Very saline	Total
Reeves County					
Collapse	0	1,072,000	134,000	0	1,206,000
Magenta	0	250,000	604,000	0	854,000
Culebra	0	1,115,000	2,451,000	0	3,566,000
Los Medaños	0	971,000	2,354,000	0	3,324,000
Rustler Aquifer	0	3,408,000	5,543,000	0	8,951,000
Ward County					
Collapse	0	0	0	0	0
Magenta	0	0	37,000	0	37,000
Culebra	0	0	173,000	0	173,000
Los Medaños	0	0	182,000	0	182,000
Rustler Aquifer	0	0	392,000	0	392,000

Table 12-4. The volumes of fresh, moderately saline, slightly saline, very saline, and total groundwater volumes in the Rustler Aquifer by Groundwater Conservation District.

Aquifer Unit	Total Volume (Acre-feet)				
	Fresh	Slightly saline	Moderately saline	Very saline	Total
Area with no Groundwater Conservation District					
Collapse	88,000	2,026,000	79,000	0	2,194,000
Magenta	0	20,000	161,000	82,000	263,000
Culebra	0	80,000	489,000	140,000	709,000
Los Medaños	0	61,000	554,000	151,000	766,000
Rustler Aquifer	88,000	2,187,000	1,283,000	373,000	3,931,000
Brewster County Groundwater Conservation District					
Collapse	0	106,000	0	0	106,000
Magenta	0	0	0	0	0
Culebra	0	0	0	0	0
Los Medaños	0	0	0	0	0
Rustler Aquifer	0	106,000	0	0	106,000
Jeff Davis County Underground Water Conservation District					
Collapse	0	661,000	0	0	661,000
Magenta	0	12,000	0	0	12,000
Culebra	0	61,000	0	0	61,000
Los Medaños	0	36,000	0	0	36,000
Rustler Aquifer	0	770,000	0	0	770,000
Middle Pecos Groundwater Conservation District					
Collapse	0	1,665,000	0	0	1,665,000
Magenta	0	128,000	69,000	0	198,000
Culebra	0	1,131,000	552,000	0	1,683,000
Los Medaños	0	776,000	458,000	0	1,234,000
Rustler Aquifer	0	3,701,000	1,079,000	0	4,780,000
Reeves County Groundwater Conservation District					
Collapse	0	1,072,000	134,000	0	1,206,000
Magenta	0	250,000	604,000	0	854,000
Culebra	0	1,115,000	2,451,000	0	3,566,000
Los Medaños	0	971,000	2,354,000	0	3,324,000
Rustler Aquifer	0	3,408,000	5,543,000	0	8,951,000

Table 12-5. The volumes of fresh, moderately saline, slightly saline, very saline, and total groundwater volumes in the Rustler Aquifer by Groundwater Management Area.

Aquifer Unit	Total Volume (Acre-feet)				
	Fresh	Slightly saline	Moderately saline	Very saline	Total
Groundwater Management Area 3					
Collapse	0	1,072,000	134,000	0	1,206,000
Magenta	0	276,000	807,000	82,000	1,165,000
Culebra	0	1,372,000	3,312,000	140,000	4,824,000
Los Medaños	0	1,135,000	3,207,000	151,000	4,493,000
Rustler Aquifer	0	3,855,000	7,459,000	373,000	11,688,000
Groundwater Management Area 4					
Collapse	88,000	2,794,000	79,000	0	2,961,000
Magenta	0	32,000	27,000	0	59,000
Culebra	0	140,000	71,000	0	212,000
Los Medaños	0	97,000	66,000	0	163,000
Rustler Aquifer	88,000	3,063,000	244,000	0	3,395,000
Groundwater Management Area 7					
Collapse	0	1,665,000	0	0	1,665,000
Magenta	0	103,000	0	0	103,000
Culebra	0	874,000	109,000	0	984,000
Los Medaños	0	612,000	93,000	0	705,000
Rustler Aquifer	0	3,254,000	202,000	0	3,456,000
Grand Total					
Collapse	`	5,531,000	213,000	0	5,832,000
Magenta	0	410,000	835,000	82,000	1,327,000
Culebra	0	2,387,000	3,493,000	140,000	6,019,000
Los Medaños	0	1,844,000	3,365,000	151,000	5,361,000
Rustler Aquifer	88,000	10,172,000	7,905,000	373,000	18,538,000

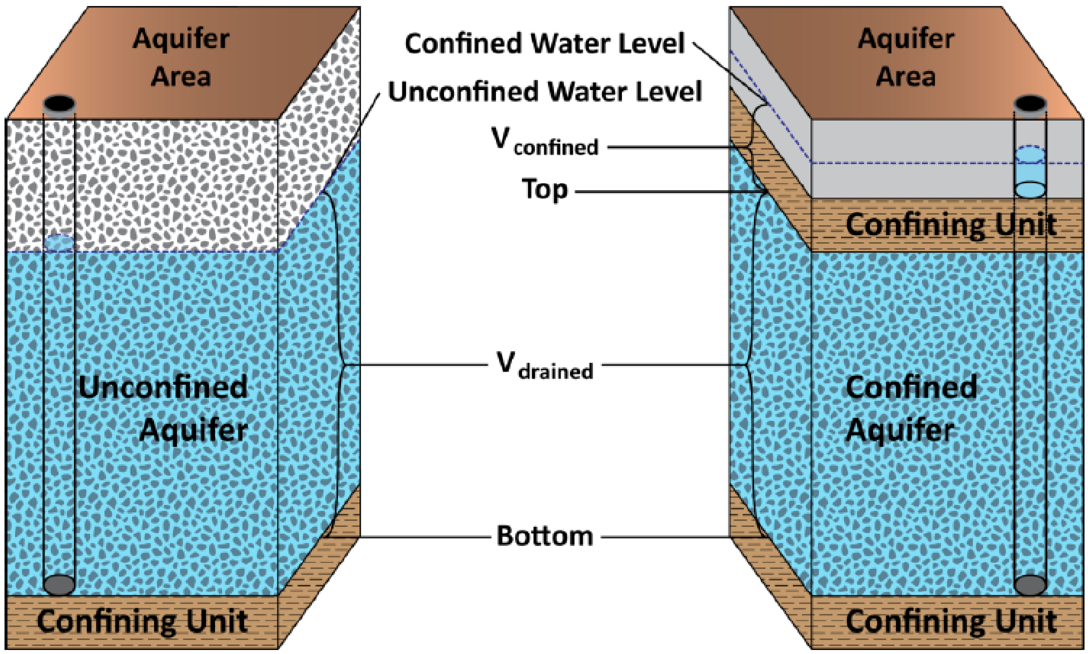

Figure 12-1. Schematic graph showing the difference between unconfined and confined aquifers (from Boghici and others, 2014).

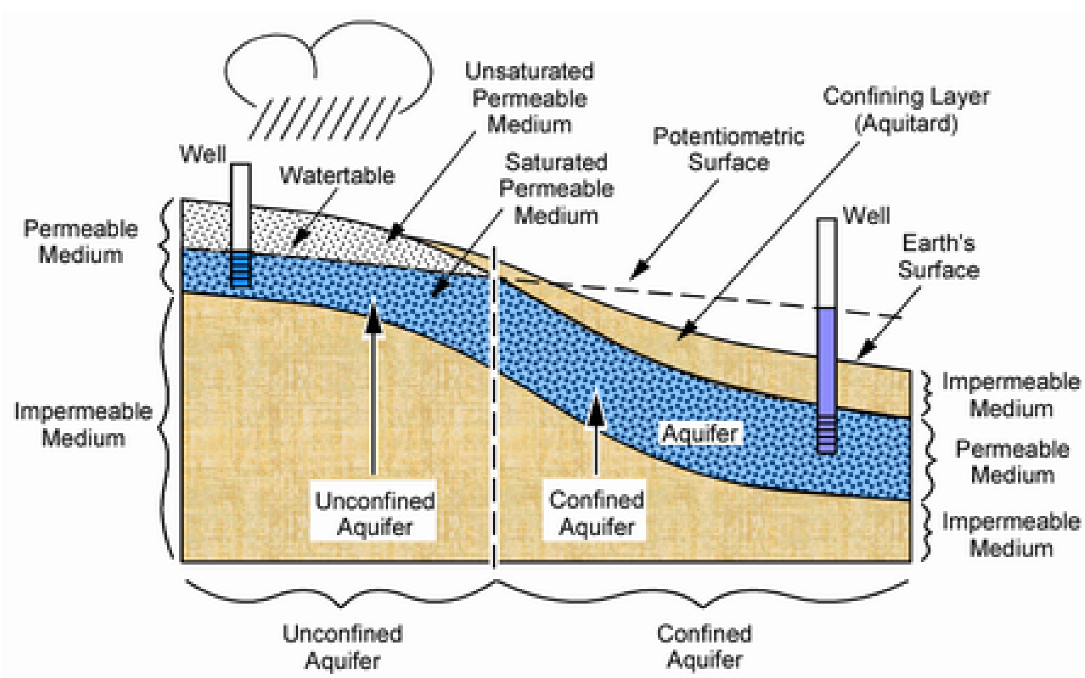

Figure 12-2. Schematic of aquifer transitioning from an unconfined outcrop region, where recharge from precipitation occurs, to confined conditions in the down dip regions of the aquifer (from Hermance, 2016).

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13 Geophysical well log analysis and methodology

The calculation of water quality (calculated total dissolved solids) from resistivity is a standard technique to supplement areas where sampled water quality (sampled total dissolved solids) measurements are sparse. Examples of these techniques include Alger (1966), Ayers and Lewis (1985), Fogg (1980), Fogg and Kreitler (1982), Fogg and Blanchard (1986), Hamlin (1988), Estepp (1998), and Meyer (2012). The majority of these applications were performed in the unconsolidated sediments of the Gulf of Mexico Basin, where data availability and geographic distribution of electric logs is far greater than it is for the Rustler Aquifer footprint. One possible exception is Collier's (1993a,b) evaluation of various consolidated formations (e.g., Cretaceous Edwards Formation, Trinity Group, Paleozoic limestones, etc.). For the Rustler Aquifer, in addition to the sparse distribution of resistivity logs, no detailed publications have been found that adequately discuss the calculation of water quality from resistivity or spontaneous potential measurements. Geologists in the Groundwater Advisory Unit at the Railroad Commission of Texas have developed some techniques (personal communication, March 2016); however, they have not been shared in a citable or widely distributed format that could have been applied to this study. In addition, given the lithologic complexity of the units that make up the Rustler, standard techniques for water quality calculations can vary over many orders of magnitude if specific properties such as layer thickness, log type, porosity, shaliness, cementation exponent, geothermal gradient, and permeability are not constrained. These specific properties can be constrained if the effect on geophysical signature is quantified through a sensitivity analysis.

Our approach to the calculation of water quality within the Rustler Aquifer is separated into the following tasks:

1. Systematically characterize the structure and stratigraphy of the Rustler Formation to better understand the distribution of hydrogeologic units that comprise the Rustler Aquifer. During this process, acquire good resistivity/induction and porosity logs that can be used to calculate water quality and porosity.
2. Evaluate all sampled water quality data that appear to be producing from the Rustler Aquifer.
3. Perform an initial sensitivity analysis to better understand the sensitivities of the various logs to variables such as borehole geometry, mud salinity and degree of shaliness.
4. Narrow down the good resistivity and porosity logs to 26 “Key Wells” that can be used along with sampled water quality data to constrain the ranges of calculated water quality.
5. Use advanced petrophysical software to evaluate these wells for water quality and porosity in an efficient and time sensitive manner. The advantage of the software is the ease at which it can process large amounts of data. The calculations and techniques used can be performed in any numerical software (Microsoft Office Excel, for example).
6. Use the key wells and sampled water quality data to constrain more simplified water quality calculations made on resistivity logs to supplement areas in-between sampled or calculated water quality.

Tasks 1 and 2 have already been explained in Sections 5 and 10 of this report. For tasks 3 through 6, it is necessary first to expand more on traditional techniques for the calculation of water quality from resistivity logs in order to better show how our technique is both similar and different from traditional approaches.

13.1 Traditional calculation of water quality from resistivity logs

Resistivity can be defined as the degree to which a substance resists the flow of an electrical current. For most applications, resistivity is inversely related to conductivity (microSiemens per meter) and inversely related to total dissolved solids. That is, the higher the resistivity, the fresher the water, and the lower the resistivity, the more brackish the water. Said another way, the higher the resistivity, the less ions available to conduct electricity, and the lower the resistivity, the more ions available to conduct electricity. Resistivity is measured in a borehole by lowering a logging tool down the borehole and using a multiple-electrode array to apply a constant current into the formation and measure the voltage drop. The resulting true resistivity (R_t) is recorded on a geophysical log and represents the varying resistivity values within and amongst the formations adjacent to the borehole. Assuming that the rock matrix of the geological units intersected by the borehole had no electronic, as opposed to electrolytic, conductivity, then the rocks themselves are electrical insulators and would exhibit an infinite resistivity. However, because rocks have at least some small amount of interconnected porosity, and that porosity is filled with a conducting fluid (e.g., oil, gas or water), the rock will have a measurable resistivity. Where the formation is 100 percent saturated with water (denoted by Archie's [1942] Saturation [S_w] variable: S_w = 100%), as opposed to some combination of water, oil or gas (S_w < 100%), then the true resistivity (R_t) is equal to the resistivity of the rock filled with formation water (R_o). The resistivity of the water equivalent (R_{we}) is related to the rock filled with formation water (R_o) through the Archie Equation (Archie, 1942):

$$R_{we} = \Phi^m \times R_o \qquad \text{(Equation 13-1)}$$

Where:

R_{we}	=	resistivity of formation water
Φ	=	porosity
m	=	the porosity exponent
R_o	=	the resistivity of a 100 percent water-saturated formation

After solving the Archie Equation for the equivalent water resistivity, the next step is to account for ionic makeup of the formation water. Sodium and chloride ions predominate most oil field brines, and ample equations exist to relate the resistivity of sodium chloride type water to its corresponding total dissolved solids (usually referred to as salinity or sodium chloride in parts per million) (see Western Atlas International [1992] or Schlumberger [2009] Chart Gen-4 for example equations and graphs). In fresher formations, other ions and molecules such as calcium, magnesium, bicarbonate and sulfate can make up a significant portion of the total ionic mass within the sample. Each of these ions and molecules has its own relationship between ionic weight and resistivity. To account for this, the sampled water quality values (see Section 10) need to be converted into an equivalent sodium chloride total dissolved solids (salinity) using Schlumberger (2009) Chart Gen-4 (Figure 13-1). Once the equivalent salinity is determined, the resistivity of the water equivalent is corrected to resistivity of water using the following Rustler specific equation:

$$cf_{Rustler} = \frac{TDS}{TDS_{NaCl}} \quad \text{(Equation 13-2a)}$$

And

$$R_w = \frac{R_{we}}{cf_{Rustler}} \quad \text{(Equation 13-2b)}$$

Where:

- $cf_{Rustler}$ = correction factor specifically derived for the Rustler Aquifer from existing water quality samples (Table 19-4) and Schlumberger (2009) Chart Gen-4 (Figure 13-1)
- TDS = total dissolved solids in milligrams per liter from water chemistry samples (Table 19-4)
- TDS_{NaCl} = sodium chloride equivalent total dissolved solids in milligrams per liter
- R_w = calculated resistivity of the water
- R_{we} = resistivity of water equivalent

Once the resistivity of the formation water (R_w) has been corrected, water quality as total dissolved solids in milligrams per liter is calculated by first adjusting the R_w at formation temperature to R_w at 75 degrees Fahrenheit and then converting from formation water resistivity at 75 degrees Fahrenheit ($R_{w\ 75}$) to specific conductance in micromhos per centimeter at 75 degrees Fahrenheit:

$$C_{w75} = \frac{10{,}000}{R_{w75}} \quad \text{(Equation 13-3)}$$

Where:

C_{w75} = specific conductance in micromhos per centimeter at 75 degrees Fahrenheit
R_{w75} = water resistivity at 75 degrees Fahrenheit

Of importance is the calculation of a geothermal gradient, which is subsequently used to correct the resistivity of the formation water (R_w) at formation temperature to resistivity of the formation water (R_w) at 75 degrees Fahrenheit. The geothermal gradient strongly controls the mud thermal gradient which is the parameter that we are most interested in. Most well log analysts use the data on the log header to obtain a temperature at surface (T_s), Bottom Hole Temperature and Total Depth. This data is recorded on the log header so that temperature corrections can be made to the various petrophysical curves. This data is used to calculate the formation temperature at depth ($T(z)$) using the following equation:

$$T(z) = T(z_1) + \frac{T(z_2) - T(z_1)}{z_2 - z_1}(z - z_1) \quad \text{(Equation 13-4)}$$

Where:

- $T(z)$ = Temperature (degrees Fahrenheit) at depth of interest (z)
- $T(z_1)$ = Temperature (degrees Fahrenheit) at depth one, which usually corresponds to the temperature of the mud filtrate recorded by the logging engineer on the log header

$T(z_2)$ = Temperature (degrees Fahrenheit) at depth two, which usually corresponds to the bottom hole temperature recorded by the logging engineer on the log header

z = Depth at which $T(z)$ is being calculated

z_1 = Depth at which $T(z_1)$ was taken, which usually corresponds to ground surface

z_2 = Depth at which $T(z_2)$ was taken, which usually corresponds to the total depth of the log run

While there are significant opportunities to introduce errors to the calculation when using log header parameters, due to convention in the well logging industry, this approach to calculating the geothermal gradient is considered best practice. Other approaches to calculating the geothermal gradient involve using a climatic atlas (for example: Climatic Atlas of Texas [Larkin and Bomar, 1983]) in an attempt to limit the amount of surface temperature variability brought into the calculation. This technique has its merits, especially with consistency of geothermal gradient calculations, but it does not factor in the specific temperature profile of the mud at any one well and can introduce a similar amount of error. This subject deserves additional research in an attempt to standardize the procedure for water resource analysis.

Once the specific conductance in micromhos per centimeter at 75 degrees Fahrenheit (C_{w75}) has been derived, the next step is to convert specific conductance to total dissolved solids. Of importance to this conversion is the relationship between the sampled total dissolved solids in milligrams per liter and the specific conductance (C_w) in micromhos per centimeter. This relationship is commonly referred to as the *ct* factor (Estepp, 1998) and is represented as a single multiply variable such as 0.65. For the Rustler Aquifer, there were 84 “Data Accepted” water chemistry samples for 54 wells that had both a total dissolved solids and specific conductance measurement (Table 19-4). Data were plotted on a scatter plot and matched with a power curve (Figure 10-5, regression plot of total dissolved solids vs specific conductance). The correlation produced an R^2 (coefficient of determination) of 0.9 and the equation below to convert specific conductance to total dissolved solids:

$$TDS = 0.1277 \ x \ C_{w75}{}^{1.2314} \qquad \text{(Equation 13-5)}$$

Where:

TDS = total dissolved solids in milligrams per liter
C_{w75} = specific conductance of the fluid at 75 degrees Fahrenheit in micromhos per centimeter

13.2 Initial formation parameter sensitivity analysis

Where resistivity logs exist, it is paramount that the sensitivities to potential variables such as borehole geometry, mud salinity and degree of shaliness be quantified before calculations of water quality are made. To that end, the INTERA team acquired logs for 26 key wells that would be used to evaluate the sensitivity of the geophysical signatures to various petrophysical and geometrical conditions (denoted by a 3 in the “Petrophysical wells” field in Appendix 19-5).

Depending on the specific conditions, some of the petrophysical effects can be greater than the impact of water quality. Well logs acquired in water-bearing rocks can be substantially affected not only by water quality (for example: ion concentration, ion types, etc.), but also by rock properties, logging conditions and logging tools. These variables to be considered include porosity, permeability, irreducible water saturation, mud filtrate invasion, borehole size, borehole resistivity, and aquifer bedding thickness. Additionally, the properties of the specific geophysical logging tool used to acquire the logs must be factored into the analysis, especially considering the age of most of the logs available for the Rustler Aquifer. Most of the latter effects included in well logs are not typically accounted for by logging companies when providing well logs, such as gamma ray, spontaneous potential, resistivity, density porosity, and neutron porosity. These effects are usually accounted for as part of a petrophysical quality assurance/quality control workflow in most oil and gas companies. Given expected sensitivities to geometrical and petrophysical effects, modern methods used in the interpretation of well logs invoke some degree of numerical simulation to quantify the relative impact of borehole and layer environmental effects in the interpretation of layer petrophysical properties and saturating fluids.

The numerical simulation of well logs is performed by first defining all pertinent variables and available, geometrical properties such as borehole size, mud type (i.e., types of ions in solution and their concentrations), temperature, layer thicknesses, etc. Next, layer properties such as porosity, volume of shale, permeability, total water saturation, irreducible water saturation, and water chemistry are used to calculate effective layer properties such as electrical resistivity, natural radioactivity, compressional and shear wave velocities, and nuclear properties. Lastly, the calculated layer physical properties, together with layer thicknesses and specific tool properties are then used to numerically simulate all well logs (e.g., gamma, spontaneous potential, resistivity, etc.). Comparison of numerically simulated well logs against measured well logs provides quantitative verification of the relative impact of relevant formation properties on the well logs, including water quality. For example, what is the expected range in resistivity for a 30-foot-thick bedded dolomite, filled with a 5,000 milligrams per liter total dissolved solids water and sandwiched between an anhydrite and mudstone?

Based on observed average compositional and petrophysical properties in the Rustler Aquifer, we performed a sensitivity analysis of relevant formation and petrophysical variables to quantify their effect on measured well logs. The sensitivity analysis was carried out by numerically simulating the gamma-ray, spontaneous potential, resistivity (shallow-, medium-, and deep-sensing), density, and neutron logs, using software developed by the University of Texas at Austin (UTAPWeLS). Starting with borehole properties, such as borehole diameter (caliper), mud resistivity, and mud filtrate resistivity, the software simulates the physical process of mud filtrate invasion into the Rustler Aquifer by replicating the physical process of advection and diffusion of ions present in water as mud filtrate displaces formation water due to overbalance pressure between the mud column and the Rustler Aquifer. The latter process is governed by overbalance pressure, duration of invasion, permeability, porosity and ion-concentration differences between mud filtrate in formation water. Numerical simulation of the process of mud filtrate invasion gives rise to radial variations of salt concentration from the borehole wall into the formation, which are subsequently converted to radial variations of electrical resistivity using transformations such as Archie’s or shaly-resistivity equations. The resulting calculated radial variations of electrical resistivity are used to numerically simulate laterolog or induction resistivity logs with multiple depths of investigation for specific commercial tools (e.g., Schlumberger or Baker-Hughes dual laterolog). Following a similar process, compositional and radial variations of ionic concentration resulting from mud filtrate invasion are transformed into radial variations of rock density and neutron migration length to numerically simulate density and neutron logs.

The objective of numerically simulating resistivity and nuclear logs resulting from the process of invasion of mud filtrate into the Rustler Aquifer is to quantify the influence of formation water salinity on available resistivity and nuclear logs. However, in addition to salt concentration of formation water, resistivity and nuclear logs are influenced by: mud filtrate salinity, porosity, degree of shaliness (volumetric concentration of shale), matrix composition, permeability, and temperature. We began the sensitivity evaluation by performing specific sensitivity analysis of all of the above factors on numerically simulated resistivity and nuclear logs. The range of variability of these parameters is based on observed properties in the Rustler Aquifer along the key wells selected for the study. Preliminary results from the sensitivity study indicated that mud filtrate salinity, formation salinity, porosity, and degree of shaliness are the most important factors controlling the numerically simulated resistivity logs. These factors will be incorporated and accounted for when evaluating water quality from the resistivity logs.

Figure 13-2 shows an example of numerical sensitivity analysis of gamma-ray, spontaneous potential, resistivity (dual laterolog), neutron, density, and PEF logs to variation of formation water salinity. The synthetic model was constructed to resemble some of the properties of the Rustler Aquifer. There are five permeable, equal-thickness dolomites with porosity equal to 10% shouldered by shales penetrated by a vertical well. Mud filtrate salinity equals 200,000 parts per million sodium chloride, which is consistent with typical mud filtrate salinities in the area. From top to bottom, the dolomite units are saturated with formation water of salinity equal to 15,000, 10,000, 5,000, 2,000, and 500 parts per million sodium chloride. Gamma-ray, spontaneous potential, resistivity, and nuclear logs were simulated after performing the numerical simulation of the process of mud filtrate invasion in to the water-saturated dolomites. Below is an explanation of the major sensitivities and how they were accounted for when calculating water quality from resistivity logs.

Mud Filtrate Salinity: Mud filtrate salinity can have extreme effects on the calculation of water quality from resistivity logs. Specifically, where the resistivity tool does not look far enough into the formation to see the uninvaded zone, the calculated water quality will be reflective of either the mud filtrate salinity (in the flushed zone) or some combination of the mud and formation salinity in the zone of mixing. To mitigate the incorporation of mud filtrate salinity into the calculations, the following techniques will be applied:

1. A calculation of the resistivity of the mud filtrate (R_{mf}) at formation temp will be made and subsequently compared to resistivity of water (R_w) values to evaluate the potential for mixing.
2. Specific resistivity/inductions tools that have deep investigation length will be used to guide the range of expected resistivity of water values. In addition, calculations made on tools known to have a shallow investigation length will be treated with caution.
3. Sampled water quality data, along with deep sensing resistivity logs, will be used as a guide to determine if a calculated resistivity of water (R_w) value is spurious, given the surrounding data.

Formation Water Salinity: Resistivity logs in particular were simulated by assuming a commercial dual laterolog tool. Simulation results indicate that both spontaneous potential and deep resistivity logs have a measurable and discernable influence from formation water salinity (notice that resistivity logs are plotted with a logarithmic scale). The ratio of deep- to shallow-sensing resistivity logs is equal to the ratio of formation water resistivity to mud filtrate resistivity, which enables the direct calculation of formation water resistivity.

1. When making calculations of water quality in key wells, care must be taken to ensure that the calculation made is reflective of the formation water quality and not the mud filtrate. This can be accomplished through comparison of the resistivity of mud filtrate at depth.

Porosity: Porosity can have a profound effect on the calculation of water quality. In fact, it likely exhibits the largest influence on the calculation of water quality. Therefore, porosity values used in the calculations should come from either direct calculation at the well or from calculation at a nearby well. In addition, it was clear from the sensitivity analysis that shale volume had a significant effect on the calculation of porosity and need to be incorporated.

1. For key wells, make a calculation of porosity at the well where the water quality calculation is being made. Use either neutron porosity log, sonic log, 32-inch limestone resistivity log or a spherically focused shallow log to calculate porosity specifically for the matrix composition in question (dolomite matrix for Magenta and Culebra Dolomites and limestone matrix for the limestones of the Los Medaños Unit).
2. If at all possible, use more than one porosity calculation method and compare those calculations to neighboring calculations in other wells.
3. Initial attempts to calculate porosity should be in zones with low volumetric shale concentrations.
4. If porosity calculation results in a much lower total dissolved solids value than should be expected and, gypsum is suspected, use a calculation technique that factors mixed solid rock compositions (like gypsum/dolomite for example).

Volume of Shale: Volume of shale calculations should be made in order to concentrate water quality and porosity calculations in areas with as low a volume shale as possible. However, areas of the Rustler Formation are suspected of having high potassium values which could serve to artificially (at least with respect to shale content) increase the volume shale calculation.

1. First attempts at water quality from resistivity and porosity calculations should be in zones that have low calculated shale volumes.
2. If high gamma values persist, evaluate the character of the other curves to see if there is a proportional change accompanying the gamma ray signature. If the gamma increases without a corresponding change in the resistivity or porosity value, postassium-rich zones could be suspected.

13.3 Advanced techniques used to calculate porosity, resistivity of formation water, and subsequently water quality

While the title of this section implies that the techniques used in this analysis are advanced, these workflows, or ones similar, have been used for decades in the oil and gas industry to standardize log interpretation. However, to perform these types of analyses on large numbers of geophysical logs would go beyond a typical water resource characterization project budget. Therefore, we decided that the “key well” approach would represent a good compromise, and we could draw inferences from the combination of key well results and sampled water quality values that could be used to constrain additional calculations of water quality using more simplified techniques.

Additionally, the specific conversion between equivalent water resistivity (R_{we}), resistivity of water (R_w), specific conductance (C_w) and ultimately total dissolved solids (TDS) have been simplified and or nullified. It is also very important that well logs be devoid of borehole and tool effects before using them for calculations. For instance, depending on borehole size and mud weight, the gamma-ray log needs to be corrected before comparing gamma-ray values among multiple wells and using it for evaluation of volume of shale. Such corrections need to be implemented formation by formation so that the calculation method will be the same regardless of well location. This "well-log balancing" procedure is extremely important in the analysis of neutron logs for calculation of porosity given that the latter are overly sensitive to borehole conditions. Likewise, whenever rocks exhibit mixed solid compositions (i.e., departing from simplified limestone, dolomite, or quartz compositions), apparent neutron porosity values need to be corrected for matrix (solid composition) effects to yield values of total porosity (which in turn can affect the corresponding calculations of formation water resistivity).

13.3.1 Step 1: Evaluate all header information for consistency

The first step in this process is to acquire all of the header parameters for the geophysical logs and verify that values make sense. For example, the temperature at which the resistivity of the mud is measured (either R_m or R_{mf}) needs to check out with the time of year that the sample was taken. That is, the temperature of the mud at surface should be consistent with the time of year that the measurement was taken. Another example is the Bottom Hole Temperature. A check was made on the key wells to make sure that these values are consistent and that there is small variation in the geothermal gradient. It is critical to look at the header parameters from a statistical analysis approach to highlight any outliers in the datasets (e.g., mud weight, caliper, etc.) In addition, it is critical to understand the impact that the outliers can have on the calculation of porosity or water quality.

13.3.2 Step 2: Send .tif images of the geophysical logs to get digitized and converted to Log ASCII Standard (.LAS)

After evaluating the header parameters, the logs that showed consistency were sent off to WellGreen LLC in Calgary, Canada to have the .tif images converted into Log ASCII Standard (.LAS) files. This process is called digitizing geophysical curves and usually starts with a systematic "straightening" of the geophysical log. Geophysical logs can be skewed when a paper log is being scanned in to make a .tif image. Most digitizing companies have fairly sophisticated image processing software that will straighten .tif images until the operator is satisfied with the results. WellGreen is no exception and implements industry standard straightening algorithms before digitizing the curves. After the image has been straightened, the digitizer will then put a right and left scale onto the geophysical curve and then proceed to trace it. Results are a .LAS file for each of the log curves on a half-foot basis.

13.3.3 Step 3: Correct depth shifting

Upon receiving all of the digitized logs from WellGreen LLC, the next step was to evaluate each of the log pairs to make sure that correct depth shifting had occurred. Depth shifts usually occur when the original log is being acquired by the well logging company and involve inadequate quality assurance/quality control on the part of the well logging company because of log splicing and/or abrupt cable tension and speed variations. An example of this is the shallow and deep resistivity in Figure 13-3. As can be observed, the deep resistivity is offset from the shallow resistivity, which is consistent with the gamma ray log. Depth shifting can be done outside of petrophysical calculation software using standard interpretation software and .LAS viewing software to evaluate the results. Care must be exercised not to over-depth-shift the various well logs.

13.3.4 Step 4: Choose reference wells

The majority of the logs run in the Rustler Aquifer are fairly old in age (1940s, 1950s and 1960s). Thus, logs that were eventually standardized, are not and depending on the specific service company, will have different units. For example, we have gamma ray logs in radiation-equivalents per ton, American Petroleum Institute units or, for the very old logs, no scale at all. While these logs are on different scales, the Rustler Formation signature is still readily identifiable. This is okay for qualitative tasks like making picks for structural and stratigraphic contacts but, when systematically making calculations across multiple wells, data for logs need to be standardized and then normalized.

For the gamma ray tool, all of the logs were converted to American Petroleum Institute units, which is the standard unit for all gamma ray logs post 1960s. One technique used to convert non-American Petroleum Institute scales to American Petroleum Institute is the process of normalization. By looking at all of the wells, the one with the most reliable and least borehole-influenced logs is picked and subsequently called a reference well. This process is performed for both the gamma ray logs and the neutron porosity logs, as both of them have similar age-related issues. Once a reference well is selected, all of the other logs will be transformed to bring them onto the same value range as the reference log.

For this analysis, well 423893012300 will be used as the reference well for the gamma ray logs. Well 423890108900 will be the well that is being normalized to the reference log. Gamma ray values over the entire interval of the Rustler Formation were extracted for both the reference log (42389301230000) and the log that is going to be normalized (423890108900). As can be observed from Figure 13-4, the reference log is in American Petroleum Institute units on a scale of 0-100 and the log to be normalized is in Radiation-equivalents per ton on a scale of 0-7.5. After converting the Radiation-equivalents per ton values to an American Petroleum Institute scale, the values were still anomalously low and needed to be normalized to the reference well (see histogram in Figure 13-4). Standard petrophysical software provides a variety of normalization techniques, but the approach used here involves starting with a 0 and 100 percent normalization range and adjusting the percentages until you get the best fit with the reference gamma ray log (Figure 13-5). This process was performed on all gamma ray and neutron porosity logs in the key wells to ensure consistency across all of the gamma ray and neutron porosity logs. Furthermore, the normalization process was performed independently for the Magenta Dolomite, Culebra Dolomite, and limestones of the Los Medaños.

13.3.5 Step 5: Calculate temperature

For the 26 key wells, the temperature of formation was calculated on a foot by foot basis using the following equation assuming a linear geothermal gradient:

$$T(z) = T(z_1) + \frac{T(z_2) - T(z_1)}{z_2 - z_1}(z - z_1) \qquad \text{(Equation 13-6)}$$

Where:

$T(z)$	=	Temperature (degrees Fahrenheit) at depth of interest (z)
$T(z_1)$	=	Temperature (degrees Fahrenheit) at depth one, which usually corresponds to ground surface
$T(z_2)$	=	Temperature (degrees Fahrenheit) at depth two, which usually corresponds to the bottom hole temperature
z	=	Depth at which $T(z)$ is being calculated
z_1	=	Depth at which $T(z_1)$ was taken, which usually corresponds to ground surface
z_2	=	Depth at which $T(z_2)$ was taken, which usually corresponds to the total depth of the log run

13.3.6 Step 6: Calculate mud-filtrate resistivity at depth $R_{mf}(z)$

We converted resistivity of mud filtrate (R_{mf}) to resistivity of mud filtrate at depth using the following equation:

$$R_{mf}(z) = R_{mf1} * \frac{T_1 + 6.77}{T_{(z)} + 6.77} \qquad \text{(Equation 13-7)}$$

Where:

$R_{mf}(z)$	=	corresponding electrical resistivity (ohm-meter) of mud filtrate at Temperature $T(z)$ (degrees Fahrenheit)
R_{mf1}	=	Electrical resistivity (ohm-meter) of mud filtrate measured at Temperature T_1 (degrees Fahrenheit)
T_1	=	Temperature (degrees Fahrenheit) at R_{mf1}
T_z	=	Temperature at depth (degrees Fahrenheit)

13.3.7 Step 7: Calculate porosity (Φ) from geophysical logs

Seminal to the calculation of water quality in the Rustler Aquifer is the derivation of the most accurate porosity value possible. Using variations of the Archie's (1942) water saturation equation to calculate resistivity of water can cause resistivity to range over two orders of magnitude if using a porosity range between five and 35 percent. This will result in a range of approximately an order of magnitude in the resulting calculated total dissolved solids value. Therefore, given the somewhat inconsistent nature of porosity logs in the Permian Basin, the

INTERA team went to great lengths not only to calculate porosity but also to cross check the calculated porosity using log normalization (formation-by-formation balancing) techniques.

Since the late 1970s, logging companies have provided neutron curves in apparent (limestone, sandstone or dolomite) porosity units. In the Permian Basin, these have been standardized to limestone porosity units. For wells logged in apparent porosity units, processing and corrections for borehole effects are made automatically by the geophysical logging company and are reflected on the .tif image of the log. However, as most logs run through the Rustler are old (pre-1970s), there are multiple types of porosity tools that have a range of units including: Standard Counts Per Second, American Petroleum Institute units, Porosity Units, or even with no scale at all. To calculate the porosity from these curves, a conversion between old and new porosity units must be made.

In the Rustler Aquifer, water-bearing zones are in both dolomite (Magenta and Culebra) and limestone (Los Medaños). Therefore, we will need to make the calculations in apparent limestone porosity and apparent dolomite porosity. In addition, we will also need to know how to convert between the two lithologies. The calculation of porosity from the various logs is as follows:

Neutron Log in Limestone Porosity units:

This is the simplest case. If water saturation is equal to 1 ($S_w = 1$), and if the rock is clean (local minima of the gamma ray log), and if the neutron log is expressed in the right lithology (sandstone, limestone or dolomite), then neutron porosity equals the total porosity recorded on the log. For the limestones within the Los Medaños Unit, the value can be read directly from the local gamma ray minima over the limestone unit. If we are trying to evaluate the Magenta or Culebra, then the log must be converted from apparent limestone porosity to apparent dolomite porosity.

Converting an apparent limestone porosity to an apparent dolomite porosity is done using Schlumberger (2009) Por-11 Chart. To convert from limestone porosity to dolomite porosity, enter the graph at the corresponding apparent limestone porosity value and follow the line up until it intersects at the dolomite porosity curve and that is the dolomite porosity. For wells that had apparent limestone porosity, the apparent porosity values were calculated for all of the units.

Convert Neutron Log from Standard Counts Per Second to Limestone Porosity units using calculations:

Neutron porosity logs run in Standard Counts Per Second can be converted to percent limestone porosity for a 6-, 8-, and 10-inch borehole using:

For 6-inch borehole: $$\Phi_{ls} = 10^{(2.247-0.00335*CPS)}/100 \quad \text{(Equation 13-8a)}$$

For 8-inch borehole: $$\Phi_{ls} = 10^{(2.4-0.00438*CPS)}/100 \quad \text{(Equation 13-8b)}$$

For 10-inch borehole: $$\Phi_{ls} = 10^{(2.547-0.0052*CPS)}/100 \quad \text{(Equation 13-8c)}$$

Where:

Φ_{ls}= Apparent limestone porosity (in porosity units)
CPS = Counts Per Second

When one has a borehole diameter different from those listed above use, one can use a linear approximation. For instance, for a 8.75-inch borehole: where $\frac{(10-8.75)}{(10-8)} = 0.625$, one has

$$\Phi_{LS} = (0.625 * 10^{(2.4-0.00438*CPS)} + (1-0.625) * 10^{(2.547-0.0052*CPS)})/100$$

One can also solve this problem point by point using a graphical method (Figure 13-6). If abnormal porosity values are acquired, it could be due to borehole effects such as:

- Standard Counts Per Second<150 or Standard Counts Per Second>750
- The pad tool was not completely against the side wall
- The borehole is filled with high salinity mud

Convert Neutron Log from American Petroleum Institute units to Limestone Porosity units using calculations:

American Petroleum Institute units can be converted into limestone porosity units using the following equations:

Hole size	Equation for API ∈ [250-1500]	
4-inch	$\Phi_{ls} \approx \frac{10^{1.911-0.000531API}}{100}$	(Equation 13-9a)
6-inch	$\Phi_{ls} \approx \frac{10^{1.9179-0.000559API}}{100}$	(Equation 13-9b)
8-inch	$\Phi_{ls} \approx \frac{10^{1.9338-0.000623API}}{100}$	(Equation 13-9c)
10-inch	$\Phi_{ls} \approx \frac{10^{1.9532-0.0007API}}{100}$	(Equation 13-9d)
12-inch	$\Phi_{ls} \approx \frac{10^{1.9739-0.000783API}}{100}$	(Equation 13-9e)

Or:

Hole size	Equation for API ∈ [1500-5000]	
4-inch	$\Phi_{ls} \approx \frac{10^{1.8283-0.000476API}}{100}$	(Equation 13-9f)
6-inch	$\Phi_{ls} \approx \frac{10^{2.0584-0.000653API}}{100}$	(Equation 13-9g)
8-inch	$\Phi_{ls} \approx \frac{10^{2.3043-0.00087API}}{100}$	(Equation 13-9h)
10-inch	$\Phi_{ls} \approx \frac{10^{2.4135-0.001007API}}{100}$	(Equation 13-9i)
12-inch	$\Phi_{ls} \approx \frac{10^{2.5076-0.001139API}}{100}$	(Equation 13-9j)

Where:

$\in$	=	Neutron response in American Petroleum Institute units
Φ_{ls}	=	Neutron porosity in percent
API	=	American Petroleum Institute units for neutron porosity

This conversion can also be performed using the graph provided in Figure 13-7. If abnormal neutron porosity values occur using this method, it is likely due to borehole effects, and the normalization method would provide more reliable estimates of apparent porosity.

Convert Neutron Log Standard Counts Per Second or American Petroleum Institute units to limestone porosity using the normalization method:

In wells where borehole effects produced biased neutron porosity values, the normalization method was used. The porosity log normalization method is similar to the gamma ray log normalization method in that reference wells are needed. These wells required a neutron porosity log that, when converted to limestone porosity units, the data were not anomalous. The following key wells were used as reference wells for the porosity log: 421093138300, 423713514900, 423890014200, 423890090500 and 4237102194. Again, the normalization method for the porosity logs is similar to the gamma ray log method, with the exception that there are minor differences in applying the method depending on what nearby reference well is being considered. For example, when there was a reference well that had a neutron log expressed in Standard Counts Per Second or American Petroleum Institute units, then the log curve to normalize will also need to be in Standard Counts Per Second. If the two wells had different borehole diameters, the reference well was converted to limestone porosity units using the diameter of the reference borehole. The well was then normalized and corrected back to its reference borehole diameter.

The normalization method was also used to quality control some of the porosity calculations to make sure that there was consistency between the two apparent porosity values.

Sonic porosity from acoustic logs:

Sonic porosity can be approximated using the Wyllie equation:

$$\Phi = \frac{\Delta t_b - \Delta t_m}{\Delta t_f - \Delta t_m} \qquad \text{(Equation 13-10)}$$

Where:

Φ	=	porosity
Δt_b	=	the bulk sonic slowness (microSiemens per foot)
Δt_f	=	the sonic slowness of the fluid occupying the rock's pore space (microSiemens per foot)
Δt_m	=	the sonic slowness of the matrix (solid component) contained in the rock (microSiemens per foot)

In the Rustler Aquifer, water-bearing zones are in dolomite and limestone. Thus, sonic porosity can be calculated as:

$$\Phi_{dolomite} = \frac{\Delta t - 43.5}{190 - 43.5} \quad \text{and} \quad \Phi_{limestone} = \frac{\Delta t - 48}{190 - 48} \qquad \text{(Equation 13-11)}$$

Where:

Δt	=	the bulk sonic slowness (microSiemens per foot) read directly from the log
$\Phi_{dolomite}$	=	dolomite sonic porosity
$\Phi_{limestone}$	=	limestone sonic porosity

Porosity from 32-inch limestone resistivity log:

The 32-inch limestone (Res32”) device was developed in 1945 and sometime in the early 1950s went out of use (Hilchie, 1984). The tool was used to determine porosity along the same lines as the short normal resistivity tool. The life and use of the limestone device was short and geographically restricted to West Texas and, to a much lesser degree, Alberta, Canada (Hilchie, 1984). The tool was usually run in combination with a 10-inch normal and 19-foot lateral devices.

In theory, porosity can be acquired from the 32-inch limestone device using the following technique proposed by Hilchie (1984):

$$\max\left(\frac{Res32"}{Rmf}\right) = \frac{4*AM*AN}{(d^2-ds^2)} \qquad \text{(Equation 13-12)}$$

Where:

$\max\left(\frac{Res32"}{Rmf}\right)$	=	the maximum value over the entire log of the ratio of Res32” to R_m
$Res32"$	=	Value, in ohm-meters, from the 32-inch limestone resistivity curve
Rmf	=	resistivity, in ohm-meters, of the mud filtrate at depth
d	=	borehole diameter
ds	=	the sonde diameter
AM	=	30-inch for a 32-inch limestone device
AN	=	34-inch for a 32-inch limestone device

For a typical 3 5/8-inch diameter sonde used by Schlumberger (2009), the following values are representative of what should be expected for the max $\left(\frac{Res32"}{Rm}\right)$ values given different borehole diameters:

Hole diameter (inches)	$[\boldsymbol{max}(\frac{Res32"}{R_{mf}})]$
4 ¾	866
6 ¾	252
8	160
9	120
10	94
12	62

The table is provided in the instance that a zone of infinite resistivity does not occur in the well. For all key wells that had 32-inch limestone device runs, the maximum value for the ratio between the 32-inch limestone resistivity and mud filtrate resistivity at depth were calculated.

The maximum value should be measured in a zone of essentially infinite resistivity. If the maximum value of the calculated ratio is out of the range, it is possible that the sonde used has a different diameter from the 3 5/8-inch. The sonde diameter is usually reported in the header of the file.

After calculating the max $\left(\frac{Res32"}{Rmf}\right)$ value, the next step is to calculate the relative percent deflection using the following equation:

$$\%Deflection = 100 * (\frac{Res32"}{R_{mf}}) / [max(\frac{Res32"}{R_{mf}})] \quad \text{(Equation 13-13)}$$

where:

max $\left(\frac{Res32"}{Rmf}\right)$	=	the maximum value over the entire log of the ratio of Res32” to R_m
$Res32"$	=	Value, in ohm-meters, from the 32-inch limestone resistivity curve
R_{mf}	=	resistivity, in ohm-meters, of the mud filtrate at depth

Once the $\%Deflection$ has been calculated, depending on the borehole size, the equations below can be used to convert $\%Deflection$ to apparent porosity:

Hole size	**Equation for Porosity**	
4-inch	$\Phi \approx \frac{-5.577\ln(\%Deflection) + 27.889}{100}$	(Equation 13-14a)
5-inch	$\Phi \approx \frac{-8.018\ln(\%Deflection) + 38.957}{100}$	(Equation 13-14b)
6-inch	$\Phi \approx \frac{-9.668\ln(\%Deflection) + 46.984}{100}$	(Equation 13-14c)
7-inch	$\Phi \approx \frac{-11.38\ln(\%Deflection) + 54.988}{100}$	(Equation 13-14d)
8-inch	$\Phi \approx \frac{-12.78\ln(\%Deflection) + 61.585}{100}$	(Equation 13-14e)
9-inch	$\Phi \approx \frac{-14.18\ln(\%Deflection) + 68.118}{100}$	(Equation 13-14f)
10-inch	$\Phi \approx \frac{-15.54\ln(\%Deflection) + 74.299}{100}$	(Equation 13-14g)
11-inch	$\Phi \approx \frac{-16.77\ln(\%Deflection) + 79.852}{100}$	(Equation 13-14h)
12-inch	$\Phi \approx \frac{-17.74\ln(\%Deflection) + 84.374}{100}$	(Equation 13-14i)
13-inch	$\Phi \approx \frac{-18.71\ln(\%Deflection) + 88.885}{100}$	(Equation 13-14j)
14-inch	$\Phi \approx \frac{-19.76\ln(\%Deflection) + 93.736}{100}$	(Equation 13-14k)
15-inch	$\Phi \approx \frac{-20.91\ln(\%Deflection) + 98.999}{100}$	(Equation 13-14l)
16-inch	$\Phi \approx \frac{-21.93\ln(\%Deflection) + 103.77}{100}$	(Equation 13-14m)

The porosity can also be solved for using Figure 13-8 taken from Hilchie (1984).

Porosity from spherically focused resistivity log (SFL):

While only one of the key wells had a spherically focused resistivity log, calculation of porosity from a combination of the mud filtrate resistivity (R_{mf}) and the spherically focused resistivity (R_{xo}) curve is relatively straightforward. The main assumption is that the spherically focused log is measuring the flushed zone and if so, porosity can be approximated using Archie's 1942 equation:

$$R_t = \frac{a * R_w}{\Phi^m * {S_w}^n} \qquad \text{(Equation 13-15)}$$

Where:

R_t	=	True resistivity as measured from the spherically focused resistivity curve (R_{xo})
a	=	the lithology constant which is 1 in this case
R_w	=	resistivity, in ohm-meters, of formation water which is assumed to be equal to the resistivity of mud filtrate at depth ($R_{mf}z$)
Φ	=	porosity in decimal units (fraction)
m	=	porosity exponent, which is assumed to be 2.0 (dolomite-limestone average)
${S_w}^n$	=	Archie (1942) water saturation variable, which is assumed to be 1 in the flushed zone

Which can be simplified to:

$$R_{xo} \approx \frac{R_{mf}(z)}{\Phi^2} \qquad \text{(Equation 13-16a)}$$

And finally:

$$\Phi \approx \sqrt{\frac{R_{mf}(z)}{R_{xo}}} \qquad \text{(Equation 13-16b)}$$

Where:

Φ	=	porosity in decimal units (fraction)
$R_{mf}(z)$	=	resistivity, in ohm-meters, of mud filtrate at depth
R_{xo}	=	resistivity, in ohm-meters, of the flushed zone which is equal to true resistivity from the spherically focused log

Porosity in gypsiferous portions of the Magenta Dolomite

When making calculations of porosity in the Magenta Dolomite in wells 423890055500 and 423890089000 in Reeves County, it was immediately apparent that the Magenta Dolomite in this area was lithologically different from other portions of the Rustler Formation. Specifically, when using the porosity values to make the calculations for water quality, values within the Magenta were around 100 milligrams per liter while the calculations for the Culebra and Limestones of the Los Medaños were in the >3,000 milligrams per liter total dissolved solids range. Boghici and Broekhoven (2001), in their table 15-1, state that the Magenta Member is an interbedded gray dolomite and gray gypsiferous dolomite in Reeves County. If the unit is suspected to contain gypsum, this would reduce the porosity value. When making water quality calculations using the resistivity log, reducing the porosity value serves to attribute more of the true resistance (R_t) to the tortuosity of the interconnected flow paths as opposed to the conductivity of the water in the formation (R_w).

When matrix composition is not limestone, dolomite, or quartz, the apparent neutron porosity needs to be converted to the specific matrix composition of the rock so that the resulting porosity can be a reliable expression of the fluid-occupied relative rock volume (typically referred to as matrix correction of apparent neutron porosity). The correction can be readily implemented with the method developed by Ortega and Torres-Verdin (2015), wherein the inverse of the migration lengths of both dolomite and gypsum are weighted average with their relative solid compositions. Migration length is the fundamental property of materials that quantifies the sum of scattering and diffusion lengths traveled by a neutron before it is absorbed by the material. Migration lengths for specific minerals can be calculated using Monte Carlo methods of multi-particle analysis. Ortega and Torres-Verdin (2015) (Table 1 of their paper) provided tabulated values of migration length and inverse of migration length for some of the most common minerals typically encountered in rock compositions. Using Table 1 of Ortega and Torres-Verdin (2015), we calculated the inverse of migration length for a wide range of dual dolomite-gypsum solid concentrations. Assuming 100% water saturation, we subsequently calculated the corresponding value of neutron porosity, which gave us the correction factor needed to convert the original limestone (or dolomite) apparent neutron porosity to the equivalent porosity for a mixture of gypsum-dolomite solid composition in the Magenta Dolomite. This procedure yielded a reliable porosity value from which to calculate formation water resistivity.

It must be noted that the porosity exponent has a profound effect on the calculated apparent porosity and data to empirically derive the porosity exponent either did not exist or was not available to this project. Therefore, for consistency, the INTERA team decided to use a value of 2.0, which is the high end for a dolomitic limestone, for all calculations. Variations of this parameter can be found in Appendix B of Estepp, 2010.

Porosity values were calculated for all 26 of the key wells using one or more of the above mentioned porosity calculation techniques on one or more of the principal water-bearing units. These values are tabulated in Table 13-1 and geographically distributed on Figure 13-9. As can been observed on Table 13-1, the standard deviation of the apparent porosity value between the units averages about five percent and has a minimum and maximum deviation of 0 and 14 percent, respectively. Averages for all of the values did not differ significantly. Maximum values for all three of the units are in the high range of apparent porosity values and likely represent a very transmissive/karstified portion of the carbonate units.

The geographic distribution of the porosity values is shown on Figure 13-9. It is immediately apparent that the three wells (423013023600, 424951085300 and 424750289700) in the northern portion of the project area are representative of the suspected tightening of porosity due to halite cementation. While we made picks for the Los Medaños Limestones in the area, it is possible that the limestone units were either transitioning into their halitic counterpart or were cemented with halite cements. In the northwestern portion of the project area, wells show a consistently high porosity, likely due to solution enhancement. Toward the middle of hydrostructural zone 9, just to the west of Pecos, wells 423890024500 and 423890035500 show lower porosities likely attributed to burial related compaction of the Rustler Formation in the Pecos-Loving Trough. However, attributing to the complex nature of the Rustler, well 423890075400 in the same areas shows higher porosity values. This also appears to be happening with well 423710418600 as it transitions into the Monument Draw Trough. Porosities in and around the Fort Stockton area appear to be consistently in the 0.20 to 0.26 range for the Culebra Dolomite the limestones of the Los Medaños. High porosities in well 423713514900 are likely due to solution enhancement, and picks here were extremely difficult and were geared toward trying to find signatures reflective of dolomite and limestone, as opposed to stratigraphically following the member units into the area.

13.3.8 Step 8: Calculate the resistivity of the formation water ($\boldsymbol{Rw}$)

Once the calculation of porosity was made for the wells, assuming the correct type of log was available, calculation of water quality from the deep resistivity signature was relatively straightforward. Formation water resistivity can be approximated using Archie's (1942) water saturation equation:

$$R_t = \frac{a * R_w}{\Phi^m * {S_w}^n} \qquad \text{(Equation 13-17)}$$

Where:

- R_t = True resistivity as measured from the spherically focused resistivity curve (Rxo)
- a = Winsauer's constant, which is 1 in this case
- R_w = resistivity, in ohm-meters, of the water which is assumed to be equal to the resistivity of the mud filtrate at depth ($Rmfz$)
- Φ = porosity in decimal units (fraction)
- m = porosity exponent, which is assumed to be 2.0 (dolomite-limestone average)
- ${S_w}^n$ = Archie (1942) water saturation variable which is assumed to be 1 in the flushed zone

Which can be simplified to:

$$R_w = R_t * \Phi^2 \qquad \text{(Equation 13-18)}$$

Where:

- R_w = resistivity, in ohm-meters, of the formation water
- R_t = True resistivity as measured from the deepest sensing geophysical tool
- Φ^2 = porosity in decimal units with a cementation exponent of 2.0

13.3.9 Step 9: Calculate equivalent NaCl concentration from Rw

The resistivity of formation water is then converted to equivalent sodium chloride concentration in parts per million, further referred to as salinity (TDS_{NaCl}) using the following equation derived from Western Atlas International (1992):

$$TDS_{NaCl} = 10^{\frac{3.562-\log_{10}[(\frac{T(z)+6.77}{81.77})*R_W-0.0123]}{0.955}} \quad \text{(Equation 13-19)}$$

Where:

TDS_{NaCl} = Equivalent sodium chloride in parts per million
$T(z)$ = Temperature at depth calculated using geothermal gradient
R_w = resistivity, in ohm-meters, of formation water

13.3.10 Step 10: Discrimination of values to low gamma ray intervals

While all of the aforementioned calculations were made over the entire depth of the geophysical logs, the INTERA team was only interested in depth intervals that exhibit low gamma ray signals within the main water-bearing zones. This selection minimizes the effect of shale (clay minerals) on the measured electrical resistivity (surface conduction effects which could reduce the accuracy and reliability of Archie's equation). For this portion of the work, petrophysical software was used to provide a histogram of the normalized gamma ray log. Based on each histogram for each water-bearing unit, a gamma ray value was chosen to represent the volume shale cutoff. For each of the water-bearing units, if the volume shale cutoff was not exceeded then the corresponding calculated sodium chloride value at that same depth increment was taken and all of the values were tabulated and subsequently averaged.

13.3.11 Step 11: Using sampled water quality data to convert equivalent sodium chloride concentration to total dissolved solids (milligrams per liter)

As discussed in Section 10, sampled water quality data, along with Schlumberger Chart Gen-4 (Schlumberger, 2009) (Figure 13-1) was used to calculate sodium chloride equivalent total dissolved solids for each of the samples. For samples that had an ionic balance less than 15%, and had a total dissolved solids value less than 10,000 milligrams per liter, a regression plot of total dissolved solids vs sodium chloride equivalent total dissolved solids was created (Figure 13-10). The values less than 10,000 milligrams per liter were used because that range is most reflective of the ionic makeup of the Rustler Aquifer. The regression was fit with a simple polynomial equation and produced a coefficient of determination (R^2) of 0.98. The equation, which was used to convert sodium chloride in parts per million to total dissolved solids in milligrams per liter is as follows:

$$TDS = 1.1784(TDS_{NaCl}) + 94.788 \quad \text{(Equation 13-20)}$$

Where:

TDS = total dissolved solids in milligrams per liter
TDS_{NaCl} = Equivalent sodium chloride total dissolved solids in parts per million

All of these steps have been summarized on a petrophysical workflow table (Figure 13-11). The workflow table is meant to serve as a guide when attempting to calculate porosity and or water quality within the Rustler Formation. In addition, examples of the application of these techniques have been provided in appendix 19.7.

Results of water quality calculations are summarized on Table 13-2. Calculations were made on all but 11 of the key wells due to availability of quality resistivity/induction log signature in those wells. It is important to point out that the calculation for water quality in the key geophysical wells was performed without considering the geographic location of the well that was being analyzed. This is important because it provided for a more reliable and unbiased product when the interpretations were geographically distributed and the resulting distribution of calculated water quality values was in general agreement with the sampled water quality distribution (Figure 6-1). Wells that were not in general agreement with the sampled water quality include the two Magenta Dolomite calculations (423890055500 and 423890089000) that necessitated the inclusion of gypsum into the porosity calculation, well 423890101100 with a calculated total dissolved solids value of 18,416 for the Culebra Dolomite and well 423013023600 with a calculated total dissolved solids value in the Los Medaños of 143,400 milligrams per liter. Varying the volumetric ratio between gypsum and dolomite in the calculation of porosity for wells 423890055500 and 423890089000 increased the calculated water quality into an acceptable range. The water quality value calculated at well 423890101100 is inconsistent with the general understanding of the water quality distribution within the Rustler Aquifer and is likely a localized feature. For well 423013023600, it would appear that we either mis-classified the unit as a limestone or, the porosity has been clogged with halite cements. This value was reported but, it was not averaged into the total dissolved solids values posted on any of the figures or statistically analyzed in Table 13-2.

Calculated water quality values for the Magenta Dolomite range between 827 and 22,641 with an average of 6,022 milligrams per liter. Calculated water quality values for the Culebra Dolomite ranged between 1,641 and 22,756, with an average of 6,453 milligrams per liter. Calculated water quality values for the limestones of the Los Medaños Unit between 1,052 and 37,147, with an average of 3,453 milligrams per liter. Average calculated water quality values for the Rustler Aquifer ranged from 1,044 to 22,699 and averaged 6,456 milligrams per liter. Standard deviation between the calculated water quality in each unit had a range between 6 and 1,955 with an average of 1,754 milligrams per liter. With the average standard deviation being 1,754 between the units, and the fact that all of the sampled water quality was had to be assigned to the entire extent of the Rustler Aquifer, it was determined that when contouring water quality zones, the up to three values calculated over the Rustler Aquifer should be averaged to represent a water quality value at the well.

13.4 Additional calculations of water quality on non-key wells

Additional calculations of water quality were performed using an adaptation to the technique proposed above for the key wells. In general, sampled water quality and calculations of water quality at key wells are consistent (Figure 6-1). Therefore, the combination of the key wells and the sampled water quality will serve as a guide when evaluating the results of water quality calculations made on non-key wells. If a calculated water quality is inconsistent with those results, then it is generally assumed that the calculated water quality value is not reflective of the formation water quality and is likely more reflective of the invaded zone of the well.

An adaption to the technique(s) used for the key wells allows for the calculation of water quality without using petrophysical algorithms. The first major difference between the two techniques is the normalization of the gamma ray curve. Because the water quality calculation will be made on one well, the low gamma ray values will be relative to the gamma ray signature for that particular well and the normalization is not strictly necessary. The second major difference is that this technique was performed using porosity values in nearby key wells. The exception to this is when a porosity value could be calculated using the 32-inch limestone resistivity log. If that value resulted in a spurious water quality value, then the nearest porosity calculation from one of the key wells was used.

Eighty-six calculations of water quality in 19 wells were made using a technique adapted from the technique proposed in the previous section. These wells are designated with a “4” in Appendix 19-5. Multiple resistivity values were selected to evaluate on the geophysical log within the carbonate units (Figure 13-12). Specifically, an attempt was made to apply these calculations at the lower gamma intervals of the units where possible. Where not possible, it was assumed that potassium was responsible for the increased gamma ray values. Using the digitized resistivity curves (shallow and deep) along with all of the tabulated mud parameters, a calculation for porosity was made for all of the selected units using the 32-inch limestone porosity calculation technique explained in section 13.1.3 (Equation 13-12). If the values in these samples were consistent with expected porosity values (as compared to the closest key well) then the value was used, if they were not, porosity calculation in nearby key wells would be used on a unit by unit basis.

Using the calculated porosity, deep resistivity from the LAS file, and a porosity exponent of 2.0, the formation water resistivity (R_w) was calculated and subsequently converted into TDS_{NaCl} in parts per million. This value was then converted into total dissolved solids in milligrams per liter using the linear regression equation derived in Figure 13-10. The calculated values were then averaged by formation, and the average value was geographically distributed to check for consistency with sampled and key well total dissolved solids distributions. Variables used in the calculations were input into the BRACS database and an example of the calculations was put in Appendix 19.7, along with key well calculation examples.

Table 13-3 is a tabulation of the results from the additional calculations. As can be seen, the majority of the calculations were made in the Culebra Dolomite and limestones of the Los Medaños Unit. For the Culebra Dolomite, the average calculated total dissolved solids for the seven wells was 3,424 milligrams per liter, with a minimum value of 1,126 and a maximum value of 5,672 milligrams per liter. For the limestones of the Los Medaños Unit, the average calculated total dissolved solids value was 4,547 milligrams per liter, the minimum was 2,851 milligrams per liter, and the maximum was 7,937 milligrams per liter. Attempts at additional calculations were made in the suspected collapse zone in the southern portion of the Rustler Aquifer (Subdomain 5) with somewhat conflicting results. Well 423710281200 showed a calculated total dissolved solids of 7,378 milligrams per liter in what appeared to be a carbonate unit. This value is inconsistent with the current hypothesis that recharge is entering the system from the south (Tessey Limestone outcrop) and serving to freshen this area. However, it is also possible that localized portion of the system are cutoff from the main flow paths that are freshening the majority of subdomain 5. Additional data in this area would be beneficial.

Finally, a calculation was made on what appeared to be a water-bearing portion of A2, directly atop the Culebra Dolomite in well 423710594800. While stratigraphically this unit is considered A2 for consistency's sake, the resistivity signature is not reflective of an anhydrite over its entire extent. Anhydrite signatures on the resistivity log in the well are clear in the Tamarisk Unit and at the top of the A2. It is anticipated that this calculation was made on a limestone/dolomite atop the Culebra Dolomite that is either lithologically distinct or, based on calculated total dissolved solids values, hydraulically separated.

An attempt was made to supplement geographic areas where there was no key well or sampled total dissolved solids values (Figure 6-1). However, after evaluating a number of ideally placed resistivity logs (identified in Appendix 19-5), it appeared that mud filtrate consistently invaded the zone that the resistivity log was evaluating. This was confirmed by making a calculation of mud filtrate resistivity at depth and comparing it with the resistivity of the formation water. If the calculated water resistivity value was similar to the mud filtrate or somewhere in the spectrum between the calculated mud filtrate resistivity and expected formation water resistivity value, then it was assumed that the log was reading the mixed zone and that the calculation was not reflective of the formation water resistivity.

Table 13-1. Calculated porosity values from the Rustler Aquifer using Key Wells.

American Petroleum Institute	Magenta Dolomite	Culebra Dolomite	Los Medaños Limestone	Standard Deviation Amongst Units
421090003900	-	33%	27%	**4%**
421093138300	34%	19%	-	**11%**
423013023600	13%	15%	8%	**4%**
423710058300	-	11%	-	**0%**
423710060900	-	17%	19%	**1%**
423710219300	-	19%	15%	**3%**
423710219400	-	20%	20%	**0%**
423710268700	-	19%	30%	**8%**
423710418600	-	14%	13%	**1%**
423710543000	-	25%	29%	**2%**
423713254800	-	23%	36%	**9%**
423713514900	40%	30%	-	**7%**
423713631000	-	20%	30%	**7%**
423890014200	29%	38%	35%	**5%**
423890024500	12%	11%	19%	**4%**
423890035500	17%	17%	20%	**2%**
423890041800	21%	23%	26%	**3%**
423890048900	18%	24%	27%	**5%**
423890055500	3%	24%	30%	**14%**
423890089000	9%	21%	24%	**8%**
423890090500	22%	30%	35%	**7%**
423890101100	-	33%	-	**0%**
423890108900	33%	20%	-	**9%**
423893012300	34%	26%	33%	**4%**
424750289700	-	14%	-	**0%**
424951085300	7%	18%	30%	**12%**
Minimum	3%	11%	8%	0%
Maximum	40%	38%	36%	14%
Average	21%	22%	25%	5%
Standard Deviation	12%	7%	8%	4%

Table 13-2. Calculated total dissolved solids values from the Rustler Aquifer using Key Wells.

American Petroleum Institute	Magenta Dolomite	Culebra Dolomite	Los Medaños Limestone	Standard Deviation Amongst Units	Average over Rustler
421093138300	826	1,261	-	308	1,044
423013023600	22,641	22,756	143,400	81	22,699
423710058300	-	1,081	-	-	1,081
423710219400	-	4,583	2,398	1,545	3,491
423710268700	-	3,737	2,588	812	3,163
423713254800	-	1,061	1,052	6	1,057
423713631000	-	641	2,713	1,465	1,677
423890014200	1,428	1,180	1,822	324	1,477
423890041800	4,796	3,594	7,417	1,955	5,269
423890055500	6,965	5,103	5,286	1,026	5,785
423890089000	3,384	5,296	5,894	1,311	4,858
423890090500	5,646	5,489	2,946	1,516	4,694
423890101100	-	20,372	-	-	20,372
423890108900	2,199	2,410	-	149	2,305
424750289700	-	18,154	-	-	18,154
Minimum	826	641	1,052	6	1,044
Maximum	22,641	22,756	143,400	1,955	22,699
Average	6,002	6,453	17,448	754	6,456
Standard Deviation	6,988	7,475	44,297	683	7,436

Table 13-3. Additional calculations of water quality from geophysical logs.

American Petroleum Institute	Magenta Dolomite	A2	Culebra Dolomite	Los Medaños Limestone	Collapse	Standard Deviation Amongst Units	Average over Rustler
422430000200	-	-	-	-	1,265	-	1,265
423710281200	-	-	-	-	7,378	-	7,378
423710594800	-	4,574	1,805	3,063	-	1,387	3,147
423711013900	-	-	-	4,330	-	-	4,330
423711036200	-	-	1,126	3,009	-	1,331	2,068
423711054200	-	-	5,672	2,977	-	1,905	4,324
423890015900	-	-	5,492	7,667	-	1,538	6,579
423890039900	-	-	3,571	7,935	-	3,086	5,753
423890040900	-	-	2,690	-	-	-	2,690
423890075400	2,844	-	3,610	2,851	-	440	3,102
Minimum	2,844	4,574	1,126	2,851	-	1,408	2,849
Maximum	2,844	4,574	5,672	7,935	-	2,131	5,256
Average	2,844	4,574	3,424	4,547	-	857	3,847
Standard Deviation	-	-	1,724	2,279	-	393	2,001

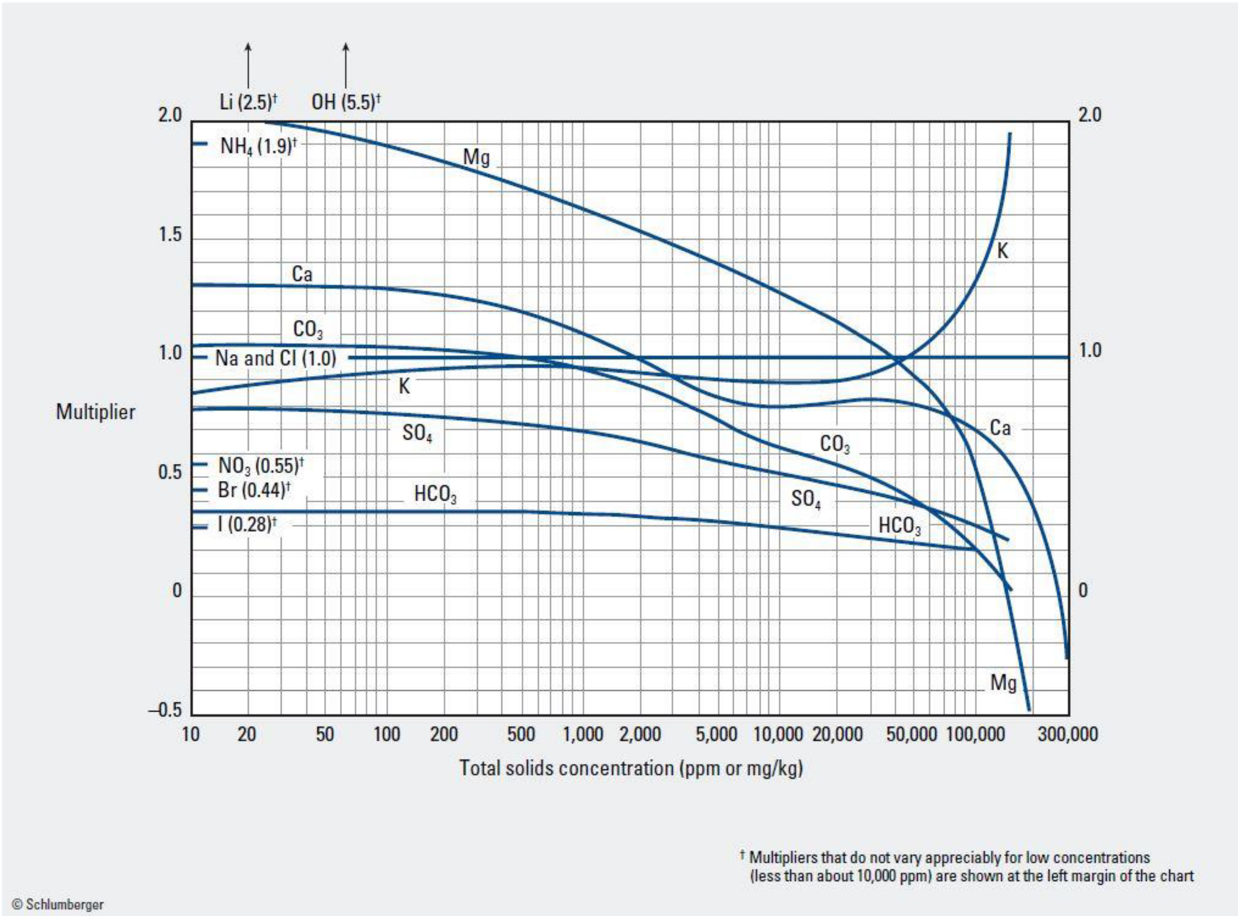

Figure 13-1. Schlumberger chart GEN-4 (Schlumberger, 2009) used to calculate equivalent sodium chloride total dissolved solids from a known water chemistry sample.

Note: ppm=stands for parts per million; mg/kg=milligrams per kilogram.

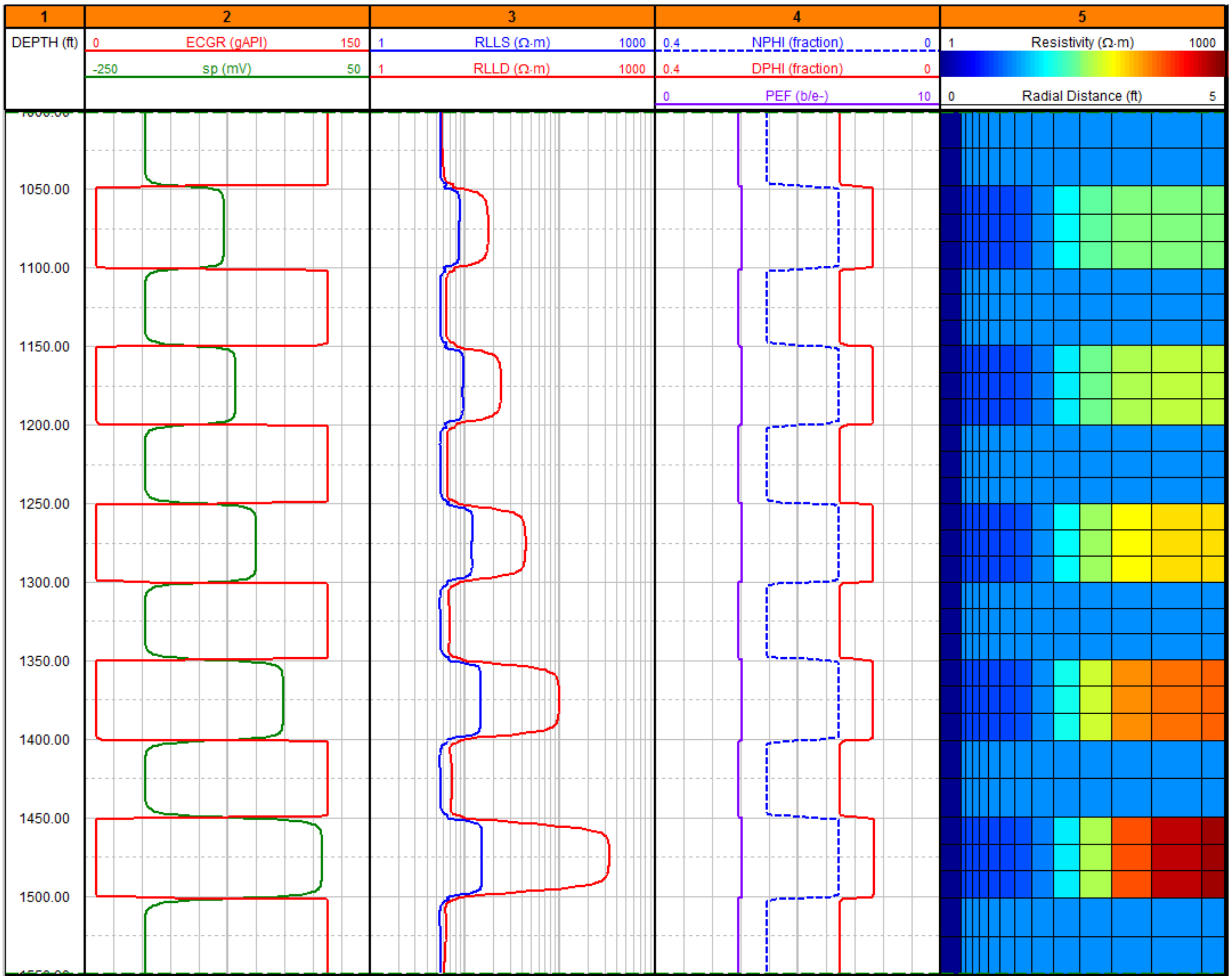

Figure 13-2. **Example sensitivity analysis simulation showing a dolomitic unit straddled above and below by low resistivity shales.**

Note: Borehole salinity is 200,000 parts per million sodium chloride and formation water salinity for each of the five units is 500, 1,000, 5,000, 10,000 and 15,000 parts per million sodium chloride.

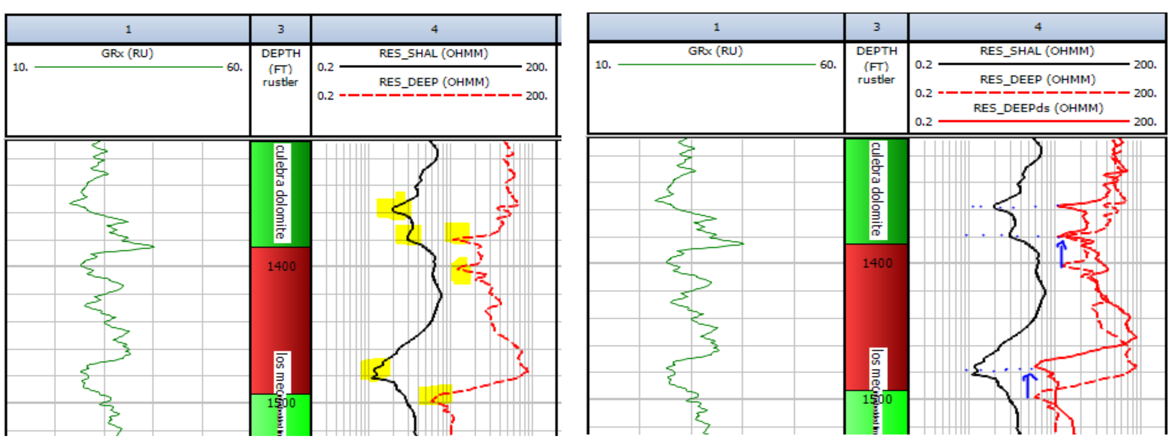

Figure 13-3. **Example of depth shifting logs to better match between the resistivity signatures.**

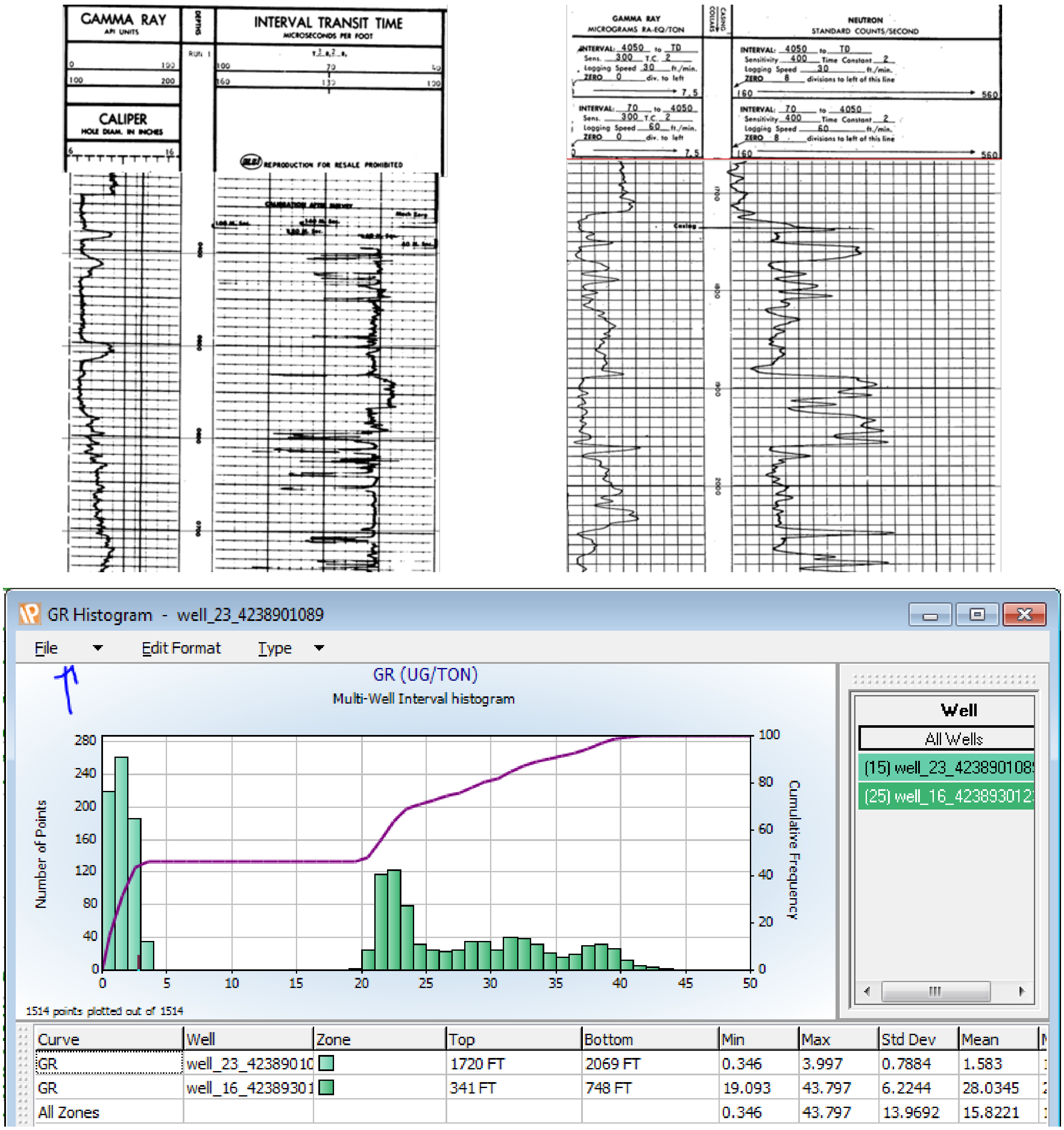

Figure 13-4. Example logs (423890108000 and 423893012000) for the gamma ray normalization process.

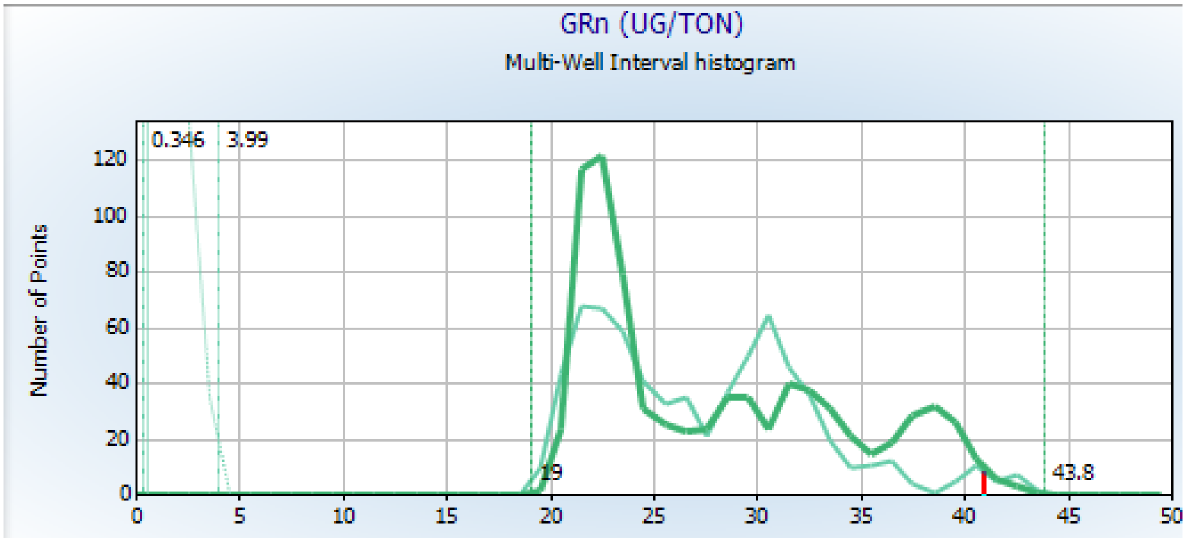

Figure 13-5. Example results from the gamma ray log normalization process.

Note: The thicker green line is the reference well and the thinner line is the well being normalized to the reference well. This process was iterated on with all gamma ray logs until there was consistency with the reference wells.

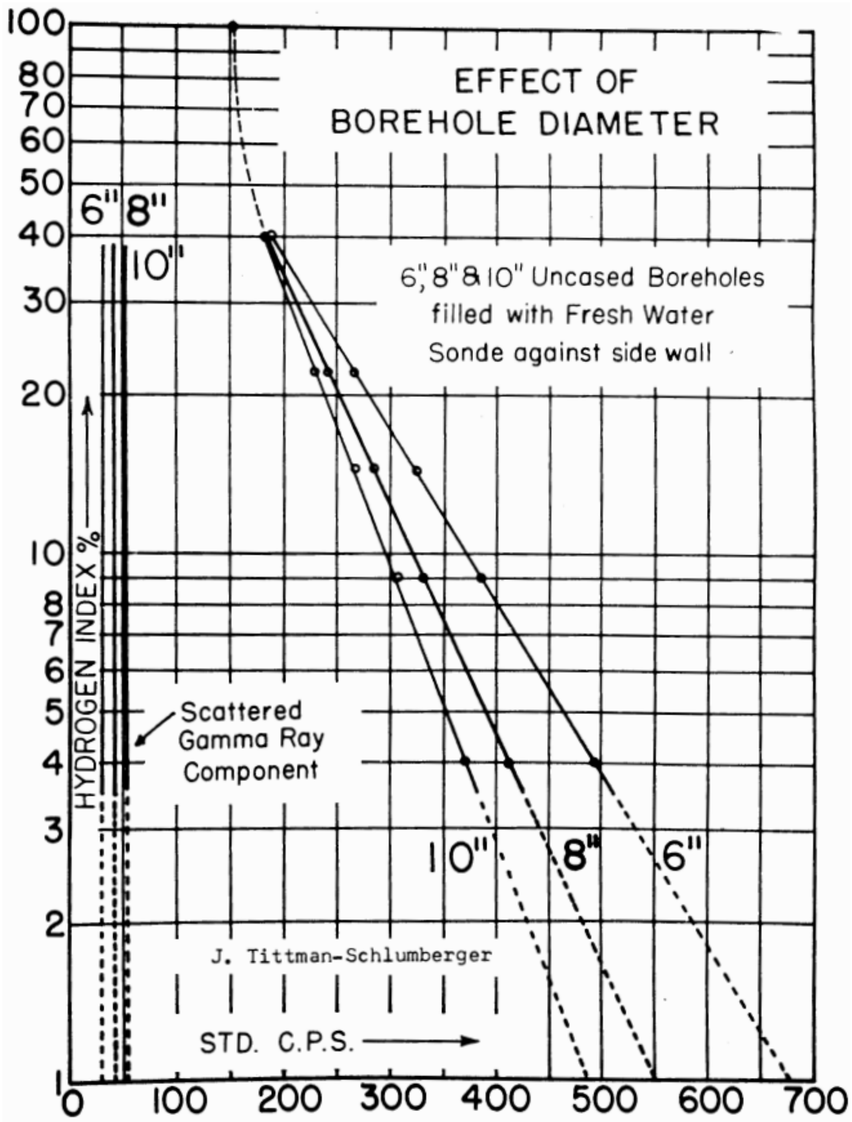

Figure 13-6 **Calibration curve for a conventional neutron log to convert from Standard Counts Per Second (STD CPS) to Neutron Porosity Units (Hilchie, 1984)**

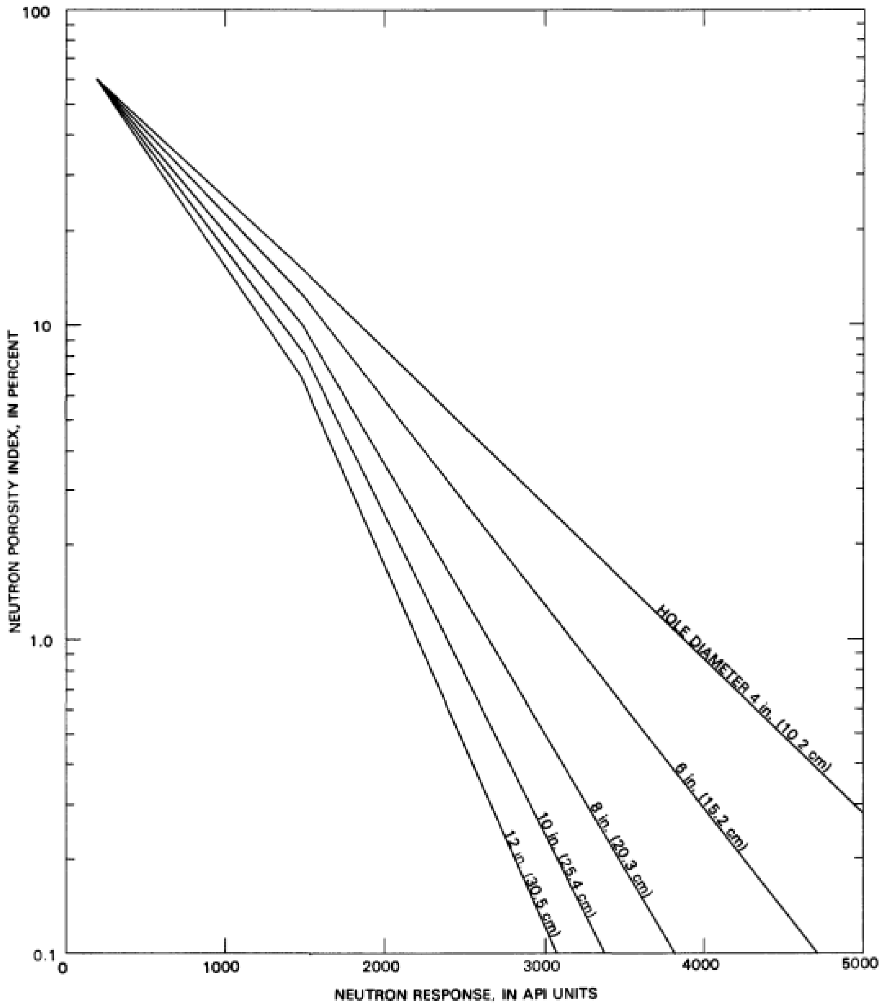

Figure 13-7. Graph from Scott, 1984 showing calibration information used to transform neutron API (American Petroleum Institute) units to porosity index, for holes of various diameters in inches.

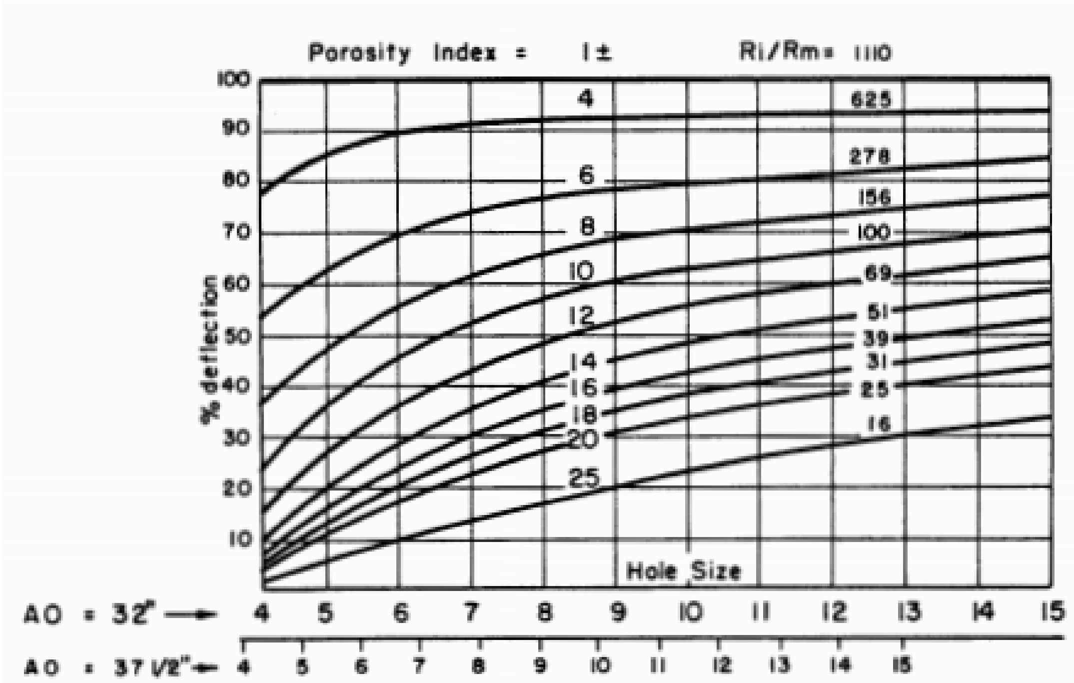

Figure 13-8. Graph used to calculate porosity from percent deflection and borehole diameter (Hilchie, 1984).

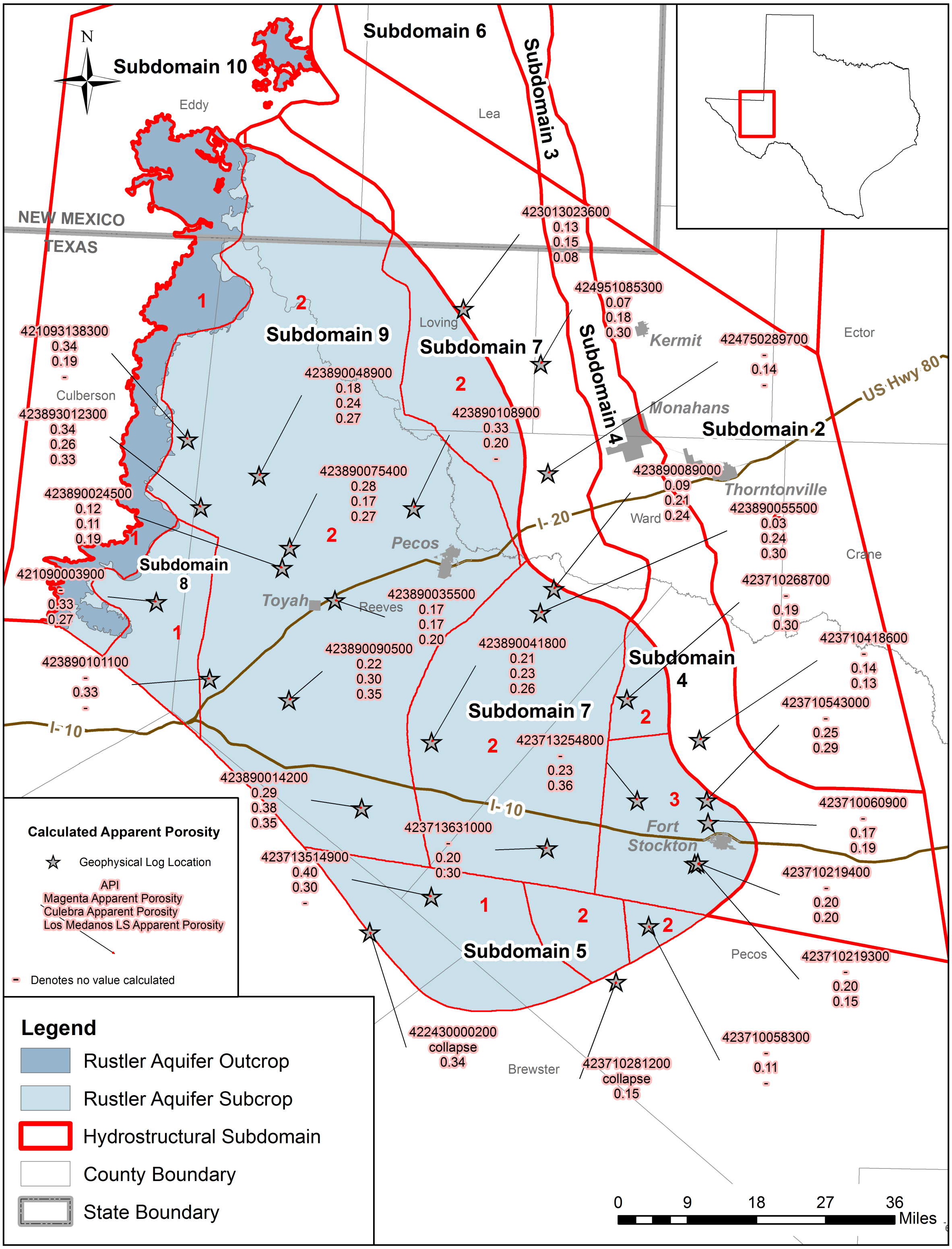

Figure 13-9. Apparent porosity values calculated from key well geophysical logs.

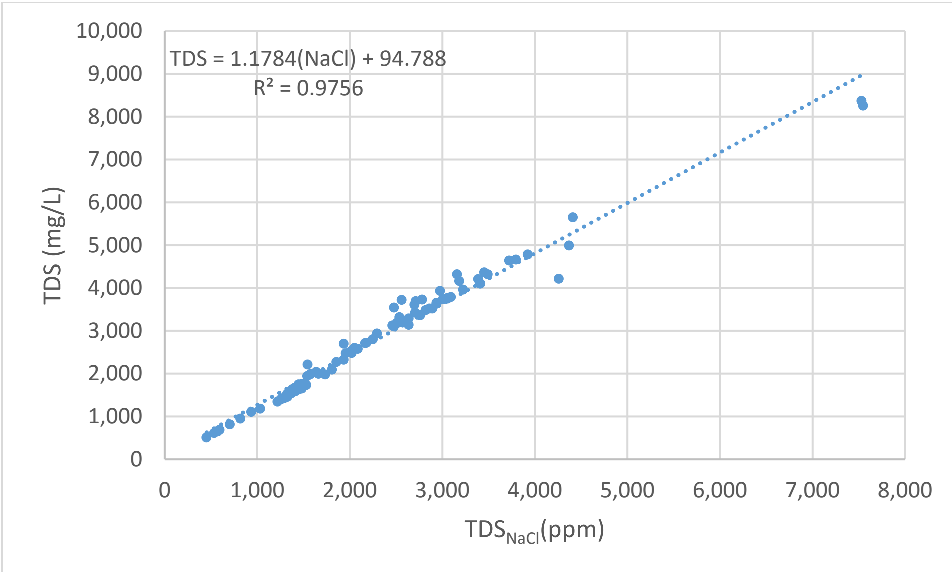

Figure 13-10. Total dissolved solids (TDS) milligrams per liter (mg/L) from sampled water quality values less than 10,000 milligrams per liter plotted against sodium chloride equivalent total dissolved solids.

Note: Conversions between total dissolved solids and sodium chloride equivalent total dissolved solids (TDS_{NaCl}) in parts per million (ppm) were performed using Schlumberger Chart Gen-4 (Schlumberger, 2009) (Figure 13-1).

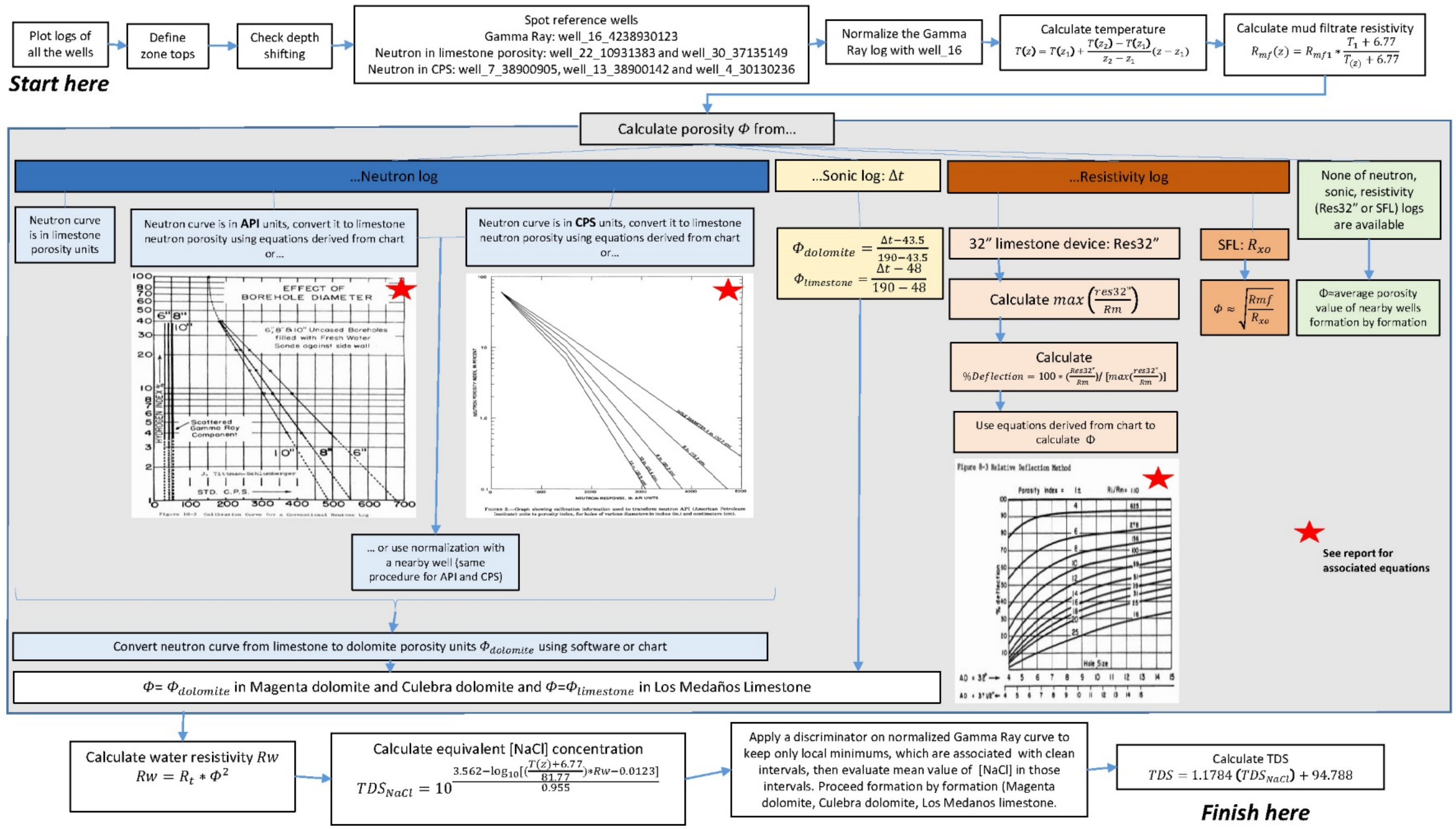

Figure 13-11 **Rustler specific chart guide used to guide the calculation of porosity (ϕ), formation water resistivity (R_w), equivalent sodium chloride Total Dissolved Solids (TDS_{NaCl}) and Total Dissolved Solids (TDS).**

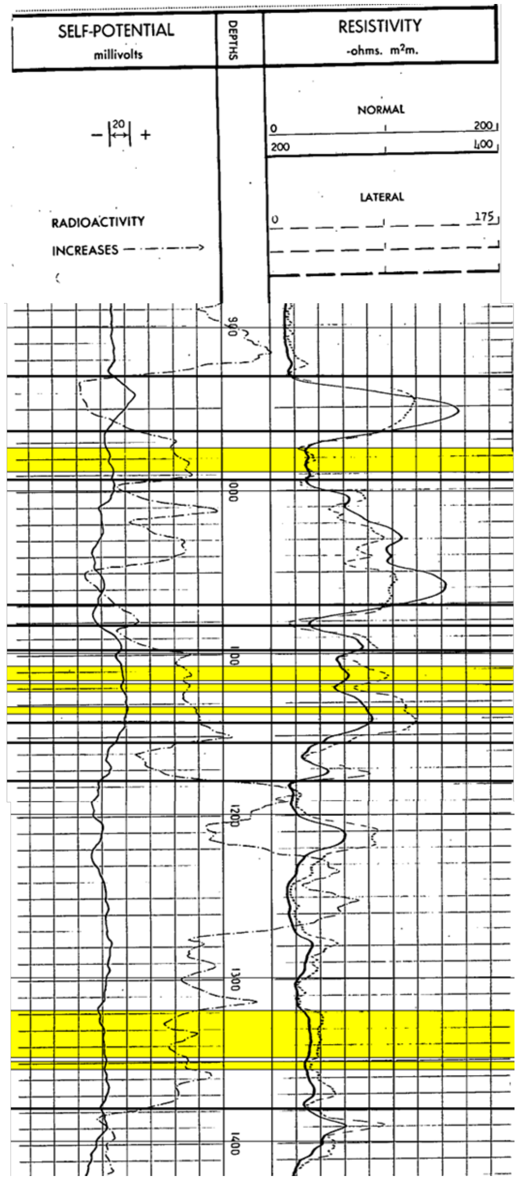

Figure 13-12. Example geophysical log used in additional calculations of total dissolved solids. Yellow highlights indicate areas where water quality was calculated.

14 Potential brackish groundwater production area analysis and modeling methodology

This section discusses the selection and definition of the potential production areas and the modeling methodology and analysis of potential impacts of these potential production areas based upon simulated changes in groundwater levels caused by pumping. potential production areas are developed consistent with the criteria defined in House Bill 30 passed by the 84th Texas Legislative Session. The modeling simulates pumping from candidate well fields for 50 years at a range of withdrawal rates. Drawdown in the Rustler Aquifer is tabulated at the potential production area boundaries and at the nearest protected well after 30 and 50 years of pumping consistent with the requirements of House Bill 30. In order to support the evaluation of the potential for significant drawdown impact in areas of concern, a sensitivity analysis was performed to document the sensitivity of simulated drawdown and the capacity of the aquifer to supply water to changes in aquifer properties in the groundwater model.

14.1 Selection of potential production areas

House Bill 30 provides direction to TWDB to identify and designate local or regional brackish groundwater production zones in areas of the state with moderate to high availability and productivity of brackish groundwater that can be used to reduce the use of fresh groundwater. Table 14-1 defines the criteria set forth in House Bill 30 to be used for designation of brackish groundwater production zones. It is important to note that TWDB designates brackish groundwater production zones. This report uses the information presented here and the criteria defined below to define potential production areas that will be considered for designation as brackish groundwater production zones by TWDB.

As we described in Sections 10 and 13, nearly the entire Rustler Aquifer contains groundwater that is between 1,000 milligrams per liter and 5,000 milligrams per liter total dissolved solids.

As discussed in Section 5 of this report, this study has refined the regional structural analysis performed as part of the development of the Rustler Groundwater Availability Model (Ewing and others, 2012). The structure of the Rustler Aquifer is very complex (see Figure 5-11 showing the disrupted structure contour of the aquifer). Ewing and others (2012) developed a conceptualization for the Rustler Aquifer, termed a hydrostructural model, that was used to help define flow systems within the aquifer and has been adopted and built upon in this study. The Rustler Aquifer has extensive faulting, some of which completely disconnects the Rustler Aquifer as a geologic formation with hundreds of feet of off lap (fault throw) in some cases. The subdomains described earlier in this report and modified from Ewing and others (2012) were used to help define potential production area boundaries along with other factors that will be discussed below.

Figure 14-1 shows the potential production areas defined in this study for the Rustler Aquifer. The boundaries are defined based upon the criteria provided in Table 14-1. Through definition of potential production areas, excluded zones of the aquifer are naturally defined and have been termed EZ-1 through EZ-6 (Figure 14-1). The factors defining the exclusion zones will be used to define the boundaries of the potential production areas. A total of six potential production areas were originally defined and termed PPA-1 through PPA-6. PPA-6, not shown in Figure 14-1, was located in the far north portion of EZ-2. Based upon stakeholder input, PPA-6 was taken out of consideration because we believe hydraulic isolation cannot be demonstrated and because of the proximity of Diamond-Y Springs located just north of Fort Stockton.

In some cases, a potential production area boundary is defined based upon the concept that distance from a potential brackish well field can act as a hydraulic barrier between the brackish zone and the excluded area. This type of isolation will be termed a distance isolation boundary, and they are somewhat arbitrary in nature because the definition of "significant impact" to fresh water availability or quality is not determined in this study. The TWDB will use this study, additional data they may have, and stakeholder input to define brackish groundwater production zones. Each of the potential production areas in Figure 14-1 will be described below, as they are defined by their boundaries to adjacent exclusion zones. Table 14-2 lists the House Bill 30 criteria which were used to designate each of the exclusion zones.

EZ-1 is in the farthest western portion of the Rustler Aquifer, including the TWDB-identified outcrop for the aquifer (see Figure 14-2). EZ-1 was partially defined based upon groundwater samples measuring total dissolved solids less than 1,000 milligrams per liter in the far southwestern portion of the aquifer. This is the only portion of the aquifer where we have data supporting total dissolved solids measurements less than 1,000 milligrams per liter. The remainder of Exclusion Zone 1 is based upon the presence of several stock and domestic wells, which are a protected class in House Bill 30 (see Figure 14-2). The western boundary of EZ-1 is defined by the western edge of the Rustler Aquifer outcrop. The eastern boundary is generally coincident with the hydrostructural subdomain 9 boundary of Ewing and others (2012; Figure 4.6.6) south to the Pecos River, where the boundary is defined by the presence of protected class wells. The northern boundary is the Texas-New Mexico State Line. EZ-1 is adjacent to PPA-1 and PPA-2, which will be described below.

EZ-2 (see Figure 14-3) is within hydrostructural subdomain 4 and is defined on the west by the boundary between hydrostructural subdomain 4 and 7 and in the south by the boundary between hydrostructural subdomain 4 and 5. The eastern boundary of EZ-2 is defined by the boundaries of the Rustler Aquifer as defined by the TWDB. From Table 14-2, one can see that EZ-2 is based upon significant use by protected classes of use (wells) which are shown in Figure 14-3. EZ-2 shares a boundary with PPA-3 and PPA-4.

EZ-3 (see Figure 14-4) is within hydrostructural subdomain 7 and PPA-3. Its boundaries are defined on the west by the boundary between hydrostructural subdomain 7 and 9, and all other boundaries are set as hydraulic distance boundaries meant to prevent significant impact from occurring in EZ-3. EZ-3 is based upon significant use by protected classes of use (wells), which are shown in Figure 14-4. EZ-3 is within PPA-3 and shares a structurally defined boundary with PPA-1 to the west.

EZ-4 (see Figure 14-5) is within hydrostructural subdomain 5. Its boundaries are structurally defined to the east by a fault, to the west by the approximate boundary between a collapsed Rustler-Aquifer section to the west and a complete Rustler- Aquifer member section to the east. The northern boundary is the boundary between hydrostructural subdomains 5, 7 and 4. The remaining boundary is defined by the extent of the Rustler Aquifer as defined by the TWDB. EZ-4 is based upon the presence of a Texas Water Code, Title 2, Subtitle D, Chapter 27 wastewater injection well associated with the Oates oil and gas field. EZ-4 shares structurally-controlled boundaries with PPA-3, PPA-4 and PPA-5.

EZ-5 (see Figure 14-6) has boundaries that are defined as hydraulic distance boundaries meant to prevent significant impact from occurring in EZ-5 from pumping in adjacent PPA-2 and PPA-1. EZ-5 is based upon significant use by protected classes of use (wells) which are shown in Figure 14-6 and are dominantly irrigation wells.

EZ-6 (see Figure 14-7) has boundaries that are defined as hydraulic distance boundaries meant to prevent significant impact from occurring in EZ-6 from pumping in surrounding PPA-1. EZ-6 is also based upon significant use by protected classes of use (wells), which are shown in Figure 14-7 and include two known irrigation wells.

Table 14-3 provides a summary of the characteristics of the five potential production areas defined in the Rustler Aquifer. The potential production areas have largely been described in the discussion of the Exclusion Zones above. However, we will define the nature of the hydraulic isolation that has been used to justify the potential production area boundaries. For most of the potential production areas, the Rustler Aquifer is hydraulically isolated from above by the very low permeability Dewey Lake Red Beds and below by the even lower permeability Salado Formation. In PPA-4 and PPA-5, the Rustler could be transitioning into a facies equivalent (the Tessey Limestone) and may directly overlie the Capitan Limestone.

In PPA-1, the horizontal isolation is a combination of structural boundaries and distance boundaries from exclusion zones (EZ-6 and EZ-5). In PPA-2, horizontal isolation is a combination of distance boundaries from exclusion zones (EZ-5 and EZ-1) and the limits of the aquifer as defined by the TWDB and structural boundaries. PPA-3 boundaries are almost all based upon structural displacement of the Rustler Aquifer across faults or fault systems. The other type of boundary for PPA-3 is a hydraulic distance boundary for EZ-3. PPA-4 horizontal isolation comes from structural displacement boundaries and the limits of the aquifer as defined by the TWDB. Similarly, PPA-5 horizontal isolation comes from structural displacement boundaries and the limits of the aquifer as defined by the TWDB.

14.2 Modeling methodology and results

The primary modeling objective is to provide the TWDB with sufficient modeling results to adequately address House Bill 30 requirements to determine the amount of brackish groundwater that a potential production area is capable of producing over a 30-year period and a 50-year period without causing a significant impact to water availability.

14.2.1 Modeling and sensitivity methodology

The approach is based upon six primary features: the modeling tool used; the well field assumptions which includes completion, location, number of wells and production rates; the metrics used to assess potential impacts; and the sensitivity methodology. Table 14-4 provides an overview of these key features defining the modeling approach used to predict potential impacts. Each of these will be described below.

Based on the complexity of the Rustler Aquifer and the limited time frame and budget available for model development activities, the Rustler Groundwater Availability Model (Ewing and others (2012) is the tool used to make calculations regarding potential impacts. Because of the scoping nature of this project and through consultation with TWDB on modeling approach, it was not considered necessary to refine the model grid below the current 1/4-mile grid scale. The version of the Rustler GAM used was the original version delivered to the TWDB. An alternative model was provided in the sensitivity analysis reported by Ewing and others (2012) which added additional pumping to three wells located in hydrostructural subdomains 7. Because only pumping differ between these models and the superposition approach used to estimate impacts described below, the difference between these versions of the Groundwater Availability Model do not impact results.

The Rustler Groundwater Availability Model limitations (Ewing and others, 2012) state that there are large areas of the aquifer domain that are lacking fundamental data for calibration. This is not surprising because, in most of the region where the Rustler Aquifer exists, it would generally be the deepest aquifer of interest because more prolific and shallower aquifers exist. The bottom line is that there is a great deal of uncertainty in the predictive accuracy of the Groundwater Availability Model or any other tools for predicting regional availability of groundwater regionally in the Rustler Aquifer. To address this uncertainty, a sensitivity analysis is used.

Figure 14-8 plots the well field locations used to assess potential production and potential impacts for the five potential production areas. Table 14-5 provides a summary of the number of well fields per potential production area with a total number of 11. There is no unique way to locate the well fields, and the number of well fields modeled is somewhat constrained by number of model runs practical, which will be discussed in more detail below. Because this study is meant to provide insight into the potential for production, we adopted an approach that is based upon having at least one well field in each potential production area and not having a well field density below one per 400 square miles. The modeled hydraulic conductivity in the Rustler Aquifer Groundwater Availability Model is very heterogeneous. Therefore, for larger potential production areas, we include a larger number of well fields to attempt to sample the potential range in properties and productivity in a given potential production area. By performing a sensitivity analysis, the potential range of results is expanded. For most of its extent, the Rustler is a low to moderately yielding aquifer. The highest known producing regions are in Exclusion Zones. Therefore, it is assumed that each well field is composed of nine wells in a linear array approximately 1,250 feet apart. We also ran the results for a three-well linear array to see how total production was impacted, as the economics on a per well basis may be more attractive. Wells are assumed to be completed across the entire Rustler Aquifer, which would effectively be connecting the more transmissive portions of the aquifer, which are the Magenta and Culebra Dolomites and limestones of the Los Medaños Unit.

Developing appropriate flow rates for each well field in each potential production area is very difficult *a priori* because transmissivity is quite variable based upon on limited field data and a lack of data in entire potential production areas (Ewing and others, 2012). Instead of taking the usual approach and specifying a rate at each well, we used the MODFLOW Drain package to determine how much water could be removed under the constraint of a 50 percent reduction in available drawdown (measured from the top of the Rustler Aquifer) at the well field. The resulting volume of water removed by the Drain package was then averaged over the predictive period and applied to each simulated well in a second predictive simulation. We then verified that this pumping rate achieved the specified 50 percent reduction in available drawdown.

The metrics used to quantify the potential impacts of potential production area well field development are based upon drawdown from a baseline condition. The sensitivity approach used to assess potential impacts and underlying uncertainty in model parameterization is a standard one-off methodology where each parameter considered uncertain is changed sequentially and model results are relative to the calibrated base case model. Hydraulic parameters considered in the sensitivity analysis include:

- Horizontal hydraulic conductivity,
- Vertical hydraulic conductivity,
- Specific Storage, and
- Fault hydraulic characteristic.

The parameter ranges used were determined on a potential production area basis based upon the qualitative degree of uncertainty considered for that parameter in that potential production area constrained by practical maximum flow rates under the 50 percent of available drawdown well-head constraint. Table 14-6 lists the factors by which each sensitivity parameter is changed for the 12 sensitivity scenarios considered. Scenario 1 is the base case simulation using calibrated Groundwater Availability Model hydraulic parameter values model wide. Scenarios 2 through 4 vary horizontal hydraulic conductivity. Scenarios 5 and 6 vary vertical hydraulic conductivity. Scenarios 7 and 8 vary specific storage and Scenarios 9 through 12 vary fault hydraulic characteristic of the MODFLOW Horizontal Flow Barrier package. Table 14-7 lists the parameter values for each sensitivity parameter for the 11 sensitivity scenarios considered.

For Scenario 1, all parameters were held at calibrated base-case values, and each well field was sequentially simulated. Scenario 1 is represented by 11 predictive simulations; one for each well field. For scenarios 2 through 12, one parameter was modified from base case, and model sensitivity simulations were performed for each potential production area and well field. Because we performed the calculations in a superposition framework, each scenario required many individual model runs. First, a model run was made in which the properties were varied, but no production occurred at any of the well fields. The water level at the end of this run became the baseline against which water levels at the end of subsequent runs were compared to calculate drawdown. Two model runs were then performed for each well field, one using the MODFLOW Drain package and one using the MODFLOW Well package as described above. By taking the difference between the two simulations, the impact of the parameter change on aquifer conditions can be assessed. Running predictive simulations for Scenarios 2 through 12 requires

242 simulations. In total, the sensitivity analysis for one-well field layout design at all locations for all parameters requires 253 predictive simulations.

The pumping rate for each simulation is based upon a head constraint defined as 50 percent of the available drawdown (defined as the simulated Rustler Aquifer groundwater elevation at the end of 2008 minus the top elevation of the Rustler Aquifer). The Rustler Aquifer Groundwater Availability Model is calibrated through 2008. For any simulation, only one well field is pumping at a time.

14.3 PPA pumping analysis and results for 30 and 50 years

The series of predictive scenarios described above were developed to evaluate the potential of the Rustler Aquifer to serve as a water source within the potential production areas. This process acknowledges and seeks to account for uncertainty in the aquifer properties that most influence the potential for production, including horizontal hydraulic conductivity, vertical hydraulic conductivity, specific storage, and the hydraulic characteristics of the faults within the Rustler Aquifer.

Table 14-9 shows the pumping rate in each well field for each of the 12 sensitivity scenarios. Scenario 1 is the base case in which all hydraulic properties are unchanged from the calibrated groundwater availability model. The pumping rate that achieves a depletion of 50 percent of the available drawdown in Scenario 1 ranges from 4.8 gallons per minute (total across 9 wells) for well field 1-1 in PPA-1 to 490 gallons per minute for well field 5-1 in PPA-5. The wide range is due to differences in hydraulic properties, which are shown in Table 14-7. The sensitivity of the results to changes in these properties over a reasonable range are shown in subsequent scenarios.

In Scenario 2 in Table 14-9, no pumping rate is provided for PPAs 1 through 3, as the horizontal hydraulic conductivity in these areas is not likely to be much lower than the calibrated value in the Groundwater Availability Model. In PPAs 4 and 5, the 80 percent decrease in horizontal hydraulic conductivity (i.e., a factor of 0.2) decreased the amount of pumping that could occur to achieve 50 percent of available drawdown to 127 and 166 gallons per minute, respectively.

The volume of pumping that the aquifer can support is strongly influenced by the horizontal hydraulic conductivity. This is true for decreases in this parameter (Scenario 2) and increases (Scenarios 3 and 4). For Scenario 3 in Table 14-9, PPA-1 and PPA-2 had substantial gains in productivity relative to the baseline Scenario 1, though a productivity of less than 100 gallons per minute for a nine well field is still unlikely to be economical. PPAs 3 through 5 could support pumping of approximately 350 to 690 gallons per minute for a nine well field for this scenario.

For Scenario 4, the horizontal hydraulic conductivity was increased between 10 and 100 times higher than the baseline value in PPAs 1 through 3. If these substantial increases over the baseline/calibrated values in the Groundwater Availability Model reflect actual aquifer conditions, the aquifer could support approximately 200 to 300 gallons per minute at each well field in PPAs 1 and 2 and over 500 gallons per minute in PPA 3. PPAs 4 and 5 were not evaluated in Scenario 4, as it was not considered reasonable to increase the horizontal hydraulic conductivity above the values in Scenario 3 for these areas.

Scenarios 4 through 12 in Table 14-9 reflect the sensitivity of the pumping the aquifer can support to changes in vertical hydraulic conductivity, specific storage, and fault hydraulic characteristics. These parameters have much less influence on the pumping results than horizontal hydraulic conductivity.

Table 14-10 shows the maximum drawdown at an existing excluded well for each scenario due to pumping at each well field after 30 and 50 years. In general, impacts at existing wells are quite low outside of PPA-5 (high pumping and small area) and Scenario 4 (high pumping). This is largely due to two factors. First, many of the well fields can support modest levels of pumping, so regional drawdowns are limited. Second, by design, the PPAs are delineated to be a substantial distance or have some other hydrologic barrier insulating them from impacting most protected class existing wells within exclusion zones.

Table 14-11 shows the location of the well identified in Table 14-10. Note that, in two cases the protected well with maximum drawdown was not located within a PPA. The first case is if the well is in New Mexico where it is denoted "NM" in the table. The second case is isolated to PPA-3. During report write-up it was determined that a stock well has been included in PPA-3. This well is located in the far southeastern corner of PPA-3 next to EZ-2 and EZ-4 (see Figure 14-1). This presence of this well in PPA-3 is an error while impacts to it are de minimis. Therefore, if the TWDB decides to keep PPA-3 as a Brackish Production Zone, we would recommend that the southeastern boundary of PPA-3 be pulled away to not include the stock well. As a result of this mistake in including a stock well within PPA-3, one will note that maximum drawdown at a protected well can occur within PPA-3 from pumping at PPA-3 well field 2.

In some cases, no drawdown was observed at a protected well. In some cases, a very small drawdown is observed in a well at 30 years (less than 0.01 feet) and then no drawdown is observed in any protected well at 50 years. This is because we did not set a drawdown threshold for reporting, and some of the drawdowns observed are below the numerical precision of the MODFLOW solver.

Tables 14-12 and 14-13 are similar to the tables described above, except they show the maximum drawdown and its location at an exclusion zone boundary. As with the protected well impacts tables, drawdowns are minimal outside of PPAs 4 and 5 and Scenario 4 due to relatively limited pumping.

Tables 14-14 through 14-17 show the drawdown results and accompanying locations at existing protected wells and exclusion zone boundaries for a separate set of model simulations from those presented previously. In these simulations, the hydraulic properties for each scenario were adjusted as before, but the pumping rate was held constant at the rates in Scenario 1. This comparison was done to isolate the degree to which hydraulic properties alone influence drawdown impacts as opposed to the interrelationship between hydraulic property changes and pumping rate changes reflected in Tables 14-10 through 14-13. In general, the drawdown impacts with constant pumping did not vary greatly across the range of sensitivity scenarios, though there was some sensitivity to changes in specific storage. These results indicate that the variation in drawdown impacts in Tables 14-10 through 14-13 are most strongly influenced by the impact that the property change has on the ability of the aquifer to supply water rather than the manner in which the aquifer propagates drawdown impacts to existing wells and exclusion zones.

Tables 14-18 and 14-19 show the pumping results for a third set of simulations. The approach implemented for these scenarios was identical to the first approach described except the well field consists of three wells instead of nine wells. In each scenario as before, the well field pumping achieves a drawdown of 50 percent of the initial available drawdown. We ran this set of runs because the per-well pumping rates in many of the runs described above is often not very large and could lead the reader to question the economics of a potential well field on that basis alone. While the total well field production capacity increases as the number of wells in the field increases, the per-well capacity decreases with each additional well due to the effects of overlapping drawdowns. The pumping rate for each well field and each scenario is shown in Table 14-18. Table 14-19 shows the fraction of the nine-well field pumping rate that is achieved using the three-well field arrangement. The three-well field generally achieves at least half the production of the nine-well field. In the areas with higher hydraulic conductivity (PPAs 4 and 5) the three-well field can produce as much as 70 to 80 percent of the capacity of the nine-well field. This highlights the nature of diminishing returns inherent with adding additional wells to a field.

Figures 14-9 through 14-19 show plots of drawdown for Scenario 3 for each well field. We selected this scenario over the baseline Scenario 1 for displaying drawdowns because it supported higher pumping rates than the baseline in each PPA. This selection does not, however, indicate that it is a more probable scenario. Note that the drawdowns shown are on a log scale. That is, the area with some level of drawdown extends over a large area in many cases, but the magnitude of drawdown is relatively small other than near the well field. Note also the influence of the faults within the Rustler Aquifer. This can be seen in many of the figures (for example, Figure 14-17 for well field 3-2 in PPA 3). Performing pump tests on either side of these barriers with monitoring wells would better quantify this effect.

In order to illustrate the effect of changes in the most sensitive parameter (horizontal hydraulic conductivity), we have also plotted drawdowns for a single well field – well field 3-2 in PPA 3 – for the baseline Scenario 1 and the highest horizontal hydraulic conductivity Scenario 4. These are shown in Figures 14-20 and 14-21.

Table 14-1. House Bill 30 Criteria for designation of potential production areas.

Criteria Type	Criteria for Designation of a Brackish Groundwater Production Zone
Water Quality	Has an average total dissolved solids level of more than 1,000 milligrams per liter.
Hydraulic Isolation	Separated by hydrogeologic barriers sufficient to prevent significant impacts to water availability or water quality in the area of the same or other aquifers, subdivisions of aquifers, or geologic strata that have an average total dissolved solids level of 1,000 milligrams per liter or less at the time of designation of the zone.
Aquifer Use	Is not serving as a significant source of water supply for municipal, domestic, or agricultural purposes at the time of designation of the zone.
Aquifer Use	Is not in an area or geologic stratum that is designated or used for wastewater injection through the use of injection wells or disposal wells permitted under Chapter 27.
Regulatory Jurisdiction	Is not located in: an area of the Edwards Aquifer subject to the jurisdiction of the Edwards Aquifer Authority; the boundaries of the: (a) Barton Springs-Edwards Aquifer Conservation District; (b) Harris-Galveston Subsidence District; or (c) Fort Bend Subsidence District.

Table 14-2. House Bill 30 criteria used for designation of Exclusion Zones.

Exclusion Zone Number	Average Total Dissolved Solids Less than or Equal to 1,000 milligrams per liter	Significant Protected Use *and Limited Alternatives*	Chapter 27 Injection Wells
1	Yes	Yes	NA
2	NA	Yes	NA
3	NA	Yes	NA
4	NA	NA	Yes
5	NA	Yes	NA
6	NA	Yes	NA

Table 14-3. Characteristics of the Rustler potential production areas.

Potential Production Area Number	Counties	Aquifer Members	Brackish Groundwater Type	Hydrogeologic Barriers
1	Reeves Ward	Magenta Culebra Los Medaños	slightly and moderately saline	Structural and hydraulic distance boundaries Dewey Lake Formation above and Salado Formation below
2	Loving Ward	Magenta Culebra Los Medaños	moderately to very saline	Structural and hydraulic distance boundaries Dewey Lake Formation above and Salado Formation below
3	Reeves Pecos	Magenta Culebra Los Medaños	mostly moderately saline	Structural and hydraulic distance boundaries Dewey Lake Formation above and Salado Formation below
4	Reeves Pecos Brewster Jeff Davis	Collapsed Rustler Aquifer	mostly slightly saline	Structural boundaries Dewey Lake Formation above and Salado Formation below
5	Pecos	Magenta Culebra Los Medaños	mostly slightly saline	Structural boundaries Dewey Lake above and Salado below

Table 14-4. Overview of the main features of modeling approach.

Major Feature of the Modeling Approach	Rationale for the Modeling Approach
Use the Rustler Groundwater Availability Model for Impacts Model	The Rustler Aquifer is immensely complex. Because of the extreme structural features and the lack of identifiable boundaries, we chose to not use analytical methods but rather use the Rustler Groundwater Availability Model. Because the Rustler Groundwater Availability Model was calibrated using effective properties for the more transmissive member units mapped in this study, we used it as it was calibrated under the assumption that inherent uncertainties in properties would be addressed in the sensitivity analysis.
Assume Wells Are Fully Completed in the Rustler Aquifer	Most wells in the Rustler Aquifer are completed across the entire formation, which effectively mixes pumped water and water quality from the three potential transmissive units.
Well Field Design and Approach to Production Rates Analyzed	For most of its extent, the Rustler Aquifer is a low to moderately yielding aquifer. The highest known producing regions are in Exclusion Zones. We have assumed that each well field is composed of nine wells in a linear array approximately 1,250 feet apart. Because transmissivity is quite variable in the Groundwater Availability Model, we use a drawdown constraint of 50 percent of available drawdown to predict well field yield and average well pumping rate.
Location of Well Fields	There was no unique way to come up with a way to locate the well fields. Because this study is meant to provide insight into the potential for production, we adopted an approach that is based upon having at least one well field in each potential production area and not having a well field density below one per 400 square miles.
Metric Used for Impacts is Relative Change in Head from Baseline	Because we are using the Groundwater Availability Model as the modeling tool, any change to model parameters to look at predictive sensitivity results in bringing the model out of calibration and potentially inconsistent with model boundary conditions. As a result, for simulations other than the base case defined by calibrated parameters, results are reported as relative drawdown, not absolute head. This technique allows us to use the Groundwater Availability Model as a superposition model.
Sensitivity Analysis	Because of the uncertainties associated with defining the aquifer properties based on limited field data, a sensitivity analysis was performed. Each sensitivity model simulation involved adjusting one hydraulic property of the Rustler Aquifer at a time.

Table 14-5. Number of well fields per Potential Production Area.

Potential Production Area Number	Number of Well Fields
1	5
2	2
3	2
4	1
5	1
Total number of well fields	11

Table 14-6. Scalar multiplier for parameter sensitivity analyses by sensitivity scenario by potential production area.

	PPA-1		PPA-2		PPA-3		PPA-4		PPA-5	
Scenario	**Variable**	**Multiplier**	**Variable**	**Multiplier**	**Variable**	**Multiplier**	**Variable**	**Multiplier**	**Variable**	**Multiplier**
1	All	1.0	All	1.0	All	1.0	All	1.0	All	1.0
2	NA	NA	NA	NA	NA	NA	Kh	0.2	Kh	0.2
3	Kh	10	Kh	5	Kh	10	Kh	2.0	Kh	2.0
4	Kh	100	Kh	10	Kh	20	NA	NA	NA	NA
5	Kz	0.5	Kz	0.5	Kz	0.5	Kz	0.5	Kz	0.5
6	Kz	5	Kz	5	Kz	5	Kz	5	Kz	5
7	Ss	0.1	Ss	0.1	Ss	0.1	Ss	0.1	Ss	0.1
8	Ss	10	Ss	10	Ss	10	Ss	10	Ss	10
9	FHC	0.01	FHC	0.01	FHC	0.01	FHC	0.01	FHC	0.01
10	FHC	0.1	FHC	0.1	FHC	0.1	FHC	0.1	FHC	0.1
11	FHC	10	FHC	10	FHC	10	FHC	10	FHC	10
12	FHC	100	FHC	100	FHC	100	FHC	100	FHC	100

Note: Kh=horizontal hydraulic conductivity; Kz=vertical hydraulic conductivity; Ss = Specific Storage; FHC = fault hydraulic characteristic, NA = not applicable

Table 14-7. Parameter values for parameter sensitivity analyses by sensitivity scenario by potential production area.

	PPA-1		PPA-2		PPA-3		PPA-4		PPA-5	
Scenario	**Variable**	**Value**	**Variable**	**Value**	**Variable**	**Value**	**Variable**	**Value**	**Variable**	**Value**
1	All	Base	All	Base	All	Base	All	Base	All	Base
2	NA	NA	NA	NA	NA	NA	Kh[(a)]	1.0	Kh[(a)]	1.0
3	Kh[(a)]	0.2	Kh[(a)]	0.8	Kh[(a)]	2.1	Kh[(a)]	9.9	Kh[(a)]	9.9
4	Kh[(a)]	2	Kh[(a)]	1.6	Kh[(a)]	4.2	NA	NA	NA	NA
5	Kz[(a)]	$1x10^{-5}$	Kz[(a)]	$8x10^{-5}$	Kz[(a)]	$1.05x10^{-4}$	Kz[(a)]	$2.47x10^{-3}$	Kz[(a)]	$2.47x10^{-3}$
6	Kz[(a)]	$1x10^{-4}$	Kz[(a)]	$8x10^{-4}$	Kz[(a)]	$1.05x10^{-3}$	Kz[(a)]	$2.47x10^{-2}$	Kz[(a)]	$2.47x10^{-2}$
7	Ss	$1x10^{-7}$	Ss	$1X10^{-7}$; $1x10^{-8}$	Ss	$1x10^{-7}$	Ss	$1x10^{-7}$	Ss	$1x10^{-7}$
8	Ss	$1x10^{-5}$	Ss	$1X10^{-4}$; $1x10^{-5}$	Ss	$1x10^{-5}$	Ss	$1x10^{-5}$	Ss	$1x10^{-5}$
9	FHC	1; 0.10; $1x10^{-11}$	FHC	0.001	FHC	0.00001; 0.01	FHC	1; 0.10; $1x10^{-11}$	FHC	0.00001; 0.01
10	FHC	10; 1.0; $1x10^{-10}$	FHC	0.01	FHC	0.0001; 0.1	FHC	10; 1.0; $1x10^{-10}$	FHC	0.0001; 0.1
11	FHC	1000; 100; $1x10^{-8}$	FHC	1.0	FHC	0.01; 10	FHC	1000; 100; $1x10^{-8}$	FHC	0.01; 10
12	FHC	10000; 1000; $1x10^{-7}$	FHC	10	FHC	0.1; 100	FHC	10000; 1000; $1x10^{-7}$	FHC	0.1; 100

[a] All hydraulic conductivity values are reported median values by PPA

Note: Kh=median horizontal hydraulic conductivity (feet per day); Kz=median vertical hydraulic conductivity (feet per day); Ss = Specific Storage (1/foot); FHC = fault hydraulic characteristic (1/day)

Table 14-8. Summary of steps taken to perform a single sensitivity simulation within a scenario.

Modeling Step	Rationale for the Modeling Approach
Calculate Well Field Flow Rate	Modify the sensitivity parameter to the appropriate sensitivity value and assign drain elevations based upon the criterion of 50% available drawdown from the base case simulation and run simulation for 30 and 50 years into the future (from end of 2008). Post process drain flow rates to calculate pumping at each well.
Perform Sensitivity Predictive Simulation	Modify the sensitivity parameter to the appropriate sensitivity value and assign well field flow rates to each well based on drain outflow in above step. Run the predictive simulation from the end of 2008 for 30 and 50 years.
Verify Results	Compare water level declines from the end of the base case simulation (in which only properties changed) to water level declines in the pumping simulation to verify that drawdown matches 50% of the available drawdown at the end of 2008.
Post-Process Pumping and Drawdown	Evaluate performance metrics of pumping rate, drawdown at the nearest well and drawdown at the nearest exclusion zone boundary at 30 and 50 years.

Table 14-9. Pumping rate by well field (in gallons per minute) and sensitivity scenario. The rate shown represents the total for the nine wells in each well field.

		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12
PPA	**Well Field**	**Base**	**Kh-low**	**Kh-high1**	**Kh-high2**	**Kv-low**	**Kv-high**	**Ss-low**	**Ss-high**	**FHC-low2**	**FHC-low1**	**FHC-high1**	**FHC-high2**
PPA 1	1	-4.8	NA	-26.9	-195.0	-4.3	-5.6	-4.9	-6.1	-4.8	-4.8	-4.8	-4.8
	2	-10.5	NA	-51.1	-297.4	-8.7	-18.6	-9.9	-14.8	-10.5	-10.5	-10.5	-10.5
	3	-8.2	NA	-48.6	-306.6	-7.3	-10.4	-7.7	-11.5	-8.2	-8.2	-8.2	-8.2
	4	-6.5	NA	-36.5	-236.2	-6.0	-8.4	-5.3	-12.3	-6.5	-6.5	-6.5	-6.5
	5	-6.5	NA	-36.8	-217.0	-6.0	-8.6	-5.5	-11.6	-6.5	-6.5	-6.5	-6.5
PPA 2	1	-9.9	NA	-35.0	-63.6	-8.9	-12.2	-9.5	-12.8	-9.9	-9.9	-9.9	-9.9
	2	-46.2	NA	-134.1	-204.7	-44.9	-47.5	-45.5	-55.7	-46.2	-46.2	-46.2	-46.2
PPA 3	1	-73.3	NA	-357.7	-537.9	-72.4	-74.1	-59.9	-123.8	-73.3	-73.3	-73.3	-73.3
	2	-66.2	NA	-354.4	-542.0	-65.0	-67.5	-52.4	-117.6	-66.2	-66.2	-66.1	-66.2
PPA 4	1	-376.8	-127.1	-551.9	NA	-375.4	-378.0	-370.8	-428.9	-376.1	-376.6	-377.0	-377.7
PPA 5	1	-490.5	-166.1	-690.6	NA	-489.5	-491.4	-465.3	-589.6	-484.4	-488.0	-492.0	-492.3

Note: PPA=potential production area; Kh=median horizontal hydraulic conductivity (feet per day); Kv=vertical hydraulic conductivity (feet per day); Ss = Specific Storage (1/foot); FHC = fault hydraulic characteristic (1/day)

Table 14-10. Maximum drawdown at an existing protected well by well field (consisting of 9 wells) and sensitivity scenario in feet.

Time	PPA	Well Field	Scenario 1 Base	Scenario 2 Kh-low	Scenario 3 Kh-high1	Scenario 4 Kh-high2	Scenario 5 Kv-low	Scenario 6 Kv-high	Scenario 7 Ss-low	Scenario 8 Ss-high	Scenario 9 FHC-low2	Scenario 10 FHC-low1	Scenario 11 FHC-high1	Scenario 12 FHC-high2
After 30 Years	PPA 1	1	0.0	NA	0.1	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		2	0.0	NA	0.1	2.6	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
		3	0.0	NA	0.8	11.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		4	0.0	NA	3.1	18.8	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
		5	0.0	NA	0.8	13.9	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
	PPA 2	1	0.0	NA	0.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		2	1.9	NA	6.2	8.1	2.2	1.6	1.9	1.0	1.9	1.9	1.9	1.9
	PPA 3	1	0.6	NA	5.8	9.1	0.6	0.6	3.0	0.0	0.6	0.6	0.6	0.6
		2	0.0	NA	8.3	14.5	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0
	PPA 4	1	2.2	0.2	4.6	NA	2.2	2.2	2.5	0.4	1.9	2.1	2.2	2.2
	PPA 5	1	21.9	6.6	30.2	NA	21.9	21.8	23.1	12.1	22.5	22.1	21.7	21.7
After 50 Years	PPA 1	1	0.0	NA	0.2	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		2	0.0	NA	0.1	2.9	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
		3	0.0	NA	1.1	12.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		4	0.0	NA	4.4	20.8	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
		5	0.0	NA	1.5	15.9	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
	PPA 2	1	0.0	NA	0.3	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		2	1.9	NA	6.3	8.1	2.3	1.6	1.9	1.6	1.9	1.9	1.9	1.9
	PPA 3	1	0.9	NA	6.8	10.4	0.9	0.9	3.2	0.0	0.9	0.9	0.9	0.9
		2	0.2	NA	12.2	19.9	0.2	0.2	1.2	0.0	0.3	0.3	0.1	0.1
	PPA 4	1	2.5	0.2	5.1	NA	2.5	2.4	2.6	0.9	2.2	2.4	2.4	2.4
	PPA 5	1	23.6	7.2	32.3	NA	23.6	23.5	23.2	15.6	24.4	23.8	23.4	23.3

Note: PPA=potential production area; Kh=median horizontal hydraulic conductivity (feet per day); Kv=vertical hydraulic conductivity (feet per day); Ss = Specific Storage (1/foot); FHC = fault hydraulic characteristic (1/day)

Table 14-11. Location of maximum drawdown at an existing protected well by well field (consisting of 9 wells) and sensitivity scenario.

			Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12
Time	**PPA**	**Well**	**Base**	**Kh-low**	**Kh-high1**	**Kh-high2**	**Kv-low**	**Kv-high**	**Ss-low**	**Ss-high**	**FHC-low2**	**FHC-low1**	**FHC-high1**	**FHC-high2**
After 30 Years	PPA 1	1	EZ-1	NA	EZ-1	EZ-1	EZ-1	EZ-1	EZ-1	EZ-3	EZ-1	EZ-1	EZ-1	EZ-1
		2	EZ-3	NA	EZ-5	EZ-5	EZ-3	EZ-3	EZ-5	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3
		3	EZ-1	NA	EZ-6	EZ-6	EZ-1	EZ-1	EZ-1	EZ-3	EZ-1	EZ-1	EZ-1	EZ-1
		4	EZ-6	NA	EZ-6	EZ-6	EZ-6	EZ-3	EZ-6	EZ-3	EZ-6	EZ-6	EZ-6	EZ-6
		5	EZ-3	NA	EZ-6	EZ-6	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3
	PPA 2	1	EZ-5	NA	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-3	EZ-5	EZ-5	EZ-5	EZ-5
		2	EZ-5	NA	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5
	PPA 3	1	EZ-3	NA	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3
		2	PPA-3	NA	PPA-3	PPA-3	PPA-3	PPA-3	EZ-3	EZ-3	PPA-3	PPA-3	PPA-3	PPA-3
	PPA 4	1	EZ-2	EZ-2	EZ-2	NA	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2
	PPA 5	1	EZ-2	EZ-2	EZ-2	NA	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2
After 50 Years	PPA 1	1	EZ-1	NA	EZ-1	EZ-1	EZ-1	EZ-1	EZ-1	EZ-3	EZ-1	EZ-1	EZ-1	EZ-1
		2	EZ-5	NA	EZ-5	EZ-6	EZ-5	NA*	EZ-5	EZ-3	EZ-5	EZ-5	EZ-5	EZ-5
		3	EZ-1	NA	EZ-6	EZ-6	EZ-1	EZ-1	EZ-1	EZ-3	EZ-1	EZ-1	EZ-1	EZ-1
		4	EZ-3	NA	EZ-6	EZ-6	EZ-6	EZ-3	EZ-6	EZ-3	EZ-6	EZ-6	EZ-6	EZ-6
		5	EZ-3	NA	EZ-6	EZ-6	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3
	PPA 2	1	EZ-5	NA	EZ-5	EZ-5	EZ-5	EZ-5	NA*	EZ-3	EZ-5	EZ-5	EZ-5	EZ-5
		2	EZ-5	NA	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5
	PPA 3	1	EZ-3	NA	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3
		2	PPA-3	NA	PPA-3	PPA-3	PPA-3	PPA-3	EZ-3	EZ-3	PPA-3	PPA-3	PPA-3	PPA-3
	PPA 4	1	EZ-2	EZ-2	EZ-2	NA	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2
	PPA 5	1	EZ-2	EZ-2	EZ-2	NA	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2

Note: PPA=potential production area; EZ=Exclusion Zone; Kh=median horizontal hydraulic conductivity (feet per day); Kv=vertical hydraulic conductivity (feet per day); Ss = Specific Storage (1/foot); FHC = fault hydraulic characteristic (1/day); NA=Not Applicable

Table 14-12. Maximum drawdown at an exclusion zone boundary by well field (consisting of 9 wells) and sensitivity scenario in feet.

			Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12
Time	**PPA**	**Well**	**Kh-low**	**Kh-high1**	**Kh-high2**	**Kv-low**	**Kv-high**	**Ss-low**	**Ss-high**	**FHC-low2**	**FHC-low1**	**FHC-high1**	**FHC-high2**
After 30 Years	PPA 1	1	NA	0.9	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		2	NA	1.3	9.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
		3	NA	4.2	19.5	0.3	0.1	0.2	0.0	0.2	0.2	0.2	0.2
		4	NA	17.2	44.0	0.3	0.2	4.5	0.1	0.3	0.3	0.3	0.2
		5	NA	14.0	43.6	0.1	0.1	2.9	0.1	0.1	0.1	0.1	0.1
	PPA 2	1	NA	1.7	3.0	0.3	0.1	0.2	0.0	0.2	0.2	0.2	0.2
		2	NA	9.8	12.1	3.9	3.0	3.4	2.3	3.5	3.5	3.5	3.5
	PPA 3	1	NA	22.0	26.2	5.0	4.9	10.5	0.1	5.0	5.0	4.9	4.8
		2	NA	12.6	18.2	0.7	0.6	3.3	0.0	0.7	0.7	0.7	0.6
	PPA 4	1	2.6	22.4	NA	14.0	13.7	13.7	12.7	13.9	13.9	13.8	13.8
	PPA 5	1	10.6	38.3	NA	28.9	28.8	29.4	21.5	29.4	29.0	28.7	28.7
After 50 Years	PPA 1	1	NA	0.9	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		2	NA	1.3	9.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
		3	NA	4.2	19.6	0.4	0.1	0.2	0.0	0.2	0.2	0.2	0.2
		4	NA	17.5	44.1	0.3	0.2	4.5	0.1	0.3	0.3	0.3	0.2
		5	NA	15.8	45.4	0.3	0.1	2.9	0.1	0.2	0.2	0.2	0.1
	PPA 2	1	NA	1.7	3.0	0.3	0.1	0.2	0.0	0.2	0.2	0.2	0.2
		2	NA	9.8	12.2	3.9	3.0	3.4	2.4	3.5	3.5	3.5	3.5
	PPA 3	1	NA	22.2	26.6	5.0	4.9	10.6	0.1	5.1	5.1	5.0	4.9
		2	NA	12.7	19.8	0.7	0.9	3.4	0.0	0.7	0.9	0.9	0.9
	PPA 4	1	2.6	22.4	NA	14.1	13.7	13.8	12.8	13.9	13.9	13.8	13.8
	PPA 5	1	10.9	38.7	NA	29.3	29.2	29.5	21.6	29.8	29.4	29.1	29.1

Note: PPA=potential production area; Kh=median horizontal hydraulic conductivity (feet per day); Kv=vertical hydraulic conductivity (feet per day); Ss = Specific Storage (1/foot); FHC = fault hydraulic characteristic (1/day)

Table 14-13. Location of maximum drawdown at an exclusion zone boundary by well field (consisting of 9 wells) and sensitivity scenario.

			Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12
Time	**PPA**	**Well**	**Base**	**Kh-low**	**Kh-high1**	**Kh-high2**	**Kv-low**	**Kv-high**	**Ss-low**	**Ss-high**	**FHC-low2**	**FHC-low1**	**FHC-high1**	**FHC-high2**
After 30 Years	PPA 1	1	EZ-1	NA	EZ-1	EZ-1	EZ-1	EZ-1	EZ-1	EZ-3	EZ-1	EZ-1	EZ-1	EZ-1
		2	EZ-5	NA	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-3	EZ-5	EZ-5	EZ-5	EZ-5
		3	EZ-1	NA	EZ-1	EZ-1	EZ-1	EZ-1	EZ-1	EZ-3	EZ-1	EZ-1	EZ-1	EZ-1
		4	EZ-3	NA	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3
		5	EZ-3	NA	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3
	PPA 2	1	EZ-5	NA	NM	NM	NM	EZ-5	EZ-5	EZ-1	EZ-5	EZ-5	EZ-5	EZ-5
		2	EZ-5	NA	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5
	PPA 3	1	EZ-2	NA	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-3	EZ-2	EZ-2	EZ-2	EZ-2
		2	EZ-4	NA	EZ-4	EZ-4	EZ-4	EZ-4	EZ-4	EZ-3	EZ-4	EZ-4	EZ-4	EZ-4
	PPA 4	1	EZ-4	EZ-4	EZ-4	NA	EZ-4	EZ-4	EZ-4	EZ-4	EZ-4	EZ-4	EZ-4	EZ-4
	PPA 5	1	EZ-2	EZ-2	EZ-2	NA	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2
After 50 Years	PPA 1	1	EZ-1	NA	EZ-1	EZ-1	EZ-1	EZ-1	EZ-1	EZ-3	EZ-1	EZ-1	EZ-1	EZ-1
		2	EZ-5	NA	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-3	EZ-5	EZ-5	EZ-5	EZ-5
		3	EZ-1	NA	EZ-1	EZ-1	EZ-1	EZ-1	EZ-1	EZ-3	EZ-1	EZ-1	EZ-1	EZ-1
		4	EZ-3	NA	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3
		5	EZ-3	NA	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3
	PPA 2	1	EZ-5	NA	NM	NM	NM	EZ-5	NM	EZ-1	EZ-5	EZ-5	EZ-5	EZ-5
		2	EZ-5	NA	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5
	PPA 3	1	EZ-2	NA	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-3	EZ-2	EZ-2	EZ-2	EZ-2
		2	EZ-4	NA	EZ-4	EZ-4	EZ-4	EZ-4	EZ-4	EZ-3	EZ-4	EZ-4	EZ-4	EZ-4
	PPA 4	1	EZ-4	EZ-4	EZ-4	NA	EZ-4	EZ-4	EZ-4	EZ-4	EZ-4	EZ-4	EZ-4	EZ-4
	PPA 5	1	EZ-2	EZ-2	EZ-2	NA	EZ-2	EZ-2	EZ-2	EZ-4	EZ-4	EZ-2	EZ-2	EZ-2

Note: PPA=potential production area; EZ=Exclusion Zone; NM=New Mexico; Kh=median horizontal hydraulic conductivity (feet per day); Kv= vertical hydraulic conductivity (feet per day); Ss = Specific Storage (1/foot); FHC = fault hydraulic characteristic (1/day)

Table 14-14. Maximum drawdown at an existing protected well by well field (consisting of 9 wells) and sensitivity scenario in feet. Pumping rate for each scenario was kept constant at the rate shown for Scenario 1 – Base in Table 14-9.

Time	PPA	Well Field	Scenario 1 Base	Scenario 2 Kh-low	Scenario 3 Kh-high1	Scenario 4 Kh-high2	Scenario 5 Kv-low	Scenario 6 Kv-high	Scenario 7 Ss-low	Scenario 8 Ss-high	Scenario 9 FHC-low2	Scenario 10 FHC-low1	Scenario 11 FHC-high1	Scenario 12 FHC-high2
After 30 Years	PPA 1	1	0.0	NA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		2	0.0	NA	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
		3	0.0	NA	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		4	0.0	NA	0.6	0.5	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0
		5	0.0	NA	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	PPA 2	1	0.0	NA	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		2	1.9	NA	2.1	1.8	2.3	1.5	1.9	0.8	1.9	1.9	1.9	1.9
	PPA 3	1	0.6	NA	1.2	1.2	0.6	0.6	3.7	0.0	0.6	0.6	0.6	0.6
		2	0.0	NA	1.6	1.8	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0
	PPA 4	1	2.2	0.5	3.1	NA	2.2	2.2	2.6	0.3	1.9	2.1	2.2	2.2
	PPA 5	1	21.9	19.5	21.4	NA	22.0	21.8	24.4	10.0	22.8	22.2	21.7	21.6
After 50 Years	PPA 1	1	0.0	NA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		2	0.0	NA	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
		3	0.0	NA	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		4	0.0	NA	0.8	0.6	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0
		5	0.0	NA	0.3	0.5	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
	PPA 2	1	0.0	NA	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		2	1.9	NA	2.2	1.8	2.3	1.5	1.9	1.3	1.9	1.9	1.9	1.9
	PPA 3	1	0.9	NA	1.4	1.4	0.9	0.9	4.0	0.0	0.9	0.9	0.9	0.9
		2	0.2	NA	2.3	2.4	0.2	0.2	1.6	0.0	0.3	0.3	0.1	0.1
	PPA 4	1	2.5	0.6	3.5	NA	2.5	2.4	2.6	0.8	2.2	2.4	2.4	2.4
	PPA 5	1	23.6	21.3	22.9	NA	23.7	23.5	24.5	13.0	24.7	24.0	23.3	23.2

Note: PPA=potential production area; Kh=median horizontal hydraulic conductivity (feet per day); Kv= vertical hydraulic conductivity (feet per day); Ss = Specific Storage (1/foot); FHC = fault hydraulic characteristic (1/day)

Table 14-15. Location of maximum drawdown at an existing protected well by well field (consisting of 9 wells) and sensitivity scenario. Pumping rate for each scenario was kept constant at the rate shown for Scenario 1 – Base in Table 14-9

			Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12
Time	**PPA**	**Well**	**Base**	**Kh-low**	**Kh-high1**	**Kh-high2**	**Kv-low**	**Kv-high**	**Ss-low**	**Ss-high**	**FHC-low2**	**FHC-low1**	**FHC-high1**	**FHC-high2**
After 30 Years	PPA 1	1	EZ-1	NA	EZ-1	EZ-1	EZ-1	EZ-1	EZ-1	EZ-3	EZ-1	EZ-1	EZ-1	EZ-1
		2	EZ-3	NA	EZ-5	EZ-5	EZ-1	EZ-3	EZ-5	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3
		3	EZ-1	NA	EZ-6	EZ-6	EZ-1	EZ-1	EZ-1	EZ-3	EZ-1	EZ-1	EZ-1	EZ-1
		4	EZ-6	NA	EZ-6	EZ-6	EZ-6	EZ-3	EZ-6	EZ-3	EZ-6	EZ-6	EZ-6	EZ-6
		5	EZ-3	NA	EZ-6	EZ-6	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3
	PPA 2	1	EZ-5	NA	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-3	EZ-5	EZ-5	EZ-5	EZ-5
		2	EZ-5	NA	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5
	PPA 3	1	EZ-3	NA	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3
		2	PPA-3	NA	PPA-3	PPA-3	PPA-3	PPA-3	EZ-3	EZ-3	PPA-3	PPA-3	PPA-3	PPA-3
	PPA 4	1	EZ-2	EZ-2	EZ-2	NA	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2
	PPA 5	1	EZ-2	EZ-2	EZ-2	NA	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2
After 50 Years	PPA 1	1	EZ-1	NA	EZ-1	EZ-1	EZ-1	EZ-1	EZ-1	EZ-3	EZ-1	EZ-1	EZ-1	EZ-1
		2	EZ-5	NA	EZ-5	EZ-6	EZ-5	EZ-3	EZ-5	EZ-3	EZ-5	EZ-5	EZ-5	EZ-5
		3	EZ-1	NA	EZ-6	EZ-6	EZ-1	EZ-1	EZ-1	EZ-3	EZ-1	EZ-1	EZ-1	EZ-1
		4	EZ-3	NA	EZ-6	EZ-6	EZ-6	EZ-3	EZ-6	EZ-3	EZ-6	EZ-6	EZ-6	EZ-6
		5	EZ-3	NA	EZ-6	EZ-6	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3
	PPA 2	1	EZ-5	NA	EZ-5	EZ-5	EZ-5	EZ-5	EZ-3	EZ-3	EZ-5	EZ-5	EZ-5	EZ-5
		2	EZ-5	NA	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5
	PPA 3	1	EZ-3	NA	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3
		2	PPA-3	NA	PPA-3	PPA-3	PPA-3	PPA-3	EZ-3	NA	PPA-3	PPA-3	PPA-3	PPA-3
	PPA 4	1	EZ-2	EZ-2	EZ-2	NA	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2
	PPA 5	1	EZ-2	EZ-2	EZ-2	NA	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2

Note: PPA=potential production area; EZ=Exclusion Zone; Kh=median horizontal hydraulic conductivity (feet per day); Kv= vertical hydraulic conductivity (feet per day); Ss = Specific Storage (1/foot); FHC = fault hydraulic characteristic (1/day)

Table 14-16. Maximum drawdown at an exclusion zone boundary by well field (consisting of 9 wells) and sensitivity scenario in feet. Pumping rate for each scenario was kept constant at the rate shown for Scenario 1 – Base in Table 14-9

Time	PPA	Well Field	Scenario 1 Base	Scenario 2 Kh-low	Scenario 3 Kh-high1	Scenario 4 Kh-high2	Scenario 5 Kv-low	Scenario 6 Kv-high	Scenario 7 Ss-low	Scenario 8 Ss-high	Scenario 9 FHC-low2	Scenario 10 FHC-low1	Scenario 11 FHC-high1	Scenario 12 FHC-high2
After 30 Years	PPA 1	1	0.0	NA	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		2	0.0	NA	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		3	0.2	NA	0.7	0.5	0.4	0.0	0.2	0.0	0.2	0.2	0.2	0.2
		4	0.3	NA	3.1	1.2	0.3	0.1	5.5	0.0	0.3	0.3	0.3	0.2
		5	0.1	NA	2.5	1.3	0.1	0.1	3.4	0.0	0.1	0.1	0.1	0.1
	PPA 2	1	0.2	NA	0.5	0.5	0.3	0.1	0.2	0.0	0.2	0.2	0.2	0.2
		2	3.5	NA	3.4	2.7	4.0	2.9	3.5	1.9	3.5	3.5	3.5	3.5
	PPA 3	1	5.0	NA	4.5	3.6	5.1	4.8	12.8	0.1	5.0	5.0	4.9	4.8
		2	0.7	NA	2.4	2.2	0.7	0.6	4.2	0.0	0.7	0.7	0.7	0.6
	PPA 4	1	13.8	7.6	15.3	NA	14.0	13.7	14.0	11.2	14.0	13.9	13.8	13.7
	PPA 5	1	28.8	31.2	27.2	NA	28.9	28.7	31.0	17.9	29.8	29.2	28.6	28.6
After 50 Years	PPA 1	1	0.0	NA	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		2	0.0	NA	0.3	0.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
		3	0.2	NA	0.7	0.5	0.4	0.0	0.2	0.0	0.2	0.2	0.2	0.2
		4	0.3	NA	3.1	1.2	0.3	0.2	5.5	0.0	0.3	0.3	0.3	0.2
		5	0.2	NA	2.8	1.4	0.3	0.1	3.5	0.0	0.2	0.2	0.2	0.1
	PPA 2	1	0.2	NA	0.5	0.5	0.3	0.1	0.2	0.0	0.2	0.2	0.2	0.2
		2	3.5	NA	3.4	2.8	4.0	2.9	3.5	2.0	3.5	3.5	3.5	3.5
	PPA 3	1	5.0	NA	4.5	3.6	5.1	4.8	12.9	0.1	5.1	5.1	5.0	4.9
		2	0.9	NA	2.4	2.4	0.7	0.8	4.3	0.0	0.9	0.7	0.9	0.9
	PPA 4	1	13.8	7.7	15.3	NA	14.1	13.7	14.0	11.2	13.9	14.0	13.8	13.7
	PPA 5	1	29.2	32.1	27.5	NA	29.3	29.1	31.1	18.0	29.6	30.2	29.0	29.0

Note: PPA=potential production area; Kh=median horizontal hydraulic conductivity (feet per day); Kv= vertical hydraulic conductivity (feet per day); Ss = Specific Storage (1/foot); FHC = fault hydraulic characteristic (1/day)

Table 14-17. Location of maximum drawdown at an exclusion zone boundary by well field (consisting of 9 wells) and sensitivity scenario. Pumping rate for each scenario was kept constant at the rate shown for Scenario 1 – Base in Table 14-9.

Time	PPA	Well	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12
			Base	**Kh-low**	**Kh-high1**	**Kh-high2**	**Kv-low**	**Kv-high**	**Ss-low**	**Ss-high**	**FHC-low2**	**FHC-low1**	**FHC-high1**	**FHC-high2**
After 30 Years	PPA 1	1	EZ-1	NA	EZ-1	EZ-1	EZ-1	EZ-1	EZ-1	EZ-3	EZ-1	EZ-1	EZ-1	EZ-1
		2	EZ-5	NA	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-3	EZ-5	EZ-5	EZ-5	EZ-5
		3	EZ-1	NA	EZ-1	EZ-1	EZ-1	EZ-1	EZ-1	EZ-3	EZ-1	EZ-1	EZ-1	EZ-1
		4	EZ-3	NA	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3
		5	EZ-3	NA	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3
	PPA 2	1	EZ-5	NA	NM	NM	NM	EZ-5	EZ-5	EZ-1	EZ-5	EZ-5	EZ-5	EZ-5
		2	EZ-5	NA	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5
	PPA 3	1	EZ-2	NA	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-3	EZ-2	EZ-2	EZ-2	EZ-2
		2	EZ-4	NA	EZ-4	EZ-4	EZ-4	EZ-4	EZ-4	EZ-3	EZ-4	EZ-4	EZ-4	EZ-4
	PPA 4	1	EZ-4	EZ-4	EZ-4	NA	EZ-4	EZ-4	EZ-4	EZ-4	EZ-4	EZ-4	EZ-4	EZ-4
	PPA 5	1	EZ-2	EZ-2	EZ-2	NA	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2
After 50 Years	PPA 1	1	EZ-1	NA	EZ-1	EZ-1	EZ-1	EZ-1	EZ-1	EZ-3	EZ-1	EZ-1	EZ-1	EZ-1
		2	EZ-5	NA	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-3	EZ-5	EZ-5	EZ-5	EZ-5
		3	EZ-1	NA	EZ-1	EZ-1	EZ-1	EZ-1	EZ-1	EZ-3	EZ-1	EZ-1	EZ-1	EZ-1
		4	EZ-3	NA	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3
		5	EZ-3	NA	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3	EZ-3
	PPA 2	1	EZ-5	NA	NM	NM	NM	EZ-5	NM	EZ-1	EZ-5	EZ-5	EZ-5	EZ-5
		2	EZ-5	NA	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5	EZ-5
	PPA 3	1	EZ-2	NA	EZ-2	EZ-2	EZ-2	EZ-2	EZ-2	EZ-3	EZ-2	EZ-2	EZ-2	EZ-2
		2	EZ-4	NA	EZ-4	EZ-4	EZ-4	EZ-4	EZ-4	EZ-3	EZ-4	EZ-4	EZ-4	EZ-4
	PPA 4	1	EZ-4	EZ-4	EZ-4	NA	EZ-4	EZ-4	EZ-4	EZ-4	EZ-4	EZ-4	EZ-4	EZ-4
	PPA 5	1	EZ-2	EZ-2	EZ-2	NA	EZ-2	EZ-2	EZ-2	EZ-4	EZ-4	EZ-2	EZ-2	EZ-2

Note: PPA=potential production area; EZ=Exclusion Zone; NM=New Mexico; Kh=median horizontal hydraulic conductivity (feet per day); Kv= vertical hydraulic conductivity (feet per day); Ss = Specific Storage (1/foot); FHC = fault hydraulic characteristic (1/day)

Table 14-18. Pumping rate by well field (in gallons per minute) and sensitivity scenario. The rate shown represents the total for the three wells in each well field.

		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12
PPA	**Well Field**	**Base**	**Kh-low**	**Kh-high1**	**Kh-high2**	**Kv-low**	**Kv-high**	**Ss-low**	**Ss-high**	**FHC-low2**	**FHC-low1**	**FHC-high1**	**FHC-high2**
PPA 1	1	-4.8	NA	-26.9	-195.0	-4.3	-5.6	-4.9	-6.1	-4.8	-4.8	-4.8	-4.8
	2	-10.5	NA	-51.1	-297.4	-8.7	-18.6	-9.9	-14.8	-10.5	-10.5	-10.5	-10.5
	3	-8.2	NA	-48.6	-306.6	-7.3	-10.4	-7.7	-11.5	-8.2	-8.2	-8.2	-8.2
	4	-6.5	NA	-36.5	-236.2	-6.0	-8.4	-5.3	-12.3	-6.5	-6.5	-6.5	-6.5
	5	-6.5	NA	-36.8	-217.0	-6.0	-8.6	-5.5	-11.6	-6.5	-6.5	-6.5	-6.5
PPA 2	1	-9.9	NA	-35.0	-63.6	-8.9	-12.2	-9.5	-12.8	-9.9	-9.9	-9.9	-9.9
	2	-46.2	NA	-134.1	-204.7	-44.9	-47.5	-45.5	-55.7	-46.2	-46.2	-46.2	-46.2
PPA 3	1	-73.3	NA	-357.7	-537.9	-72.4	-74.1	-59.9	-123.8	-73.3	-73.3	-73.3	-73.3
	2	-66.2	NA	-354.4	-542.0	-65.0	-67.5	-52.4	-117.6	-66.2	-66.2	-66.1	-66.2
PPA 4	1	-376.8	-127.1	-551.9	NA	-375.4	-378.0	-370.8	-428.9	-376.1	-376.6	-377.0	-377.7
PPA 5	1	-490.5	-166.1	-690.6	NA	-489.5	-491.4	-465.3	-589.6	-484.4	-488.0	-492.0	-492.3

Note: PPA=potential production area; Kh=median horizontal hydraulic conductivity (feet per day); Kv=vertical hydraulic conductivity (feet per day); Ss = Specific Storage (1/foot); FHC = fault hydraulic characteristic (1/day)

Table 14-19. Fraction of nine-well field pumping rate achieved with three-well field.

		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12
PPA	**Well Field**	**Base**	**Kh-low**	**Kh-high1**	**Kh-high2**	**Kv-low**	**Kv-high**	**Ss-low**	**Ss-high**	**FHC-low2**	**FHC-low1**	**FHC-high1**	**FHC-high2**
PPA 1	1	0.48	NA	0.58	0.64	0.50	0.47	0.48	0.47	0.48	0.48	0.48	0.48
	2	0.38	NA	0.58	0.72	0.44	0.26	0.39	0.38	0.38	0.38	0.38	0.38
	3	0.54	NA	0.63	0.73	0.55	0.50	0.54	0.49	0.54	0.54	0.54	0.54
	4	0.58	NA	0.69	0.77	0.60	0.53	0.62	0.48	0.58	0.58	0.58	0.58
	5	0.54	NA	0.66	0.77	0.56	0.50	0.57	0.45	0.54	0.54	0.54	0.54
PPA 2	1	0.57	NA	0.63	0.65	0.59	0.54	0.58	0.53	0.57	0.57	0.57	0.57
	2	0.70	NA	0.80	0.83	0.71	0.69	0.70	0.66	0.70	0.70	0.70	0.70
PPA 3	1	0.64	NA	0.78	0.82	0.64	0.64	0.68	0.53	0.64	0.64	0.64	0.64
	2	0.65	NA	0.77	0.82	0.65	0.64	0.69	0.53	0.65	0.65	0.65	0.65
PPA 4	1	0.79	0.69	0.84	NA	0.79	0.79	0.79	0.77	0.79	0.79	0.79	0.79
PPA 5	1	0.72	0.61	0.78	NA	0.72	0.72	0.73	0.68	0.72	0.72	0.72	0.72

Note: PPA=potential production area; Kh=median horizontal hydraulic conductivity (feet per day); Kv= vertical hydraulic conductivity (feet per day); Ss = Specific Storage (1/foot); FHC = fault hydraulic characteristic (1/day)

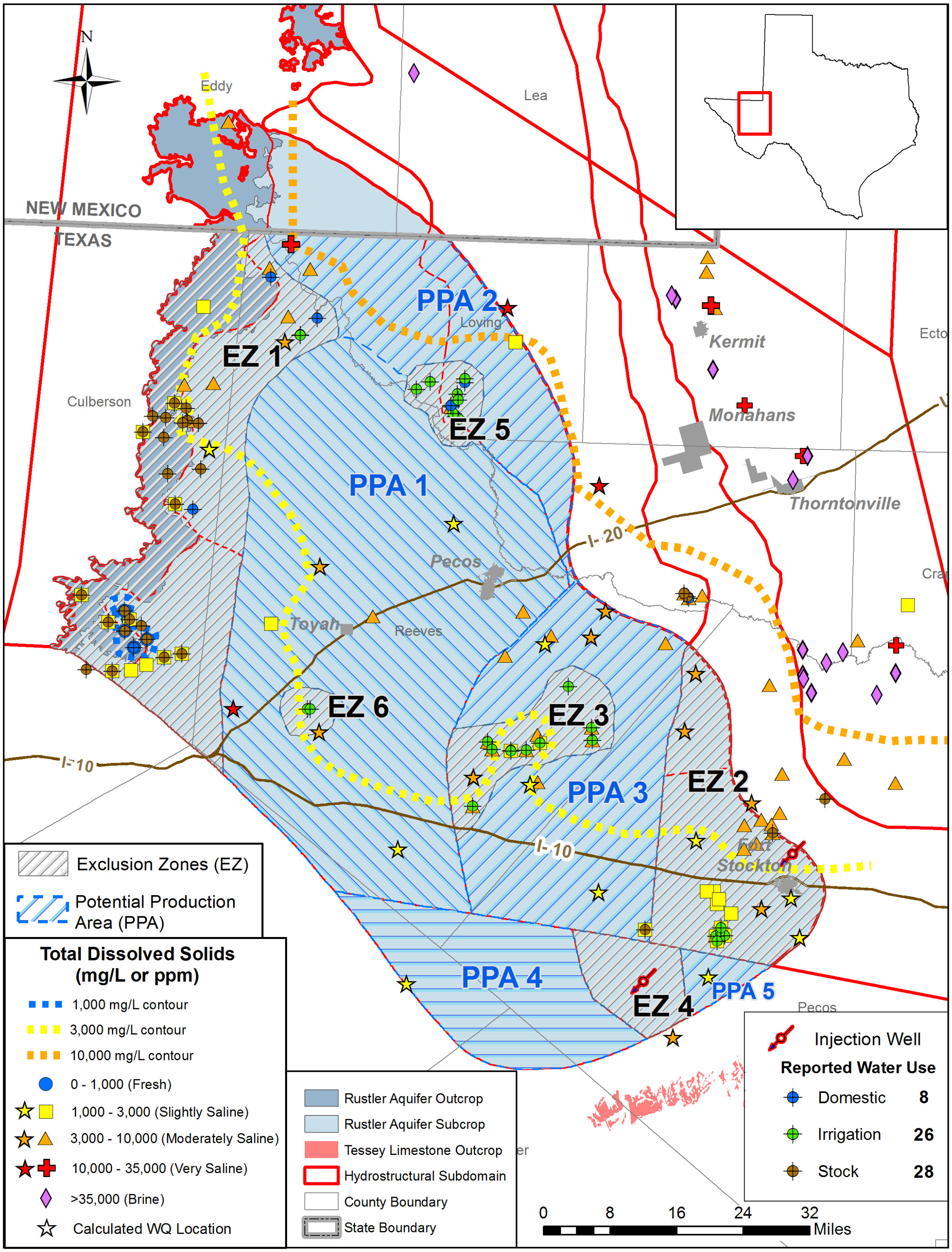

Figure 14-1. Map showing the distribution of Exclusion Zones and potential production areas with water quality data and protected class well locations and usage.

Note: mg/L=milligrams per liter; ppm=parts per million.

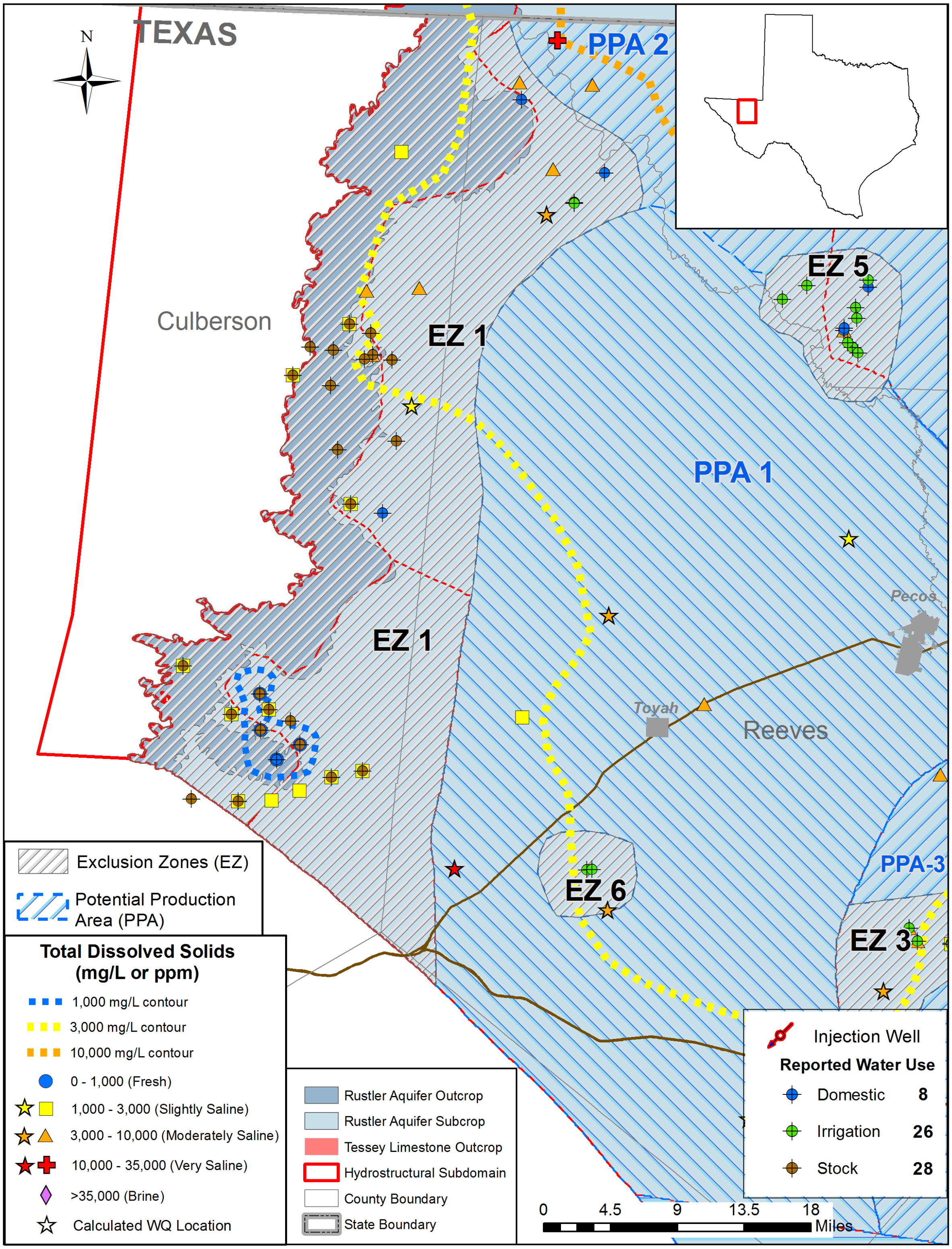

Figure 14-2. Exclusion Zone 1 with water quality data and protected class well locations and usage.

Note: mg/L=milligrams per liter; ppm=parts per million.

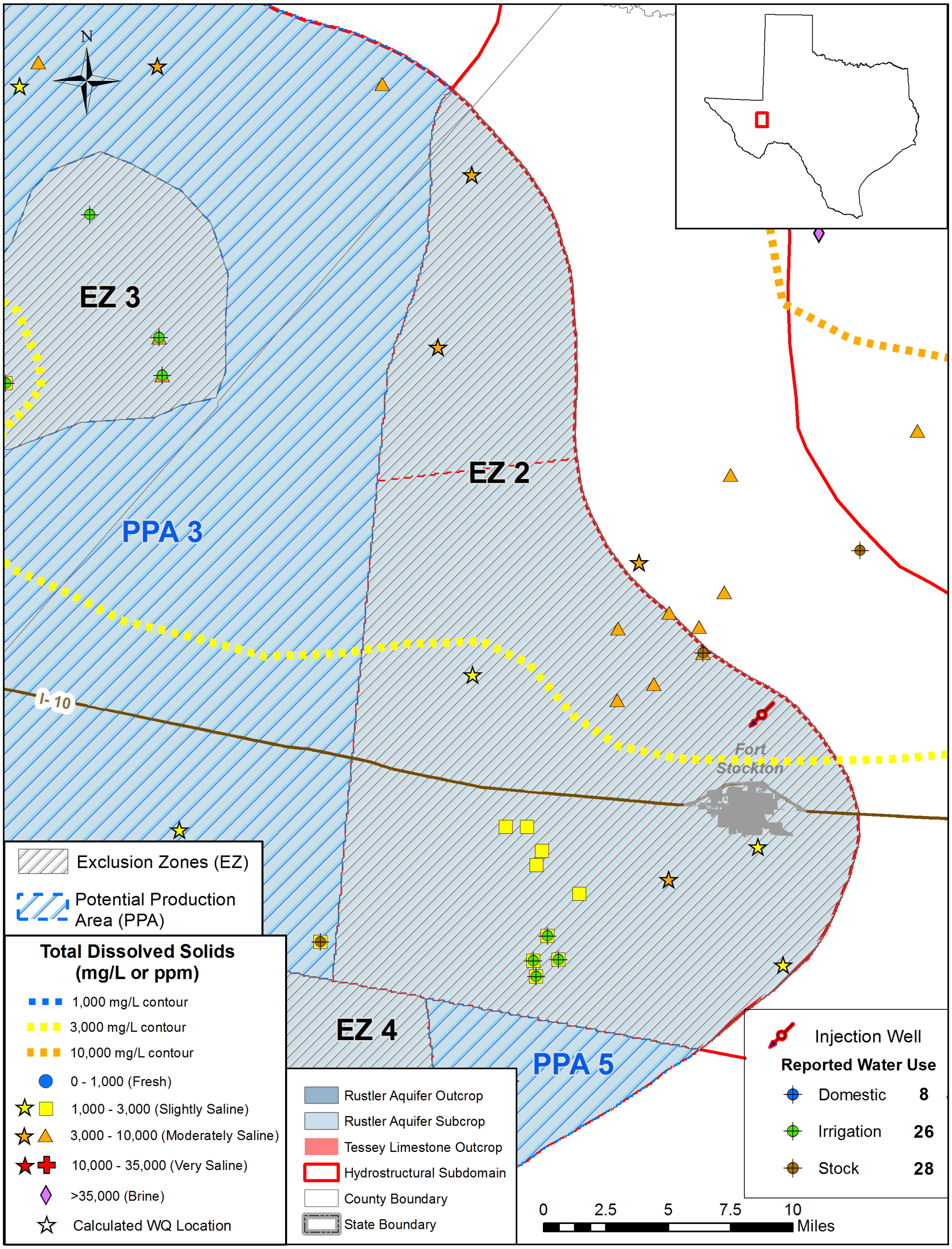

Figure 14-3. Exclusion Zone 2 with water quality data and protected class well locations and usage.

Note: mg/L=milligrams per liter; ppm=parts per million.

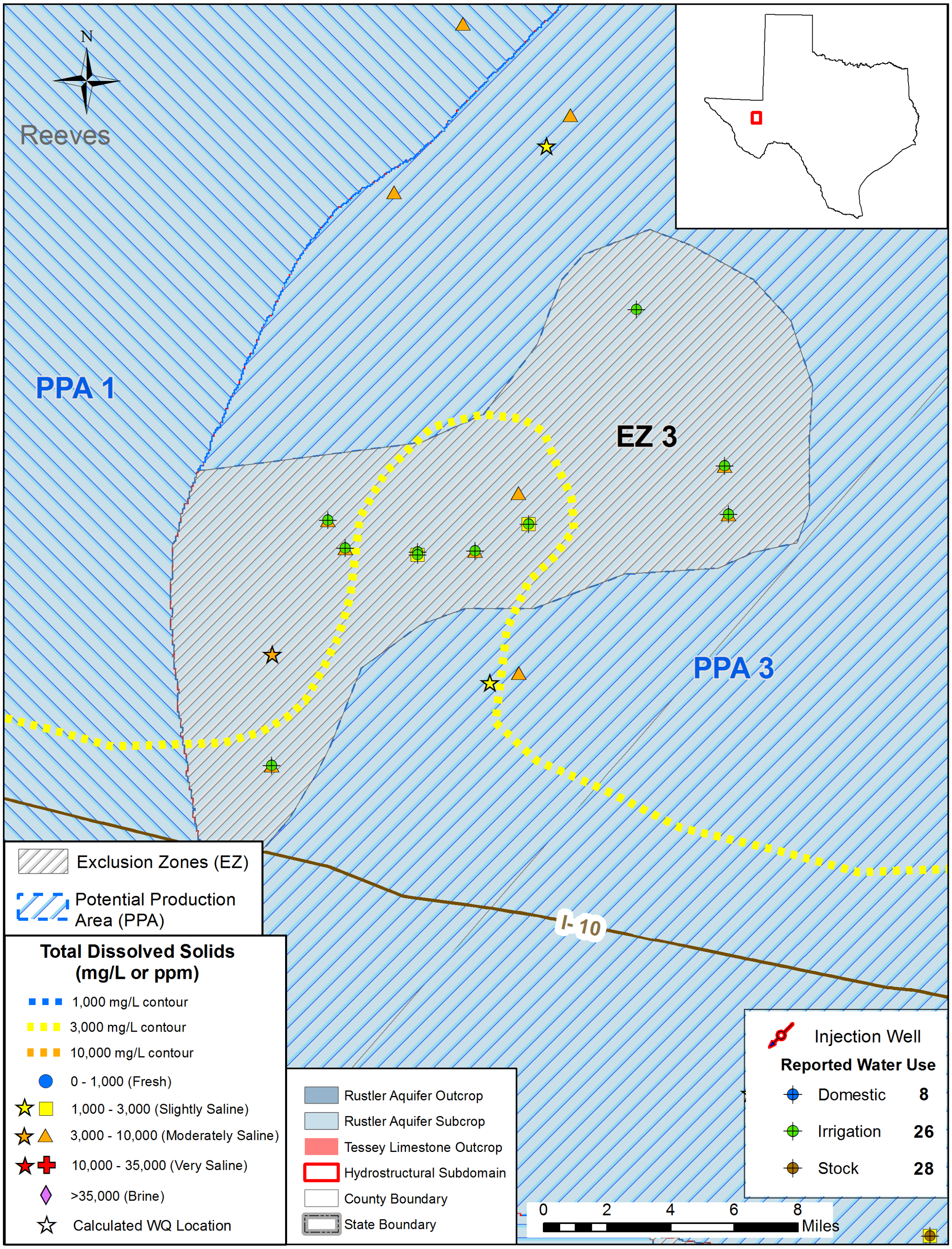

Figure 14-4. **Exclusion Zone 3 with water quality data and protected class well locations and usage.**

Note: mg/L=milligrams per liter; ppm=parts per million.

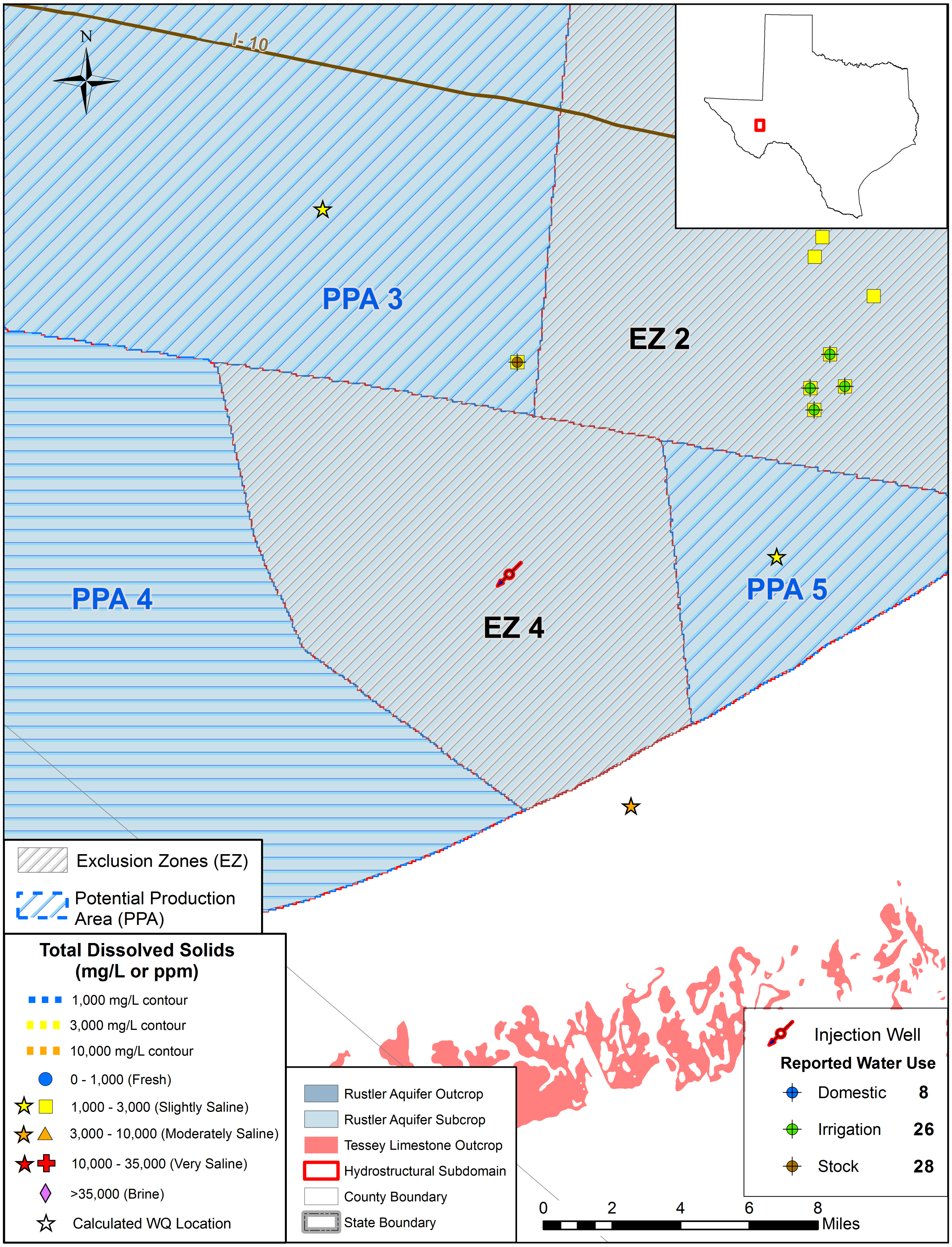

Figure 14-5. Exclusion Zone 4 with water quality data and protected class well locations and usage.

Note: Emg/L=milligrams per liter; ppm=parts per million.

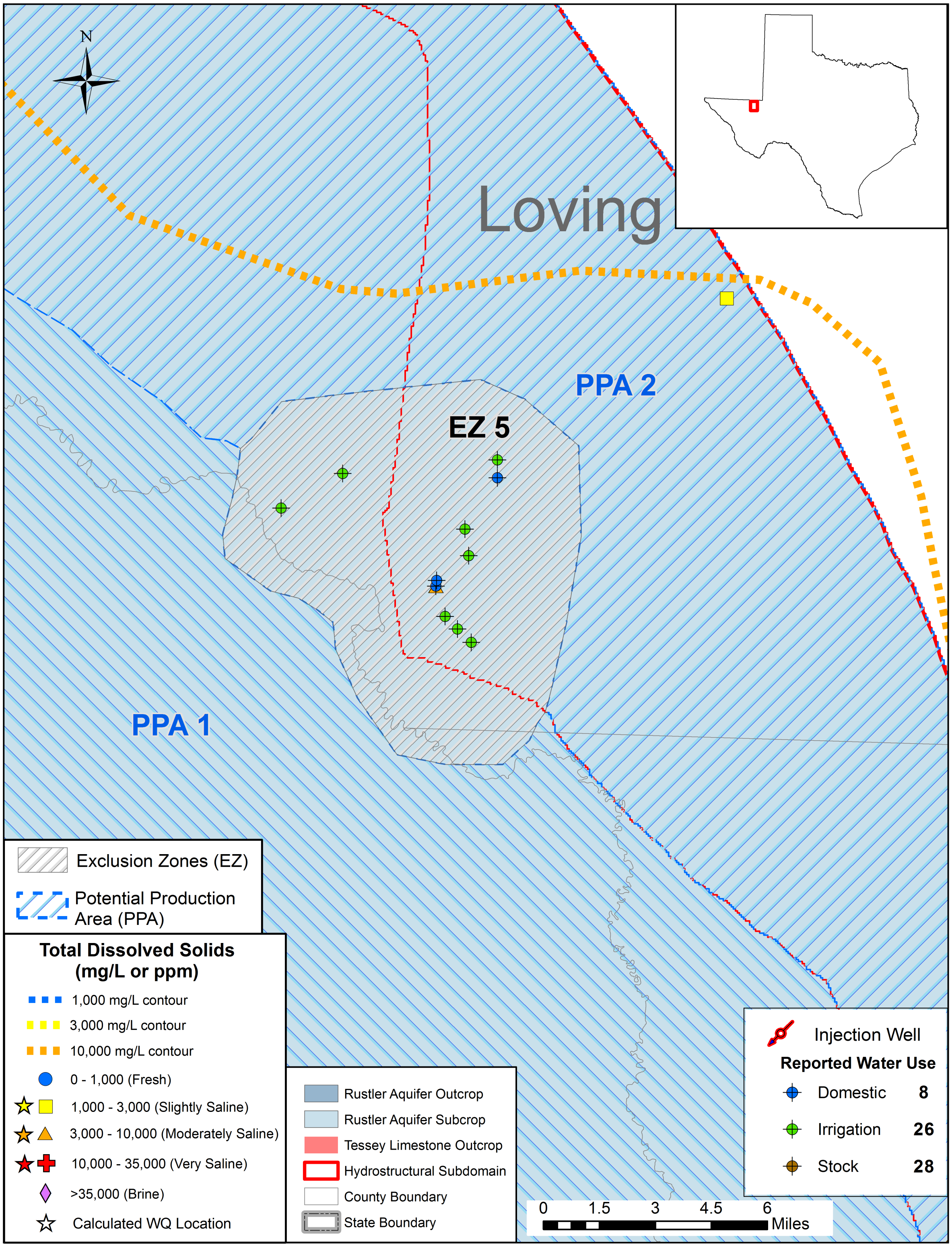

Figure 14-6. Exclusion Zone 5 with water quality data and protected class well locations and usage.

Note: mg/L=milligrams per liter; ppm=parts per million.

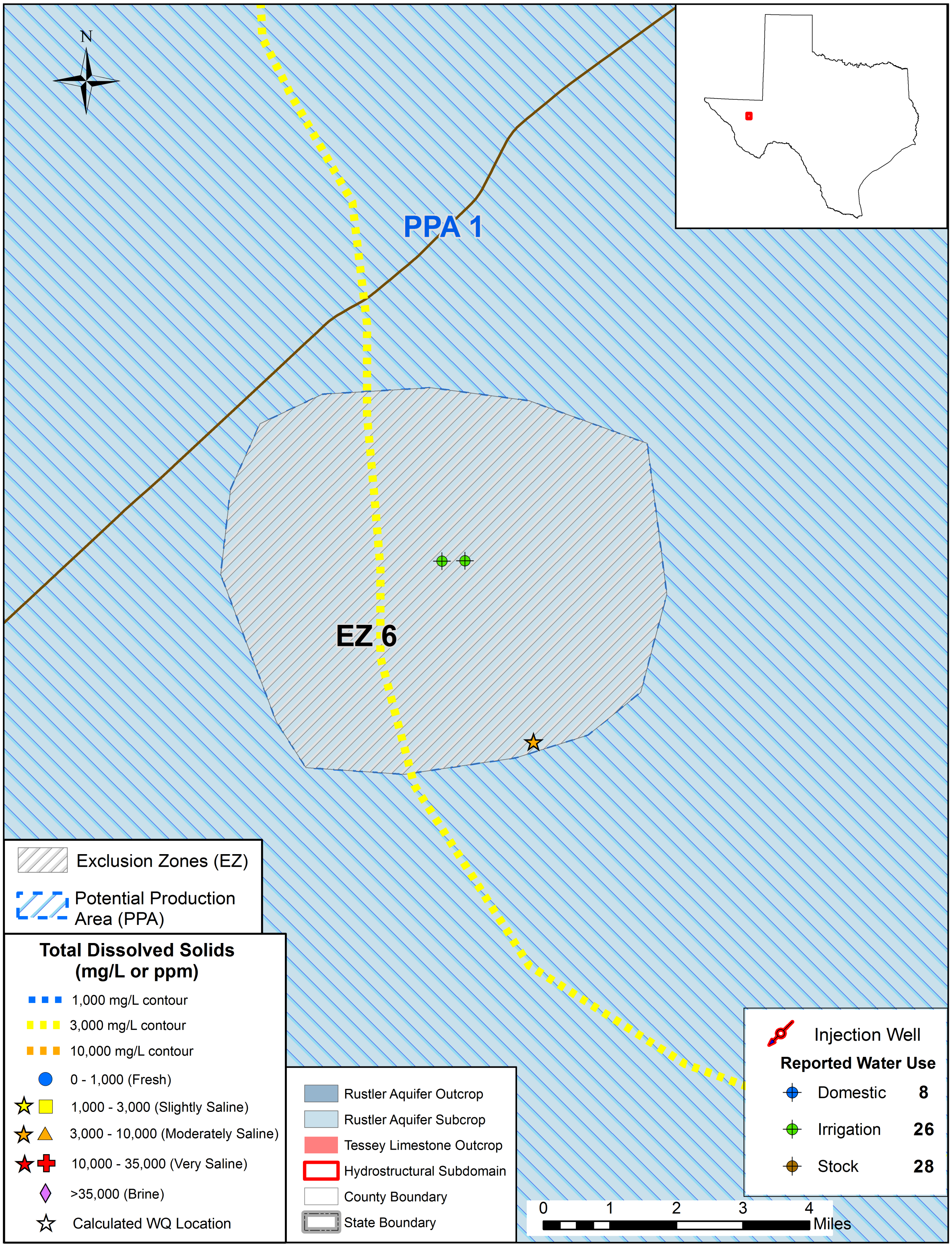

Figure 14-7. Exclusion Zone 6 with water quality data and protected class well locations and usage.

Note: mg/L=milligrams per liter; ppm=parts per million.

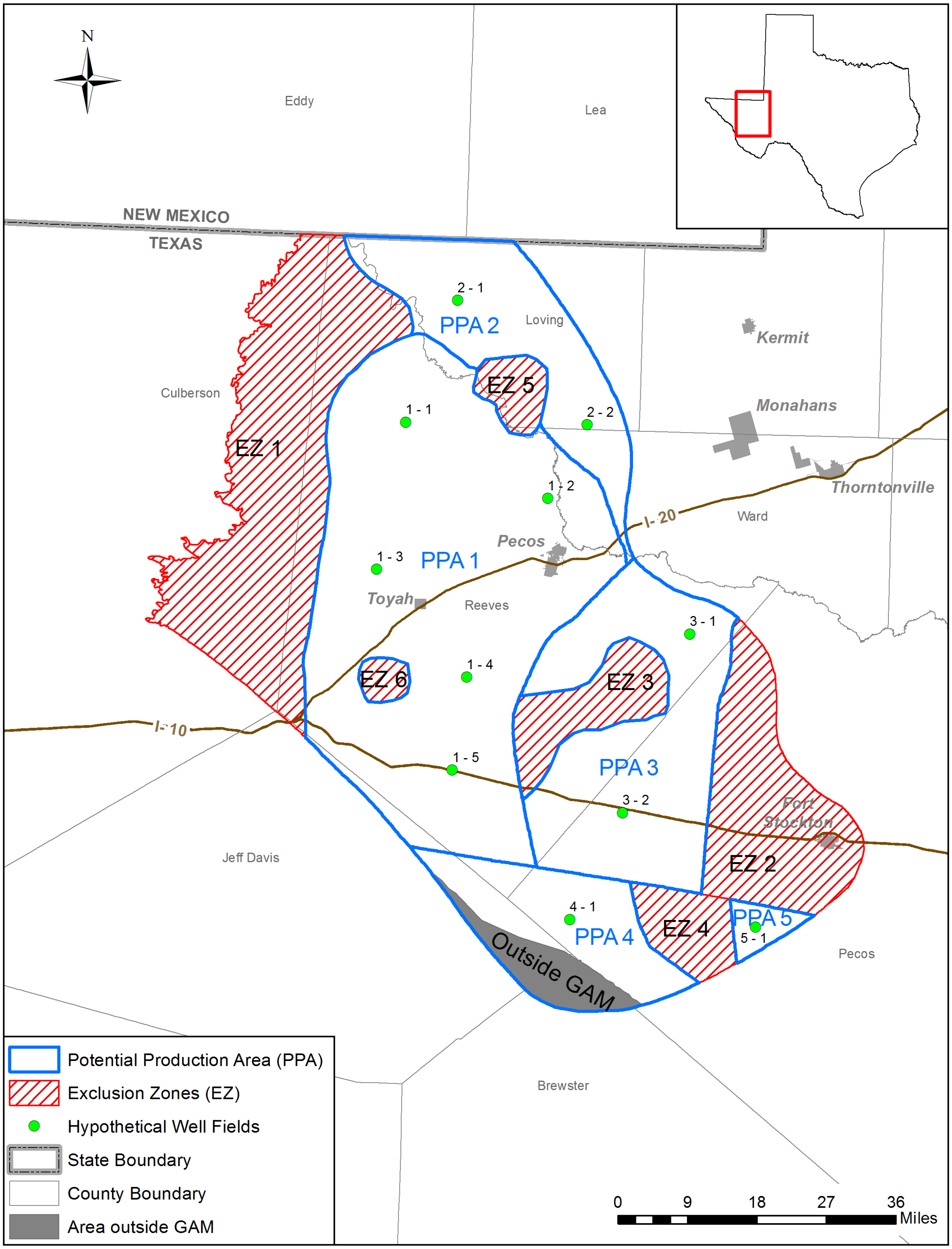

Figure 14-8. Location of well fields evaluated in predictive scenarios.

Note: GAM=Groundwater Availability Model.

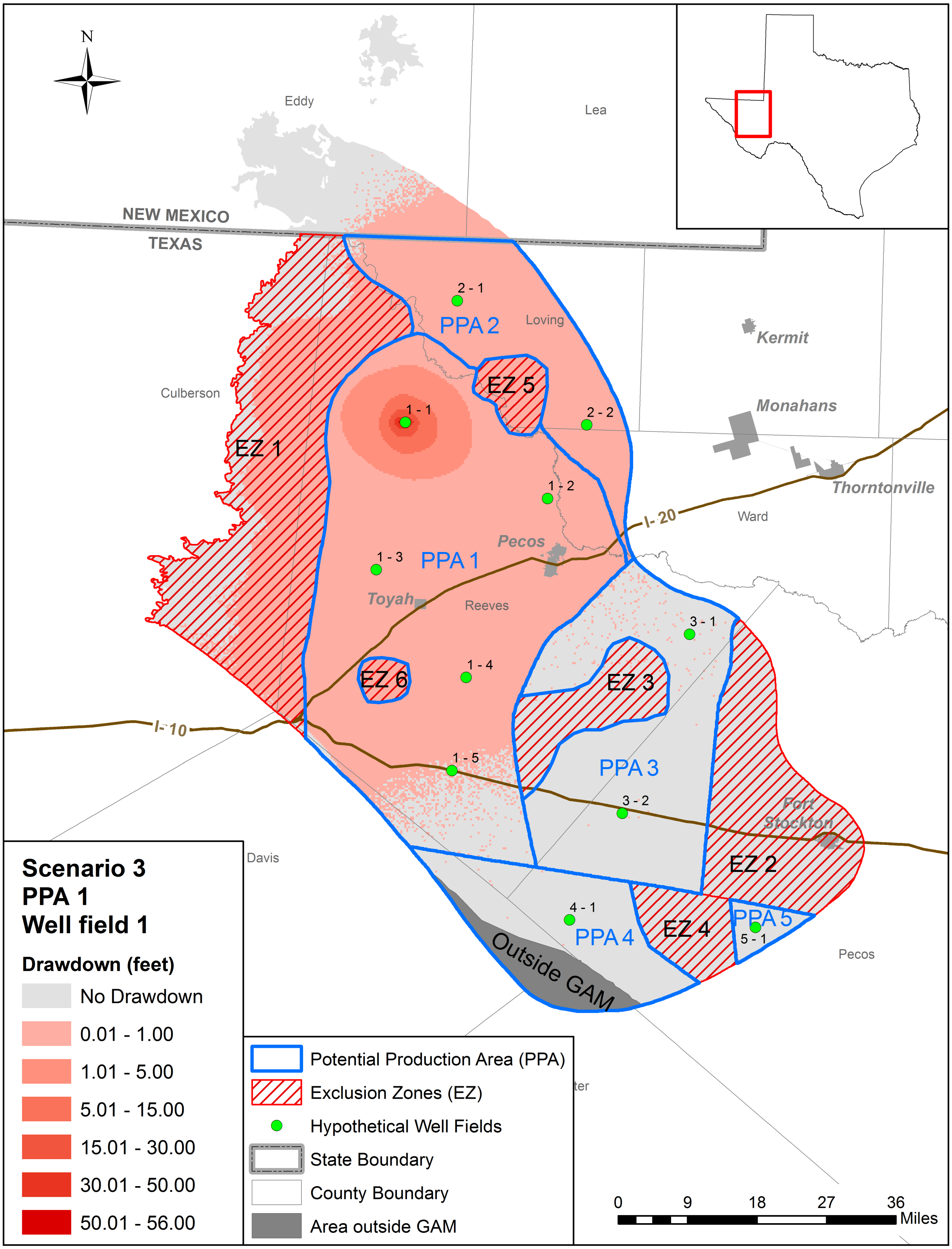

Figure 14-9. Scenario 3 drawdown for well field 1 in PPA 1, 50 years pumping.

Note: AM=Groundwater Availability Model.

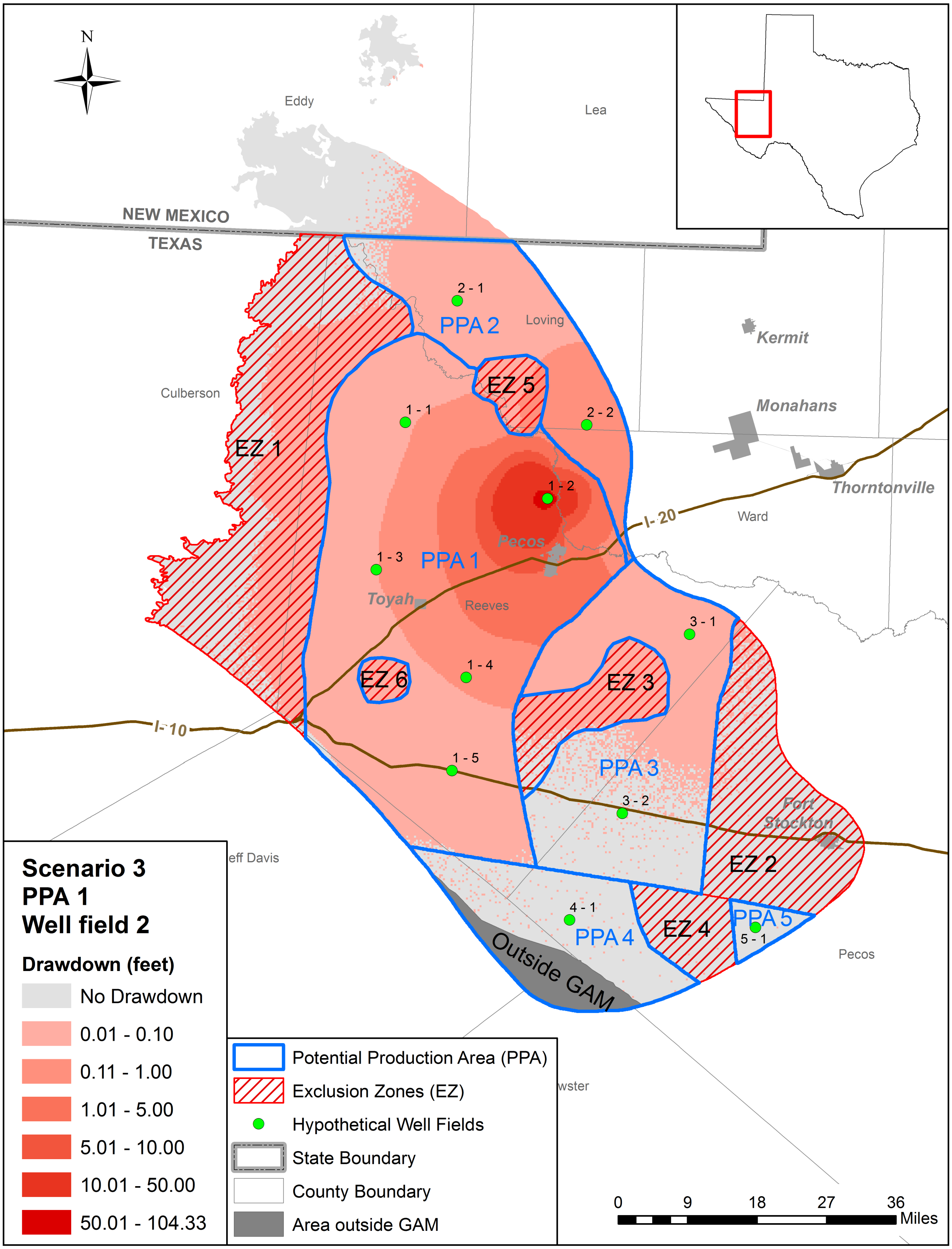

Figure 14-10. Scenario 3 drawdown for well field 2 in PPA 1, 50 years pumping.

Note: GAM=Groundwater Availability Model.

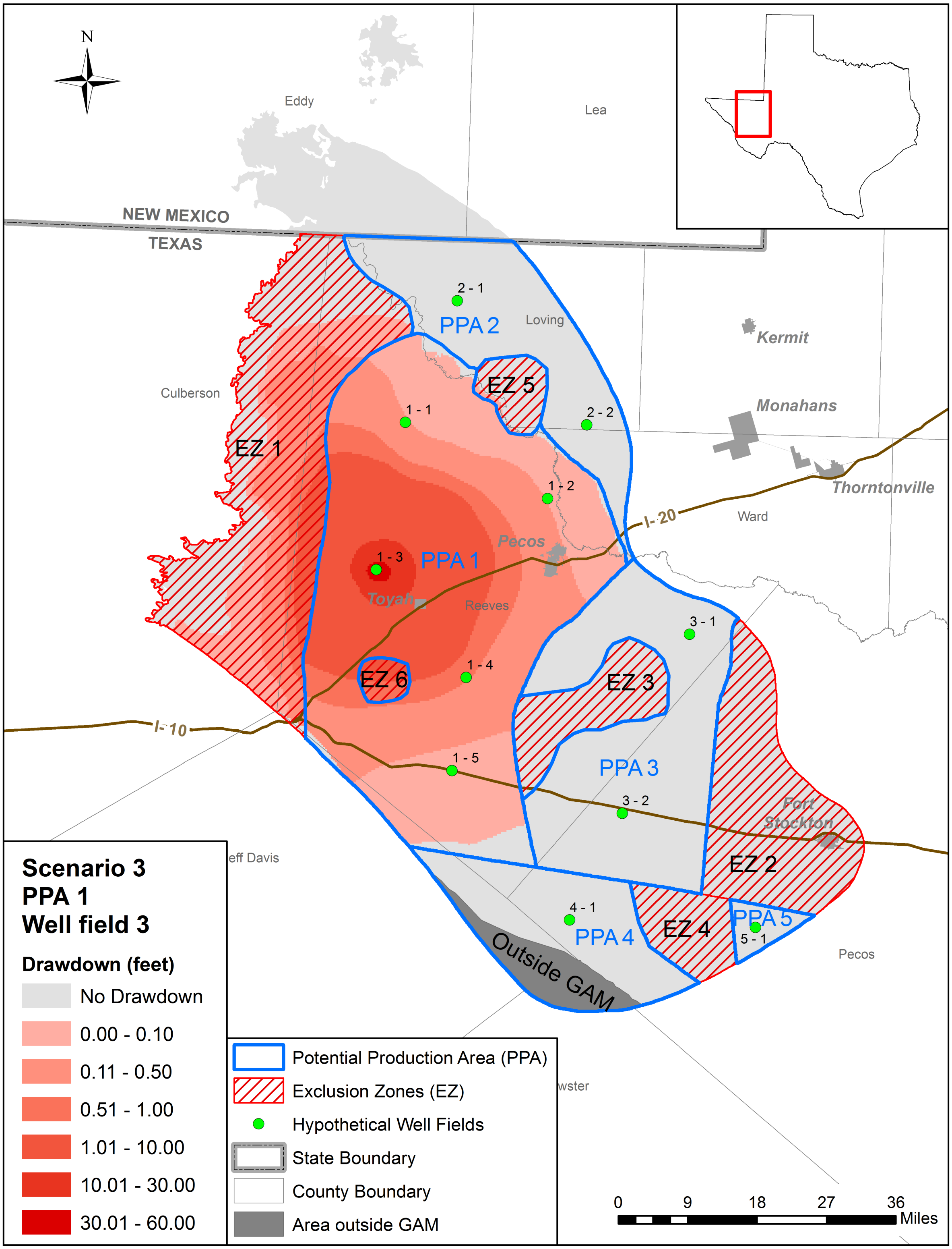

Figure 14-11. Scenario 3 drawdown for well field 3 in PPA 1, 50 years pumping.

Note: GAM=Groundwater Availability Model.

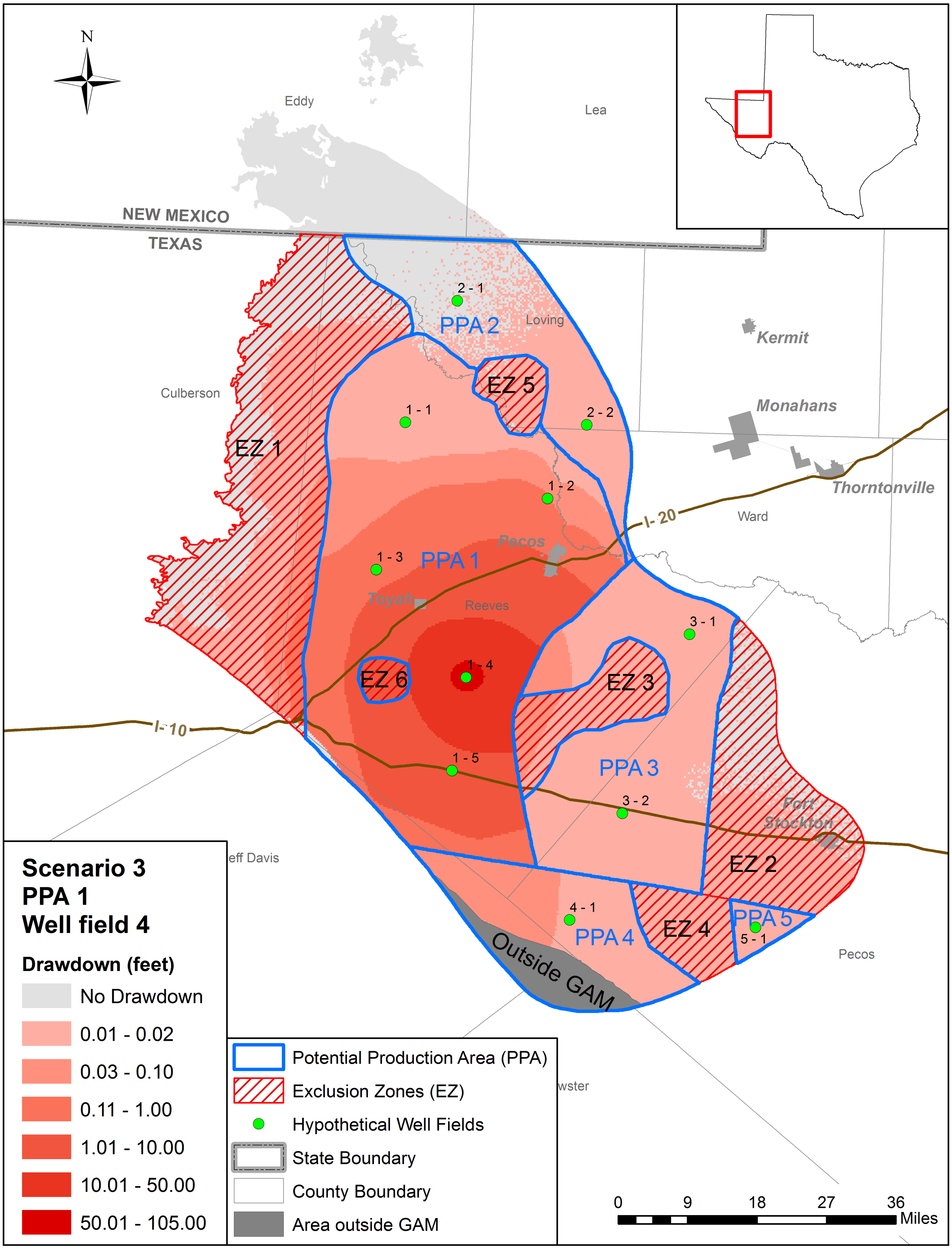

Figure 14-12. Scenario 3 drawdown for well field 4 in PPA 1, 50 years pumping.

Note: GAM=Groundwater Availability Model.

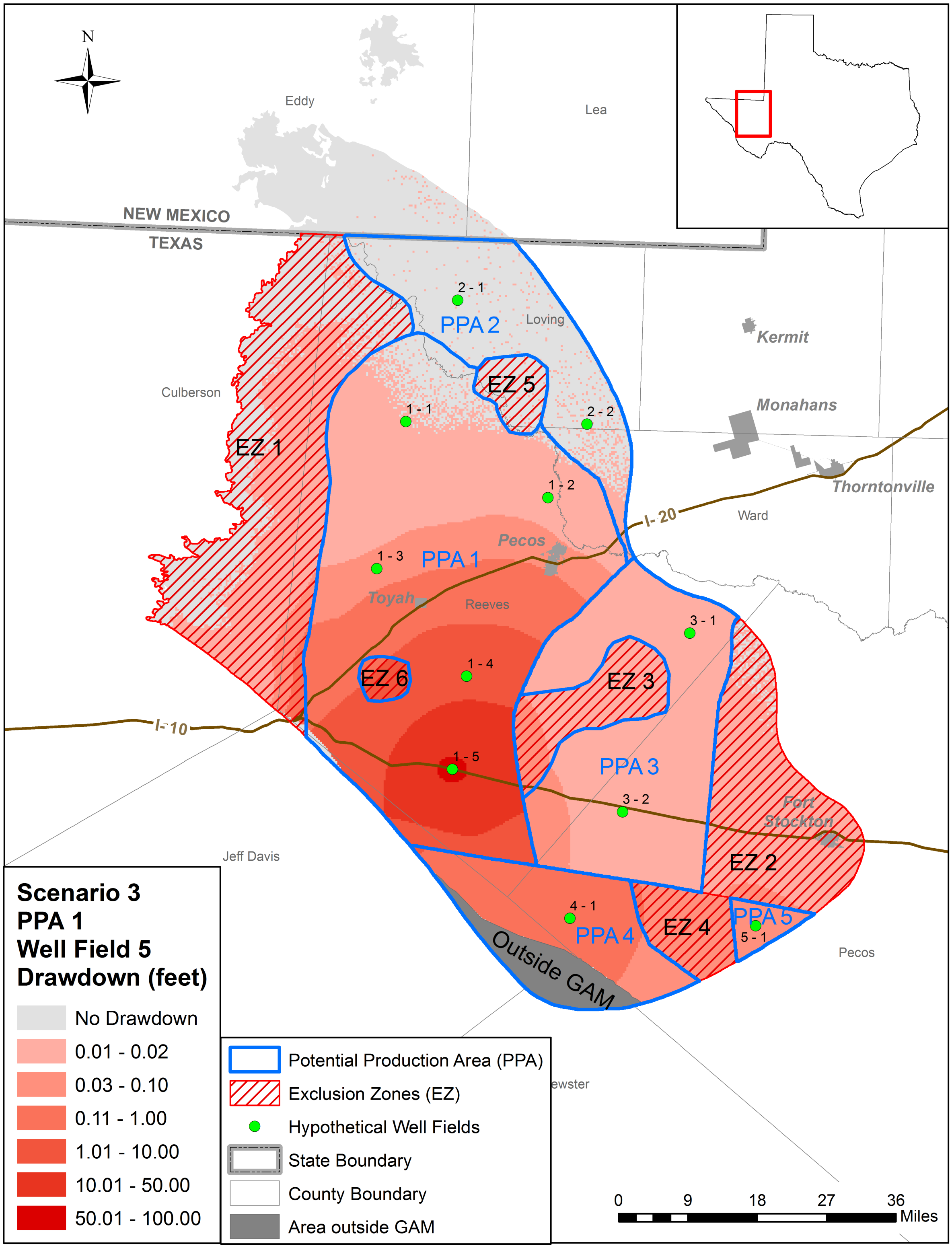

Figure 14-13. Scenario 3 drawdown for well field 5 in PPA 1, 50 years pumping.

Note: GAM=Groundwater Availability Model.

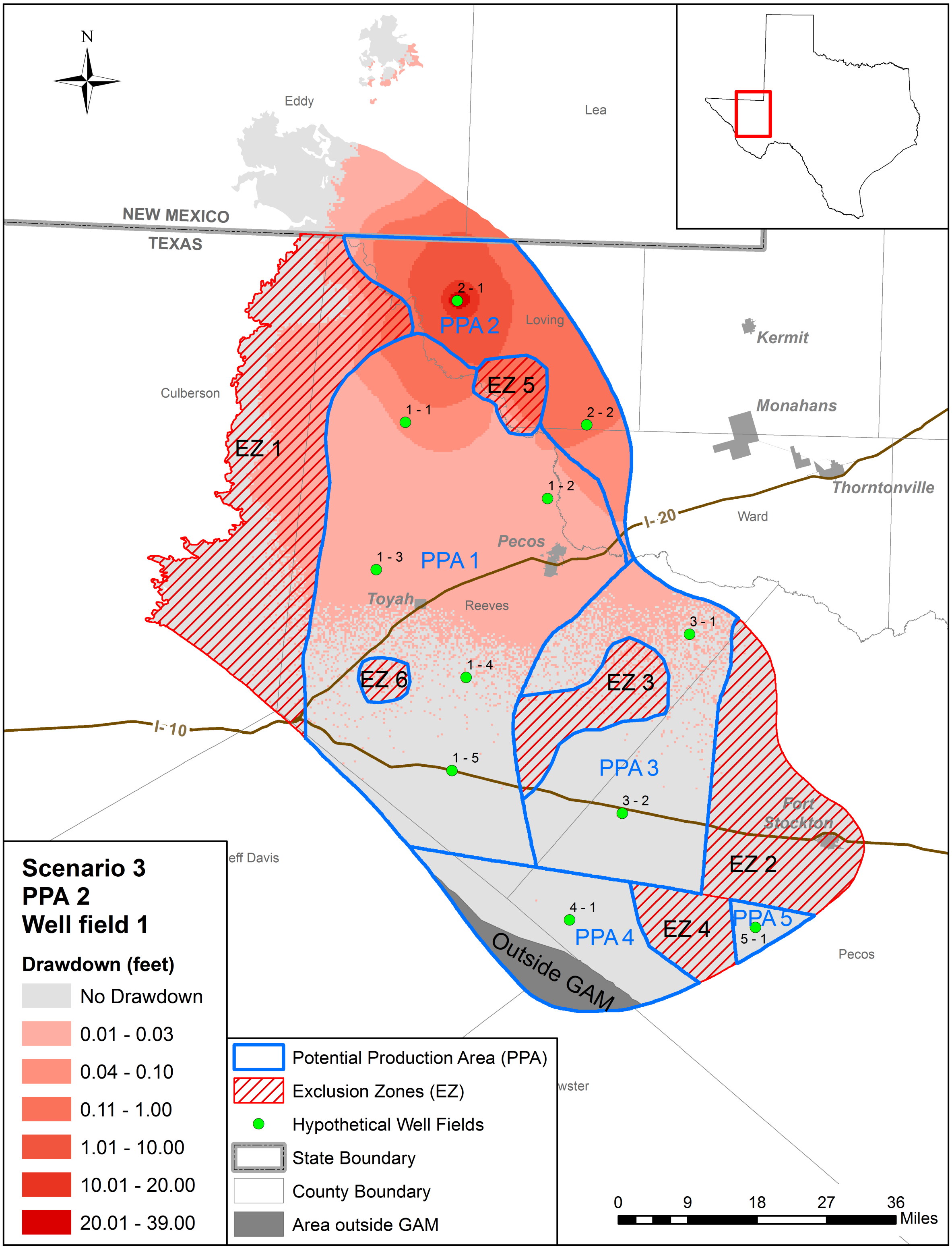

Figure 14-14. Scenario 3 drawdown for well field 1 in PPA 2, 50 years pumping.

Note: GAM=Groundwater Availability Model.

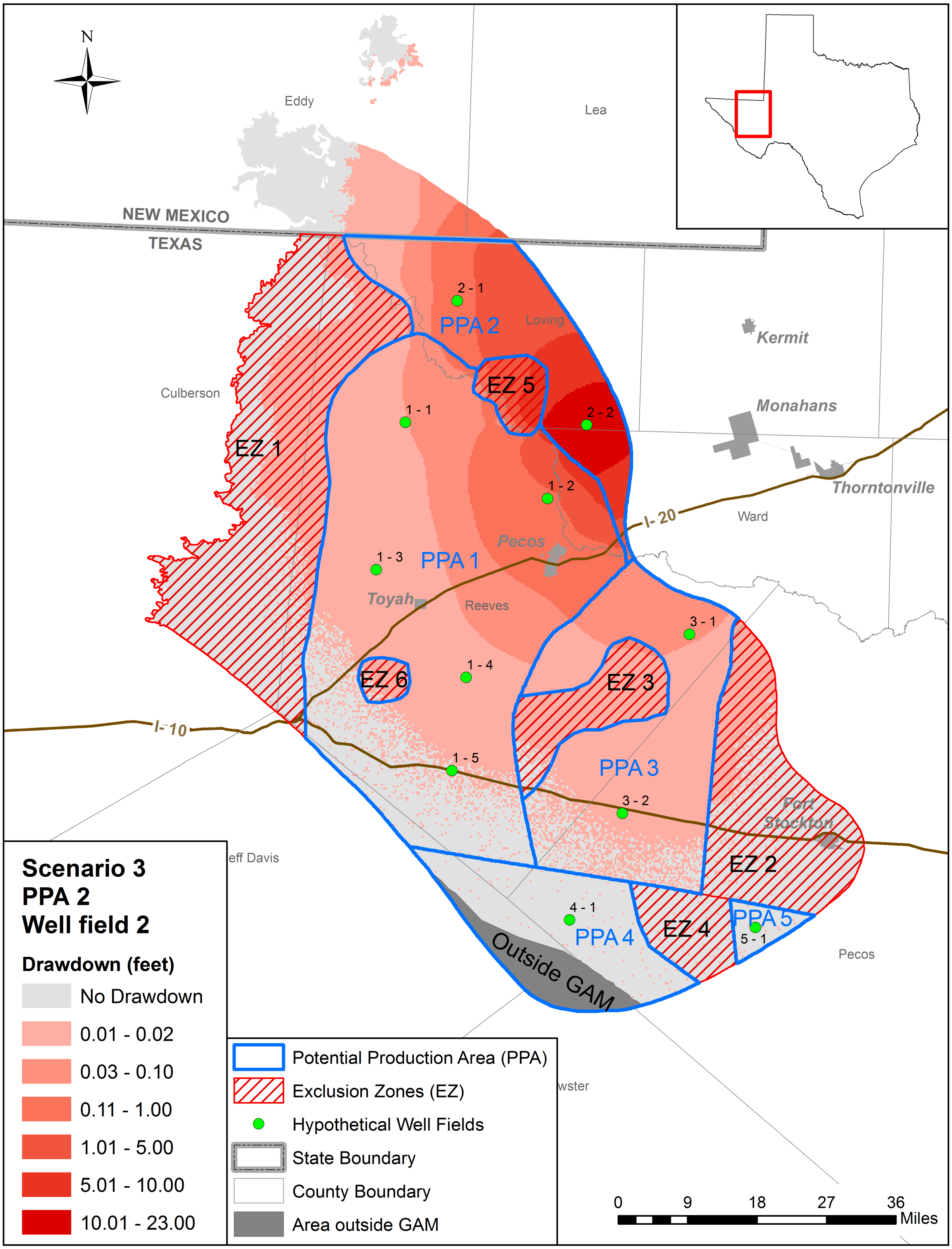

Figure 14-15. Scenario 3 drawdown for well field 2 in PPA 2, 50 years pumping.

Note: GAM=Groundwater Availability Model.

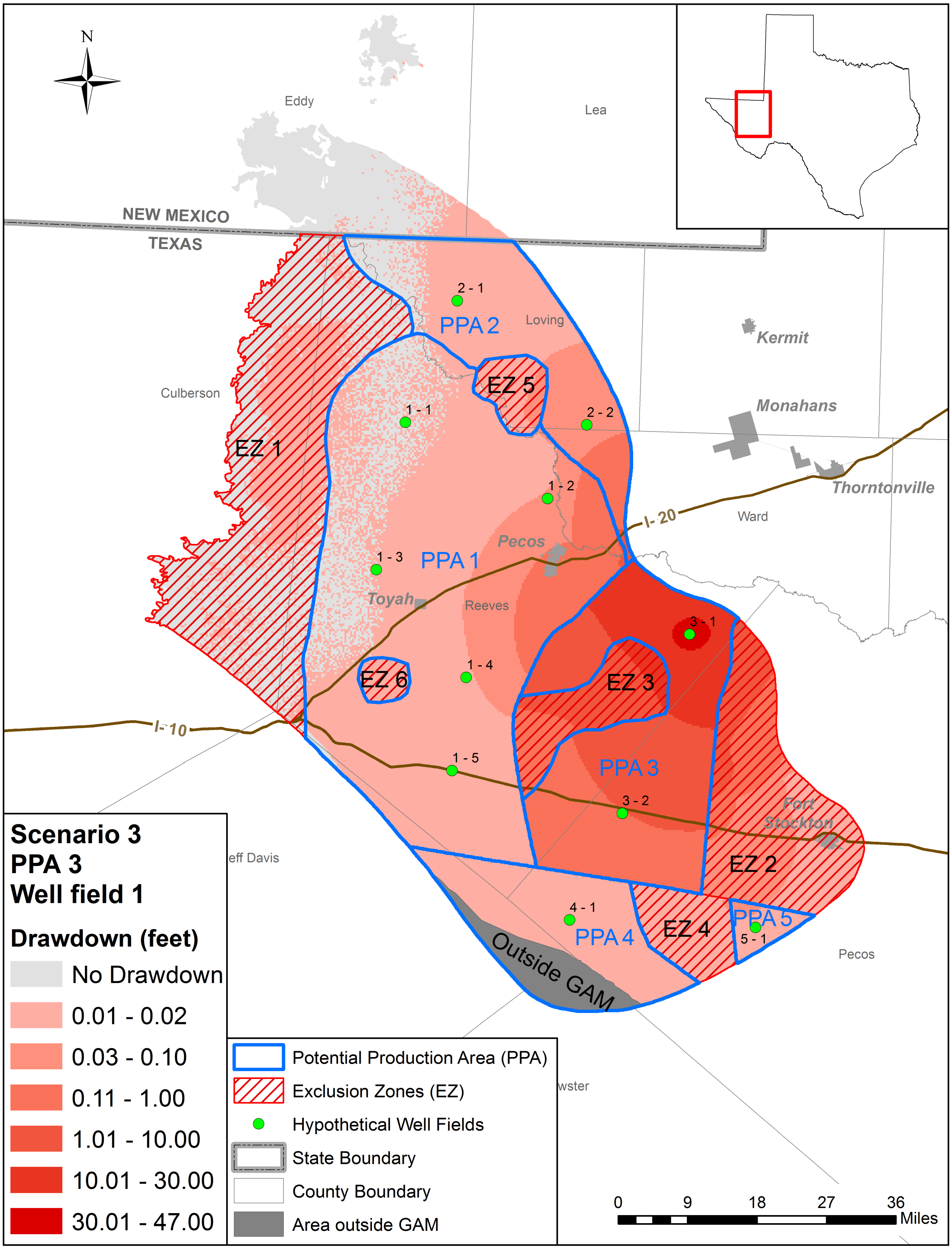

Figure 14-16. **Scenario 3 drawdown for well field 1 in PPA 3, 50 years pumping.**

Note: GAM=Groundwater Availability Model.

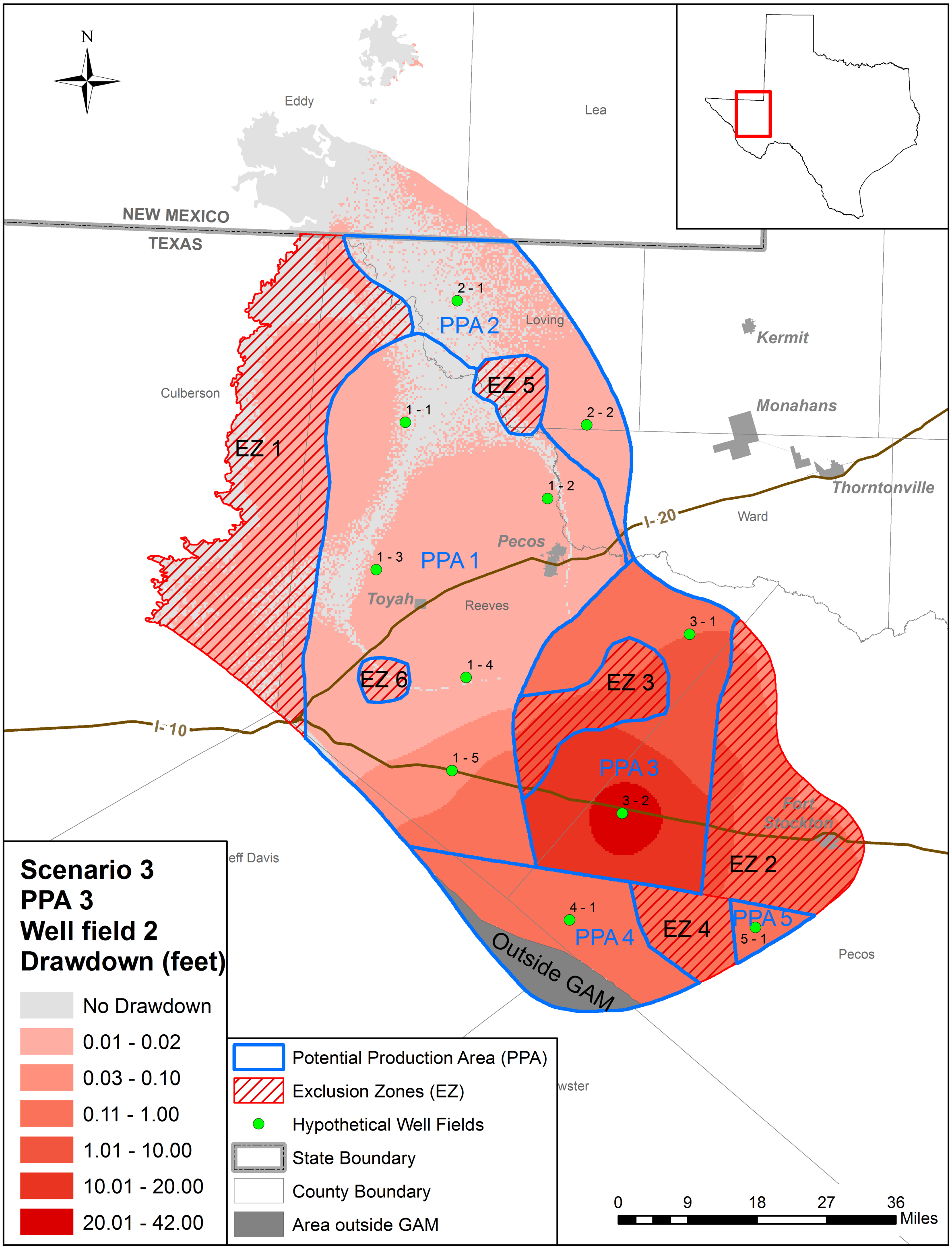

Figure 14-17. Scenario 3 drawdown for well field 2 in PPA 3, 50 years pumping.

Note: GAM=Groundwater Availability Model.

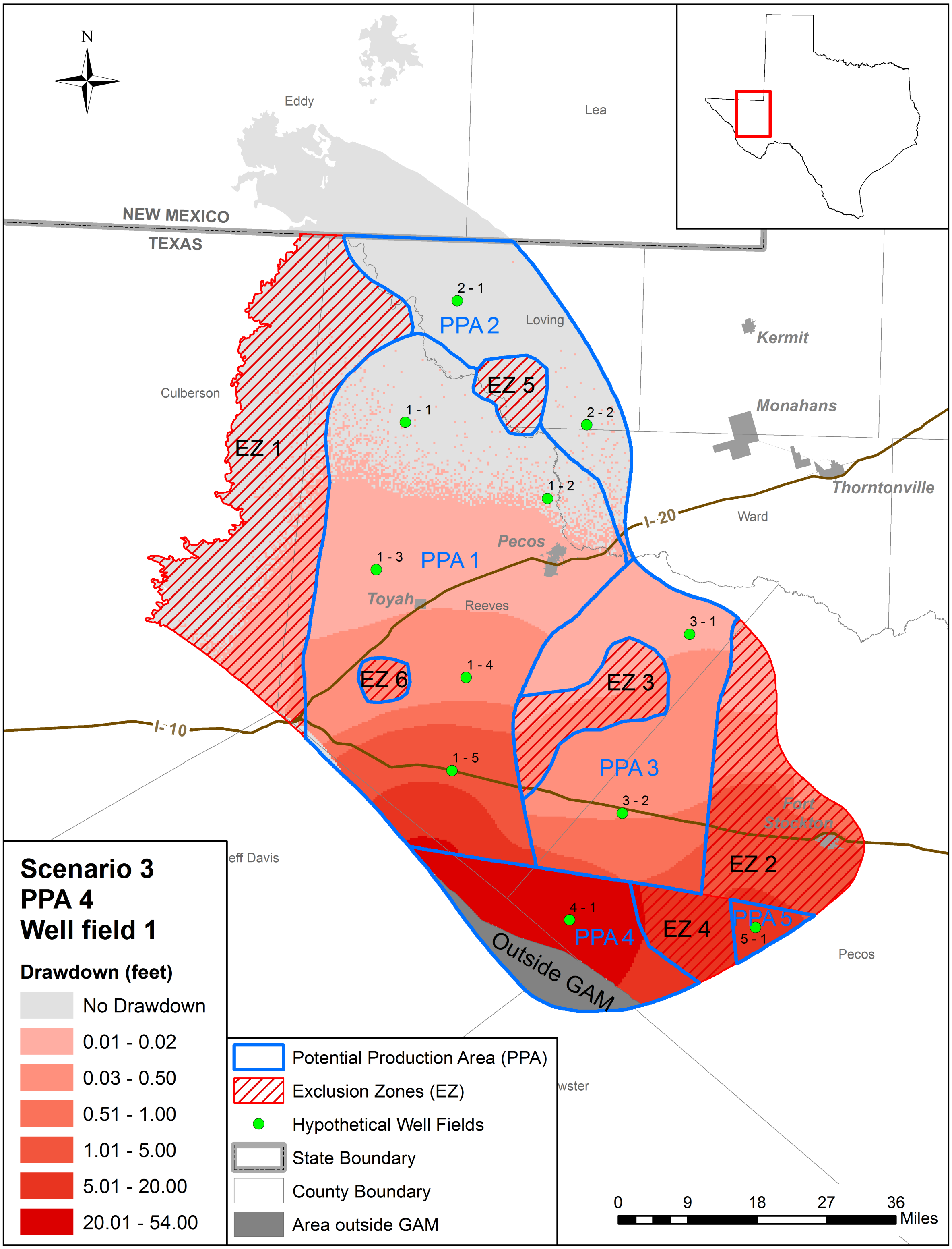

Figure 14-18. Scenario 3 drawdown for well field 1 in PPA 4, 50 years pumping.

Note: GAM=Groundwater Availability Model.

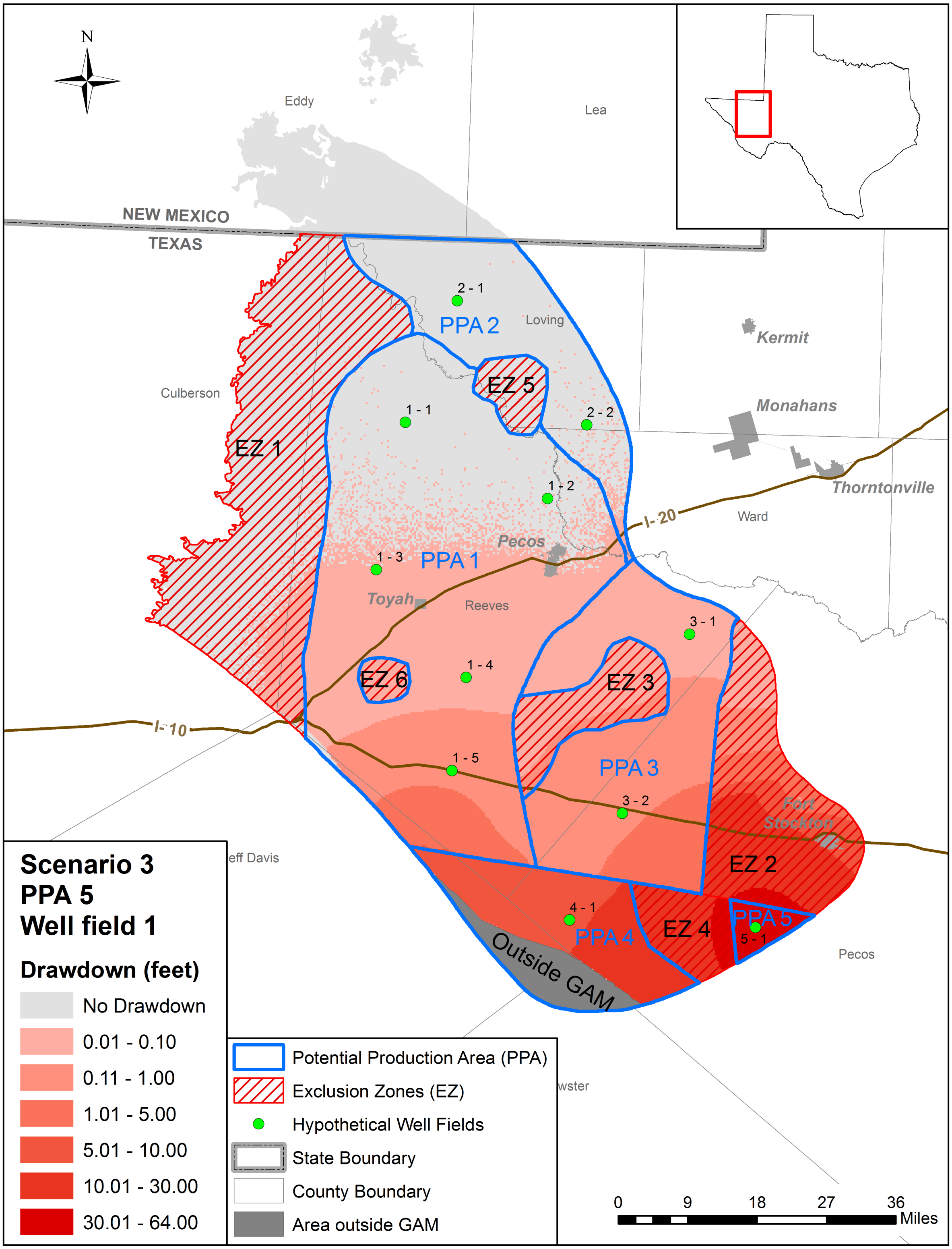

Figure 14-19. Scenario 3 drawdown for well field 1 in PPA 5, 50 years pumping.

Note: GAM=Groundwater Availability Model.

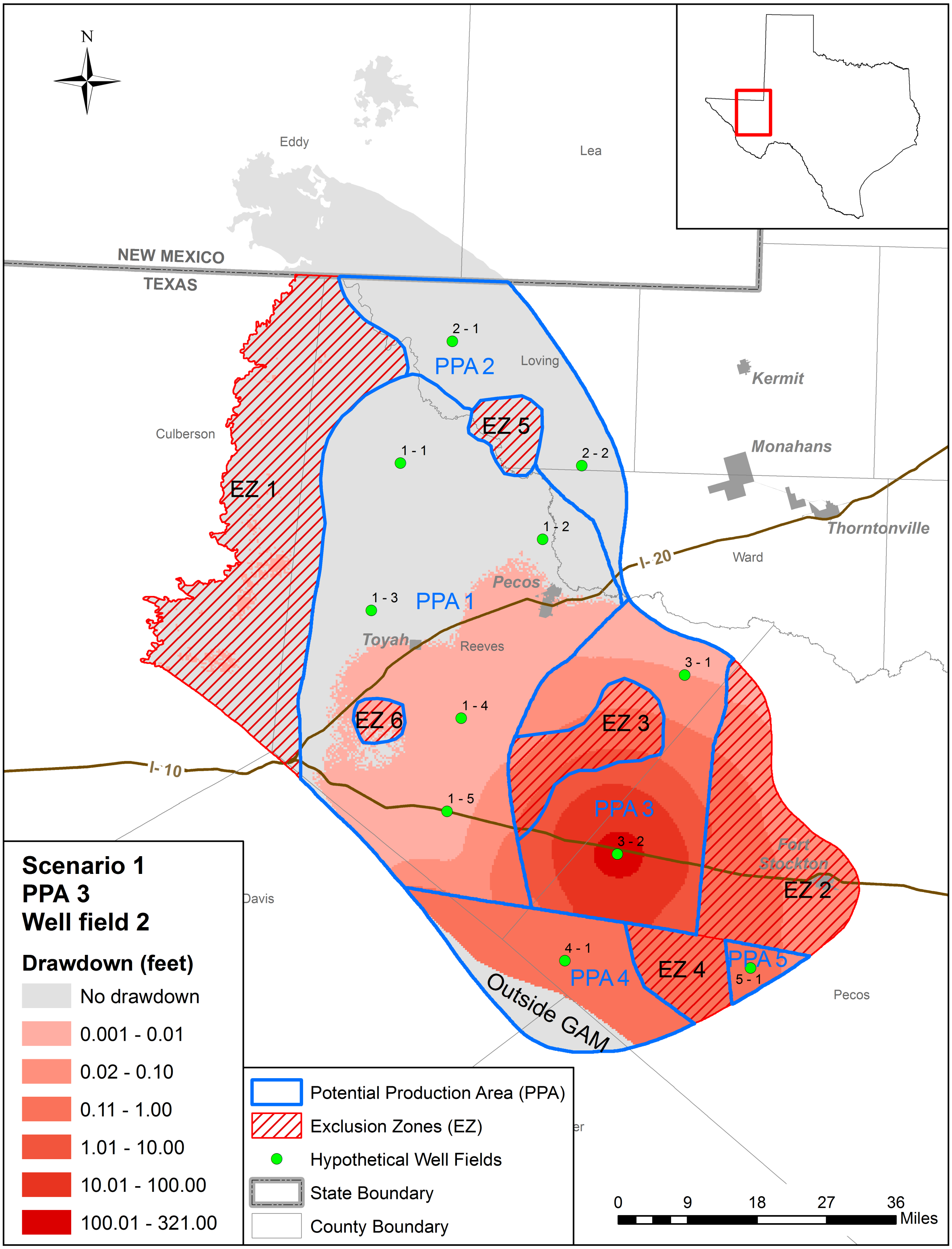

Figure 14-20. Scenario 1 drawdown for well field 2 in PPA 3, 50 years pumping.

Note: GAM=Groundwater Availability Model.

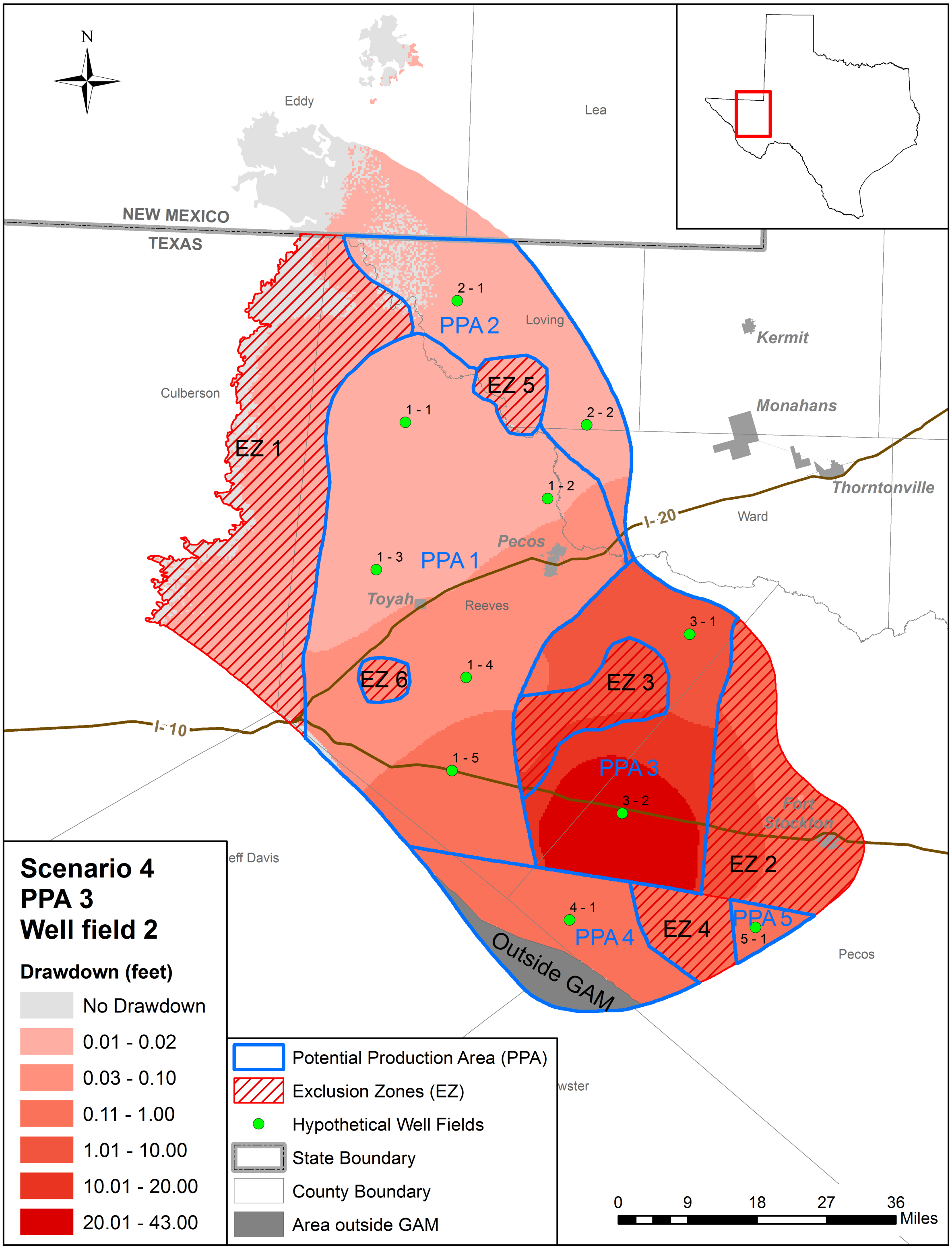

Figure 14-21. **Scenario 4 drawdown for well field 2 in PPA 3, 50 years pumping.**

Note: GAM=Groundwater Availability Model.

15 Future improvements

This project has been funded by and completed for the TWDB's Innovative Water Technologies Section to support the Brackish Resources Aquifer Characterization System Program. Key to their mission is the collection and organization of basic aquifer data to support the understanding and delineation of brackish resources in Texas. This specific study was work authorized under House Bill 30 passed by the 84th Texas Legislative Session and is specific to the Rustler Aquifer in Texas. Our list of potential future improvements focuses both on the larger mission of the Brackish Resources Aquifer Characterization System Program and further study in the Rustler Aquifer.

The following are future improvements that we propose for consideration by the TWDB:

- There is a general lack of data in the brackish aquifers in Texas, but there is an extreme lack of good hydrogeologic data that can be used to describe aquifer hydraulic properties in the Rustler Aquifer. Many of the characterization projects that have been performed in the Rustler Aquifer over the last ten years have been performed for private land owners or the energy sector, who have tended not to make their data public. Our understanding of the Rustler Aquifer can only be improved by the collection of additional publicly available aquifer data, with an emphasis on modern geophysical logs and aquifer test data. Areas such as potential production area one, evaluated as part of this study, show potential as a production zone, but there are effectively no aquifer test data publicly available from which to ground our conclusions. The TWDB should continue their efforts to collect data from those who are investigating the aquifer.

- This study has been very successful in defining the five members and 8 submember units of the Rustler Formation across the project area. The geologic cross-sections developed in this study provide evidence of the lithologic and structural complexity of this aquifer. Future investigators would be aware that we have in no way mapped all of the faults in this system, nor can interpolated surfaces be locally accurate in this complex of a structural setting over such a large project area. Future investigators of the brackish resources of the Rustler Aquifer will have to perform their own drilling and mapping to better understand the local aspects of the aquifer and how that may impact brackish resources. Local investigators are urged to provide local characterization data to the TWDB to support the improvement in understanding of the aquifer.

- The Rustler Aquifer is an extremely complex aquifer system, both from lithologic perspective and a structural perspective. We have modeled the aquifer using a superposition approach using the Rustler Aquifer Groundwater Availability Model (Ewing and others, 2012). While we believe the approach we took was the best approach given the project objectives and timeline, the analysis is inherently uncertain because of poor model constraints (described in Ewing and others, 2012) and regional nature of the model. Future investigators of the brackish resources of the Rustler Aquifer will have to perform their own due diligence when it comes to local availability within this aquifer. Local investigators are urged to provide local resource analyses to the TWDB to support the improvement in understanding of the aquifer.

- We recommend that the Brackish Resources Aquifer Characterization System Program expand their data management system and software to work more closely with modern petrophysics work flows and modern log suites. Large quantities of data are going to continue to be generated as part of these types of brackish resource studies. This data is primarily going to be in the form of geophysical logs (.tif files), digital logs (Log ASCII Standard [.LAS] files) and their derivative data. Current programs available to the Brackish Resource Aquifer Characterization System Program are limiting and will only serve to increase the amount of effort necessary to process and understand the results of these types of studies. It is recommended that the Brackish Resource Aquifer Characterization System Program further investigate the option of having a petrophysical analysis and log databasing software specifically built and made publicly available. We would propose that the Brackish Resources Aquifer Characterization System build off of this analysis to develop an improved analysis suite consistent with modern techniques.

16 Conclusions

The Rustler Aquifer is a TWDB designated minor aquifer in the state of Texas and underlies parts of Brewster, Culberson, Jeff Davis, Loving, Pecos, Reeves and Ward counties (Figure 2-1). The aquifer is designated as minor because it provides small quantities of water to a relatively small number of users. However, where it is the only source of water, the Rustler is a critical water resource to local users. The Rustler Aquifer is almost completely a brackish groundwater resource. Because of general water scarcity in the region and desire on the part of the energy sector to utilize groundwater sources that are not in conflict with fresh or currently used water sources, the Rustler Aquifer has gained attention in the last ten years.

This study was performed under contract to the TWDB to support work authorized under House Bill 30, passed by the 84th Texas Legislative Session. This bill requires the TWDB to identify and designate brackish groundwater production zones in the aquifers of the state. The Rustler Aquifer is one of four aquifers that required initial study. The objective of this study is to characterize the quantity and quality of groundwater within the Rustler Aquifer, identify potential production areas, and model 30- and 50-year pumping in those areas. This information can be used by TWDB staff to make recommendations to the Executive Administrator and the Board on designation of brackish groundwater production zones. The designated brackish groundwater production zones will be reported to the Texas Legislature by December 1, 2016.

The following conclusions can be drawn from this study:

- The Rustler Aquifer is composed of a complex assemblage of lithologies ranging from dolomite to limestone to anhydrite to halite to siltstone. In addition to a complex range of lithologies, post-depositional processes such as cementation, collapse, faulting, etc., have further complicated the ability to systematically define the Rustler Formation and differentiate its five member units and its eight informal submember units.

- Adding 346 additional geophysical logs to those available from Ewing and others (2012) and Meyer (2012), we analyzed 589 geophysical logs and were successful in defining the five Members and eight sub-units of the Rustler Formation across the project area. The hydrostructural subdomains defined by Ewing and others (2012) were modified to include three stratigraphy zones in the project area.
    - Zone 1 – regions where all individual member units are not consistently distinguishable, and collapse due to karstification is suspected.
    - Zone 2 – regions where the individual member units are consistently distinguishable, and the hydraulic potential of the zone is the combination of the Magenta Dolomite, Culebra Dolomite and limestones of the Los Medaños Unit.
    - Zone 3 – regions where member units above the Tamarisk are consistently eroded, and the hydraulic potential of the zone is the combination of the Culebra Dolomite and limestones of the Los Medaños Unit.
- This study has documented that water quality analysis from geophysical logs in the Rustler Aquifer is very complex and requires advanced petrophysical techniques to derive accurate water quality (total dissolved solids) estimates. This study provides a framework for these techniques.

- Volumes of groundwater in place were calculated by salinity class (Winslow and Kister, 1956) for four Rustler Aquifer units: collapse areas, the Magenta Dolomite, the Culebra Dolomite, and the limestones of the Los Medaños. The Rustler Aquifer contains approximately 18,538,000 acre-feet of groundwater. Of the approximate 18 million acre-feet of groundwater in place within the Rustler Aquifer, 88,000 acre-feet is fresh groundwater, 10,172,000 acre-feet is slightly saline groundwater, 7,905,000 acre-feet is moderately saline groundwater, and 373,000 acre-feet is very saline groundwater. It is important to note that a large percentage of this groundwater would not be economical to produce due to the productivity of the Rustler Aquifer.

- Based upon the criteria in House Bill 30, five potential production areas were defined in this study. Nearly the entire Rustler Aquifer is brackish groundwater, with total dissolved solids concentrations in excess of 1,000 milligrams per liter. Therefore, the primary House Bill 30 exclusion metric was existing use based on known domestic, irrigation, and stock wells completed in the Rustler Aquifer. There are no known municipality wells completed in the Rustler Aquifer that are currently in use. Six exclusion zones were delineated within the project area using this information.

- Groundwater modeling was performed in each of the potential brackish production zones to determine potential production rates (a proxy to groundwater availability) and to assess impacts within excluded zones and at protected wells. The Rustler Groundwater Availability Model was used as the modeling tool because it includes the complex fault hydraulic boundaries and the hydrostratigraphy was too complex to create a new model or models in the available timeline.
  - Eleven well fields comprised of nine wells in a linear array were distributed across the potential production areas, and pumping was restricted to 50 percent of available drawdown at each well in the well field.
  - Because of the general lack of hydraulic property data for the Rustler Aquifer, sensitivity analyses were performed to understand the potential productivity and impacts of production. Twelve predictive scenarios described above were developed to evaluate the potential of the Rustler Aquifer to serve as a water source within the potential production areas. This process acknowledges and seeks to account for uncertainty in the aquifer properties that most influence the potential for production, including horizontal hydraulic conductivity, vertical hydraulic conductivity, specific storage, and the hydraulic characteristics of the faults within the Rustler Aquifer.
  - The highest well field production capacity at 50 years in a nine-well field array for the baseline scenario was estimated for potential production area 5 of 491 gallons per minute. Potential production area 5 also had the highest 50-year, nine-well field total production capacity in the sensitivity analyses estimated to be 691 gallons per minute.
  - Nearly all 50-year impacts to protected wells were minimal and below 10 feet. The maximum 50-year drawdown at a protected well was 32 feet in Exclusion Zone 2.
  - Modeling presented provides a good basis for the TWDB to designate brackish production zones. However, the approach used to assess potential impacts is

inherently non-unique because it used hypothetical well fields, arrays, locations, and pumping rates.

- The ranking of potential production areas from high to low potential productivity is: potential production area 5, potential production area 4, potential production area 3, potential production area 1, and potential production area 2.

This study provides a good basis for the TWDB staff to make recommendations to the Board regarding brackish resources and brackish groundwater production zones in the Rustler Aquifer.

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19 Appendices

19.1 Raster interpolation documentation

We began the process of creating surfaces for the Rustler Formation by analyzing a dataset of digitized publicly available geophysical logs (See Appendix 19-5). Data for this analysis were generated by making a series of structural picks for the Rustler Formation on geophysical logs. Logs for this study came from previous BRACS projects (Ewing and others 2012 and Meyer, 2012) as well as new logs from publicly available databases integrated as part of this study. For consistency purposes, we discarded all logs that were located outside the geographic extent of the Rustler Aquifer. The Rustler Formation in this area is highly faulted, and it was anticipated that incorporating log picks outside of a hydrostructural subdomain would result in error. In addition, we identified several wells in the remaining dataset that had stratigraphic picks that were significantly higher or lower than picks in neighboring wells. If we could not correct this anomaly by re-examination of the log (for example, if the kelly bushing elevation was erroneously reported) or justify the anomaly using a reasonable geologic explanation (localized faulting not accounted for by the hydrostructural subdomains), we discarded the problem well log. This filtering process left a total of 397 well logs in the Rustler Formation subcrop and 16 well logs in the Rustler Formation outcrop that could be used to interpolate structural surfaces.

From youngest to oldest (top to bottom), stratigraphic picks were made for: the top of Rustler Formation or Rustler A-5, Rustler M/H-4, Rustler A-4 (also could be top of Rustler Formation in eroded areas), Magenta dolomite, Tamarisk gypsum/anhydrite (also could be top of Rustler Formation in eroded areas), Rustler M/H-3, Rustler A-2, Culebra dolomite, Upper Los Medaños, Rustler A-1, Middle Los Medaños, Los Medaños Limestone, and Lower Los Medaños (Figure 2-2). If we were able to distinguish all, or the great majority of, these layers in the well log, we classified it as a "Normal" stratigraphic column (Zone 2). If the top four layers were missing, but the older layers (that is, the Tamarisk gypsum/anhydrite and older) were distinguishable, we classified that as an "Eroded" stratigraphic column (Zone 3). If we could not distinguish any intermediate layers between the top and bottom of the Rustler Formation, we classified that as a "Collapsed" stratigraphic column (Zone 1). The differences between our interpretations of "Normal", "Eroded", and "Collapsed" stratigraphic zones are shown graphically in Figure 19-1, and the geographic distribution is shown in Figure 4-10.

Well logs with similar stratigraphic columns tended to be grouped by hydrostructural subdomain. However, we cannot use this distinction alone to choose the points and extents for interpolating geologic surfaces. The Rustler Formation is split by a number of faults, so even nearby wells with the same stratigraphic column classification could be significantly vertically offset from one another. In that scenario, interpolating points together that are actually on two sides of a fault would cause the surface to be incorrectly represented. To better capture both the fault-related vertical offsets and the different stratigraphic columns present in the Rustler Formation, we split the well points into distinct hydrostructural subdomains and interpolated separate geologic surfaces for each of these regions individually. Again, the distribution of these regions can be seen in Figure 5-10.

Our delineation of hydrostructural subdomains draws heavily on the "structural subdomains" used in the original Rustler Groundwater Availability Model (Ewing and others, 2012) to split the Rustler Formation into sections based on faults and other structural interpretations. We subdivided some of these "structural domains" based on patterns observed in our interpreted stratigraphic columns. We also refined the boundaries of these "structural subdomains" to better match the fault locations provided in the original Rustler Groundwater Availability Model geodatabase, which has also been provided as a deliverable for this project. Figure 19-2 illustrates the differences between the "structural subdomains" defined in the original Rustler Groundwater Availability Model (Ewing and others, 2012) and the hydrostructural subdomains we used in the current study to create our geologic surfaces. The hydrostructural subdomain labels shown in this figure follow a naming convention we developed for the interpolation of the structural surfaces and are not specifically referenced in the body of the report. The first number (before the underscore) represents the corresponding "structural subdomain" number defined in the original Rustler Groundwater Availability Model (Ewing and others, 2012). The second number (after the underscore) represents our stratigraphic column classification, with "1" meaning "Collapsed", "2" meaning "Normal" and "3" meaning "Eroded". Therefore, our hydrostructural region "4_3" is the portion of the original Groundwater Availability Model's "Structural Subdomain #4" where the majority of wells display a "Eroded" stratigraphic column. If an original "structural subdomain" containing wells with all the same stratigraphic column classification was split by a fault, we assigned an "a" or "b" to either side of the fault. For instance, our hydrostructural regions "5a_2" and "5b_2" both fall within the original Groundwater Availability Model's "Structural Subdomain #5" and have wells with "Normal" stratigraphic columns, but are offset from one another by a fault. This naming convention was necessary for coding the interpolation of the raster surfaces.

In the current study, we were able to incorporate additional well control points that were not available during the development of the original structural surfaces for the Rustler Groundwater Availability Model. Additionally, the original Rustler Groundwater Availability surface for the top of the Rustler Formation was created through hand contouring thousands of picks for the top of the Rustler Formation and subsequently interpolating those hand contours. For this study, we wanted to find a compromise between adding in the additional data and honoring the large amount of work that went into creating the original Rustler Formation structural surface. Therefore, rather than using the original Groundwater Availability Model surface or creating a wholly new one, we instead modified the original Groundwater Availability Model top of Rustler Formation surface using corrections based on the new well control points.

To begin the process, we sampled the original Groundwater Availability Model raster at each well control point and calculated the difference between our new well-log-based Rustler Formation top stratigraphic pick and the original surface. For each hydrostructural subdomain, we selected only the well logs falling inside and then interpolated the differences at each point for all of the wells in that region. This interpolated "residual" surface was added to the original surface which resulted in a new top of Rustler Formation surface for each hydrostructural subdomain. We did not calculate a correction raster for the outcrop since the top is based on ground surface rather than a structural interpretation. We also did not calculate a correction factor for the New Mexico portion of region 8_2. There were no new well control points added to this region during the current study and so we had no justification for altering the original Groundwater Availability Model surface. Dummy points were added to the southern section of 5_1 due to a lack of data in the area. After making corrected surfaces for each individual hydrostructural subdomain, the surfaces were then mosaicked together into one aquifer-wide surface for the new top of Rustler Formation.

To test whether the resulting modified top of Rustler Formation surface was reasonable, we sampled the well control points to the new surface and calculated the difference between our stratigraphic pick for the top of the Rustler Formation at our control point and the new surface value. All residuals (Rustler Formation top elevation at the well minus new surface) were very low, with stratigraphic picks and the new surface values within plus or minus 13 feet of each other at all well control points. Low residual values at the new structure picks mean that there is good agreement between the new surface and picks for the top of the Rustler Formation.

To create surfaces for the component Rustler Formation layers, we selected only the well logs falling inside each individual hydrostructural subdomain and used these stratigraphic picks to create a region-scale geologic surface raster via the TopoToRaster tool in ESRI ArcMap 10.2. The geologic surface was then clipped to the extent of that particular hydrostructural subdomain. In the smaller hydrostructural regions (4_2, 5a_2, 5b_2), some geologic layers did not have enough stratigraphic picks to run the TopoToRaster tool because that tool requires at least 5 points to interpolate. For these layers, we calculated an average thickness value from the existing stratigraphic points. Using the Map Algebra tool in ESRI ArcMap 10.2, we added this constant value to the underlying layer surface to create a top surface for the missing layer. Future improvements to the understanding of the Rustler Formation structure should involve integration of additional data in this area.

The interpolation process can introduce errors to the surfaces, including layer inversions or areas where the layer becomes unrealistically thick or thin. To address this, we developed an iterative process using the Map Algebra tool in ESRI ArcMap 10.2. Given our objective of calculating brackish water volumes, we focused primarily on the three water-bearing units of interest: the Magenta and Culebra Dolomites and the limestone of the Los Medaños Unit. The Magenta Dolomite is only present in the areas with a “Normal” stratigraphic column, whereas the Culebra Dolomite and the limestones of the Los Medaños Unit are present in areas with both “Normal” and “Eroded” stratigraphic columns. We used different approaches for adjusting the top surface of a water-bearing unit compared to the bottom of the unit. While adjusting the top of the unit, we aimed to eliminate layer inversions while still honoring our stratigraphic elevation picks as much as possible. While adjusting the bottom of the unit, we aimed to preserve the water-bearing thickness calculated from our stratigraphic picks as much as possible.

Where it existed, the Magenta Dolomite is the shallowest water-bearing unit. We sampled our well control points to the new top of Rustler Formation surface and then calculated the difference between that value and the stratigraphic elevation pick for top of Magenta at each well control point. Based on that difference value, we interpolated an “ideal” thickness raster using the Topo to Raster tool in ESRI ArcMap 10.2. The interpolation was constrained to the maximum and minimum thickness values at the points. Using the Map Algebra tool in in ESRI ArcMap 10.2, we then subtracted this "ideal" thickness from the top of Rustler Formation surface, resulting in an "ideal" top of Magenta Dolomite elevation surface. Again making use of the Map Algebra tool in ESRI ArcMap 10.2, we created a new Magenta Dolomite top surface as follows: if a portion of the original Magenta Dolomite surface (the one we interpolated directly from the stratigraphic picks) was higher than this "ideal" top of Magenta Dolomite surface, we adjusted the Magenta Dolomite surface by substituting the "ideal" value in that area. In this way, we created a new top of the Magenta Dolomite that eliminated inversions between the top of the Magenta Dolomite and the new Rustler Formation top surface but still largely honors our Magenta Dolomite stratigraphic elevation picks.

The bottom of the Magenta Dolomite water-bearing unit is the top Tamarisk Unit (Figure 19-1). At all our well control points, we calculated a thickness of the Magenta Dolomite by subtracting the top of the Magenta Dolomite stratigraphic pick from the top of the Tamarisk Unit stratigraphic pick. Based on that difference, we interpolated an "ideal" thickness raster using the Topo to Raster tool in ESRI ArcMap 10.2. Again, the interpolation was constrained to the maximum and minimum thickness values at the points. Using the Map Algebra tool in ESRI ArcMap 10.2, we created a new top of Tamarisk Unit surface as follows: If the difference between the new Magenta Dolomite surface and the original top of Tamarisk Unit surface (the one we interpolated directly from the stratigraphic picks) was smaller than that "ideal" thickness raster, we adjusted the Tamarisk surface down until the difference matched the "ideal" thickness. If the difference was larger than the maximum value of the "ideal" thickness raster, we adjusted the Tamarisk surface upwards until the difference matched the "ideal" thickness. In this way, we created a new top of Tamarisk that preserved the Magenta thickness calculated from our stratigraphic picks.

The next water-bearing unit below Magenta Dolomite is the Culebra Dolomite. However, in the "Eroded" region 4_3, where the Magenta Dolomite does not exist, the Culebra Dolomite is actually the first water-bearing unit. In this region, we adjusted the Culebra Dolomite surface using the method described above for adjusting the Magenta Dolomite surface relative to the new Rustler top. In the rest of the "Normal" regions, however, we adjusted the Culebra Dolomite surface relative to the new Tamarisk Unit surface created above. At our well control points, we sampled the new Tamarisk Unit surface and calculated a difference between this value and our stratigraphic pick. We then interpolated an "ideal" thickness raster from those values and subtracted this from the new Tamarisk surface, resulting in an "ideal" elevation raster. If the Culebra Dolomite surface was higher than this "ideal" elevation, we enforced the "ideal" value in order to eliminate inversions.

The bottom of the Culebra Dolomite water-bearing unit is the Upper Los Medaños unit. We adjusted this surface based on an "ideal" thickness raster interpolated from the calculated differences between Culebra Dolomite and Upper Los Medaños Unit stratigraphic picks at the well control points. As with the Tamarisk Unit surface, the Upper Los Medaños Unit surface was adjusted downwards if the thickness was too thin and upwards if the thickness was too thick.

The next water-bearing unit below Culebra Dolomite is the limestone of the Los Medaños Unit. The surface for this was adjusted in the same manner as the Magenta and the Culebra Dolomite surfaces, except relative to the new surface for Upper Los Medaños Unit. The bottom of the limestones of the Los Medaños Unit is the lower Los Medaños Unit. We adjusted this in the same manner as the Tamarisk and Los Medaños surfaces, except relative to an “ideal” thickness raster interpolated from the calculated differences between the limestones of the Los Medaños Unit and the lower Los Medaños Unit stratigraphic picks at the well control points.

There are no water-bearing units below the Los Medaños Limestone, so the last step was creating a surface for the top of the Salado Formation, which represents the bottom of the Rustler Formation. The surface for the top of the Salado Formation was interpolated using stratigraphic picks adjusted in a similar way to the Magenta, Culebra and Los Medaños surfaces, except relative to an “ideal” elevation derived from the new Lower Los Medaños surface. While this process provides new top of Salado Formation surface for all the “Normal” and “Eroded” hydrostructural regions, it does not create new Salado surfaces for the “Collapsed” regions or in the outcrop. Unfortunately, the original surfaces for these regions (the ones we calculated solely on stratigraphic picks) did not agree with the new adjusted surfaces for the other regions. The vertical offset at the boundaries of the “Collapsed” regions and the outcrops were so significant that there appeared to be “faults” at the edge of the regions. However, this is misleading since there are no known faults in those areas and thus no justifiable reason for such a significant vertical offset at these edges. We therefore adjusted the top of the Salado Formation surface in these areas as described below.

To adjust the top of Salado Formation surfaces in Subdomains 8_1 (“Collapsed”) and 10_1 (”Outcrop”), we first contoured the new adjusted Salado surface for Subdomain 9_2 (“Normal”). In the Topo to Raster tool in ESRI ArcMap 10.2, we interpolated these contours combined with the point values for the Salado Formation stratigraphic picks at wells in Subdomains 8_1 and 10_1. We the clipped the resulting raster to the extents of Subdomains 8_1 and 10_1 to create the new top of Salado Formation surfaces for those regions. To adjust the top of Salado Formation surfaces in Subdomain 5_1 (“Collapsed”), we first contoured the new adjusted top of Salado Formation surfaces in Subdomain 5a_2 (“Normal”). We interpolated these contours combined with the point values of Salado stratigraphic picks at wells in Subdomain 5_1. We clipped the resulting raster to Subdomain 5_1 extent to create the new top of Salado Formation surface for that region. In this way, we honored the stratigraphic picks in the “Collapsed” and outcrop regions but blended it with the new Salado surfaces in other regions so as not to produce misleading “faults.”

Once we had created and corrected the geologic surfaces for each of the hydrostructural subdomains individually, we then used the Mosaic to New Raster tool in ESRI ArcMap 10.2 to mosaic those region-scale surfaces together into one model-wide surface for that geologic layer. This method preserved the sharp vertical offsets between hydrostructural subdomains and provides the most realistic geologic surfaces for the layers comprising the Rustler Formation.

To check how reasonable all of our new surfaces were, we calculated residuals by subtracting our stratigraphic picks at all the well control points from the value of the new surface rasters. The calculated residuals were acceptably low, with the exception of certain well control points that we found to be problematic (Figure 19-3). These are points that fall within a “Normal” hydrostructural subdomain, but do not have a top of Magenta Dolomite stratigraphic pick, even while there are picks for subsequent layers. Initially, these points displayed residuals exceeding several hundred feet but by inserting “dummy” values for the top of Magenta Dolomite, we were able to reduce these residuals to under 70 feet, which we found acceptable given the complexity represented by the surfaces. Because adjustments get propagated downwards through our subsequent layers, this residual remains approximately the same at these points in all layers. The residuals for each layer are given in Table 19-1. For the reasons discussed, we have separated out the residual statistics for our problem points from the residual statistics for the rest of our well control points in order to provide a less misleading representation of our results.

Table 19-1. Residuals between our stratigraphic picks at well control points and new geologic surfaces.

Surface	Standard Wells*				Wells with missing Stratigraphic Picks**			
	Number	Min	Max	Average	Number	Min	Max	Average
Magenta	298	-12	10	-0.05	--	--	--	--
Tamarisk	298	-13	11	-0.07	39	-68	-8	-62
Culebra	326	-13	6	-0.07	41	-67	0.08	-4
Upper Los Medaños	326	-18	2	-0.1	42	-67	0.2	-5
Los Medaños Limestone	267	-19	15	-0.2	30	-4	1	-0.2
Lower Los Medaños	267	-21	15	-0.2	30	-6	2	-0.2
Salado	278	-61	50	-0.2	135	-407	165	-41

min=minimum; max=maximum

* only includes wells with a calculated residual – i.e. there is stratigraphic pick for that layer at each those wells

** Explanation of "wells with missing stratigraphic picks" by layer:

Magenta Dolomite– no wells since no residuals could be calculated for wells without Magenta Dolomite stratigraphic picks

Tamarisk – represents wells missing Magenta stratigraphic picks

Culebra Dolomite – represents wells missing Magenta Dolomite stratigraphic picks in Zone 2-Normal and no wells in Zone3 – Eroded since no residuals could be calculated for wells without Culebra Dolomite stratigraphic picks

Upper Los Medaños – represents wells missing either Magenta or Culebra stratigraphic picks in Zone 2-Normal and wells missing Culebra stratigraphic picks in Zone 3- Eroded.

Los Medaños l*imestones* – represents wells missing either Magenta Dolomite or Culebra Dolomite stratigraphic picks in Zone 2-Normal and wells missing Culebra Dolomite stratigraphic picks in Zone 3- Eroded.

Lower Los Medaños - represents wells missing either Magenta, Culebra, or a Los Medaños limestone stratigraphic picks in Zone 2-Normal and wells missing either Culebra Dolomite or a Los Medaños limestone stratigraphic picks in Zone 3- Eroded.

Salado - represents wells missing either Magenta Dolomite, Culebra Dolomite, or a Los Medaños limestone stratigraphic picks in Zone 2-Normal and wells missing either Culebra Dolomite or a Los Medaños limestone stratigraphic picks in Zone 3- Eroded.

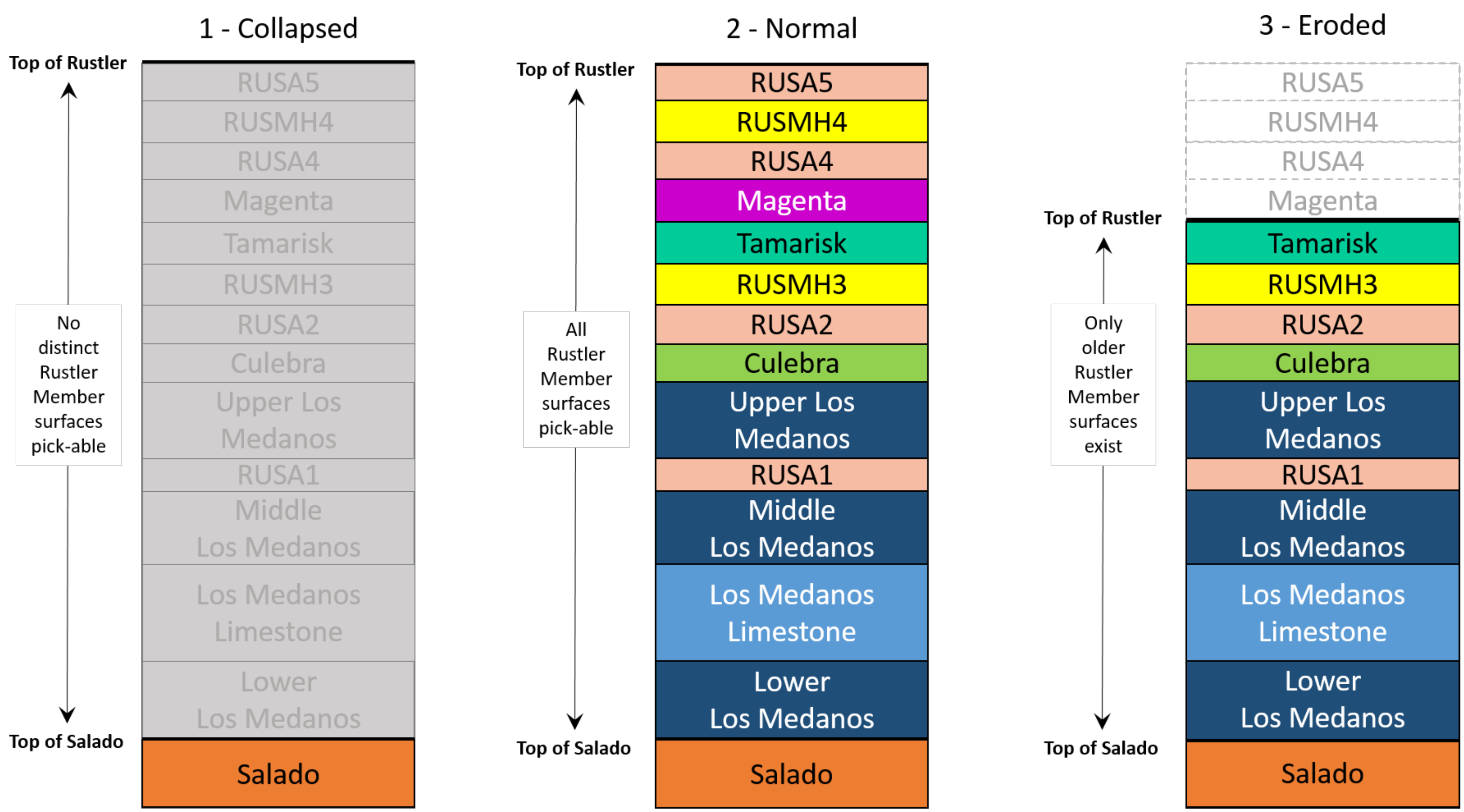

Figure 19-1. **INTERA classification of stratigraphic columns from interpreted well logs for the creation of stratigraphy zones and volumetric regions.**

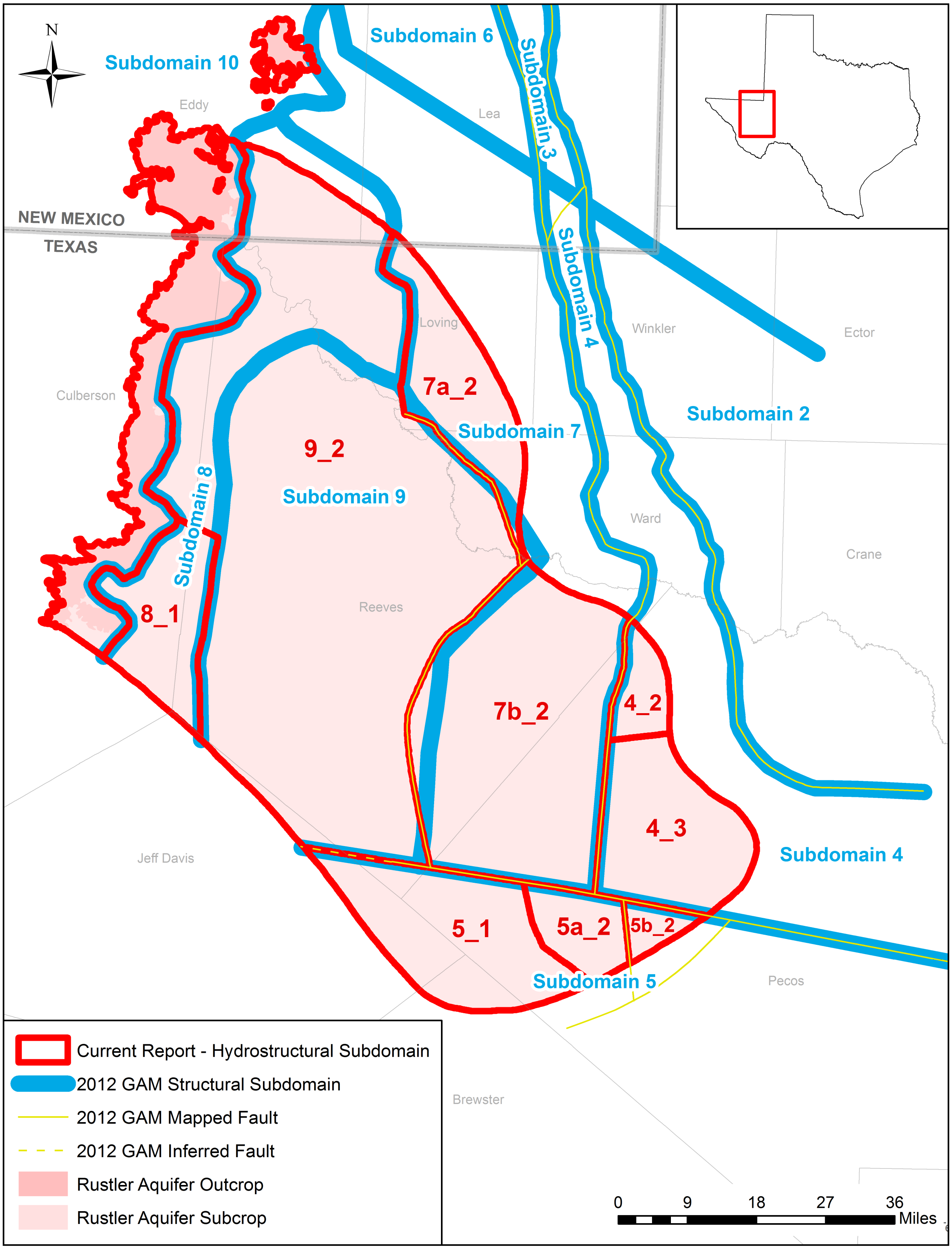

Figure 19-2. Hydrostructural subdomains used in the current report compared to the structural subdomains mapped in the original Rustler Groundwater Availability Model (GAM) (Ewing and others, 2012).

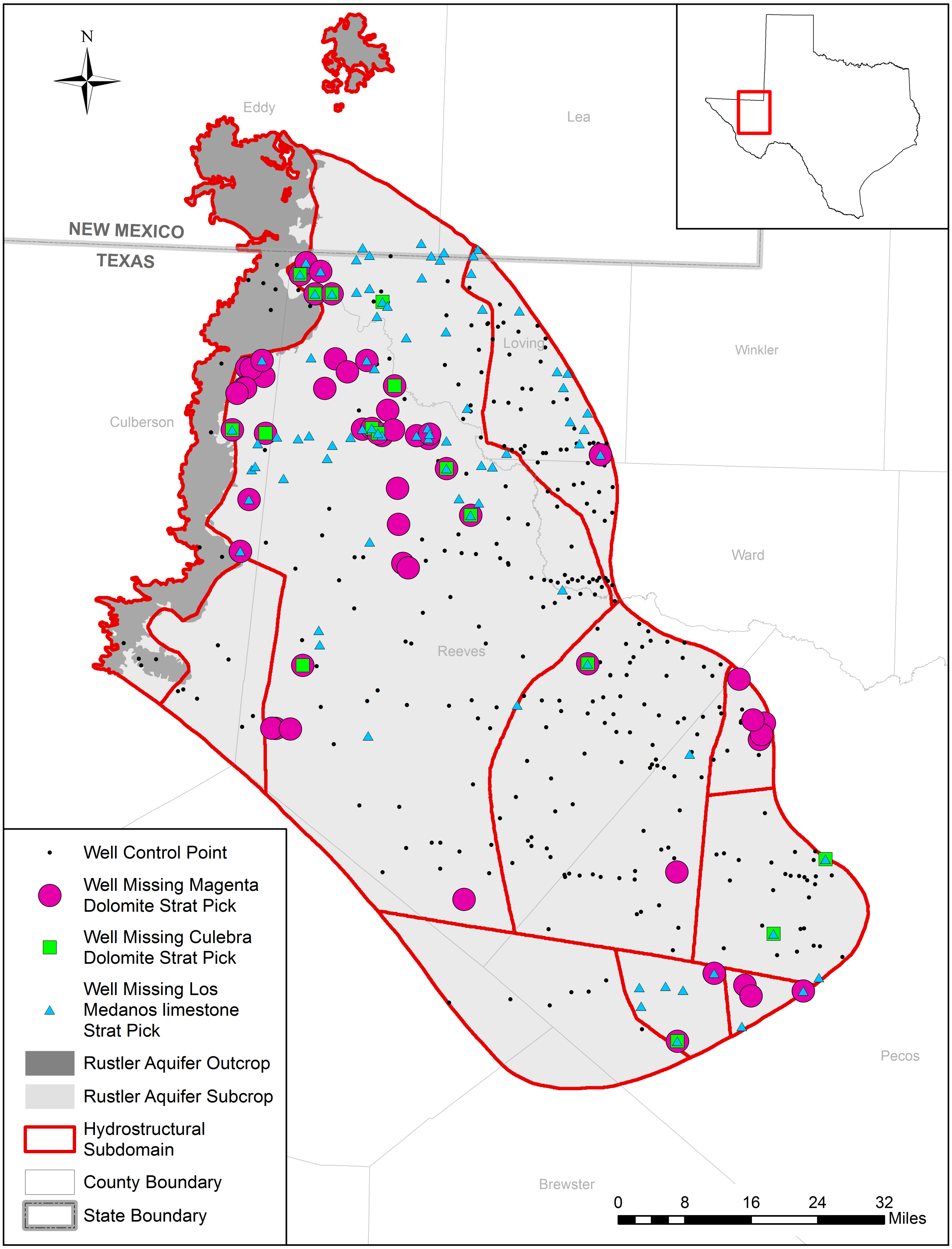

Figure 19-3. Well control points used in the surface interpolation process.

19.2 Oversized cross-sections

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0
NORTH
0'
SOUTH
Subsea Depth(ft)
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
30388
2,867 ft msl
DL: ND
Rus: 2 ft
Sal: 252 ft
32674
2,904 ft msl
DL: 189 ft
Rus: 320 ft
Sal: 624 ft
00074
2,952 ft msl
DL: 272 ft
Rus: 379 ft
Sal: 767 ft
31403
2,932 ft msl
DL: 354 ft
Rus: 495 ft
Sal: 596 ft
00443
2,982 ft msl
DL: 165 ft
Rus: 313 ft
Sal: 600 ft
31270
3,010 ft msl
DL: 35 ft
Rus: 239 ft
Sal: 540 ft
00594
2,995 ft msl
DL: 47 ft
Rus: 124 ft
Sal: 931 ft
32901
3,097 ft msl
DL: 340 ft
Rus: 766 ft
Sal: 1,069 ft
00489
3,233 ft msl
DL: 563 ft
Rus: 801 ft
Sal: 1,300 ft
30243
3,176 ft msl
DL: 701 ft
Rus: 1,136 ft
Sal: 1,500 ft
00245
2,983 ft msl
DL: 690 ft
Rus: 1,170 ft
Sal: 1,590 ft
01103
2,878 ft msl
DL: 800 ft
Rus: 1,230 ft
Sal: 1,614 ft
32472
3,110 ft msl
DL: 1,450 ft
Rus: 1,683 ft
Sal: 2,089 ft
31421
3,058 ft msl
DL: 1,263 ft
Rus: 1,691 ft
Sal: 2,110 ft
32331
3,198 ft msl
DL: 1,396 ft
Rus: 1,871 ft
Sal: 2,284 ft
10509
3,094 ft msl
DL: 1,285 ft
Rus: 1,787 ft
Sal: 2,257 ft
00142
3,214 ft msl
DL: 1,270 ft
Rus: 1,834 ft
Sal: 2,252 ft
10513
3,271 ft msl
DL: 1,343 ft
Rus: 1,841 ft
Sal: 2,217 ft
35149
3,797 ft msl
DL: 1,240 ft
Rus: 1,654 ft
Sal: 2,079 ft
30002
3,773 ft msl
DL: 1,300 ft
Rus: 1,458 ft
Sal: 1,682 ft
DEWEY LAKE
SALADO
Tamarisk
Culebra
Magenta
Collapse
Los Medaños Limestone
No available logs along cross section trace in this area
VE ~130x
1 A5
2 M4
3 A4
4 M3
5 A2
6 Los Medaños
7 A1
8 Los Medaños
Subdomain 10
Subdomain 6
Subdomain 8
Subdomain 7
Subdomain 2
Subdomain 9
Subdomain 4
Subdomain 5
NEW MEXICO
TEXAS
Legend
Rustler Aquifer Outcrop
Rustler Aquifer Subcrop
Tessey Limestone Outcrop
Hydrogeologic Boundaries
County Boundary
State Boundary
Miles


Subsea Depth(ft)
1
NORTH-NW
1'
SOUTH-SE
Subsea Depth(ft)
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
DEWEY LAKE
SALADO
DL
Magenta
Tamarisk
Culebra
Los Medaños Limestone
VE ~90x
1 A5
2 M4
3 A4
4 M3
5 A2
6 Los Medaños
7 A1
8 Los Medaños
Legend
Rustler Aquifer Outcrop
Rustler Aquifer Subcrop
Tessey Limestone Outcrop
Hydrogeologic Boundaries
County Boundary
State Boundary
Miles

A
WEST
A'
EAST
Subsea Depth(ft)
3400
3300
3200
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
Collapse
DEWEY LAKE
(Upper Surface Undetermined)
SALADO
Magenta
Tamarisk
Culebra
Los Medaños Limestone
DL
VE ~70x
1 A5
2 M4
3 A4
4 M3
5 A2
6 Los Medaños
7 A1
8 Los Medaños
Subdomain 10
Subdomain 6
Subdomain 3
Subdomain 8
Subdomain 7
Subdomain 2
Subdomain 9
Subdomain 4
Subdomain 5
NEW MEXICO
TEXAS
Legend
Rustler Aquifer Outcrop
Rustler Aquifer Subcrop
Tessey Limestone Outcrop
Hydrogeologic Boundaries
County Boundary
State Boundary
Miles

B WEST
B' EAST
Subsea Depth(ft)
DEWEY LAKE
SALADO
Magenta
Tamarisk
Culebra
Los Medaños Limestone
VE ~100x
1 A5
2 M4
3 A4
4 M3
5 A2
6 Los Medaños
7 A1
8 Los Medaños
Subdomain 10
Subdomain 6
Subdomain 3
Subdomain 8
Subdomain 7
Subdomain 2
Subdomain 9
Subdomain 4
Subdomain 5
NEW MEXICO
TEXAS
Legend
Rustler Aquifer Outcrop
Rustler Aquifer Subcrop
Tessey Limestone Outcrop
Hydrogeologic Boundaries
County Boundary
State Boundary
Miles

19.3 Water wells determined to be producing from the Rustler Aquifer

Table 19-3. Water wells determined to be producing from the Rustler Aquifer.

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
4533906	--	Buckles & Hostetler	TWDB GW Database	Yes	Yes	31.41389	-102.90333	4017524.459	19756598.37	2,540.1	982	Withdrawal of Water	Plugged or Destroyed	Well screen / open intervals	--	787	982	O	1	160	--	--	--	--	PLUGGED; yield reported in 1960
4533912	--	Forest Oil Corp.	TWDB GW Database	Yes	Yes	31.39444	-102.91167	4014742.54	19749578.65	2,532.4	1,033	Withdrawal of Water	Plugged or Destroyed	Well screen / open intervals	--	833	1,033	O	1	--	--	--	--	--	DESTROYED
4535901	--	T.C. Barnsley	TWDB GW Database	Yes	Yes	31.38472	-102.65306	4095156.02	19744012.22	2,427.5	243	Withdrawal of Water	Unused	Well depth	--	--	--	--	--	--	--	--	--	--	--
4541603	--	Payton Water-flood Co.	TWDB GW Database	Yes	No	31.304444	-102.88111	4023400.89	19716533.58	2,442.0	761	Withdrawal of Water	Unused	Well screen / open intervals	--	637	761	O	1	200	--	--	--	Bull 6106	--
4542603	--	Hal Eudaly, Jr	TWDB GW Database	Yes	Yes	31.30028	-102.78389	4053653.176	19714240.76	2,410.9	1695	Oil or Gas	Plugged or Destroyed	Well depth	--	--	--	--	--	--	--	--	--	--	DESTROYED

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
4542703	--	Walbet Inc.	TWDB GW Database	Yes	Yes	31.2525	-102.863055	4028536.39	19697458.42	2,436.1	774	Withdrawal of Water	Plugged or Destroyed	Well depth	--	--	--	--	--	--	--	--	--	Bull 6106	PLUGGED
4542802	--	Signal Oil & Gas Co	TWDB GW Database	Yes	Yes	31.28083	-102.81722	4043087.685	19707415.64	2,410.9	491	Withdrawal of Water	Plugged or Destroyed	Well screen / open intervals	--	440	491	SO	2	--	--	--	--	R125	PLUGGED
4544601	--	Jax Cowden Est.	TWDB GW Database	Yes	Yes	31.30778	-102.52583	4134125.056	19715044.92	2,351.0	550	Withdrawal of Water	Plugged or Destroyed	Well screen / open intervals	--	430	550	SO	1	--	--	--	--	--	DESTROYED
4549203	US-45-49-203 (31142210255 5101)	Enstor-Waha WW Site	TWDB GW Database	Yes	Yes	31.239721	-102.93111	4007198.081	19693357.11	2,521.0	see note	Withdrawal of Water	Industrial	USGS well classification	--	3,135	3,830	S	1	--	--	--	833 gpm	--	USGS station US-45-49-203 (311422102555101); USGS WQ measurement not in GWDB; Reported transmissivity of 129,000 gpd/ft; Reported original depth 10,993 ft; Flow w/ 166 ft of head in 2005; MPGCD reports total depth of 2800 ft in 2010; GWDB reports 4121 ft
4558502	--	San Pedro Ranch	TWDB GW Database	Yes	Yes	31.044444	-102.8125	4042369.2	19621236.63	2,663.8	1364	Withdrawal of Water	Stock	Well depth	--	--	--	--	--	--	--	--	50 gpm	Bull 6106	FLOWED in 1956; field conductance 4030 in 1987

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
4558601	--	Farmland Industries	TWDB GW Database	No	No	31.059722	-102.755	4060472.29	19626352.11	2,572.1	311	Withdrawal of Water	Industrial	Well depth	--	--	--	--	--	1,500	25	60	--	--	56-hr test in 1969
4558602	--	Farmland Industries	TWDB GW Database	No	No	31.059166	-102.755	4060467.25	19626149.5	2,573.3	314	Withdrawal of Water	Industrial	Well screen / open intervals	--	292	312	O	1	689	44	15.7	--	--	24-hr test in 1974
4558603	--	Farmland Industries	TWDB GW Database	No	No	31.060277	-102.753611	4060911.22	19626543.55	2,569.8	354	Withdrawal of Water	Industrial	Well screen / open intervals	--	334	354	O	1	1,000	--	--	--	--	24-hr test in 1974
4558604	--	Farmland Industries	TWDB GW Database	No	No	31.060833	-102.7525	4061263.31	19626737.53	2,569.7	355	Withdrawal of Water	Industrial	Well screen / open intervals	--	312	355	O	1	1,000	125	8	--	--	Test in 1977
4558801	--	--	TWDB GW Database	No	No	31.016388	-102.804722	4044540.1	19610951.32	2,691.9	3600	Withdrawal of Water	--	Well depth	--	--	--	--	--	--	--	--	--	--	--
4559501	US-45-59-501 (31043010240 1201)	Buena Vista Ranch	TWDB GW Database	Yes	Yes	31.07528	-102.67055	4086989.643	19631374.95	2,482.9	--	Withdrawal of Water	Unused	TWDB classification	--	--	--	--	--	10	--	--	--	Bull 6106	USGS station US-45-59-501 (310430102401201); CAVED IN
4601202	--	W. D. Johnson Est.	TWDB GW Database	No	Yes	31.994999	-103.931388	3705158.99	19978188.99	2,862.9	80	Withdrawal of Water	Stock	TWDB classification	--	--	--	--	--	3	24	0.1	--	--	Test in 1966

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
4601701	--	Jack Camp Estate	TWDB GW Database	No	Yes	31.906111	-103.964444	3693777.72	19946170.1	2,882.6	150	Withdrawal of Water	Unused	Well depth	in_or _near	--	--	--	--	--	--	--	--	TWC Bull 6214	--
4601702	--	Jeff Lindsay	TWDB GW Database	No	Yes	31.906388	-103.972499	3691288.42	19946360.44	2,890.1	220	Withdrawal of Water	Stock	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	--
4602401	--	Johnson Ranch	TWDB GW Database	No	Yes	31.92361	-103.874721	3721769.58	19951561.71	2,885.4	308	Withdrawal of Water	Domestic	Well depth	--	--	--	--	--	--	--	--	--	--	--
4609301	--	Jeff Lindsay	TWDB GW Database	No	Yes	31.855277	-103.916388	3707994.97	19927120.24	2,853.7	200	Withdrawal of Water	Stock	Well depth	--	--	--	--	--	--	--	--	--	--	--
4613402	--	B. K. Boyd	TWDB GW Database	Yes	Yes	31.821943	-103.469721	3845938.47	19910356.93	3,042.3	1000	Withdrawal of Water	Unused	Well screen / open intervals	--	860	955	S	2	--	--	--	--	--	--
4620201	--	McGinley Corp.	TWDB GW Database	No	No	31.715833	-103.552777	3818965.57	19872510.67	2,750.9	175	Withdrawal of Water	Unused	Well depth	--	--	--	--	--	--	--	--	--	TBWE Misc Pub 209A	--
4620405	--	E. Jones	TWDB GW Database	Yes	Yes	31.706666	-103.598055	3804813.92	19869624.39	2,686.3	400	Withdrawal of Water	Domestic	Well screen / open intervals	--	277	400	O	1	--	--	--	--	--	--

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
4630601	--	Humble Oil & Refining	TWDB GW D atabase	Yes	No	31.5625	-103.270832	3904763.57	19813940.68	2,791.1	975	Withdrawal of Water	Unused	Open interval info (from Remarks table)	--	749	975	O	1	18	--	--	--	--	Open hole 749-975 in Rustler Formation.""
4634903	--	Billy Mack Jobe	TWDB GW Database	No	Yes	31.388888	-103.756111	3751858.64	19755474.86	2,858.2	1200	Withdrawal of Water	Stock	Well depth	--	--	--	--	--	--	--	--	--	TWC Bull 6214	Formerly well #4635703
4638601	--	C.M. Haughton	TWDB GW Database	No	Yes	31.427777	-103.257222	3907546.8	19764724.31	2,544.7	4670	Test Hole	Unused	Well depth	--	--	--	--	--	--	--	--	36 to 1800 gpm; see Note	--	Flow decreased from 1800 gpm in 1923 to 206 gpm in 1940 to 36 gpm in 1964, back up to 49 gpm in 1967. Produces from "four horizons 700 to 1200 ft deep."
4640701	--	Mr. Bethel L. Eiland	TWDB GW Database	Yes	Yes	31.387221	-103.100833	3955790.52	19748547.69	2,494.0	1100	Withdrawal of Water	Domestic	Well screen / open intervals	--	20	1,100	O	1	--	--	--	8 to 140 gpm; see Note	--	1931: 140gpm; 1959: 40gpm; 1961: 15gpm; 1967: 8gpm; Rustler top @ 900 ft; top of dolomite @ 1025 ft
4640702	--	Mr. Bethel Eiland	TWDB GW Database	Yes	No	31.389721	-103.103888	3954865.14	19749485.35	2,495.0	1080	Withdrawal of Water	Stock	Well screen / open intervals	--	31	150	O	2	250	147	1.7	--	--	83-hr test in 1967; Still flowing in 1995; Flow rates in 1948: 200gpm; 1959: 150gpm; 1967: 47gpm; Top of Rustler anydrite @ 888 ft; main producing zone @ 1024 ft
4640703	--	Mr. Bethel Eiland	TWDB GW Database	Yes	Yes	31.394999	-103.110277	3952930.53	19751464.49	2,515.7	1125	Withdrawal of Water	Stock	Well screen / open intervals	--	30	1,125	O	1	650	--	--	--	--	41-hr test in 1967; Still flowing in 1995; Flow in 1959: 150gpm; 1967: 53gpm

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
4640705	--	A.G. Riley Est.	TWDB GW Database	Yes	No	31.395833	-103.104166	3954841.09	19751714.99	2,545.0	1300	Withdrawal of Water	Unused	Well depth	--	--	--	--	--	--	--	--	16 gpm	--	Flowing in 1967
4640706	--	Mr. Bethel Eiland	TWDB GW Database	Yes	No	31.395833	-103.104166	3954841.09	19751714.99	2,545.0	1200	Withdrawal of Water	Unused	Well depth	--	--	--	--	--	--	--	--	30 gpm	--	Flowing in 1967
4640801	--	Mr. Bethel Eiland	TWDB GW Database	Yes	Yes	31.392221	-103.07361	3964314.96	19750133.28	2,483.9	1680	Withdrawal of Water	Unused	Well depth	--	--	--	--	--	--	--	--	0.25 to 900 gpm; see Note	--	Flowing 900 gpm in 1932; 0.25 in 1967; ""barely flowing"" in 1995
4641101	--	Atlantic Richfield	TWDB GW Database	No	No	31.35	-103.981943	3681069.84	19743765.49	3,143.3	802	Test Hole	--	Well depth	--	--	--	--	--	--	--	--	--	--	--
4641502	--	T. Cheeves #1	TWDB GW Database	Yes	Yes	31.319166	-103.950277	3690526.95	19732179.02	3,171.0	2960	Oil or Gas	--	TWDB classificat ion	--	--	--	--	--	--	--	--	reported	TWC Bull 6214	Reportedly flowed in 1956
4643102	--	W. H. Groves	TWDB GW Database	Yes	Yes	31.338333	-103.743333	3755212.11	19736921.23	2,862.2	4133	Test Hole	--	Well depth	--	--	--	--	--	--	--	--	--	TWC Bull 6214	Water sample from Rustler at 1440 ft""
4645701	--	B. Prewitt	TWDB GW Database	Yes	No	31.256388	-103.472777	3838523.67	19704316.46	2,617.6	1200	Withdrawal of Water	Unused	Well depth	--	--	--	--	--	--	--	--	--	TWC Bull 6214	Reported yield in 1979

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
4649503	--	Freeport Sulphur	TWDB GW Database	No	No	31.176943	-103.941944	3691275.89	19680274.14	3,351.0	1020	Withdrawal of Water	Unused	Well depth	--	--	--	--	--	--	--	--	--	--	--
4649505	--	Freeport Sulphur	TWDB GW Database	No	Yes	31.173332	-103.925554	3696341.11	19678776.89	3,301.3	1200	Withdrawal of Water	Unused	Well screen / open intervals	--	775	1,200	O	1	460	--	--	--	--	Reported yield in 1979
4649507	--	Freeport Sulphur	TWDB GW Database	No	Yes	31.19361	-103.944166	3690799.34	19686370.61	3,358.3	1595	Withdrawal of Water	Unused	Well screen / open intervals	--	710	1,292	O	2	400	--	--	--	--	Reported yield in 1979
4649508	--	Freeport Sulphur	TWDB GW Database	No	Yes	31.181943	-103.933888	3693853.25	19682006.2	3,352.3	1345	Withdrawal of Water	Unused	Well screen / open intervals	--	1,257	1,345	O	1	550	--	--	--	--	Reported yield in 1979
4649509	--	Freeport Sulphur	TWDB GW Database	No	No	31.191388	-103.939166	3692329.69	19685505.58	3,353.1	1520	Withdrawal of Water	Unused	Well screen / open intervals	--	1,260	1,520	S	1	800	145	5.5	--	--	Reported yield in 1979
4649601	--	Cedarville Farms Inc.	TWDB GW Database	No	No	31.175554	-103.883888	3709365.4	19679127.69	3,209.9	1524	Withdrawal of Water	Unused	Well depth	--	--	--	--	--	--	--	--	--	--	--
4649605	--	Penzoil Corp.	TWDB GW Database	No	No	31.183333	-103.915833	3699502.09	19682312.82	3,310.6	1198	Withdrawal of Water	Industrial	Well screen / open intervals	--	635	1,198	O	1	760	56	13.6	--	--	Reported yield in 1979

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
4649606	--	Penzoil Corp.	TWDB GW Database	Yes	No	31.17111	-103.904722	3702810.14	19677737.46	3,288.8	1581	Withdrawal of Water	Industrial	Well screen / open intervals	--	1,325	1,570	S	1	550	183	3	--	--	Reported yield in 1979
4649701	--	Freeport Sulphur Co.	TWDB GW Database	No	Yes	31.144444	-103.999444	3672914.37	19669078.72	3,610.1	1090	Withdrawal of Water	Unused	Well screen / open intervals	--	799	1,090	S	1	710	--	--	--	--	Reported yield in 1979
4650403	--	Stoeckman Farms	TWDB GW Database	Yes	No	31.173054	-103.870554	3713492.43	19678071.17	3,188.7	1558	Withdrawal of Water	Irrigation	Well depth	--	--	--	--	--	1,000	--	--	--	--	--
4650404	--	Stoeckman Farms	TWDB GW Database	Yes	No	31.173332	-103.864722	3715315.03	19678108.86	3,175.3	1492	Withdrawal of Water	Irrigation	Well depth	--	--	--	--	--	1,000	--	--	--	--	--
4651523	--	K. Lindemann	TWDB GW Database	Yes	No	31.205833	-103.690277	3770122.57	19688092.04	2,864.0	2022	Test Hole	--	Well depth	--	--	--	--	--	--	--	--	--	--	--
4652107	--	Passmore Bros.	TWDB GW Database	Yes	No	31.224166	-103.615833	3793554.22	19694004.99	2,723.5	2365	Test Hole	Unused	Well depth	--	--	--	--	--	--	--	--	--	--	--
4652901	--	Randy Taylor	TWDB GW Database	Yes	Yes	31.126666	-103.501666	3828023.94	19657336.26	2,790.0	1300	Withdrawal of Water	Irrigation	Well depth	--	--	--	--	--	--	--	--	--	--	--

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
4653903	--	Barilla Farms	TWDB GW Database	Yes	Yes	31.127777	-103.394721	3861414.13	19656700.84	2,792.8	1405	Withdrawal of Water	Irrigation	Well depth	--	--	--	--	--	--	--	--	--	TWC Bull 6214	Additional WQ data in TWC Bull 6214 not included in GWDB (well W-10)
4654802	--	Flat Top Farms	TWDB GW Database	Yes	No	31.148333	-103.297777	3891894.31	19663275.66	2,773.8	1212	Withdrawal of Water	Unused	Well screen / open intervals	--	1,110	1,212	O	1	--	--	--	--	--	--
4654901	WD-46-54-901 (31080610317 1901)	Flat Top Farms	TWDB GW Database	Yes	Yes	31.134999	-103.28861	3894610.42	19658332.07	2,781.8	1250	Withdrawal of Water	Irrigation	Well screen / open intervals	--	1,145	1,250	O	1	--	--	--	--	--	USGS station WD-46-54-901 (310806103171901); USGS WQ measurement not in GWDB; ""WQ well""
4654903	--	Flat Top Farms	TWDB GW Database	Yes	Yes	31.156944	-103.291388	3893981.29	19666353.86	2,770.8	--	Withdrawal of Water	Irrigation	Well depth	--	--	--	--	--	--	--	--	--	--	H2S smell
4655601	--	Burkholder Rustler #2	TWDB GW Database	Yes	No	31.184999	-103.133888	3943414.38	19675149.75	2,693.9	1555	Withdrawal of Water	Unused	Well depth	--	--	--	--	--	--	--	--	--	--	--
4655604	--	B. Burkholder	TWDB GW Database	Yes	No	31.187777	-103.129999	3944656.14	19676127.68	2,689.0	1500	Withdrawal of Water	Unused	Well screen / open intervals	--	1,300	1,500	O	1	600	--	--	--	Bull 6106	Reported yield in 1959
4655605	--	B. Burkholder	TWDB GW Database	Yes	No	31.187499	-103.129999	3944653.27	19676026.38	2,689.6	1570	Withdrawal of Water	Unused	Well depth	--	--	--	--	--	600	--	--	--	Bull 6106	--

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
4660202	--	F. F. Bradley	TWDB GW Database	Yes	No	31.104444	-103.573332	3805395.91	19649955.13	2,819.7	1625	Withdrawal of Water	Unused	Well screen / open intervals	--	503	658	S	2	--	--	--	--	TWC Bull 6214	--
4660811	--	Ben Powell	TWDB GW Database	Yes	No	31.030277	-103.555555	3810076.9	19622754.87	2,903.5	1415	Withdrawal of Water	Unused	Well screen / open intervals	--	1,230	1,415	O	1	--	--	--	--	--	--
4660902	--	R. W. Winterowd	TWDB GW Database	Yes	No	31.013055	-103.519999	3820985.38	19616125.15	2,948.7	1450	Withdrawal of Water	Unused	Well depth	--	--	--	--	--	750	--	--	--	TWC Bull 6214	Measured yield in 1959
4660903	--	Winterowd Brothers	TWDB GW Database	No	No	31.019166	-103.517777	3821750.48	19618329.5	2,943.7	1030	Withdrawal of Water	Unused	Well depth	--	--	--	--	--	650	--	--	--	TWC Bull 6214	--
4660904	--	B. Powell	TWDB GW Database	Yes	No	31.008611	-103.538055	3815291.67	19614686.02	2,934.4	1500	Withdrawal of Water	Unused	Well screen / open intervals	--	1,050	1,500	S	1	1,100	--	--	When drilled	TWC Bull 6214	Reported yield in 1958; Reportedly flowed when drilled
4660905	--	Dale Toone	TWDB GW Database	Yes	Yes	31.014166	-103.527499	3818654.77	19616604.56	2,939.7	1311	Withdrawal of Water	Irrigation	Well depth	--	--	--	--	--	--	--	--	--	--	--
4661103	--	Rudolph Hoefs	TWDB GW Database	Yes	Yes	31.114166	-103.491944	3830914.42	19652686.07	2,813.8	1270	Withdrawal of Water	Irrigation	Well screen / open intervals	--	1,166	1,270	O	1	--	--	--	--	--	H2S smell

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
4661203	--	--	TWDB GW Database	Yes	Yes	31.114722	-103.422777	3852510.65	19652214	2,815.9	--	Withdrawal of Water	Irrigation	Well depth	--	--	--	--	--	--	--	--	--	--	Conductance of 2890 in 1995
4661205	--	K&D Farms	TWDB GW Database	Yes	Yes	31.113333	-103.453333	3842957.03	19652004.3	2,825.8	--	Withdrawal of Water	Irrigation	Well depth	--	--	--	--	--	--	--	--	--	--	--
4661206	--	K&D Farms	TWDB GW Database	Yes	Yes	31.112222	-103.453333	3842944.4	19651599.51	2,826.8	--	Withdrawal of Water	Irrigation	Well depth	--	--	--	--	--	--	--	--	--	--	--
4723501	--	Pennzoil Sulphur Co.	TWDB GW Database	Yes	No	31.672221	-104.207777	3615231.3	19863747.73	3,441.7	140	Withdrawal of Water	Stock	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	--
4723502	--	Pennzoil Sulphur Co.	TWDB GW Database	Yes	No	31.669999	-104.18111	3623473.71	19862624.59	3,342.9	150	Withdrawal of Water	Stock	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	--
4723601	--	Pennzoil Sulphur Co.	TWDB GW Database	Yes	Yes	31.695833	-104.164166	3629084.73	19871837.5	3,367.2	200	Withdrawal of Water	Stock	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	--
4723602	--	Freeport Sulphur Co.	TWDB GW Database	Yes	Yes	31.666943	-104.13611	3637393.12	19860986.48	3,311.6	110	Withdrawal of Water	Stock	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	--

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
4723603	--	Pennzoil Sulphur Co.	TWDB GW Database	Yes	No	31.687777	-104.139444	3636642.71	19868614.95	3,221.8	--	Withdrawal of Water	Stock	Well depth	in_or_near	--	--	--	--	--	--	--	--	--	--
4723701	--	Freeport Sulphur	TWDB GW Database	Yes	Yes	31.643888	-104.226666	3608976.98	19853649.79	3,490.1	--	Spring	Stock	Spring - located in Rustler Hills; TWDB classification	in_or_near	--	--	--	--	--	--	--	200 gpm	--	Rustler Spring""; flow rate reported in 1961; reportedly had flowed continuously for 50 years in 1961
4723801	--	Pennzoil Sulphur Co.	TWDB GW Database	Yes	No	31.635555	-104.183054	3622396.14	19850099.73	3,470.6	200	Withdrawal of Water	Stock	Well depth	in_or_near	--	--	--	--	--	--	--	--	--	--
4724501	--	Pennzoil Sulphur Co.	TWDB GW Database	No	No	31.696388	-104.081943	3654594.79	19871089.22	3,149.2	30	Withdrawal of Water	Stock	Well depth	--	--	--	--	--	--	--	--	--	--	--
4724701	--	Pennzoil Sulphur Co.	TWDB GW Database	Yes	Yes	31.6625	-104.113611	3644313.44	19859107.62	3,235.1	138	Withdrawal of Water	Stock	Well screen / open intervals	in_or_near	120	138	S	1	40	30	1.3	--	--	0.5-hr bailing test
4731101	--	Nevill	TWDB GW Database	Yes	No	31.593888	-104.225832	3608540.01	19835425.63	3,778.6	534	Test Hole	Unused	Well depth	in_or_near	--	--	--	--	--	--	--	--	--	Former SWN 47-31-701; ""no water sand encountered""
4731901	--	M. A. Grisham	TWDB GW Database	Yes	Yes	31.520554	-104.154722	3629615.8	19807874.27	3,424.9	200	Withdrawal of Water	Stock	Well depth	in_or_near	--	--	--	--	--	--	--	--	--	Former SWN 47-31-801

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
4740902	--	A. B. Tinnin	TWDB GW Database	No	No	31.397499	-104.032777	3665875.28	19761642.62	3,284.0	260	Withdrawal of Water	Unused	Well depth	--	--	--	--	--	--	--	--	--	TWC Bull 6214	--
4745302	--	--	TWDB GW Database	Yes	No	31.361666	-104.379166	3557584.2	19752687.78	4,406.4	--	Spring	--	Spring - located in Rustler Hills; TWDB classificat ion	in_or _near	--	--	--	--	--	--	--	--	--	--
4746101	--	Elcor Chemical Corp.	TWDB GW Database	Yes	Yes	31.356944	-104.339166	3569966.26	19750477.15	4,159.1	400	Withdrawal of Water	Stock	Well screen / open intervals	in_or _near	150	400	O	1	--	--	--	--	--	--
4746601	--	Hughes-Kent Ranch	TWDB GW Database	Yes	Yes	31.311666	-104.281943	3587139.02	19733289.83	3,834.9	430	Withdrawal of Water	Stock	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	--
4746602	--	Hughes-Kent Ranch	TWDB GW Database	Yes	Yes	31.322499	-104.259722	3594210.87	19736968.8	3,742.9	320	Withdrawal of Water	Unused	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	--
4746701	--	Jobe Ranch	TWDB GW Database	No	No	31.275554	-104.356666	3563351.7	19721044.41	4,160.7	1530	Test Hole	Plugged or Destroyed	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	PLUGGED
4746801	--	Hughes-Kent Ranch	TWDB GW Database	Yes	No	31.268332	-104.300833	3580642.79	19717733.1	3,937.7	628	Withdrawal of Water	Unused	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	Reported DRY in 1970

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
4746804	--	Jobe Ranch	TWDB GW Database	No	No	31.2575	-104.306944	3578585.28	19713861.51	3,849.7	2135	Test Hole	Plugged (see Remarks table)	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	PLUGGED
4747401	--	Hughes-Kent Ranch	TWDB GW Database	Yes	Yes	31.317777	-104.239166	3600545.67	19735002.84	3,675.4	320	Withdrawal of Water	Stock	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	--
4747402	--	Hughes-Kent Ranch	TWDB GW Database	Yes	No	31.307222	-104.214166	3608184.13	19730860.48	3,606.7	300	Withdrawal of Water	Stock	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	--
4747403	--	Hughes-Kent Ranch	TWDB GW Database	Yes	Yes	31.297499	-104.248055	3597494.02	19727722.35	3,713.9	330	Withdrawal of Water	Stock	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	--
4747404	--	Hughes-Kent Ranch	TWDB GW Database	Yes	Yes	31.332499	-104.250277	3597291.8	19740498.39	3,743.2	552	Withdrawal of Water	Stock	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	--
4747701	--	Hughes-Kent Ranch	TWDB GW Database	Yes	Yes	31.269166	-104.228332	3603242.51	19717166.12	3,820.7	230	Withdrawal of Water	Unused	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	--
4747703	--	Hughes-Kent Ranch	TWDB GW Database	Yes	No	31.258333	-104.208888	3609150.31	19712988.95	3,777.7	--	Withdrawal of Water	--	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	Hurd Spring""; data from USGS

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
4747704	--	Hughes-Kent Ranch	TWDB GW Database	Yes	Yes	31.269166	-104.228332	3603242.51	19717166.12	3,820.7	--	Withdrawal of Water	Domestic	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	--
4747801	--	Hughes-Kent Ranch	TWDB GW Database	Yes	Yes	31.284721	-104.202222	3611592.54	19722522.43	3,599.2	180	Withdrawal of Water	Stock	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	--
4747901	--	Palafox Exploration	TWDB GW Database	Yes	Yes	31.261388	-104.129999	3633773.58	19713175.36	3,470.5	450	Withdrawal of Water	Stock	Well depth	--	--	--	--	--	--	--	--	--	--	--
4747902	--	Hughes-Kent Ranch	TWDB GW Database	Yes	Yes	31.253888	-104.165277	3622678.4	19710855.4	3,500.7	187	Withdrawal of Water	Stock	Well depth	--	--	--	--	--	--	--	--	--	--	--
4748701	--	T-Diamond Ranch	TWDB GW Database	No	Yes	31.281666	-104.092777	3645645.05	19720131.33	3,407.6	280	Withdrawal of Water	Stock	Well depth	--	--	--	--	--	--	--	--	--	TWC Bull 6214	Field conductance in 2040 umhos/cm in 2002
4754201	--	Jobe Ranch	TWDB GW Database	No	Yes	31.223332	-104.292499	3582603.22	19701240.54	3,757.4	160	Withdrawal of Water	Unused	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	--
4754202	--	Jobe Ranch	TWDB GW Database	No	Yes	31.222499	-104.304166	3578954.81	19701078.41	3,788.2	150	Withdrawal of Water	Unused	TWDB classificat ion	--	--	--	--	--	--	--	--	--	--	--

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
4754203	--	Jobe Ranch	TWDB GW Database	No	Yes	31.222777	-104.304166	3578958.75	19701179.68	3,788.3	150	Withdrawal of Water	Unused	TWDB classification	--	--	--	--	--	--	--	--	--	--	--
4754204	--	Jobe Ranch	TWDB GW Database	Yes	No	31.227499	-104.32361	3572965.28	19703136.03	3,838.4	--	Withdrawal of Water	Stock	TWDB classification	--	--	--	--	--	--	--	--	--	--	--
4754205	--	Jobe Ranch	TWDB GW Database	No	No	31.240555	-104.315833	3575574.78	19707797.11	3,831.1	1780	Test Hole	Unused	Well depth	in_or_near	--	--	--	--	--	--	--	--	--	--
4754206	--	Foster Ranch HQ	TWDB GW Database	No	Yes	31.222499	-104.303888	3579041.47	19701075.04	3,787.1	260	Withdrawal of Water	Unused	TWDB classification	--	119	125	S	2	15	--	--	--	--	Reported yield in 1977; field conductance 2530 umhos/cm in 1999; could not pump in 2002
4754207	--	Jobe Ranch	TWDB GW Database	No	No	31.220277	-104.303611	3579096.32	19700262.3	3,793.3	400	Withdrawal of Water	Unused	TWDB classification	--	128	131	S	2	7	--	--	--	--	Reported yield in 1977
4754208	--	Jobe Ranch	TWDB GW Database	No	Yes	31.241666	-104.32111	3573946.06	19708266	3,842.4	219	Withdrawal of Water	Stock	Well depth	in_or_near	--	--	--	--	--	--	--	--	--	Field conductance 1559 umhos/cm in 1993
4754301	--	Hughes-Kent Ranch	TWDB GW Database	Yes	No	31.247221	-104.263055	3592116.33	19709587.52	3,735.5	370	Withdrawal of Water	Unused	Well depth	in_or_near	--	--	--	--	--	--	--	--	--	Dry or caved in 1995; inaccessible in 2007

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
4754302	--	Hughes-Kent Ranch	TWDB GW Database	Yes	Yes	31.226943	-104.270277	3589580.64	19702287.81	3,714.3	280	Withdrawal of Water	Stock	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	--
4754303	--	Hughes-Kent Ranch	TWDB GW Database	No	No	31.22361	-104.265	3591178.63	19701010.27	3,717.3	2249	Test Hole	Unused	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	--
4755102	--	Jobe Ranch	TWDB GW Database	No	Yes	31.2125	-104.23611	3600028.8	19696617.27	3,692.9	358	Withdrawal of Water	Domestic	Well depth	--	--	--	--	--	19	2.62	7.3	--	--	4-hr pumping in 2002; field WQ: pH=7.28; T=22.6C; 2410 umhos/cm in 2002
4755103	--	Jobe Ranch	TWDB GW Database	No	No	31.213611	-104.235555	3600217.32	19697015.34	3,686.2	357	Withdrawal of Water	Unused	Well depth	--	--	--	--	--	--	--	--	--	--	--
4755104	--	Hughes-Kent Ranch	TWDB GW Database	Yes	Yes	31.229166	-104.232221	3601473.43	19702641.73	3,632.4	270	Withdrawal of Water	Unused - "capped"	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	CAPPED
4755106	--	Hughes-Kent Ranch	TWDB GW Database	Yes	No	31.227499	-104.226943	3603095.32	19701971.6	3,626.8	458	Withdrawal of Water	Rig Supply	Well screen / open intervals	in_or _near	418	458	S	1	250	--	--	--	--	Reported yield in 2006
4755201	--	Hughes-Kent Ranch	TWDB GW Database	No	No	31.213888	-104.18111	3617193.92	19696470.58	3,608.4	343	Withdrawal of Water	Unused	Well depth	--	--	--	--	--	--	--	--	--	--	Inaccessible in 2007

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
4755202	--	Hughes-Kent Ranch	TWDB GW Database	No	No	31.240277	-104.16861	3621452.96	19705936.36	3,522.7	1800	Test Hole	Plugged or Destroyed	Well depth	--	--	--	--	--	--	--	--	--	--	PLUGGED
4755203	--	Hughes-Kent Ranch	TWDB GW Database	Yes	Yes	31.239721	-104.200833	3611402.75	19706113.71	3,572.3	275	Withdrawal of Water	Unused	Well depth	in_or _near	--	--	--	--	--	--	--	--	--	Dry and caved in 1995
4755302	--	G. S. Rachal Estate	TWDB GW Database	No	No	31.244444	-104.162222	3623500.94	19707379.34	3,540.6	1800	Test Hole	Unused	Well depth	--	--	--	--	--	--	--	--	--	--	--
4755304	--	Palafox Exploration	TWDB GW Database	No	No	31.2125	-104.136388	3631116.93	19695440.85	3,610.8	183	Withdrawal of Water	Unused	TWDB classification	--	--	--	--	--	--	--	--	--	--	--
4755401	--	Yearwood Ranch	TWDB GW Database	No	Yes	31.203333	-104.214166	3606742.5	19693016.75	3,672.8	200	Withdrawal of Water	Stock	Well depth	--	--	--	--	--	--	--	--	--	--	Field conductance 1791 in 2003
4755402	--	Foster Ranch	TWDB GW Database	No	No	31.201388	-104.216943	3605849.7	19692341.24	3,682.1	1300	Test Hole	Unused	Well depth	--	--	--	--	--	--	--	--	--	--	--
4755406	--	Yearwood Ranch	TWDB GW Database	No	No	31.197221	-104.216666	3605878.2	19690820.05	3,681.9	220	Withdrawal of Water	Stock	Well depth	--	--	--	--	--	--	--	--	--	--	--

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
4755502	--	Foster Ranch	TWDB GW Database	No	No	31.205555	-104.204722	3609717.68	19693714.12	3,631.8	1981	Test Hole	Unused	Well depth	--	--	--	--	--	--	--	--	--	--	--
4755601	--	Yearwood Ranch	TWDB GW Database	No	No	31.167221	-104.144166	3628074.24	19679037.58	3,883.4	1602	Withdrawal of Water	Stock	Well depth	--	--	--	--	--	--	--	--	--	--	--
4755604	--	Yearwood Ranch	TWDB GW Database	No	Yes	31.199444	-104.136944	3630765.74	19690691.33	3,657.3	3180	Withdrawal of Water	Stock	Well depth	--	--	--	--	--	--	--	--	--	--	--
4755901	--	Yearwood Ranch	TWDB GW Database	No	No	31.130277	-104.145277	3627223.45	19665592.9	3,925.7	1150	Withdrawal of Water	Unused	Well depth	--	--	--	--	--	--	--	--	--	--	--
4756604	--	Palafox Exploration	TWDB GW Database	No	No	31.184999	-104.03861	3661234.31	19684296.25	3,573.4	722	Oil or Gas	--	TD - petroleu m	--	--	--	--	--	--	--	--	--	--	--
4756902	--	Banky Stocks	TWDB GW Database	Yes	No	31.165833	-104.022777	3665918.03	19677134.4	3,621.5	1245	Withdrawal of Water	Unused	Well screen / open intervals	--	575	1,245	O	1	--	--	--	--	--	--
4756904	--	Duval Corp.	TWDB GW Database	No	No	31.149721	-104.013611	3668564.14	19671161.14	3,633.1	1060	Withdrawal of Water	Unused	Well screen / open intervals	--	717	1,050	S	1	640	--	--	--	--	Reported yield in 1979

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
4756905	--	Duval Corp.	TWDB GW Database	No	No	31.16	-104.022499	3665927.48	19675006.35	3,610.1	925	Withdrawal of Water	Unused	Well screen / open intervals	--	600	925	S	1	680	--	--	--	--	Reported yield in 1974
4764101	--	Springhills Ranch	TWDB GW Database	No	Yes	31.115555	-104.108055	3638638.49	19659796.82	3,867.9	1300	Withdrawal of Water	Irrigation	Well screen / open intervals	--	348	1,300	O	1	--	--	--	--	--	--
5204211	--	McMahon	TWDB GW Database	Yes	No	30.970832	-103.547499	3811899.27	19601016.61	2,971.1	1500	Withdrawal of Water	Unused	Well screen / open intervals	--	1,350	1,500	O	1	--	--	--	--	--	--
5204302	--	R. Hoefs	TWDB GW Database	Yes	No	30.977221	-103.528888	3817791.44	19603158.25	2,978.9	1381	Withdrawal of Water	Unused	Well depth	--	--	--	--	--	--	--	--	--	TWC Bull 6214	--
5206301	--	Tinkler #1	TWDB GW Database	Yes	No	30.969721	-103.272777	3897770.47	19597964.82	2,980.8	1480	Oil or Gas	--	TD - petroleu m	--	--	--	--	--	--	--	--	--	--	--
5215502	--	M.R. Kennedy	TWDB GW Database	Yes	Yes	30.808888	-103.170277	3928136.88	19538431.57	3,219.0	1000	Withdrawal of Water	Stock	Well depth	--	--	--	--	--	--	--	--	--	Bull 6106	--
5216202	--	McKenzie, M.	TWDB GW Database	Yes	No	30.854444	-103.058333	3963653.88	19554043.56	3,097.5	--	Withdrawal of Water	Unused	Well depth	--	--	--	--	--	--	--	--	--	--	--

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
5216504	US-52-16-504 (304807103025301)	Belding Farms	TWDB GW Database	No	Yes	30.802222	-103.048333	3966259.995	19534929.61	3,169.7	3265	Withdrawal of Water	Irrigation	USGS well classification	--	2,668	3,265	O	1	--	--	--	--	--	USGS station US-52-16-504 (304807103025301); USGS WQ measurement not in GWDB
5216608	US-52-16-608 (304830103002001)	Belding Farms	TWDB GW Database	Yes	Yes	30.8025	-103.009166	3978530.05	19534695.12	3,194.0	1600	Withdrawal of Water	Irrigation	Well screen / open intervals	--	1,375	1,600	O	1	3,100	--	--	--	--	USGS station US-52-16-608 (304830103002001); Top of Rustler at 1390 ft
5216609	US-52-16-609 (304805103013301)	Belding Farms	TWDB GW Database	Yes	Yes	30.801388	-103.02611	3973212.02	19534434.68	3,191.2	1975	Withdrawal of Water	Irrigation	TWDB classification; no other support	--	1,718	1,975	O	1	4,400	11	400	--	--	USGS station US-52-16-609 (304805103013301); USGS WQ measurement not in GWDB; Reported yield in 1964
5216612	--	Belding Farms	TWDB GW Database	Yes	Yes	30.792221	-103.023888	3973816.7	19531075.58	3,213.1	1856	Withdrawal of Water	Irrigation	Well depth	--	--	--	--	--	--	--	--	--	--	--
5216613	--	Belding Farms	TWDB GW Database	Yes	Yes	30.815833	-103.016943	3976226.71	19539619.46	3,152.9	1617	Withdrawal of Water	Irrigation	Well depth	--	--	--	--	--	--	--	--	--	--	--
5216701	--	TXL-PECOS #1	TWDB GW Database	Yes	No	30.773888	-103.124999	3941956.61	19525276	3,452.2	1070	Oil or Gas	--	TD - petroleum	--	--	--	--	--	--	--	--	--	--	--
5224501	US-52-24-501 (304020103025202)	La Escalera Ranch	TWDB GW Database	No	Yes	30.672221	-103.047777	3965129.488	19487559.09	3,547.1	688	Withdrawal of Water	Stock	USGS well classification	--	645	688	S	2	30	125	0.24	--	--	USGS station US-52-24-501 (304020103025202); USGS WQ measurement not

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																									in GWDB; 2-hr jet test in 1983
5230701	--	R. Sims	TWDB GW Database	No	No	30.512777	-103.335555	3873125.5	19432076.55	3,770.1	1000	Withdrawal of Water	Domestic	Well depth	--	--	--	--	--	--	--	--	--	--	--
5231701	--	Robert Zoch	TWDB GW Database	No	Yes	30.515277	-103.23861	3903606.16	19432082.57	4,076.5	942	Withdrawal of Water	Stock	Well depth	--	--	--	--	--	--	--	--	--	--	--
5232501	--	La Escalera Ranch	TWDB GW Database	No	Yes	30.566111	-103.07111	3956738.55	19449102.19	3,988.1	1008	Withdrawal of Water	Stock	Well depth	--	--	--	--	--	--	--	--	--	--	--
5232701	--	La Escalera Ranch	TWDB GW Database	No	Yes	30.516388	-103.09361	3949167.58	19431183.95	4,244.9	1300	Withdrawal of Water	Stock	Well depth	--	--	--	--	--	--	--	--	--	--	"Changed to Capitan Reef Complex aquifer on 8/21/2014 per info from John Shomaker & Assoc., Inc."
5238301	--	El Corazon De Crystal	TWDB GW Database	No	Yes	30.475277	-103.263333	3895410.11	19417738.9	4,120.3	1040	Withdrawal of Water	Stock	Well depth	--	--	--	--	--	4.5	82	0.1	--	--	5-hr pumping in 1961; 4 to 5 gpm
5301201	--	Mrs. B. Downs	TWDB GW Database	Yes	Yes	30.963888	-102.949721	3998716.3	19592999.38	2,866.4	2997	Withdrawal of Water	Unused	Well screen / open intervals	--	400	2,997	O	1	--	--	--	0 to 2,000 gpm	Bull 6106	Flowing in 1956; abandoned & not flowing; caved @ 30 ft

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
5301203	--	Sibley Estate	TWDB GW Database	Yes	Yes	30.982777	-102.916943	4009146.77	19599610.57	2,817.3	3300	Withdrawal of Water	Stock	Well depth	--	--	--	--	--	--	--	--	--	Bull 6106	H2S smell
5302418	--	Lee O. White	TWDB GW Database	Yes	No	30.932777	-102.849721	4029692.6	19580843.46	2,882.2	1480	Withdrawal of Water	Unused	Well depth	--	--	--	--	--	--	--	--	0 to 400 gpm	Bull 6106	Flowing in 1956; not flowing in 1995; abandoned
5319701	US-53-19-7xx (PC QW) (303852102432902)	Clayton Mill	TWDB GW Database	No	Yes	30.647777	-102.724721	4066234.641	19476009.59	3,542.0	634	Withdrawal of Water	Unused	USGS well classification	--	--	--	--	--	--	--	--	--	--	USGS station US-53-19-7xx (PC QW) (303852102432902); USGS WQ measurement not in GWDB
5319801	US-53-19-801 (303751102404401)	Floyd Henderson	TWDB GW Database	No	Yes	30.63111	-102.679443	4080292.994	19469589.8	3,436.9	700	Withdrawal of Water	Stock	Well depth & USGS classification	--	--	--	--	--	--	--	--	--	Bull 6106	USGS station US-53-19-801 (303751102404401)
5325102	--	La Escalera Ranch	TWDB GW Database	No	Yes	30.623054	-102.973888	3987822.17	19469014.81	3,749.8	600	Withdrawal of Water	Stock	Well depth	--	--	--	--	--	--	--	--	--	--	--
5325301	--	La Escalera Ranch	TWDB GW Database	No	Yes	30.624443	-102.885277	4015641.7	19468784.7	3,600.4	600	Withdrawal of Water	Stock	Well depth	--	--	--	--	--	--	--	--	--	--	--
22S.30E.05.431	USGS_322502103540801	--	USGS NWIS	Yes	Yes	32.417344	-103.902717	3719452.119	20131743.32	3,124.9	--	well	--	USGS aqfr_cd indicates Rustler	in or near	--	--	--	--	--	--	--	--	--	--

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
23S.32E.20.3442 H-10C	USGS_321701103413903	--	USGS NWIS	Yes	Yes	32.283734	-103.696873	3781188.588	20080888.42	3,691.7	--	well	--	USGS aqfr_cd indicates Rustler	--	--	--	--	--	--	--	--	--	--	--
24S.28E.27.4111	USGS_321115104043501	--	USGS NWIS	Yes	Yes	32.188455	-104.074658	3663605.821	20050217.42	2,970.7	--	Spring	--	USGS aqfr_cd indicates Rustler	in or near	--	--	--	--	--	--	--	--	--	--
26S.29E.22.330	USGS_320118104574401	--	USGS NWIS	Yes	Yes	32.022347	-103.978815	3691001.32	19988624.92	2,885.1	--	well	--	USGS aqfr_cd indicates Rustler	in or near	--	--	--	--	--	--	--	--	--	WQ data from GAM data set; not available on USGS NWIS website in early Feb. 2016
US-53-01-5xx (Apache 3)	USGS_305529102560601	--	USGS NWIS	No	Yes	30.9247	-102.9349	4002971.786	19578596.77	2,961.6	1640	well	--	TD within Rustler	--	--	--	--	--	--	--	--	--	--	Does not appear to be the same as GWDB wells 5301501, 5301502, or 5301503 which have significantly different depths and locations from that reported for this well
D-160	--	Texas Pacific Coal & Oil Co.	TBWE Bulletin 5916	Yes	Yes	31.912071	-103.153622	3944809.741	19940269.05	2,876.8	1234	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	TBWE Bulletin 5916	--
D-193	--	Standard Oil Co. of Texas	TBWE Bulletin 5916	Yes	Yes	31.895869	-103.07211	3969877.456	19933654.84	2,912.6	1062	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	TBWE Bulletin 5916	--

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
C-32	--	C. Williams	TBWE Bulletin 6106	Yes	Yes	31.270798	-102.723743	4072129.525	19703030.37	2,398.6	--	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	TBWE Bulletin 6106	--
C-72	--	George Atkins Estate	TBWE Bulletin 6106	Yes	Yes	31.227632	-102.713065	4075072.062	19687217.89	2,402.8	--	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	TBWE Bulletin 6106	Rustler cased off after water sample taken per Table 4
G-25	--	D. J. Sibley	TBWE Bulletin 6106	Yes	Yes	31.005568	-102.940683	4001946.043	19608111.88	2,800.9	1680	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	TBWE Bulletin 6106	--
H-35	--	J. R. Bennett	TBWE Bulletin 6106	Yes	Yes	31.114815	-102.775569	4054550.625	19646588.85	2,523.9	900	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	TBWE Bulletin 6106	--
J-14	--	Neal and Ratliff	TBWE Bulletin 6106	No	Yes	31.16569	-102.553344	4124357.652	19663458.88	2,360.0	452	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	TBWE Bulletin 6106	--
P-120	--	Clayton Williams	TBWE Bulletin 6106	Yes	Yes	30.856956	-103.025773	3973871.308	19554678.57	3,075.8	1373	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	TBWE Bulletin 6106	--
P-85	--	Chandler Co.	TBWE Bulletin 6106	Yes	Yes	30.878848	-103.032837	3971878.685	19562715.99	3,028.9	1812	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	TBWE Bulletin 6106	--

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
P-86	--	Chandler Co.	TBWE Bulletin 6106	Yes	Yes	30.878568	-103.047219	3967374.944	19562737.31	3,039.8	1756	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	TBWE Bulletin 6106	--
P-95	--	Chandler Co.	TBWE Bulletin 6106	Yes	Yes	30.865293	-103.022256	3975054.987	19557686.28	3,062.0	1550	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	TBWE Bulletin 6106	--
Q-137	--	Ernest Riggs	TBWE Bulletin 6106	Yes	Yes	30.953911	-102.974288	3990936.975	19589569.7	2,892.8	1435	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	TBWE Bulletin 6106	--
Q-2	--	Bodie Smith	TBWE Bulletin 6106	Yes	Yes	30.995536	-102.975094	3991092.713	19604743.79	2,847.3	1600	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	TBWE Bulletin 6106	--
R-21	--	Billie Prewit	TWC Bulletin 6214	Yes	Yes	31.277091	-103.471959	3839015.434	19711851.91	2,582.6	1360	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	TWC Bulletin 6214	--
S-14	--	J.C. Trees Estate	TWC Bulletin 6214	Yes	Yes	31.307727	-103.145172	3941165.723	19719970.25	2,591.5	1400	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	TWC Bulletin 6214	--
W-12	--	Barilla Farms	TWC Bulletin 6214	Yes	Yes	31.141724	-103.400794	3859674.957	19661840.52	2,785.7	1400	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	TWC Bulletin 6214	--

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
W-60	--	E.G. Bowles	TWC Bulletin 6214	No	Yes	31.115474	-103.276369	3898219.993	19651104.34	2,794.9	5612	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	TWC Bulletin 6214	--
P-57	--	--	Winslow & Kister, 1956	Yes	Yes	31.865136	-104.111895	3647589.818	19932908.45	3,348.3	--	Spring	--	indicated as Rustler in report	in or near	--	--	--	--	--	--	--	--	Winslow & Kister, 1956	--
P-58	--	--	Winslow & Kister, 1956	Yes	Yes	31.733847	-104.085778	3653909.422	19884779.7	3,157.6	--	Spring	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	Winslow & Kister, 1956	--
P-59	--	--	Winslow & Kister, 1956	No	Yes	31.140635	-104.282944	3584415.13	19671002.02	4,527.0	451	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	Winslow & Kister, 1956	--
P-60	--	--	Winslow & Kister, 1956	Yes	Yes	31.354797	-103.437993	3850478.993	19739834.46	2,563.0	--	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	Winslow & Kister, 1956	--
P-61	--	--	Winslow & Kister, 1956	No	Yes	31.337413	-103.609518	3796869.11	19735201.51	2,696.4	195	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	Winslow & Kister, 1956	--
P-62	--	--	Winslow & Kister, 1956	Yes	Yes	31.059777	-103.397632	3859744.899	19631952.85	2,882.6	1525	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	Winslow & Kister, 1956	--

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
P-63	--	--	Winslow & Kister, 1956	Yes	Yes	31.059777	-103.397632	3859744.899	19631952.85	2,882.6	1405	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	Winslow & Kister, 1956	--
P-64	--	--	Winslow & Kister, 1956	Yes	Yes	31.314568	-103.379161	3868348.954	19724611.9	2,607.3	--	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	Winslow & Kister, 1956	--
P-65	--	--	Winslow & Kister, 1956	Yes	Yes	31.596914	-102.894883	4021898.248	19823227.61	2,622.0	965	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	Winslow & Kister, 1956	--
P-66	--	--	Winslow & Kister, 1956	Yes	Yes	31.321574	-102.75429	4063069.31	19721769.91	2,400.9	461	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	Winslow & Kister, 1956	--
P-67	--	--	Winslow & Kister, 1956	No	Yes	31.181093	-103.14213	3940802.982	19673799.39	2,698.9	5326	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	Winslow & Kister, 1956	--
P-68	--	--	Winslow & Kister, 1956	No	Yes	31.149311	-102.460616	4153160.288	19656834.21	2,323.8	430	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	Winslow & Kister, 1956	--
P-69	--	--	Winslow & Kister, 1956	No	Yes	31.085838	-102.505798	4138535.129	19634018.96	2,380.6	1415	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	Winslow & Kister, 1956	--

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
P-70	--	--	Winslow & Kister, 1956	Yes	Yes	30.840983	-102.996351	3982923.439	19548608.03	3,093.3	1373	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	Winslow & Kister, 1956	--
P-71	--	--	Winslow & Kister, 1956	Yes	Yes	30.840983	-102.996351	3982923.44	19548608.03	3,093.3	1550	Well	--	indicated as Rustler in report	--	--	--	--	--	--	--	--	--	Winslow & Kister, 1956	--
55950	--	--	BRACS database	Yes	Yes	31.979166	-103.9375	3703063.868	19972487.89	2,843.51	280	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--
55951	--	--	BRACS database	No	Yes	31.9375	-103.812499	3741198.083	19955953.43	2,990.41	400	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--
55952	--	--	BRACS database	Yes	Yes	31.854166	-103.937499	3701443.351	19926947.52	2,859.53	360	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--
55953	--	--	BRACS database	Yes	Yes	31.9375	-103.979171	3689631.213	19957769.31	2,861.18	350	Withdrawal of Water	--	recommendation by BRACS Program	in_or_near	--	--	--	--	--	--	--	--	BRACS database	--
55954	--	--	BRACS database	Yes	Yes	31.937499	-103.895828	3715416.459	19956851.23	2,851.51	600	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
55955	--	--	BRACS database	No	Yes	31.854166	-103.937499	3701443.351	19926947.52	2,859.53	300	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--
55956	--	--	BRACS database	No	Yes	31.854167	-103.854171	3727247.183	19926039.22	2,798.11	290	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--
55957	--	--	BRACS database	No	Yes	31.854167	-103.854171	3727247.183	19926039.22	2,798.11	300	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--
55958	--	--	BRACS database	No	Yes	31.812499	-103.9375	3700902.761	19911767.27	2,940.34	280	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--
55959	--	--	BRACS database	Yes	Yes	31.729167	-104.145828	3635227.541	19883767.37	3,240.71	202	Withdrawal of Water	--	recommendation by BRACS Program	in_or_near	--	--	--	--	--	--	--	--	BRACS database	--
55960	--	--	BRACS database	No	Yes	31.729167	-104.104171	3648143.454	19883285.77	3,211.88	220	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--
55961	--	--	BRACS database	No	Yes	31.770832	-103.895828	3713278.213	19896129.77	2,926.98	360	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
55962	--	--	BRACS database	No	Yes	31.770832	-103.937499	3700362.79	19896587.01	2,981.59	305	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--
55980	--	--	BRACS database	No	Yes	31.854166	-103.6875	3778861.471	19924279.67	2,922.43	260	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--
55981	--	--	BRACS database	No	Yes	31.854166	-103.6875	3778861.471	19924279.67	2,922.43	460	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--
55982	--	--	BRACS database	No	Yes	31.854166	-103.6875	3778861.471	19924279.67	2,922.43	360	Other	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--
55983	--	--	BRACS database	No	Yes	31.812499	-103.854171	3726718.319	19910858.2	2,797.39	220	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--
55984	--	--	BRACS database	No	Yes	31.854167	-103.854171	3727247.183	19926039.22	2,798.11	320	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--
55985	--	--	BRACS database	No	Yes	31.854166	-103.812499	3740151.813	19925591.73	2,736.63	320	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--

Well ID	Alternate Well ID	Owner	DataSource	Confirmed Rustler	Available Water Quality Data	Latitude (dd)	Longitude (dd)	Easting (ft, GAM proj.)	Northing (ft, GAM proj.)	Surface Elevation (ft, DEM from GAM)	Total Depth (ft)	Type	Well Use	Basis for Inclusion	Rustler Hills (outcrop area)	Depth to Top of Well Opening (ft)	Depth to Base of Well Opening (ft)	Opening Type	Number of Screened or Open Intervals	Well Yield (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Flowing	Reference	Comments
55986	--	--	BRACS database	No	Yes	31.854166	-103.812499	3740151.813	19925591.73	2,736.63	320	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--
55987	--	--	BRACS database	No	Yes	31.479167	-103.354171	3877951.376	19784350.87	2,649.92	240	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--
55988	--	--	BRACS database	No	Yes	31.479167	-103.354171	3877951.376	19784350.87	2,649.92	200	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--
55989	--	--	BRACS database	No	Yes	31.479167	-103.354171	3877951.376	19784350.87	2,649.92	180	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--
55990	--	--	BRACS database	No	Yes	31.479167	-103.354171	3877951.376	19784350.87	2,649.92	180	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--
55991	--	--	BRACS database	No	Yes	31.520832	-103.354171	3878411.612	19799532.77	2,630.07	200	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--
55992	--	--	BRACS database	No	Yes	31.562499	-103.354171	3878871.872	19814715.46	2,690.55	450	Withdrawal of Water	--	recommendation by BRACS Program	--	--	--	--	--	--	--	--	--	BRACS database	--

ID = identification
BRACS = Brackish Resource Aquifer Characterization System
GW Database = groundwater database
dd = drawdown
ft, GAM proj. = feet, Groundwater Availability Model Project
ft, DEM from GAM = feet, depth elevation model from Groundwater Availability Model
ft = feet
gpm = gallons per minute
gpm/ft = gallons per minute per foot

19.4 Water quality data for wells determined to be producing from the Rustler Aquifer

Table 19-4. Water quality data for wells determined to be producing from the Rustler Aquifer

Well ID	Alternate Well ID	WQ Data Source	Sample Date	Na (mg/L)	K (mg/L)	Na + K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	TDS (mg/L)	Sp. Cond. (umhos/cm)	NaCl Equivalent (ppm)	Ion Balance (%)	Rw (ohm-m at 77°F)	Data Accepted	Reason for Exclusion	Median Accepted TDS Value for Well (mg/L)	Number of Accepted TDS Observations
55950	--	BRACS database	6/4/2015	2,160	24.9	--	807	215	5,010	123	--	2,610	--	10,300	9,980	9,847	-12.9%	0.569	No	TDS > 10,000 mg/L	NA	NA
55952	--	BRACS database	6/4/2015	464	14.2	--	364	204	254	101	--	3,180	--	4,100	3,340	3,408	-15.0%	1.558	Yes	--	4,100	1
55953	--	BRACS database	6/4/2015	1,670	15.1	--	600	233	3,200	126	--	2,820	--	8,260	7,550	7,548	-10.6%	0.733	Yes	--	8,260	1
55954	--	BRACS database	5/21/2015	863	15.6	--	658	182	2,300	86.6	--	2,480	--	6,870	4,790	5,674	-15.8%	0.960	No	Excessive charge imbalance	NA	NA
55959	--	BRACS database	6/4/2015	210	10.3	--	519	160	339	149	--	2,260	--	3,520	2,810	2,864	-9.9%	1.816	Yes	--	3,520	1
4533906	--	GWDB	6/22/1953	--	--	--	1,350	692	28,000	69.56	0	3,580	--	--	--	31,733	-74.9%	0.194	No	Excessive charge imbalance	NA	NA
4533912	--	GWDB	3/6/1958	--	--	--	1,840	142	58,600	85.42	0	6,050	--	--	--	62,128	-89.0%	0.106	No	Excessive charge imbalance	NA	NA
4535901	--	GWDB	10/26/1954	67 (U?)	--	--	592	78	44	101	0	1,720	3.8	2,595	2,730	2,051	0.1%	2.535	Yes	--	2,595	1
4542603	--	GWDB	5/15/1940	20,800	--	--	1,420	1,040	33100	67.12	0	6,100	--	62,493	79,800	58,604	0.0%	0.111	No	TDS > 10,000 mg/L	NA	NA
4542703	--	GWDB	4/20/1995	18,300	224	--	1,310	559	30340	12.2	9.6	3,875	0.13	54,649	--	51,858	-1.3%	0.125	No	TDS > 10,000 mg/L	NA	NA

Well ID	Alternate Well ID	WQ Data Source	Sample Date	Na (mg/L)	K (mg/L)	Na + K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	TDS (mg/L)	Sp. Cond. (umhos/cm)	NaCl Equivalent (ppm)	Ion Balance (%)	Rw (ohm-m at 77°F)	Data Accepted	Reason for Exclusion	Median Accepted TDS Value for Well (mg/L)	Number of Accepted TDS Observations
4542802	--	GWDB	2/4/1958	25,300	--	--	1,700	981	40800	129.36	0	5,450	--	74,303	--	70,302	0.0%	0.098	No	TDS > 10,000 mg/L	NA	NA
4544601	--	GWDB	7/18/1974	29,194	--	--	683	7,240	39310	191.59	0	38,019	5.3	114,562	236,096	91,809	-0.1%	0.076	No	TDS > 10,000 mg/L	NA	NA
4544601	--	GWDB	8/10/1978	30,554	--	--	502	7,567	41398	164.75	0	38,754	0.4 (U)	118,857	251,720	95,552	0.0%	0.073	No	TDS > 10,000 mg/L	NA	NA
4549203	US-45-49-203 (311422102555101)	GWDB	12/3/2007	424	17	--	770	365	335	377.08	0	3,530	0.15 (U)	5,652	4,840	4,411	-0.9%	1.206	Yes	--	4,160	3
4549203	US-45-49-203 (311422102555101)	USGS	8/11/2010	234	12.1	--	675	201	354	182	0.1	2,320	0.04 (U)	4,160	4,160	3,182	-0.3%	1.669	Yes	--		
4549203	US-45-49-203 (311422102555101)	GWDB	8/17/2010	243	11.6	--	739	206	297	250.17	0	2,310	0.1 (U)	3,963	4,200	3,225	3.5%	1.647	Yes	--		
4558502	--	GWDB	4/10/1946	--	--	--	--	--	221	214.06	0	1,420	--	--	--	1,210	-100.0%	4.166	No	Excessive charge imbalance	NA	NA
4559501	US-45-59-501 (310430102401201)	GWDB	4/9/1987	1500	33	--	830	330	3100	439.32	0	2,300	24.35	8,365	10,700	7,528	-3.0%	0.735	Yes	--	8,365	1
4613402	--	GWDB	1/16/1990	30500	702	--	1420	790	49763	45.15	0	6,508	0.01 (U)	89,716	--	84,611	-2.0%	0.082	No	TDS > 10,000 mg/L	2,712	1
4613402	--	GWDB	8/8/2012	105	3.57	--	523	116	73.7	118.37	0	1,780	16.2	2,712	2,920	2,169	-1.1%	2.398	Yes	--	2,712	1

Well ID	Alternate Well ID	WQ Data Source	Sample Date	Na (mg/L)	K (mg/L)	Na + K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	TDS (mg/L)	Sp. Cond. (umhos/cm)	NaCl Equivalent (ppm)	Ion Balance (%)	Rw (ohm-m at 77°F)	Data Accepted	Reason for Exclusion	Median Accepted TDS Value for Well (mg/L)	Number of Accepted TDS Observations
4620405	--	GWDB	1/12/1990	344	14	--	633	180	689	89.09	0	2,163	0	4,103	4,540	3,411	-3.3%	1.557	Yes	--	4,103	1
4640701	--	GWDB	5/22/1995	285	25.7	--	589	250	2693	93.97	0	297	0.08	4,216	--	4,261	-13.9%	1.249	Yes	--	4,288.5	2
4640701	--	GWDB	3/16/2000	315	25.3	--	587	264	291	97.99	0	2,800	0.09 (U)	4,361	4,680	3,453	-1.9%	1.538	Yes	--		
4640703	--	GWDB	6/1/1967	666	--	--	580	163	510	104.95	0	2,650	0.9	4,640	5,190	3,724	0.0%	1.426	Yes	--	4,640	1
4640801	--	GWDB	12/18/1932	311	--	--	596	271	338	92.75	0	2,620	0.6	4,208	--	3,387	0.0%	1.568	Yes	--	4,264.5	2
4640801	--	GWDB	8/25/1939	342	--	--	603	277	350	101.29	0	2,700	--	4,321	4,980	3,490	0.0%	1.521	Yes	--		
4641502	--	GWDB	5/28/1940	--	--	--	579	132	223	138	0	1,800	--	2,940	3,440	2,296	-7.3%	2.265	Yes	--	2,940	1
4643102	--	GWDB	10/13/1930	580	20	--	626	221	645	219	0	2,560	--	4,782	--	3,922	0.1%	1.354	Yes	--	4,782	1
4643102	--	GWDB	4/14/1932	--	--	--	651	223	845	204	0	2,690	--	5,250	--	3,629	-24.1%	1.463	No	Excessive charge imbalance	4,782	1
4652901	--	GWDB	4/22/1995	89	15.4	--	598	220	52	137.9	0	2,352	0.04 (U)	3,421	--	2,708	-0.2%	1.920	Yes	--	3,421	1
4653903	W-10 from TWC Bull 6214	TWC Bull. 6214	8/21/1940	--	--	5.3	605	216	24	130	--	2,180	--	3,100	3,280	2,477	-0.2%	2.099	Yes	--	2,312	2

Well ID	Alternate Well ID	WQ Data Source	Sample Date	Na (mg/L)	K (mg/L)	Na + K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	TDS (mg/L)	Sp. Cond. (umhos/cm)	NaCl Equivalent (ppm)	Ion Balance (%)	Rw (ohm-m at 77°F)	Data Accepted	Reason for Exclusion	Median Accepted TDS Value for Well (mg/L)	Number of Accepted TDS Observations
4653903	W-10 from TWC Bull 6214	TWC Bull. 6214	3/1/1941	--	--	74	598	216	26	128	--	2,260	--	,3230	3,290	3,117	22.6%	1.704	No	Excessive charge imbalance		
4653903	W-10 from TWC Bull 6214	GWDB	4/22/1995	101	7.6	--	335	57.5	239	208.68	0	740	12.04	1,634	--	1,893	31.1%	2.749	No	Excessive charge imbalance		
4653903	W-10 from TWC Bull 6214	GWDB	10/13/1999	86.6	6.75	--	313	50.1	220	183.05	0	696	17.62	1,524	2,320	1,325	-0.4%	3.804	Yes	--		
4654901	WD-46-54-901 (310806103171901)	GWDB	4/22/1995	61.7	15.8	--	584	204	35	137.9	0	2,232	0.04	3,227	--	2,560	-0.5%	2.031	Yes	--	3,227	1
4654901	WD-46-54-901 (310806103171901)	USGS	8/29/2010	100	13.1	--	67.6	30.5	110	32.2	1.9	354	0.04 (U)	706	1,080	3,904	77.6%	1.360	No	Excessive charge imbalance	3,227	1
4654903	--	GWDB	4/22/1995	86.6	13.8	--	554	203	84	136.68	0	2,154	13.28	3,203	--	2,562	-1.0%	2.030	Yes	--	3,203	1
4660905	--	GWDB	5/24/1995	42.08	11.82	--	674.9	213.6	29	150.1	0	2,219	0.04	3,291	--	2,636	4.0%	1.973	Yes	--	3,291	1
4661103	--	GWDB	4/22/1995	54.3	13.5	--	562	200	30	134.24	0	2,260	0.04	3,213	--	2,531	-2.7%	2.054	Yes	--	3,213	1
4661203	--	GWDB	4/24/1995	43.8	11.7	--	586	204	21	133.02	0	2,235	0.17	3,194	--	2,528	-0.9%	2.057	Yes	--	3,158.5	2
4661203	--	GWDB	10/13/1999	44.9	11.3	--	548	195	20	133.02	0	2,210	0.09 (U)	3123	3,460	2,461	-3.1%	2.113	Yes	--		

Well ID	Alternate Well ID	WQ Data Source	Sample Date	Na (mg/L)	K (mg/L)	Na + K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	TDS (mg/L)	Sp. Cond. (umhos/cm)	NaCl Equivalent (ppm)	Ion Balance (%)	Rw (ohm-m at 77°F)	Data Accepted	Reason for Exclusion	Median Accepted TDS Value for Well (mg/L)	Number of Accepted TDS Observations
4661205	--	GWDB	10/13/1999	--	7	--	--	64	21.5	140.34	0	2,400	0	--	3,470	1,662	-81.3%	3.066	No	Excessive charge imbalance	NA	NA
4661206	--	GWDB	10/13/1999	171	7.98	--	225	50.6	323	239.19	0	486	3.3	1,418	2,320	1,281	-0.2%	3.934	Yes	--	1,418	1
4723601	--	GWDB	10/20/1999	44.8	3.12	--	384	119	40.2	175.73	0	1,280	11.69	1,995	2,440	1,663	0.4%	3.065	Yes	--	1,995	1
4723602	--	GWDB	9/15/1995	165.1	6.05	--	666	220.4	210	200.14	0	2,326	16.65	3,738	--	3,008	0.8%	1.765	Yes	--	3,695.5	2
4723602	--	GWDB	10/20/1999	198	6.13	--	565	224	218	222.1	0	2,280	14.26	3,653	4,000	2,939	-1.6%	1.769	Yes	--		
4723701	--	GWDB	4/20/1961	82	--	--	600	42	46	128	0	1,590	24	2,473	2,640	1,958	0.1%	2.657	Yes	--	2,537.5	2
4723701	--	GWDB	9/15/1995	72.45	15.42	--	599.9	49.32	59	115.93	0	1,695	21.69	2,602	--	2,052	-1.9%	2.534	Yes	--		
4731901	--	GWDB	4/20/1961	37	--	--	610	77	11	272	0	1,610	2.2	2,504	2,640	2,003	0.1%	2.597	Yes	--	2,504	1
4746101	--	GWDB	7/29/1960	45	--	--	502	137	50	193	0	1,590	38	2,478	2,760	2,022	0.0%	2.571	Yes	--	2,478	1
4746601	--	GWDB	10/7/1970	35	--	--	365	83	26	122.03	0	1,130	0.4 (U)	1,708	3,132	1,437	0.6%	3.547	Yes	--	1,872	2
4746601	--	GWDB	10/16/1999	382 (U?)	1.2	--	122	94	35	141.56	0	1,300	15.5	2,036	1,970	1,638	-0.3%	3.112	Yes	--		

Well ID	Alternate Well ID	WQ Data Source	Sample Date	Na (mg/L)	K (mg/L)	Na + K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	TDS (mg/L)	Sp. Cond. (umhos/cm)	NaCl Equivalent (ppm)	Ion Balance (%)	Rw (ohm-m at 77°F)	Data Accepted	Reason for Exclusion	Median Accepted TDS Value for Well (mg/L)	Number of Accepted TDS Observations
4746602	--	GWDB	5/22/1995	--	2.1	--	188.6	82	27.5	137.9	0	1,325	--	--	--	1,327	-30.8%	3.799	No	Excessive charge imbalance	NA	NA
4747401	--	GWDB	10/16/1999	83	6.01	--	378	162	69.6	214.78	0	1,500	0.09 (U)	2,324	2,620	1,935	-0.8%	2.689	Yes	--	2,324	1
4747403	--	GWDB	5/22/1995	--	2.3	--	173.7	66	24	154.98	0	900	--	--	1,307	1,026	-21.6%	4.875	No	Excessive charge imbalance	948	1
4747403	--	GWDB	7/27/2003	44.3	2.03	--	161	58.5	31.2	151.32	0	527	29	948	,1319	820	0.3%	6.246	Yes	--	948	1
4747404	--	GWDB	10/7/1970	12	--	--	199	26	13	36.61	0	540	0.4 (U)	811	1,472	706	1.5%	7.336	Yes	--	811	1
4747701	--	GWDB	7/29/1960	31	--	--	103	40	16	156	0	308	21	613	856	535	0.1%	0.002	Yes	--	633	2
4747701	--	GWDB	10/6/1970	22	--	--	122	43	15	162.31	0	337	18	653	1,188	574	0.9%	0.002	Yes	--		
4747704	--	GWDB	10/16/1999	22.4	1.06	--	251	39.2	12.8	167.19	0	645	34.53	1,109	1,368	935	-0.9%	5.474	Yes	--	686	3
4747704	--	GWDB	7/27/2003	20.7	1	--	120	40.6	11.3	168.41	0	327	24.88	649	953	563	0.0%	0.002	Yes	--		
4747704	--	GWDB	3/17/2009	24	1.21	--	125	43.5	12.4	162.3	0	352	27.18	686	938	595	0.7%	0.002	Yes	--		
4747801	--	GWDB	10/7/1970	29	--	--	87	35	26	161.09	0	216	20	507	927	452	1.7%	0.002	Yes	--	507	1

Well ID	Alternate Well ID	WQ Data Source	Sample Date	Na (mg/L)	K (mg/L)	Na + K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	TDS (mg/L)	Sp. Cond. (umhos/cm)	NaCl Equivalent (ppm)	Ion Balance (%)	Rw (ohm-m at 77°F)	Data Accepted	Reason for Exclusion	Median Accepted TDS Value for Well (mg/L)	Number of Accepted TDS Observations
4747901	--	GWDB	6/21/1979	152	--	--	357	108	223	187.93	0	1,148	0.1 (U)	2093	3924	1,809	0.1%	2.876	Yes	--	2,093	1
4747901	--	GWDB	2/2/2000	127	63.3	--	304	96.6	238.3	--	--	1,107.7	--	--	--	1,693	1.0%	3.011	Yes	--	2,093	1
4747902	--	GWDB	10/6/1970	91	--	--	172	86	40	319.73	0	620	1	1,179	2,210	1,035	0.8%	4.832	Yes	--	1,179	1
4754302	--	GWDB	10/14/1999	39	3.55	--	301	111	21.8	123.25	0	1,100	80.13	1,746	1,950	1,447	-1.5%	3.523	Yes	--	1,692.5	2
4754302	--	GWDB	7/27/2003	39.1	3.46	--	299	110	21.5	124.48	0	1,010	66.85	1,639	1,930	1,382	2.2%	3.648	Yes	--		
4755104	--	GWDB	10/6/1970	52	--	--	411	145	34	102.51	0	1,490	70	2,274	4,140	1,858	-0.1%	2.800	Yes	--	2,274	1
4755203	--	GWDB	10/6/1970	82	--	--	337	90	83	152.54	0	1,050	27	1,764	3,240	1,496	1.2%	3.406	Yes	--	1,764	1
5215502	--	GWDB	4/25/1995	55.1	6.96	--	595	126	70	152.54	0	1,844	0.04	2,799	3,020	2,251	0.0%	2.311	Yes	--	2,760	2
5215502	--	GWDB	10/14/1999	45.1	5.96	--	567	123	59.6	150.1	0	1,820	0.09 (U)	2,721	2,950	2,182	-1.6%	2.383	Yes	--		
5216608	US-52-16-608 (304830103002001)	USGS	7/11/1979	226	11	--	240	56	314	--	--	686	--	1,660	--	1,399	7.1%	3.602	Yes	--	1,600.5	6
5216608	US-52-16-608 (304830103002001)	GWDB	4/21/1995	227	11.8	--	230	53.6	329	256.27	0	630	0.04	1,633	2,250	1,455	-0.9%	3.503	Yes	--		

Well ID	Alternate Well ID	WQ Data Source	Sample Date	Na (mg/L)	K (mg/L)	Na + K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	TDS (mg/L)	Sp. Cond. (umhos/cm)	NaCl Equivalent (ppm)	Ion Balance (%)	Rw (ohm-m at 77°F)	Data Accepted	Reason for Exclusion	Median Accepted TDS Value for Well (mg/L)	Number of Accepted TDS Observations
5216608	US-52-16-608 (304830103002001)	GWDB	10/12/1999	219	10.4	--	233	49	317	246.51	0	607	0.09 (U)	1,583	2,390	1,411	-0.2%	3.613	Yes	--		
5216608	US-52-16-608 (304830103002001)	GWDB	9/9/2004	218	10.1	--	210	47.8	316	251.39	0	591	0.09 (U)	1,543	2,360	1,371	-2.3%	3.675	Yes	--		
5216608	US-52-16-608 (304830103002001)	GWDB	4/28/2009	224	10.5	--	239	52.6	304	252.61	0	638	0.02 (U)	1,618	2,330	1,439	0.7%	3.541	Yes	--		
5216608	US-52-16-608 (304830103002001)	GWDB	8/9/2012	236	11.2	--	220	48.4	286	248.95	0	586	0.02 (U)	1,536	2,560	1,369	2.5%	3.680	Yes	--		
5216609	US-52-16-609 (304805103013301)	GWDB	10/12/1999	299	22.7	--	169	73.1	307	247.73	0	607	0.09 (U)	1,652	2,337	1,484	6.2%	3.435	Yes	--		
5216609	US-52-16-609 (304805103013301)	GWDB	9/7/2004	215	9.99	--	236	49	316	268.47	0	697	0.09 (U)	1,681	2,420	1,476	-4.4%	3.453	Yes	--		
5216609	US-52-16-609 (304805103013301)	GWDB	4/28/2009	221	10	--	251	54.2	298	245.28	0	681	0.02 (U)	1,662	2,320	1,472	0.6%	3.462	Yes	--	1,657	4
5216609	US-52-16-609 (304805103013301)	USGS	8/19/2010	220	10.4	--	251	53.1	332	262	0.2	704	0.04 (U)	1,760	2,510	4,611	55.7%	1.154	No	Excessive charge imbalance		
5216609	US-52-16-609 (304805103013301)	GWDB	8/9/2012	246	11.6	--	161	47.4	306	258.71	0	421	0.15	1,347	2,190	1,221	3.0%	4.129	Yes	--		

Well ID	Alternate Well ID	WQ Data Source	Sample Date	Na (mg/L)	K (mg/L)	Na + K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	TDS (mg/L)	Sp. Cond. (umhos/cm)	NaCl Equivalent (ppm)	Ion Balance (%)	Rw (ohm-m at 77°F)	Data Accepted	Reason for Exclusion	Median Accepted TDS Value for Well (mg/L)	Number of Accepted TDS Observations
5216612	--	GWDB	5/9/1995	237	25.1	--	183	44.4	323	264.82	0	489	0.04 (U)	1,456	2,110	1,308	0.3%	3.853	Yes	--	1,456	5
5216612	--	GWDB	10/12/1999	215	10.1	--	226	51.2	318	258.71	0	482	0.09 (U)	1,456	2,230	1,325	4.0%	3.803	Yes	--		
5216612	--	GWDB	9/7/2004	219	10.1	--	171	46.5	315	259.49	6.21	475	0.09 (U)	1,396	2,200	1,253	-2.3%	4.021	Yes	--		
5216612	--	GWDB	4/28/2009	230	10.4	--	184	50.2	311	259.93	0	486	0.02 (U)	1,425	2,170	1,285	1.1%	3.922	Yes	--		
5216612	--	GWDB	8/9/2012	230	11	--	252	51.8	283	242.84	0	685	0.02 (U)	1,658	2,430	1,466	1.8%	3.476	Yes	--		
5216613	--	GWDB	5/9/1995	226	11.2	--	198	46.5	324	258.71	0	509	0.13	1,466	2,010	1,320	-0.2%	3.819	Yes	--	1,447.5	2
5216613	--	GWDB	4/28/2009	217	9.6	--	195	51.5	312	255.05	0	496	0.02 (U)	1,429	2,130	1,294	0.9%	3.896	Yes	--		
5301201	--	GWDB	1/5/1948	117	--	--	588	225	230	87.86	0	2,160	1	3364	3,770	2,762	0.0%	1.882	Yes	--	3,423.5	2
5301201	--	GWDB	4/7/1956	143	--	--	638	199	208	206.24	0	2,170	0.03	3483	3,850	2,820	0.0%	1.844	Yes	--		
5301203	--	GWDB	3/11/1992	231	16	--	629	212	323	250.17	0	2,232	0.44	3,787	4,130	3,092	-0.3%	1.717	Yes	--	3,756.5	6
5301203	--	GWDB	4/21/1995	233	15.2	--	608	205	312	248.95	0	2,226	0.04	3,750	4,050	3,055	-1.1%	1.738	Yes	--		

Well ID	Alternate Well ID	WQ Data Source	Sample Date	Na (mg/L)	K (mg/L)	Na + K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	TDS (mg/L)	Sp. Cond. (umhos/cm)	NaCl Equivalent (ppm)	Ion Balance (%)	Rw (ohm-m at 77°F)	Data Accepted	Reason for Exclusion	Median Accepted TDS Value for Well (mg/L)	Number of Accepted TDS Observations
5301203	--	GWDB	3/27/1998	213.9	13.58	--	582.3	199.7	282	184.6	0	2120.7	--	3,521	4,430	2,892	0.2%	1.798	Yes	--		
5301203	--	GWDB	10/13/1999	212	13.1	--	586	199	258	247.73	0	2,210	0.09 (U)	3,630	4,180	2,940	-1.7%	1.769	Yes	--		
5301203	--	GWDB	12/4/2007	375	18.7	--	620	370	291	408.81	0	2,760	0.15 (U)	4,659	4,330	3,794	4.0%	1.399	Yes	--		
5301203	--	GWDB	3/18/2009	216	13.5	--	635	211	281	231.86	0	2,260	0.1 (U)	3,763	3,730	3,057	0.2%	1.737	Yes	--		
22S.30E. 05.431	USGS_ 32250210 3540801	USGS	9/19/1972	5,600	810	--	1,000	600	11,000	--	--	2,300	--	21300	32,600	20,295	0.8%	0.296	No	TDS > 10,000 mg/L	NA	NA
23S.32E. 20.3442 H-10C	USGS_ 321701103413903	USGS	5/19/1980	100,000	4,000	--	1,500	11000	190000	--	--	3,300	--	323,000	216,000	NA	NA	NA	No	TDS > 10,000 mg/L	NA	NA
24S.28E. 27.4111	USGS_ 32111510 4043501	USGS	10/22/1947	230	--	--	568	146	480	--	--	1,630	2.7 or 12	3,140	3,880	2,637	2.9%	1.972	Yes	--	3140	1
26S.29E. 22.330	USGS_ 32011810 4574401	USGS	3/24/1975	--	--	--	--	--	2,100	--	--	--	--	--	--	2,034	-100.0%	2.556	No	Excessive charge imbalance	NA	NA
C-32	--	TBWE Bull. 6106	3/6/1950	--	--	--	--	--	24,800	166	--	4,690	--	--	58,000	26,717	-100.0%	0.225	No	Excessive charge imbalance	NA	NA
C-72	--	TBWE Bull. 6106	3/23/1949	--	--	14,000	1,340	714	22,700	160	--	4,430	--	43,400	59,200	27,079	-70.8%	0.222	No	Excessive charge imbalance, TDS > 10,000 mg/L	NA	NA
C-72	--	TBWE Bull. 6106	7/25/1949	--	--	13,900	1,160	653	22,300	72	--	4080	0	42,200	56,500	26,235	-73.0%	0.229	No	Excessive charge imbalance,	NA	NA

Well ID	Alternate Well ID	WQ Data Source	Sample Date	Na (mg/L)	K (mg/L)	Na + K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	TDS (mg/L)	Sp. Cond. (umhos/cm)	NaCl Equivalent (ppm)	Ion Balance (%)	Rw (ohm-m at 77°F)	Data Accepted	Reason for Exclusion	Median Accepted TDS Value for Well (mg/L)	Number of Accepted TDS Observations
																				TDS > 10,000 mg/L		
D-160	--	TBWE Bull. 5916	9/25/1956	--	--	57,400	1,380	1,400	89,700	56	--	7,140	--	157,000	--	94,224	-87.1%	0.074	No	Excessive charge imbalance, TDS > 10,000 mg/L	NA	NA
D-193	--	TBWE Bull. 5916	1/25/1957	--	--	4,810	627	845	7,720	133	--	4,320	--	18,400	24500	12,028	-50.9%	0.474	No	Excessive charge imbalance, TDS > 10,000 mg/L	NA	NA
G-25	--	TBWE Bull. 6106	3/16/1948	--	--	262	581	210	190	296	--	2,280	0	3,690	3,910	2,715	-11.0%	1.915	Yes	--	3,690	1
H-35	--	TBWE Bull. 6106	4/7/1932	869	30	899	512	208	1280	361	--	1,880	0.2	4,990	--	4,368	0.0%	1.218	Yes	--	4,990	1
P-120	--	TBWE Bull. 6106	4/3/1944	--	--	194	342	83	292	252	--	959	0	,1990	--	1,576	-15.0%	3.234	Yes	--		
P-120	--	TBWE Bull. 6106	3/28/1949	--	--	217	295	76	308	213	--	874	2.2	1,890	2,580	1,460	-18.4%	3.490	No	Excessive charge imbalance	1,860	2
P-120	--	TBWE Bull. 6106	3/6/1956	214	9.2	--	265	62	300	225	--	750	0.4	,1730	2,430	1,532	0.2%	3.327	Yes	--		
P-57	--	Winslow & Kister, 1956	4/19/1940	--	--	64	615	51	51	105	--	1,640	25	2,700	2,630	1,936	-3.9%	2.687	Yes	--	2,700	1
P-58	--	Winslow & Kister, 1956	5/16/1940	--	--	92	677	166	83	141	--	2,240	4	3,720	3,650	2,561	-4.0%	2.030	Yes	--	3,720	1

Well ID	Alternate Well ID	WQ Data Source	Sample Date	Na (mg/L)	K (mg/L)	Na + K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	TDS (mg/L)	Sp. Cond. (umhos/cm)	NaCl Equivalent (ppm)	Ion Balance (%)	Rw (ohm-m at 77°F)	Data Accepted	Reason for Exclusion	Median Accepted TDS Value for Well (mg/L)	Number of Accepted TDS Observations
P-60	--	Winslow & Kister, 1956	6/13/1949	--	--	504	600	285	730	112	--	2,540	0.2	4,730	5,850	3,456	-17.0%	1.536	No	Excessive charge imbalance	NA	NA
P-62	--	Winslow & Kister, 1956	1/17/1940	--	--	46	599	218	37	143	--	2,230	--	3,200	3,330	2,518	-2.0%	2.065	Yes	--	3,200	1
P-63	--	Winslow & Kister, 1956	8/21/1940	--	--	5.3	605	216	24	130	--	2,180	2.5	3,540	3,280	2,478	-0.3%	2.098	Yes	--	3,540	1
P-64	--	Winslow & Kister, 1956	8/25/1939	--	--	342	603	277	350	101	--	2,700	--	4,320	4,980	3,159	-12.3%	1.681	Yes	--	4,320	1
P-65	--	Winslow & Kister, 1956	3/30/1951	2800	19	--	984	622	19300	113	--	4,920	--	38,700	52,000	26,277	-48.9%	0.228	No	Excessive charge imbalance, TDS > 10,000 mg/L	NA	NA
P-66	--	Winslow & Kister, 1956	4/2/1941	--	--	1480	852	197	2660	98	--	2,190	3	7,420	10,540	5,237	-35.1%	1.041	No	Excessive charge imbalance	NA	NA
P-70	--	Winslow & Kister, 1956	4/3/1944	--	--	194	342	83	292	252	--	959	0	1,990	--	1,576	-15.0%	3.234	Yes	--	1,990	1
P-71	--	Winslow & Kister, 1956	4/11/1946	--	--	184	327	83	308	141	8	960	0.5	2,210	--	1,544	-14.9%	3.300	Yes	--	2,210	1
P-85	--	TBWE Bull. 6106	4/7/1956	195	9.2	204	314	87	282	192	--	984	0.2	1,980	2,690	1,734	-0.1%	2.999	Yes	--	1,980	1

Well ID	Alternate Well ID	WQ Data Source	Sample Date	Na (mg/L)	K (mg/L)	Na + K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	TDS (mg/L)	Sp. Cond. (umhos/cm)	NaCl Equivalent (ppm)	Ion Balance (%)	Rw (ohm-m at 77°F)	Data Accepted	Reason for Exclusion	Median Accepted TDS Value for Well (mg/L)	Number of Accepted TDS Observations
P-86	--	TBWE Bull. 6106	4/11/1946	--	--	113	504	115	250	154	--	1,480	0.5	2,560	--	2,040	-7.7%	2.549	Yes	--	2,570	2
P-86	--	TBWE Bull. 6106	10/15/1947	--	--	109	530	118	265	172	--	1,470	0.5	2,580	3,150	2,087	-6.2%	2.491	Yes	--		
P-95	--	TBWE Bull. 6106	4/11/1946	--	--	184	327	83	308	149	--	960	0.5	1,940	--	1,540	-14.7%	3.309	Yes	--	1,940	1
Q-137	--	TBWE Bull. 6106	4/7/1956	--	--	146	584	198	132	199	--	2,150	0	3,320	3,580	2,538	-6.5%	2.049	Yes	--	3,320	1
Q-2	--	TBWE Bull. 6106	11/3/1949	--	--	224	628	209	205	255	--	2,320	0.2	3,730	3,920	2,783	-9.1%	1.869	Yes	--	3,730	1
R-21	--	TWC Bull. 6214	6/7/1940	--	--	170	595	227	99	77	--	2,480	0.8	3,610	3,870	2,701	-7.0%	1.925	Yes	--	3,610	1
S-14	--	TWC Bull. 6214	7/24/1940	--	--	208	627	259	266	114	--	2,510	0.2	3,930	4,410	2,976	-7.9%	1.747	Yes	--	3,930	1
W-12	--	TWC Bull. 6214	3/1/1941	--	--	34	604	221	34	132	--	2,240	0.5	3,200	3,410	2,527	-1.5%	2.058	Yes	--	3,190	2
W-12	--	TWC Bull. 6214	1/24/1947	--	--	40	608	212	40	146	--	2,210	0	3,180	3,210	2,511	-1.8%	2.071	Yes	--		

ID = identification
WQ = water quality
mg/L = milligrams per liter
Na = sodium
K = potassium
Na + K = soduim plus potassium
Ca = calcium

Mg = magnesium

HCO_3 = bicarbonate

CO_3 = carbonate

SO_4 = sulfate

NO_3= nitrate

TDS = total dissolved solids

SP. Cond. = specific conductance

umhos/cm = micromhos per centimeter

NaCl = salinity

ppm = parts per million

Rw = resistivity of water

Ohm-m = ohm-meter

°F = degrees Fahrenheit

19.5 Summary table for geophysical logs

Table 19-5. Summary Table for Geophysical Logs.

API	Latitude (NAD27)	Longitude (NAD27)	Well Datum Elevation (ft)	WELL TD (ft)	State	County	Operator	Lease	Lease Number	Field	Dewey Lake (ft-msl)	Ruster (ft-msl)	MH4 (ft-msl)	A4 (ft-msl)	Magenta Dolomite (ft-msl)	Tamarisk (ft-msl)	M3 (ft-msl)	A2 (ft-msl)	Culebra Dolomite (ft-msl)	Los Medaños (ft-msl)	A1 Top (ft-msl)	A1 Bot (ft-msl)	Los Medaños LS Top (ft-msl)	Los Medaños LS Bot (ft-msl)	Salado (ft-msl)	Delaware Mountain Group (ft-msl)	Resistivity Log	BRACS Well	Petrophysical Well	Well Used in Interpolation	Interim Cross-Section Well	Final Cross-Section Well
423713093800	30.676485	-103.057091	3,544	14,400	TX	Pecos	Texas O&G Corp	Elsinore	1	Pikes Peak	2,774	2,354		2,354	2,345	2,332	2,287	2,261	2,240	2,187	-	-	-	-	2,134	-1,549	-	1	-	1	-	-
423890080200	31.242492	-103.357514	2,734	5,424	TX	Reeves	Lawless-Wahlenmaier	Carl Stanberry	1	-	2,625	1,940	1,918	1,904	1,891	1,884	1,814	1,754	1,746	1,661	1,644	1,626	1,582	1,482	1,444	-2,450	-	-	-	1	1	1
423890077900	31.213531	-103.335987	2,776	5,387	TX	Reeves	Kimbell Kay	Mr Murray	1	-	2,668	1,995	1,971	1,964	1,946	1,940	1,858	1,788	1,779	1,694	1,674	1,656	1,601	1,506	1,466	-2,372	-	-	-	1	1	1
423890110300	31.328631	-103.763873	2,878	4,060	TX	Reeves	Cree Oil Co & Armr	Von Trotha	1	-	2,078	1,648	1,621	1,609	1,595	1,576	1,516	1,494	1,477	1,424	1,419	1,403	1,339	1,296	1,264	-970	-	-	-	1	-	1
423890101100	31.16949	-104.02173	3,625	9,704	TX	Reeves	Txl Oil	Reeves Fee Kt	1	-	2,965	2,666	-	-	-	2,665	2,588	2,533	2,523	2,480	2,473	2,462	2,413	2,391	2,358	227	1	-	3	1	-	-
423890106700	31.065488	-103.451576	2,896	5,410	TX	Reeves	Walling Jb-Hissom Dr	Balmorhea Ranches D	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
423890058000	31.6805	-103.89016	3,000	3,623	TX	Reeves	R&G Drlg-Gulf	Txl Bs	1	-	-	2,729	2,693	2,674	2,651	2,627	2,579	2,537	2,520	2,494	2,480	2,457	-	-	1,832	-313	-	-	-	1	1	1
423890007400	31.933538	-104.008074	2,952	2,740	TX	Reeves	Continental Oil Co	Ge Ramsey Jr 19	15	Ford	2,680	2,573	-	-	-	2,574	2,558	2,534	2,425	2,390	2,384	2,378	-	-	2,185	361	-	-	-	1	1	1
423890093100	31.11513	-103.319184	2,818	5,380	TX	Reeves	Texas Crude Oil Co	Gillespie 27	1	-	2,369	1,796	1,768	1,755	1,741	1,728	1,659	1,641	1,620	1,549	1,524	1,508	1,463	1,373	1,332	-2,311	-	-	-	1	1	1
423893355600	31.245338	-103.32292	2,784	12,029	TX	Reeves	Chevron U S A Inc	Reeves Txl Fee T7-50	1	Wolfbone	2,366	1,725	1,703	1,694	1,680	1,669	1,613	1,562	1,555	1,467	1,453	1,432	1,356	1,291	1,221	-2,465	-	-	-	1	1	-
423890009600	31.815143	-103.936602	2,936	3,059	TX	Reeves	Sinclair Oil & Gas C	Agnes Beckham	2	Sabre	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
423890085500	31.680716	-103.975092	3,101	3,155	TX	Reeves	O B Oil Co-Gulf	Txl	1	-	-	2,927	2,883	2,861	2,830	2,814	2,765	2,753	2,747	2,695	2,689	2,681	-	-	2,318	151	-	-	-	1	1	1
423890090500	31.134418	-103.845755	3,233	11,715	TX	Reeves	Txl Oil	Reeves-State	1	-	2,432	2,219	2,188	2,183	2,177	2,171	2,103	2,059	2,050	1,997	1,989	1,982	1,947	1,809	1,785	-709	1	1	3	1	-	1
423890059400	31.665621	-103.92699	2,995	3,240	TX	Reeves	Reaves Jack S Est	State Of Texas	1	Reaves	2,948	2,871	2,847	2,835	2,795	2,766	2,732	2,715	2,696	2,639	2,572	2,563	-	-	2,064	-86	-	-	-	1	1	1

API	Latitude (NAD27)	Longitude (NAD27)	Well Datum Elevation (ft)	WELL TD (ft)	State	County	Operator	Lease	Lease Number	Field	Dewey Lake (ft-msl)	Ruster (ft-msl)	MH4 (ft-msl)	A4 (ft-msl)	Magenta Dolomite (ft-msl)	Tamarisk (ft-msl)	M3 (ft-msl)	A2 (ft-msl)	Culebra Dolomite (ft-msl)	Los Medaños (ft-msl)	A1 Top (ft-msl)	A1 Bot (ft-msl)	Los Medaños LS Top (ft-msl)	Los Medaños LS Bot (ft-msl)	Salado (ft-msl)	Delaware Mountain Group (ft-msl)	Resistivity Log	BRACS Well	Petrophysical Well	Well Used in Interpolation	Interim Cross-Section Well	Final Cross-Section Well
423890111600	31.928269	-103.973484	2,897	2,921	TX	Reeves	Reaves Js-Doolin We	Davis Heirs	1	Geraldine	-	2,662	-	-	-	-	-	-	-	-	-	-	-	-	2,501	210	-	-	-	1	1	-
423890044300	31.816662	-103.976892	2,982	2,908	TX	Reeves	Brown&Scrbr-Thrn-Glf	Txl 29	1	-	2,817	2,670	-	2,669	2,625	2,598	2,579	2,569	2,558	2,520	2,509	2,495	-	-	2,382	246	-	-	-	1	-	1
423890024800	31.853437	-103.857773	2,802	3,530	TX	Reeves	Crouch Eugene Louis	Olive Mccamey	1	Tunstill	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-
423890016200	31.604473	-103.57025	2,711	4,594	TX	Reeves	Sun Oil Company	Mae Rawlins	1	-	1,568	1,182	1,170	1,144	1,137	1,122	1,051	1,005	998	964	956	941	930	816	754	-1,756	-	1	-	1	1	1
423890040900	31.80951	-103.943299	2,978	3,041	TX	Reeves	Atlantic Richfld Co	At Randolph State	1	Sabre	-	2,296	-	-	-	2,296	2,280	2,271	2,260	2,229	2,213	2,196	-	-	2,048	-	4	-	-	-	-	-
423890108400	31.788257	-103.994402	2,988	2,920	TX	Reeves	White Eagle Oil&Refi	At Randolph	1	-	-	2,922	-	-	-	2,923	2,905	2,896	2,883	2,834	2,824	2,813	2,746	2,691	2,655	332	-	-	-	1	1	-
423890012200	31.695219	-103.866598	2,930	3,550	TX	Reeves	Skaggs Jk Jr-Gulf	Txl	1	-	-	2,176	-	-	-	2,175	2,142	2,112	2,052	1,978	1,952	1,941	-	-	1,585	-388	-	-	-	1	1	1
423890032900	31.470979	-103.560227	2,650	4,482	TX	Reeves	Frazier-Hendon	Tom B Flack	1	-	-	870	855	842	830	814	760	754	751	675	659	647	642	586	527	-1,687	-	-	-	1	1	
423890039900	31.3002	-103.391495	2,614	5,710	TX	Reeves	Amercn Trading&Prod	Hallie M Lyster	1	-	2,059	1,774	1,754	1,737	1,730	1,704	1,671	1,624	1,610	1,524	1,510	1,494	1,424	1,384	1,362	-	4	-	-	-	-	-
423893290100	31.642415	-103.936633	3,096.5	11,381	TX	Reeves	Resolute Natural Res	Armstrong 14	1	Phantom	2,757	2,331	2,311	2,300	2,281	2,264	2,231	2,219	2,151	2,100	2,093	2,089	-	-	2,027	-101	-	-	-	1	-	1
423890108900	31.503882	-103.585071	2,647	4,531	TX	Reeves	Wilson Expl Co	John Bush Est	1	-	1,370	927	907	894	876	865	826	759	745	689	681	674	645	622	578	-1,575	1	-	3	1	-	-
423890077400	31.026398	-103.56028	2,906	5,083	TX	Reeves	Keljikan Commercial	Cp Yadon	1	-	2,319	1,771	1,743	1,733	1,717	1,704	1,608	1,582	1,567	1,472	1,460	1,431	1,334	1,288	1,237	-2,071	-	-	-	1	-	-
423890015900	31.054914	-103.413016	2,904	5,491	TX	Reeves	Sun Oil Company	Balmorhea Ranches I	1	-	2,592	1,958	1,931	1,921	1,907	1,892	1,828	1,795	1,767	1,658	1,646	1,630	1,550	1,492	1,450	-2,287	4	-	1	1	-	-
423890108300	30.979906	-103.576135	2,946	5,344	TX	Reeves	Wenfrey Sa Etal Ltd	Greene	1	-	-	1,496	1,478	1,466	1,456	1,444	1,375	1,347	1,336	1,197	1,187	1,170	1,125	1,060	1,021	-1,822	1	-		1	1	1
423890048900	31.555025	-103.92905	3,233	3,613	TX	Reeves	Cmpbll-Frnkl-Brgg-Hw	Hr Burden	1	-	2,670	2,432	2,401	2,384	2,369	2,352	2,307	2,274	2,246	2,174	2,164	2,154	2,099	1,970	1,933	-215	-	-	3	1	-	1
423890048800	31.555045	-103.931633	3,257	3,854	TX	Reeves	Campbell Francis K	Pb Wilson	1	-	-	2,157	-	-	-	-	-	-	-	-	-	-	-	-	-	-164	1	1	-	-	-	-

API	Latitude (NAD27)	Longitude (NAD27)	Well Datum Elevation (ft)	WELL TD (ft)	State	County	Operator	Lease	Lease Number	Field	Dewey Lake (ft-msl)	Ruster (ft-msl)	MH4 (ft-msl)	A4 (ft-msl)	Magenta Dolomite (ft-msl)	Tamarisk (ft-msl)	M3 (ft-msl)	A2 (ft-msl)	Culebra Dolomite (ft-msl)	Los Medaños (ft-msl)	A1 Top (ft-msl)	A1 Bot (ft-msl)	Los Medaños LS Top (ft-msl)	Los Medaños LS Bot (ft-msl)	Salado (ft-msl)	Delaware Mountain Group (ft-msl)	Resistivity Log	BRACS Well	Petrophysical Well	Well Used in Interpolation	Interim Cross-Section Well	Final Cross-Section Well
423890111900	31.468178	-103.559326	2,653	4,543	TX	Reeves	Hill&Hill-Emco Prod	Hrtfrd Acdnt & Indm	1	-	-	873	855	841	831	811	768	759	749	671	655	637	631	583	529	-1,697	-	-		1	1	-
423890081500	31.202412	-103.268041	2,758	11,258	TX	Reeves	Magnolia Pet Co	Rape Marvin J	1	Cable	-	1,748	-	1,749	1,725	1,708	1,613	1,566	1,557	1,480	1,474	1,453	1,428	1,342	1,290	-	4	-	-	-	-	-
423890092600	31.414314	-103.368328	2,558	5,106	TX	Reeves	Texas Crude Oil Co	Hf Beckham 9	1	Scott	-	1,058	1,033	1,023	1,013	998	958	935	920	853	847	825	-	-	669	-	4	-	1	-	-	-
423710154700	31.012445	-103.267701	2,925	5,435	TX	Pecos	Davis Fred A	Ammer	1	-	2,366	1,769	1,759	1,743	1,734	1,722	1,672	1,655	1,637	1,558	1,553	1,534	1,461	1,421	1,312	-2,261	-	-	-	1	-	-
423890081600	31.205767	-103.268173	2,741	5,340	TX	Reeves	Magnolia Pet Co	Rape Marvin J	2	Cable	-	1,728	1,701	1,681	1,673	1,651	1,599	1,561	1,544	1,489	1,461	1,446	1,353	1,316	1,286	-	4	-	-	-	-	-
423890033800	31.540375	-103.518593	2,608	4,505	TX	Reeves	Geochemical Surv-Int	Mandell	1	-	-	894	873	860	855	843	798	785	774	712	704	695	-	-	568	-	4	-	-	-	-	-
423890054600	31.342939	-103.700655	2,812	13,160	TX	Reeves	Gulf Oil Corp	Wl Todd Jr Etal	1	-	-	680	-	-	-	-	-	-	-	-	-	-	-	-	462	-	1	-	-	-	-	-
423890109600	31.324678	-103.974764	3,186	3,690	TX	Reeves	Yarborough W B	Cm Caldwell	1	-	2,693	2,513	2,494	2,483	2,470	2,440	2,421	2,399	2,369	2,293	2,256	2,245	2,171	2,117	2,035	-176	-	-	-	1	-	-
423890016000	31.047554	-103.429995	2,917	5,497	TX	Reeves	Sun Oil Company	Balmorhea Ranches I	2	-	-	2,024	2,005	1,987	1,974	1,953	1,890	1,874	1,867	1,847	1,837	1,830	-	-	1,537	-	1	-	-	-	-	-
423890088700	31.353575	-103.275652	2,606	5,040	TX	Reeves	Union Oil Co Of Cal	Hf Anthony	1	Worsham	-	1,936	1,916	1,906	1,903	1,894	1,826	1,776	1,759	1,703	1,688	1,676	-	-	1,538	-	1	-	-	-	-	-
423890089000	31.359932	-103.269972	2,568	4,994	TX	Reeves	Union Oil Co Of Cal	Nt Evans	1	Worsham	2,448	1,821	1,799	1,788	1,773	1,765	1,701	1,681	1,671	1,596	1,583	1,570	1,537	1,451	1,418	-2,250	1	-	3	1	-	-
423890088900	31.348438	-103.301699	2,656	5,122	TX	Reeves	Union Oil Co Of Cal	Cm Bell Unit	1	Worsham	-	1,846	1,822	1,812	1,800	1,776	1,738	1,704	1,691	1,626	1,614	1,606	-	-	1,386	-	1	-	-	-	-	-
423890055500	31.314245	-103.298322	2,696	5,165	TX	Reeves	Gulf Oil Corp	Ja Worsham Etal A	1	Wildcat	2,229	1,770	1,751	1,742	1,729	1,705	1,645	1,616	1,605	1,484	1,464	1,452	1,356	1,323	1,260	-	1	-	3	-	-	-
423890019800	31.374474	-103.318012	2,582	5,006	TX	Reeves	Gulf Oil Corp	State School Board	1	Worsham	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
423890064100	31.680105	-103.694039	2,721	4,075	TX	Reeves	Tyson Lh&Brenn and R	Zollman	1	Dixieland	-	1,885	1,870	1,846	1,824	1,813	1,777	1,755	1,723	1,642	1,630	1,610	-	-	1,455	-1,174	1	1	1	1	1	1
423890001700	31.604909	-104.024485	3,269	3,100	TX	Reeves	Continental Oil Co	Durer-Alston	1	-	-	2,987	2,973	2,960	2,945	2,912	2,844	2,835	2,824	2,751	2,742	2,726	-	-	2,374	395	1	1	-	1	-	-
423890104500	31.683346	-103.730815	2,786	3,892	TX	Reeves	Trico Expl Co	As Chapman	1	Dixieland	2,668	1,941	-	-	-	1,942	1,887	1,842	1,808	1,701	1,691	1,678	-	-	1,312	-1,036	-	-	-	1	1	1

API	Latitude (NAD27)	Longitude (NAD27)	Well Datum Elevation (ft)	WELL TD (ft)	State	County	Operator	Lease	Lease Number	Field	Dewey Lake (ft-msl)	Ruster (ft-msl)	MH4 (ft-msl)	A4 (ft-msl)	Magenta Dolomite (ft-msl)	Tamarisk (ft-msl)	M3 (ft-msl)	A2 (ft-msl)	Culebra Dolomite (ft-msl)	Los Medaños (ft-msl)	A1 Top (ft-msl)	A1 Bot (ft-msl)	Los Medaños LS Top (ft-msl)	Los Medaños LS Bot (ft-msl)	Salado (ft-msl)	Delaware Mountain Group (ft-msl)	Resistivity Log	BRACS Well	Petrophysical Well	Well Used in Interpolation	Interim Cross-Section Well	Final Cross-Section Well
423890035500	31.325441	-103.752087	2,910	4,113	TX	Reeves	Grisham Hunter Corp	Hj Strief	1	-	-	1,675	1,653	1,634	1,612	1,594	1,539	1,523	1,511	1,446	1,441	1,429	1,380	1,328	1,289	-1,042	1	-	3	1	-	-
423890041800	31.064585	-103.529028	2,880	14,073	TX	Reeves	Argo Oil Company	Dora Roberts	1	Verhalen	2,399	1,789	1,770	1,759	1,743	1,729	1,655	1,609	1,585	1,494	1,490	1,468	1,387	1,330	1,282	-2,252	1	-	3	1	-	-
423890075400	31.42144	-103.855868	3,010	3,452	TX	Reeves	Hunt Oil Co	Tina Brooker Fite	1	-	-	2,080	-	2,080	2,047	2,017	1,940	1,927	1,913	1,868	1,855	1,832	1,698	1,652	1,630	-	4	1	-	-	-	-
423890106600	31.181902	-103.827499	3,093	4,785	TX	Reeves	Walling & Chandler	Earl Vest	1	-	-	1,763	-	-	-	-	-	-	-	-	-	-	-	-	1,503	-	1	1	-	-	-	-
423890044400	31.198972	-103.611399	2,734	5,000	TX	Reeves	Bryant M D	Webb Armstrong	1	-	1,314	745	720	710	694	682	607	550	539	495	488	466	424	287	245	-2,021	-	-	-	1	1	-
423711044600	30.927114	-103.282594	3,115	5,450	TX	Pecos	Forest Oil Corporatn	Davis Matt	1	-	2,426	1,859	-	1,859	1,835	1,825	1,767	1,728	1,716	1,651	1,642	1,627	1,567	1,524	1,465	-1,891	-	-	-	1	1	1
423893029200	31.479047	-103.5766	2,676	20,422	TX	Reeves	Texas West O&G Corp	Pecos Unit	1	L N D	-	938	916	905	891	872	833	825	821	763	740	719	705	649	580	-1,616	-	-	-	1	1	-
421093143000	31.933586	-104.055029	3,103	4,110	TX	Culberson	Orla Petco Inc	Txl `27`	Wd -1	Ford West	-	3,103	-	-	-	-	3,051	3,033	3,020	2,977	2,973	2,967	2,867	2,836	2,802	560	-	-	-	1	1	-
423891009900	31.233791	-103.482325	2,681	21,368	TX	Reeves	Sun Oil Company	Terrill State Unit	1	Wildcat	2,339	1,623	1,600	1,590	1,582	1,559	1,500	1,449	1,432	1,343	1,328	1,307	1,261	1,152	1,094	-2,254	-	1	-	1	1	-
423710281200	30.622922	-103.108281	3,742	2,000	TX	Pecos	Hunt Oil Co	Elsinore Royalty Co	47	-	-	1,865	-	-	-	-	-	-	-	-	-	-	-	-	1,512	-	4	-	-	-	-	-
423711046400	30.74829	-103.05338	3,493	17,050	TX	Pecos	Humble Oil & Refg Co	Oates Gas Unit 1	1	Oates Northeast	2,589	2,071	-	-	-	2,069	1,991	1,971	1,945	1,854	1,846	1,834	1,795	1,771	1,731	-96	-	-	-	1	1	-
423710281800	30.647394	-103.187082	3,694	3,605	TX	Pecos	Hunt Oil Co	Elsinore Royalty Co	55	-	2,970	2,698	-	-	-	-	-	-	-	2,498	2,489	2,484	2,444	2,417	2,191	-	4	-	1	1	-	-
423710281700	30.63902	-103.166792	3,612	4,485	TX	Pecos	Hunt Oil Co	Elsinore Royalty Co	54	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
423711013900	31.033994	-102.962197	2,800	21,603	TX	Pecos	Union Oil Co Of Cal	Wc Tyrrell	1	Gomez	-	1,117	-	-	-	1,117	1,080	1,065	1,050	1,005	988	976	920	885	817	-	4	-	-	-	-	-
423711013200	30.94773	-102.875852	2,890	3,260	TX	Pecos	Gulf Oil Corp	Tb Rhodes Jr Etal	1	U S M	2,051	1,438	-	-	-	1,438	1,417	1,393	1,378	1,335	1,325	1,311	1,262	1,216	1,172	-	-	-	-	1	1	1
423711034500	31.213663	-103.153984	2,676	6,188	TX	Pecos	Amercn Trading& Prod	Rg Lloyd Etal	1	Coyanosa West	2,185	1,590	-	1,590	1,575	1,553	1,485	1,466	1,451	1,372	1,365	1,343	1,311	1,213	1,147	-2,485	-	-	-	1	1	-

API	Latitude (NAD27)	Longitude (NAD27)	Well Datum Elevation (ft)	WELL TD (ft)	State	County	Operator	Lease	Lease Number	Field	Dewey Lake (ft-msl)	Ruster (ft-msl)	MH4 (ft-msl)	A4 (ft-msl)	Magenta Dolomite (ft-msl)	Tamarisk (ft-msl)	M3 (ft-msl)	A2 (ft-msl)	Culebra Dolomite (ft-msl)	Los Medaños (ft-msl)	A1 Top (ft-msl)	A1 Bot (ft-msl)	Los Medaños LS Top (ft-msl)	Los Medaños LS Bot (ft-msl)	Salado (ft-msl)	Delaware Mountain Group (ft-msl)	Resistivity Log	BRACS Well	Petrophysical Well	Well Used in Interpolation	Interim Cross-Section Well	Final Cross-Section Well
423711054200	31.256569	-103.082718	2,599	6,488	TX	Pecos	Socony Mobil Oil Co	Moore Wayne	5	Waha South	-	691	-	691	684	677	653	609	597	549	546	537	444	379	359	-	4	-	-	-	-	-
423710173000	31.188312	-103.099987	2,687	5,400	TX	Pecos	Engeo Company	Wj Worsham Etal	1	-	1,168	798	774	752	741	727	675	647	631	552	541	528	488	420	376	-2,461	-	-	-	1	-	-
423710484400	30.766403	-103.104928	3,361	17,768	TX	Pecos	Tenneco Oil Co	Pecos Fee	1	Oates Northeast	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
423710312300	30.948335	-102.772811	2,852	16,470	TX	Pecos	Humble Oil & Refg Co	Wc Tyrrell Trustee	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
423710058300	30.729907	-103.040351	3,392	4,512	TX	Pecos	Comer W D	John S Oates-State	1	-	2,503	1,960	-	-	-	1,961	1,921	1,899	1,884	1,848	1,846	1,841	1,782	1,736	1,700	62	1	1	3	1	-	-
423710415300	30.727588	-103.404188	3,522	4,916	TX	Pecos	Santana Pet Corp	Eh&Cr Cartledge	1	-	2,849	2,620	-	-	-	-	-	-	-	-	-	-	2,355	2,295	2,250	-1,011	-	-	-	1	1	-
423710579100	30.853164	-103.021873	3,090	3,260	TX	Pecos	Redfern & Herd Inc	Pryor	1	-	2,354	1,724	-	-	-	1,723	1,674	1,629	1,621	1,569	1,562	1,551	1,501	1,466	1,396	-	-	-	-	1	-	-
423710578400	31.027279	-103.221155	2,869	5,425	TX	Pecos	Reaves Jack S Est	Hd Mendel	1	-	2,019	1,200	-	1,200	1,188	1,179	1,106	1,094	1,061	1,004	989	977	936	870	804	-2,334	-	-	-	1	1	1
423710682000	30.742657	-103.213541	3,444	5,130	TX	Pecos	Gregg Oil Company	Mr Kennedy	1	-	2,846	2,304	2,251	2,202	2,194	2,181	2,084	2,050	2,038	1,948	1,941	1,936	-	-	1,914	-901	-	-	-	1	1	-
421090004000	31.270297	-104.300131	3,972	2,702	TX	Culberson	Central Drlg-Amer	Rachel-Cerf	1	-	-	3,972	-	-	-	-	-	-	-	-	-	-	-	-	3,742	1,750	-	1	-	1	1	-
423710158000	30.99907	-103.166158	2,934.8	1,900	TX	Pecos	Delta Drlg Co	Camp	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
422431000100	31.02977	-104.029062	4,274	10,250	TX	Jeff Dav	Texaco Incorporated	Roxie Neal	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-
422430000200	30.702426	-103.650916	4,019	3,050	TX	Jeff Dav	Atlantic Refg Co	Hl Kokernot Jr	1	-	2,400	2,286	-	-	-	-	-	-	-	-	-	-	-	-	1,901	-	4	1	-	1	1	-
422430000300	30.7125	-103.689498	4,170	9,563	TX	Jeff Dav	Continental Oil Co	Mccutcheon	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-
422430000400	30.950696	-103.991657	4,104	8,630	TX	Jeff Dav	Continental Oil Co	Felma C Rounsaville	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-
423710208000	31.068592	-102.936023	2,738	3,417	TX	Pecos	Graham-Hayford-Rankn	Roxie Neal Etal	1	-	-	898	-	-	-	-	-	-	-	-	-	-	-	-	568	-	1	-	-	-	-	-

API	Latitude (NAD27)	Longitude (NAD27)	Well Datum Elevation (ft)	WELL TD (ft)	State	County	Operator	Lease	Lease Number	Field	Dewey Lake (ft-msl)	Ruster (ft-msl)	MH4 (ft-msl)	A4 (ft-msl)	Magenta Dolomite (ft-msl)	Tamarisk (ft-msl)	M3 (ft-msl)	A2 (ft-msl)	Culebra Dolomite (ft-msl)	Los Medaños (ft-msl)	A1 Top (ft-msl)	A1 Bot (ft-msl)	Los Medaños LS Top (ft-msl)	Los Medaños LS Bot (ft-msl)	Salado (ft-msl)	Delaware Mountain Group (ft-msl)	Resistivity Log	BRACS Well	Petrophysical Well	Well Used in Interpolation	Interim Cross-Section Well	Final Cross-Section Well
423710296900	30.953388	-102.813879	2,819	5,803	TX	Pecos	Humble Oil & Refg Co	San Pedro Ranch C	1	-	2,316	1,700	-	1,701	1,694	1,682	1,651	1,624	1,607	1,575	1,564	1,551	1,499	1,464	1,418	-2,136	-	-	-	1	1	1
423710268700	31.155871	-103.102284	2,725	5,365	TX	Pecos	Hankamer & Kirklin	George W Athey	1	-	1,411	866	-	866	858	851	784	737	713	621	614	604	532	502	484	-2,469	1	-	3	1	-	-
423710387300	30.84562	-103.037215	3,105	2,700	TX	Pecos	Pan American	Wh Whitman	1	-	-	1,475	-	1,475	1,467	1,455	1,425	1,397	1,377	1,313	-	-	1,135	1,096	1,063	-	4	-	-	-	-	-
423710594800	30.870761	-102.876626	2,967	3,330	TX	Pecos	Riley George	Mr Gonzales	1	-	-	1,685	-	-	-	1,685	1,654	1,637	1,617	1,567	1,557	1,547	1,482	1,461	1,406	-	4	-	-	-	-	-
423710418600	31.083313	-102.940164	2,694	5,962	TX	Pecos	Seaboard Oil Co	Dco Wilson Etal	1	-	1,705	854	-	-	-	854	827	803	794	736	729	715	651	630	583	-	1	-	3	-	-	-
423710245300	30.840784	-102.935512	3,081	2,895	TX	Pecos	Gulf Oil Corp	State Dv	2	Leon Valley	-	1,737		1,737	1,727	1,717	1,691	1,671	1,641	1,594	-	-	-	-	1,431	-	1	-	-	-	-	-
423710061900	30.923152	-102.904079	2,954	3,980	TX	Pecos	Continental Oil Co	Pecos County Airpor	11	-	-	1,547	-	-	-	1,547	1,524	1,504	1,486	1,436	1,425	1,415	1,372	1,324	1,304	-	4	-	-	-	-	-
423710196700	30.846625	-102.772901	3,066	4,610	TX	Pecos	La Gloria-Morrs-Wgnr	Wl Winfield	1	-	-	1,826	-	-	-	-	-	-	-	-	-	-	-	-	1,536	-	1	-	-	-	-	-
423710219400	30.850623	-102.936484	3,061	2,730	TX	Pecos	Meriwether J S Jr	State Du	2	Leon Valley	2,324	1,721	-	-	-	1,721	1,698	1,679	1,674	1,611	1,601	1,589	1,567	1,492	1,446	-	1	-	3	1	-	-
421091004400	31.196907	-104.284235	3,927	4,000	TX	Culberson	Smith Ray Drlg Co	Foster 30	1	-	2,937	2,422	-	-	-	-	-	-	-	-	-	-	2,397	2,310	2,295	1,146	-	-	-	1	-	-
421090039700	31.475359	-104.106687	3,409	12,088	TX	Culberson	Tidewater Oil Co	Delawar Basinprti es	1	-	3,182	3,139	-	-	-	3,140	3,111	3,081	3,040	2,975	2,959	2,946	-	-	2,899	1,137	1	-	-	1	1	-
421090023800	31.307912	-104.33751	4,131	2,809	TX	Culberson	Lovelady I W	Jb Foster	1	-	-	4,128	-	-	-	-	-	-	-	-	-	-	-	-	3,826	1,520	-	1	-	1	1	-
421090007300	31.68018	-104.175692	3,379	2,100	TX	Culberson	Continental Oil Co	Jh Fisher A	1	-	-	3,379	-	-	-	-	-	-	-	-	-	-	-	-	3,162	1,414	-	-	-	1	1	1
421090002200	31.281711	-104.305452	4,040	7,504	TX	Culberson	Burford & Sams	Mb Foster	1	-	-	4,040	-	-	-	-	-	-	-	-	-	-	-	-	3,803	1,711	-	-	-	1	1	-
421091002500	31.775965	-104.051535	3,050	2,625	TX	Culberson	Mcgrath & Smith Inc	Cris Antone	1	-	-	2,827	2,792	2,774	2,746	2,720	2,653	2,641	2,613	2,581	2,573	2,562	2,466	2,434	2,421	546	-	-	-	1	1	-
421091004700	31.231311	-104.212466	3,609	3,210	TX	Culberson	Smith Ray Drlg Co	Republic 12	1	-	-	3,409	-	-	-	-	-	-	-	-	-	-	3,262	3,203	3,178	712	1	1	-	1	1	-
421091004900	31.800703	-104.15985	3,461	5,905	TX	Culberson	Smith Raymond	James T Windham Eta	1	-	-	3,461	-	-	-	-	-	-	-	-	-	-	3,352	3,323	3,287	1,305	-	-	-	1	1	-

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423710419300	31.065115	-102.957659	2,738	3,235	TX	Pecos	Sharples Oil Crp The	State-Latheo	1	-	-	945	-	-	-	945	911	882	870	823	808	798	-	-	643		1	1	-	-	-	-
423710270900	31.240929	-102.973361	2,563	5,124	TX	Pecos	Houston Oil Co Of Tx	Edith Trees Etal	1	-	-	478	-	-	-	-	-	-	-	-	-	-	-	-	58	-2,017	-	-	-	1	1	-
421090001700	31.240095	-104.370994	3,983	1,800	TX	Culberson	Brown Tom Inc	Jb Foster-State	1	-	3,578	3,338	-	-	-	-	-	-	-	-	-	-	-	-	3,247	2,534	-	-	-	1	-	-
421090003900	31.310333	-104.145606	3,400	3,223	TX	Culberson	Canter Rgr-Holt	Caldwell	1	-	3,059	2,862	-	-	-	-	-	-	-	-	-	-	2,660	2,585	2,543	301	-	1	3	1	-	-
421090045500	31.78091	-104.072025	3,091	2,653	TX	Culberson	Germany& Page&Gulf	Txl 45	1	-	-	3,043	-	-	-	3,043	2,962	2,933	2,914	2,870	2,854	2,838	2,807	2,781	2,720	746	-	-	-	1	1	-
423710219300	30.849275	-102.943513	3,071	3,000	TX	Pecos	Meriwether J S Jr	State Du	1	Leon Valley	2,357	1,760	-	-	-	1,760	1,731	1,717	1,705	1,640	1,630	1,613	1,592	1,522	1,473	-	1	1	3	1	-	-
423710060000	30.920077	-102.898838	2,959	4,300	TX	Pecos	Continental Oil Co	Em Fountain	1	Fort Stockton	-	1,539	-	-	-	1,539	1,513	1,494	1,476	1,429	1,417	1,407	-	-	1,259	-	1	-	-	-	-	-
423710489700	30.920219	-103.018062	3,072	3,080	TX	Pecos	Texaco Incorporated	Cm Hartgrove	1	Fort Stockton	-	1,582	-	1,582	1,572	1,560	1,517	1,477	1,448	1,389	1,377	1,366	-	-	1,250	-	1	-	-	-	-	-
423710173200	30.941345	-102.915499	2,920	3,030	TX	Pecos	Falcon Oil Co	Mrs Bertha Kellner	1	Fort Stockton	2,060	1,524	-	1,526	1,518	1,507	1,478	1,450	1,434	1,382	1,371	1,358	1,330	1,271	1,220	-	-	-	-	1	1	1
423710543000	30.969799	-102.920677	2,849	3,591	TX	Pecos	Magnolia Pet Co	Vf Wallace	1	Fort Stockton	2,013	1,369	-	-	-	1,368	1,339	1,316	1,305	1,248	1,242	1,229	1,200	1,130	1,080	-	1		3	1	-	-
421090031600	31.464397	-104.143926	3,542	10,008	TX	Culberson	Richardson & Bass	Grisham-Hunter-Stat	1	-	-	3,541	-	-	-	-	-	-	3,541	3,471	3,460	3,448	-	-	3,336	1,495		1		1	1	-
423710060900	30.927697	-102.916566	2,949	2,955	TX	Pecos	Texaco Incorporated	Fort Stockton So Un	47-1	Fort Stockton	2,331	1,525	-	-	-	1,525	1,495	1,476	1,460	1,404	1,397	1,384	1,361	1,291	1,239	-	1		3	1	-	-
423710200500	30.727103	-103.024651	3,378	2,274	TX	Pecos	Great Western Drl Co	Js Oates	1	-	2,447	1,855	-	1,855	1,849	1,837	1,780	1,749	1,739	1,695	1,681	1,668	1,622	1,577	1,521	-	-	-	-	1	1	-
423710493000	30.91685	-103.006531	2,991	3,122	TX	Pecos	Texaco Incorporated	Lillian Rudicil	1	Fort Stockton	-	1,671	-	1,671	1,661	1,638	1,586	1,547	1,531	1,461	1,448	1,437	1,391	1,356	1,281	-	4	-	-	-	-	-
423710342400	30.9441	-102.977505	2,913	2,975	TX	Pecos	Weaver Wr	Hj Eaton	3	Fort Stockton	2,013	1,486	-	-	-	1,486	1,442	1,419	1,401	1,339	1,332	1,317	1,282	1,215	1,141	-	-	-	-	1	1	1
423710282200	30.88442	-102.759024	2,921	10,025	TX	Pecos	Hunt Nlsn Bnkr Tr Es	Wa Stroman Trust	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-

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423710544800	30.91917	-102.985136	2,948	4,000	TX	Pecos	Crutchfield John W E	Eaton Hj	1	Fort Stockton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
423710394400	30.839275	-102.998166	3,099	3,542	TX	Pecos	Stanolnd Oil Co	State Of Texas A	1	-	-	1,695	-	-	-	1,695	1,666	1,645	1,617	1,562	1,529	1,515	-	-	1,416	-	1	1	-	-	-	-
423710159700	30.899809	-102.959807	2,988	3,152	TX	Pecos	Doheny Patrick A	Leon Farms	1	-	-	1,605	-	-	-	1,605	1,576	1,555	1,538	1,477	1,468	1,458	-	-	1,388	-	1	-	-	-	-	-
423710366700	30.96255	-102.937571	2,873	2,884	TX	Pecos	Texaco Incorporated	Fort Stockton So Un	1-Feb	Fort Stockton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
423710187600	30.903498	-103.008148	3,057	3,356	TX	Pecos	Lion Oil Co	Hj Eaton Etal	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
423710568400	30.941364	-102.936674	2,903	2,985	TX	Pecos	Magnolia Pet Co	Fj Ellyson	2	Fort Stockton	-	1,491	-	-	-	-	-	-	-	-	-	-	-	-	1,143	-	1	-	-	-	-	-
423710504700	30.956002	-102.949418	2,881	2,939	TX	Pecos	Texaco Incorporated	Fort Stockton So Un	1-May	Fort Stockton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
423710492700	30.948652	-102.953646	2,885	2,903	TX	Pecos	Texaco Incorporated	Fort Stockton So Un	1-Aug	Fort Stockton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
423710489500	30.97433	-102.957686	2,851	3,153	TX	Pecos	Texaco Incorporated	Or Hart	2	Fort Stockton	-	1,376	-	-	-	-	-	-	-	-	-	-	-	-	1,041	-	1	-	-	-	-	-
423710506100	30.934002	-102.945331	2,941	2,972	TX	Pecos	Texaco Incorporated	Jr Bennett Etal	1	Fort Stockton	-	1,516	-	-	-	-	-	-	-	-	-	-	-	-	1,191	-	1	-	-	-	-	-
423710155000	31.302913	-103.014697	2,531	6,028	TX	Pecos	Davis M O	Ce Blackmar	1	-	-	791	-	-	-	791	-	-	-	-	-	-	-	-	411	-	1	-	-	-	-	-
423710487400	30.937761	-102.932549	2,907	2889	TX	Pecos	Texaco Incorporated	Fort Stockton South	42-1	Fort Stockton	-	1,504	-	-	-	-	-	-	-	-	-	-	-	-	1,177	-	1	-	-	-	-	-
423710506000	30.934064	-102.949464	2,927	2,593	TX	Pecos	Texaco Incorporated	Bennett J R	4	Fort Stockton	-	1,507	-	-	-	-	-	-	-	-	-	-	-	-	1,207	-	1	-	-	-	-	-
423710494000	31.008293	-102.872249	2,773	4,050	TX	Pecos	Texaco Incorporated	Dj Sibley	1	-	-	1,293	-	-	-	-	-	-	-	-	-	-	-	-	1,023	-	1	-	-	-	-	-
423710212700	30.851898	-102.755864	3,030	3,383	TX	Pecos	Gregory-Mccandless	Winfield Hl	1	-	-	1,780	-	-	-	-	-	-	-	-	-	-	-	-	1,505	-	1	-	-	-	-	-
423710546200	30.846297	-102.779614	3,058	2,865	TX	Pecos	Mccandless B-Gregory	Hl Winfield C	1	-	-	2,038	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-

API	Latitude (NAD27)	Longitude (NAD27)	Well Datum Elevation (ft)	WELL TD (ft)	State	County	Operator	Lease	Lease Number	Field	Dewey Lake (ft-msl)	Ruster (ft-msl)	MH4 (ft-msl)	A4 (ft-msl)	Magenta Dolomite (ft-msl)	Tamarisk (ft-msl)	M3 (ft-msl)	A2 (ft-msl)	Culebra Dolomite (ft-msl)	Los Medaños (ft-msl)	A1 Top (ft-msl)	A1 Bot (ft-msl)	Los Medaños LS Top (ft-msl)	Los Medaños LS Bot (ft-msl)	Salado (ft-msl)	Delaware Mountain Group (ft-msl)	Resistivity Log	BRACS Well	Petrophysical Well	Well Used in Interpolation	Interim Cross-Section Well	Final Cross-Section Well
423710489400	30.97441	-102.953503	2,858	2,879	TX	Pecos	Texaco Incorporated	Cr Hart	1	Fort Stockton	-	1,352	-	-	-	-	-	-	-	-	-	-	-	-	1,033	-	1	-	-	-	-	-
423710386200	30.978217	-102.957656	2,833	2,865	TX	Pecos	Crouch Eugene Louis	Harsey	1	Fort Stockton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
423893286900	31.110243	-103.492676	2,838	11,690	TX	Reeves	Clayton Williams Enr	Cwei-Chk `35-52-8`	1	Wolfbone	2,539	1,916	1,881	1,872	1,857	1,844	1,777	1,734	1,726	1,579	1,574	1,563	1,477	1,440	1,379	-2,374	-	-	-	1	-	-
423893282200	31.098511	-103.458675	2,845	12,660	TX	Reeves	Clayton Williams Enr	Cwei-Chk `31-51-8`	1	Wolfbone	2,472	1,822	1,811	1,796	1,788	1,776	1,683	1,658	1,653	1,549	1,545	1,529	1,429	1,373	1,287	-2,360	-	-	-	1	-	-
423893340900	31.127758	-103.508482	2,805	11,410	TX	Reeves	Clayton Williams Enr	Cwei-Chk 298-13	2	Wolfbone	2,449	1,832	1,809	1,796	1,783	1,767	1,695	1,639	1,619	1,547	1,524	1,511	1,409	1,362	1,310	-2,373	-	-	-	1	-	-
424753564600	31.453561	-103.443419	2,582	6,350	TX	Ward	Oxy U S A Inc	Adobe	18	Collie	1,540	951	929	914	900	891	831	827	810	721	709	697	679	595	541	-2,121	-	-	-	1	1	1
424753049600	31.444176	-103.4166	2,583	18,125	TX	Ward	Shell Oil Co	Edwards Deep Unit	1	Barstow North	1,583	969	945	935	923	910	859	798	790	733	730	716	684	597	487	-2,129	-	-	-	1	1	-
423893372900	31.20994	-103.192194	2,716	11,745	TX	Reeves	Patriot Resources Inc	Mongoose 20	1	Wolfbone	2,185	1,710		1,710	1,692	1,669	1,604	1,556	1,540	1,470	1,459	1,438	1,410	1,320	1,270	-2,552	-	-	-	1	1	-
424751072900	31.614209	-103.412826	2,720	21,603	TX	Ward	Gulf Oil Corp	Greer-Mcginleas Unt	1	Vermejo East	2,632	2,123	2,097	2,084	2,066	2,056	1,986	1,945	1,929	1,874	1,865	1,849	1,779	1,741	1,674	-2,189	-	1	-	1	-	-
424753063900	31.566164	-103.297324	2,839	17,648	TX	Ward	Gulf Oil Corp	University `18-31`	1	War-Wink South	2,706	2,103	-	2,103	2,078	2,063	2,000	1,950	1,942	1,903	1,885	1,874	1,812	1,764	1,726	-2,279	-	1	-	1	-	-
423013019400	31.684925	-103.393001	2,811	6,700	TX	Loving	Hng Oil Company	University /19-19/	1	Wildcat	2,755	2,176	2,151	2,136	2,122	2,103	2,047	2,019	2,008	1,971	1,952	1,936	1,912	1,814	1,787	-2,229	-	-	-	1	1	1
423893042100	31.548699	-103.562589	2,680	19,060	TX	Reeves	Pennzoil Co Inc	Petrey	1	Mi Vida	-	1,007	979	966	947	937	899	886	879	806	803	791	780	701	636	-1,646	-	-	-	1	-	-
423713077400	30.963817	-103.037729	3,003	22,821	TX	Pecos	Texas Pacific Oil Co	Gulf-Baker	1	Gomez	1,777	1,257	-	-	-	1,257	1,215	1,173	1,150	1,085	1,077	1,058	1,022	943	844	-1,839	-	-	-	1	1	1
423713061900	30.941839	-103.282447	3,090	20,936	TX	Pecos	Signal O&G Co Incorp	Signal 71 Alexander	1	Joho	2,291	1,750	-	1,750	1,742	1,736	1,678	1,635	1,619	1,534	1,514	1,503	1,468	1,429	1,319	-1,944	-	-	-	1	1	1
423890014200	30.93553	-103.677717	3,214	11,312	TX	Reeves	Standard Oil Co Tx	Balmorhea	1	Wildcat	1,944	1,380	1,364	1,351	1,343	1,327	1,266	1,238	1,224	1,157	1,151	1,124	1,054	995	962	-1,302	1	1	3	1	-	1

API	Latitude (NAD27)	Longitude (NAD27)	Well Datum Elevation (ft)	WELL TD (ft)	State	County	Operator	Lease	Lease Number	Field	Dewey Lake (ft-msl)	Ruster (ft-msl)	MH4 (ft-msl)	A4 (ft-msl)	Magenta Dolomite (ft-msl)	Tamarisk (ft-msl)	M3 (ft-msl)	A2 (ft-msl)	Culebra Dolomite (ft-msl)	Los Medaños (ft-msl)	A1 Top (ft-msl)	A1 Bot (ft-msl)	Los Medaños LS Top (ft-msl)	Los Medaños LS Bot (ft-msl)	Salado (ft-msl)	Delaware Mountain Group (ft-msl)	Resistivity Log	BRACS Well	Petrophysical Well	Well Used in Interpolation	Interim Cross-Section Well	Final Cross-Section Well
								Ranches 1																								
423013000900	31.675655	-103.534025	2,722	19,457	TX	Loving	El Paso Nat Gas Co	Texas Bend Unit	1	Texas Bend	-	2,292	2,256	2,243	2,223	2,188	2,124	2,091	2,078	2,006	1,998	1,986	1,946	1,898	1,811	-1,728	-	-	-	1	1	1
421093171800	31.97609	-104.053976	3,027	4,800	TX	Culberson	Conoco Incorporated	Ramsey G E `10`	1	Ford West	-	2,657	-	-	-	-	-	-	-	-	-	-	-	-	2,211	454	1	1	-	1	-	-
423713183300	30.927851	-103.424268	3,305	16,325	TX	Pecos	Northern Nat Gas Co	Hershenson	1	Hershey West	2,707	2,174	2,149	2,143	2,138	2,125	2,057	2,021	2,001	1,932	1,902	1,886	1,815	1,768	1,708	-2,036	-	-	-	1	1	1
423711036400	30.930209	-103.089571	3,068	18,125	TX	Pecos	Texaco Incorporated	Pecos Fee A	1	Wildcat	2,034	1,488	-	-	-	1,488	1,439	1,381	1,374	1,279	1,264	1,249	1,217	1,149	1,072	-1,912	-	-	-	1	1	1
423711095600	31.226005	-103.109863	2,642	16,478	TX	Pecos	Sun Oil Company	Colville Pd Est	2	-	2,136	1,563	-	1,563	1,549	1,535	1,442	1,409	1,394	1,314	1,302	1,288	1,262	1,160	1,101	-2,442	-	-	-	1	1	-
423893392500	31.413232	-103.533017	2,617	69,22	TX	Reeves	High Roller Wells	Highroller Reeves Sw	2	Wolfbone	-	737	713	701	684	670	637	586	567	517	503	487	-	-	377	-	1	-	-	-	-	-
423713040600	30.806056	-103.201571	3,199	16,000	TX	Pecos	Cabot Corporation	Kennedy	1	-	2,881	2,262	-	2,262	2,240	2,230	2,171	2,104	2,084	1,977	1,933	1,914	1,878	1,839	1,789	-1,294	-	-	-	1	-	-
423893012300	31.491862	-104.055206	3,320	15,638	TX	Reeves	Humble Oil & Refg Co	Bryce Jr Jr	1	-	3,287	2,985	2,946	2,937	2,912	2,898	2,822	2,804	2,786	2,726	2,715	2,691	2,678	2,613	2,572	691	-	1	3	1	1	-
423713043900	30.90436	-102.928089	3,107	18,666	TX	Pecos	Bta Oil Producers	709-B Jv-S Dewitt	1	Gomez	2,177	1,577	-	-	-	1,577	1,555	1,540	1,527	1,470	1,458	1,445	1,401	1,359	1,302	-	-	1	-	1	-	-
423893016800	31.551969	-103.639975	2,740	16,860	TX	Reeves	Mallard Expl Inc	State Gas Unit	1	Greasewood	-	1,152	-	-	-	-	-	-	-	-	-	-	-	-	820	-1,388	-	1	-	1	-	-
423893020400	31.446832	-103.511559	2,613	21,520	TX	Reeves	Getty Oil Company	Amarillo Samedan Sch	1	Runway	1,463	814	788	775	763	743	693	682	674	582	560	551	547	445	388	-1,870	-	1	-	1	1	-
423893024300	31.472204	-103.87368	3,176	13,752	TX	Reeves	Getty Oil Company	State 17	1	Wildcat	2,475	2,040	-	2,040	2,031	2,016	1,953	1,948	1,942	1,889	1,874	1,863	1,822	1,737	1,676	-200	1	-	1	1	-	1
423713098100	30.963415	-103.006238	2,994	22,825	TX	Pecos	Coastal States Gas T	Walker /A/	2	Gomez	1,896	1,305	-	-	-	1,305	1,292	1,244	1,234	1,150	1,135	1,124	1,095	1,034	976	-1,291	-	1		1	1	1
423713099700	30.608549	-103.055698	3,831	16,010	TX	Pecos	El Paso Nat Gas Co	S Pikes Peak	1	Wildcat	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
423893047600	31.580456	-103.664108	2,811	18,898	TX	Reeves	Northern Nat Gas Co	Txl /19/	1	Arno	1,886	1,585	1,555	1,548	1,525	1,511	1,443	1,423	1,410	1,336	1,328	1,320	-	-	1,050	-1,348	-	1	-	1	-	-
423891025100	31.285382	-103.137141	2,609	17,800	TX	Reeves	Shell Oil Co	Becken Op	1-Nov	Waha West	2,224	1,636	-	1,636	1,614	1,602	1,522	1,483	1,475	1,369	1,359	1,341	1,302	1,220	1,196	-2,330	-	1	-	1	-	-

API	Latitude (NAD27)	Longitude (NAD27)	Well Datum Elevation (ft)	WELL TD (ft)	State	County	Operator	Lease	Lease Number	Field	Dewey Lake (ft-msl)	Ruster (ft-msl)	MH4 (ft-msl)	A4 (ft-msl)	Magenta Dolomite (ft-msl)	Tamarisk (ft-msl)	M3 (ft-msl)	A2 (ft-msl)	Culebra Dolomite (ft-msl)	Los Medaños (ft-msl)	A1 Top (ft-msl)	A1 Bot (ft-msl)	Los Medaños LS Top (ft-msl)	Los Medaños LS Bot (ft-msl)	Salado (ft-msl)	Delaware Mountain Group (ft-msl)	Resistivity Log	BRACS Well	Petrophysical Well	Well Used in Interpolation	Interim Cross-Section Well	Final Cross-Section Well
423893008100	31.48571	-103.65521	2,761	16,210	TX	Reeves	Superior Oil Co Etal	Kirk Etal Unit	1	Medusa	-	982	963	948	935	920	869	860	850	800	794	783	765	654	622	-1,347	-	1	-	1	1	-
421093143900	31.943535	-104.08	3,204	4,096	TX	Culberson	Petroleum Techl Srvs	Mecom Trust	1	Wildcat	-	3,204	-	-	-	-	3,194	3,174	3,116	3,072	3,064	3,055	2,979	2,950	2,913	700	-	1	-	1	1	-
421093142900	31.94794	-104.11084	3,253	3,979	TX	Culberson	Petroleum Techl Srvs	Prewitt	1-X	Wildcat	-	3,253	-	-	-	-	-	-	-	-	-	-	-	-	3,179	856	-	1	-	1	1	-
421091002400	31.281858	-104.270356	4,096	7,923	TX	Culberson	Mcfarland Corp	Rachel-Cerf 44	1	-	-	4,096	-	-	-	-	-	-	-	-	-	-	-	-	3,769	1,799	-	1	-	1	1	-
421093157300	31.794942	-104.107719	3,200	3,850	TX	Culberson	Orla Petco Inc	Middleton	1	-	-	3,052	-	-	-	3,053	3,001	2,975	2,960	2,879	2,875	2,868	2,818	2,763	2,704	979	-	-	-	1	1	-
422433000100	30.711643	-103.527264	3,732	12,500	TX	Jeff Dav	Mobil Oil Corp	State-Lea	1	-	2,386	2,226	-	-	-	-	-	-	-	-	-	-	-	-	1,939	-1,163	-	1	-	1	1	-
424951085300	31.783259	-103.314074	2,872	5,283	TX	Winkler	Gulf Oil Corp	Mitchell Gp	1	Wildcat	2,701	2,019	1,988	1,975	1,967	1,952	1,894	1,857	1,845	1,811	1,799	1,782	1,777	1,733	1,704	-2,282	-	-	3	1	1	-
423893025500	31.78466	-103.938125	2,960	15,841	TX	Reeves	Coastal States Gas T	M & W Mcguire /B/	3	Chapman Deep	-	2,819	-	-	-	2,821	2,797	2,789	2,781	2,757	2,750	2,741	2,706	2,674	2,615	97	-	1	-	1	1	-
423013157100	31.925851	-103.883843	2,882	7,010	TX	Loving	Chaparral Energy Llc	Johnson 32	1	Red Bluff	2,505	2,347	2,312	2,302	2,285	2,258	2,185	2,172	2,152	2,127	2,114	2,105	2,041	2,017	2,008	-294	-	-	-	1	1	-
423893267400	31.960816	-104.005769	2,904	2,840	TX	Reeves	Finley Resources Inc	Ford Geraldine Unit	401	Geraldine	2,715	2,584	-	-	-	-	-	-	-	-	-	-	-	-	2,280	297	-	-	-	1	-	1
424951081100	31.959087	-103.300671	2,923	22,180	TX	Winkler	Sinclair Oil & Gas C	Tubb Estate	1	Crittendon	-	2,201	2,176	2,163	2,150	2,131	2,076	2,039	2,022	1,997	1,988	1,974	1,914	1,892	1,863	-1,924	-	-	-	1	1	-
423893314200	31.443756	-103.485522	2,592	6,338	TX	Reeves	Oxy U S A Inc	Heard 68	1	Collie	1,466	823	800	788	775	750	719	673	655	596	586	569	558	479	443	-1,957	-	-	-	1	1	-
423893029300	31.676659	-104.040995	3,204	15,575	TX	Reeves	Chevron U S A Inc	Reeves-State	1	Wildcat	-	2,980	2,944	2,932	2,908	2,888	2,818	2,790	2,768	2,722	2,712	2,699	-	-	2,517	557	-	-	-	1	1	1
424953004900	31.977096	-103.222838	2,900	3,487	TX	Winkler	Clark Oil Company	Lineberry T	1	Scarborough	1,709	1,145	1,111	1,087	1,083	1,065	1,043	1,010	992	963	946	931	-	-	799	-	-	-	-	1	1	-
423890024500	31.382946	-103.870791	2,982.6	13,007	TX	Reeves	Continental Oil Co	Warren Wright	1	-	2,293	1,813	1,784	1,770	1,752	1,733	1,652	1,634	1,625	1,594	1,575	1,562	1,529	1,482	1,393	-447	1	1	3	1	-	1
423713110200	30.767673	-103.116486	3,484	15,490	TX	Pecos	Gas Prod Entp Inc	R M	1	Oates Northeast	3,132	2,493	-	-	-	2,492	2,384	2,353	2,340	2,272	2,259	2,249	-	-	2,183	-752	-	1	-	1	1	-
423891054200	31.379469	-103.730466	2,824	12,900	TX	Reeves	Apache Corp	Sunray-Fuller	1	Toyah	1,734	1,430	1,416	1,409	1,400	1,392	1,351	1,338	1,330	1,290	1,279	1,262	1,258	1,217	1,174	-1,058	-	1	-	1	-	-
423893026200	31.392735	-103.29165	2,575	17,608	TX	Reeves	Amercn Quasar Petro	Worsham /19/	1	Worsham North	2,440	1,825	1,795	1,784	1,775	1,755	1,702	1,677	1,660	1,587	1,577	1,556	-	-	1,375	-2,337	-	1	-	1	-	-

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423891011500	30.969298	-103.748175	3,232	10,031	TX	Reeves	Brandywine Oil	Balmorhea Ranches I	1	-	1,894	1,332	1,322	1,308	1,301	1,287	1,226	1,206	1,169	1,068	1,039	1,023	995	942	906	-1,269	-		-	1	1	1
423893026300	31.464456	-103.774594	2,979	13,080	TX	Reeves	Coastal States Gas T	Cleveland Reese	1	Athens	2,382	1,952	-	-	-	1,952	1,892	1,821	1,808	1,769	1,764	1,747	1,734	1,661	1,639	-669	-	1	-	1	1	
423893268700	31.303433	-103.366103	2,654	10,900	TX	Reeves	Cog Operating Llc	Dutch 24	1	Wolfbone	2,414	1,856	1,835	1,819	1,803	1,793	1,725	1,688	1,680	1,604	1,599	1,580	1,528	1,450	1,429	-2,451	-	-	-	1	1	1
423713064500	30.739167	-103.505975	3,620	10,912	TX	Pecos	Gulf Oil Corp	Margaret Lea St D	1	Wildcat	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
423713292200	31.320299	-102.97143	2,538	18,122	TX	Pecos	Hill Ag	Brandenburg	1	A G H	-	908	-	-	-	908	868	848	838	803	800	791	-	-	684	-	1	-	1	-	-	-
423710220800	30.809145	-102.768258	3,064	15,468	TX	Pecos	Gulf Oil Corp	Theo Winfield	1	-	-	1,777	-	-	-	-	-	-	-	-	-	-	-	-	1,484	-	1	-	-	-	-	-
423711065800	31.049742	-103.19571	2,858	23,860	TX	Pecos	Forest Oil Corporatn	Mendel M C `A`	1	Mendel	2,184	1,670	-	1,670	1,660	1,636	1,548	1,535	1,520	1,449	1,443	1,422	1,371	1,301	1,229	-2,424	-	-	-	1	1	1
423713158400	31.156908	-102.939941	2,581	11,269	TX	Pecos	Brown H L Jr	Amoco-Fee	1	Coyanosa North	1,271	579	-	579	570	551	499	481	476	424	416	406	374	353	309	-	-	1	-	1	-	-
423893226200	31.853322	-103.921189	2,867	6,240	TX	Reeves	Penn Vrgnia Oil&Gas	Matthews Pvog	2	Matthews	-	2,089	-	-	-	2,090	2,006	1,996	1,987	1,922	1,915	1,907	-	-	1,809	-18	-	-	-	1	-	-
423893264200	31.809172	-103.841536	2,818	11,683	TX	Reeves	Chesapeake Operg Inc	Reagan State 56-2-34	1h	Zuma	-	2,313	2,275	2,263	2,244	2,218	2,160	2,133	2,108	2,082	2,069	2,048	2,016	1,940	1,918	-492	-	-	-	1	1	-
423893298500	31.2804	-103.475242	2,615	11,518	TX	Reeves	Thompsn J Cleo	Young `269`	3	Wolfbone	1,907	1,387	1,362	1,345	1,332	1,316	1,253	1,195	1,185	1,095	1,081	1,061	967	911	849	-2,265	-	-	-	1	-	-
421093228900	31.286489	-104.122856	3,430	14,260	TX	Culberson	Range Production Co	Josephine 38	1	Toyah Nw	-	2,973	-	-	-	-	-	-	-	-	-	-	2,597	2,545	2,505	81	-	-	-	1	-	-
423893252200	31.288581	-103.742941	2,916	16,471	TX	Reeves	Chesapeake Operg Inc	Methodist State 72-3	1h	Toyah Nw	2,007	1,548	1,517	1,509	1,491	1,481	1,448	1,408	1,402	1,320	1,313	1,301	1,246	1,187	1,161	-1,149	-	-	-	1	-	-
423013138300	31.802183	-103.350162	2,928	17,000	TX	Loving	Chesapeake Operg Inc	Haley 28-27	1	Haley	-	2,031	2,006	1,994	1,982	1,969	1,906	1,875	1,863	1,832	1,821	1,808	-	-	1,718	-2,270	-		-	1	1	-
423893265300	31.2349	-103.378644	2,687	12,570	TX	Reeves	Thompsn J Cleo	Cooper `25`	1	Hoban	2,476	1,992	1,970	1,958	1,944	1,937	1,870	1,810	1,779	1,703	1,685	1,663	1,607	1,495	1,447	-2,387	-		-	1	1	1
424753019000	31.431997	-103.31592	2,595	21,041	TX	Ward	Humble Oil & Refg Co	Scott Fh	1	Scott	2,440	1,855	1,842	1,831	1,820	1,802	1,736	1,729	1,721	1,647	1,626	1,612	1,587	1,468	1,432	-2,293	-	1	-	1	1	-
423893157800	31.484889	-103.626384	2,701	4,500	TX	Reeves	Txo Prod Corp	Amoco Fee `B`	1	Sand Lake	959	870	844	825	813	785	755	746	735	702	697	685	663	547	511	-1,421	-	1	-	1	1	-

API	Latitude (NAD27)	Longitude (NAD27)	Well Datum Elevation (ft)	WELL TD (ft)	State	County	Operator	Lease	Lease Number	Field	Dewey Lake (ft-msl)	Ruster (ft-msl)	MH4 (ft-msl)	A4 (ft-msl)	Magenta Dolomite (ft-msl)	Tamarisk (ft-msl)	M3 (ft-msl)	A2 (ft-msl)	Culebra Dolomite (ft-msl)	Los Medaños (ft-msl)	A1 Top (ft-msl)	A1 Bot (ft-msl)	Los Medaños LS Top (ft-msl)	Los Medaños LS Bot (ft-msl)	Salado (ft-msl)	Delaware Mountain Group (ft-msl)	Resistivity Log	BRACS Well	Petrophysical Well	Well Used in Interpolation	Interim Cross-Section Well	Final Cross-Section Well
423013137400	31.664348	-103.378306	2,846	17,925	TX	Loving	Chesapeake Operg Inc	University 19-22	1	Haley	-	2,115	2,089	2,070	-	2,059	1,985	1,954	1,943	1,904	1,895	1,880	-	-	1,738	-	-	1	-	1	-	-
423013148900	31.898667	-103.387108	3,104	16,866	TX	Loving	Chesapeake Operg Inc	Boyd D K 75-13	1	Haley	2,770	2,137	2,107	2,095	2,064	2,054	1,990	1,968	1,949	1,915	1,898	1,887	1,797	1,781	1,760	-2,106	-		-	1	1	-
423893279100	31.281122	-103.344646	2,705	6550	TX	Reeves	Thompsn J Cleo	Mariinsky `8`	2w	Balmorhea Ranch	2,459	1,793	1,768	1,754	1,744	1,732	1,671	1,617	1,596	1,525	1,512	1,493	1,420	1,331	1,255	-	-		-	1	-	-
423893269300	31.281727	-103.344743	2,745	12,452	TX	Reeves	Thompsn J Cleo	Mariinsky State 8	1	Wolfbone	2,505	1,843	1,817	1,804	1,793	1,783	1,714	1,658	1,646	1,562	1,535	1,511	1,486	1,401	1,338	-2,437	-		-	1	1	1
421093227600	31.227972	-104.223181	3,626.5	5,975	TX	Culberson	Quicksilver Resource	Hughes Kent Ranch	1	Golden Corral	-	3,172	-	-	-	-	-	-	-	-	-	-	3,140	3,080	3,066	-	-		-	1	1	-
423893258400	31.083956	-103.617153	2,907	13,220	TX	Reeves	Chesapeake Operg Inc	Toone 13-157	1	Bush	1,680	1,075	1,052	1,044	1,029	1,018	939	902	875	793	787	779	725	683	642	-1,966	-		-	1	-	-
423893251700	31.470363	-103.728061	2,901	14,275	TX	Reeves	Crusader Energy Grp	Denman State	1026	Medusa	-	1,347	-	1,347	1,333	1,315	1,252	1,193	1,170	1,064	1,054	1,042	1,031	984	964	-928	-		-	1	1	-
423893262600	31.213786	-103.243355	2,742	12,894	TX	Reeves	Thompsn J Cleo	Panther `23`	1	Hoban	2,286	1,690	1,674	1,669	1,656	1,615	1,556	1,544	1,499	1,417	1,413	1,393	1,359	1,255	1,189	-2,501	-		-	1	1	-
423893263200	31.219997	-103.476283	2,692	12,775	TX	Reeves	Thompsn J Cleo	Terrill State `36`	1	Wolfbone	2,460	1,755	1,734	1,722	1,708	1,692	1,631	1,555	1,547	1,472	1,447	1,427	1,359	1,309	1,254	-2,272	-	1	-	1	-	-
424753554200	31.442192	-103.471803	2,587.2	6,300	TX	Ward	Oxy U S A Inc	Vaughan-Mcelvain Ene	1	Collie	1,422	800	791	740	720	705	670	660	651	619	606	592	548	494	472	-1,999	-		-	1	1	-
423891013700	31.929186	-103.938912	2,846	3,002	TX	Reeves	Ritchie Jmc	Rd Bluff Cntrist 26	26-Jan	-	2,632	2,450	-	-	-	-	-	-	-	-	-	-	-	-	1,980	-25	-		-	1	1	-
423013117700	31.657183	-103.543336	2,661	4,664	TX	Loving	Forest Oil Corporatn	Rainbow State	5	Vermejo	2,169	1,543	1,506	1,496	1,477	1,461	1,423	-	1,367	1,337	-	-	-	-	1,231	-	-	1	-	1	-	-
423013064200	31.763291	-103.406873	2,983	23,012	TX	Loving	Amoco Prod Co	Haley `36`	2	Haley	2,613	2,171	2,148	2,132	2,119	2,107	2,056	2,018	2,007	1,971	1,959	1,940	-	-	1,833	-	-	1	-	1	-	-
423713774000	31.280984	-103.082856	2,573	6,453	TX	Pecos	Chesapeake Operg Inc	Hodge J H	9	Waha West	1,593	903	-	-	-	902	854	841	834	766	762	756	640	579	475	-2,173	-	1	-	1	-	-
424753447900	31.578498	-103.403132	2,634	4,995	TX	Ward	Seaboard Oil Co	Hill P C State `A`	5	Quito West	2,444	1,864	1,837	1,825	1,814	1,806	1,772	1,758	1,751	1,678	1,671	1,660	1,609	1,545	1,482	-2,078	-	1	-	1	-	-
421093224500	31.686024	-104.132402	3,322	3,495	TX	Culberson	Capitan Energy Inc	Stars And Stripes	1	Geraldine South	-	3,322	-	-	-	-	-	-	-	-	-	-	-	-	2,982	1,076	-	-	-	1	1	1
423893125200	31.532067	-103.786233	3,032	21,447	TX	Reeves	Cox John L	Texaco Fee	1	Wildcat	2,242	1,692	-	-	-	1,692	1,637	1,628	1,619	1,581	1,572	1,563	1,486	1,432	1,381	-836	-	1	-	1	-	-
423893090500	31.574047	-103.623634	2,753	18,915	TX	Reeves	Northern Nat Gas Co	Betts Gas Unit	1	Arno	1,474	1,143	1,129	1,117	1,110	1,086	1,054	1,028	1,022	943	933	919	-	-	487	-1,506	-	1	-	1	-	-

API	Latitude (NAD27)	Longitude (NAD27)	Well Datum Elevation (ft)	WELL TD (ft)	State	County	Operator	Lease	Lease Number	Field	Dewey Lake (ft-msl)	Ruster (ft-msl)	MH4 (ft-msl)	A4 (ft-msl)	Magenta Dolomite (ft-msl)	Tamarisk (ft-msl)	M3 (ft-msl)	A2 (ft-msl)	Culebra Dolomite (ft-msl)	Los Medaños (ft-msl)	A1 Top (ft-msl)	A1 Bot (ft-msl)	Los Medaños LS Top (ft-msl)	Los Medaños LS Bot (ft-msl)	Salado (ft-msl)	Delaware Mountain Group (ft-msl)	Resistivity Log	BRACS Well	Petrophysical Well	Well Used in Interpolation	Interim Cross-Section Well	Final Cross-Section Well
423893261800	31.240631	-103.519042	2,701	12,795	TX	Reeves	Thompsn J Cleo	Hendrick State 13-25	1	Wolfbone	2,154	1,477	1,453	1,439	1,424	1,410	1,369	1,290	1,277	1,192	1,180	1,158	1,102	1,013	916	-2,234	-	1	-	1	1	-
423890031000	30.979944	-103.494396	3,051	17,866	TX	Reeves	Elpaso Nat&Odessa	Hoefs	1	-	2,587	2,067	2,056	2,036	2,011	1,990	1,935	1,867	1,849	1,795	1,780	1,765	1,707	1,631	1,530	-2,082	-	1	-	1	1	1
424753541300	31.437087	-103.301221	2,645	14,717	TX	Ward	Eagle Oil&Gas Compan	Miller State 30	1	Phantom	-	1,964	1,940	1,928	1,911	1,899	1,840	1,821	1,802	1,729	1,718	1,701	1,679	1,583	1,555	-2,346	-	-	-	1	1	-
423713038500	30.811864	-103.098407	3,289	22,122	TX	Pecos	Texaco Incorporated	Davis Paul	1	Wildcat	2,744	2,146	-	-	-	2,146	2,091	2,054	2,044	1,961	1,953	1,933	1,871	1,830	1,744	-1,156	-	-	-	1	-	-
423713138600	30.764976	-102.903534	3,416	24,888	TX	Pecos	Atapco	Clayton Lwe Univ	1	Wildcat	-	2,116	-	-	-	2,117	2,097	2,078	2,072	2,008	2,001	1,994	-	-	1,867	-	-	-	-	1	1	-
423711090600	31.223945	-103.007119	2,620	12,500	TX	Pecos	Sun Oil Company	Kenneth Scotts Unit	1	-	-	651	-	-	-	-	-	-	651	572	567	562	501	418	334	-2,160	-	-	-	1	1	-
423013119300	31.739767	-103.353719	2,840	17,914	TX	Loving	Chesapeake Operg Inc	University 20-5	1	Haley	2,595	1,991	1,969	1,953	1,944	1,931	1,884	1,852	1,818	1,791	1,780	1,769	-	-	1,660	-	-	1	-	1	-	-
423013133300	31.708225	-103.413002	2,795	17,950	TX	Loving	Chesapeake Operg Inc	University 19-9	1	Haley	-	2,227	2,195	2,181	2,175	2,159	2,087	2,045	2,034	1,965	1,954	1,939	-	-	1,787	-2,170	-	1	-	1	-	-
423713777300	31.233769	-102.953436	2,566	5,835	TX	Pecos	Huntington Energy	Trainer Trust	1073	Athey	1,473	884	-	884	877	860	816	768	751	703	696	684	636	593	528	-	-	1	-	1	-	-
423713757100	31.177029	-103.037823	2,665	6,500	TX	Pecos	Chesapeake Operg Inc	Sibley 48	9	Coyanosa	1,328	780	-	-	-	780	730	689	683	585	560	547	523	442	395	-1,995	-	1	-	1	-	-
424753524400	31.60884	-103.351235	2,839	15,220	TX	Ward	Cimarex Energy Co	Cimarex University 1	1h	War-Wink West	-	2,052	2,027	2,014	2,004	1,995	1,927	1,896	1,886	1,842	1,833	1,812	1,752	1,698	1,639	-2,327	-	1	-	1	-	-
423013120000	31.918428	-103.823685	2,912	4,900	TX	Loving	Chaparral Energy Llc	Fraser Txl	12	Tunstill	-	2,562	2,529	2,512	2,494	2,468	2,407	2,394	2,387	2,332	2,326	2,311	2,234	2,197	2,177	-554	-	1	-	1	1	-
423893238800	31.29359	-103.716107	2,856	13,815	TX	Reeves	Chesapeake Operg Inc	Block 72 State 36	1	Toyah Nw	-7,143	881	855	832	817	806	775	756	751	722	683	667	637	611	550	-1,254	-	-	-	1	-	-
423713745600	30.664227	-103.25999	3,497	4,518	TX	Pecos	Riata Energy Inc	La Escalera A	701	Elsinore W Farm	-	2,477	-	2,477	2,463	2,443	2,393	2,379	2,369	2,324	2,320	2,311	-	-	2,297	-	1	-	-	-	-	-
423013065300	31.801366	-103.627196	2,865	17,300	TX	Loving	Cities Serv O&G Corp	Texaco `35`	1	White Mule	2,587	2,027	1,995	1,982	1,959	1,947	1,881	1,857	1,823	1,806	1,801	1,782	1,766	1,681	1,670	-1,498	-	1	-	1	1	-
423013123200	31.887103	-103.61683	2,974	4,650	TX	Loving	Sharon Resources Inc	Txl Ax	4	Grice	2,689	2,246	2,216	2,204	2,188	2,167	2,107	2,081	2,065	2,031	2,014	2,007	1,949	1,907	1,882	-1,450	-	1	-	1	1	-

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300253154000	32.008004	-103.590605	3,186	6,815	NM	Lea	Yates Petroleum Corp	Arapaho `Akp` Federa	1	Rattlesnake Flat	-	2,469	2,436	2,424	2,408	2,390	2,346	2,313	2,273	2,243	2,231	2,218	2,166	2,138	2,116	-1,594	-	1	-	1	-	-
423893042300	31.162036	-103.833155	3,128	11,737	TX	Reeves	Superior Oil Co Etal	El Paso State	1	Wildcat	2,019	1,742	1,718	1,708	1,694	1,661	1,571	1,552	1,531	1,407	1,402	1,383	-	-	1,317	-836	-	-	-	1	-	1
423891020500	31.13078	-103.316673	2,814	21,800	TX	Reeves	Hamon Jake L	Waples-Platter	1	Hamon	2,471	1,938	1,914	1,903	1,891	1,881	1,804	1,740	1,723	1,645	1,633	1,614	1,547	1,486	1,463	-2,299	1	1	-	1	1	1
423713235300	30.93401	-103.368084	3,173	16,625	TX	Pecos	C & K Petroleum Inc	Maddox-State	1	Hershey	2,815	2,237	-	2,237	2,224	2,197	2,113	2,073	2,068	1,988	1,975	1,952	1,877	1,831	1,717	-1,852	-	-	-	1	1	1
424753542500	31.445132	-103.377332	2,577	6,505	TX	Ward	Jetta Oper Co Inc	Neely S T	2	Scott	-	745	729	719	715	689	672	653	646	618	614	606	592	460	333	-2,219	-	-	-	1	1	-
423891046400	30.93042	-103.578562	3,067	11,978	TX	Reeves	Pan American	Tenney Gerald E	1	-	1,902	1,452	1,444	1,435	1,425	1,407	1,339	1,311	1,299	1,218	1,203	1,183	1,138	1,070	1,019	-1,544	-	-	-	1	1	1
423893232000	31.332251	-103.281576	2,672	6,999	TX	Reeves	Pitts Energy Co	Cleveland R Et Al	10	Worsham	2,458	1,858	1,838	1,831	1,826	1,818	1,712	1,686	1,677	1,629	1,626	1,619	1,533	1,460	1,390	-2,239	-	1	-	1	-	-
423013135400	31.682623	-103.422296	2,814	17,810	TX	Loving	Chesapeake Operg Inc	University 19-15	1	Haley	-	2,183	-	2,184	2,155	2,137	2,041	2,010	1,991	1,920	-	-	-	-	1,814	-	-	1	-	1	-	-
423013023600	31.882284	-103.489008	3,197	22,265	TX	Loving	Border Expl Co	Johnson-Txl Unt No1	1	Central Pinal Dom	3,105	2,527	2,499	2,482	2,464	2,451	2,388	2,367	2,356	2,301	2,288	2,275	2,241	2,173	2,163	-1,930	1	-	3	1	-	-
424753352700	31.564084	-103.350527	2,730	16,362	TX	Ward	Arco Oil & Gas Corp	Dunagan Ranch	1	Wildcat	2,658	2,005	-	2,005	1,980	1,965	1,909	1,842	1,836	1,775	1,762	1,749	1,689	1,632	1,590	-2,217	-	1	-	1	-	-
423893208400	31.700769	-103.73362	2,781	7,458	TX	Reeves	Read & Stevens Inc	Monroe `13`	1	Wildcat	2,436	1,951	1,933	1,924	1,912	1,878	1,806	1,781	1,773	1,730	1,725	1,715	-	-	1,535	-1,033	-	1	-	1	-	-
423893001600	31.183012	-103.328583	2,804	20,950	TX	Reeves	Texaco Incorporated	Reeves Txl Fee Unit	7	Toro	-	1,911	1,888	1,879	1,873	1,865	1,767	1,733	1,720	1,633	1,625	1,604	1,493	1,424	1,363	-2,347	-	-	-	1	-	-
423893266700	31.224514	-103.532247	2,701	12,230	TX	Reeves	Thompsn J Cleo	Bush `13-253`	2	Hoban	1,956	1,421	1,399	1,389	1,373	1,361	1,297	1,252	1,232	1,139	1,125	1,106	-	-	941		-	-	-	1	-	-
423893247200	31.241719	-103.81724	3,110	11,780	TX	Reeves	Chesapeake Operg Inc	Johnson State 56-10	1	Toyah Nw	1,660	1,427	1,398	1,385	1,371	1,354	1,294	1,269	1,259	1,189	1,170	1,157	1,141	1,051	1,021	-982	-	1	-	1	1	1
423893260700	31.234564	-103.446793	2,654	12,532	TX	Reeves	Thompsn J Cleo	Chevron Minerals 29	1	Hoban	2,266	1,651	1,625	1,610	1,600	1,572	1,525	1,481	1,467	1,388	1,373	1,356	1,253	1,195	1,127	-2,321	-	1	-	1	1	-
423891051300	30.883153	-103.627624	3,271	8,163	TX	Reeves	Holly Corporation	Willbanks Henry	4-Jan	-	1,928	1,430	-	-	-	1,430	1,370	1,328	1,314	1,252	1,231	1,220	1,139	1,099	1,054	-1,096	1	-	-	1		1
423013115600	31.66825	-103.559944	2,676	4,586	TX	Loving	Forest Oil Corporatn	Grayling	4	Vermejo	1,981	1,906	1,883	1,868	1,857	1,837	1,759	1,728	1,721	1,679	1,661	1,651	1,632	1,527	1,480	-1,656	-	1	-	1	1	1

API	Latitude (NAD27)	Longitude (NAD27)	Well Datum Elevation (ft)	WELL TD (ft)	State	County	Operator	Lease	Lease Number	Field	Dewey Lake (ft-msl)	Ruster (ft-msl)	MH4 (ft-msl)	A4 (ft-msl)	Magenta Dolomite (ft-msl)	Tamarisk (ft-msl)	M3 (ft-msl)	A2 (ft-msl)	Culebra Dolomite (ft-msl)	Los Medaños (ft-msl)	A1 Top (ft-msl)	A1 Bot (ft-msl)	Los Medaños LS Top (ft-msl)	Los Medaños LS Bot (ft-msl)	Salado (ft-msl)	Delaware Mountain Group (ft-msl)	Resistivity Log	BRACS Well	Petrophysical Well	Well Used in Interpolation	Interim Cross-Section Well	Final Cross-Section Well
423893046300	31.219395	-103.670665	2,842	14,560	TX	Reeves	Hunt Caroline Tr Est	Poulter Gas Unit	1-Dec	Nine Mile Draw	1,461	911	882	869	855	844	776	754	735	653	644	630	585	510	476	-1,603	-	-	-	1	1	-
300150586300	32.022572	-103.759036	3,154	4,208	NM	Eddy	Hankamer Curtis Corp	Bauerdorf Est	1	Mason North	2,585	1,981	1,959	1,951	1,930	1,902	1,879	1,870	1,861	1,839	1,824	1,817	-	-	1,765	-858	-	-	-	1	1	1
423010024100	31.95805	-103.702575	3,013	4,395	TX	Loving	Davis F A & Gulf	Txl 13	1	-	2,038	1,863	1,844	1,837	1,829	1,816	1,802	1,794	1,783	1,763	1,752	1,742	1,688	1,624	1,583	-1,145	-	1	-	1	1	1
423013128800	31.691035	-103.336847	2,806	17,800	TX	Loving	Chesapeake Operg Inc	University 20-20	1	Haley		2,030	1,998	1,983	1,966	1,947	1,909	1,880	1,873	1,837	1,820	1,808	1,770	1,658	1,617	-2,322	-	1	-	1	1	1
423013119700	31.882367	-103.425666	3,122	17,507	TX	Loving	Patterson Pet Lp	Leiman 10	1	Kennedy Bill	2,772	2,152	2,127	2,115	2,090	2,080	2,015	1,997	1,972	1,937	1,925	1,915	1,826	1,804	1,788	-2,069	-	1	-	1	1	-
423011007600	31.683362	-103.401031	2,817	5,105	TX	Loving	Forest Oil Corporatn	University O	1	Meridian	2,720	2,201	2,172	2,160	2,149	2,127	2,070	2,036	2,023	1,960	1,945	1,926	1,916	1,826	1,802	-2,232	-		-	1	1	1
424753065800	31.571848	-103.46374	2,666	4,760	TX	Ward	Union Texas Pet Corp	Monroe Unit	31	Monroe	1,706	1,090	1,064	1,055	1,044	1,036	1,006	987	976	946	936	922	863	803	766	-1,934	-	1	-	1	-	-
423713718400	30.983211	-102.958959	2,840	3,603	TX	Pecos	Energen Res Corp	Fort Stockton Unit	1527	Fort Stockton	1,925	1,343	-	-	-	1,343	1,305	1,287	1,272	1,206	1,191	1,180	1,141	1,083	1,025	-	-	1	-	1	-	-
423893218700	31.280178	-103.943108	3,171	11,700	TX	Reeves	Pogo Producing Co	Caldwell	1	San Martine Sw	2,021	1,846	1,820	1,806	1,788	1,775	1,701	1,666	1,663	1,577	1,574	1,569	1,470	1,421	1,346	-559	-	1	-	1	-	-
423713651500	30.977272	-103.103328	2,988	11,200	TX	Pecos	Texaco Expl&Prod Inc	Pecos `J` Fee	5	Gomez	1,843	1,346	-	1,346	1,334	1,309	1,243	1,202	1,175	1,103	1,092	1,075	1,022	952	907	-2,157	-	1	-	1	1	1
423713396000	31.108402	-103.153073	2,790	5,378	TX	Pecos	Pogo Producing Co	Page Royalty	2	-	2,332	1,760	-	1,760	1,751	1,741	1,662	1,626	1,617	1,554	1,541	1,528	1,459	1,419	1,340	-2,514	-	1	-	1	-	-
424753505100	31.447517	-103.385921	2,636	6,517	TX	Ward	Jetta Oprtng Company	Barstow 40	1	Scott	1,666	919	897	891	880	865	813	773	753	728	723	711	691	611	571	-2,130	-	1	-	1	1	-
423013127800	31.749975	-103.570044	2,809	11,912	TX	Loving	Pogo Producing Co	Wheat James J	2	Moore-Hooper	-	2,372	2,338	2,327	2,314	2,292	2,232	2,206	2,189	2,128	2,120	2,103	2,018	1,954	1,911	-1,628	-	1	-	1	-	-
423893221400	31.750419	-103.782777	2,799	15,510	TX	Reeves	Helmerich &Payne Inc	Darcy State	3201	Dixieland	-	2,096	2,088	2,074	2,066	2,053	2,003	1,946	1,937	1,856	1,848	1,836	1,731	1,692	1,637	-775	-	1	-	1	-	-
423013115700	31.8925	-103.844722	2,773	5,304	TX	Loving	Chaparral Energy Llc	Hacienda State	1046	Chaparral Draw	-	2,623	2,576	2,564	2,543	2,513	2,444	2,438	2,429	2,378	2,372	2,361	-	-	2,224	-397	-	1	-	1	-	-
423891008500	30.925839	-103.794597	3,401	8,525	TX	Reeves	Burford & Sams	Jo Kingston	1	-	2,219	1,603	1,573	1,565	1,554	1,537	1,487	1,478	1,442	1,334	1,320	1,305	1,281	1,232	1,199	-1,199	-	1	-	1	1	1

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424753504400	31.441317	-103.436695	2,576	6,050	TX	Ward	Latigo Pet Tx Lp	Mobil \`A\`	6	Collie	1,441	852	829	816	796	776	706	681	670	607	599	589	577	472	406	-2,076	-	1	-	1	1	-
423010016800	31.68345	-103.383527	2,799	5,206	TX	Loving	Leblond & Healey	University	1	-	2,729	2,124		2,126	2,100	2,080	1,993	1,963	1,952	1,915	1,909	1,887	1,867	1,768	1,743	-2,264	-		-	1	1	1
423013108400	31.684684	-103.366587	2809	11,750	TX	Loving	Pioneer Nat Res Usa	Block 19 University	1	Two Georges	2,732	2,070	2,043	2,028	1,998	1,979	1,938	1,911	1,899	1,866	1,852	1,832	1,814	1,712	1,688	-2,282	-	1	-	1	1	1
423891042900	31.136876	-103.246801	2,798	22,000	TX	Reeves	Texaco Incorporated	Txl Reeves-State Un	1	Rojo Caballos W	2,432	1,816	1,793	1,787	1,779	1,772	1,716	1,671	1,664	1,567	1,553	1,530	1,467	1,403	1,317	-2,410	-	1	-	1	-	-
423893142100	31.218285	-103.756478	3,058	12,500	TX	Reeves	Texaco Incorporated	Reeves\`Bm\`Fee	1	Five Mile Draw	1,795	1,367	1,338	1,322	1,306	1,295	1,236	1,194	1,179	1,089	1,086	1,082	1,056	1,012	948	-1,169	-	1	-	1	1	1
423893181400	31.713486	-103.66954	2,702	4,143	TX	Reeves	Hillin Production Co	River Bend \`A\`	1a	Arno North	1,445	1,320	1,308	1,296	1,272	1,262	1,218	1,204	1,168	1,137	1,121	1,103	1,075	1,058	1,017	-1,285	-	-	-	1	1	1
423893099900	31.594793	-103.791041	3,051	6,031	TX	Reeves	Hng Oil Company	Felmont-State \`16\`	1	Golden Eagle	2,178	1,478	-	-	-	1,478	1,453	1,433	1,422	1,347	1,341	1,333	1,264	1,238	1,181	-824	-	-	-	1	-	-
424753515400	31.438228	-103.346164	2,610	6,500	TX	Ward	Jetta Oper Co Inc	Barstow 10	3	Scott	2,275	1,660	1,634	1,624	1,615	1,599	1,541	1,528	1,518	1,442	1,434	1,417	1,388	1,287	1,220	-2,186	-	1	-	1	1	-
423891012000	31.790515	-103.974155	3,063	3,160	TX	Reeves	Fox & Randsdell	At Randolph	4	Sabre	2,283	2,138	-	-	-	2,138	2,132	2,123	2,110	2,070	2,066	2,050	1,986	1,954	1,887	169	-	-	-	1	1	1
423890010500	31.816038	-103.927261	2,921	3,100	TX	Reeves	Sinclair Oil & Gas C	Agnes Beckham	11	Sabre		2,461	-	-	-	2,462	2,432	2,417	2,409	2,372	2,361	2,353	2,342	2,230	2,192	11	-	-	-	1	1	
423893140300	31.906664	-103.982748	2,932	4,000	TX	Reeves	Texaco Incorporated	Reeves \`Ad\` Fee	2	Jess Burner	2,578	2,437	-	-	-	-	-	-	-	-	-	-	-	-	2,336	271	-	-	-	1		1
423893233100	31.040556	-103.765	3,198	10,496	TX	Reeves	K2x Company	Johnson	134	Balmorea	1,802	1,327	1,305	1,294	1,282	1,272	1,240	-	1,190	1,166	1,161	1,144	1,065	991	914	-1,280	-	-	-	1		1
423711044200	30.829199	-102.769952	3,144	2,810	TX	Pecos	El Paso Nat Gas Co	Winfield	D1	Fort Stockton S	2,387	1,756	-	-	-	1,756	1,750	1,745	1,736	1,705	1,692	1,683	1,656	1,609	1,568	-	-	1	-	1	-	-
423710281900	30.666708	-103.258685	3,479	16,735	TX	Pecos	Hunt Oil Co	Elsinore Royalty Co	56	Elsinore W Farm	2,792	2,448	-	-	-	-	-	-	-	-	-	-	-	-	1,861	-400	1		1	1	-	-
423710036900	30.931049	-103.394457	3,230	17,006	TX	Pecos	Atlantic Refg Co	Willbanks-Herson Gu	1	Hershey	2,819	2,252	2,239	2,232	2,223	2,196	2,135	2,093	2,081	1,998	1,979	1,964	1,913	1,849	1,730	-1,965	-	-	-	1	1	1
423711013701	30.931711	-103.425297	3,293	17,303	TX	Pecos	Freedom Energy Incor	Hershens on \`5\`	1	Hershey West	2,755	2,183	2,164	2,149	2,138	2,126	2,065	1,991	1,971	1,907	1,897	1,858	1,807	1,737	1,679	-2,064	-	-	-	1	1	1

API	Latitude (NAD27)	Longitude (NAD27)	Well Datum Elevation (ft)	WELL TD (ft)	State	County	Operator	Lease	Lease Number	Field	Dewey Lake (ft-msl)	Ruster (ft-msl)	MH4 (ft-msl)	A4 (ft-msl)	Magenta Dolomite (ft-msl)	Tamarisk (ft-msl)	M3 (ft-msl)	A2 (ft-msl)	Culebra Dolomite (ft-msl)	Los Medaños (ft-msl)	A1 Top (ft-msl)	A1 Bot (ft-msl)	Los Medaños LS Top (ft-msl)	Los Medaños LS Bot (ft-msl)	Salado (ft-msl)	Delaware Mountain Group (ft-msl)	Resistivity Log	BRACS Well	Petrophysical Well	Well Used in Interpolation	Interim Cross-Section Well	Final Cross-Section Well
423013132700	31.920778	-103.594139	3,099	6,845	TX	Loving	Chaparral Energy Llc	Johnson W D Jr Et Al	8031	Grice	-	2,544	2,503	2,487	2,472	2,448	-	-	2,337	2,299	-	-	2,209	2,188	2,164	-1,524	-	1	-	1	-	-
424753516900	31.434308	-103.367242	2,560	6,505	TX	Ward	Jetta Oper Co Inc	Cox	2	Scott	1,460	870	843	830	817	801	768	739	719	670	659	641	598	538	480	-2,251	-	1	-	1	-	-
421093223800	31.793889	-104.098853	3,173	3,600	TX	Culberson	Pogo Producing Co	Middleton	1	Wildcat	-	2,923	-	-	-	2,923	2,838	2,833	2,824	2,785	2,781	2,771	2,718	2,678	2,652	902	-	1	-	1	1	-
423013115900	31.918265	-103.834534	2,919	7,350	TX	Loving	Chaparral Energy Llc	Fraser Txl	9	Tunstill	2,729	2,599	2,571	2,556	2,544	2,523	-	-	-	-	-	-	-	-	2,059	-500	-		-	1	-	-
423013094800	31.885416	-103.515619	3,115	6,734	TX	Loving	J R P Resources Inc	Brunson `47`	8	Pinal Dome	2,985	2,461	2,436	2,424	2,408	2,395	2,339	2,325	2,307	2,271	2,261	2,248	2,181	2,156	2,130	-1,818	-	1	-	1	1	-
424753454300	31.509674	-103.334892	2,748	11,326	TX	Ward	Bright & Co	Monroe `178`	1	Quito	2,508	1,948	1,921	1,905	1,897	1,884	1,844	1,784	1,772	1,708	1,700	1,684	1,607	1,567	1,485	-2,327	-	1	-	1	-	-
423893264300	31.182525	-103.586022	2,744	13,500	TX	Reeves	Thompsn J Cleo	Polo Grounds `150`	1	Wolfbone	1,585	964	933	924	902	877	771	757	744	662	653	642	532	469	399	-2,147	-	-	-	1	-	-
423013126800	31.806946	-103.472132	3,042	17,750	TX	Loving	Chesapeake Operg Inc	Boyd 29-9	1	Wheat	2,807	2,385	2,354	2,341	2,320	2,308	2,242	2,207	2,196	2,159	2,145	2,136	-	-	2,012	-1,903	-	1	-	1	1	-
424753541600	31.438841	-103.254813	2,600	11,158	TX	Ward	Cimarex Energy Co	Khc 33-26	2h	Phantom	-	1,982	1,959	1,946	1,936	1,925	1,886	1,848	1,828	1,754	1,747	1,739	1,705	1,616	1,597	-2,447	-	1	-	1	1	-
423893261100	31.187333	-103.472125	2,761	12,570	TX	Reeves	Thompsn J Cleo	Floyd	1	Hoban	2,461	1,721	1,695	1,690	1,676	1,666	1,606	1,551	1,536	1,445	1,432	1,412	1,318	1,262	1,175	-2,327	-	1	-	1		-
423010024200	31.811854	-103.702531	2,821	4,327	TX	Loving	Davis Holt & Lvldglf	Txl 25	1	-	2,571	2,181	2,150	2,134	2,121	2,096	2,063	2,041	2,019	1,986	1,976	1,963	1,939	1,862	1,826	-1,238	-	1	-	1	1	1
424750075100	31.440119	-103.356976	2,561	5,688	TX	Ward	Adobe Oil Company	Monroe Cynthia	1	Scott	-	1,388	1,367	1,351	1,347	1,325	1,276	1,256	1,241	1,168	1,157	1,141	-	-	971	-	1	-	-	-	-	-
421093223300	31.759722	-104.111925	3,268	3,004	TX	Culberson	Capitan Energy Inc	Reagan Ronald	1	Geraldine South	-	3,085	-	-	-	3,086	2,974	2,954	2,944	2,913	2,905	2,897	2,869	2,843	2,798	973	-	-	-	1	-	-
421093224100	31.759714	-104.108742	3,269	3,005	TX	Culberson	Capitan Energy Inc	U S A	1	Geraldine South	-	3,058	-	-	-	3,059	3,023	2,981	2,948	2,883	2,876	2,864	2,790	2,729	2,653	982	-	-	-	1	-	-
424750289700	31.577553	-103.29065	2,846	5,165	TX	Ward	Humble Oil & Refg Co	State Universit y `Ad	1	Quito East	2,509	2,096	2,075	-	-	2,056	1,972	1,940	1,929	1,891	1,882	1,866	-	-	1,712	-	1	-	3	-	-	-
424750289600	31.582054	-103.287905	2,830	5,397	TX	Ward	Humble Oil & Refg Co	State Universit y `Av	1	Quito East	-	2,076	-	-	-	2,076	2,052	2,035	2,015	1,937	1,918	1,900	-	-	1,690	-	1	-	-	-	-	-
423713763400	30.966111	-103.204167	2,975	11,498	TX	Pecos	Thompsn J Cleo	Kelly 46	1	Maralo	2,075	1,547	-	1,547	1,538	1,523	1,452	1,420	1,406	1,333	1,318	1,302	1,267	1,193	1,143	-2,026	-	1	-	1	1	1

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423013070900	31.911683	-103.629748	3,000	4,600	TX	Loving	Read & Stevens Inc	Johnson W D	1	Grice	2,645	1,987	1,958	1,950	1,922	1,909	1,856	1,842	1,810	1,773	1,752	1,740	-	-	1,510	-1,461	-	1	-	1	-	-
423893260600	31.216415	-103.442491	2,687	12,500	TX	Reeves	Thompsn J Cleo	Chapman State	1	Wolfbone	2,412	1,752	1,728	1,714	1,700	1,691	1,618	1,544	1,537	1,439	1,434	1,413	1,344	1,293	1,247	-2,338	-	1	-	1	-	-
423713771800	31.264154	-103.044791	2,586	6,500	TX	Pecos	Chesapeake Operg Inc	State Trees	1802	Waha West	1,186	726	-	726	712	695	647	632	619	576	569	554	478	380	345	-2,285	-	1	-	1	-	-
423013086200	31.661952	-103.570524	2,679	18,735	TX	Loving	Forest Oil Corporatn	Catfish	2	Vermejo	1,739	1,328	1,319	1,296	1,290	1,281	1,195	1,183	1,170	1,109	1,106	1,099	-	-	969		-	1	-	1	-	-
424753550300	31.420725	-103.32535	2,554	6,491	TX	Ward	Pitts Energy Co	Scott F H	7	Scott	2,446	1,747	1,720	1,708	1,696	1,684	1,621	1,599	1,582	1,498	1,479	1,466	1,381	1,359	1,325	-2,270	-	1	-	1	-	-
423893243500	31.637647	-103.598347	2,686	18,170	TX	Reeves	Anadarko Pet Corp	Sievers A Unit	1r	Moore-Hooper	1,491	1,273	1,253	1,245	1,228	1,207	1,110	1,098	1,080	1,001	997	993	-	-	889	-1,686	-	1	-	1	-	-
424750271700	31.544495	-103.366727	2,598	4,916	TX	Ward	Honolulu Oil Corp	Ww Gary	1	Quito	-	1,895	1,870	1,855	1,846	1,830	1,778	1,758	1,738	1,698	1,673	1,658	-	-	1,486		1	-	-	-	-	-
423011035300	31.682597	-103.427905	2,770	4,993	TX	Loving	Linehan&Stoltenberg	University	1a	-	2,602	2,176	2,156	2,142	2,128	2,111	2,035	2,002	1,987	1,918	1,907	1,884	1,879	1,772	1,735	-2,180	-	-	-	1	1	1
423893002100	30.976786	-103.462933	3,050	20,075	TX	Reeves	Southwest Nat Gas	Wilbanks	1	Pec Reeves	2,658	2,076	2,053	2,039	2,030	2,016	1,961	1,897	1,878	1,805	1,788	1,772	1,707	1,649	1,582	-2,229	-	-	-	1	1	1
423713822900	30.979594	-102.896569	2,866	3,700	TX	Pecos	Tandem Energy Corp	Shelton George M Jr	23	U S M	1,946	1,396	-	1,396	1,391	1,378	1,348	1,334	1,323	1,287	1,274	1,263	-	-	1,116	-	1	1	1	-	-	-
424753513400	31.421083	-103.381068	2,568	6,500	TX	Ward	Jetta Oprtng Company	Cox	1	Scott	1,828	1,225	1,202	1,189	1,179	1,167	1,119	1,094	1,090	1,012	1,003	993	672	626	827	-2,232	-	1	-	1	-	-
423713330200	30.706786	-103.261904	3,386	16,512	TX	Pecos	Getty Oil Company	Hudgins P T	1	Oates Southwest	2,618	2,283	2,192	2,141	2,135	2,122	2,054	1,980	1,955	1,921	-	-	-	-	1,775	-480	-	-	-	1	-	-
421093223900	31.808775	-104.076961	3,148	2,750	TX	Culberson	Mesquite Swd Inc	Shalin	1	Geraldine South	-	3,148	-	-	-	-	2,892	2,886	2,875	2,853	2,846	2,836	-	-	2,703	786	-	-	-	1	-	-
423713736800	31.208163	-103.07592	2,664	4,975	TX	Pecos	E G L Resources Inc	Cg 19	4	Coyanosa North	1,311	843	-	843	825	821	792	709	698	625	622	616	582	471	405	-2,112	-	1	-	1	1	-
423893219200	31.49992	-103.843895	3,136	15,390	TX	Reeves	Pure Resources Lp	Harder `3`	1	Wildcat	-	1,851	1,828	1,815	1,803	1,782	1,729	1,700	1,687	1,635	1,627	1,616	-	-	1,490	-611	-	1	-	1	-	-
424750289800	31.57964	-103.282531	2,821	5,175	TX	Ward	Humble Oil & Refg Co	State University `Ah	1	Quito East	-	2,074	2,068	2,031	2,021	1,998	1,946	1,935	1,931	1,871	1,858	1,848	-	-	1,701	-	1	-	-	-	-	-
424753544000	31.549634	-103.365388	2,615	5,120	TX	Ward	Southwest Royalties	Forrister	10	Quito West	2,327	1,895	-	1,895	1,868	1,854	1,816	1,742	1,736	1,670	1,658	1,640	1,606	1,557	1,503	-2,163	-	1	-	1	-	-

API	Latitude (NAD27)	Longitude (NAD27)	Well Datum Elevation (ft)	WELL TD (ft)	State	County	Operator	Lease	Lease Number	Field	Dewey Lake (ft-msl)	Ruster (ft-msl)	MH4 (ft-msl)	A4 (ft-msl)	Magenta Dolomite (ft-msl)	Tamarisk (ft-msl)	M3 (ft-msl)	A2 (ft-msl)	Culebra Dolomite (ft-msl)	Los Medaños (ft-msl)	A1 Top (ft-msl)	A1 Bot (ft-msl)	Los Medaños LS Top (ft-msl)	Los Medaños LS Bot (ft-msl)	Salado (ft-msl)	Delaware Mountain Group (ft-msl)	Resistivity Log	BRACS Well	Petrophysical Well	Well Used in Interpolation	Interim Cross-Section Well	Final Cross-Section Well
423713300400	30.94234	-103.198083	3,033	21,650	TX	Pecos	Bta Oil Producers	8004 Jv-P Grande	1	Pecos Grande	2,226	1,690	-	-	-	1,690	1,628	1,598	1,588	1,503	1,497	1,472	1,409	1,373	1,342	-1,906	-	-	-	1	-	-
423893124300	31.143539	-103.392234	2,782	5,375	TX	Reeves	Gulf Oil Corp	Woods J R F Et Al	1	Hamon Northwest	2,462	1,881	1,858	1,846	1,833	1,819	1,757	1,715	1,706	1,627	1,613	1,590	1,500	1,443	1,385	-2,330	-	-	-	1	-	-
423713731800	31.274071	-103.038643	2,567	5,200	TX	Pecos	Roca Operating Inc	Trees Joe B Estate	1	Waha	1,121	659	-	659	643	621	527	511	504	422	411	398	352	263	245	-2,253	-	1	-	1	-	-
424753511900	31.439803	-103.457618	2,575	7,892	TX	Ward	Latigo Pet Tx Lp	Adobe	13	Collie	1,576	1,005	980	967	957	943	892	871	864	815	805	794	763	670	630	-2,025	-	1	-	1	1	-
423893040900	31.222897	-103.837772	3,089	12,070	TX	Reeves	Union Texas Pet Corp	Utp Johnson	1	Wildcat	1,879	1,647	1,616	1,604	1,591	1,572	1,497	1,479	1,465	1,390	1,370	1,361	1,345	1,275	1,208	-811	-	-	-	1	1	-
423891045300	31.04075	-103.84642	3,322	9,408	TX	Reeves	Sinclair Oil & Gas C	Johnson Wd	1	-	2,221	1,846	1,818	1,809	1,801	1,781	1,724	1,705	1,680	1,605	1,596	1,585	1,551	1,460	1,404	-909	-	-	-	1	-	-
423893002600	31.183106	-103.301097	2,797	20,986	TX	Reeves	Southwest Nat Gas	Smallwood	1	Toro	2,707	1,919	1,901	1,889	1,879	1,864	1,803	1,749	1,741	1,662	1,640	1,618	1,555	1,486	1,400	-2,368	-	-	-	1	1	1
423893003400	30.949462	-103.532151	3,081	10,880	TX	Reeves	Texaco Incorporated	State Of Texa Fh	1	Barilla	2,502	1,975	1,951	1,939	1,925	1,901	1,833	1,738	1,724	1,651	1,620	1,599	1,578	1,510	1,458	-1,921	-	-	-	1	1	1
423713161000	30.729731	-103.32766	3,380	13,100	TX	Pecos	Hng Oil Company	Tex Amercn Synd 316	1	Perry Bass	2,809	2,483	-	-	-	-	-	-	-	-	-	-	-	-	2,073	-908	-	-	-	1	1	-
423711067800	31.205854	-103.028432	2,646	11,572	TX	Pecos	Mobil Oil Corp	Athey Cb	3	Athey	1,428	891	-	-	-	891	886	868	853	811	787	778	753	698	578	-2,111	-	-	-	1	-	-
423013020900	31.66994	-103.541738	2,723	4,676	TX	Loving	Forest Oil Corporatn	Tadpole	1	Vermejo	-	2,261	2,224	2,209	2,185	2,166	2,090	2,075	2,069	2,015	2,006	1,999	1,983	1,887	1,839	-1,747	-	-	-	1	1	1
423013073500	31.738372	-103.653494	2,728	5,140	TX	Loving	Pogo Producing Co	Morley \`A\`	2	Wildcat	2,338	2,240	2,185	2,180	2,164	2,152	2,106	2,082	2,066	2,013	2,005	1,997	-	-	1,785	-1,345	-	-	-	1	1	1
423893213400	31.518056	-103.663056	2,757	15,300	TX	Reeves	Penwell Energy Inc	Oatman	1	Greasewood	-	996	992	985	974	963	917	910	894	843	835	820	786	738	712	-1,304	-	1	-	1	-	-
423893212500	31.624045	-103.650963	2,794	18,902	TX	Reeves	Penwell Energy Inc	Txl \`1\`	1	Arno	-	1,778	1,749	1,724	1,710	1,704	1,663	1,628	1,593	1,519	1,513	1,496	1,456	1,416	1,376	-1,397	-	1	-	1	-	-
423893224800	31.79415	-103.90194	2,896	3,222	TX	Reeves	Boyd&Mcwiliams Group	Regan	42-1	Mikado	-	2,536	-	-	-	2,537	2,511	2,505	2,477	2,447	2,443	2,431	2,422	2,342	2,285	-106	-	1	-	1	1	-
423893244700	31.431115	-103.903517	3,059	3,280	TX	Reeves	Petro-Hunt Llc	Block 59 State 36	2	Toyah Lake West	2,779	2,421	2,384	2,372	2,362	2,351	2,331	2,283	2,274	2,217	2,211	2,205	2,183	2,156	2,109	-185	-	1	-	1	-	-

API	Latitude (NAD27)	Longitude (NAD27)	Well Datum Elevation (ft)	WELL TD (ft)	State	County	Operator	Lease	Lease Number	Field	Dewey Lake (ft-msl)	Ruster (ft-msl)	MH4 (ft-msl)	A4 (ft-msl)	Magenta Dolomite (ft-msl)	Tamarisk (ft-msl)	M3 (ft-msl)	A2 (ft-msl)	Culebra Dolomite (ft-msl)	Los Medaños (ft-msl)	A1 Top (ft-msl)	A1 Bot (ft-msl)	Los Medaños LS Top (ft-msl)	Los Medaños LS Bot (ft-msl)	Salado (ft-msl)	Delaware Mountain Group (ft-msl)	Resistivity Log	BRACS Well	Petrophysical Well	Well Used in Interpolation	Interim Cross-Section Well	Final Cross-Section Well
423713051800	30.967804	-102.998317	2,960	22,660	TX	Pecos	Ladd Petroleum Corp	Ft Stockton-Dixel	2	Gomez	1,961	1,479	1,464	1,459	1,451	1,436	1,384	1,364	1,345	1,262	1,252	1,240	1,204	1,154	1,117	-1,453	-	-	-	1	1	1
300252715400	32.002547	-103.574707	3,251	16,180	NM	Lea	Getty Oil Company	Federal \`33\`	1	Lea Co Undesigntd	3,101	2,493	2,461	2,451	2,432	2,413	2,353	2,339	2,320	2,269	2,257	2,247	-	-	2,136	-1,672	-	1	-	1	-	-
423713681900	31.13957	-103.129906	2,764	15,729	TX	Pecos	Mobil Prducng Tx&Nm	Cross R B \`21\`	2	Rojo Caballos	1,688	1,100	-	1,100	1,093	1,081	1,014	983	967	902	890	878	805	764	714	-2,480	-	1	-	1	-	-
423891015200	31.170193	-104.089945	3,729	10,700	TX	Reeves	Texaco Incorporated	Ha Everest Nct1	1	Wildcat	3,282	2,975	-	-	-	-	-	-	-	-	-	-	2,790	2,674	2,635	255	-	1	-	1	1	-
423893008700	31.090229	-103.719397	3,021	11,450	TX	Reeves	Lowe Ralph L	Conoco 44	1	-	-	1,241	1,213	1,201	1,186	1,169	1,106	1,071	1,051	971	967	958	-	-	811		1	-	-	-	-	-
424753169400	31.433399	-103.325567	2,551	6,515	TX	Ward	Hunt D H	Watson	Jan-32	Scott	2,258	1,590	1,563	1,551	1,540	1,531	1,456	1,442	1,435	1,357	1,342	1,330	1,308	1,223	1,171	-2,252	-	-	-	1	1	-
423893035700	31.14553	-103.902823	3,306	9,440	TX	Reeves	Monsanto Co Etal	Johnson	1	Casey Draw	2,109	1,837	1,826	1,797	1,779	1,759	1,710	1,696	1,689	1,648	1,641	1,631	1,532	1,470	1,442	-436	-	-	-	1	-	-
423893243100	31.410539	-103.339867	2,557	6,500	TX	Reeves	Jetta Oper Co Inc	Worsham B	5	Scott	2,182	1,632	1,600	1,583	1,565	1,556	1,496	1,450	1,435	1,373	1,328	1,315	1,288	1,244	1,217	-2,279	-	1	-	1	-	-
423010104300	31.671165	-103.460054	2,756	5,108	TX	Loving	Mobil Oil Corp	Twofrds Dlwr D Unit	1401	Twofreds	2,426	2,185	2,155	2,141	2,128	2,105	2,040	2,011	2,003	1,943	1,938	1,922	1,888	1,799	1,746	-2,098	1	-	1	1	1	1
423013121200	31.759167	-103.450556	2,884	18,100	TX	Loving	Anadarko Pet Corp	Walsh 33	1	Haley	2,686	2,290	2,264	2,249	2,236	2,221	2,152	2,106	2,094	2,054	2,046	2,030	1,977	1,918	1,884	-2,096	-	1	-	1	-	-
423893035300	31.219436	-103.574127	2,699	12,140	TX	Reeves	Shell Oil Co	Marsden /147/	1	Marsden D8	1,442	778	754	744	731	716	646	582	578	492	462	448	394	323	272	-2,147	-	1	-	1	1	-
423713287700	30.82013	-102.903381	3,126	2,722	TX	Pecos	Rial Oil Co	Belding-State 29	1	Belding East	2,454	1,903	-	-	-	1,903	1,872	1,855	1,837	1,789	1,774	1,761	1,719	1,669	1,620	-	-	1	-	1	1	1
423010091500	31.708509	-103.43338	2,749	5,325	TX	Loving	Magnolia Pet Co	State Of Tx Lands	1	-	2,516	2,173	2,145	2,131	2,117	2,105	2,031	1,988	1,971	1,895	1,886	1,871	1,820	1,779	1,721	-2,138	1	1	-	1	-	-
423893242600	31.421244	-103.410547	2,586	6,077	TX	Reeves	Marshall& Winston Inc	Sieber	1	Collie	1,456	827	806	796	787	783	739	731	721	675	672	661	646	573	523	-2,189	-	1	-	1	1	1
423013140800	31.859497	-103.606447	2,948	4,652	TX	Loving	Atlantic Operating	China Beach	4	Grice	2,768	2,359	2,328	2,318	2,294	2,279	2,208	2,182	2,165	2,132	2,119	2,102	2,029	2,013	1,956	-1,557	-	1	-	1	-	-
423010057700	31.911443	-103.824305	2,865	3,484	TX	Loving	Ambassador Oil Corp	Johnson Jr	30	Tunstill	-	2,607	2,574	2,563	2,545	2,515	2,475	2,438	2,416	2,375	-	-	-	-	2,215	-552	-	1	-	1	-	-
421093227200	31.68203	-104.06419	3,277	4,100	TX	Culberson	Samson Lone Star L P	Bateman 28	2	Marsh South	-	3,032	-	-	-	-	-	-	-	-	-	-	2,707	2,668	2,618	688	-	1	-	1	1	1

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423713039200	31.085134	-102.944386	2,681	3,140	TX	Pecos	Tejay Operating	Neal A	1	M P F	1,466	882	-	-	-	882	865	820	809	760	745	736	683	635	583	-	-	-	-	1	-	-
423713318100	30.739327	-103.26657	3,413	17,050	TX	Pecos	Texaco Incorporated	Manzanita Unit	1	Manzanita	2,668	2,356	2,291	2,254	2,233	2,212	2,118	2,076	2,059	1,973	1,964	1,958	-	-	1,940	-950	-	-	-	1	1	-
423713732100	31.049189	-103.02228	2,806	20,054	TX	Pecos	Pure Resources Lp	Palmer	3	Gomez	1,736	981	-	-	-	981	931	893	879	783	779	768	705	648	586	-2,149	-	1	-	1	-	-
423893151300	31.178611	-104.037778	3,700	6,642	TX	Reeves	Ped Oil Corp	Ped Palafox	1	Wildcat	3,096	2,811	2,785	2,762	2,751	2,736	2,662	2,627	2,623	2,555	2,550	2,530	2,521	2,431	2,393	183	-		-	1	1	-
421093227400	31.652911	-104.064236	3,335	4,100	TX	Culberson	Samson Lone Star L P	Mays 40	2	Marsh South		3,045	3,005	2,995	2,965	2,935	2,865	2,837	2,817	2,764	2,751	2,745	2,649	2,628	2,560	688	-	1	-	1	-	-
423893253800	31.337567	-103.147356	2,544	5,964	TX	Reeves	Staley Operating Co	Ligon State 22	4	Tmbring	2,301	1,709	-	1,709	1,687	1,673	1,573	1,549	1,537	1,470	1,454	1,444	1,403	1,377	1,330	-2,368	-	1	-	1	-	-
423013129700	31.918409	-103.852786	2,870	,5360	TX	Loving	Chaparral Energy Llc	Johnson 34 `A`	1	Zuni		2,658	2,626	2,606	2,596	2,566	2,485	2,477	2,467	2,400	2,387	2,373	2,303	2,262	2,240	-434	-	1	-	1	1	-
423711090700	30.943779	-102.883076	2,912	22,642	TX	Pecos	Gulf Oil Corp	Abell East Unit	1	Gomez	2,089	1,491	-	-	-	1,491	1,469	1,452	1,440	1,396	1,383	1,372	1,322	1,285	1,240	-1,921	-	-	-	1	1	1
423711047900	31.238997	-103.062957	2,635	12,963	TX	Pecos	Sinclair Oil & Gas C	Calvert A	1	Coyanosa	1,236	807	796	787	776	762	750	679	632	572	566	555	-	-	418	-2,191	-	-	-	1	-	-
423893190600	31.697145	-103.847488	2,867	3,550	TX	Reeves	New Horizon Expl Inc	Meeker Hill `D`	8	Ken Regan	-7,132	1,817	-	-	-	-	-	-	-	-	-	-	-	-	1,487	-515	-	1	-	1	1	-
423713633500	31.02045	-102.816049	2,736	23,236	TX	Pecos	Hunt Oil Co	Tomahawk	1	Wildcat	1,871	1,447	-	1,447	1,439	1,425	1,393	1,377	1,372	1,321	1,307	1,295	1,256	1,215	1,187		-	1	-	1	-	-
423893207600	31.456927	-103.763448	3,026	13,270	TX	Reeves	Lbo Energy Inc	Spencer `33`	1	Athens	1,771	1,526	-	-	-	1,526	1,504	1,463	1,448	1,381	1,376	1,366	1,348	1,252	1,224	-702	-	1	-	1	1	-
424753481300	31.647551	-103.506075	2,715.5	6,498	TX	Ward	Forest Oil Corporatn	Elmer	2	Vermejo	2,478	2,226	2,195	2,184	2,165	2,142	2,090	2,053	2,038	2,008	1,987	1,970	1,895	1,851	1,821	-1,885	-	1	-	1	-	-
423013113000	31.895392	-103.435891	3,162	19,115	TX	Loving	Tmbr/Sharp Drlg Inc	Leiman	1	Wildcat	2,850	2,216	2,188	2,172	2,151	2,139	2,065	2,045	2,031	2,012	1,992	1,983	1,893	1,873	1,862	-2,066	-	1	-	1	1	-
423893218800	31.631833	-103.692215	2,811	17,436	TX	Reeves	Cimarex Energy Co	Sempra	1-Apr	Dixieland	-	1,539	-	-	-	-	-	-	-	-	-	-	-	-	1,331	-1,207	-	-	-	1	-	-
421093139600	31.368963	-104.394722	4,435	9,979	TX	Culberson	Castile Minerals	State `7`	1	Wildcat	-	4,432	-	-	-	-	-	-	-	-	-	-	-	-	4,315	3,106	-	-	-	1	-	-
423713585900	30.980576	-103.230347	2,964	11,500	TX	Pecos	Page Exploration	Tenneco-Mendel `40`	1	Wildcat	1,991	1,411	1,401	1,394	1,389	1,379	1,307	1,283	1,269	1,195	1,181	1,166	1,097	1,054	1,019	-2,164	-	1	-	1	-	-

API	Latitude (NAD27)	Longitude (NAD27)	Well Datum Elevation (ft)	WELL TD (ft)	State	County	Operator	Lease	Lease Number	Field	Dewey Lake (ft-msl)	Ruster (ft-msl)	MH4 (ft-msl)	A4 (ft-msl)	Magenta Dolomite (ft-msl)	Tamarisk (ft-msl)	M3 (ft-msl)	A2 (ft-msl)	Culebra Dolomite (ft-msl)	Los Medaños (ft-msl)	A1 Top (ft-msl)	A1 Bot (ft-msl)	Los Medaños LS Top (ft-msl)	Los Medaños LS Bot (ft-msl)	Salado (ft-msl)	Delaware Mountain Group (ft-msl)	Resistivity Log	BRACS Well	Petrophysical Well	Well Used in Interpolation	Interim Cross-Section Well	Final Cross-Section Well
423893157700	31.31788	-103.938306	3,162	12,975	TX	Reeves	Pennzoil Co Inc	Caldwell	1	San Martine	1,967	1,847	1,832	1,815	1,809	1,799	1,765	1,742	1,725	1,672	1,658	1,646	-	-	1,532	-220	-	1	-	1	-	-
423893229700	31.300991	-103.154612	2,631	17,664	TX	Reeves	Pure Resources Lp	Rape 13	2h	Waha West	2,185	1,591	-	1,591	1,570	1,560	1,485	1,462	1,451	1,373	1,356	1,344	1,286	1,233	1,211	-2,344	-	1	-	1	-	-
423713744000	31.2053	-103.076236	2,668	5,065	TX	Pecos	E G L Resources Inc	Cg 19	6	Coyanosa North	1,292	843	-	843	838	819	755	718	709	658	649	639	542	479	371	-	-	1	-	1	-	-
423891012900	30.966276	-103.639968	3,021	4,750	TX	Reeves	Jones Mac	Weinacht	1	-	1,654	1,274	1,248	1,237	1,225	1,212	1,153	1,126	1,105	1,064	1,053	1,043	994	923	876	-1,526	-	-	-	1	1	1
421093220300	31.897171	-104.063075	3,098	4,375	TX	Culberson	Burkholder Terry Inc	Bass	1	Ford West	-6,901	3,098	-	-	-	-	-	-	2,912	2,813	2,805	2,796	-	-	2,633	685	-	-	-	1	-	-
421093138300	31.618334	-104.089635	3,346	16,471	TX	Culberson	Exxon Corporation	Kirk T A	1	Wildcat	3,114	3,011	2,967	2,954	2,924	2,898	2,813	2,783	2,766	2,722	2,708	2,695	-	-	2,542	743	1	-	3	1	-	-
421093140600	31.565929	-104.093002	34,42	2,820	TX	Culberson	Harper Oil Company	Cleveland	1	Cottonwood Ranch	3,239	3,170	-	-	-	3,169	3,096	3,085	3,072	2,982	2,976	2,962	-	-	2,874	779	-	1	-	1	-	-
300150589700	32.001274	-103.737667	3,120	4,115	NM	Eddy	Hutchco Production	Eddy-State Ag-A	3	Mason North	2,360	2,120	-	2,120	2,105	2,080	2,035	2,023	2,007	1,971	1,957	1,949	-	-	1,836	-933	-		-	1	1	1
424753501200	31.4275	-103.447417	2,591	5,200	TX	Ward	Latigo Pet Tx Lp	Worsham `42`	6	Collie	1,639	923	899	887	878	860	827	806	797	750	736	724	-	-	589	-2,077	-	1	-	1	-	-
423893239100	31.815117	-103.862849	2,817	3,800	TX	Reeves	Draco Energy Inc	Trinity State 28	1	Sand Bend Draw	-	2,499	-	-	-	2,500	2,438	2,429	2,423	2,377	2,370	2,356	-	-	2,222	-363	-	1	-	1	-	-
423013063000	31.775148	-103.542449	2,847	4,800	TX	Loving	Pet Corp Of Delaware	Bass `46-B`	8	Wheat	2,657	2,354	2,327	2,317	2,297	2,282	2,197	2,164	2,143	2,110	2,091	2,077	2,005	1,968	1,923	-1,725	-	1	-	1	-	-
423713244000	30.934085	-103.415898	3,342	16,860	TX	Pecos	Northern Natural Gas	Hershenson 6	1	Hershey West	2,722	2,160	2,140	2,129	2,115	2,095	2,023	1,974	1,958	1,893	1,871	1,854	1,792	1,731	1,652	-2,036	-	1	-	1	1	1
423893170700	31.685477	-103.826214	2,871	3,720	TX	Reeves	Blair Ryltes Of Orla	Shelly	1	Ken Regan	2,471	2,021	-	-	-	2,022	1,990	1,951	1,937	1,902	1,898	1,882	-	-	1,315	-656	-	1	-	1	1	1
423893189800	31.729682	-103.81661	2,850	3,999	TX	Reeves	Kinlaw Oil Corp	Smith Paul	1	Orla South	2,490	2,102	-	-	-	-	-	2,099	2,089	2,048	2,039	2,028	1,960	1,910	1,880	-621	-	1	-	1	-	-
423013077300	31.857501	-103.783281	2,841	3,800	TX	Loving	Rosewood Res Inc	Rri State	108	Wildcat	2,736	2,388	2,353	2,339	2,320	2,296	2,254	2,221	2,204	2,168	2,161	2,148	-	-	2,011	-724	-	1	-	1	-	-
423893212100	31.283381	-103.229827	2,676	7,000	TX	Reeves	Lario Oil & Gas Co	Tire Track	1	Wildcat	2,432	1,779	1,775	1,761	1,753	1,740	1,689	1,665	1,646	1,568	1,561	1,546	1,480	1,411	1,312	-2,389	-	1	-	1	-	-

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423893203200	31.315072	-103.198684	2,625	6,610	TX	Reeves	Campana Petroleum Co	Ligon	1	Wildcat	2,397	1,754	1,749	1,742	1,724	1,705	1,646	1,614	1,600	1,526	1,516	1,502	1,453	1,385	1,312	-2,379	-	-	-	1	-	-
423893038200	30.961773	-103.455039	3,115	16,532	TX	Reeves	Clayton Williams Enr	Chicora Modesta	1	Pec Reeves	2,773	2,196	2,181	2,170	2,159	2,148	2,083	1,998	1,982	1,906	1,886	1,871	1,829	1,750	1,695	-2,191	-	1	-	1	1	1
423013125000	31.804961	-103.45051	3,073	17,860	TX	Loving	Anadarko Pet Corp	Anderson 15	1	Haley	-	2,245	2,217	2,208	2,188	2,181	2,127	2,080	2,067	2,022	2,013	1,995	-	-	1,912	-2,034	-	1	-	1	1	
423893229200	31.341794	-103.195728	2,613	16,900	TX	Reeves	Finley Resources Inc	Dudley-Rudman State	2h	Worsham -Bayer	2,196	1,588	-	1,588	1,566	1,555	1,479	1,450	1,438	1,371	1,358	1,345	1,302	1,277	1,253	-2,426	-	1	-	1	-	-
421093222500	31.749731	-104.125506	3,316	2,748	TX	Culberson	Capitan Energy Inc	Columbia 7	5	Geraldine South	-	3,111	-	-	-	3,111	3,053	3,020	3,012	2,960	2,956	2,941	2,903	2,837	2,805	1,050	-	1	1	1	-	-
423013079500	31.743298	-103.647197	2,717	5,390	TX	Loving	Pogo Producing Co	Regan Unit	1	Hubbard	2,527	2,432	2,396	2,386	2,364	2,348	2,258	2,246	2,237	2,199	2,189	2,169	2,115	2,068	1,979	-1,373	-	-	-	1	1	1
423893241800	31.811933	-103.867152	2,825	3,457	TX	Reeves	Draco Energy Inc	Trinity State 28	2	Tunstill	-	2,125	2,086	2,072	2,059	2,046	2,006	1,976	1,957	1,928	1,912	1,899	1,890	1,804	1,760	-355	-	1	-	1	1	-
424753481000	31.599678	-103.378831	2,720	5,214	TX	Ward	Seaboard Operating	Monroe	2	Double E	2,445	2,048		2,048	2,024	2,006	1,917	1,885	1,877	1,830	1,816	1,800	1,741	1,686	1,670	-2,254	-	1	-	1	-	-
423013140900	31.888908	-103.585491	3,041	4,665	TX	Loving	Atlantic Operating	Arctic	6	Grice	2,893	2,567	2,528	2,516	2,498	2,476	2,398	2,372	2,351	2,316	2,297	2,285	2,226	2,199	2,186	-1,555	-	1	-	1	1	-
423893219700	31.408531	-103.675207	2,789	5,123	TX	Reeves	Concho Resources Inc	Hammon d	1	Wildcat	1,264	946	920	910	899	887	836	824	808	769	758	748	683	628	587	-1,153	-	1	-	1	-	-
423893198600	31.343346	-103.264462	2,623	13,035	TX	Reeves	Dakota Resources Inc	Clevelan d R	1	Worsham -Bayer	2,490	1,862	1,839	1,830	1,817	1,796	1,742	1,720	1,709	1,625	1,618	1,600	1,542	1,469	1,393	-2,241	-	-	-	1	-	-
423893179000	31.715167	-103.672509	2,704	5,851	TX	Reeves	Williamson Jc	Hill	1	Una Mas	1,331	1,037	1,007	996	985	979	932	909	895	873	826	814	-	-	724	-1,258	-		-	1	1	1
423893172900	31.506959	-103.736938	2,893	5,541	TX	Reeves	Texaco Incorporate d	Reeves \`By\` Fee	1	Wildcat	-	1,463	1,458	1,451	1,447	1,442	1,400	1,391	1,378	1,335	1,326	1,316	1,254	1,198	1,153	-1,005	-	1	-	1	-	-
423713259400	31.12568	-102.897661	2,634	9,114	TX	Pecos	Florida Gas Expl Co	State-Reed	Feb -36	Wildcat	1,604	1,061	-	1,061	1,058	1,048	1,030	1,015	1,001	955	951	942	909	866	804	-	-	1	-	1	-	-
423710487500	30.934083	-102.932572	2931	2975	TX	Pecos	Texaco Incorporate d	Fort Stockton So Un	42-2	Fort Stockton	2,056	1,522	-	-	-	1,522	1,492	1,470	1,453	1,396	1,385	1,374	1,333	1,279	1,231	-	-	1	-	1	1	1
423013102000	31.751042	-103.599835	2,771	6,175	TX	Loving	Maralo Incorporate d	Concord	1	Wheat	-	2,419	2,411	2,393	2,383	2,372	2,330	2,309	2,292	2,248	2,241	2,219	2,158	2,122	2,061	-1,536	-	1	-	1	-	-

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423013091700	31.68793	-103.624336	2,685	5,400	TX	Loving	Remuda Operg Co Inc	Hahman State	1	Hubbard	2,573	2,377	2,344	2,336	2,309	2,293	2,215	2,185	2,162	2,128	2,107	2,094	2,076	1,993	1,969	-1,471	-	1	-	1	1	1
423893231000	31.358769	-103.615752	2,708	5,545	TX	Reeves	Stanolind Operating	Caldwell	1	Wildcat	1,208	778	752	743	720	705	642	628	616	538	531	516	458	403	328	-1,611	-	1	-	1	-	-
424753191300	31.442855	-103.21695	2,673	6,500	TX	Ward	Boyd Foy Mgmt Corp	Pitzer	1	Pitzer North	2,570	1,931	-	1,931	1,910	1,898	1,835	1,801	1,775	1,713	1,700	1,685	1,657	1,562	1,512	-2,407	-	1	-	1	1	-
423893210900	31.336667	-103.314444	2,685	6,460	TX	Reeves	Enron Oil & Gas Co	Worsham `14`	1	Worsham	2,442	1,821	1,791	1,767	1,761	1,750	1,632	1,616	1,606	1,538	1,522	1,502	1,454	1,380	1,316	-2,349	-	-	-	1	-	-
423710536100	30.941382	-102.949424	2,900	2,983	TX	Pecos	Texaco Incorporated	Fort Stockton So Un	28-7	Fort Stockton	2,100	1,485	-	-	-	1,485	1,451	1,432	1,413	1,356	1,347	1,333	1,290	1,236	1,188	-	-	1	-	1	1	1
423013100600	31.998317	-103.82123	3,069	7,710	TX	Loving	Trail Mountain Inc	Texaco Ross Draw	1	Wildcat	2,217	1,979	-	1,979	1,969	1,941	1,890	1,879	1,869	1,832	1,816	1,806	1,748	1,715	1,699	-640	-	1	-	1	-	-
423893238000	31.342767	-103.941248	3,127	11,091	TX	Reeves	Chesapeake Operg Inc	Pelican Ranch	2	Unnamed	2,577	2,437	2,408	2,382	2,376	2,367	2,332	2,299	2,293	2,239	2,235	2,223	-	-	2,157	-117	-	1	-	1	-	-
423893246800	31.126584	-103.243498	2,792	5,500	TX	Reeves	Shenandoah Petr Corp	Red Horse 29	2	Rojo Caballos	2,477	1,828	-	1,828	1,809	1,802	1,719	1,695	1,684	1,578	1,560	1,541	1,480	1,423	1,327	-2,371	-	1	-	1	-	-
423893233900	31.414166	-103.43374	2,579	5,335	TX	Reeves	Latigo Pet Tx Lp	Perkins F	13	Collie	1,468	844	823	812	802	792	754	733	724	657	647	635	598	555	472	-2,156	-	1	-	1	-	-
423893148900	31.687416	-103.755617	2,834	5,490	TX	Reeves	R K Petroleum Corp	Monroe Rk `15`	1	Dixieland	-	1,655	-	-	-	1,656	1,544	1,499	1,487	1,427	1,417	1,392	-	-	1,116	-922	-	-	-	1	1	1
422433000200	30.682182	-103.464926	3,773	8,901	TX	Jeff Dav	Occidental Petr	State-Lea	1	-	2,473	2,315	-	-	-	-	-	-	-	-	-	-	2,163	2,117	2,091	-569	-	1	-	1	1	1
423013113200	31.790833	-103.4175	3,008	17,920	TX	Loving	Anadarko Pet Corp	Haley J E `24`	1	Haley	2,798	2,151	2,127	2,116	2,104	2,090	2,038	1,999	1,988	1,948	1,943	1,928	-	-	1,831	-2,198	-	1	-	1	1	-
424753519800	31.649238	-103.403608	2,783	15,860	TX	Ward	Chesapeake Operg Inc	Wright 22e	1h	Two Georges	2,603	2,175	2,150	2,132	2,122	2,115	2,052	2,018	2,005	1,962	1,950	1,935	1,874	1,837	1,783	-2,249	-	1	-	1	-	-
424753518200	31.631376	-103.310976	2,822	15,440	TX	Ward	Cimarex Energy Of Co	War-Wink University	4h	War-Wink West	2,572	1,965	-	1,965	1,939	1,926	1,871	1,826	1,816	1,776	1,762	1,750	1,681	1,633	1,607	-2,330	-	1	-	1	-	-
423713747600	31.005473	-102.937006	2,809	3,646	TX	Pecos	Energen Res Corp	Fort Stockton Unit	316	Fort Stockton	1,819	1,237	-	-	-	1,237	1,207	1,188	1,169	1,127	1,117	1,106	1,062	1,009	934	-	-	1	-	1	-	-
423713737100	31.185766	-103.033722	2,665	6,540	TX	Pecos	Pecos Production Co	Sibley 48	4	Coyanosa	1,367	810	-	-	-	810	765	704	695	635	630	624	601	531	482	-2,039	-	1	-	1	-	-

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421093174700	31.663852	-104.079094	3,311	15,717	TX	Culberson	Bta Oil Producers	7816 Jv-P Duval `C`	1	King Edward	3,211	3,055	3,023	3,004	2,980	2,951	2,886	2,860	2,845	2,798	-	-	-	-	2,661	785	-		-	1	-	-
423713671300	30.883619	-103.231555	3,198	12,276	TX	Pecos	Louis Dreyfus Natura	Kennedy State `C`	280 1	Wildcat	2,678	2,063	-	2,063	2,043	2,027	1,960	1,922	1,897	1,835	1,810	1,797	1,758	1,722	1,681	-1,733	-	1	-	1	-	-
423891057300	30.98081	-103.679026	3,071	5,000	TX	Reeves	Omar Oil Ltd	Weinacht Etal	1	-	1,642	1,266	1,241	1,230	1,219	1,201	1,126	1,103	1,088	994	977	963	906	833	789	-1,423	-	-	-	1	1	1
423713836800	31.000447	-102.902231	2,821	3,639	TX	Pecos	Energen Res Corp	Bennett J R `B`	7	Fort Stockton	1,891	1,251	-	1,251	1,244	1,226	1,193	1,181	1,172	1,121	1,114	1,102	1,060	1,015	951		-	1	-	1	-	-
424753399000	31.445545	-103.3551	2,576	4,991	TX	Ward	Pitts Energy Co	Talley Unit	1	Scott	2,185	1,600	1,572	1,559	1,545	1,537	1,479	1,461	1,450	1,371	1,358	1,343	1,315	1,215	1,162	-2,240	-	-	-	1	1	-
423713639500	31.171258	-103.093853	2,726	16,500	TX	Pecos	Leede Oil & Gas Inc	Hoelscher `11`	1	Wildcat	1,448	898	887	876	869	844	776	733	714	640	636	624	593	542	509		-	1	-	1	-	-
423713571100	30.97468	-103.118311	2,954	11,204	TX	Pecos	Maralo Incorporated	Tenneco-Mendel Estat	1	Maralo	1,900	1,363	-	-	-	1,363	1,308	1,248	1,237	1,154	1,144	1,128	1,091	1,010	941	-2,188	-	-	-	1	1	1
423893215400	31.371967	-103.289015	2,589	6,604	TX	Reeves	Pitts Energy Co	Allen	1	Scott	2,416	1,843	1,822	1,813	1,801	1,775	1,723	1,688	1,675	1,606	1,591	1,576	1,489	1,454	1,389	-2,285	-	-	-	1	-	-
423893156100	31.329801	-103.600479	2,613	5,800	TX	Reeves	Mobil Prducng Tx&Nm	Schluter F A	1	Wildcat	1,013	544	513	505	492	466	409	383	371	311	294	276	210	154	93	-1,851	-	-	-	1	-	-
424753380200	31.449005	-103.369091	2,569	6,501	TX	Ward	Pitts Energy Co	Nichols	1	Scott	1,835	1,120	1,093	1,084	1,067	1,056	994	976	968	899	892	872	844	728	698	-2,230	-	-	-	1	1	-
423893214400	31.213807	-103.388196	2,699	6,350	TX	Reeves	Great Tx Crude Inc	Gtc-Texaco	1	Wildcat	-	1,997	1,967	1,957	1,947	1,931	1,871	1,799	1,788	1,705	1,688	1,672	1,587	1,534	1,439	-2,348	-	1	-	1	-	-
423893120500	31.689123	-103.83439	2,916	3,705	TX	Reeves	Southern Union Expl	Sxt Cheesman	1	Wildcat	-	1,905	-	-	-	-	-	-	-	-	-	-	-	-	1,195	-603	-	-	-	1	1	1
423893051600	31.727746	-103.875301	2,932	3,448	TX	Reeves	Hanover Mgmt Co	Arco-State	2	Ken Regan	2,756	2,410	2,400	2,370	2,333	2,325	2,294	2,280	2,273	2,208	2,199	2,187	2,186	2,160	2,104	-333	-	-	-	1	-	-
423013107000	31.719208	-103.661202	2,722	5,246	TX	Loving	Pogo Producing Co	Flores	2	Pecos Bend	2,411	2,162	2,119	2,107	2,097	2,076	2,064	2,059	2,051	2,033	2,027	2,007	1,999	1,848	1,797	-1,278	-	-	-	1	1	1
423013104400	31.874154	-103.554247	3,018	6,804	TX	Loving	Amerac Energy Corp	Leland	2	Myrtle B	2,867	2,435	2,407	2,397	2,375	2,360	2,303	2,291	2,258	2,221	2,203	2,191	2,126	2,096	2,048	-1,711	-	1	-	1	1	-
424753496300	31.442175	-103.393175	2,567	6,536	TX	Ward	Jetta Oper Co Inc	Barstow 13	2	Scott	1,582	888	868	856	845	829	789	783	774	696	673	657	612	567	528	-2,171	-	1	-	1	1	-

API	Latitude (NAD27)	Longitude (NAD27)	Well Datum Elevation (ft)	WELL TD (ft)	State	County	Operator	Lease	Lease Number	Field	Dewey Lake (ft-msl)	Ruster (ft-msl)	MH4 (ft-msl)	A4 (ft-msl)	Magenta Dolomite (ft-msl)	Tamarisk (ft-msl)	M3 (ft-msl)	A2 (ft-msl)	Culebra Dolomite (ft-msl)	Los Medaños (ft-msl)	A1 Top (ft-msl)	A1 Bot (ft-msl)	Los Medaños LS Top (ft-msl)	Los Medaños LS Bot (ft-msl)	Salado (ft-msl)	Delaware Mountain Group (ft-msl)	Resistivity Log	BRACS Well	Petrophysical Well	Well Used in Interpolation	Interim Cross-Section Well	Final Cross-Section Well
423893250000	31.448653	-103.993716	3,191	11,727	TX	Reeves	Chesapeake Operg Inc	Munn State 59-30	1	Toyah Nw	-	2,824	2,788	2,771	2,744	2,726	2,644	2,633	2,610	2,540	2,525	2,502	2,464	2,363	2,335	280	-	1	-	1	1	-
423713661600	30.867008	-103.27598	3,363	6,530	TX	Pecos	Titan Resources	Legros	3	Chancellor D8	2,823	2,289	2,278	2,272	2,268	2,252	2,235	2,218	2,203	2,125	2,122	2,105	2,071	1,907	1,867	-1,765	-	1	-	1	-	-
423713649300	31.108733	-103.208234	2,787	5,500	TX	Pecos	Tipperary O&G Corpor	Holbert \`A\`	1	Rojo Caballos	2,457	1,848	-	1,848	1,837	1,824	1,740	1,705	1,692	1,615	1,598	1,587	1,535	1,451	1,397	-2,485	-	1	-	1	1	1
423893038800	31.981894	-103.994464	2,867	2,788	TX	Reeves	Continental Oil Co	Ramsey G E Jr /7/	12	Geraldine	-	2,865	-	-	-	2,865	2,839	2,813	2,797	2,747	2,739	2,724	-	-	2,615	181	-	-	-	1	-	1
424753044300	31.450181	-103.407349	2,575	6,400	TX	Ward	Shell Oil Co	Edwards	1	Wildcat	1,450	852	829	821	807	788	736	708	691	625	614	600	574	436	375	-2,180	-	1	-	1	1	-
423013105300	31.664592	-103.49003	2,773	4,950	TX	Loving	Great Western Drl Co	Bailey \`A\`	1	Twofreds	2,477	2,233	2,203	2,193	2,182	2,171	2,096	2,074	2,062	1,995	1,983	1,965	1,952	1,877	1,823	-1,975	-	1	-	1	1	1
423013088600	31.93648	-103.838005	2,924	3,488	TX	Loving	Siete Oil & Gas Corp	Zuni \`26\`	4	Zuni	2,860	2,463	2,427	2,415	2,393	2,376	2,339	2,309	2,298	2,256	2,241	2,228	2,186	2,134	2,059	-497	-	1	-	1	-	-
423893253900	31.1282	-103.254156	2,793	5,490	TX	Reeves	Shenandoah Petr Corp	Red Horse 19	1	Rojo Caballos	2,429	1,778	1,759	1,748	1,743	1,733	1,668	1,635	1,622	1,526	1,511	1,495	1,431	1,366	1,330	-2,376	-		-	1	-	-
423013117600	31.664058	-103.536365	2,729	4,705	TX	Loving	Forest Oil Corporatn	El Paso State	2	Vermejo	2,419	2,245	2,208	2,195	2,179	2,164	2,101	2,076	2,063	2,014	2,001	1,987	1,935	1,880	1,829	-1,761	-	1	-	1	-	-
424753476700	31.565185	-103.387598	2,612	4,924	TX	Ward	Seaboard Operating	Lost Frog	1	Horned Toad	2,262	1,809	1,782	1,768	1,757	1,752	1,681	1,665	1,659	1,592	1,580	1,564	1,493	1,448	1,400	-2,087	-	1	-	1	-	-
423713048300	30.729333	-103.369071	3,503	13,490	TX	Pecos	Superior Oil Co Etal	Cartledge -State	1	Perry Bass	2,845	2,664	-	-	-	-	-	-	-	-	-	-	-	-	2,223	-976	-		-	1	1	-
423893244500	31.169456	-104.029903	3,688	3,540	TX	Reeves	Thompsn J Cleo	Fasken Ranch 34	4	Casey Draw	3,061	2,744	-	-	-	2,742	2,669	2,604	2,595	2,553	2,539	2,509	2,459	2,438	2,408	260	-	1	-	1	-	-
423893235300	31.472581	-103.855706	3,151	13,500	TX	Reeves	Burlington Res O&G	Dornfield	1	Medusa	-	2,035	2,025	1,990	1,975	1,962	1,930	1,921	1,912	1,862	1,856	1,845	1,798	1,715	1,644	-338	-	1	-	1	1	-
423713726800	31.001389	-103.094167	2,966	11,400	TX	Pecos	Chaparral Energy Llc	Mendel 26	4	Gomez	1,581	1,112	-	1,112	1,103	1,076	1,014	962	940	862	846	838	799	742	698	-2,285	-	1	-	1	-	-
423713594100	30.984459	-103.21637	2,942	11,752	TX	Pecos	Maralo Incorporated	Tenneco-Mendel \`34\`	1	Maralo	1,952	1,420	-	1,420	1,411	1,399	1,322	1,305	1,286	1,201	1,187	1,173	1,136	1,069	992	-2,123	-	1	-	1	1	1
423893228200	31.539515	-103.522372	2,619	5,394	TX	Reeves	Pure Resources Lp	Mandell	2	Mi Vida	1,369	841	825	819	807	794	779	771	754	713	698	688	675	585	529	-1,739	-	1	-	1	1	1
423713669100	30.971914	-102.896657	2,867	3,700	TX	Pecos	D & B Operating Inc	Usm Shelton Pilot	18	U S M	1,997	1,435	-	1,435	1,429	1,407	1,380	1,359	1,347	1,299	1,290	1,280	-	-	1,177	-	1	1	1	-	-	-

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423713505400	31.201207	-102.940285	2,571	3,450	TX	Pecos	Transierra Expl Corp	Neal `C`	1	Wildcat	1,451	749	742	737	731	723	672	650	636	585	578	567	525	495	459	-	-	1	-	1	-	-
423013084400	31.998733	-103.864629	2,993	6,800	TX	Loving	Tamarack Petr Co Inc	Johnson Ranch	1	Red Bluff	2,669	2,504	2,477	2,464	2,445	2,430	2,361	2,352	2,346	2,278	2,271	2,258	-	-	2,130	-436	-	1	-	1	-	-
423893177700	31.289747	-103.095285	2,574	6,460	TX	Reeves	Mobil Prducng Tx&Nm	Hodge `B`	4	Waha West	1,496	882	-	882	860	845	798	767	759	676	669	660	609	552	480	-2,094	-	-	-	1	-	-
423013095300	31.833881	-103.571182	2,934	6,500	TX	Loving	Richmond Petrlm Inc	Richmond Fee `F20`	2	Dimmitt	2,735	2,450	2,419	2,408	2,385	2,371	2,288	2,274	2,258	2,217	2,197	2,183	2,098	2,074	2,013	-1,711	-	1	-	1	-	-
424753452600	31.621903	-103.329384	2,828	11,800	TX	Ward	Enron Oil & Gas Co	University `18-36`	2	War-Wink West	2,629	1,999	1,972	1,961	1,951	1,940	1,878	1,852	1,842	1,805	1,785	1,772	1,692	1,643	1,628	-2,348	-	-	-	1	-	-
423713514900	30.773109	-103.518543	3,797	10,150	TX	Pecos	Cities Serv O&G Corp	Rash `A`	1	Wildcat	2,557	2,143	2,136	2,122	2,097	2,069	2,010	1,997	1,973	1,908	1,895	1,888	1,797	1,756	1,718	-1,083	-	1	3	1	-	1
423893227600	31.325949	-103.082988	2,550	5,255	TX	Reeves	Shinnery Oil Co Inc	Trees	1	Waha North	2,081	1,540	1,530	-	1,520	1,508	1,440	1,406	1,397	1,340	1,328	1,315	1,254	1,193	1,141	-2,399	-	1	-	1	-	-
423713630600	30.941466	-102.966458	2,903	3,020	TX	Pecos	Burleson Lewis B Inc	Howenstine `A`	5	Fort Stockton	2,133	1,503	-	-	-	1,503	1,470	1,448	1,421	1,360	1,353	1,341	1,298	1,238	1,181	-	-	1	-	1	1	1
423713652100	30.836389	-103.454167	3,472	11,520	TX	Pecos	Xeric Oil & Gas Corp	Lindsey State	4001	Chancellor D8	2,544	2,092	2,082	2,044	2,031	2,018	1,964	1,909	1,891	1,834	1,829	1,821	1,747	1,713	1,668	-1,653	-	1	-	1	-	-
423713631000	30.871329	-103.267956	3,352	5,210	TX	Pecos	Dyad Petroleum Co	Chancellor	1	Chancellor D8	2,676	2,256	-	2,256	2,235	2,220	2,149	2,114	2,075	2,016	1,983	1,975	1,951	1,901	1,874	-	-	-	3	1	-	-
424753452500	31.48434	-103.37356	2,613	17,875	TX	Ward	Enron Oil & Gas Co	Chevron Unit	1	Quibar	2,382	1,783	1,762	1,744	1,735	1,723	1,660	1,651	1,638	1,564	1,549	1,534	1,461	1,414	1,361	-2,292	-	1	-	1	-	-
423713635700	31.151943	-103.174583	2,744	5,828	TX	Pecos	Mobil Prducng Tx&Nm	Schlosser Fred Estat	13	Rojo Caballos	2,456	1,849	1,845	1,841	1,832	1,819	1,743	1,724	1,708	1,625	1,614	1,599	1,550	1,488	1,432	-2,518	-	1	-	1	-	-
423713559200	31.150149	-103.038122	2,717	5,100	TX	Pecos	Arco Oil & Gas Corp	Neal J O `42`	9	Coyanosa	1,377	847	837	829	826	808	757	697	689	626	610	601	542	502	437	-2,084	-	1	-	1	-	-
423013083500	31.879913	-103.481444	3,083	5,241	TX	Loving	Exxon Corporation	Centerre Bank Truste	2	Pinal Dome	-	2,526	2,503	2,485	2,464	2,452	2,390	2,353	2,322	2,293	2,273	2,266	2,197	2,169	2,153	-1,951	-	1	-	1	1	-
423013074800	31.823309	-103.506622	2,961	6,650	TX	Loving	Texaco Incorporated	Loving `Bb` Fee	1	Dimmitt	2,871	2,352	2,321	2,309	2,286	2,275	2,196	2,163	2,151	2,116	2,103	2,085	2,015	1,990	1,925	-1,854	-	-	-	1	-	-
423013069200	31.774642	-103.524418	2,874	4,911	TX	Loving	Renaud Christopher P	Texaco `47`	1	Wheat	-	2,370	2,343	2,331	2,308	2,296	2,223	2,179	2,167	2,134	2,117	2,099	2,029	1,995	1,946	-1,764	-	-	-	1	-	-

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423893166300	31.801661	-103.846439	2,820	3,500	TX	Reeves	Pearce Roy F	Northrup Estate Et A	2	Wildcat	2,713	2,269	2,236	2,224	2,209	2,137	2,115	2,103	2,094	2,067	2,052	2,037	-	-	1,958	-486	-	-	-	1	-	-
423713734500	30.985128	-102.918006	2,818	3,619	TX	Pecos	Energen Res Corp	Fort Stockton Unit	518	Fort Stockton	1,988	1,328	-	-	-	1,328	1,289	1,269	1,255	1,210	1,199	1,188	1,155	1,101	1,033	-	-	1	-	1	-	-
423713691300	31.220565	-103.116692	2,667	6,400	TX	Pecos	Nortis Energy Texas	Colville `16`	1	Wildcat	2,197	1,591	-	1,591	1,577	1,559	1,480	1,450	1,437	1,362	1,349	1,332	1,304	1,211	1,142	-2,464	-	1	-	1	1	-
423713584800	30.809581	-102.949611	3,195	3,010	TX	Pecos	Santa Fe Andover Oil	Puckett `G`	1-A	Belding	2,475	1,950	-	1,950	1,942	1,930	1,904	1,886	1,876	1,801	1,772	1,764	1,740	1,708	1,645	-	1	1	-	1	1	1
423713645800	30.703302	-103.447304	3,744	3,265	TX	Pecos	P A F Expl L C	Leoncita Land Co	11c	Wildcat	2,610	2,420	-	-	-	-	-	-	-	-	-	-	2,313	2,266	2,254	-	1	1	-	1	1	-
424753404700	31.450069	-103.360216	2,600	6,565	TX	Ward	Pitts Energy Co	Hill	2	Scott	2,443	1,715	1,690	1,680	1,667	1,658	1,596	1,577	1,566	1,487	1,475	1,461	1,439	1,330	1,284	-2,282	-	1	-	1	1	-
423713661000	31.122561	-103.229732	2,775	6,977	TX	Pecos	Banks R C	Buechy State	1	Rojo Caballos W	2,424	1,796	-	1,796	1,779	1,767	1,689	1,666	1,651	1,575	1,567	1,539	1,486	1,423	1,326	-2,396	-	-	-	1	-	-
424753312300	31.601423	-103.463274	2,98	7,000	TX	Ward	Cox John L	Dunagan	1		2,271	1,670	1,642	1,616	1,606	1,597	1,551	1,537	1,516	1,478	1,466	1,450	1,380	1,339	1,291	-2,129	-	1	-	1	-	-
423713762900	31.210875	-103.051939	2,645	5,014	TX	Pecos	E G L Resources Inc	Cg 54-117	11	Coyanosa North	1,305	784	-	-	-	784	765	733	716	677	669	659	612	520	475	-2,079	-	1	-	1	1	-
423893254000	31.122339	-103.258185	2,781	5,520	TX	Reeves	Shenandoah Petr Corp	Hudson Lea State `30	1	Rojo Caballos	2,456	1,817	-	1,817	1,797	1,787	1,709	1,673	1,650	1,568	1,548	1,532	1,479	1,417	1,382	-2,395	-	1	-	1	1	1
424753493300	31.450541	-103.373171	2,572	6,512	TX	Ward	Jetta Oper Co Inc	Barstow 30	3	Scott	-7,427	755	749	745	741	738	698	675	657	609	593	573	543	428	381	-2,208	-	1	-	1	1	-
423893242100	31.508092	-103.941514	3,157	14,775	TX	Reeves	Bulldog Operating Co	Armstrong State	1	Pamela	2,887	2,652	2,627	2,619	2,615	2,598	-	-	2,497	2,472	-	-	2,380	2,327	2,287	-123	-	1	-	1	-	-
423891050900	30.980289	-103.696817	3,094	4,890	TX	Reeves	Fields Bert Jr	Weinacht La	1	-	1,809	1,307	1,281	1,271	1,262	1,244	1,174	1,148	1,125	1,043	1,018	1,003	947	882	837	-1,579	-	-	-	1	1	1
423713647600	31.09025	-102.9275	2,693	3,095	TX	Pecos	Sonat Expl Inc	Reed `C15`	8	M P F	1,528	943	-	943	937	924	903	874	863	823	807	795	754	706	613	-	-	1	-	1	-	-
423713691200	31.231285	-103.120557	2,654	7,000	TX	Pecos	Rubicon O&G Llc	Moore-Gilmore	3	Wildcat	2,215	1,641	1,624	1,613	1,575	1,555	1,492	1,462	1,419	1,371	1,364	1,348	1,299	1,233	1,171	-2,405	-	1	-	1	-	-
423713742000	31.184973	-103.017391	2,655	6,500	TX	Pecos	Pecos Production Co	Neal 47	10	Coyanosa	1,420	856	852	834	824	820	764	733	710	630	623	609	572	478	440	-1,974	-	1	-	1	-	-

API	Latitude (NAD27)	Longitude (NAD27)	Well Datum Elevation (ft)	WELL TD (ft)	State	County	Operator	Lease	Lease Number	Field	Dewey Lake (ft-msl)	Ruster (ft-msl)	MH4 (ft-msl)	A4 (ft-msl)	Magenta Dolomite (ft-msl)	Tamarisk (ft-msl)	M3 (ft-msl)	A2 (ft-msl)	Culebra Dolomite (ft-msl)	Los Medaños (ft-msl)	A1 Top (ft-msl)	A1 Bot (ft-msl)	Los Medaños LS Top (ft-msl)	Los Medaños LS Bot (ft-msl)	Salado (ft-msl)	Delaware Mountain Group (ft-msl)	Resistivity Log	BRACS Well	Petrophysical Well	Well Used in Interpolation	Interim Cross-Section Well	Final Cross-Section Well
423713730800	31.020825	-102.927369	2,862	3,500	TX	Pecos	Dean Energy Inc	Stockton A	10	Fort Stockton	2,087	1,217	-	-	-	1,217	1,182	1,169	1,147	1,100	1,094	1,081	1,043	994	937	-	-	1	-	1	-	-
423893226800	31.169467	-103.99237	3,512	7,800	TX	Reeves	Dallas Prod Inc	Fasken State 36	1	Golden Corral	2,563	2,300	-	-	-	2,302	2,246	2,204	2,185	2,115	2,106	2,096	2,027	1,965	1,943	-97	-	1	-	1	-	-
423893238100	31.404208	-103.46214	2,575	5,262	TX	Reeves	Latigo Pet Tx Lp	Collie B	8	Collie	1,503	855	831	822	816	793	755	728	714	643	634	621	578	515	415	-2,125	-	1	-	1	-	-
423713582000	30.939755	-102.938628	2,914	3,184	TX	Pecos	Texaco Incorporated	Fort Stockton South	2813	Fort Stockton	2,089	1,495	-	-	-	1,495	1,463	1,435	1,422	1,364	1,357	1,345	1,307	1,251	1,198	-	-	-	-	1	1	1
423893205400	31.16224	-103.254441	2,770	5,468	TX	Reeves	Southwest Royalties	Rojo Caliente	2	Rojo Caballos Nw	2,251	1,775	1,752	1,745	1,734	1,719	1,680	1,637	1,629	1,531	1,516	1,497	1,432	1,370	1,320	-2,418	-	1	-	1	-	-
423713284000	30.747367	-103.133813	3,561	1,080	TX	Pecos	Great Western Drl Co	Jones L F	1	Wildcat	3,255	2,738	2,679	2,606	2,600	2,592	-	-	-	-	-	-	-	-	-	-	-	1	-	1	1	-
423013105200	31.720655	-103.44237	2,781	5,050	TX	Loving	Great Western Drl Co	Anderson	1	Wildcat	2,561	2,209	2,176	2,163	2,149	2,132	2,069	2,009	1,995	1,956	1,944	1,927	-	-	1,781	-2,091	-	1	-	1	-	-
423013090800	31.671845	-103.447844	2,770	5,100	TX	Loving	Enron Oil & Gas Co	Twofreds (Delaware)	1704	Twofreds	2,572	2,202	2,175	2,164	2,141	2,128	2,057	2,026	2,014	1,964	1,949	1,934	1,907	1,778	1,732	-2,121	-	1	-	1	1	1
423713342700	30.802431	-102.989641	3,071	2,720	TX	Pecos	Burleson Lewis B Inc	Spool Trust	1	Belding West	2,461	1,831	-	-	-	1,831	1,801	1,772	1,748	1,696	1,667	1,651	1,614	1,585	1,535	-	-	1	-	1	-	-
423713709700	31.228373	-103.074627	2,654	15,429	TX	Pecos	E G L Resources Inc	Thagard `18`	1h	Coyanosa	1,416	950	-	950	932	923	889	869	862	791	785	778	751	598	560	-2,168	-	1	-	1	1	-
423893156600	31.488721	-103.689972	2,858	6,010	TX	Reeves	Tamarack Petr Co Inc	Texaco State	1	Sand Lake West	-	1,138	1,117	1,107	1,092	1,078	1,019	997	989	912	888	871	858	762	709	-1,162	-	1	-	1	1	-
423893201900	31.845322	-103.900017	2,824	3,197	TX	Reeves	Bc Operating Inc	Reynaud Sallie Wynne	7	Olds	-	2,750	-	-	-	2,750	2,699	2,692	2,681	2,626	2,622	2,611	-	-	2,496	-138	-	1	-	1	-	-
423893167700	31.819828	-103.816651	2,752	5,051	TX	Reeves	Renaud Christopher P	Hng-Camp	1	Zuma	-	2,248	2,190	2,154	2,143	2,135	2,085	2,072	2,051	2,019	2,013	1,998	1,983	1,903	1,874	-639	-	1	-	1	1	-
423893189500	31.198237	-103.35287	2,793	5,250	TX	Reeves	Drilmor Inc	Parker State	1	Toro	2,654	1,999	1,980	1,970	1,960	1,948	1,824	1,768	1,742	1,662	1,645	1,627	1,603	1,500	1,453	-2,319	-	1	-	1	1	1
423013112100	31.986649	-103.787009	3,142	13,030	TX	Loving	Eog Resources Inc	Kyle `6`	1	Wildcat	-	2,282	-	-	-	2,282	2,242	2,232	2,220	2,195	2,182	2,172	-	-	2,045	-749	-	1	-	1	-	-

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423013106400	31.885551	-103.618324	2,969	4,560	TX	Loving	Sable Energy Inc	Txl `Ax`	2	Grice	2,755	2,246	2,217	2,205	2,188	2,169	2,110	2,081	2,062	2,029	2,008	1,996	1,939	1,907	1,869	-1,456	-	-	-	1	1	-
423013090500	31.910841	-103.553573	3,099	6,970	TX	Loving	Richmond Petrlm Inc	Johnson `40`	2	Jamar	3,008	2,545	2,514	2,503	2,490	2,466	2,399	2,369	2,340	2,312	2,297	2,283	-	-	2,167	-1,821	-	-	-	1	-	-
421093134900	31.479489	-104.190374	3,512	841	TX	Culberson	Lovelady I W	Brooks	2	Brooks Ranch D8	-	3,463	-	-	-	-	-	-	3,464	3,427	3,416	3,407	-	-	3,313	-	-	1	-	1	1	-
424753525100	31.424807	-103.247131	2,606	14,900	TX	Ward	Cimarex Energy Of Co	Khc 33-24	1h	Phantom	-	2,001	1,974	1,966	1,955	1,949	1,877	1,861	1,851	1,774	1,767	1,758	1,684	1,634	1,586	-2,464	-	1	-	1	-	-
300152199200	32.011356	-103.879252	2,982	8,837	NM	Eddy	Penroc Oil Corp	Ross Draw Unit	6	-	2,960	2,712	2,698	2,682	2,674	2,657	2,575	2,568	2,562	2,498	2,488	2,476	-	-	2,318	-381	-	-	-	1	-	-
423713635800	31.148231	-103.178688	2,771	5,746	TX	Pecos	Mobil Prducng Tx&Nm	Schlosser Fred Estat	9	Rojo Caballos	2,466	1,896	1,880	1,867	1,858	1,851	1,787	1,752	1,744	1,661	1,643	1,625	-	-	1,435	-2,459	-	-	-	1	-	-
423713701300	31.18169	-102.96963	2,626	12,020	TX	Pecos	Pure Resources Lp	Neal State	14-1	Athey	1,396	674		674	667	658	624	539	531	460	449	436	379	326	266	-1,938	-	1	-	1	-	-
423893198100	30.995311	-103.495039	3,018	10,541	TX	Reeves	Blair Expl Inc	Lindsay	1	Wildcat	2,532	2,002	1,976	1,966	1,949	1,928	1,874	1,818	1,803	1,723	1,705	1,690	1,641	1,552	1,499	-2,178	-		-	1	1	1
423893119800	31.209451	-103.931618	3,311	5,470	TX	Reeves	Mesa Petroleum Co	Gozar `22`	1	Wildcat	2,359	2,180	2,165	2,159	2,151	2,143	2,015	1,992	1,981	1,935	1,932	1,923	1,881	1,775	1,740	-696	-	1	-	1	1	-
423713684800	30.736774	-103.17826	3,528	4,704	TX	Pecos	Burlington Res O&G	Kennedy State `174`	1	Wildcat	3,148	2,598	2,536	2,489	2,483	2,476	2,379	2,340	2,320	2,232	2,222	2,217	-	-	2,183	-997	-	1	-	1	1	-
423710491400	30.934083	-102.936819	2,926	2,950	TX	Pecos	Texaco Incorporated	Fort Stockton So Un	41-2	Fort Stockton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
423713637400	31.126551	-102.939646	2,636	3,182	TX	Pecos	Canyon Expl Co Inc	Merilee State	1	Roxie	1,461	824	820	814	809	783	696	629	622	577	568	560	472	396	378	-	-	1	-	1	-	-
423713686200	30.845565	-103.191683	3,144	5,753	TX	Pecos	Corda Corporation	Kennedy Ranch `47`	1	Wildcat	2,646	2,116	-	2,116	2,105	2,094	2,047	1,975	1,961	1,876	1,843	1,830	1,791	1,749	1,674	-1,516	-	-	-	1	-	-
423013111000	31.752523	-103.383497	2,874	10,350	TX	Loving	Patterson Petrlm Inc	Bowdle `42`	2	Haley South	2,670	2,067	2,046	2,034	2,021	2,006	1,951	1,918	1,909	1,871	1,858	1,845	-	-	1,714	-2,275	-	1	-	1	-	-
423893116600	31.304371	-103.305266	2,697	5,132	TX	Reeves	Petroleum Techl Srvs	Worsham /11/	2	Worsham Southwest	2,372	1,730	1,701	1,695	1,690	1,668	1,618	1,564	1,557	1,478	1,465	1,450	1,391	1,341	1,275	-2,381	-	1	-	1	-	-

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423893119500	31.695785	-103.803208	2,888	3,730	TX	Reeves	Hanover Mgmt Co	Thompson Alfred-Stat	1	Orla Southeast	-	1,914	-	-	-	1,915	1,888	1,854	1,825	1,734	1,724	1,701	1,670	1,632	1,310	-695	-	-	-	1	1	1
423713606800	30.820756	-102.91598	3,152	2,994	TX	Pecos	Mewbourne Oil Co	University `P`	1	Belding	2,424	1,862	-	-	-	1,862	1,837	1,819	1,805	1,746	1,732	1,718	1,679	1,630	1,591	-	-	-	-	1	1	1
423013078200	31.994561	-103.719335	3,143	4,304	TX	Loving	Marathon Oil Company	Kyle Minnie `D`	5	Mason North	2,693	2,183	2,153	2,140	2,126	2,105	2,045	2,031	2,004	1,976	1,965	1,960	-	-	1,843	-995	-	1	-	1	1	1
423013065600	31.736636	-103.406956	2,888	18,000	TX	Loving	Amoco Prod Co	Bowdle Estate `47`	1	Haley	2,797	2,181	2,160	2,145	2,131	2,112	2,053	2,020	2,008	1,965	1,957	1,941	-	-	1,856	-2,168	-	1	-	1	-	-
423013059300	31.972334	-103.571234	3,163	5,100	TX	Loving	Harper Oil Company	Grice N E-Getty	1-Aug	-	3,049	2,474	2,445	2,430	2,414	2,395	2,337	2,314	2,297	2,263	2,251	2,237	-	-	2,122	-1,693	-	1	-	1	-	-
423013053000	31.688576	-103.528764	2,768	4,650	TX	Loving	Holly Energy	Wheat James	1	-	2,572	2,388	2,371	2,359	2,337	2,313	2,230	2,208	2,192	2,147	2,133	2,116	2,075	2,003	1,948	-1,773	-	1	-	1	-	-
423713614800	30.91547	-103.001267	2,988	3,100	TX	Pecos	Odessa Expl Inc	Eaton H J `F`	4	Fort Stockton	2,233	1,658	-	-	-	1,658	1,615	1,586	1,579	1,489	1,477	1,468	1,419	1,367	1,343	-	-	1	-	1	1	1
423013083300	31.962919	-103.755412	3,045	4,300	TX	Loving	Marathon Oil Company	North Mason (Delawar	1503	Mason North	2,235	2,075	2,047	2,037	2,019	1,997	1,946	1,932	1,899	1,869	1,860	1,849	-	-	1,751	-876	-	1	-	1	-	-
423013075000	31.732425	-103.646828	2,713	5,450	TX	Loving	Arco Oil & Gas Corp	Loving Fee `87`	1	Hubbard	2,441	2,371	2,358	2,347	2,328	2,309	2,223	2,203	2,188	2,153	2,147	2,134	2,051	2,030	1,971	-1,376	-	1	-	1	1	1
423713753800	30.638611	-102.916915	3,574	9,850	TX	Pecos	Riata Energy Inc	La Escalera `D`	4201	Wildcat	3,374	3,114	3,091	3,079	3,070	3,054	-	-	2,948	2,910	-	-	-	-	2,824	-	-	1	-	1	-	-
424753493100	31.597799	-103.483804	2,662	6,500	TX	Ward	Nearburg Prod Co	Dunagan 28	2	Wildcat	1,832	1,262	1,232	1,217	1,209	1,192	1,119	1,100	1,071	1,033	-	-	934	908	872	-	-	1	-	1	-	-
424753502600	31.446361	-103.428333	2,576	6,500	TX	Ward	Latigo Pet Tx Lp	Worsham `42`	7	Collie	1,451	849	829	819	807	794	745	729	720	656	644	623	596	519	420	-2,110	-	1	-	1	1	-
423893239300	31.396433	-103.485668	2,594	6,300	TX	Reeves	Latigo Pet Tx Lp	Blake	2	Collie	1,459	942	923	912	900	888	843	826	816	739	725	714	673	624	604	-2,076	-	1	-	1	-	-
423013072000	31.848279	-103.49853	3,013	6,770	TX	Loving	Exxon Corporation	Txl `13`	13	Dimmitt	-	2,442	2,409	2,394	2,377	2,362	2,295	2,266	2,252	2,217	2,206	2,192	2,124	2,097	2,072	-1,867	-		-	1	-	-
423013083900	31.778915	-103.67324	2,788	4,189	TX	Loving	Grauten Wm F	Lindley `44`	1	Wildcat	2,698	2,058	2,035	2,011	1,994	1,972	1,887	1,869	1,856	1,823	1,816	1,801	1,728	1,688	1,627	-1,287	-	1	-	1	1	1
423893170100	31.34244	-103.230249	2,618	6,767	TX	Reeves	Flag Redfern Oil Co	Strain `13`	2	Worsham	2,376	1,752	-	1,752	1,727	1,716	1,622	1,605	1,596	1,523	1,507	1,492	1,438	1,372	1,317	-2,300	-	1	-	1	-	-
423893203300	31.772853	-103.803939	2,775	3,650	TX	Reeves	Collins & Ware Inc	Lindley `43`	1	Wildcat	2,625	2,135	-	-	-	-	-	-	-	-	-	-	1,820	1,796	1,746	-684	-	1	-	1	-	-

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423893092000	31.674893	-103.997609	3,188	3,070	TX	Reeves	W T G Exploration	Hill /42/	1	Reaves North	-	2,754	2,719	2,708	2,688	2,660	2,595	2,567	2,539	2,503	2,497	2,478	-	-	2,348	279	-	1	-	1	1	1
423013105500	31.811976	-103.51995	2,923	6,850	TX	Loving	Wiser Oil Co	Johnson W D `26s`	4	Dimmitt	2,838	2,325	2,294	2,283	2,262	2,248	2,170	2,157	2,128	2,095	2,081	2,070	2,050	1,970	1,923	-1,809	-	1	-	1	1	-
423013086900	31.739039	-103.544406	2,833	6,272	TX	Loving	Richmond Petrlm Inc	Johnson `76`	3	Dimmitt	2,594	2,383	2,352	2,342	2,319	2,306	2,231	2,211	2,202	2,138	2,122	2,106	2,042	2,013	1,952	-1,705	-	-	-	1	-	-
423013082600	31.86369	-103.497989	3,054	6,822	TX	Loving	Exxon Corporation	Santa Fe Andover	7	Dimmitt	2,961	2,459	2,431	2,417	2,397	2,379	2,311	2,276	2,261	2,217	2,213	2,200	2,134	2,108	2,056	-1,853	-	-	-	1	-	-
423013084000	31.990348	-103.891482	2,971	4,940	TX	Loving	Brown H L Jr	Red Bluff `6`	2	Red Bluff	2,809	2,610	2,581	2,565	2,555	2,515	2,498	2,492	2,475	2,453	2,439	2,430	-	-	2,295	-324	-	1	-	1	-	-
423013061100	31.664225	-103.495988	2,770	4,875	TX	Loving	Txo Prod Corp	O`Hare	1	Unnamed	-	2,280	2,253	2,240	2,231	2,213	2,138	2,117	2,100	2,035	2,024	2,006	1,998	1,917	1,859	-1,962	-	-	-	1	1	1
423713454900	31.126425	-102.977432	2,634	6,035	TX	Pecos	Seely Oil Co	Reed E	1	Wildcat	-	749	-	749	742	735	708	643	634	575	570	567	524	395	377	-1,954	-	1	-	1	-	-
424751098100	31.420301	-103.180516	2,596	20,406	TX	Ward	Texaco Incorporated	Ponder Dc	2	Lockridge	2,496	1,836	-	1,836	1,816	1,804	1,745	1,701	1,684	1,615	1,599	1,584	1,522	1,468	1,408	-2,442	-	1	-	1	-	-
423893187000	30.98916	-103.502011	3,021	10,520	TX	Reeves	Kimsey Roy E Jr	Lindsay `326`	2	Hoefs T-K	2,539	2,017	1,998	1,979	1,965	1,953	1,847	1,812	1,795	1,701	1,693	1,681	1,634	1,549	1,501	-2,117	-	1	-	1	1	1
423893246200	31.967614	-103.963991	2,846	3,060	TX	Reeves	T-N-T Engineerng Inc	Red Bluff 16	4a	Ford East	2,810	2,626	-	-	-	2,626	2,568	2,565	2,559	2,518	2,511	2,501	-	-	2,316	101	-	-	-	1	-	-
423013130400	31.881594	-103.596568	2,995	4,770	TX	Loving	Atlantic Operating	June	4	Grice	2,825	2,540	2,511	2,499	2,481	2,458	2,400	2,384	2,355	2,323	2,307	2,293	2,198	2,167	2,149	-1,527	-	1	-	1	1	-
423013118700	31.674054	-103.575713	2,669	4,570	TX	Loving	Forest Oil Corporatn	Catfish Gregg	8	Vermejo	2,072	1,950	1,919	1,907	1,895	1,880	1,813	1,781	1,771	1,737	1,730	1,717	1,712	1,600	1,589	-1,643	-	1	-	1	1	1
423013118900	31.669921	-103.569463	2,668	4,495	TX	Loving	Forest Oil Corporatn	Mcginley Catfish	6	Vermejo	1,788	1,362	1,333	1,325	1,314	1,304	1,256	1,233	1,195	1,116	1,112	1,102	1,100	1,000	988	-1,626	-	1	-	1	1	1
424953133900	31.971486	-103.171873	2,930	3,430	TX	Winkler	-	Daughtery	1	Scarborough		2,178	2,150	2,141	2,130	2,103	2,062	2,027	2,012	1,980	1,964	1,951	-	-	1,878	-	-	1	-	1	1	-
423713412000	31.014608	-102.839176	2,856	9,626	TX	Pecos	-	Commnche Creek Unit	1	Wildcat	1,916	1,342	-	-	-	1,343	1,272	1,249	1,234	1,198	1,189	1,176	1,127	1,092	1,046	-	-	1	-	1	-	-
423713425900	30.828983	-102.956345	3,094	2,792	TX	Pecos	-	Cuervo State	1	-	2,288	1,676	-	-	-	1,676	1,646	1,626	1,619	1,524	1,517	1,504	1,474	1,440	1,391	-	-	1	-	1	1	1
423713648300	30.741201	-102.934845	3,569	4,871	TX	Pecos	-	Puckett	1	Wildcat	2,914	2,379	-	-	-	2,380	2,346	2,293	2,285	2,227	2,215	2,209	-	-	2,163	-	-	1	-	1	1	-
423013101900	31.779651	-103.458327	2,973	17,670	TX	Loving	-	Haley `1-21`	1	Haley	2,743	2,322	2,294	2,281	2,271	2,252	2,183	2,149	2,139	2,101	2,085	2,074	-	-	1,923	-2,041	-	1	-	1	-	-

API	Latitude (NAD27)	Longitude (NAD27)	Well Datum Elevation (ft)	WELL TD (ft)	State	County	Operator	Lease	Lease Number	Field	Dewey Lake (ft-msl)	Ruster (ft-msl)	MH4 (ft-msl)	A4 (ft-msl)	Magenta Dolomite (ft-msl)	Tamarisk (ft-msl)	M3 (ft-msl)	A2 (ft-msl)	Culebra Dolomite (ft-msl)	Los Medaños (ft-msl)	A1 Top (ft-msl)	A1 Bot (ft-msl)	Los Medaños LS Top (ft-msl)	Los Medaños LS Bot (ft-msl)	Salado (ft-msl)	Delaware Mountain Group (ft-msl)	Resistivity Log	BRACS Well	Petrophysical Well	Well Used in Interpolation	Interim Cross-Section Well	Final Cross-Section Well
423713268000	31.182926	-103.164327	2,718	21,640	TX	Pecos	-	Stewart	1	Sixty-Nine	2,390	1,813	1,806	1,803	1,796	1,787	1,706	1,652	1,641	1,575	1,560	1,544	1,496	1,428	1,346	-2,461	-	1	-	1	-	-
423893138500	31.30916	-103.523719	2,632	5,945	TX	Reeves	-	Wadley	1203	Balmorhea Ranch	1,219	900	881	865	852	839	776	752	739	654	638	621	558	509	487	-2,105	-	1	-	1	-	-
423890085700	31.31851	-103.09923	2,546	4,986	TX	Reeves	-	Fidelity Truso Etal	1	Waha	2,084	1,547	1,526	1,519	1,514	1,505	1,442	1,422	1,416	1,344	1,330	1,315	1,259	1,197	1,154	-2,220	-	1	-	1	-	-
423893127000	31.763951	-103.946997	3,010	14,300	TX	Reeves	-	Fortune Unit	2r	Chapman Deep	2,975	2,771	-	-	-	2,772	2,722	2,649	2,602	2,563	2,560	2,555	2,523	2,496	2,470	94	-	1	-	1	-	1
423893240700	31.644203	-103.709311	2,828	16,581	TX	Reeves	-	State 71	1	Dixieland	2,004	1,730	1,704	1,697	1,683	1,669	1,575	1,539	1,530	1,473	1,467	1,458	1,429	1,391	1,358	-	-	1	-	1	-	-
423713375500	30.928636	-103.313955	3,121	16,826	TX	Pecos	-	Maddox Unit	2	-	2,725	2,172	2,164	2,155	2,144	2,132	2,105	2,052	2,040	1,950	1,937	1,911	1,849	1,807	1,742	-1,910	-	1	-	1	-	-
423713424500	30.773622	-102.80969	3161	2900	TX	Pecos	-	Getty \`33\`	1	-	2,383	1,821	-	-	-	1,821	1,767	1,737	1,725	1,708	1,695	1,681	1,657	1,618	1,589	-	-	1	-	1	1	1
423713627200	30.749889	-103.334519	3,458	12,730	TX	Pecos	-	Texas American Syndi	2	Perry Bass	2,838	2,583	-	-	-	-	-	-	-	-	-	-	-	-	2,157	-999	-	1	-	1	-	-
423893116000	31.280812	-103.971601	3,232	12,995	TX	Reeves	-	Lowe Estate-State	1	Wildcat	2,214	1,964	-	-	-	-	-	-	-	-	-	-	1,646	1,594	1,562	-423	-	1	-	1	-	-
423893206700	31.30597	-103.120752	2,566	5,650	TX	Reeves	-	Trees J C Estate Eta	10	Waha West	2,180	1,604	-	1,604	1,586	1,577	1,494	1,468	1,459	1,394	1,387	1,372	1,331	1,253	1,204	-2,325	-	1	-	1	-	-
423710036300	30.929742	-103.351689	3,140	17,050	TX	Pecos	-	Lucas-State	1	Hershey	2,760	2,186	-	2,186	2,175	2,162	2,099	2,034	2,019	1,946	1,929	1,917	1,868	1,806	1,740	-1,864	-	1	-	1	1	1
423713269200	31.132851	-103.148989	2,771	12,746	TX	Pecos	-	Weatherby Ivy B	3	Rojo Caballos	2,492	1,944	1,932	1,924	1,916	1,898	1,818	1,794	1,785	1,703	1,691	1,671	1,597	1,552	1,481	-2,456	-	1	-	1	-	-
423010004500	31.948232	-103.657317	3,096	4,595	TX	Loving	-	Txl 21	1	-	2,941	2,686	2,647	2,633	2,616	2,592	2,551	2,497	2,474	2,436	-	-	2,356	2,328	2,275	-1,390	-	1	-	1	-	-
423010046500	31.882505	-103.650879	2,977	4,486	TX	Loving	-	Wd Johnson	1	-	2,647	2,147	2,117	2,100	2,079	2,059	1,984	1,962	1,952	1,927	1,899	1,888	1,812	1,783	1,725	-1,399	-	1	-	1	1	-
423010054000	31.973485	-103.654831	3,072	4,550	TX	Loving	-	Txl Ba Nct A	2	El Mar	-	2,697	2,677	2,666	2,644	2,629	2,583	2,538	2,513	2,477	2,467	2,457	-	-	2,315	-1,337	-	1	-	1	-	-
423010077000	31.840328	-103.6342	2,914	4,555	TX	Loving	-	Txl 15	1	-	2,354	1,839	1,813	1,802	1,784	1,767	1,713	1,707	1,691	1,662	1,660	1,654	1,599	1,578	1,546	-1,498	-	1	-	1	-	-
423010095900	31.898747	-103.702354	3,066	4,345	TX	Loving	-	Txl 37	1	-	2,366	1,936	1,909	1,896	1,880	1,861	1,833	1,816	1,804	1,776	1,748	1,739	1,681	1,655	1,606	-1,119	-	1	-	1	1	1
423010098300	31.869897	-103.702326	2,965	4,210	TX	Loving	-	Txl Au	1	-	2,523	2,044	2,024	2,007	1,993	1,969	1,918	1,899	1,872	1,836	1,829	1,814	-	-	1,685	-1,160	-	1	-	1	1	1
423893303900	31.041533	-103.448072	2,950	11,121	TX	Reeves	Cog Operating Llc	Big Chief	4715	Wolfbone	2,570	1,913	1,891	1,875	1,862	1,853	1,771	1,703	1,683	1,598	1,583	1,571	1,501	1,437	1,390	-2,276	-	-	-	1	-	-

API	Latitude (NAD27)	Longitude (NAD27)	Well Datum Elevation (ft)	WELL TD (ft)	State	County	Operator	Lease	Lease Number	Field	Dewey Lake (ft-msl)	Ruster (ft-msl)	MH4 (ft-msl)	A4 (ft-msl)	Magenta Dolomite (ft-msl)	Tamarisk (ft-msl)	M3 (ft-msl)	A2 (ft-msl)	Culebra Dolomite (ft-msl)	Los Medaños (ft-msl)	A1 Top (ft-msl)	A1 Bot (ft-msl)	Los Medaños LS Top (ft-msl)	Los Medaños LS Bot (ft-msl)	Salado (ft-msl)	Delaware Mountain Group (ft-msl)	Resistivity Log	BRACS Well	Petrophysical Well	Well Used in Interpolation	Interim Cross-Section Well	Final Cross-Section Well
423891020500	31.13078	-103.316673	2,814	21,800	TX	Reeves	Staley Operating Co	Waples-Platter	1	Hamon	-	1,940	-	-	-	-	-	-	-	-	-	-	1,547	1,486	1,624	-	1	-	-	-	-	-
423893295400	31.231516	-103.281098	2,743	11,640	TX	Reeves	Patriot Resources Inc	Vj Ranch-Sable `25`	2	Wolfbone	2,405	1,823	1,790	1,770	1,755	1,720	1,704	1,652	1,643	1,551	1,536	1,530	1,487	1,354	1,277	-2,489	-	-	-	1	1	-
423893301800	31.232346	-103.273687	2,714	6,470	TX	Reeves	Patriot Resources Inc	Vj Ranch-Sable `25`	1sw	Balmorhea Ranch	2,309	1,662	1,643	1,630	1,619	1,606	1,537	1,503	1,496	1,418	1,398	1,383	1,339	1,222	1,177	-2,511	-	-	-	1	-	-
423893296500	31.230174	-103.625628	2,734	11,302	TX	Reeves	Clayton Williams Enr	Cwei-Chk 10-54-7 B	1	Wolfbone	1,213	620	592	585	569	552	483	448	430	343	339	323	272	205	162	-1,910	-	-	-	1	1	-
423893294900	31.282582	-103.311213	2,708	11,650	TX	Reeves	Patriot Resources Inc	Zebra State 10	1	Wolfbone	2,369	1,725	1,700	1,691	1,683	1,671	1,615	1,561	1,551	1,478	1,471	1,457	1,412	1,347	1,289	-2,383	-	-	-	1	-	-
423713292200	31.320299	-102.97143	2,514	18,122	TX	Pecos	Pearl Resources Oper	Brandenburg	1	Wolfbone	-	884	-	-	-	884	844	824	814	779	776	767	-	-	660	-	1	-	-	-	-	-
423891009000	31.361409	-103.373433	2,617	6,825	TX	Reeves	Amercn Trading&Prod	State Of Texas 9	1	-	2,429	1,769	1,748	1,732	1,724	1,702	1,621	1,607	1,596	1,517	1,506	1,497	1,476	1,380	1,294	-2,381	-	-	-	1	1	1
423713355400	30.652703	-103.001684	3,671	-	TX	Pecos	-	Elsinor Cttl Compny	14-1	-	2,221	1,888	-	-	-	-	-	-	1,889	1,874	-	-	-	-	1,785	-	-	1	-	1	-	-
423890047400	31.690918	-103.728902	2,772	-	TX	Reeves	-	Monroe	1	-	-	1,815	-	-	-	1,815	1,736	1,715	1,695	1,619	1,604	1,561	-	-	1,200	-1,045	1	1	1	1	1	1
423890065700	31.202575	-103.204666	2,727	-	TX	Reeves	-	Elijah Hall	1	-	2,281	1,668	-	1,671	1,655	1,633	1,561	1,538	1,524	1,448	1,435	1,412	1,381	1,272	1,180	-2,557	1	1	-	1	1	-
423890046200	31.639534	-103.621288	2,730	-	TX	Reeves	-	Sievers	1	-	-	1,366	1,332	1,321	1,312	1,291	1,226	1,194	1,175	1,106	1,099	1,070	-	-	936	-1,539	1	1	1	1	-	-
423010055900	31.933689	-103.888616	2,876	-	TX	Loving	-	Txl	1	-	2,826	2,557	2,536	2,529	2,510	2,491	2,428	2,423	2,417	2,373	2,366	2,351	-	-	2,269	-279	-	1	1	1	-	-
423010058300	31.75346	-103.477993	2,848	-	TX	Loving	-	Ia Stevens	1	-	2,609	2,295	2,269	2,254	2,236	2,226	2,165	2,130	2,120	2,062	2,051	2,030	1,939	1,918	1,854	-1,965	-	1	-	1	-	-
423010022800	31.8672	-103.648381	2,944	-	TX	Loving	-	Johnson Et Al	1	-	-	1,324	-	-	1,244	1,221	1,169	1,144	1,135	991	978	954	-	-	754	-1,420	1	1	-	-	-	-
423711036200	30.802638	-102.857429	3,172	3,003	TX	Pecos	Southern Minerals Co	Th Wright Est	1	-	2,443	1,933	-	-	-	1,933	1,902	1,885	1,868	1,815	1,802	1,788	1,747	1,704	1,671	-	4	1	-	1	1	1
423713254800	30.966182	-103.072836	2,995	-	TX	Pecos	-	Mendel Est	1	-	1,833	1,320	-	-	-	1,320	1,279	1,204	1,196	1,108	1,096	1,084	1,047	978	915	-2,044	1	1	1	1	1	1

API	Latitude (NAD27)	Longitude (NAD27)	Well Datum Elevation (ft)	WELL TD (ft)	State	County	Operator	Lease	Lease Number	Field	Dewey Lake (ft-msl)	Ruster (ft-msl)	MH4 (ft-msl)	A4 (ft-msl)	Magenta Dolomite (ft-msl)	Tamarisk (ft-msl)	M3 (ft-msl)	A2 (ft-msl)	Culebra Dolomite (ft-msl)	Los Medaños (ft-msl)	A1 Top (ft-msl)	A1 Bot (ft-msl)	Los Medaños LS Top (ft-msl)	Los Medaños LS Bot (ft-msl)	Salado (ft-msl)	Delaware Mountain Group (ft-msl)	Resistivity Log	BRACS Well	Petrophysical Well	Well Used in Interpolation	Interim Cross-Section Well	Final Cross-Section Well
424750026200	31.610797	-103.430741	2,704	-	TX	Ward	-	Josephine Cadenhead	1	-	-	2,058	2,037	2,023	2,010	2,005	1,898	1,878	1,869	1,835	1,820	1,801	1,716	1,685	1,626	-2,136	1	1	-	1	-	-
421091004500	31.22789	-104.350559	3,937	-	TX	Culberson	-	Jb Foster 15	1	-	-	3,277	-	-	-	-	-	-	-	-	-	-	-	-	3,146	2,360	-	1	-	1	-	-
421091004800	31.216185	-104.183696	3,602	-	TX	Culberson	-	Republic 18	1	-	3,363	3,119	-	-	-	-	-	3,080	3,063	3,003	2,989	2,983	2,926	2,865	2,805	-	-	1	-	1	1	-
421093142500	31.471847	-104.122928	3,473	-	TX	Culberson	-	Triken State `A`	1	-	-	3,473	-	-	-	-	-	-	3,473	3,394	3,389	3,383	-	-	3,222	1,360	-	1	-	1	1	-
424753084700	31.646045	-103.369598	2,857	-	TX	Ward	-	University	1	-	2,713	2,069	2,055	2,047	2,040	2,025	1,940	1,918	1,905	1,870	1,851	1,835	1,771	1,696	1,664	-2,287	-	1	-	1	-	-
424753240600	31.503264	-103.431712	2,640	-	TX	Ward	-	Trueblood	1	-	1,580	956	938	930	921	907	868	791	778	670	664	650	579	537	485	-2,081	-	1	-	1	-	-
423891055200	31.189553	-104.068686	3,609	-	TX	Reeves	-	Texaco	29-Jan	-	3,111	2,811	2,801	2,794	2,768	2,752	2,706	2,684	2,683	2,642	2,636	2,621	-	-	2,527	259	-	1	-	1	1	-
421093092700	31.520899	-104.078597	3,321	-	TX	Culberson	-	Delaware Basin-St	1	-	3,096	2,772	2,742	2,728	2,716	2,697	2,674	2,662	2,639	2,571	2,567	2,560	-	-	2,411	-	-	-	-	1	-	-
300250829700	32.01531	-103.642908	3,116	-	NM	Lea	-	Wilder-Federal	25	-	-	2,573	2,541	2,530	2,513	2,492	2,424	2,413	2,399	2,352	2,339	2,320	-	-	2,177	-	-	-	-	1	-	-
300250830200	32.00785	-103.711711	3,127	-	NM	Lea	-	Russell-Federal 30	1	-	2,705	2,288	2,255	2,241	2,226	2,202	2,146	2,137	2,119	2,079	2,069	2,059	-	-	1,935	-	-	-	-	1	-	-
300250830900	32.004227	-103.65166	3,106	-	NM	Lea	-	Bradley-Federal 35	2	-	3,058	2,624	2,594	2,581	2,563	2,541	2,474	2,457	2,431	2,392	2,383	2,372	-	-	2,234	-1,327	-	-	-	1	-	-
300250842500	32.019724	-103.527788	3,358	-	NM	Lea	-	Elliott-Federal 25	1	-	3,006	2,536	2,513	2,489	2,473	2,443	2,408	2,381	2,360	2,321	2,310	2,300	-	-	2,176	-1,843	-	-	-	1	-	-
300250843700	32.005291	-103.617304	3,105	-	NM	Lea	-	Payne-Federal	7	-	3,037	2,486	2,456	2,441	2,425	2,405	2,360	2,325	2,306	2,257	2,242	2,230	-	-	2,090	-1,496	-	-	-	1	-	-
421093165000	31.623818	-104.082666	3,470	-	TX	Culberson	-	Kirk T A Estate Etal	C27 3	-	3,260	3,160	-	3,162	3,112	3,099	3,067	3,038	3,010	2,950	-	-	-	-	2,690	-	-	-	-	1	-	-
423013193900	31.941032	-103.862217	2,940	-	TX	Loving	-	Cbr 28	1h	-	2,706	2,388	2,371	2,359	2,351	2,338	2,315	2,310	2,304	2,231	2,221	2,216	-	-	1,963	-	-	-	-	1	-	-

- = no data

API = American Petroleum Institute 12 digit identification number

Latitude NAD27 = latitude in North American Datum 27

Longitude NAD27 = longitude in North American Datum 27

ft = feet

Datum = Reference elevation for where the structural picks are measured from, traditionally Kelley Bushing elevation in feet above sea level

TD = total depth in feet

State = Texas or New Mexico

County = County in either Texas or New Mexico

Operator = Well operator as reported on log header

Lease = Well lease as reported on log header

Lease Number = lease number as reported on geophysical log header

Field = Oil and gas field that the well is located in

Dewey Lake (ft-msl)= Top of the Dewey Lake Formation in feet above mean sea level

Rustler (ft-msl) = Top of the Rustler Formation in feet above mean sea level

MH4 (ft-msl) = Top of the MH4 sub-unit in feet above mean sea level

A4 (ft-msl) = Top of the A4 sub-unit in feet above mean sea level

Magenta Dolomite (ft-msl) = Top of the Magenta Dolomite member unit in feet above mean sea level

Tamarisk (ft-msl) = Top of the Tamarisk Member Unit in feet above mean sea level

M3 (ft-msl) = Top of the M3 sub-unit in feet above mean sea level

A2 (ft-msl) = Top of the A2 sub-unit in feet above mean sea level

Culebra Dolomite (ft-msl) = Top of the Culebra Dolomite member unit in feet above mean sea level

Los Medaños (ft-msl) = Top of the Los Medaños Member Unit in feet above mean sea level

A1 Top (ft-msl) = Top of the A1 sub-unit in feet above mean sea level

A1 Bot (ft-msl) = Base of the A1 sub-unit in feet above mean sea level

Los Medaños LS Top (ft-msl) = Top of the highest limestone within the Los Medaños limestone in feet above mean sea level

Los Medaños LS Bot (ft-msl) = Base of the lowest limestone within the Los Medaños limestone in feet above mean sea level

Salado (ft-msl) = Top of the Salado Formation in feet above mean sea level

Delaware Mountain Group (ft-msl) = Top of the Delaware Mountain Group in feet above mean sea level

Resistivity Log = This identifies if the well has a resistivity geophysical log. One (1) denotes that a .tif image is available and 4 denotes that a .tif and .las file of the deep resistivity is available

BRACS Well = Identifies if the well is in the BRACS database

Petrophysical Well = Key well analyzed by Dr. Carlos Torres-Verdin. One (1) denotes that the well was originally selected due to high quality and 3 denotes well was digitized and subsequently evaluated

Well Used in Interpolation = These wells were used to interpolate the various Member and submember units of the Rustler Formation

Interim Cross-Section Well = These wells were part of the interim cross-sections put together in the beginning of the project

Final Cross-Section Well = These are wells in the final cross-section in Appendix 19-2

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19.6 Groundwater volume calculation and methodology and documentation

As part of the Brackish Resources Aquifer Characterization System Program, INTERA developed a GIS tool in ESRI ArcGIS 10.2 to calculate volumes for each aquifer unit and groundwater salinity class considered in the analysis. This appendix discusses the tool groundwater volume calculation, toolbox interface, data inputs, and output tables.

19.6.1 Groundwater volume calculation

The volume calculations are performed for each aquifer unit as explained below and in Section 12 of the report. Volume estimates are calculated for each cell and then tabulated in different ways by spatial units (County, Groundwater Management Area, Groundwater Conservation District, potential production area), water quality classes (fresh, moderately saline, slightly saline, and very saline), and aquifer units (Collapsed, Magenta Dolomite, Culebra Dolomite, and limestones of the Los Medaños). This tool also has an option to include additional spatial units to estimate summaries for areas defined by the user using shapefile polygon.

The calculations are defined by the type of transmissive members Zone ('1 – Outcrop', '1 – Collapsed', '2 – Normal', '3 – Eroded') defined in Section 5. The total volume for each aquifer unit is estimated following equations 12-1 through 12-4 in Section 12 as follows.

- $Volume_{total_{Rustler}} = Volume_{total_{CO}} + Volume_{total_{MG}} + Volume_{total_{CL}} + Volume_{total_{LM}}$

If Zone is 1 – Outcrop

- $Volume_{total_{MG}} = 0$
- $Volume_{total_{CL}} = 0$
- $Volume_{total_{LM}} = 0$
- $Volume_{total_{CO}} = \left(WL - RUS_{GAM_{base}}\right) \times Area_{cell} \times S_y$

else if Zone is 1 – Collapsed

- $Volume_{total_{MG}} = 0$
- $Volume_{total_{CL}} = 0$
- $Volume_{total_{LM}} = 0$

$$Volume_{unconfined_{CO}} = Thickness_{RU} \times Area_{cell} \times S_y$$

If model cell is active:

$$Volume_{confined_{CO}} = \left(WL - RUS_{GAM_{top}}\right) \times Area_{cell} \times S_s \times Thickness_{CO}$$

- $Volume_{total_{CO}} = Volume_{unconfined_{CO}} + Volume_{confined_{CO}}$
-
- *else:*

- $Volume_{total_{CO}} = Volume_{unconfined_{CO}}$

else if Zone is 3 – Eroded Zone

- $Volume_{total_{CO}} = 0$
- $Volume_{total_{MG}} = 0$
- $Volume_{unconfined_{CL}} = Thickness_{CL} \times Area_{cell} \times S_y$
- $Volume_{unconfined_{LM}} = Thickness_{LM} \times Area_{cell} \times S_y$

If model cell is active:

$$Volume_{confined_{CL}} = \left[\left(WL - RUS_{GAM_{top}}\right) + \left(Surface_{RU_{top}} - Surface_{CL_{top}}\right)\right] \times Area_{cell} \times S_s \times Thickness_{CL}$$

- $Volume_{confined_{LM}} = \left[\left(WL - RUS_{GAM_{top}}\right) + \left(Surface_{RU_{top}} - Surface_{CL_{top}}\right)\right] \times Area_{cell} \times S_s \times Thickness_{LM}$
- $Volume_{total_{CL}} = Volume_{unconfined_{CL}} + Vlume_{confined_{CL}}$
- $Volume_{total_{LM}} = Volume_{unconfined_{LM}} + Volume_{confined_{LM}}$

else:

- $Volume_{total_{CL}} = Volume_{unconfined_{CL}}$
- $Volume_{total_{LM}} = Volume_{unconfined_{LM}}$

else if Zone is '2 – Normal'

- $Volume_{total_{CO}} = 0$

$$Volume_{unconfined_{MG}} = Thickness_{MG} \times Area_{cell} \times S_y$$

$$Volume_{unconfined_{CL}} = Thickness_{CU} \times Area_{cell} \times S_y$$

$$Volume_{unconfined_{LM}} = Thickness_{LM} \times Area_{cell} \times S_y$$

If model cell is active:

- $Volume_{confined_{MG}} = \left[\left(WL - RUS_{GAM_{top}}\right) + \left(Surface_{RU_{top}} - Surface_{MG_{top}}\right)\right] \times Area_{cell} \times S_s \times Thickness_{MG}$
- $Volume_{confined_{CL}} = [\left(WL - RUS_{GAM_{top}}\right) + \left(Surface_{RU_{top}} - Surface_{MG_{top}}\right)] \times Area_{cell} \times S_s \times Thickness_{CL}$
- $Volume_{confined_{LM}} = [\left(WL - RUS_{GAM_{top}}\right) + \left(Surface_{RU_{top}} - Surface_{MG_{top}}\right)] \times Area_{cell} \times S_s \times Thickness_{LM}$

- $Volume_{total_{MG}} = Volume_{unconfined_{MG}} + Volume_{confined_{MG}}$

- $Volume_{total_{CL}} = Volume_{unconfined_{CL}} + Volume_{confined_{CL}}$
- $Volume_{total_{LM}} = Volume_{unconfined_{LM}} + Volume_{confined_{LM}}$
-
- Else:

$$Volume_{total_{MG}} = Thickness_{MG} \times Area_{cell} \times S_y$$

$$Volume_{total_{CL}} = Thickness_{CU} \times Area_{cell} \times S_y$$

$$Volume_{total_{LM}} = Thickness_{LM} \times Area_{cell} \times S_y$$

where:

$Area_{cell}$ = area of a single grid cell (0.0625 square miles)
CO = Collapsed (Rustler)
MG = Magenta Dolomite
CL = Culebra Dolomite
LM = Los Medaños limestone
S_s = specific storage (1/feet)
Surface = Elevation of stratigraphic unit surface (feet)
S_y = specific yield (unitless)
RUS_GAM_{base}= elevation of base of Rustler Aquifer (feet) from Rustler GAM (Ewing and others, 2012)
RUS_GAM_{top} = elevation of top of Rustler Aquifer (feet) from Rustler GAM (Ewing and others, 2012)
$Thickness_{RU}$= thickness of updated Rustler Formation (feet)
$Surface_{RU}$= elevation of top of updated Rustler Formation (feet)
$Thickness_{CL}$= thickness of Culebra Dolomite (feet)
$Surface_{CL}$= elevation of top of updated Culebra Dolomite (feet)
$Thickness_{MG}$= thickness of Magenta Dolomite (feet)
$Surface_{MG}$= elevation of top of the Magenta Dolomite (feet)
$Thickness_{LM}$= thickness of Los Medaños limestone (feet)
WL = water level elevation (feet) modeled for the year 2008 in the Rustler GAM (Ewing and others, 2012).

19.6.2 Tool interfaces

Figure 19-4 shows the six files required to run the Calculate Volumes tool. The steps required to run this tool are as follows:

1. *RustlerHydrogeology* is imported to ArcToolbox and will show the two available scripts.
2. *RustlerHydroGeoTool_v3* is labelled "Rustler Brackish Calculate Volumes" within ArcGIS and the script is run first to output calculated volumes in Rustler.gdb. The three shp files in the directory are required for this step, while an Area of Interest can also be defined.
3. *RustlerHydroGeoTables* is labelled "Rustler Brackish Create Summary Tables" within ArcGIS and the script is run second to output the calculated volumes as csv files.

4. The three csv files are output in the designated folder and are to be formatted as required using pivot tables. Examples of these pivot tables have been provided (Final_Electronic_Deliverables\Volume_Calculator) so that the user can simply replicate the process or add additional fields.

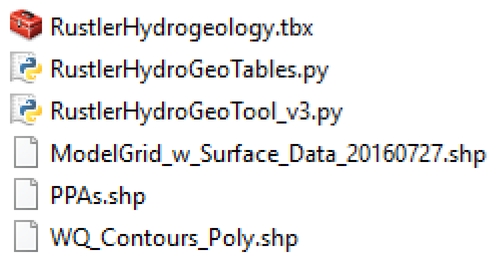

Figure 19-4. Rustler brackish groundwater volume calculation required files.

Figure 19-5 shows the interface for the Calculate Volumes interface. There are five inputs, four of which are required:

1. *Rustler Grid Polygon* – input polygon feature containing the Rustler hydrogeologic information (required) (ModelGrid_w_Surface_Data_20160727.shp)
2. *PPA Polygon* – input polygon feature delineating PPA zones (required) (PPA.shp)
3. *Water Quality Polygon* – input polygon feature delineating water quality classes (required) (WQ_Contours_Poly.shp)
4. *Area of Interest (User-provided)* – input polygon defining area of interest (optional). The polygon must me in the same GAM coordinate system and contain a field call 'CLASS' with the identifiers for areas of interest. The field 'CLASS' can be a .txt field and the name provided to each of the 'classes' will be carried through to the table formatting.
5. *Output* – directory path for summary outputs in string format (required), example:
   - S:\AUS\TWDB_Rustler_Brackish\VolumeCalc\D_Results\Baseline

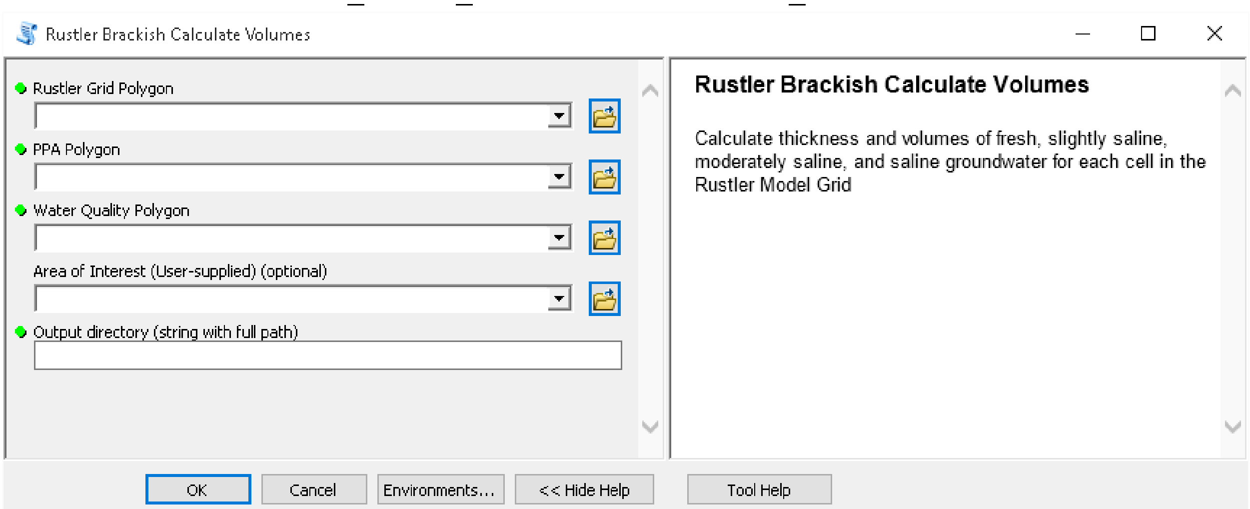

Figure 19-5. Rustler brackish calculate volumes tool interface.

This tool performs calculations on the Rustler Grid Polygon and adds additional fields to report thickness and volume for each aquifer unit (Collapsed, Magenta, Culebra, and Los Medaños).

The tool also adds fields to facilitate the tabulation of the results by PPA (PPAClass field), water quality (WQClass field), and user defined class (UserClass field). The results are then stored in the Output Directory within a File Geodatabase called Rustler.gdb. Ruster.gdb/AOI contains the Rustler Model Grid feature class with additional fields and Ruster.gdb/OutputGrid contains a table useful for tabulation and analysis.

Figure 19-6 shows the interface for the Create Summary Tables Tool interface. The only input required for this table is the same output directory used in the previous volume calculations.

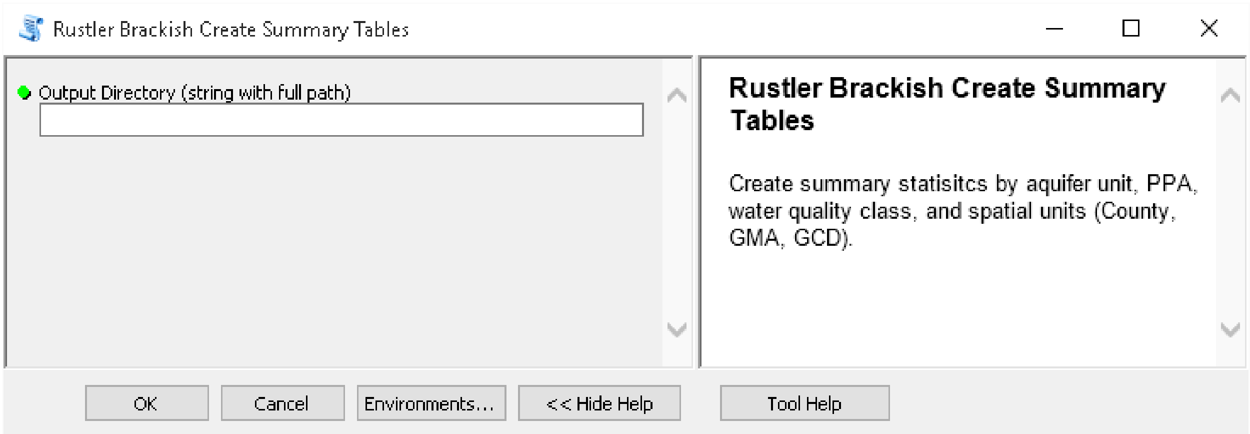

Figure 19-6. Rustler brackish create summary tables tool interface.

This tool uses the Ruster.gdb/OutputGrid table to generate the following files in the output directory with tabulated total volumes:

- Table_1_by_PPA.csv: Groundwater volumes tabulated by PPA and spatial units (requested as deliverable)
- Table_2_by_HydroUnit.csv: Groundwater volumes tabulated by aquifer unit and spatial units (requested as deliverable)
- Table_3_by_WQ.csv: Groundwater volumes tabulated by water quality zone and spatial units (used in Section 12 of the report)

These csv files can then be opened in Microsoft Excel and formatted as required using pivot tables.

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19.7 Examples of geophysical well log analysis

Note: Many of the example calculations were made before total dissolved solids calculations were finalized and therefore are slightly different form reported porosity and total dissolved solids values. These examples are meant to provide a road map for the processing of the techniques.

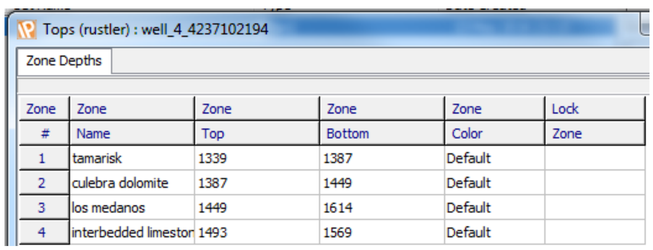
19.7.1 Example1: Well_4_4230130236 (porosity calculated from neutron CPS and 32"LS)

Available logs: Gamma Ray in Ra-eq/ton, 10" normal, 32" LS, 19' Laterolog, Neutron in CPS

Note: in the digitization process, resistivity logs are sometimes given new names such as RES_SHAL, RES_MED and RES_DEEP. It is important to know which type of tool is associated with each curve. In this example, the deepest resistivity is measured by 19' Laterolog, the associated curve name is LAT19. The 32"LS is renamed RES_DEEP. To avoid any type of confusion, make sure to check a second time which curve is the deepest resistivity and which curve is the shallowest.

Step1: Import and plot available logs

Step2: define zone tops and plot them
On IP, go to **Well-> Manage Zones/Picks -> New Tops**

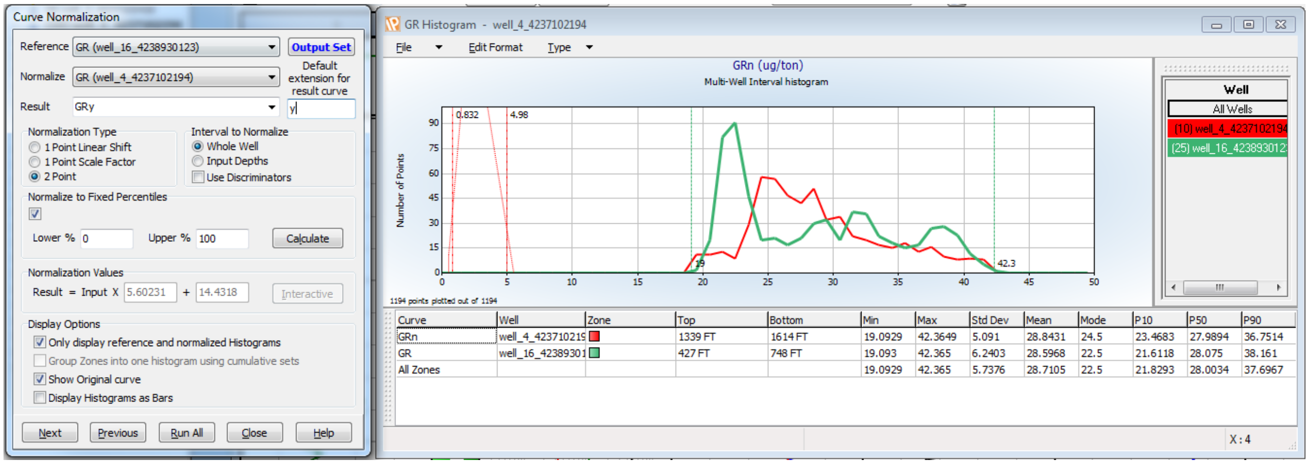

Tops (rustler) : well_4_4237102194
Zone Depths

Zone #	Zone Name	Zone Top	Zone Bottom	Zone Color	Lock Zone
1	tamarisk	1339	1387	Default	
2	culebra dolomite	1387	1449	Default	
3	los medanos	1449	1614	Default	
4	interbedded limestor	1493	1569	Default	

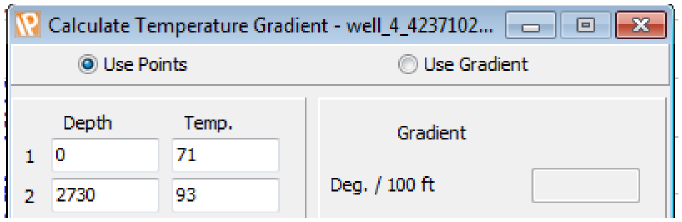
Step3: Correct depth shifting
All the logs look like they are correctly shifted

Step4: Choose reference wells
Well_16_4238930123 has a gamma ray log in API units. It is taken as reference.

Step5: normalize the Gamma ray log
The normalization of the gamma ray log is done with respect to the reference well_16_4238930123 from the top of Tamarisk to the bottom of Los Medaños


Curve Normalization
Reference
GR (well_16_4238930123)
Output Set
Normalize
GR (well_4_4237102194)
Default extension for result curve
Result
GRy
Normalization Type
1 Point Linear Shift
1 Point Scale Factor
2 Point
Interval to Normalize
Whole Well
Input Depths
Use Discriminators
Normalize to Fixed Percentiles
Lower %
Upper %
100
Calculate
Normalization Values
Result = Input X
5.60231
14.4318
Interactive
Display Options
Only display reference and normalized Histograms
Group Zones into one histogram using cumulative sets
Show Original curve
Display Histograms as Bars
Next
Previous
Run All
Close
Help
GR Histogram - well_4_4237102194
File
Edit Format
Type
GRn (ug/ton)
Multi-Well Interval histogram
Number of Points
0.832
4.98
42.3
1194 points plotted out of 1194
Well
All Wells
(10) well_4_4237102194
(25) well_16_423893012
Curve
Well
Zone
Top
Bottom
Min
Max
Std Dev
Mean
Mode
P10
P50
P90
GRn
well_4_423710219
1339 FT
1614 FT
19.0929
42.3649
5.091
28.8431
24.5
23.4683
27.9894
36.7514
GR
well_16_42389301
427 FT
748 FT
19.093
42.365
6.2403
28.5968
22.5
21.6118
28.075
38.161
All Zones
19.0929
42.365
5.7376
28.7105
22.5
21.8293
28.0034
37.6967
X : 4

Step6: Calculate Temperature



Step7: Calculate Mud Filtrate Resistivity

$$R_{mf} = 0.045 * \frac{81 + 6.77}{temp + 6.77}$$

Step8: Calculate porosity

We have two ways to calculate porosity. In this example, we will use them both and compare them.

Method 1: Convert Neutron CPS to Neutron in limestone porosity units

Since bite size=8 ¾", we convert neutron (CPS) to Φ_{ls} using the equations for 8" and 10" borehole.

$$\Phi_{LS} = (0.625 * 10^{(2.4-0.00438CPS)} + (1-0.625) * 10^{(2.547-0.0052CPS)})/100$$

Φ_{LS} will be used in the Los Medaños limestone interval

Φ_{LS} is then converted to dolomite porosity units by using IP (**Calculation-> Basic Log Functions->Porosity -> Neutron -> from limestone to dolomite**) we get Φ_{dol}

Φ_{dol} will be used in the Culebra dolomite interval

The bed boundary between Culebra dolomite and Los Medaños is at 1449 ft. we define porosity Φ in this way:

If depth≤1449 $\Phi = \Phi_{dol}$ else $\Phi = \Phi_{ls}$. This way we will have to deal with only one curve.

Method 2: Approximate porosity from the 32" LS resistivity log

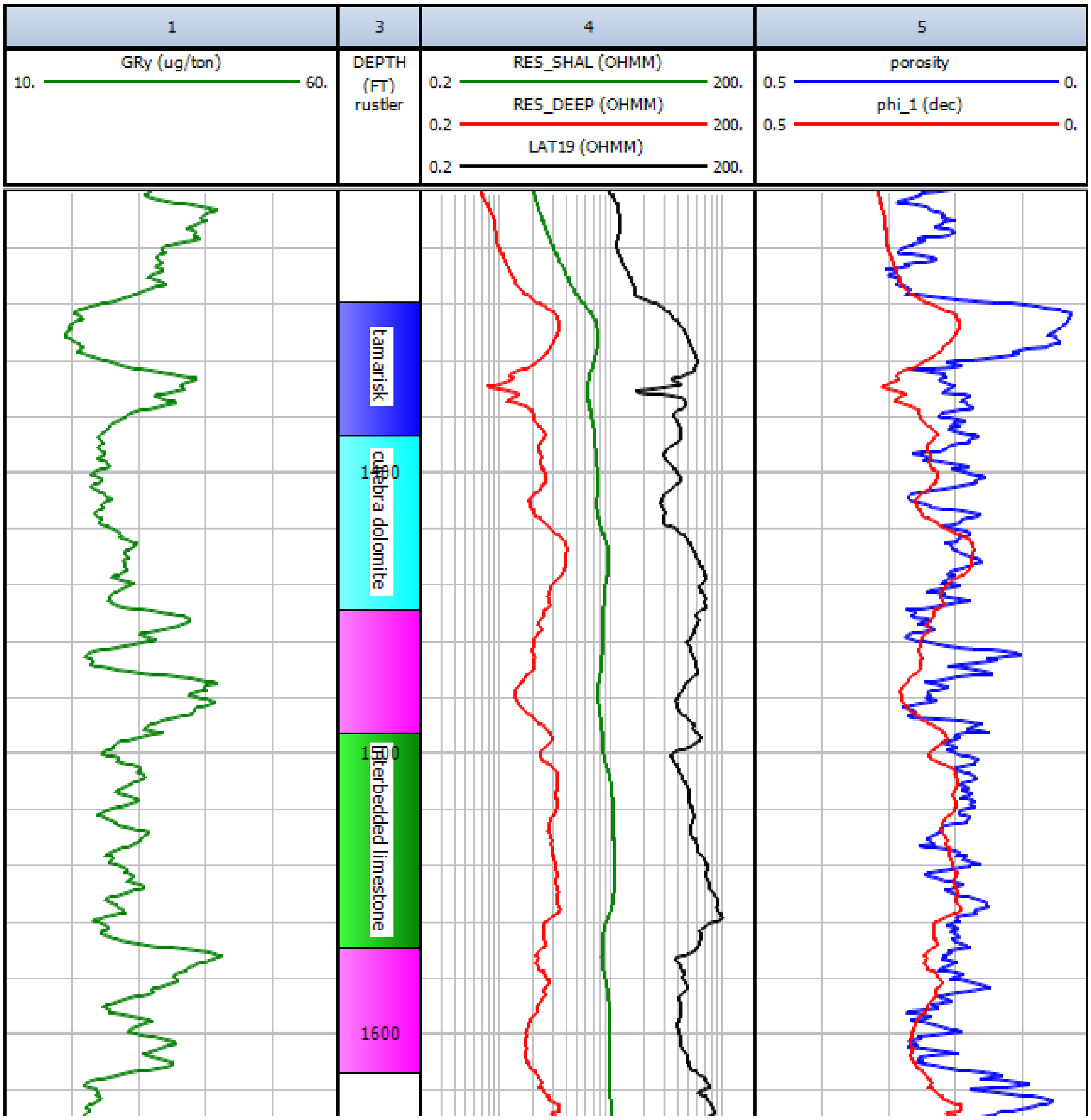
First, we calculate $\frac{res32"}{Rmf(z)}$ from top to bottom of the well. We find that max($\frac{res32"}{Rmf(z)}$)=268.45

For a 8 ¾" hole size: $\Phi \approx (0.0028 * (\%Deflection)^2 - 0.594 * (\%Deflection) + 35.068)/100$

Where $\%Deflection = 100 * (\frac{Res32"}{Rmf(z)})/\ 268.45$.

We plot porosity from both methods.

The result of the method 1 is called **porosity** and the result of method 2 is called **phi_1**. As we can see, both methods give us pretty much the same values of porosity. It is interesting to run many methods at the same time when it is possible, for quality control. From now on, well_4_4237102194 can be considered as a reference well for the nearby wells.



Step9: calculate water resistivity Rw and equivalent [NaCl] concentration

We apply these equations assuming that $Rt \approx LAT19$

$$Rw = LAT19 * \Phi^2$$

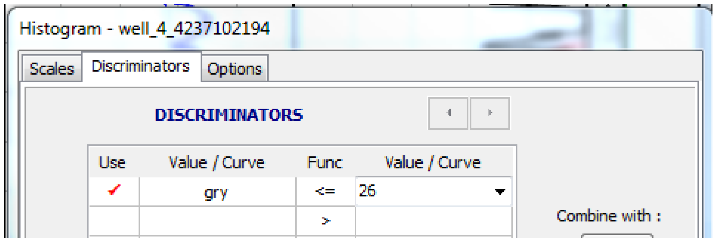
$$[NaCl]_{ppm} = 10^{\frac{3.562 - \log_{10}[(\frac{temp+6.77}{81.77})*Rw - 0.0123]}{0.955}}$$

Since the equation above is derived from Archie's equation, it is only valid in clean intervals (shale free ⇔ local minimum of Gamma Ray signal). This means that we should do some truncations when calculating mean porosity and mean [NaCl] values.

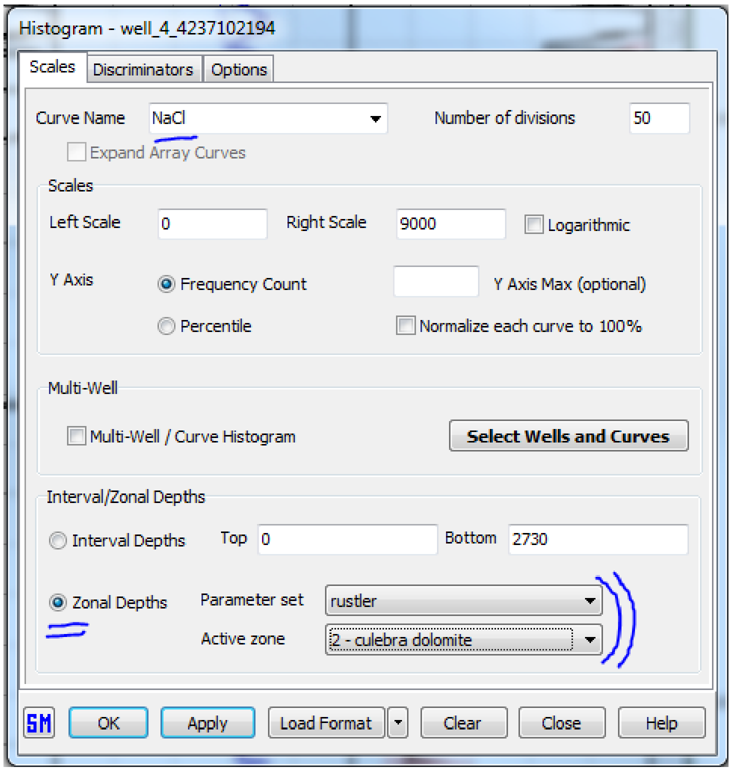
Step10: discriminators and mean value

On IP, Go to **View-> Histogram ->Discriminators**

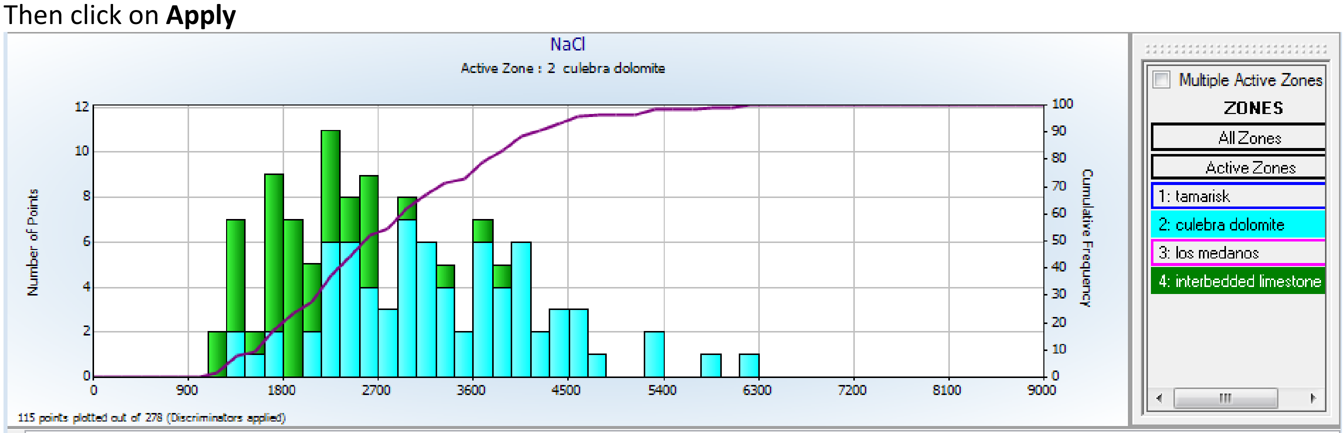
I use for example the discriminator GR≤26 (or equivalently Vsh≤0.282)



Then go back to **Scales**

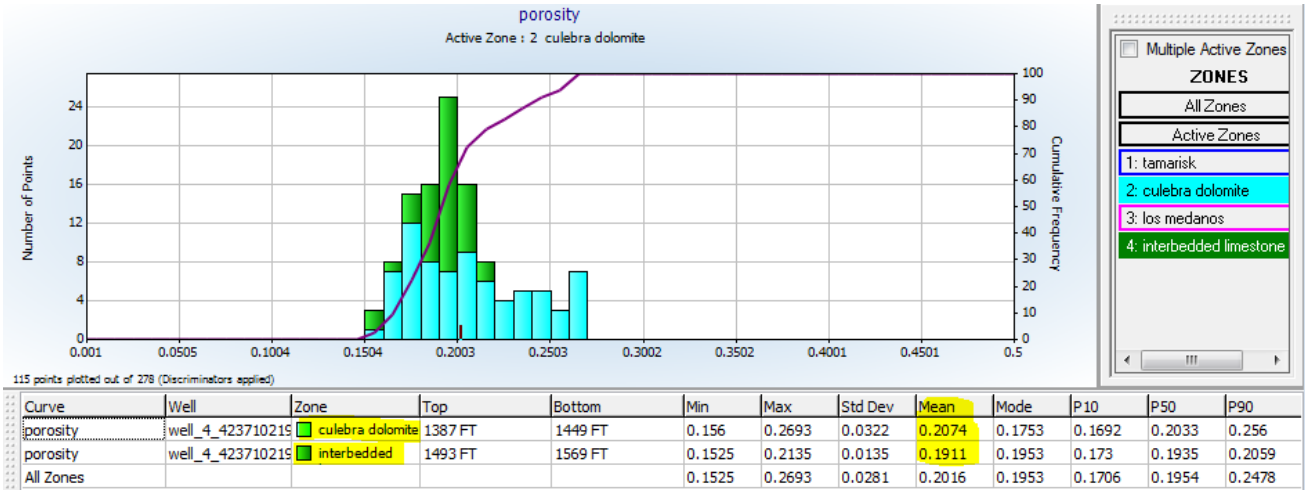


Then click on **Apply**



Curve	Well	Zone	Top	Bottom	Min	Max	Std Dev	Mean	Mode	P10	P50	P90
NaCl	well_4_42371021s	culebra dolomite	1387 FT	1449 FT	1317.454	6205.4688	1005.906	3289.0925	2970	2198.7085	3227.563	4495.4063
NaCl	well_4_42371021s	interbedded	1493 FT	1569 FT	1154.0814	3841.6772	616.5864	2078.054		1385.5286	1969.5613	2636.2478
All Zones					1154.0814	6205.4688	1058.6534	2857.3311	2250	1688.6943	2606.3645	4235.8628

We apply the same process for porosity using the same discriminator



	Magenta Dolomite	Culebra Dolomite	Los Medanos Limestone
Porosity	--	0.21	0.19
[NaCl]	--	3289	2078

Those values can slightly change when you change your discriminator. Moreover, you can apply different discriminators for dolomite and for limestone intervals.

Step11: convert equivalent [NaCl] to real $TDS_{rustler}$

We apply this equation to the mean value of [NaCl] calculated previously

$$\mathbf{TDS_{Rustler} = 2.7865 * [NaCl]^{0.9213}}$$

Finally,

	Magenta Dolomite	Culebra Dolomite	Los Medaños Limestone
Porosity	**--**	**0.21**	**0.19**
$TDS_{rustler}$	**--**	**4845**	**3174**

Step12: save and export results as a LAS file

19.7.2 Example2: Well_22_10931383 (porosity calculated from neutron porosity and SFL)

Available logs: Gamma Ray in API, SFL, Med, Deep, Neutron in porosity units

Step1: Import and plot available logs

Step2: define zone tops and plot them

On IP, go to **Well-> Manage Zones/Picks -> New Tops**

Zone #	Zone Name	Zone Top	Zone Bottom	Zone Color	Lock Zone
1	forty-inner	334	422	Default	
2	magenta dolomite	422	448	Default	
3	tamarisk	448	580	Default	
4	culebra dolomite	580	624	Default	
5	los medanos	624	804	Default	

Step3: Choose reference wells

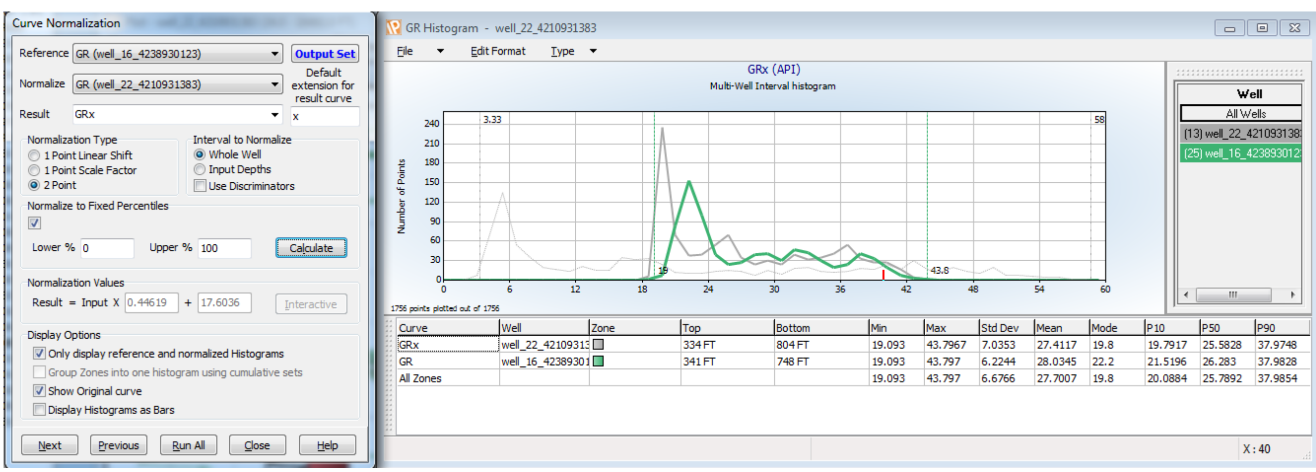
Well_16_4238930123 has a gamma ray log in API units. It is taken as reference. Even if the gamma ray log in this well is in API units too, the purpose of normalization is to bring all gamma ray logs on the same range of variation.

Step4: depth shifting

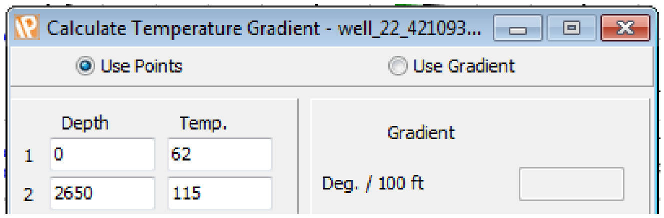
All the logs look like they are correctly shifted

Step5: normalize the Gamma ray log

The normalization of the gamma ray log is done with respect to the reference well_16_4238930123 from the top of Forty inner to the bottom of Los Medaños



Step6: Calculate Temperature



Step7: Calculate Mud Filtrate Resistivity

$$R_{mf} = 0.412 * \frac{75 + 6.77}{temp + 6.77}$$

Step8: Calculate porosity

We have two ways to calculate porosity. In this example, we will use them both and compare them.

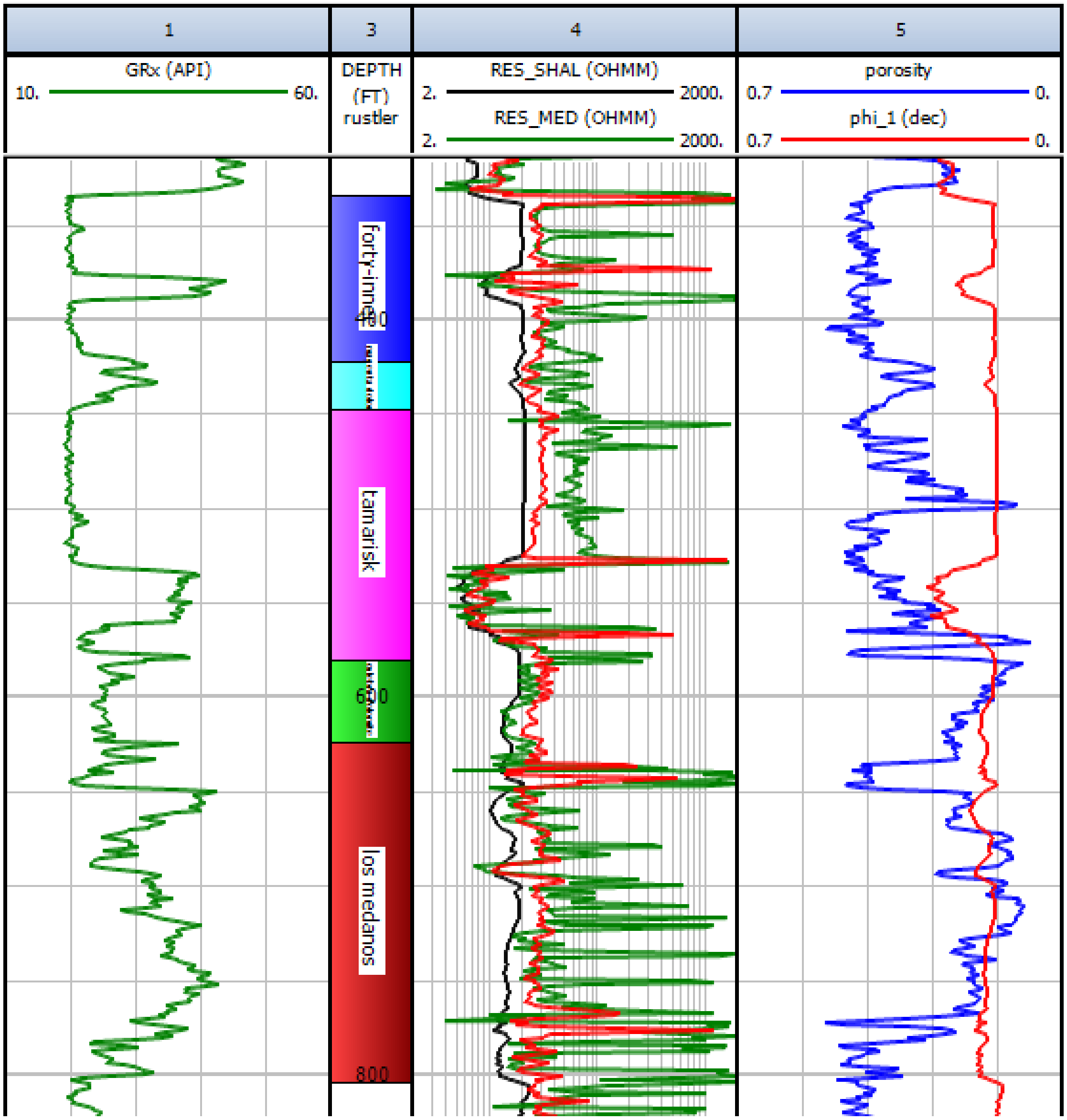
Method 1: Convert the neutron log from limestone porosity units to dolomite porosity unit
Φ_{LS} is converted to dolomite porosity units by using IP (**Calculation-> Basic Log Functions->Porosity -> Neutron -> from limestone to dolomite**) we get Φ_{dol}
Φ_{dol} will be used in the Magenta dolomite and Culebra dolomite intervals

Method 2: Approximate porosity from the SFL

$$\Phi \approx \sqrt{\frac{Rmf}{R_{xo}}}$$

We plot porosity from both methods.

The result of the method 1 is called **porosity** and the result of method 2 is called **phi_1**. As we can see, both methods give us pretty much the same values of porosity in the Culebra dolomite section, with only a difference of 3% on average. However, the two curves do not match in the magenta dolomite section. This can be due to the fact that SFL resistivity values are affected by the shoulder-bed effect of high resistive anhydrites. It is interesting to run many methods at the same time when it is possible, for quality control. **porosity** seems to be more reliable for next calculations.



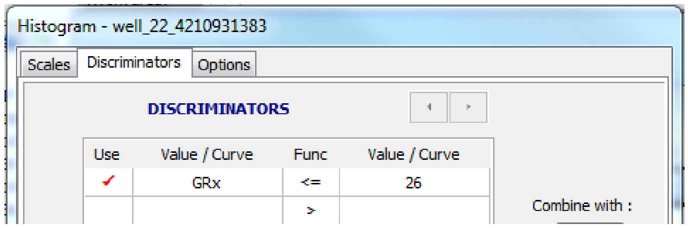
<u>Step9: calculate water resistivity and equivalent [NaCl] concentration</u>

$$Rw = Res_{deep} * \Phi^2$$

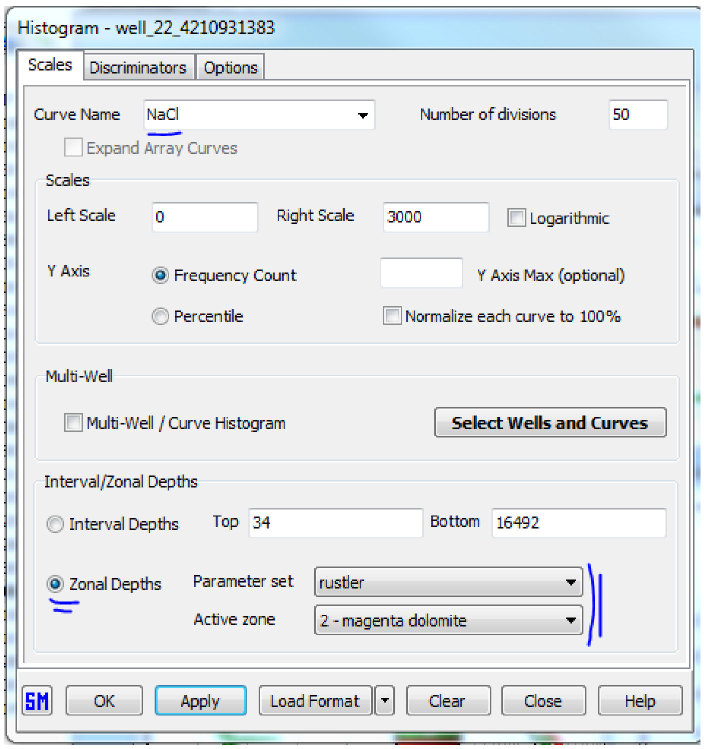
$$[NaCl]_{ppm} = 10^{\frac{3.562-\log_{10}[(\frac{temp+6.77}{81.77})*Rw-0.0123]}{0.955}}$$

Since the equation above is derived from Archie's equation, it is only valid in clean intervals (shale free ⇔ local minimum of Gamma Ray signal). This means that we should do some truncations when calculating mean porosity and mean [NaCl] values.

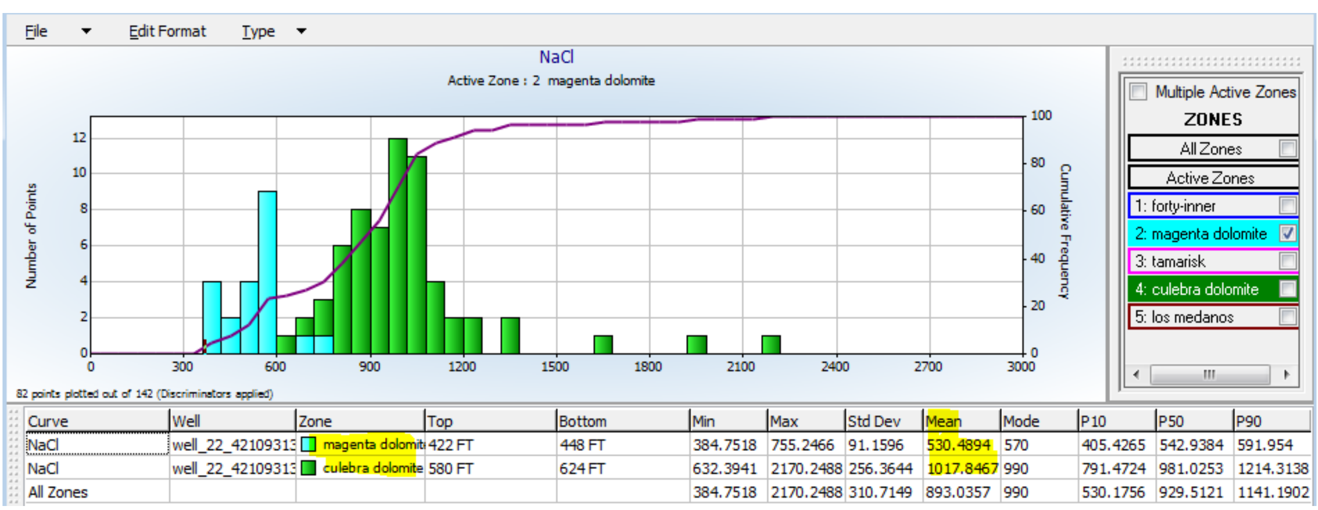
<u>Step10: discriminators and mean value</u>
On IP, Go to **View-> Histogram ->Discriminators**
I use for example the discriminator GR≤26 (or equivalently Vsh≤0.282)



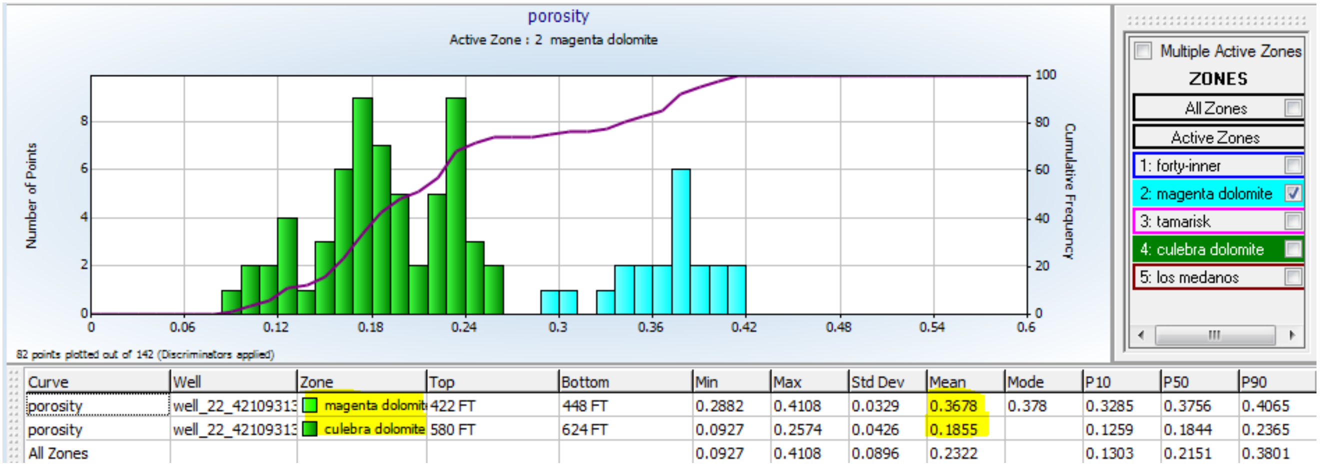
Then go back to **Scales**



Then click on **Apply**



We apply the same process for porosity using the same discriminator



	Magenta Dolomite	Culebra Dolomite	Los Medanos Limestone
Porosity	0.37	0.19	--
[NaCl]	530	1017	--

Those values can slightly change when you change your discriminator.

Step11: convert equivalent [NaCl] to real $TDS_{rustler}$

We apply this equation to the mean value of [NaCl] calculated previously

$$\mathbf{TDS_{Rustler} = 2.7865 * [NaCl]^{0.9213}}$$

Finally,

	Magenta Dolomite	Culebra Dolomite	Los Medanos Limestone
Porosity	**0.37**	**0.19**	**--**
$TDS_{rustler}$	**901**	**1643**	**--**

Step12: save and export results as a LAS file

19.7.3 Example3: Well_6_4237100583 (porosity calculated from sonic log)

Available logs: Gamma Ray in CPS, 18” normal, 40”induction, sonic

Step1: Import and plot available logs

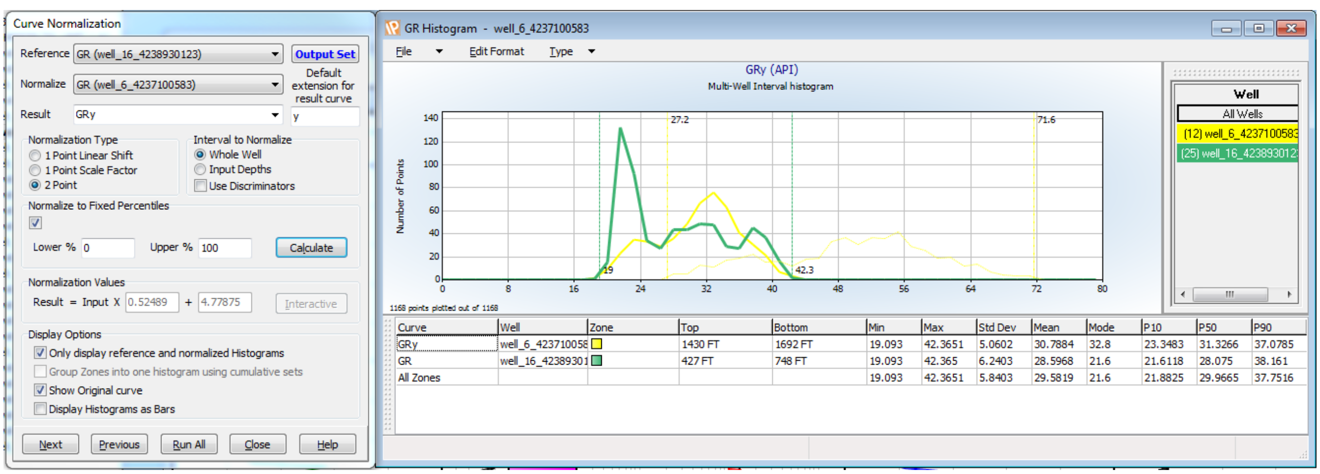
Step2: define zone tops and plot them
On IP, go to **Well-> Manage Zones/Picks -> New Tops**

Zone #	Zone Name	Zone Top	Zone Bottom	Zone Color	Lock Zone
1	tamarisk	1430	1507	Default	
2	culebra dolomite	1507	1544	Default	
3	los medanos	1544	1692	Default	

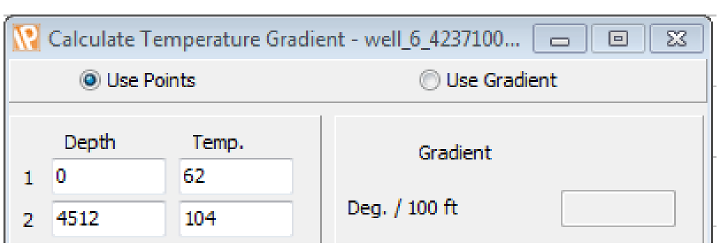
Step3: depth shifting
All the logs look like they are correctly shifted

Step4: Choose reference wells
Well_16_4238930123 has a gamma ray log in API units. It is taken as reference.

Step5: normalize the Gamma ray log
The normalization of the gamma ray log is done with respect to the reference well_16_4238930123 from the top of Tamarisk to the bottom of Los Medaños



Step6: Calculate Temperature



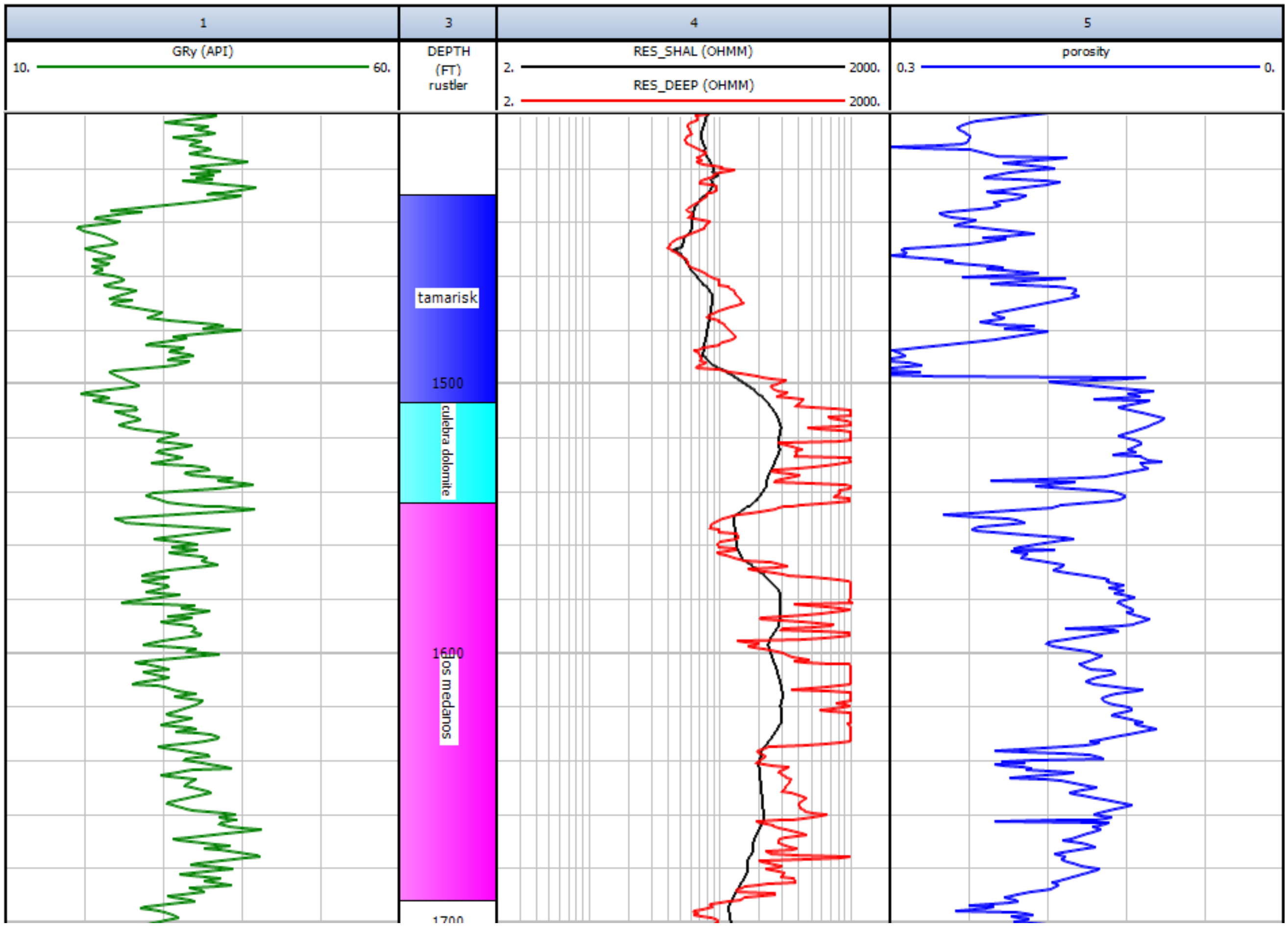
Step7: Calculate Mud Filtrate Resistivity

$$R_{mf} = 1.78 * \frac{62 + 6.77}{temp + 6.77}$$

Step8: Calculate porosity

The only way to approximate porosity in this case is to use the sonic log. Water-bearing zone is Culebra dolomite. Thus, we apply this formula:

$$\Phi_{dolomite} = \frac{\Delta t - 43.5}{190 - 43.5}$$



Step9: calculate water resistivity and equivalent [NaCl] concentration

$$Rw = Res_{deep} * \Phi^2$$

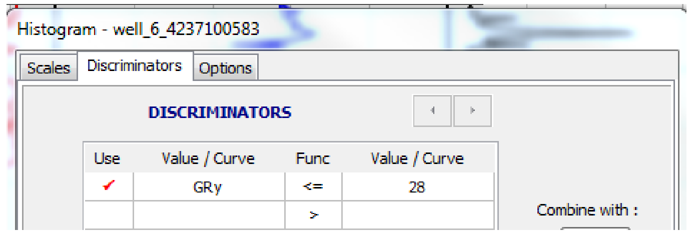
$$[NaCl]_{ppm} = 10^{\frac{3.562 - \log_{10}[(\frac{temp+6.77}{81.77}) * Rw - 0.0123]}{0.955}}$$

Since the equation above is derived from Archie's equation, it is only valid in clean intervals (shale free ⇔ local minimum of Gamma Ray signal). This means that we should do some truncations when calculating mean porosity and mean [NaCl] values.

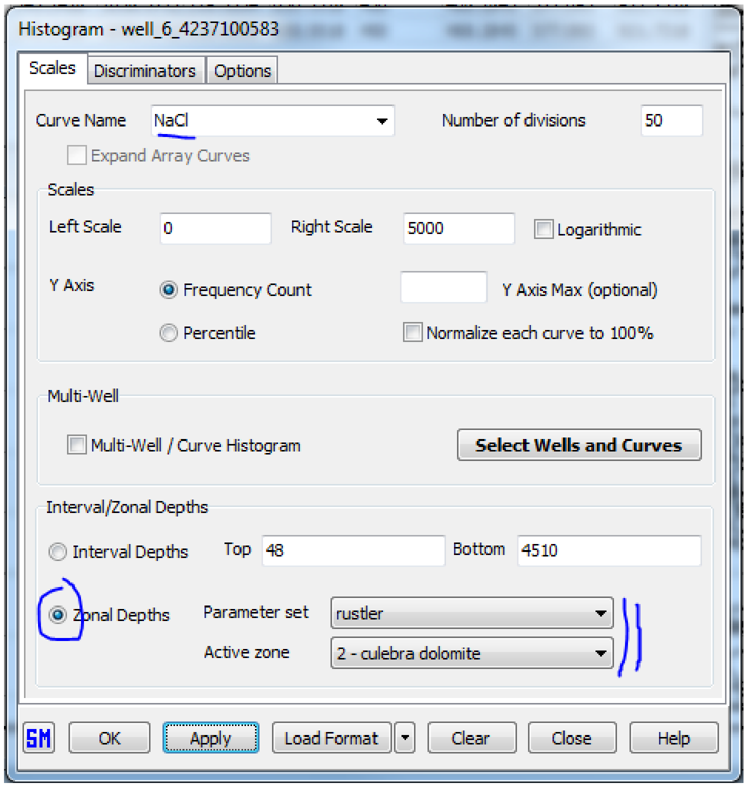
Step10: discriminators and mean value

On IP, Go to **View-> Histogram ->Discriminators**

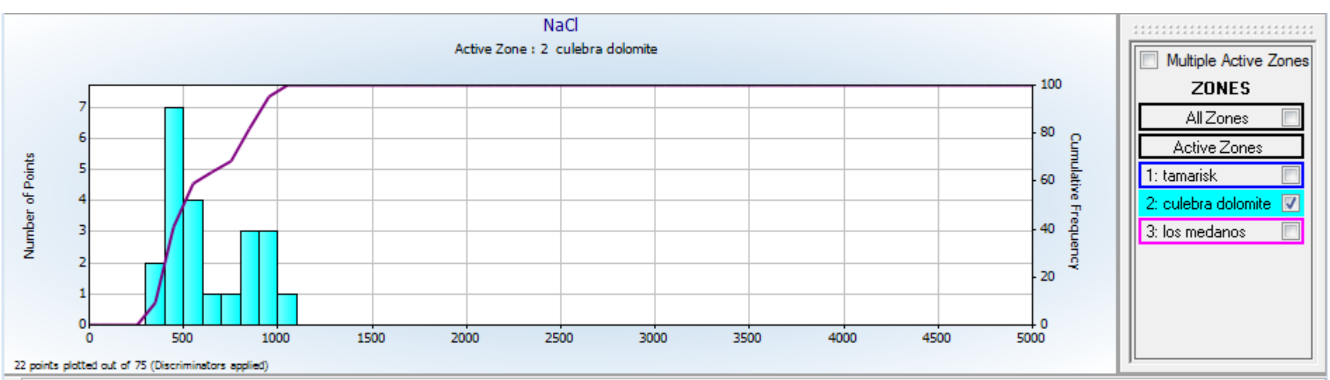
I use for example the discriminator GR≤28 (or equivalently Vsh≤0.363)



Then go back to **Scales**

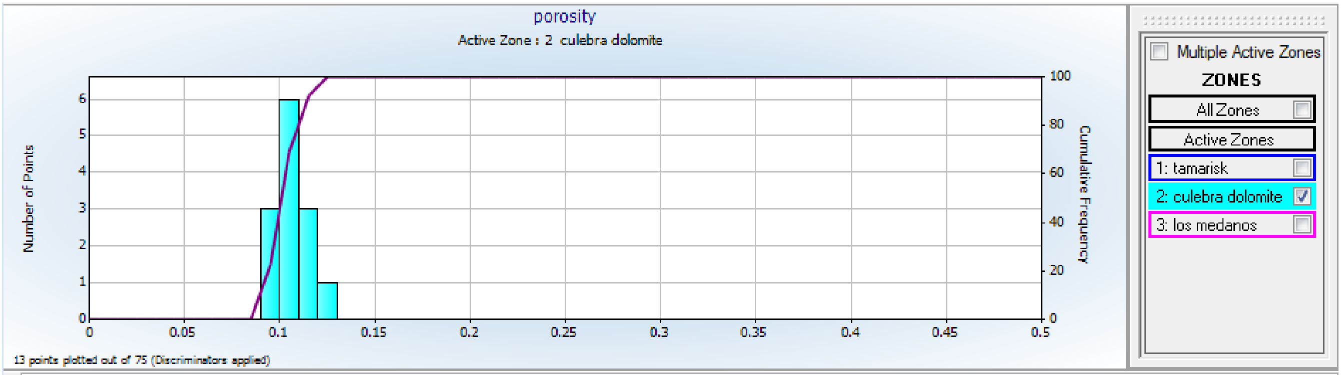


Then click on **Apply**



Curve	Well	Zone	Top	Bottom	Min	Max	Std Dev	Mean	Mode	P10	P50	P90
NaCl	well_6_42371005€	culebra dolomite	1507 FT	1544 FT	343.2428	1038.5712	219.5534	630.5518	450	408.2845	577.093	921.7318
All Zones					343.2428	1038.5712	219.5535	630.5518	450	408.2845	577.093	921.7318

We apply the same process for porosity using the same discriminator



Curve	Well	Zone	Top	Bottom	Min	Max	Std Dev	Mean	Mode	P10	P50	P90
porosity	well_6_423710058	culebra dolomite	1507 FT	1544 FT	0.0965	0.1223	0.0076	0.1068	0.105	0.099	0.1068	0.1162
All Zones					0.0965	0.1223	0.0076	0.1068	0.105	0.099	0.1068	0.1162

	Magenta Dolomite	**Culebra Dolomite**	**Los Medanos Limestone**
Porosity	--	0.11	--
[NaCl]	--	631	--

Those values can slightly change when you change your discriminator.

Step11: convert equivalent [NaCl] to real $TDS_{rustler}$

We apply this equation to the mean value of [NaCl] calculated previously

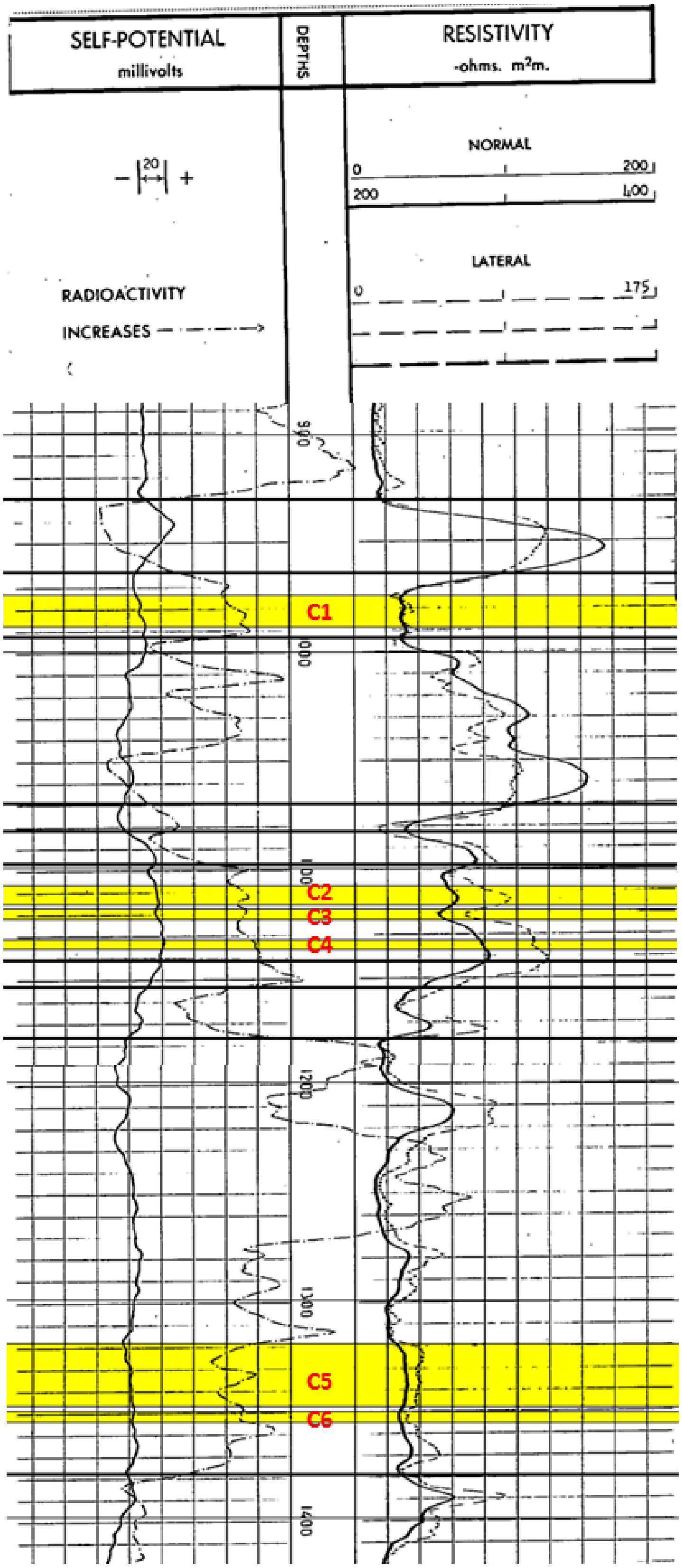
$$\mathbf{TDS_{Rustler} = 2.7865 * [NaCl]^{0.9213}}$$

Finally,

	Magenta Dolomite	**Culebra Dolomite**	**Los Medanos Limestone**
Porosity	**--**	**0.11**	**--**
$\boldsymbol{TDS_{rustler}}$	**--**	**1059**	**--**

Step12: save and export results as a LAS file

19.8 Example additional calculation of water quality



42389007540000

Variables:

- Ts = 67 F
- BHT = 107F
- TD = 3326 ft
- Hole Dia = 7.875"
- Rmf = 0.807

- Calc 1: 974-988
- Calc2: 1108-1116
- Calc3: 1118-1123
- Calc4: 1133-1137
- Calc5: 1320-1349
- Calc6: 1351-1356

Carbonate Units:

- Magenta: 963-993
- Culebra: 1097-1142
- Los Medaños Limestone(s): 1312-1358

Calculate: Formation Temp (F)

Tf =(BHT-Ts)*(Depth/TD)+TS

C1: 78.8F	C4: 80.65F
C2: 80.38F	C5: 83.05F
C3: 80.48	C6: 83.28F

Calculate: Rmf at Depth

$$R_{mf}(z) = R_{mf1} * \frac{T_1 + 6.77}{T_{(z)} + 6.77}$$

C1: 0.696	C4: 0.681
C2: 0.683	C5: 0.663
C3: 0.683	C6: 0.661

Calculate: $max\left(\frac{Res32"}{Rmf}\right)$ over entire log:

$$max\left(\frac{Res32"}{Rmf}\right) = 289$$

Calculate : %Deflection and Porosity (Φ)

$$\%Deflection = 100 * \left(\frac{Res32"}{R_m}\right) / \left[max\left(\frac{Res32"}{R_m}\right)\right]$$

$$\Phi \approx \frac{-12.59\,ln(\%Deflection) + 60.674}{100}$$

C1: 0.279	C4: 0.115
C2: 0.144	C5: 0.244
C3: 0.169	C6: 0.265

Calculate: Formation Water Resistivity (Rw)

$$Rw = R_t * \Phi^2$$

C1: 2.13	C4: 1.292
C2: 1.624	C5: 2.040
C3: 1.819	C6: 2.020

Calculate: Equivalent NaCl Concentration (TDS_{NaCl})

$$TDS_{NaCl} = 10^{\frac{3.562 - \log_{10}\left[\left(\frac{T(z)+6.77}{81.77}\right) * Rw - 0.0123\right]}{0.955}}$$

C1: 2,333	C4: 3,866
C2: 3,045	C5: 2,321
C3: 2,700	C6: 2,339

Calculate: Total Dissolved Solids (TDS)

$$TDS = 1.1784(TDS_{NaCl}) + 94.788$$

C1: 2,844	C4: 4,650
C2: 3,683	C5: 2,829
C3: 3,276	C6: 2,851

19.9 Geographic information system datasets

The geographic information system (GIS) datasets used in the current study are located in the GIS_Final" folder included in the final electronics deliverables. The structure of this folder is as follows :

A. "*GIS_Final*"(main folder)

1. All *.mxd* files corresponding to map figures in the report
   - the main folder contains all .mxds used in the report

2. "*bookmarks"* (folder)
   - contains bookmarks (.dat) files used to set the zooms and/or extents of the .mxd files within the ESRI ArcMap program

3. "*png"* (folder)
   - contains .png files of all the .mxd files included in the main GIS_Final folder.

4. "*ras*" (folder)
   a. All rasters used in the current study
      - rasters provided in .tif or ESRI grid format
      - explanation of naming conventions are described in the metadata for individual files and in Appendix 19.2.

   b. "*Appendix 19_CreatingGeologicSurfaces*" (folder)
      i. "*FinalSurfaces*" (folder)
         - contains the elevation rasters of individual geologic units across the entire study area.
         - explanation of naming conventions are included in the "README.txt" file provided in the "*Appendix 19_CreatingGeologicSurfaces" folder.*
      ii. "*StratPickSurfacesByZone*" (folder)
         - contains the component elevation rasters of individual geologic units, split by stratigraphic zone/hydrostratigraphic subdomain, used to make the surfaces in the "*FinalSurfaces*" folder.
         - explanation of naming conventions are included in the "README.txt" file provided in the "*Appendix 19_CreatingGeologicSurfaces" folder.*
      iii. "README.txt"
         - explains the naming conventions used in the "*FinalSurfaces*" and "*StratPickSurfacesByZone*" folders

5. "*shp*" (folder)

a. All shapefiles (.shp) used in the current study are included in the main "*shp*" folder

b. "*WQ_Input*" (folder)
- contains the water quality data spreadsheets used to make Table 5-3 in the report (in .xls & .xlsx format)

c. "*WellFields*" (folder)
- contains .shps related to the implementation of the proposed well field

d. "*Drawdown Scenarios*" (folder)
- contains .shps of the grids of the results of drawdown scenarios

e. "*Appendix19_CreatingGeologicSurfaces*" (folder)
i. "*StratPickPointsByZone*"(folder)
- contains the stratigraphic pick points, split by stratigraphic zone/hydrostratigraphic subdomain, used to make the surfaces in the "*StratPickSurfacesByZone*" folder.
- explanation of naming conventions are included in the "README.txt" file provided in this folder.
ii. *"ST_excluded_pt.shp*" (point shapefile)
- wells with stratigraphic picks that were not used to make the new geologic surfaces in the current report

19.10 GIS file name codes

The following section includes explanations of naming conventions and acronyms used in the GIS data delivery. Most of this information can also be found in the metadata associated with the individual rasters and shapefiles.

1. *.mxd* files and *.png* files

- For clarity, the .mxds are labelled with the corresponding report figure number and a short description of the figure. As an example, "Fig_10_03_Sampled.mxd" is the .mxd corresponding to "Figure 10-3 Sampled water quality values from wells determined to be producing from the Rustler Aquifer" in the report. All .png files are assigned the same name as the corresponding .mxd file.

2. "*ras*" (folder)

- For naming in the raster (ESRI grid) files located in the main "*ras*" folder, we mostly used the acronyms suggested by TWDB BRACS, as given in the following table:

Raster name	Raster description
snap_rust	each raster file developed will be snapped to this grid to ensure every grid cell in all rasters stack on top of each other without any offset
ru_td	depth to the top of the Ruster Fm
ru_bd	depth to the Bottom of the Rustler Formation
ru_tk	thickness of the Rustler Fm
mg_td	depth to the top of the Magenta Dolomite
mg_bd	depth to the bottom of the Magenta Dolomite
mg_tk	thickness of the Magenta Dolomite
cl_td	depth to the top of the Culebra Dolomite
cl_bd	depth to the bottom of the Culebra Dolomite
cl_tk	thickness of the Culebra Dolomite
lm_td	depth to the top of the Los Medaños limestone
lm_bd	depth to the bottom of the Los Medaños limestone
lm_tk	thickness of the Los Medaños limestone
zone_td	depth to the top of the water bearing zone (zone 1 = ru_td, zone 2 = mg_td, zone 3 = cl_td)
zone_bd	depth to the bottom of the water bearing zone (zone 1 = ru_bd, zone 2 = lm_bd, zone 3 = lm_bd)
zone_tk	water bearing zone thickness (zone 1 = ru_tk, zone 2 = mg_tk+cl_tk+lm_tk, zone 3 = cl_tk+lm_tk)
ss_td	depth to the top of the slighty saline Rustler Aquifer groundwater
ss_bd	depth to the bottom of the slighty saline Rustler Aquifer groundwater
ss_tk	thickness of the slighty saline Rustler Aquifer groundwater
ms_td	depth to the top of the moderately saline Rustler Aquifer groundwater
ms_bd	depth to the bottom of the moderately saline Rustler Aquifer groundwater
ms_tk	thickness of the moderately saline Rustler Aquifer groundwater
vs_td	depth to the top of the very saline Rustler Aquifer groundwater
vs_bd	depth to the bottom of the very saline Rustler Aquifer groundwater

vs_tk	thickness of the very saline Rustler Aquifer groundwater
br_td	depth to the top of the brine
2012GAM_demruclip.tif	ground surface elevation raster from the original 2012 Rustler GAM
2012_GAM_RusTop.tif	top of Rustler elevation surface from the original 2012 Rustler GAM.

- "*README.txt*" explains the naming conventions used for the rasters in the "*FinalSurfaces*" and "*StratPickSurfacesByZone*" folders

3. "*shp*" (folder)

- There is no consistent naming convention used for these shapefiles, but titles were made as descriptive as possible.

Raster name	**Raster description**
2012_GAM_GMA_Rustler	TWDB groundwater management areas from the original 2012 Rustler GAM
2012_GAM_Inferred_Faults	assumed extention of an intepreted fault to the edge of the Rustler Aquifer boundary from the original 2012 Rustler GAM
2012_GAM_Mapped_Faults	location of interpreted faults in the Rustler Formation from the original 2012 Rustler GAM
2012_GAM_StructuralSubdomains	Structural subdomains within the Rustler Formation from the original 2012 Rustler GAM
2012_GAM_StructuralSubdomains_Regional	Structural subdomains within the Rustler Formation from the original 2012 Rustler GAM clipped to the area outside the Rustler Aquifer boundary.
2012_GAM_Tessey_Limestone	Tessey Limestone outcrop from the original 2012 Rustler GAM
County_Boundary_GAM	County boundaries for Texas, Oklahoma, Kansas, Colorado and New Mexico
Exclusion_Zones	exclusion zones in the Rustler Formation based on criteria given in House Bill 30
HydroStructuralSubdomains	hydrostructural regions in the Rustler Formation delineated during the current work
ModelGrid_w_Surface_Data_20160727	geologic surface elevation and head values sampled to the model grid.
PPAs	potential production areas (PPAs) in the Rustler formation
Roads_GAM	primary roads in the study area
Rustler_NM_outcrop_GAM	Boundary of the Rustler Formation outcrop in NM from the original 2012 Rustler GAM
Rustler_NM_subcrop_GAM	Boundary of the Rustler Formation subcrop in NM from the original 2012 Rustler GAM
Rustler_outcrop_poly_GAM	extent of the Rustler outcrop in Texas
Rustler_TX_outline_dissolve_GAM	merged extent of the outcrop and subcrop of the Rustler Aquifer in Texas
sb1_reg_dd	TX regional water planning areas
State_Boundary_GAM	State boundary for Texas
Strat_Section_Line	stratigraphic cross-sections (Figures 5-3 and 5-4)

stratigraphy_zones_rust_pg	Rustler stratigraphic zones
StratPicksForInterpolation	well control points used to make the new geologic surfaces in the current report.
Structural_CS_Lines	structural cross-sections (Figures 5-6 to 5-9)
Towns_GAM	StratMap TX city boundaries
TWDB_GCD	Texas groundwater conservation districts (GCD)
Wells_Exclusion_GWDB	wells from the TWDB groundwater well database that fall within the Exclusion zones
Wells_Exclusion_SDR	wells from the TWDB Submitted Drillers Reports well database that fall within the Exclusion zones
Wells_Geophysical_Logs	digitized well logs with stratigraphic picks
Wells_RRC_Injection	injection wells from the Texas Railroad Commission well database
Wells_Sampled_WQ	water quality measurement locations
Wells_Sampled_WQ_Piper_Plots	wells represented in the Piper plot (Figure 10-4)
Wells_Sampled_WQ_USGS_Prod_Fluids	Water quality measurements form USGS Produced Waters database
Wells_Strat_Section	cross-sections wells (Figures 5-3 and 5-4)
Wells_Type_Wells	type wells with well logs (Figure 5-1)
Wells_WQ_POR_CALCS	geophysical well logs used to calculate water quality and porosity values in the Rustler.
WQ_Contours	water quality contours

- "*README.txt*" in the "*Appendix 19_CreatingGeologicSurfaces*" folder explains the naming conventions used for the shapefiles in that folder.

19.11 Responses to TWDB Comments on Draft Report

Identification of Potential Brackish Groundwater Production Areas – Rustler Aquifer
TWDB Contract Number 1600011949

TWDB Comments

General Comments

1. Please consider changing the title of the report to "Identification of Potential Brackish Groundwater Production Areas – Rustler Aquifer".

    1. Done.

2. Please consider adding in the header "Texas Water Development Board Contract Report Number 1600011949".

Done.

3. Please consider removing the word 'proposed' before 'potential production areas'. See page 5 for an example. For House Bill 30, contractors evaluate potential production areas, TWDB staff reviews potential production areas for recommendation, the EA proposes/recommends brackish groundwater production zones, and the Board designates brackish groundwater production zones.

Done.

4. Please consider always referring to the "Rustler" as "Rustler Formation" or "Rustler Aquifer".

Done.

5. Please consider being consistent while referring to areas such as 'potential production areas', 'brackish groundwater production zones', 'hydrostructural subdomains', 'stratigraphy zones', and 'volumetric regions'. It will be less confusing if synonymous terms like 'stratigraphic region' and 'hydrostratigraphic zone' are removed and the logic that hydrostructural subdomains from the GAM were combined with stratigraphy zones to create volumetric regions is followed.

Done.

6. For consistency, please consider using 'project area' instead of the 'study area'.

Done.

7. Please consider labeling county names in a larger font than city names on maps. This is especially helpful when cities and counties have the same name, such as 'Pecos'. See Figure 2-1 for an example.

Because of limited time and resources, we will limit figure changes to changing errors, inconsistencies or because of an intrinsic lack of clarity in presentation.

8. Please consider providing lists in alphanumerical order. For examples, see the list of counties on page 3 and the list of well numbers in Table 13-1 on page 121.

In text we will alphabetize lists. Because of the potential to interject errors by re-ordering large tables we will not make these changes because of limited time and resources. The example will be provided will be done.

9. Please consider using initial capitals only on captions and headers. See Exhibit D of the contract.

Done.

10. Please consider editing for consistency when using hyphens in words, acronyms, and numbers such as cross-section, submember, acre-feet, ohm-meters, water-bearing, mud-filtrate, well field, EZ-5, 42-389-00802 etc.

Done.

11. Please consider using 'submember' instead of 'sub-member units'.

Done.

12. Please be consistent in naming geologic units. Formal units should be capitalized, informal units should not. Examples include always referring to the 'Magenta Dolomite, Culebra Dolomite, and Los Medaños limestones' instead of 'Magenta and Culebra Dolomites and limestones of the Los Medaños Unit' etc. If Los Medaños is a formal member, use 'Member' after the name. If Los Medaños is an informal member, use 'member' or 'limestone of'.

Done.

13. Please consider defining the identification system when using well numbers. As an example, on page 17, insert 'American Petroleum Institute well number' before '42-389-00802' and 'State Well Number' before water well numbers.

Done

14. Please consider adding and reference a regional structures map showing the Northern and Southern Delaware Basin, troughs, and WIPP site.

Because of limited time and resources, we have included a reference to Figures 2.2.1 and 3.0.1 from Ewing and others (2012).

15. Please consider using 'West Texas' instead of 'west Texas'.

Done.

16. Please consider not using abbreviations or acronyms in figures and tables where there is room to spell items out. Also, if an abbreviation is defined in the figure it doesn't have to be defined in the caption. As an example, on page 68 Figure 9-1, there is room to spell out 'PPA' and 'ft/day' in the figure and then the definitions can be removed from the caption and table of contents.

We will delete abbreviations in title where they are defined in the figure. Because of limited time and resources, we will not edit every figure to rid them of acronyms.

17. Please consider using 'Groundwater Database' instead of GWDB.

Done.

18. Please consider not capitalizing 'Resistivity' and 'Specific Conductance' for consistency.

Done.

19. Please use subscripts consistently, especially for equation variables.

Done.

20. Please consider formatting all names in Section 18 References like the following example: Smith, J.J.,

Done.

21. Please consider ending all references in Section 18 with a period.

Done.

22. Please consider spelling out 'Texas' instead of using 'TX' in Section 18.

Done.

23. Please consider spelling out 'TWDB' as "Texas Water Development Board (TWDB)' in Section 18.

Done.

24. Please consider adding a table of Geographic information system dataset to the Appendices as noted in Exhibit H of the contract.

Done.

25. Please consider adding a table of GIS file code names to the Appendices as noted in Exhibit H of the contract.

Done.

26. Please use the official name of Railroad Commission of Texas throughout the report.

Done.

Specific Comments

2.

1. Page v. Figure 12-2: Please consider removing the website citation in title and replacing with (author, year). Please add the reference to Section 18.

Done.

2. Page vi. Figure 13-11: Please consider changing acronyms and unbold in the title.

Done.

3. Page vi. Figure 14-1: Please consider removing acronyms from title and defining them in the key. This comment applies to Figures 14-1 to 14-21.

Moved acronyms down to note under each figure caption. Defining them in the key would require redoing figures and add clutter.

4. Page vii. Table 9-2: Please consider removing acronyms from the title and adding them as notes at the bottom of table.

There are no acronyms in the table title.

5. Page vii. Table 9-3: Please check citation in the title. The reference section lists Baumgarner and other, 2012. Please correct citation throughout report. Please consider changing citation format to "(author, year)"in title of the Table.

The correct citation should be Clark and others (2014). Reference will be changed and text will be corrected.

6. Page 1. Second paragraph, line two: Please consider changing the sentence to, "…and to evaluate potential production areas that TWDB staff can use to make recommendations to the Executive Administrator and Board on designation of brackish groundwater production zones".

Done. Added to end of third sentence, as line two did not have appropriate place for it.

7. Page 1. Third paragraph, last line: Please consider changing the sentence to, "This information has been integrated to evaluate potential production areas for consideration by the Board for formal designation as brackish groundwater production zones."

Done.

8. Page 2. First paragraph, third sentence: Please consider adding "in Texas" at the end.

Done.

9. Page 2. First paragraph, last line: Please explain why groundwater in the Rustler Aquifer is likely uneconomical to produce. Much of the groundwater in the Rustler Aquifer is slightly saline, which is typical of raw water being treated in existing desalination facilities.

Addressed this comment with, "Due to unpredictable and generally low production rates within the Rustler Aquifer, the vast majority of the groundwater volume in the Rustler Aquifer would likely be uneconomical to produce."

10. Page 2. Second paragraph, line two: Please consider replacing the word "proposed" with "evaluated".

Done.

11. Page 2. Second paragraph, last sentence: Please consider changing the sentence to, "The TWDB staff will take the results from this study and consider recommending potential production areas to be designated to brackish groundwater production zones by the Board."

Done.

12. Page 3. Section 2: Please apply similar changes in language to opening paragraphs in the introduction. The contractor evaluates potential production areas, TWDB staff recommends brackish groundwater production zones, the Executive Administrator recommends, and the Board designates them.

Replaced first sentence with, "The objective of this study is to characterize the quantity and quality of groundwater within the Rustler Aquifer and to evaluate potential production areas that can be used by TWDB staff to recommend brackish groundwater production zones. From there the Executive Administrator will make recommendations and the Board will designate the brackish groundwater production zones for the Rustler Aquifer."

13. Page 3. First paragraph: Please consider deleting it since it is the same as the first paragraph in the Executive summary.

Done.

14. Page 3. Fourth paragraph, second to last sentence: Please consider deleting it since it was already stated in the third paragraph on this page.

Done. Note this is now the third paragraph, as the first paragraph was deleted at TWDB's request (see item 12).

15. Page 6. Table 2-1: Nice table. Please consider replacing 'Chapter 27' with 'Title 2, Texas Water Code, Chapter 27'.

Done.

16. Page 7. Figure 2-1: Please consider adding the boundary of the project area restricted to the Rustler Aquifer in Texas.

The boundary for the entire TWDB designated Rustler Aquifer was preferred because it relays aquifer geometry with respect to recharge areas, regardless of their location. The reader is reminded several times that the quantifications of brackish groundwater volumes are specifically for Texas.

17. Page 7. Figure 2-1: Please consider citing the source for the Tessey Limestone Outcrop.

Done.

18. Page 8. Figure 2-2: Please change 'Strat' to 'Stratigraphic'

Done.

19. Page 8. Figure 2-2: Please consider adding the gypsiferous part of the Magenta mentioned on page 114.

This is a generalized stratigraphic column and was taken from a referenced report (Powers, 2008).

20. Page 8. Figure 2-2: Please consider adding Los Medaños subdivisions mentioned on page 195 in the Appendix. This would include upper, middle, limestones, and lower.

This is a generalized stratigraphic column taken from a referenced report. Added reference to the report.

21. Page 9. First paragraph, line two: Please consider changing "(.LAS) and .tif" to "Log ASCII Standard and Tagged Image File Format (.LAS and .tif)".

Done.

22. Page 9. First paragraph, last sentence: Please change 'BRACS Group' to 'TWDB'.

Done.

23. Page 11. First paragraph, fifth sentence: Please change the reference to 'Figure 1-1' to 'Figure 2-1'.

Done.

24. Page 11. First paragraph, fifth sentence: Please consider mentioning the Tessey Limestone in Figure 2-1 along with the outcrop and subcrop of the Rustler Formation.

Added sentence: "In addition, outcrops of the Tessey Limestone are also shown as it is suspected these outcrops act as a concentrated recharge area similar to the Rustler Formation outcrop."

25. Page 11. Second paragraph, second sentence: Please alphabetize the list of groundwater districts, and remove Culberson County Groundwater Conservation District and include Reeves County Groundwater Conservation District.

Done.

26. Page 11. Second paragraph, second sentence: Please change first reference to 'Figure 4-2' to 'Figure 4-1'

Done.

27. Page 11. Second paragraph, second to last sentence: Please consider referring to 'Far West Texas' as 'Far West Texas (E)' to match how it is referred to in the 2017 State Water Plan.

Done.

28. Pages 12-14. Figures 4-1, 4-2, and 4-3: Please consider matching the line width of the aquifer boundary in the match to the line width in the legend.

Because of limited time and resources, we will limit figure changes to changing errors, inconsistencies or because of an intrinsic lack of clarity in presentation. We did not make this recommended edit.

29. Page 12. Figure 4-1: Please add (GCD) and (UWCD) to the caption they are used in the map.

Done.

30. Page 13. Figure 4-2: Please add (GMA) to the caption since it is used in the map.

Done.

31. Page 14. Figure 4-3: Please consider using more contrasting colors to symbolize Region E and Region F and providing those symbols in the legend.

Because of limited time and resources, we will limit figure changes to changing errors, inconsistencies or because of an intrinsic lack of clarity in presentation. We did not make this recommended edit.

32. Page 14. Figure 4-3: Please consider referring to 'Far West Texas' as 'Far West Texas (E)' to match how it is referred to in the 2017 State Water Plan.

Because of limited time and resources, we will limit figure changes to changing errors, inconsistencies or because of an intrinsic lack of clarity in presentation. We did not make this recommended edit.

33. Page 15. First paragraph, last sentence: Please change the reference 'Figure 2-1' to 'Figure 2-2'.

Done.

34. Page 15. Second paragraph, second sentence: Please change the reference 'Figure 2-2' to 'Figure 2-1'.

Done.

35. Page 15. Third paragraph, second sentence: Consider changing '.tif' to 'Tagged Image File Format (TIFF)'.

Done.

36. Page 15. Fourth paragraph, second sentence: Consider inserting a reference to Figure 5-5 at the end.

Done.

37. Page 15. Fourth paragraph, last sentence: Consider changing 'hydrostructural subdomains' into 'project area into stratigraphy zones'.

Done.

38. Page 16. Second paragraph, last sentence: Please consider rewriting the sentence about stratigraphic mode to be more readable.

Done.

39. Page 16. Third paragraph, last sentence: Please consider adding (Figure 5-10) at the end of the sentence about Zone 3.

This comment was not accepted to prevent referencing out of sequence.

40. Page 18. Fourth paragraph, last sentence: Please consider rewriting the sentence about 'freshening' to be clearer.

Changed sentence to: "Each of these beds represents a regional freshening of the paleo-depositional environment that contrasts with the paleo-depositional environment of underlying beds."

41. Page 19. Section 5.1.2, first paragraph: Please consider inserting a reference to Figure 5-2 or a regional structure map at the end of the paragraph.

Done.

42. Page 19. Last paragraph, second sentence: Please change '(Figure 2-1)' to '(Figure 2-2)'.

There is no reference to Figure 2-1 in this paragraph.

43. Page 21. Cross-Section 1-1, first paragraph: Please consider rewriting this paragraph to reflect the location of Cross-section 1-1' instead of Cross-section 0-0'.

Done.

44. Page 22. First paragraph, last sentence: Please change the vertical exaggeration value to 70 to match the value for Cross-section A-A'.

Done.

45. Page 23. Section 5.2, paragraph 3: Please consider rewriting this paragraph for readability and consistency in area terms such as subdomain, zone, and region.

Done.

46. Page 24. First full sentence: Please replace 'if' with 'of'.

Done.

47. Page 25. Last paragraph, second sentence: Please consider adding (Zone 2 in Figure 5-10) at the end of the sentence.

Done.

48. Page 26. Figure 5-1: Please correct the spelling of 'Culebra Colomite'.

Done.

49. Page 26. Figure 5-1: Please consider adding tool type and scales.

Added text to the Figure caption to explain log types

50. Page 26. Figure 5-1: Please consider adding 'American Petroleum Institute well number'.

Done.

51. Page 27. Figure 5-2: Please consider changing the well number labels to match the hyphenated format used in the report.

Because of limited time and resources, we will limit figure changes to changing errors, inconsistencies or because of an intrinsic lack of clarity in presentation. We did not make this recommended edit.

52. Page 27. Figure 5-2.: Please consider changing the figure caption to 'Stratigraphic cross-sections and type wells used to guide stratigraphy and lithology interpretations map.'

Done.

53. Page 27. Figure 5-2: Please consider changing 'Type Well' to 'Figure 5-1 type wells' in the legend.

Because of limited time and resources, we will limit figure changes to changing errors, inconsistencies or because of an intrinsic lack of clarity in presentation. We did not make this recommended edit.

54. Page 27, 30, 35-41, and 46-55. Figures 5-2, 5-5, 5-10 thru 5-16, and 6-1 thru 6-10: Please consider showing either the hydrostructural subdomains or volumetric regions, adding the corresponding symbol to the legend, and corresponding labels to the map. Currently the red

boundaries look to be volumetric regions but the labels are hydrostructural subdomains.

Done.

55. Page 28. Figure 5-3: Please consider adding large 'P1' and 'P1'' labels.

Because of limited time and resources, we will limit figure changes to changing errors, inconsistencies or because of an intrinsic lack of clarity in presentation. We did not make this recommended edit.

56. Page 29. Figure 5-4: Please consider adding large 'P' and 'P'' labels.

Because of limited time and resources, we will limit figure changes to changing errors, inconsistencies or because of an intrinsic lack of clarity in presentation. We did not make this recommended edit.

57. Page 30, Figure 5-5. Please consider changing the caption to 'Structural cross-sections and type wells map.'

Done.

58. Page 30. Figure 5-5: Please consider changing 'Cross Section' to 'cross-section' in the legend.

Done.

59. Page 31-34. Figure 5-6 thru 5-9: On the vertical scale label please consider changing 'Depth' to 'Elevation (feet)' to match the values displaced.

Subsea Depth is a specific term used to represent elevation. Additionally, descending values from top to bottom clearly convey elevation as opposed to depth from ground surface.

60. Page 31-34. Figure 5-6 thru 5-9: Please consider enlarging the labels '0' and '0'' etc.

Because of limited time and resources, we will limit figure changes to changing errors, inconsistencies or because of an intrinsic lack of clarity in presentation. We did not make this recommended edit.

61. Page 31-34. Figure 5-6 thru 5-9: Please consider showing the cross-section line on the location map.

Because of limited time and resources, we will limit figure changes to changing errors, inconsistencies or because of an intrinsic lack of clarity in presentation. We did not make this recommended edit.

62. Page 33. Figure 5-8: Please consider labeling the stratigraphic picks in the lower left corner "Delaware Mountain Group'.

Because of limited time and resources, we will limit figure changes to changing errors, inconsistencies or because of an intrinsic lack of clarity in presentation. We did not make this recommended edit.

63. Page 35. Figure 5-10: In the legend, please consider changing 'Hydrogeologic Boundary' to 'Hydrostructural subdomains', grouping the zones under the title 'Stratigraphy zones' for consistency in the report.

Done.

64. Page 37. Figure 5-12: Thank you for providing a depth map.

No change required.

65. Page 38. Figure 5-13: Please fix the outcrop in New Mexico with thickness >1,000 feet, if this is an error.

Done., only posted data that is in the main extent of the Rustler Aquifer.

66. Page 43. Second paragraph, third sentence: Please consider providing a well number with the value of 18,416. Also, if this is an error please change it to 20,372 and reference Figure 6-1.

Done.

67. Page 45. Please consider adding the header '6.4 Brine' followed by the text explaining why brine was not mapped in the project area.

Done.

68. Page 47-55. Figures 6-2 thru 6-10: Please consider changing 'HydroStructural Region' to 'Hydrostructural subdomain'

Done.

69. Page 61. Second to last sentence: Please consider changing ".LAS" to "Log ASCII Standard (.LAS)".

Done.

70. Page 64. First paragraph, last sentence: Please consider adding 'map in Figure 14-1'.

This comment was not accepted to prevent referencing out of sequence.

71. Page 64. Second paragraph, first sentence: Please consider dividing this sentence into two sentences to improve readability.

Done.

72. Page 66. Table 9-1: Please consider adding (PPA) to the end of the caption since that

abbreviation is used in the table.

Done.

73. Page 68-70. Figure 9-1 to 9-5: Please consider removing "(feet per day)" and "Ft/day stands for feet per day" in titles and define in the graph. Please consider spelling out PPA in title and removing "PPA stands for potential production area".

Did not make the edits to the figure but addressed acronyms in the caption.

74. Page 71. First paragraph, seventh sentence: Please consider changing 'quality assurance/quality control' to 'assure the quality of'.

Done.

75. Page 73 Second paragraph, second sentence: Please consider referencing Figure 13-1.

This comment was not accepted to prevent referencing out of sequence.

76. Page 73. Second paragraph, third sentence: Please consider adding Chart Gen-6 as a figure and referencing it.

Not considered a critical enough step to have a stand along figure. We request to not address this comment as this is a standard Schlumberger General Chart for well interpretation.

77. Page 73. Third paragraph, sixth sentence: Please change 'Figure 10-2' to 'Figure 10-3'.

Done.

78. Page 73. Third paragraph, seventh sentence: Please consider reformatting '(Blondes, et.al. (2016))'and providing the citation in Section 18.

Changed to "Blondes and others, 2016" based on TWDB preference and added to reference list.

79. Page 74. Second paragraph, first sentence: Please consider changing the reference to Appendix 19-3 to 19-4.

Done.

80. Page 74. Last sentence: Please change the list of elements to lowercase.

Done.

81. Page 76. Last paragraph, first sentence: Please consider changing the words 'Outcrop' and 'Subcrop' to lowercase.

Done.

82. Pages 78-80. Table 10-1 and 10-2: Please consider moving the section headers General and physical parameters, Cations, Anions, Radionuclides, and Other to the left side, similar to

the text 30 Years and 50 Year on page 150, Table 14-10.

Done.

83. Page 81. Figure 10-1: Please consider changing the color of the USGS marker to be different than the Published Report marker.

Because of limited time and resources, we will limit figure changes to changing errors, inconsistencies or because of an intrinsic lack of clarity in presentation. We did not make this recommended edit.

84. Page 81. Figure 10-1: Please consider adding the quantity of markers to the label for each source. For example 'BRACS (5)'.

These numbers are readily accessible from tables provided in the report.

85. Page 81. Figure 10-1: Please consider spelling out 'BRACS' and 'GWDB' out in the legend, providing citations, or adding the definitions to the caption.

Done. in note under figure.

86. Page 84. Figure 10-4: Thank you for labeling the Population 1 and Population 2 clusters mentioned in section 10.1 on this diagram.

No change required.

87. Page 85. Thank you for explaining why this study doesn't have a net sand analysis.

No change required.

88. Page 87. Last paragraph, third sentence: Please consider inserting ', the Tessey Limestone,' after the word 'equivalent'.

Done.

89. Page 88. Equations 12-1a through 12-4: Please consider rewriting and formatting these equations to better indicate variable substitutions and which equations are the same but with variable substitutes.

Not sure what is being asked here. However, the equations seem pretty straightforward and concise. Request not to address comment.

90. Page 89. variable list: Please consider changing Sy and Ss to S_y and S_s.

Done.

91. Page 89. Fifth paragraph: Please consider deleting the sentence 'The water level that will be used in the calculations of groundwater volumes will be those produced by the Groundwater Availability Model for the end of 1998, which is the last year of the model calibration period.' The concept is already mentioned earlier on the page under 'Rustler

Aquifer Water Level' and it uses the wrong calibration year.

Done.

92. Page 89. Last paragraph: Please consider rewriting to include reference to Figure 14-8 and the area labeled as "Outside GAM" and explain why this area is outside the GAM.

Added to the first sentence, "There are portions of the Rustler Aquifer in Brewster, Jeff Davis and Pecos counties that are not included in the Groundwater Availability Model area in Groundwater Management Area 4 and 7 (see Boghici and others, 2014; Jones and others, 2013; and Figure 14-8 of this report)."

93. Page 90. First paragraph, second sentence: Please add the word 'in' after 'differences'.

Done.

94. Page 90. First paragraph, second sentence: Please explain if the values were greater or less than Total Estimated Recoverable Storage.

The text explains that our numbers are higher in regions that include areas outside of the GAM.

95. Page 90. First paragraph, last sentence: Please consider replacing 'round off' with 'rounding error.'

Done.

96. Page 92. Table 12-1: Please consider adding Brine and coloring the rows by salinity class. Fresh blue (142,180,227), Slightly saline yellow (255,255,204), Moderately saline orange (255,213,181), Very saline red (230,185,184), Brine purple (179,162,199). Parenthesis values are Red, Green, Blue color values.

That would not be consistent with our other table formats. We would request not to have to do this edit.

97. Pages 92-97. Please swap the headers for moderately and slightly saline so the values are correct.

Done.

98. Page 92-97. Tables 12-1 to 12-5: Please consider adding a brine category to all tables in Section 12.

Substantial effort considering that section 6.4 specifically addresses that there is no brine mapped in the study area. Due to limited time, request not to address comment.

99. Page 94, Table 12-3: Please consider deleting the Grand Total section since those numbers are already in Figure 12-2.

Done.

100. Page 96, Table 12-4: Please consider deleting the Grand Total section since those numbers are already in Figure 12-2.

Done.

101. Page 98, Figure 12-2: Please consider changing the web address in the caption to a citation and add the reference to Section 18 References.

Done.

102. Page 99. First paragraph: This is well written, thank you.

No change required.

103. Page 99. First paragraph: Reference is made to the geologists at the Railroad Commission of Texas not having an aquifer-wide paradigm for the Rustler Aquifer. This statement is correct. Please consider adding a sentence that the Railroad Commission of Texas staff implemented an aquifer-wide protection for the Rustler Aquifer when proposing surface casing recommendations (please confirm this with GAU staff). This is in part due to a general lack of log data that can be used, but also due in part to the complexity of the evaluations.

New sentence: "Geologists in the Groundwater Advisory Unit at the Railroad Commission of Texas have developed some techniques (personal communication, March 2016); however, they have not been shared in a citable or widely distributed format that could have been applied to this study."

104. Page 99. Last paragraph, first sentence: Please consider replacing 'previous sections' with 'in Sections 5 and 10'.

Done.

105. Page 101, 102, and 108. Section 13: Reference is made to geothermal gradient calculations that account for drilling mud temperatures. It is assumed that the drilling mud thermal gradient is what is needed in these calculations as opposed to true geothermal gradient. Please consider modifying this section to clarify this point.

Done.

106. Page 102. Second paragraph, fifth sentence. Please consider correcting the reference to Figure 5-7 to the correct plot. Figure 5-7 is a cross section.

Made correct reference

107. Page 102. Last paragraph, second sentence: Please consider replacing '3 in petrophysical wells in Appendix 19-5' with '3 in the 'Petrophysical wells' field in Appendix 19-5'.

Done.

108. Page 103, Third paragraph, second sentence: Please consider providing a citation and reference for (UTAPWeLS).

No specific reference exists for this.

109. Page 105. Volume of Shale paragraph, second sentence. Please replace 'phosphate' with 'potassium' here and for bullet 2 under this section and on page 120 in the second paragraph in the 5th sentence.

Done.

110. Page 106. Subsection 13.3.2: Please consider changing ".LAS" to "Log ASCII Standard (.LAS)" in the title and the first time it is used in the section.

Done.

111. Page 107. Subsection 13.3.4, third paragraph last word: Please consider changing 'formation' to 'the Magenta Dolomite, Culebra Dolomite, and Los Medaños limestones'.

Done.

112. Page 108. Subsection 13.3.5, first sentence: Please change the number '25' to '26'.

Done.

113. Page 108. Equation 13-6: This equation is the same as 13-4. Please consider changing the label from '13-6' to '13-4'.

While we see the merit in this, it would cause a significant follow up effect on our numbering and referencing. Request to leave as is.

114. Page 109. Fourth paragraph, first sentence: Please consider adding the described figure and changing 'Figure 13-6' to the reference the new figure.

Done., deleted figure reference as it was referencing the wrong figure.

115. Page 112. Second paragraph. Please change 'form' to 'from'.

Done.

116. Page 112. Table at the bottom: Please consider adding a table number and caption to this table.

While this information is presented in tabular format, we believe it would break the flow of the methodology discussion to move the information back to the tables. Please consider not making this change. We will also modify the text to not refer to it as a table.

117. Page 112. Last sentence: Please consider adding 'limestone' after the second reference to '32-inch'.

Done.

118. Page 116. Equation 13-17: This equation is the same as 13-15. Please change the label from 13-17 to 13-15.

While we see the merit in this, it would cause a significant follow up effect on our numbering and referencing. Request to leave as is

119. Page 119. Second paragraph, sixth sentence: Please consider changing ‘32”LS’ to ‘32-inch limestone’.

Done.

120. Page 119. Third paragraph, first sentence. Please consider adding ‘in parts per million’ at the end of the sentence.

Done.

121. Page 119. Fourth paragraph, fifth sentence. Please add ‘the’ before ‘suspected collapse zone’.

Done.

122. Page 121. Table 13-1: Please consider sorting the well identification numbers in ascending order.

Done.

123. Page 122. Table 13-2: Please consider explaining why 11 key wells didn’t have total dissolved solids calculated and sort the well identification numbers in ascending order.

Added sentence: “Calculations were made on all but 11 of the key wells due to availability of quality resistivity/induction log signature in those wells.”

124. Page 125. Figure 13-3: Great example. Please consider providing the well identification number.

Have requested additional detail on this from CTV

125. Page 126. Figure 13-4: Please consider providing the well identification number.

Done.

126. Page 134. Figure13-12: Please consider providing the well identification number.

This is meant to be an example of the process and could represent any of the normalized logs during the normalization process. The API number is immaterial to the chart.

127. Page 135. First paragraph, first sentence: Please consider rewriting this sentence for readability.

Done.

128. Page 135. Third paragraph, first sentence: Please consider deleting it since the jurisdictions are not defined above.

Done.

129. Page 135. Last paragraph: Table 14-1 is the same as Table 2-1. Please consider removing table 14-1 and just referencing Table 2-1.

While it is correct that this table is reproduced, because of its importance we believe it is of merit to reproduce it in Section 14.

130. Page 137. First sentence: Please consider replacing 'Chapter 27' with 'Title 2, Texas Water Code, Chapter 27'.

Done.

131. Page 137. Fourth paragraph, last sentence: Please consider adding 'PPA 4 and' after 'In' and before 'PPA 5'.

Done.

132. Page 137. Fourth paragraph, last sentence: Please consider replacing 'Formation' with 'Limestone'.

Done.

133. Page 137. Section 14.2.1: Please consider clarifying that the model simulations were not based on the current GAM model for the Rustler Aquifer but a predecessor that is slightly different because it doesn't include three wells. These three wells were added by INTERA after TWDB noticed field data at these locations showed downward hydraulic gradient. Without these three wells the modeled water levels at/around the wells were much higher. For example, when the initial head from their model under Q:\rustler\model_files\TWDB_Rustler_Brackish_ConstQ\Scen5_Kv_low from the MODFLOW BAS package is compared them with the 2008 head values from the GAM, and the head value difference between these two models could be very large. This pumping difference may not impact the general conclusion in the report since a superimposed approach was used. However, it needs to mention how the model used was different than the model currently being used by the Groundwater Availability Modeling Section.

This text will be included and the reviewers are correct that the minor difference between the GAM file used (delivered as an alternative model) and the currently used GAM model file has no impact on the results because of the approach used and the differences between the model files.

134. Page141. First paragraph, third sentence: Please consider correcting "NM" to "NA*" or changing the NA* in Table 14-11 to NM and define it.

Defined "NA" in Table 14-11 as "Not Applicable." "NM" is for the state "New Mexico," and is defined in text and tables where it appears.

135. Page 141. Last paragraph: Thank you for adding the 3 well array simulations and tables and writing about them.

No change required.

136. Page 142. Second paragraph: Please consider adding 'Performing pump tests on either side of these barriers with monitoring wells would better quantify this effect.' as the last sentence.

Done.

137. Page 142. Second paragraph, second to last sentence: Please change the reference to 'well field 2' to 'well field 3-2' to match the labeling on Figures 14-20 and 14-21.

Done.

138. Page 143. Table 14-1: Please consider deleting this table and just referencing Table 2-1.

We request to be able to keep this table in here because it is useful for the reader to not have to flip all the way back to table 2-1

139. Page 145. Table 14-5: Please consider adding a total number of well fields at the bottom showing the total under of the wells at the bottom.

Done.

140. Page 147. Table 14-7: Please consider changing 1x1# values to 1x10# values.

Done.

141. Page 151. Table 14-11: Please consider defining NA* or replacing it with "NM" and a definition.

Please see response to #134.

142. Pages 152-155. Tables 14-12, 14-13, and 14-15: Please consider dividing and labeling these tables with "30 year" and "50 year" like Table 14-14 on page 154.

Done.

143. Pages 160-166. Figures 14-1 through 14-7: Please change the exclusion zone labels from "E" to "EZ" to match the text of the report.

Done.

144. Pages 160-166. Figures 14-1 through 14-7: Please consider changing the labels potential production areas from "PPA-" to "PPA" to match the text in the report.

Done.

145. Pages 160-166. Figures 14-1 through 14-7: Please consider changing the symbol for potential production zones in the legend to match the lines displayed on the maps.

Because of limited time and resources, we will limit figure changes to changing errors, inconsistencies or because of an intrinsic lack of clarity in presentation. We did not make this recommended edit.

146. Pages 160-166. Figures 14-1 through 14-7: Please consider changing the Reported Water Use symbols to match the size displayed on the maps.

Because of limited time and resources, we will limit figure changes to changing errors, inconsistencies or because of an intrinsic lack of clarity in presentation. We did not make this recommended edit.

147. Page 167-180. Figure 14-8 through 14-21: Please consider labeling 'Well field' as 'Hypothetical well field' in the legend for these maps.

Done.

148. Page 167-180. Figure 14-8 through 14-21: Please consider labeling 'Exclusion Zones' as 'Exclusion Zones (EZ)' in the legends so it doesn't have to be defined in the captions.

Done.

149. Page 167-180. Figure 14-8 through 14-21: Please consider labeling 'Area outside GAM' as 'Outside Groundwater Availability Model (GAM)' in the legends so it doesn't have to be defined in the captions.

Because of limited time and resources, we will limit figure changes to changing errors, inconsistencies or because of an intrinsic lack of clarity in presentation. We did not make this recommended edit.

150. Page 167-180. Figure 14-8 through 14-21: Please consider using the same drawdown color scale and values for all of the maps so it is easier to compare relative impacts.

We chose to use a scale that the reader could use to quantify impacts and left the tables for comparisons of magnitude of impact.

151. Page 168-180. Figure 14-9 through 14-21: Please consider adding '50 years pumping" to the captions.

Done.

152. Page 168-180. Figure 14-9 through 14-21: Please consider spelling out 'feet' in the legend so you don't have to define 'ft' in the caption.

Done.

153. Page 168-180. Figure 14-9 through 14-21: Please consider changing the reference to well field numbers in the captions and legends to match the labels on the maps. As an example, "well field 3" would become "well field 1-3" on page 170.

Done.

154. Page 181. First paragraph, first sentence: Please consider rewriting it as 'This project has been funded by and completed for TWDB's Innovative Water Technologies Section to support the Brackish Resources Aquifer Characterization System Program.'

Done.

155. Page 181, first paragraph, last sentence. Please consider rewriting it as "Our list of potential future improvements focuses both on the larger mission of the Brackish Resources Aquifer Characterization System Program and further study in the Rustler Aquifer."

Done.

156. Page 181. Third bullet: Please consider providing specific examples of tests that TWDB or the public can conduct to obtain good hydrogeological data.

Considered beyond scope.

157. Page 181. Third bullet: Please consider providing specific examples of how the groundwater availability models can be improved.

See Ewing and others (2012).

158. Page 182. First bullet, first sentence: Please consider changing it to "We recommend that the Brackish Resources Aquifer Characterization System Program expand their data management system and software to work more closely with modern petrophysics work flows and modern log suites."

Done.

159. Page 182. First bullet: Please consider consistently referring to BRACS as "Brackish Resources Aquifer Characterization System Program".

Done.

160. Page 182. First bullet: Please consider changing ".LAS" to "Log ASCII Standard (.LAS)".

Done.

161. Page 183. First paragraph, last sentence: Please insert "with" between "conflict" and "fresh".

Done.

162. Page 183. First paragraph, fourth sentence: Please consider inserting "groundwater" at the

end of the sentence.

Done.

163. Page 183. Second paragraph, last sentence: Please consider replacing it with "The objective of this study is to characterize the quantity and quality of groundwater within the Rustler Aquifer, evaluate potential production areas, and model 30 and 50 year pumping in those areas. This information can be used by TWDB staff to make recommendations to the Executive Administrator and the Board on designation of brackish groundwater production zones. The designated brackish groundwater production zones will be included in the biennial desalination report which is due to the Texas Legislature by December 1, 2016."

Done.

164. Page 183. Second bullet, last sentence: Please consider changing to "The hydrostructural subdomains defined by Ewing and others (2012) were divided to include three stratigraphy zones in the project area."

Done.

165. Page 183. Third bullet: Please change "derives" to "derive".

Done.

166. Page 184. First bullet, first sentence: Please consider changing it to "Volumes of groundwater in place were calculated by salinity class (Winslow and Kister, 1956) for four Rustler Aquifer units: collapse areas, the Magenta Dolomite, the Culebra Dolomite, and the Los Medaños limestones."

Done.

167. Page 184. Second bullet: Please consider rewriting it as "Based upon the criteria in House Bill 30, five potential production areas were defined in this study. Nearly the entire Rustler Aquifer is brackish groundwater with total dissolved solids concentrations in excess of 1,000 milligrams per liter. Therefore the primary House Bill 30 exclusion metric was existing use based on known domestic, irrigation, and stock wells completed in the Rustler Aquifer. There are no known municipality wells completed in the Rustler Aquifer that are currently in use. Six exclusion zones were delineated within the project area using this information."

Done.

168. Page 184. Third bullet, last sentence: Please consider rewriting this sentence as "The Rustler Aquifer Groundwater Availability Model was used as the modeling tool because it includes complex fault hydraulic boundaries. Also, for this project the hydrostratigraphy was too complex to create a new model in the time available."

Done.

169. Page 184. Third bullet, first subbullet: Please consider rewriting the sentence as "Eleven well fields comprised of nine wells in a linear array were distributed across the potential production areas and pumping was restricted to 50 percent of available drawdown at the well field."

Done.

170. Page 184. Third bullet, third subbullet, first sentence: Please change "potential brackish production zones" to "potential production areas."

Done.

171. Page 184. Third bullet, third subbullet: Please change "scenarios." to "scenario".

Done.

172. Page 184. Third bullet, fourth subbullet: Please consider changing it to "Nearly all 50 year impacts to protected wells was minimal and below 10 feet. The maximum 50 year drawdown at a protected well was 32 feet in Exclusion Zone 2."

Done.

173. Page 184. Third bullet, fifth subbullet: Please consider changing it to "Modeling presented provides a good basis for the TWDB to designate brackish groundwater production zones. However, the approach used to assess potential impacts is inherently non-unique because it used hypothetical well fields, arrays, locations, and pumping rates."

Done.

174. Page 184. Fourth bullet: Please consider rewriting it as "The ranking of potential production areas from high to low potential productivity is: Potential Production Area 5, Potential Production Area 4, Potential Production Area 3, Potential Production Area 1, and Potential Production Area 2."

Done.

175. Page 185. last sentence: Please consider replacing "TWDB" with "TWDB staff", "state legislature" to "Board", and inserting the word "groundwater" between "brackish" and "production".

Done.

176. Page 187. Section 17: Thank you for your acknowledgement! Please remove the word "out" from following "thank".

Done.

177. Page 187. Section 17: Please consider referring to Andrea Croskrey as a "Contract Manager" and referring to Dr. Jerry Shi as being in the "Groundwater Availability Modeling Section".

Done.

178. Page 189. Boghici and others, 2014: Please change the reference to "Boghici, R., Jones, I.C., Bradley, R.G., Shi, J., Goswami, R.R., Thorkildsen, D. and Backhouse, S., 2014, GAM Task 13-028: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area-4, Prepared by the Texas Water Development Board (TWDB), January 15th, 2014, 33 p."

Done.

179. Page 190. Eager, 1983: Please consider deleting this from the end of the reference "Estepp, J., 1998, Evaluation of ground-water quality using geophysical logs: Texas Natural Resource Conservation Commission, unpublished report, 516 p."

Done.

180. Page 190. Estepp, 2016: Please consider removing this reference and just noting the month, day, and year when this communication happened in the text of the report. For example "J. Smith proudly stated that fruity candy is much better than chocolate (personal communication, October 10, 2010)."

Done.

181. Page 191. Holt and Powers, 1988: Please consider deleting the last comma in this reference.

Done.

182. Page 192. Ortega and others, 2015: Please consider fixing the misplaced carriage return between logging-while drilling and thermal-neutron.

Done.

183. Page 194. TWDB, 2012: Please consider rewriting the reference as "TWDB (Texas Water Development Board), 2012, Water for Texas 2012: Volume 1: Texas Water Development Board, 392 p."

Done.

184. Page 195. Second paragraph, first sentence: Please change "Figure 2-1" to "Figure 2-2".

Done.

185. Page 195. Last sentence: Please change "Figure 4-10" to "Figure 5-10".

Done.

186. Page 196. First paragraph: Please consider rewriting this to use terminology consistent with the rest of the report such as hydrostructural subdomains, stratigraphic zones, and volumetric regions.

Done.

187. Page 196. Second paragraph, second sentence: Please change “had” to “hand”.

Done.

188. Page 197. Second to last paragraph: Please consider adding reference to stratigraphy zones 2 and 3.

Done.

189. Page 199. Second paragraph: Please consider adding a figure to help explain these offsets and adjustments.

Because of limited time and resources, we will limit figure changes to changing errors, inconsistencies or because of an intrinsic lack of clarity in presentation. We did not make this recommended edit.

190. Page 201. Table 19-1: Please consider rewriting the notes below the table to use terminology consistent with the rest of the report.

Done.

191. Page 202. Figure 19-1: Please consider writing the column labels as “Zone 1 (collapsed)” and adding “for the creation of stratigraphy zones and volumetric regions” to the caption.

Because of limited time and resources, we will limit figure changes to changing errors, inconsistencies or because of an intrinsic lack of clarity in presentation. We did not make this recommended edit.

192. Page 203. Figure 19-2: Please consider adding a boundary line between regions 8_2 and 9_2.

We removed the boundary in the Hydrostructural Subdomain. The boundary is represented in the 2012 GAM structural subdomain and we removed the label 8_2

193. Page 203. Figure 19-2: Please consider editing the layer names and caption to use terminology consistent with the rest of the report. Adding fill patterns for the stratigraphy zones may help.

Because of limited time and resources, we will limit figure changes to changing errors, inconsistencies or because of an intrinsic lack of clarity in presentation. We did not make this recommended edit.

194. Page 204. Figure 19.1.3: Please change the figure reference number to 19-3.

Done.

195. Page 204. Figure 19.1.3. Please consider labeling the volumetric regions since one is

referenced in the caption.

Because of limited time and resources, we will limit figure changes to changing errors, inconsistencies or because of an intrinsic lack of clarity in presentation. We did not make this recommended edit.

196. Page 204. Figure 19.1.3: Please consider changing the point symbology or labeling in the legend to better indicate wells excluded from interpolation.

It is assumed that the reader understands that if a pick is missing that well is not part of the interpolation of said unit. Request that comment is not addressed

197. Page 204. Figure 19.1.3: Please consider changing the caption to exclude the comment about 4_3 since there are no pink circles in that region on this map.

Done.

198. Page 205. Please remember to apply changes to oversized cross-sections and include them in the final report.

No change at moment.

199. Pages 231-238. Table A-19-4: Please subscript 4 and 3 in SO4 and NO3.

Done.

200. Page 273. Please proofread the notes for table A-19-5.

Done. Please have second set of eyes double-check.

201. Page 239. Table A-19-5: Please consider changing the Datum reference to NAD83 if these values are actually in North American Datum 83.

These values are in NAD 27. See BRACS database tblWell_Location for consistency.

202. Pages 275-278. For consistency with the rest of the report, please consider using “CL” to abbreviate Culebra Dolomite rather than “CU”.

Done.

203. Page 275. First paragraph: Per the contract, GIS files are supposed to be compatible with ArcGIS 10.2. Please change the reference from 10.1 to 10.2.

Done.

204. Page 275. Section 19.6: Please consider proofreading and editing for consistency in terminology used in the rest of the report.

Done.

205. Page 275. Section 19.6: Please consider spelling out all abbreviations and acronyms that aren't in equations.

Done.

206. Page 277. Subsection 19.6.2, first sentence: Please insert "19-4" after the word "Figure".

Done.

207. Page 277. Subsection 19.6.2, second bullet: Please consider inserting another sentence here setting the Python script to "RustlerHydroGeoTool_v3.py".

Done.

208. Page 278. Figure 1: Please change "Figure 1" to "Figure 19-4".

Done.

209. Page 278. Figure 1: Please consider updating this image to include "RustlerHydroGeoTool_v3.py".

Done

210. Page 278. Bullets 1-4: Please consider adding the actual file names of inputs from the GIS data provided in the "GIS_Final" folder. For example, the input for bullet 1 should be ModelGrid_w_Surface_Data_20160727.shp.

Done.

211. Page 27. Figure 2: Please change "Figure 2" to "Figure 19-5".

Done.

212. Page 278. Bullet 4: Please consider providing field parameters and example attribution for the 'CLASS' field.

Added the sentence, "The field 'CLASS' can be a .txt field and the name provided to each of the 'classes' will be carried through to the table formatting."

213. Page 278. Bullet after bullet number 5: Please remove this bullet.

Done.

214. Page 279. Figure 3: Please change "Figure 3" to "Figure 19-6".

Done.

215. Page 281-296. Section 19.7: This example of the geophysical well log analysis is well written for users of the same software available to INTERA. Please consider preparing an additional appendix written in terms that users without the software can apply the valuable

insights from the key well analysis to other wells in the Rustler Aquifer. Because this study was limited to the TWDB mapped extent of the Rustler Aquifer, there are significant areas to the east and limited areas to the south that may be investigated in the future.

It is assumed that the future practitioners of these techniques will be using a wide variety of mathematical software ranging from MatLAB to Microsoft Excel to Interactive Petrophysics. The examples shown can be readily reproduced using any of those software programs.

Data Comments

Bracs_log_Final.xlsx and Bracs_wq_final.xlsx

1. Table tblWell_Location table: Please provide the KB_Height data for each of the wells in this table. It appears this value is elevation above mean sea level. The data needs to be elevation above ground surface.

Done.

2. Table tblBracs_ForeignKey: Please provide a record for most wells that includes the well owner number for the well. For example, for BRACS well_id 10039 (API Number 4238932538) the Owner is Stayley Operating and the owner's well number would be Ligon State 22 4.

Done.

3. Table tblBracsWaterQuality: Well with a well_id of 43461, 43501 are located in Hidalgo County and well_id 53007 is located in Bandera County. We are not sure why data from these wells is in this table. Please investigate and provide the correction, if needed.

These wells had the same foreign key name in both of the reports and it was assumed that they had already been entered into the BRACS database. We corrected this by deleting the BRACS ID and numbering the three wells with new BRACS IDs and adding all additional data to the relevant tables.

4. Table tblBracsWaterQuality: Please populate the field [source_data].

Added additional data

GIS_Final Folder Comments

1. Thank you for providing metadata. The field descriptions for ModelGrid_w_Surface_Data_20160727.shp and StratPicksForInterpolation.shp are especially useful.

No change required.

2. Please consider citing the project title and contract number in the metadata and using consistent file naming for both shapefiles and rasters.

No changes made due to time constraints.

3. Please consider renaming "subdomain", "zone", and "region" shapefiles for naming consistency from the report and distinction from each. For example, Rustler_Hydro_Zones_Regional.shp and 2012_GAM_HydrostructuralSubdomains.shp are shapefiles for the same features, one is clipped polygons and one is polylines but it is difficult to know that from the file names. Additionally "HydrostructuralSubdomains" is consistent with terminology from the report but "Hydro Zones" is not.

Renamed "Rustler_Hydro_Zones_Regional.shp" to be "2012_GAM_HydrostructuralSubdomains_Regional" for consistency.

4. Please consider including the Stocks and Rounsaville faults in 2012_GAM_Mapped_Faults.shp.

These files are already readily accessible through the TNRIS surface geology dataset.

5. HydroStructuralRegionsFinal.shp: Please consider providing attributed fields for the hydrostructural subdomain and stratigraphic zone identification numbers.

Done.

6. Roads_GAM.shp: Please consider cleaning up this shapefile. There are 1080 features with unpredictable attribution.

Done.

7. Strat_Section_Line.shp: Please consider providing an attributed field with cross-section names.

Done.

8. WQ_Contours.shp: Please consider changing the "Id" attribution of FID 1 from "1000" to "10000".

Comment is unclear – FID 1 is already assigned a value of 10,000. As explained in the metadata, this value represents the "Water Quality contour value (TDS in mg/L)." No change made.

9. WQ_Contours_Poly.shp: Please consider providing metadata.

Shapefile deleted as it is not used in any of the report maps.

10. PPA4.shp: Please consider renaming it "no_GAM_area_rust_pg.shp" and providing more descriptive Summary and Description in the metadata.

Renamed "PPA4.shp" to be "no_GAM_area_rust_pg.shp." Updated metadata to clarify it is the portion of PPA 4 falling outside GAM boundary.

11. Please consider providing a description of the folder GIS_Final\shp\Old to help us determine if the content in it needs to be considered or deleted. If it isn't relevant data, please consider deleting the folder.

Folder deleted

12. ST_excluded_pt.shp: Please consider projecting this file into the TWDB GAM projection described in Exhibit G in the contract.

Done.

13. If ST_rust_pt.shp and StratPicksForInterpolation.shp are the same shapefile, please consider deleting one or use the same name.

Deleted ST_rust_pt.shp

14. Thank you for the "README.txt" in the GIS_Final\shp\Appendix19_CreatingGeologicSurfaces\StratPickPointsByZone folder.

No change required.

15. Please consider proving a shapefile of stratigraphy zones 1, 2, and 3, "stratigraphy_zones_rust_pg.shp".

Created shapefile "stratigraphy_zones_rust_pg.shp"

16. Please consider providing a point shapefile of wells with aquifer test, "AT_rust_pt.shp".

Aquifer tests were not compiled as part of this project.

17. Thank you for proving ESRI Map Documents with relative links. This really made evaluating the GIS files much easier.

No change required.

18. Please consider providing one existing use well point shapefile (existing_use_rust_pt.shp) by combining Wells_Exclusion_GWDB.shp and Wells_Exclusion_SDR.shp

As these datasets are sourced from two different databases, they contain extensive well information specific to each database. Given these differences, the shapefiles do not lend themselves easily to merging without losing potentially important well identifying information from one database or the other.

19. Please consider providing an ESRI Map Document for Figure 19-2.

Changed .mxd name from "Fig_19_1_2" to "Fig_19_2" to be consistent with the text. Added missing .mxd for Figure 19-3 ("Fig_19_3")

20. Please consider editing HydroStructuralRegionsFinal.shp to include region 9_2 or fix the attribution and Figure 19-2 so there isn't 8_2 and 9_2 but just 9_2.

Label for "9_2" removed from map. Shapefile left unchanged.

21. Please consider providing a shapefile of hydrogeologic barriers

(hydrogeologic_barrier_rust_pl.shp). This would include faults and distance barriers.

This file would be redundant as we have already provided .shp files that have these things.

22. Please consider providing a description of the folder GIS_Final\ras\del to help us determine if the content in it needs to be considered or deleted. If it isn't relevant data, please consider deleting the folder.

Folder deleted

23. Thank you for using consistent and concise file naming for the rasters, it really helped the review process.

No change required.

24. Thank you for providing a README.txt for the folder GIS_Final\ras\Appendix19_CreatingGeologicSurfaces.

No change required.

25. Please consider creating metadata for the 8 raster in the GIS_Final\ras\Appendix19_CreatingGeologicSurfaces folder.

Added descriptive names. All other relevant information for these rasters is included in the README.txt in that folder.

<u>Submitted Log Comments</u>

1. Please submit LAS file for BRACS well_id 100346 (Gulf Oil Mitchell 1; 4249510853),if a LAS file was prepared. The incorrect log was mistakenly appended to the table tblGeophysicalLog_Header table.

Cut new LAS file that has the correct information

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