FINAL REPORT

An Evaluation of Brackish and Saline Water Resources in Region F

Prepared for

Region F Regional Water Planning Group

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1.0 Introduction

Additional supplies of water in Region F may be obtained from the desalination of existing brackish or saline water sources. Desalination is the process of reducing the concentration of dissolved minerals in water to an acceptable level for its intended use. The feasibility of a desalination project lies in the cost effectiveness of producing and delivering the raw water supply to the plant, the construction and operation of the desalination plant, and the disposal of the concentrated waste stream. Recent improvements in membrane technology have resulted in making the desalination of brackish sources a viable water-supply alternative, with cost effectiveness being mostly dependent on the concentration level of the dissolved constituents in the originating supply source.

Very little, if any, surface water in Region F is available for desalination. Therefore, the emphasis of this report is a general overview of subsurface, water-producing, geologic formations that have the potential to meet desalination supply needs. For the purpose of this report, these groundwater sources are divided into the following categories:

- Groundwater formations that generally occur at relatively shallow depths and are designated by the Texas Water Development Board (TWDB) as major or minor aquifers; and
- Groundwater that is produced from deeper, hydrocarbon-producing geologic formations.

Water quality, hydraulic characteristics, and depth data used in the assessment of potential desalination supply sources were obtained from a number of sources. Of prime importance are water quality databases maintained by the TWDB and the US Geological Survey. In 2003, LBG-Guyton produced for the TWDB a survey of brackish groundwater resources in the state titled *"Brackish Groundwater Manual for*

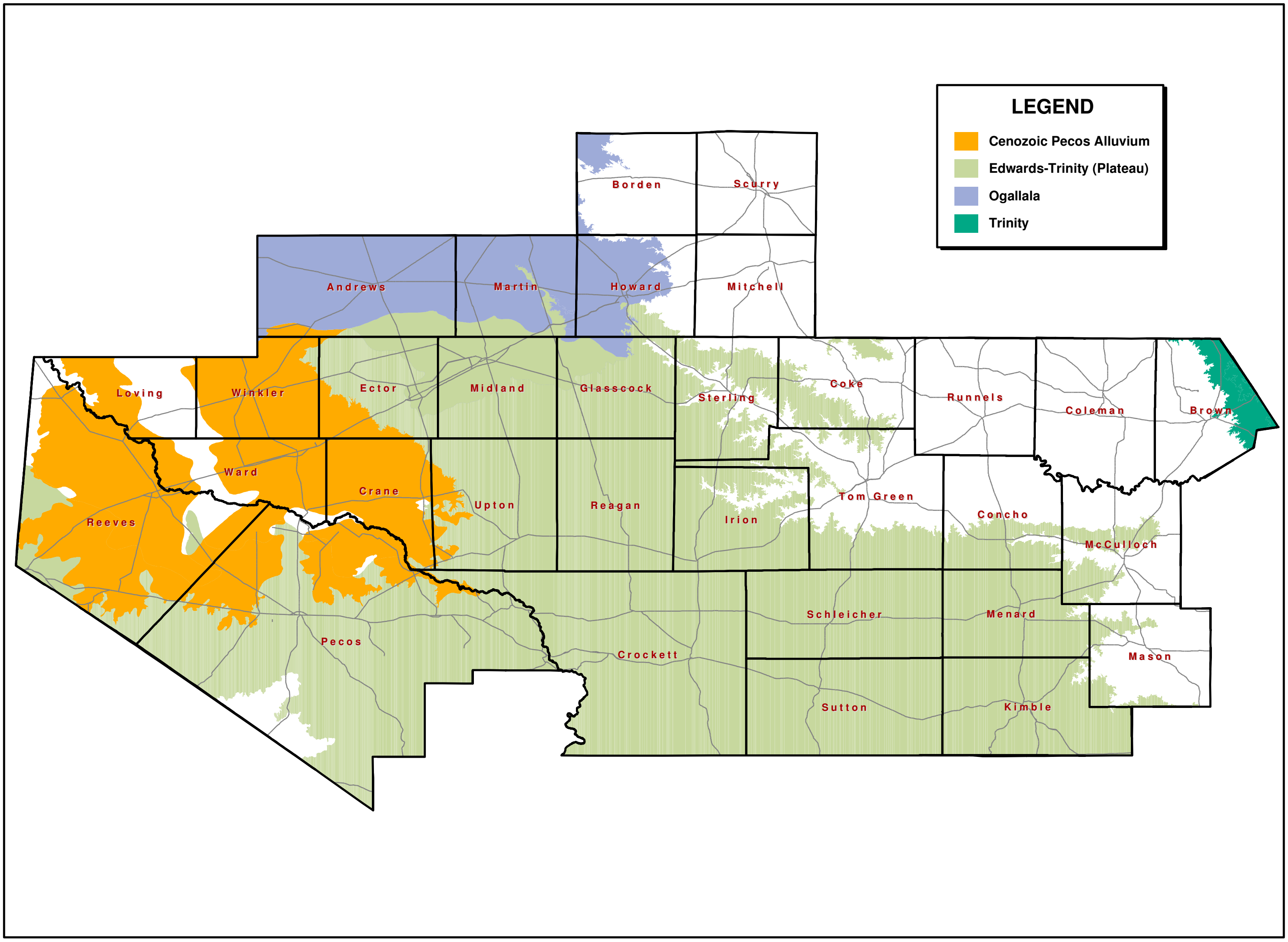

Figure 1 - Major Aquifers In Region F

Texas Regional Water Planning Groups" (LBG-Guyton, 2003). The report summarizes the brackish (1,000 to 10,000 mg/L TDS) groundwater resources of the Board's designated major and minor aquifers, and includes estimated volumes of available source water. Aquifer characteristics are available from the numerous county and regional reports prepared by the TWDB. Most of the information pertaining to deeper geologic formations is derived from TWDB Report 157, *"A Survey of the Subsurface Saline Water of Texas"* (Core Laboratories, 1972). An analysis of the potential use of oil-field produced water for desalination purposes was recently completed by Texas A&M University for the TWDB, and a draft report has been submitted. However, this draft report was not available at the time of the preparation of this report. A brief summary of the potential for oil-field produced water is included in his report. The final section in this report pertaining to desalination costs is summarized from the LBG-Guyton/TWDB brackish groundwater report.

2.0 Major and Minor Aquifers

Brackish groundwater is available from most of the major and minor aquifers present in Region F. The primary advantage of acquiring brackish groundwater supplies from major and minor aquifers is that these sources are relatively shallow and less costly to develop than other sources of groundwater that may be considered, in particular deeper, hydrocarbon-producing formations. However, in some cases, the distance from areas where the major and minor aquifers can be developed to the final destination where the water will be used to meet demands may be a detriment.

2.1 Major Aquifers

Four major aquifers are present in Region F, including the Ogallala, the Cenozoic Pecos Alluvium, the Edwards-Trinity (Plateau), and the Trinity. Figure 1 shows the location of these major aquifers within the region. Of these, the Trinity is only present in the extreme eastern portion of the region, and contains very limited brackish

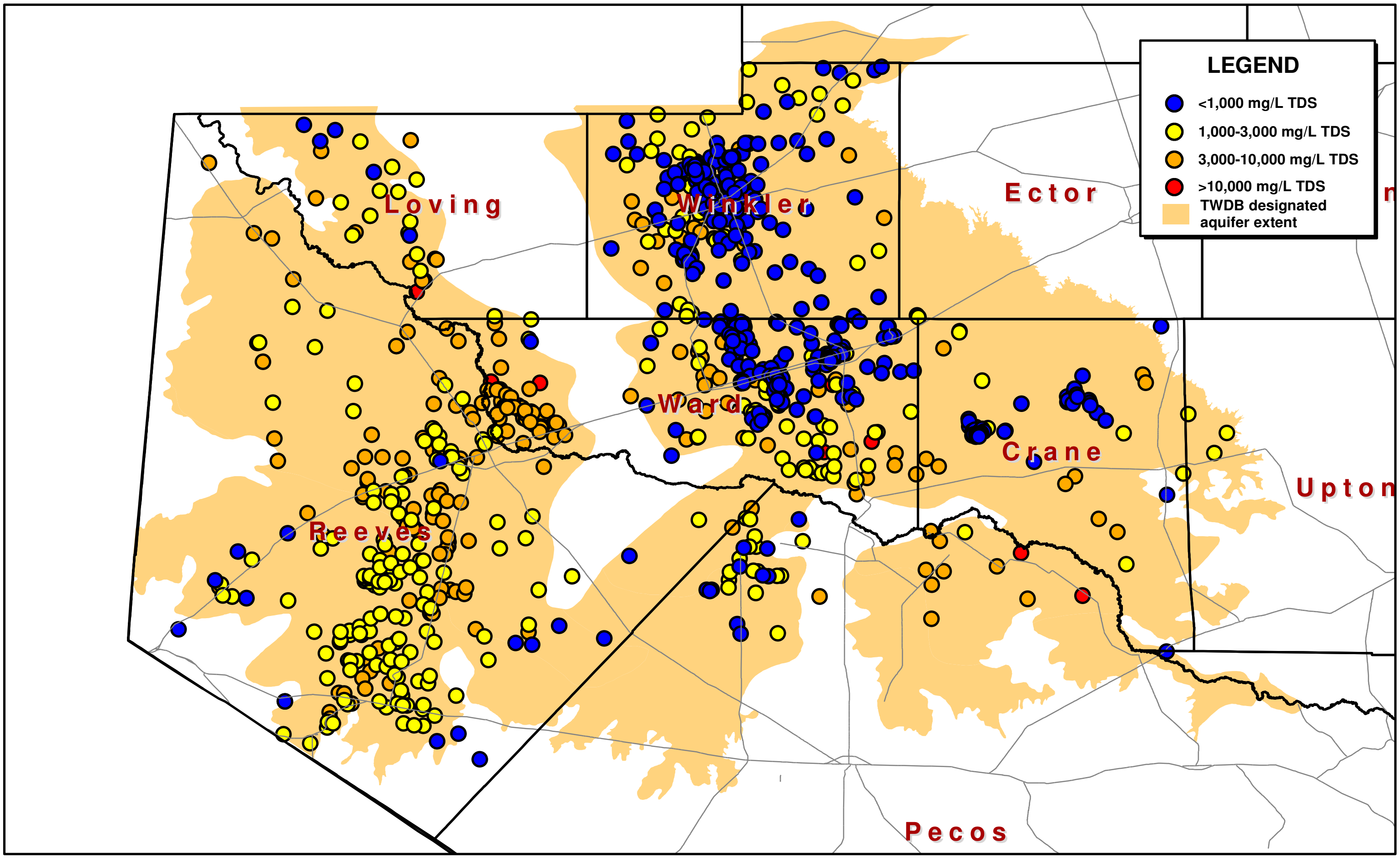

Figure 2 - Groundwater quality in the Cenozoic Pecos Alluvium Aquifer

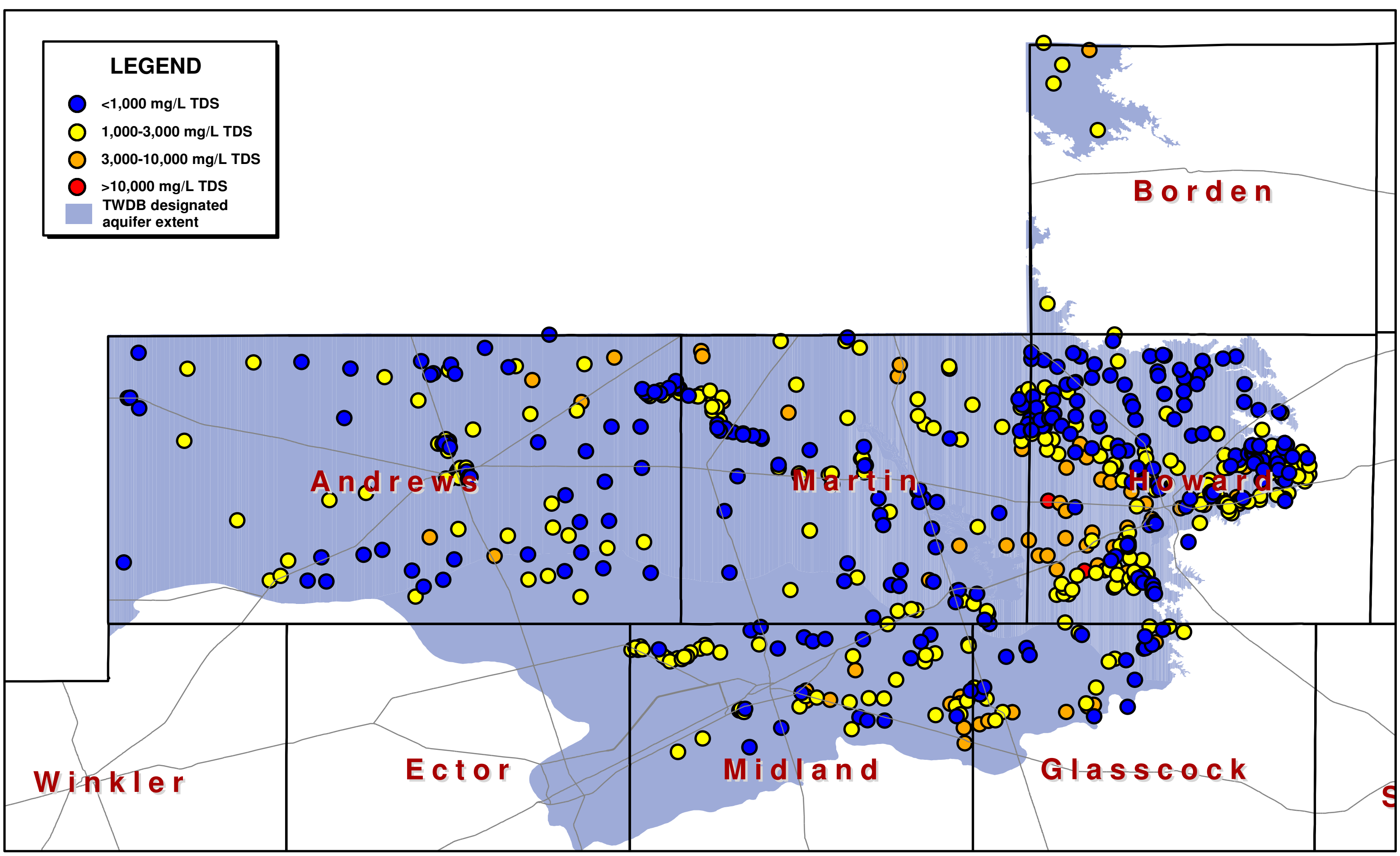

Figure 3 - Groundwater quality in the Ogallala Aquifer

groundwater. The other three major aquifers are more extensive in Region F and contain areas of brackish groundwater.

<u>Cenozoic Pecos Alluvium</u> - The Cenozoic Pecos Alluvium is located almost entirely within Region F, in Reeves, Loving, Winkler, Ward, Crane, and Pecos Counties, as shown in Figure 2. The aquifer consists of up to 1,500 feet of alluvial fill that occupies two hydrologically separate basins, the Pecos Trough to the west, mainly in Reeves County, and the Monument Draw Trough to the east, mainly in Winkler, Ward, and Crane Counties. This fill overlies, and in places is hydrologically connected to, the Edwards-Trinity (Plateau), the Dockum, and the Rustler aquifers. Most of the groundwater currently produced in the westerly Pecos Trough is used for irrigation, while most production in the Monument Draw Trough is exported to cities east of the aquifer area.

Water quality in the Cenozoic Pecos Alluvium aquifer is highly variable due to natural conditions as well as some anthropogenic affects, and brackish groundwater is found throughout the extent of the aquifer. Although water quality in the eastern trough tends to be better than groundwater in the west, significant portions of both sections of the aquifer contain poorer quality water, as shown in Figure 2.

Because the aquifer is thick, the volume of brackish groundwater in the Cenozoic Pecos Alluvium is large. As much as 116.5 million acre-feet of brackish groundwater is estimated to be available from the Cenozoic Pecos Alluvium making it one of the most significant sources of brackish groundwater supply in Region F (LBG-Guyton, 2003).

<u>Ogallala</u> - The southernmost portion of the Ogallala aquifer is present in Region F in Andrews, Borden, Ector, Martin, Howard, Midland, and Glasscock Counties, as shown in Figure 3. The aquifer is composed of Tertiary-aged sand, gravel, silt, and clay, with a maximum thickness of about several hundred feet, but becomes significantly thinner to the south and east, with an estimated average saturated thickness of only 50 feet.

Much of the groundwater produced from the Ogallala in Region F is slightly to moderately saline, as shown in Figure 3. As can be seen in this figure, the occurrence of

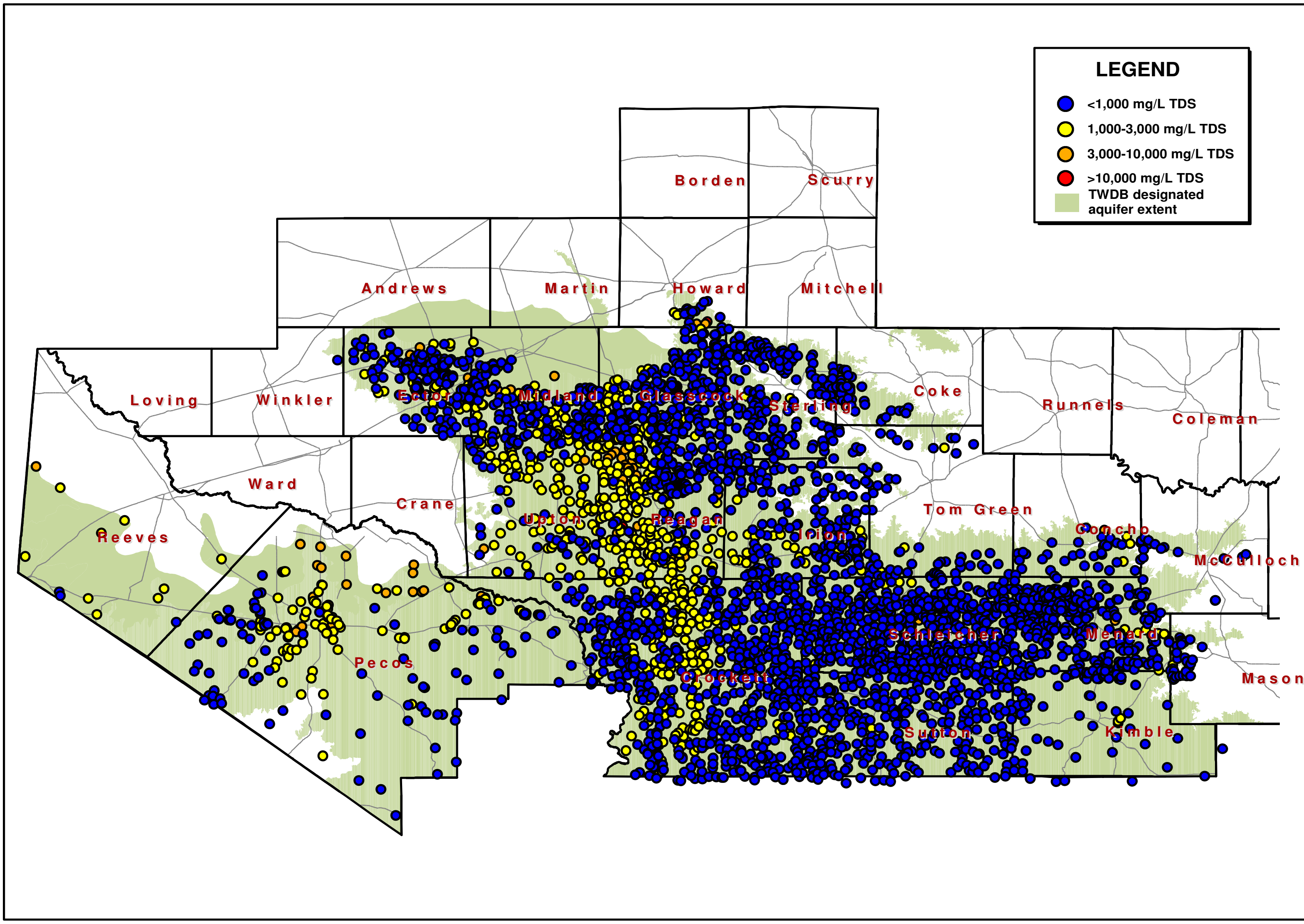

Figure 4 - Groundwater Quality in the Edwards-Trinity (Plateau) Aquifer

slightly to moderately saline groundwater is somewhat random, with no clear delineation between fresh and brackish section of the aquifer, although some areas appear to be more dominantly fresh or brackish than others. Approximately 7.7 million acre-feet of brackish groundwater are estimated to be available from the Ogallala in Region F (LBG-Guyton, 2003).

Edwards-Trinity (Plateau) - The Edwards-Trinity (Plateau) aquifer consists of Cretaceous-age limestones, sandstones, and dolomites and is present throughout much of Region F, as shown in Figure 4. Most water currently produced from the aquifer is used for irrigation purposes, however several municipalities also use water from this aquifer.

Groundwater in the Edwards portion of this aquifer occurs primarily in solution cavities that have developed along faults, fractures, and joints in the limestone. The Edwards is the main water-producing unit in about two-thirds of the aquifer extent. The underlying Trinity is used primarily in the northern third and on the extreme southeastern edge of the aquifer.

While wells producing from the Edwards-Trinity (Plateau) aquifer may be over 1,000 feet deep, a vast majority of wells present in Region F are less than 500 feet deep. The saturated thickness of the aquifer is generally less than 400 feet. Reported well yields commonly range from less than 50 gpm from the thinnest saturated section to 1,500 gpm in locations where wells are completed in jointed or cavernous limestone.

The water quality of the Edwards is generally better than that in the underlying Trinity in the Plateau region. Water produced from the Edwards units is characteristically very hard but fresh, with TDS ranges typically between 200 to 400 mg/l. The salinity of groundwater in the Trinity increases towards the west, with total dissolved solids ranging from 500 to 1,000 mg/l. Several areas of the Edwards-Trinity (Plateau) in Region F produce slightly to moderately saline groundwater, as shown in Figure 3. It is estimated that more than 24 million acre-feet of brackish groundwater is available from the Edwards-Trinity (Plateau).

Trinity - The Trinity aquifer is only present in Region F in the eastern third of Brown County, as well as a very small, isolated section in Coleman County, as shown in Figure 1. A majority of wells producing from the Trinity in these two areas are fresh,

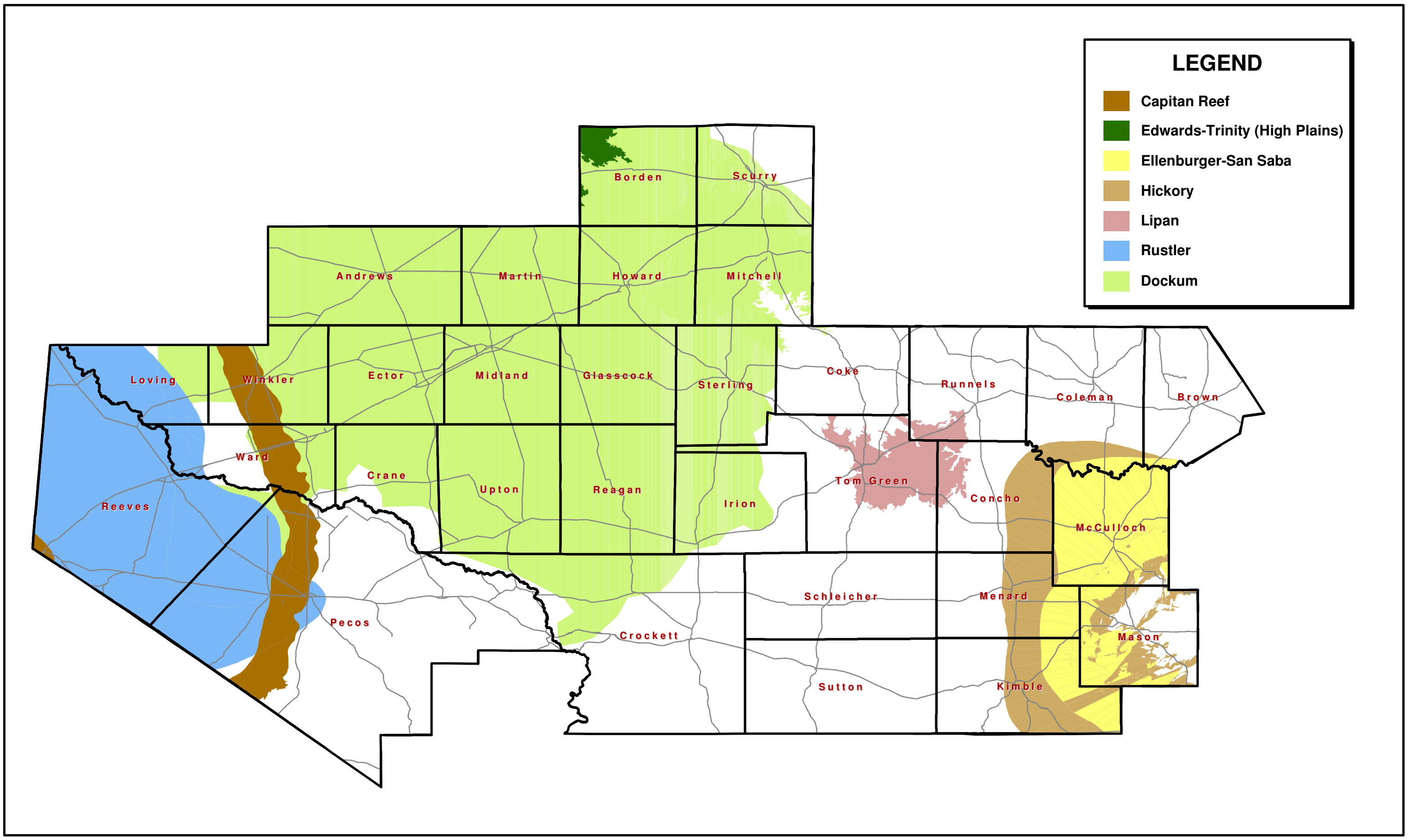

Figure 5 - Minor Aquifers In Region F

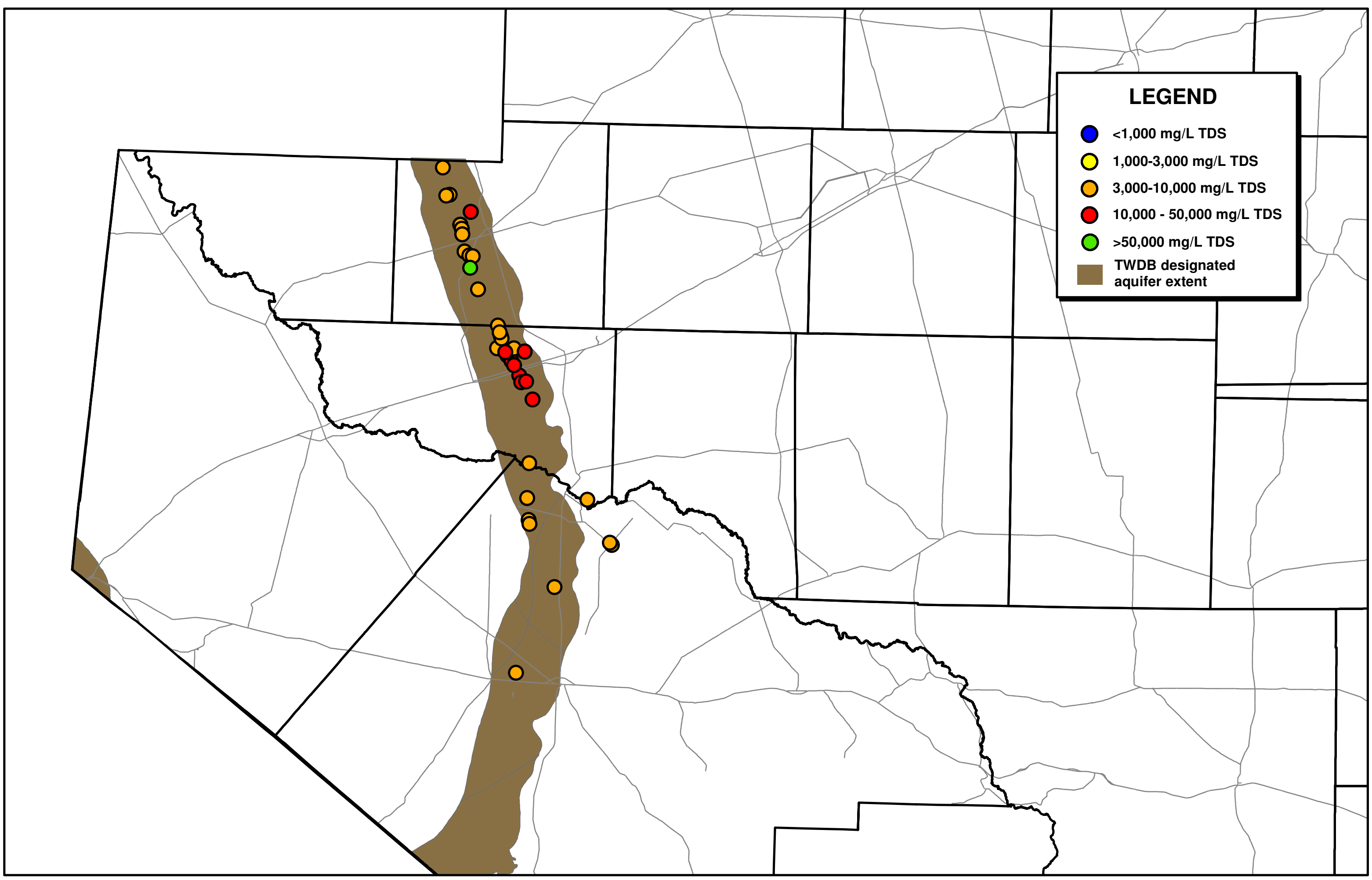

Figure 6 - Groundwater Quality in the Capitan Reef Aquifer

with approximately one-quarter producing slightly to moderately saline (1,000 to 8,000 mg/L) groundwater. Because of the limited extent of the Trinity aquifer in Region F, and because the brackish Trinity wells occur randomly in the region, no definitive supply of brackish groundwater is considered to be available from the Trinity in Region F.

2.2 Minor Aquifers

Nine minor aquifers as defined by the TWDB are present in Region F, including:

- Capitan Reef
- Rustler
- Dockum
- Blaine
- Lipan
- Hickory
- Ellenburger-San Saba
- Marble Falls
- Edwards-Trinity (High Plains)

The location of these aquifers within Region F is shown in Figure 5. Although technically located within Region F, the Edwards-Trinity (High Plains) aquifer is not considered a potential source of brackish groundwater in the region because of its very limited extent within the region, and therefore is not discussed in this report. Also, the Ellenburger, San Saba, and Marble Falls aquifers are discussed together because of their hydraulic similarities and because they are geographically located in the same area.

Capitan Reef – The Capitan Reef aquifer is located in the western part of Region F, in Winkler, Ward, and Pecos Counties, as shown in Figure 6. With well depths ranging over 4,000 feet, the aquifer is mainly used for oil-flood operations in Ward and Winkler Counties, and irrigation in Pecos Counties. Due to the cavernous nature of this aquifer, well yields commonly range from a few hundred to more than 1,000 gpm.

The aquifer generally contains water of marginal quality, with most wells yielding water between 1,000 and 3,000 mg/L TDS, as shown in Figure 6. Deeper wells in Pecos, Ward and Winkler Counties produce groundwater containing dissolved solids in excess

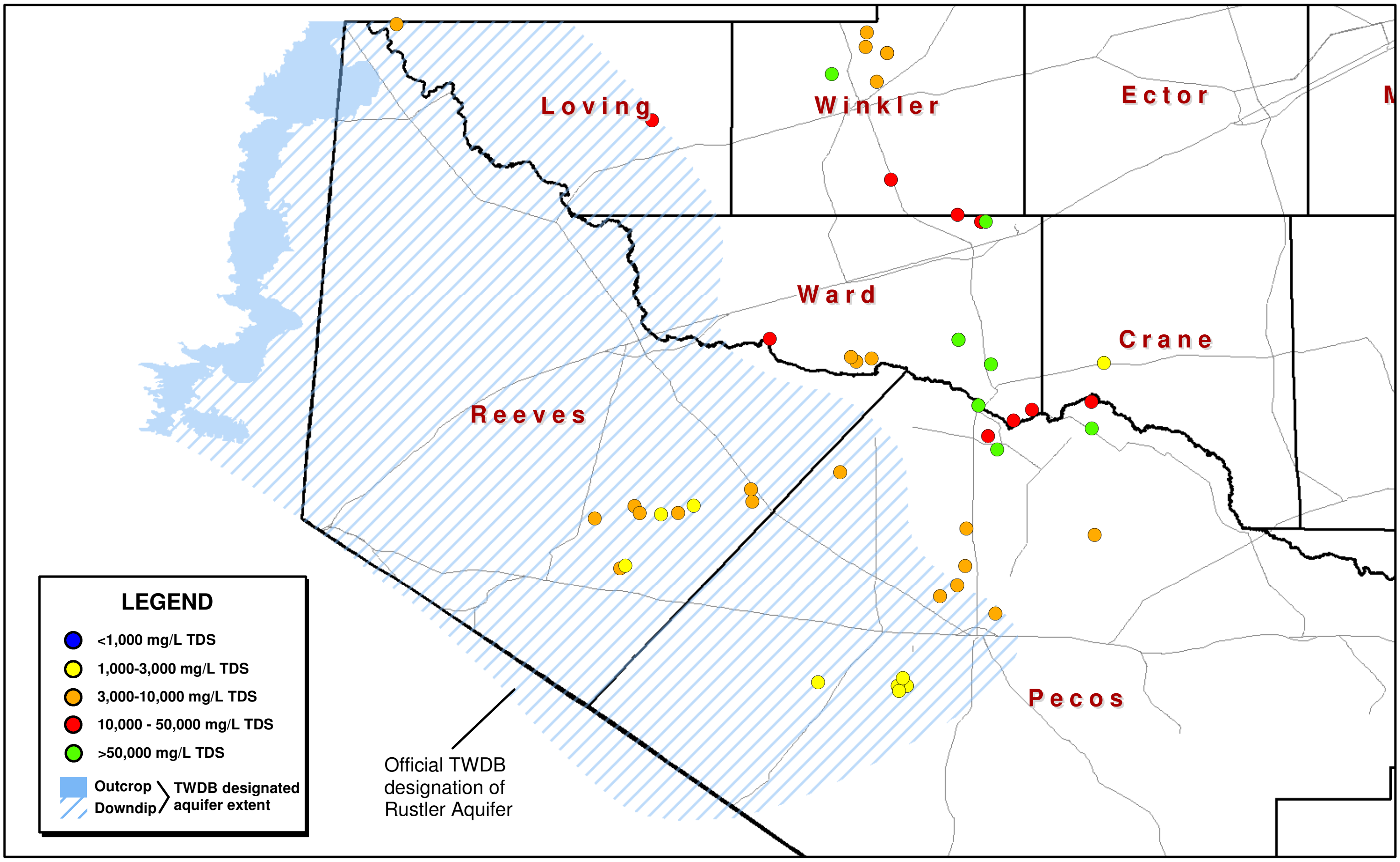

Figure 7 - Groundwater Quality in the Rustler Aquifer

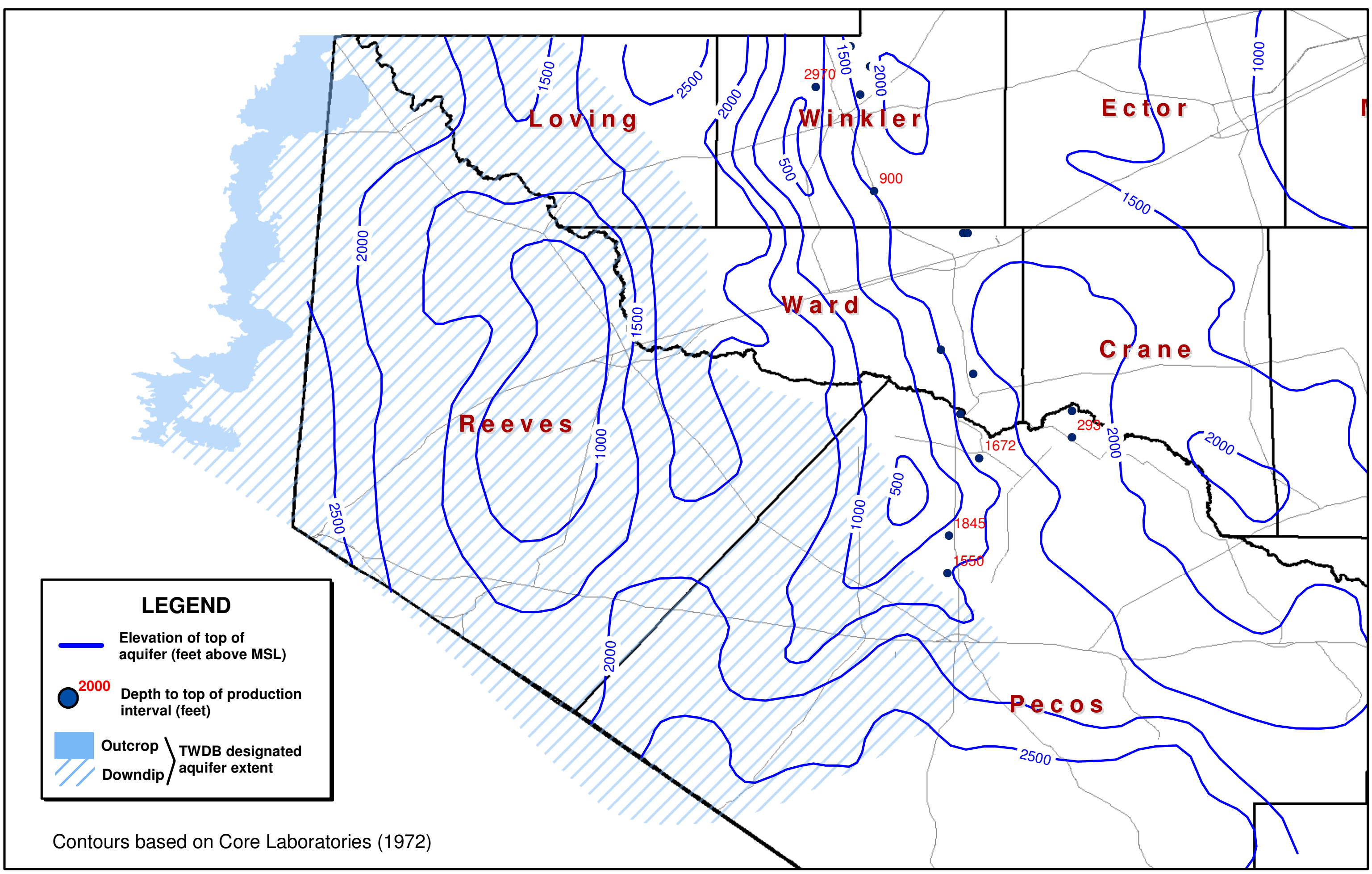

Figure 8 - Elevation of the top of the Rustler Aquifer

of 3,000 mg/L, with the highest concentrations in excess of 10,000 mg/L occurring in central Ward County. The Capitan Reef aquifer is also part of the Guadalupe aquifer system described later in this report. Approximately 48 million acre-feet of brackish groundwater are available from the Capitan Reef aquifer in Region F (LBG-Guyton, 2003).

Rustler – The Rustler Formation is located in the western part of Region F and is shown in Figure 7. The formation actually extends to the east beyond the TWDB aquifer boundary shown in this figure, although this is an area where hydrocarbons are produced and not considered to be an aquifer for water-supply purposes by the TWDB. Produced water data are also included in Figure 7 and indicate that Rustler Formation water is produced as far as eastern Crane County.

The elevation of the top of the 200 to 500 foot thick Rustler Formation is shown in Figure 8, and is generally between 1,000 and 2,000 feet above sea level, with well depths mostly between 1,000 and 2,000 feet below land surface. Yields from wells are variable, ranging from less than 10 to over 4,000 gpm. Some flowing artesian wells produce more than 1,000 gpm.

Groundwater quality in the Rustler generally contains between 1,000 and 5,000 mg/L TDS in the TWDB designated aquifer area. In general, water produced from the Upper Member of the Rustler is slightly- to moderately-saline, and the basal beds contain greater than 10,000 mg/L TDS groundwater.

As much as 4,000 acre-feet/year is estimate to be available without depleting storage, and nearly 35 million acre-feet is in storage in the region within the limits of the aquifer as defined by the TWDB (LBG-Guyton, 2003). Significant additional brackish and saline groundwater is available from the extent of the Rustler beyond the TWDB's minor aquifer designation.

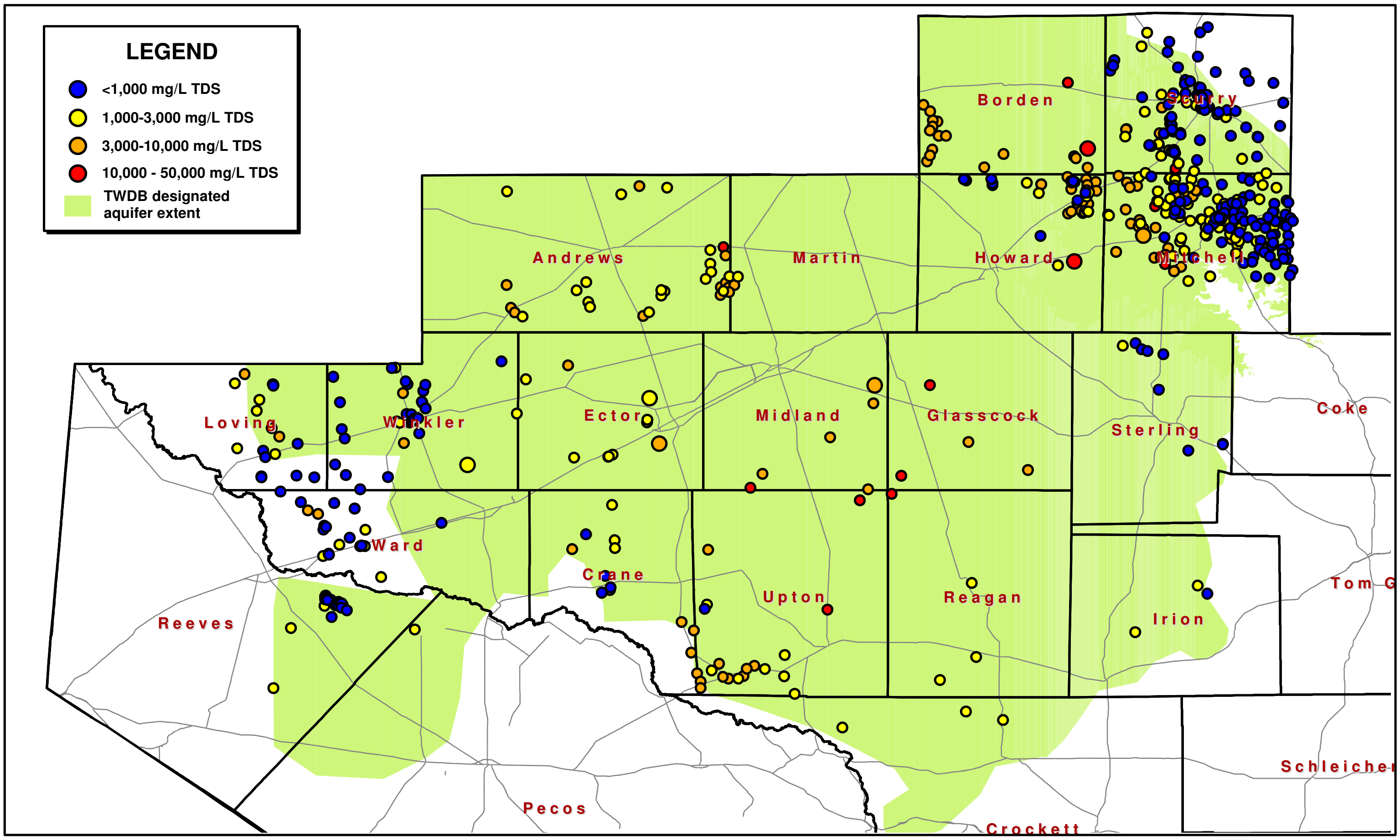

Figure 9 - Groundwater Quality in the Dockum (Santa Rosa) Aquifer

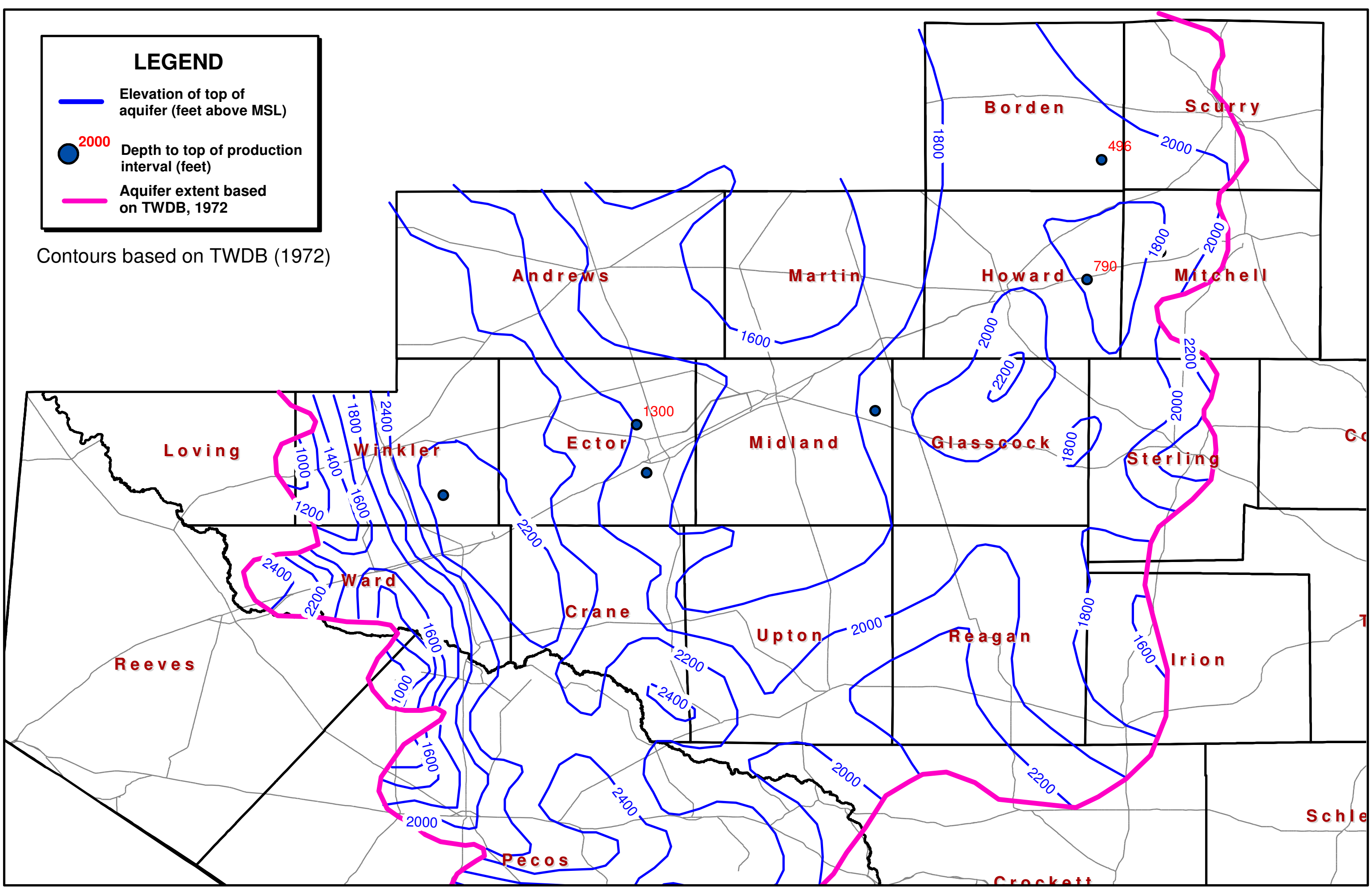

Figure 10 - Elevation of the top of and depth of production intervals for the Santa Rosa Aquifer

Dockum - The Triassic-age Dockum Group consists of up to 2,000 feet of mostly sand, silt, and shale that occurs in much of the central to western half of Region F, as shown in Figure 9. Groundwater produced from the Dockum is used primarily for irrigation in the southeastern outcrop area, and to a lesser extent for other uses elsewhere.

The primary water-bearing zone in the Dockum Group is the Santa Rosa Formation, which consists of up to 700 feet of sand, silt, and conglomerate. The elevation of the top of the Santa Rosa is generally between 1,600 and 2,400 feet above sea level throughout most of the Region F area, as shown in Figure 9. Well depths are less than 500 feet at the margins of the aquifer to depths of 1,000 to 2,000 feet in the central part of the aquifer, where brackish to saline groundwater is found. Because the permeability of the Dockum is typically low due to the fine-grained nature of the formation, most well yields are between 100 and 400 gpm.

Within Region F, the Dockum aquifer mostly contains brackish to saline groundwater (Figure 10). Approximately 65 million acre-feet of brackish groundwater are available from the aquifer in Region F. Although considered poor from a water-supply perspective, it may be a relatively attractive alternative for a source of brackish or saline groundwater, especially compared to other, deeper, hydrocarbon-producing aquifers. However, low well yields may be a limiting factor.

Blaine - The Blaine aquifer is present in outcrop only in Region F in Coke County. From the outcrop areas the beds of the Blaine dip into the subsurface to the west, reaching a maximum thickness of about 1,200 feet. The Blaine aquifer is also considered part of the Guadalupe aquifer system and thus its downdip portions are included in a description of this aquifer later in this report. Because the water quality is too poor from a drinking-water supply perspective, most of the groundwater currently produced from the Blaine is used for irrigation in counties to the north of Region F. Few, if any, wells currently produce groundwater from the Blaine outcrop in Region F.

The water quality from the Blaine aquifer varies greatly, but is generally slightly to moderately saline. Total dissolved solids range from less than 1,000 to greater than 10,000 mg/L, although higher TDS groundwater is almost certainly found downdip and farther away from the outcrop.

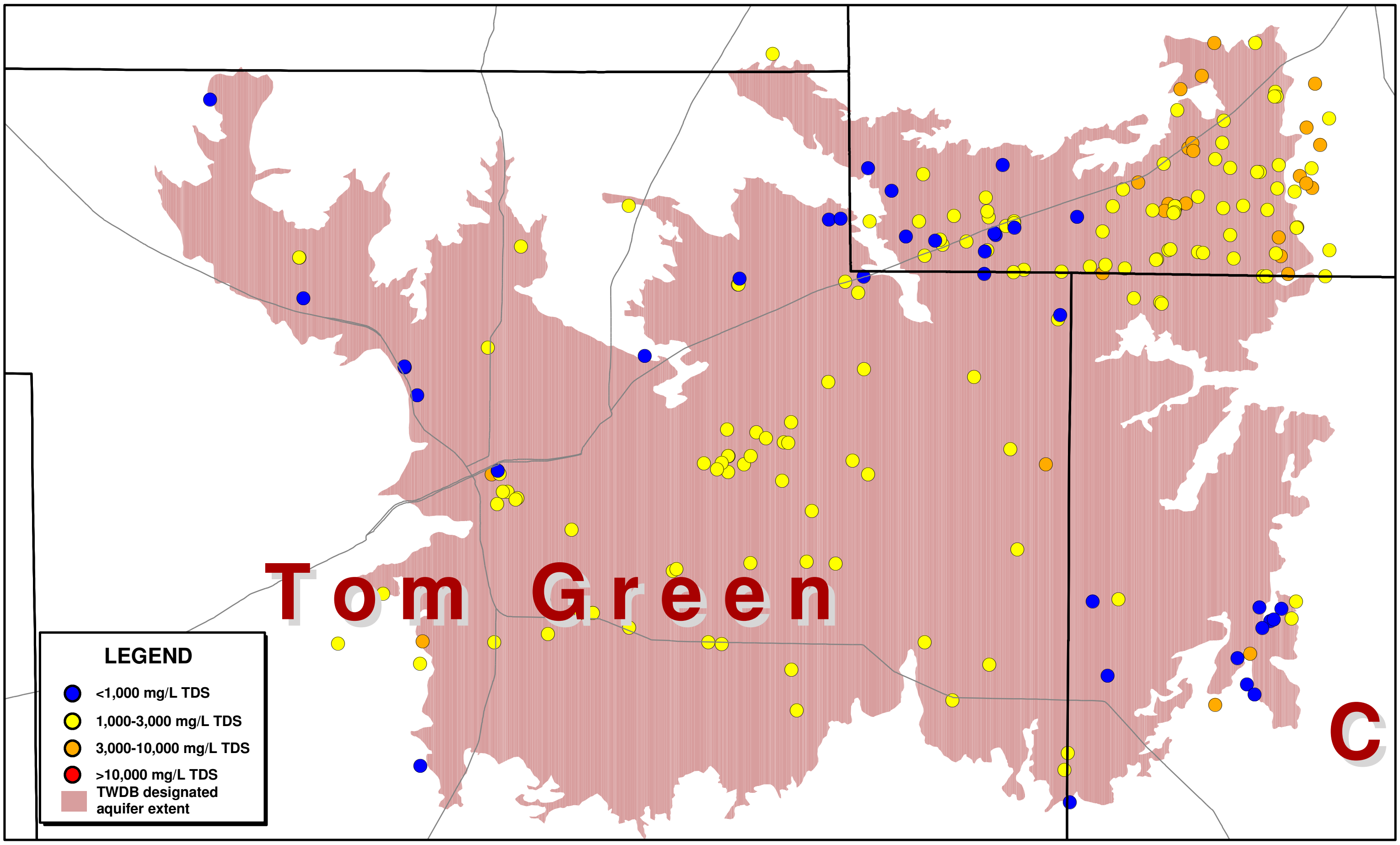

Figure 11 - Groundwater quality in the Lipan Aquifer

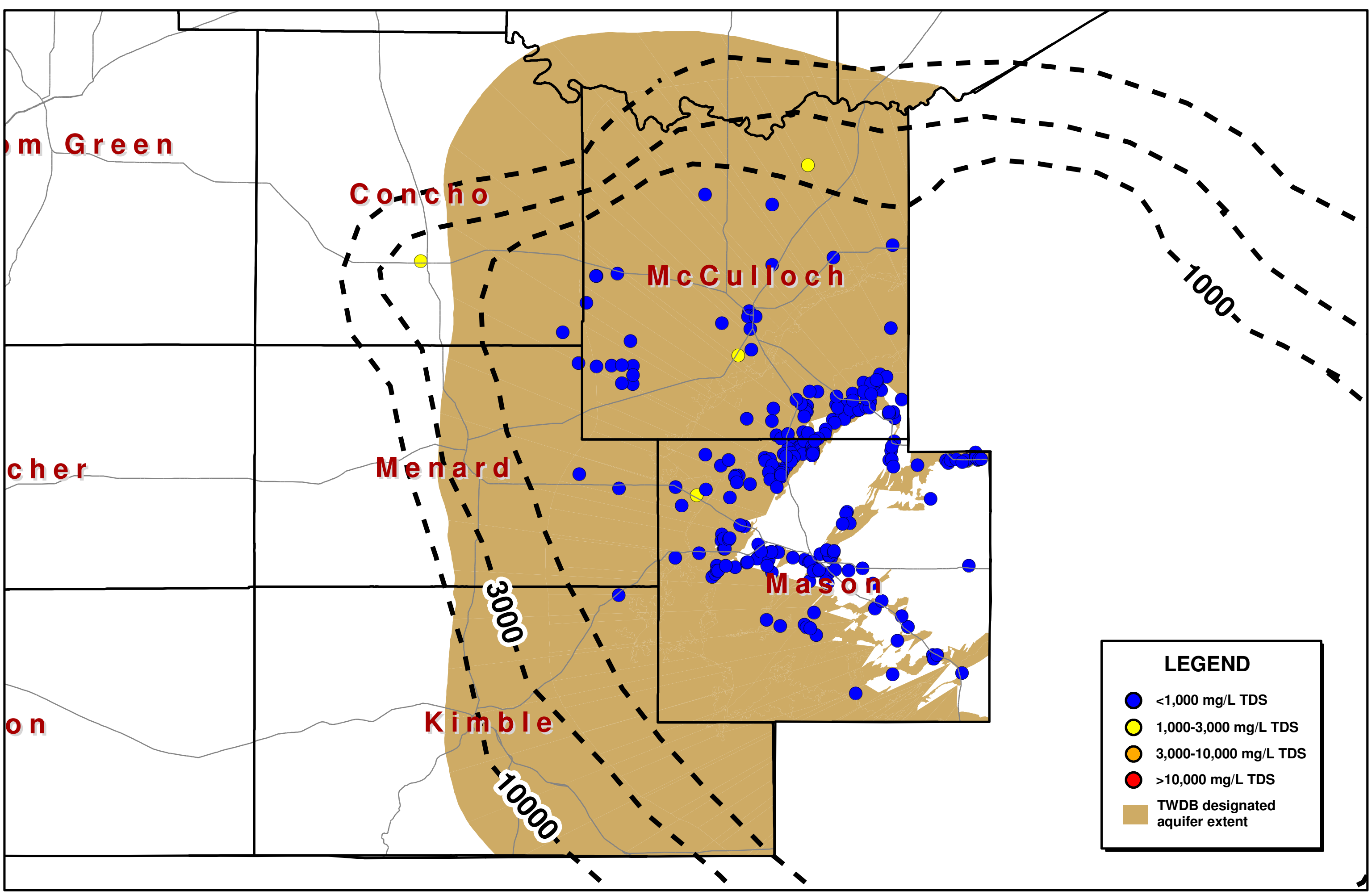

Figure 12 - Groundwater quality in the Hickory Aquifer

Lipan - The Lipan aquifer occurs in Concho, Runnels and Tom Green Counties (Figure 13) and is comprised of saturated alluvial deposits of the Quaternary-age Leona Formation and the underlying, hydrologically connected, portions of the Permian-age Choza and Bullwagon Formations. Groundwater produced from the Lipan is principally used for irrigation, with limited amounts used for rural domestic, livestock, and municipal purposes. Most of the current production from the Lipan aquifer occurs in Tom Green County. Well yields from the shallow aquifer range from 100 to 1,000 gpm.

Water quality in the Lipan aquifer ranges from fresh to moderately saline as shown in Figure 13. The total availability of brackish groundwater from the Lipan is restricted to the extent of the aquifer defined by the TWDB, and is estimated to be nearly 1.25 million acre-feet.

Hickory - The Hickory Sandstone occurs in the Llano Uplift region of Central Texas, in the extreme eastern portion of Region F, as shown in Figure 14. The Hickory is the basal unit of the Riley Formation and is the oldest unit (Cambrian age) producing groundwater in the region. Most of the water currently pumped from the Hickory is used for irrigation and livestock purposes, with a smaller amount used for municipal supply. The down-dip, confined portion of the Hickory aquifer encircles the uplift and extends to depths greater than 5,000 feet.

Yields of large-capacity Hickory wells usually range between 200 and 500 gpm, although some wells have yields in excess of 1,000 gpm. Typical well depths near the outcrop range from 50 to 200 feet, and can be as deep as 2,000 to 5,000 feet deep at the outer down-dip extents of the aquifer.

Groundwater from the Hickory aquifer is generally fresh near the outcrop of the aquifer and up to 30 miles down-dip. However, the aquifer also contains sporadic occurrences of water with 1,000 to 3,000 mg/L TDS throughout the entire extent of the aquifer as well as in the down-dip portions of the aquifer. The Hickory is only considered to be a potential source of brackish or saline groundwater in the immediate vicinity of the Llano Uplift. It is estimated that 51 million acre-feet of brackish groundwater is present in the Hickory in Region F in the area designated as a minor aquifer by the TWDB.

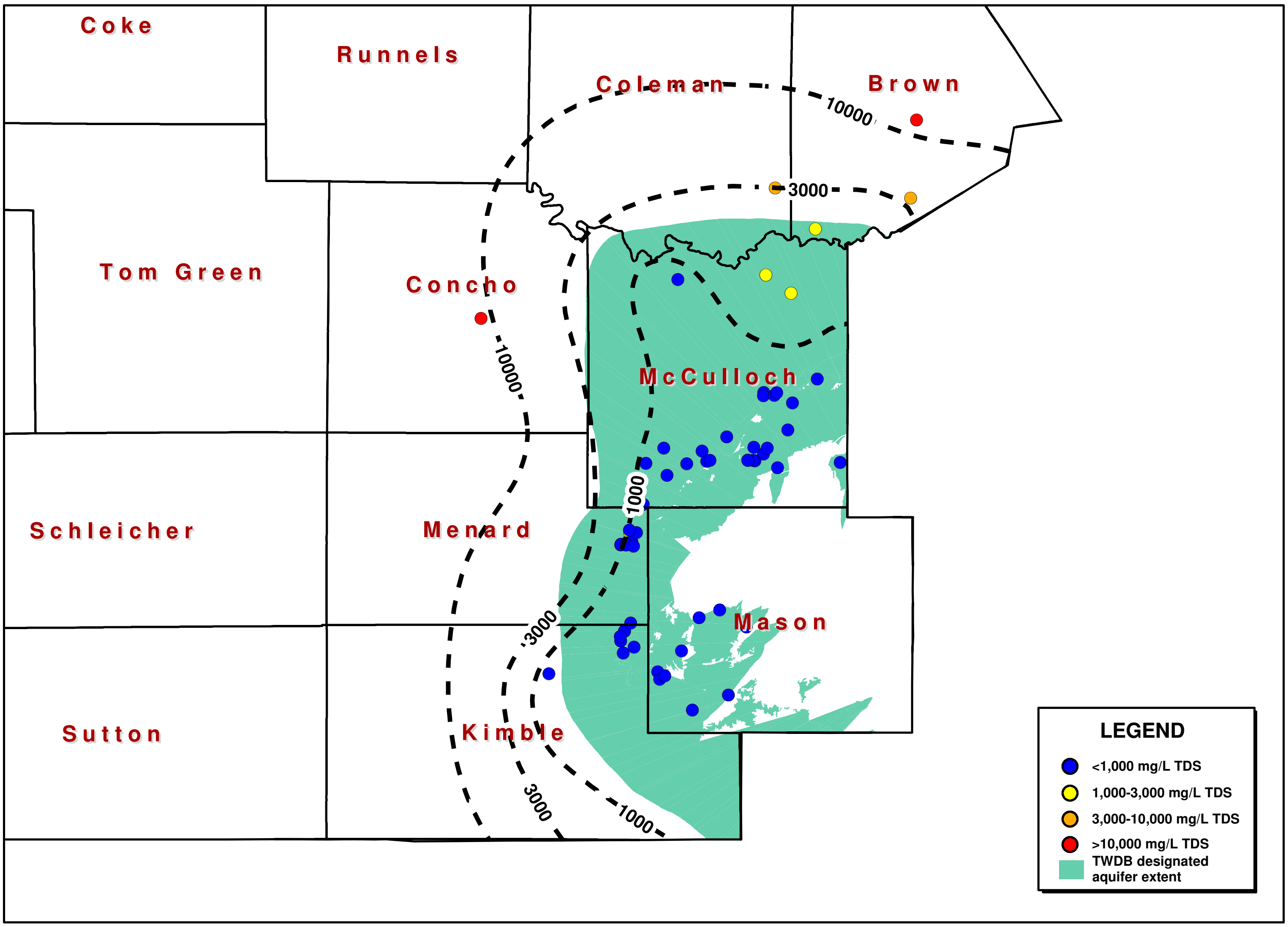

Figure 13 - Groundwater quality in the Ellenburger-San Saba Aquifer

Ellenburger-San Saba-Marble Falls - The Ellenburger-San Saba is an Ordovician to Cambrian age aquifer consisting of limestones and dolomites that crop out in the Llano Uplift area of Central Texas (Figure 15) and extend deep into the subsurface throughout all of Region F. Groundwater produced from this aquifer is primarily used for municipal and rural domestic supply in its shallow eastern extent. The Ellenburger Group is also a prolific hydrocarbon-producing formation throughout West Texas, and contains substantial brackish and saline groundwater beyond the aquifer area defined by the TWDB. This deeper part of the Ellenburger is further discussed in Section 3.0 below.

Groundwater near the outcrop of the Ellenburger-San Saba aquifer, and in some cases up to 20 miles down-dip, is generally fresh, with irregular occurrences of slightly saline groundwater, as shown in Figure 15. This portion of the aquifer is not considered a reasonable source of brackish groundwater for desalination use. However, salinity in the aquifer generally increases with distance down-dip. The down-dip extent of water containing more than 3,000 mg/L TDS ranges from about 10 miles on the south side of the outcrop to over 60 miles to the northwest of the outcrop.

It is estimated that 23 million acre-feet of brackish groundwater is present in the Ellenburger-San Saba aquifer in Region F in the official minor aquifer designated area, and substantial additional brackish to saline water is present in the Ellenburger throughout the rest of the region.

The Marble Falls aquifer occurs in the far eastern portion of Region F in the Llano Uplift area of Central Texas. Groundwater from the aquifer is mostly used for livestock watering, although small amounts are also used for municipal, domestic, and irrigation purposes. The aquifer is capable of producing small to moderate quantities of water to wells, with most wells producing less than 100 gpm.

Existing data for the Marble Falls aquifer show that it contains mostly fresh water in outcrop areas and becomes mineralized a short distance down-dip from the outcrop areas. However, the down-dip extent of the aquifer has not been explored and thus very few data exist to evaluate the extent of brackish water in the aquifer.

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Summary- Significant quantities of brackish groundwater are available from many of the major and minor aquifers located in Region F, which may be useful in helping the region meet growing water demands. For some of these aquifers, a significant amount of data is available to help estimate the volumes of brackish groundwater that may be available. However, there may be few data on other aquifers, requiring site-specific investigations to gather additional information if these are to be considered for brackish groundwater production.

Table 1 presents a summary of the brackish groundwater resources of major and minor aquifers in Region F (modified from LBG-Guyton, 2003). This table indicates that there are several aquifers with significant potential to produce brackish groundwater in large quantities with relatively low cost in the region.

Table 1- Summary of Brackish Groundwater in Major and Minor Aquifers

Aquifer	***Estimated Available Groundwater (acre-feet)***	***Productivity***	***Source Water Production Cost***
Cenozoic Pecos Alluvium	116 million	High	Moderate
Ogallala	7.7 million	High	Low to Moderate
Edwards-Trinity (Plateau)	24 million	Low	Low
Trinity	Negligible	Low	Low
Rustler	34 million	Low to High	Moderate to High
Capitan Reef	48 million	High	Moderate
Dockum	65 million	Low	High
Blaine	Unknown	Unknown	Unknown
Whitehorse-Artesia	Unknown	Low to Moderate	Moderate
Lipan	1.2 million	Moderate	Low to Moderate
Hickory	51 million	Moderate	Moderate to High
Ellenburger-San Saba-Marble Falls	23 million	Moderate	Moderate to High

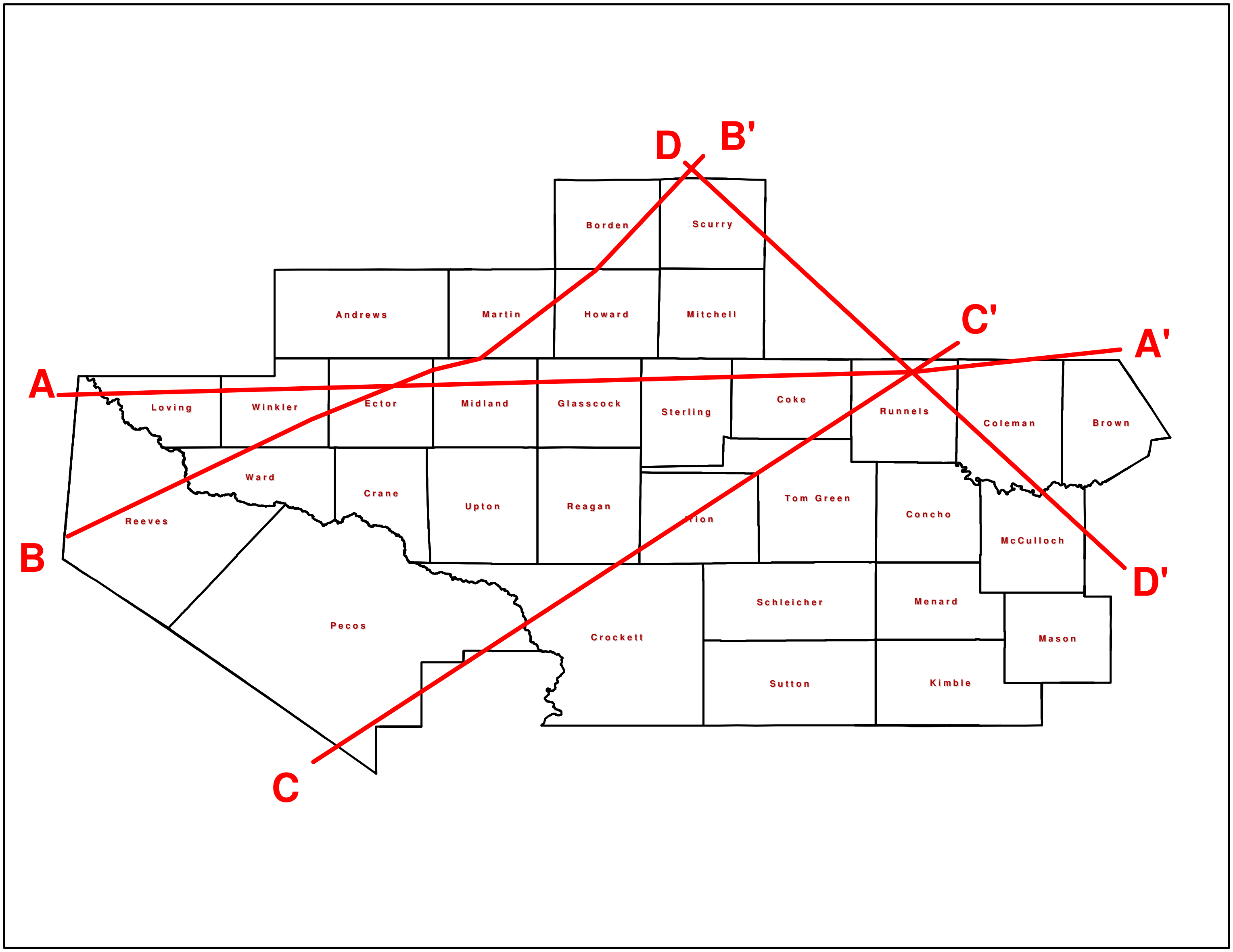
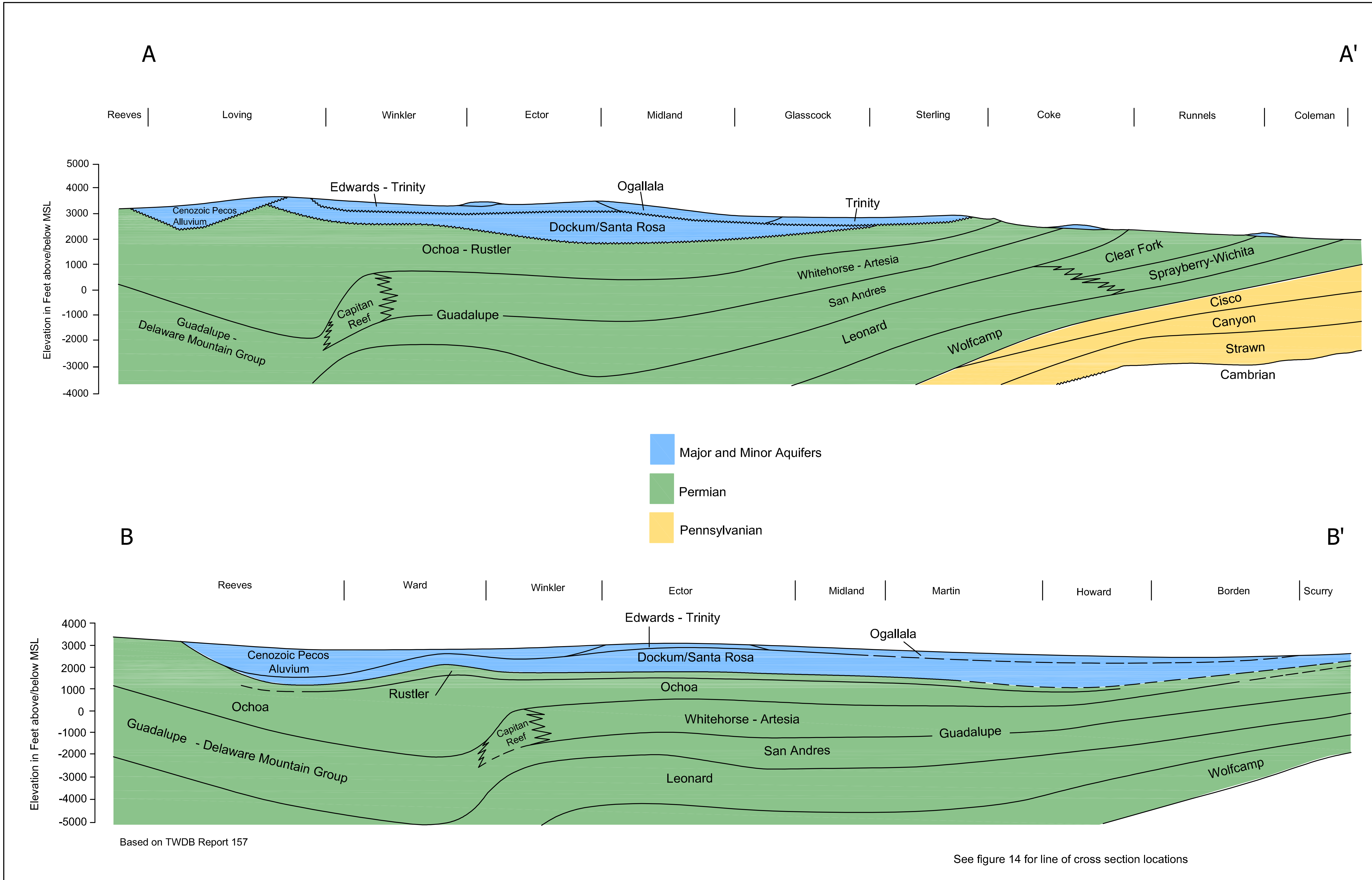


Figure 14 - Location of Cross-Sections

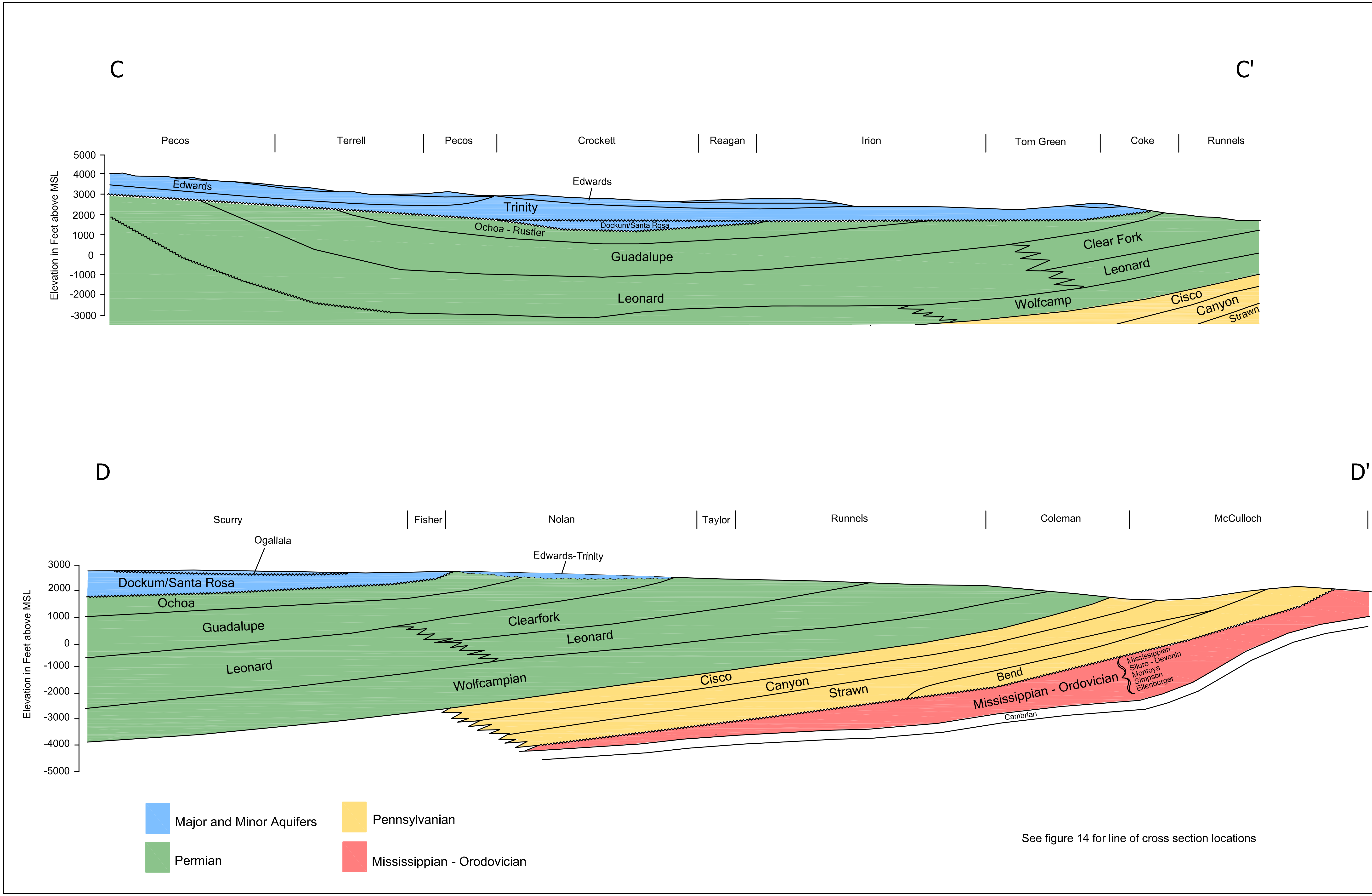


See figure 14 for line of cross section locations

CROSS SECTIONS A - A' and B - B'

FIGURE 15

LBG-GUYTON ASSOCIATES



CROSS SECTIONS C - C' and D - D'

FIGURE 16

LBG-GUYTON ASSOCIATES

3.0 Deep Oil-Field Formations

Numerous other sources of groundwater are present in Region F that are not officially designated as either major or minor aquifers by the TWDB. While not commonly described as "aquifers" due to the non-potable, high salinity nature of the groundwater contained in them, these formations are, in fact, aquifers and must be considered in order to fully assess all potential sources of brackish and saline groundwater available for desalination. These formations are typically deep, hydrocarbon-producing units, and include:

Permian-age aquifers
- Guadalupe (Delaware Mountain Group)
- Guadalupe (Whitehorse-Artesia)
- Guadalupe (San Andres)
- Leonard (Clear Fork-Wichita)
- Wolfcamp (Coleman Junction)

Pennsylvanian-age aquifers
- Cisco
- Canyon
- Strawn
- Bend

Mississippian – Ordovician-age aquifers
- Mississippian
- Siluro-Devonian
- Simpson-Montoya
- Ellenburger

Most of the above aquifers are found at much greater depths than the officially designated aquifers described in the preceding sections. Four cross-sections were developed across Region F in order to depict the location of these units stratigraphically. The location of each of the cross-sections is shown in Figure 14, and the cross-sections are shown in Figures 15 and 16.

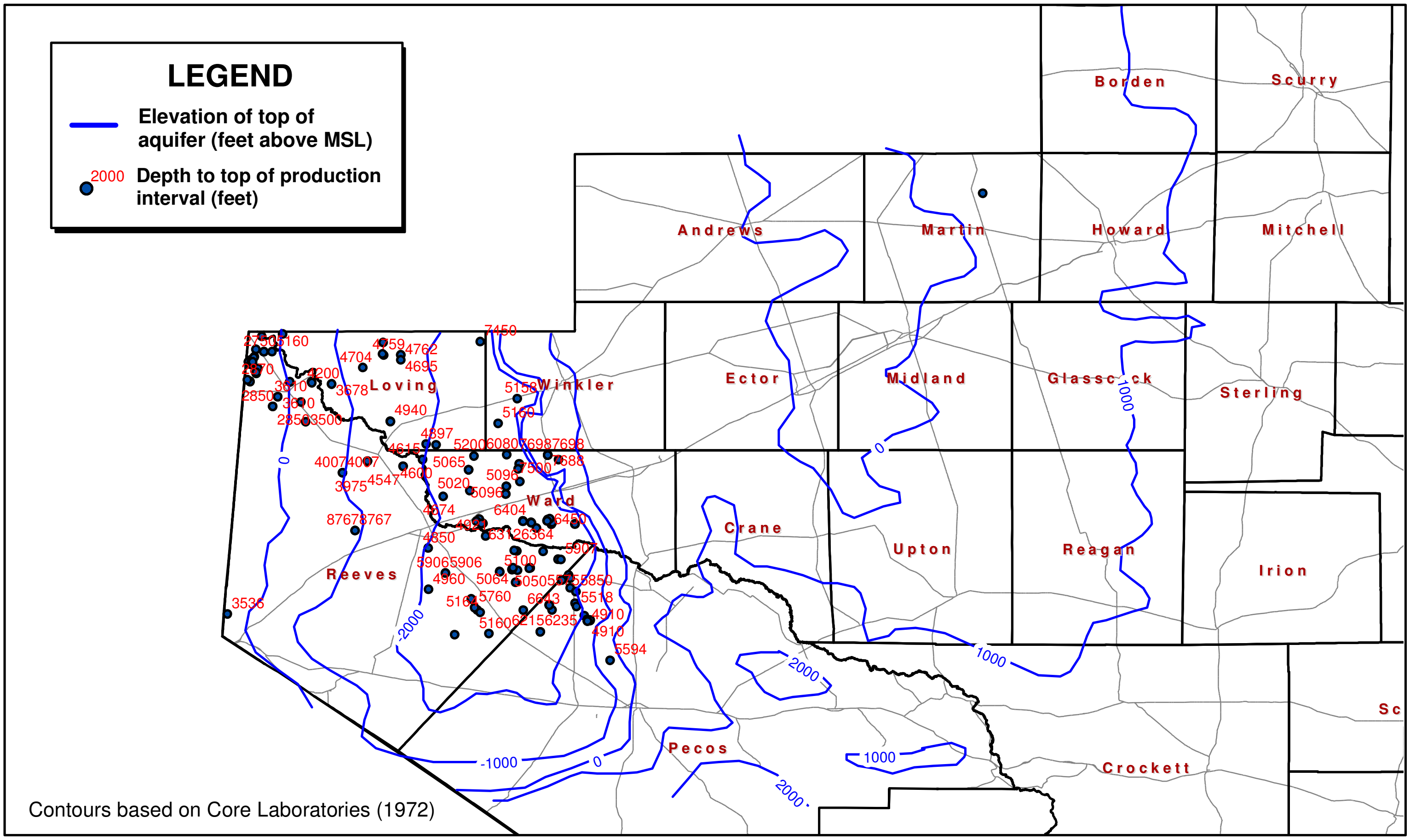


Figure 17a - Depth to the top of the Guadalupe (Delaware Mountain Group) Aquifer

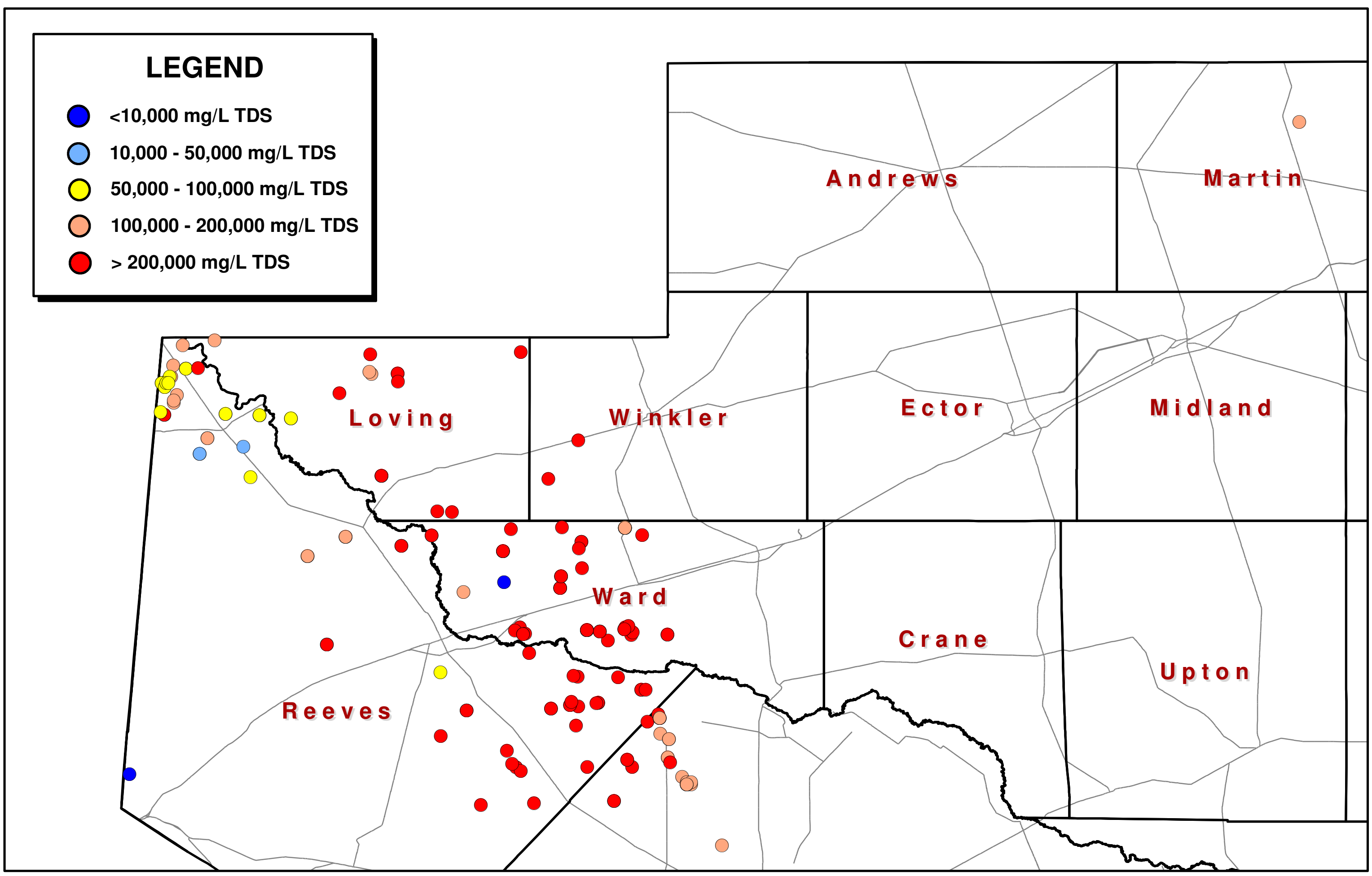


Figure 17b - Produced water quality in oil and gas wells in the Guadalupe (Delaware Mountain Group) Aquifer

3.1 Permian-age Aquifers

Guadalupe (Delaware Mountain Group) Aquifer- The Upper Guadalupe aquifer is found throughout much of West Texas, including most of the western half of Region F. The top of the Upper Guadalupe aquifer is found at depths of 1,000 to 5,000 feet (Core Laboratories, 1972). Most of the data from oil and gas wells in the western part of the region indicate production intervals between 3,000 and 8,000 feet below land surface. A structure map of the elevation of the top of the Upper Guadalupe aquifer is shown in Figure 17a.

The Upper Guadalupe Group includes the Whitehorse Group and the Capitan Reef Formation. This aquifer also includes the Delaware Mountain Group, even though technically this unit is equivalent to the San Andres and upper Guadalupe units combined. The Capitan Reef is described above in Section 2.2, and the Whitehorse is described separately below, and therefore the description of the Upper Guadalupe aquifer in this section will focus on the Delaware Mountain Group.

The Delaware Mountain Group includes the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations. These units consist of sandstone, thin limestones, and shale. Porosities and permeabilities are highly variable and generally moderate to limited productivities can be expected from the sandstone formations (Core Laboratories, 1972). Salinities of produced water from the Delaware Mountain Group are shown in Figure 17b. These data indicate very high and variable salinities from this unit, which, along with the moderate to limited productivity, make the Upper Guadalupe aquifer (Delaware Mountain Group) a poor choice for a brackish or saline water resource.

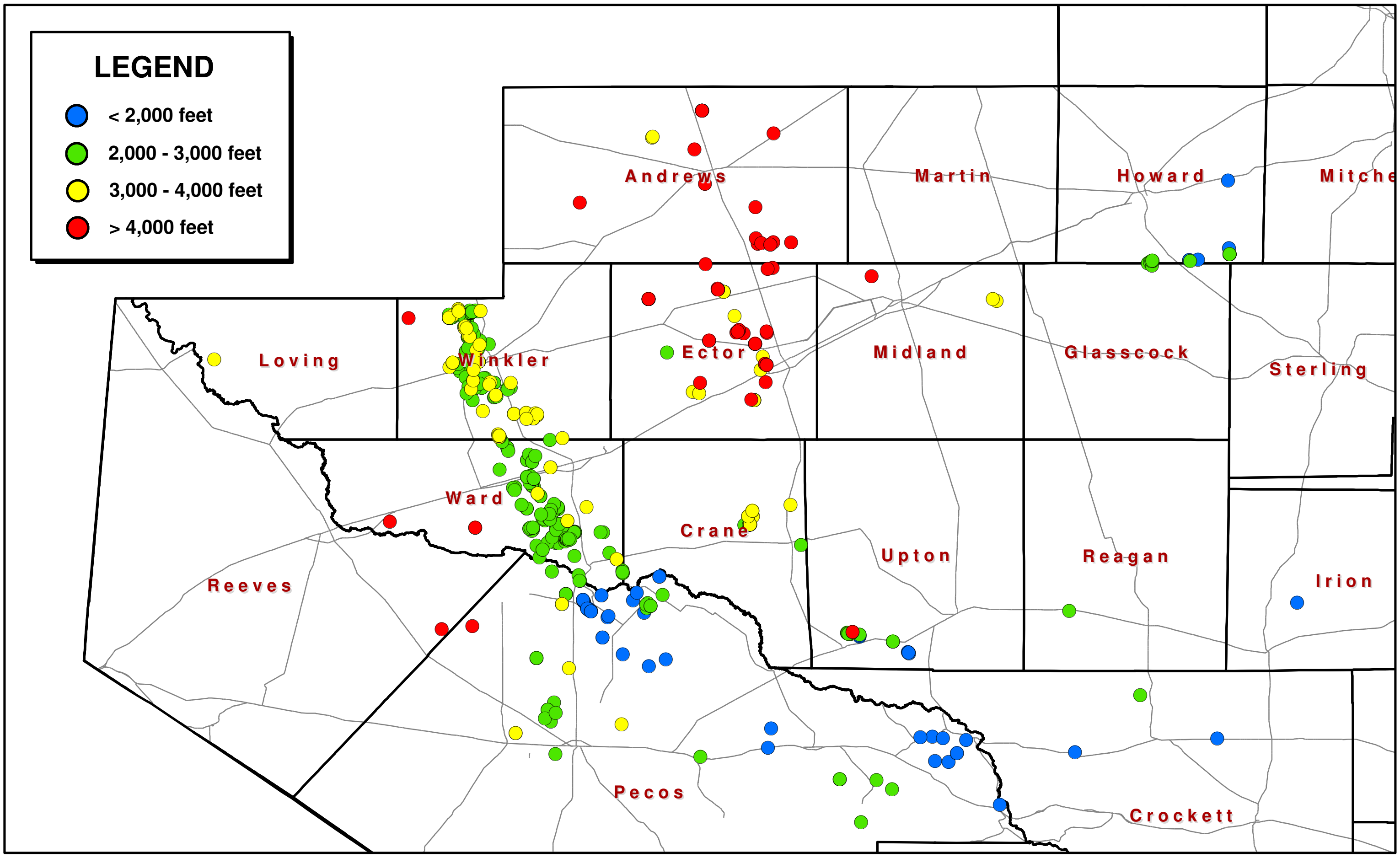


Figure 18a - Depth to the top of the production interval in oil and gas wells in the Whitehorse Aquifer

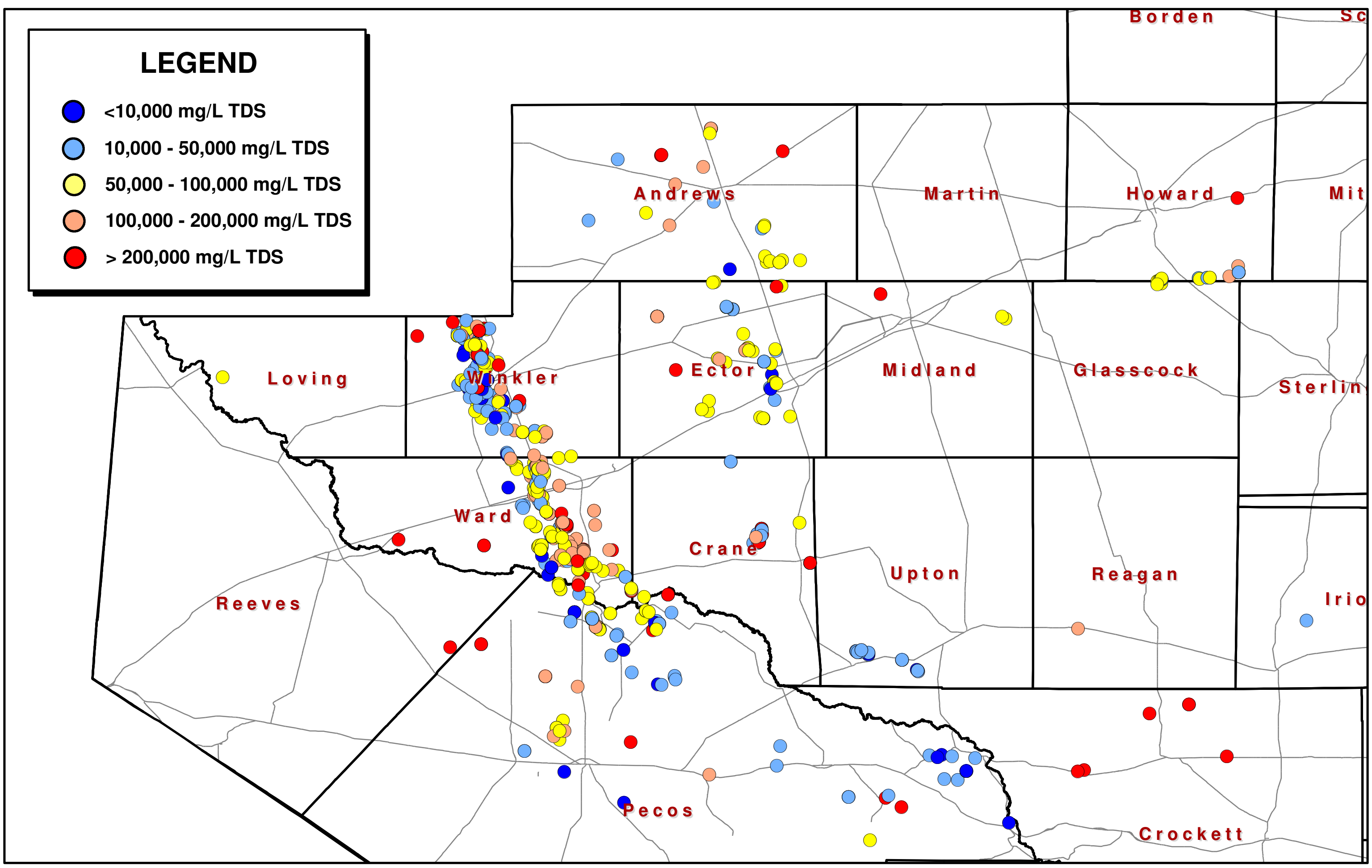


Figure 18b - Produced water quality in oil and gas wells in the Whitehorse Aquifer

Guadalupe (Whitehorse-Artesia) Aquifer - The Whitehorse and Artesia are Permian-age aquifers located in West-Central Texas. These aquifers have not produced enough water to be designated as "minor aquifers" by the TWDB; however, they hold sufficient potential as brackish groundwater supplies to be included in the TWDB brackish report as a separate aquifer. The formations that make up the Whitehorse Group are also prolific hydrocarbon producers in West Texas, and there are a large number of produced water data for these units from oil and gas wells.

The Whitehorse Group lies above the Blaine Formation and consists of up to 700 feet of fine-grained red sand, dolomite, and thick gypsum beds. Depths to the top of the production interval for some of the individual formations of the Whitehorse are between 1,000 and 5,000 feet throughout much of West Texas, as shown in Figure 18a (Core Laboratories, 1972). The downdip, hydrocarbon-producing portion of the Whitehorse Group consists of five individual formations; the Grayburg, Queen, Seven Rivers, Yates, and Tansill. High productivities can be expected from limited areas of the Whitehorse (Core Laboratories, 1972).

In the northern portion of the aquifer, yields from water-supply wells of greater than 600 gpm are possible, and in the central portion of the aquifer area, yields can be up to 1,000 gpm. Production capacity from the deeper, hydrocarbon-producing zones is unknown, but is likely not nearly as productive as from water supply wells described above.

Water quality from the Whitehorse-Artesia aquifer varies greatly. As with the Blaine, water quality from the Whitehorse-Artesia is fresh primarily in recharge areas, and TDS increases in down-dip portions of the aquifer. The TDS of produced water in the deeper sections of the aquifer ranges from less than 10,000 to over 250,000 mg/L. Several areas do contain formation water with less than 10,000 mg/L TDS, including through central Winkler and Ward Counties, as shown in Figure 18b.

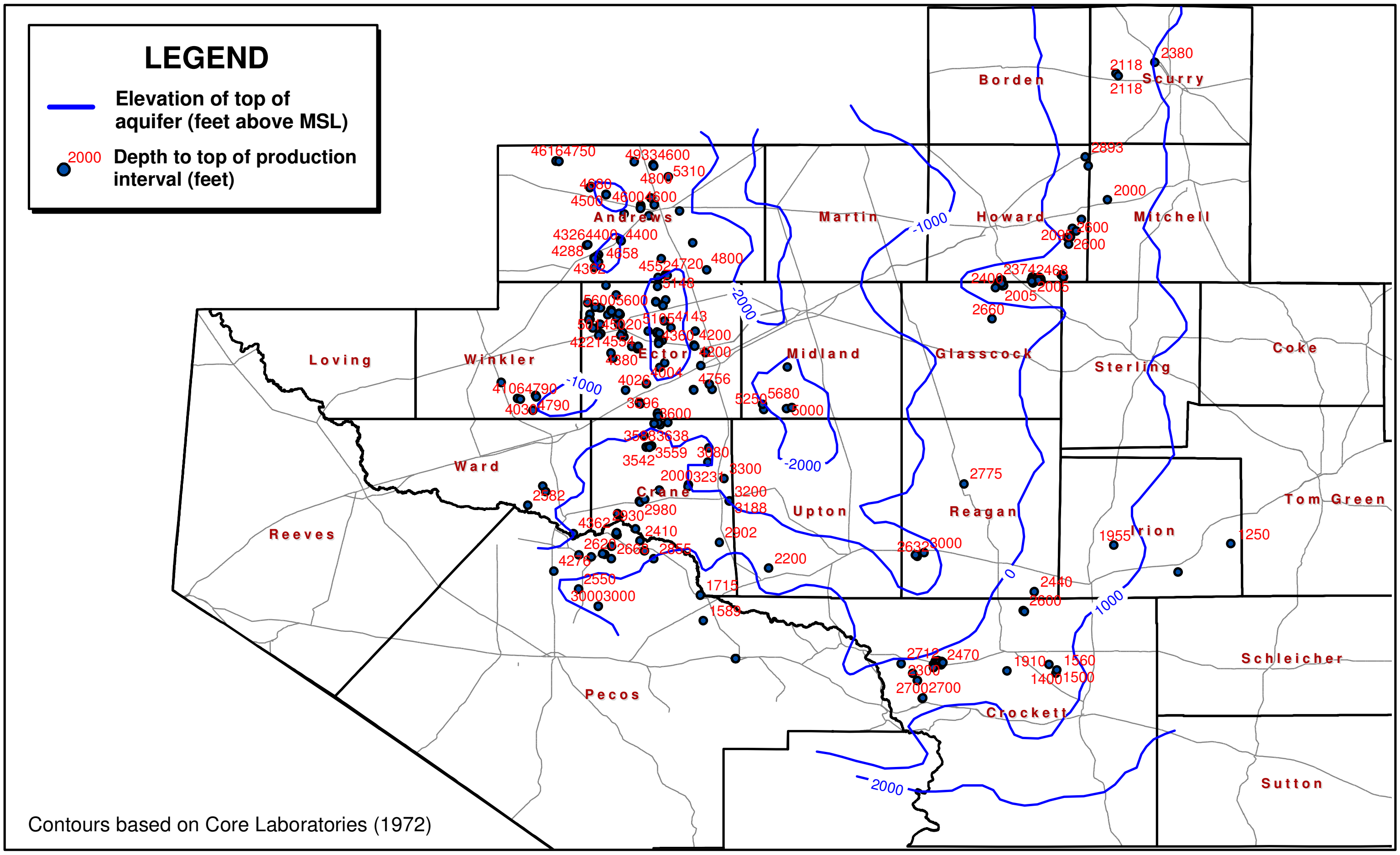


Figure 19a - Elevation of the top of the San Andres Aquifer

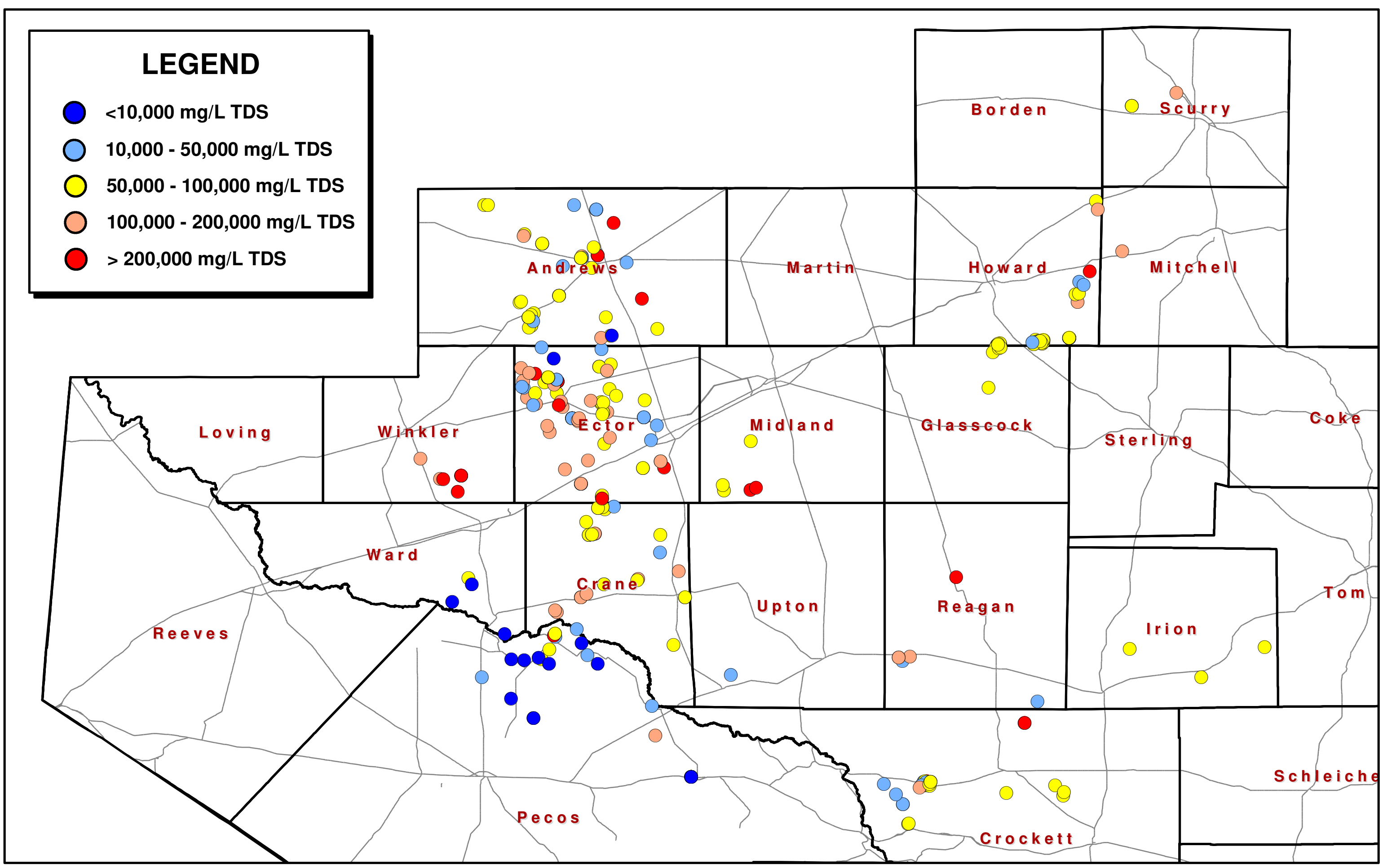


Figure 19b - Produced water quality in oil and gas wells in the San Andres Aquifer

Guadalupe (San Andres) Aquifer **–** The lower Guadalupian-age San Andres Formation is present in the central to western portion of Region F, and is the uppermost formation in the Pease River Group in the High Plains area and the lowermost formation in the Delaware Mountain Group in the Delaware Basin. The top of the formation is found at depths of 1,500 to 5,000 feet over most of its extent in Region F, as shown in Figure 19a . The formation consists of beds of limestone, dolomite, anhydrite, and sandstone with porosities averaging from 7 to 15 percent, and permeabilities from 1 to 500 millidarcies (Core Laboratories, 1972).

Produced water data from oil and gas wells shown in Figure 19b, along with other data sources, indicate a very wide range of salinities from the San Andres. Some wells have salinities below 10,000 mg/L and others are as high as nearly 400,000 mg/L. Several areas appear to produce water with less than 50,000 mg/L TDS, from Andrews County south to Pecos and Crockett Counties. Salinities of less than 10,000 mg/L are present in the southwestern portion of the extent of the aquifer, along the Pecos River, as shown in Figure 19b.

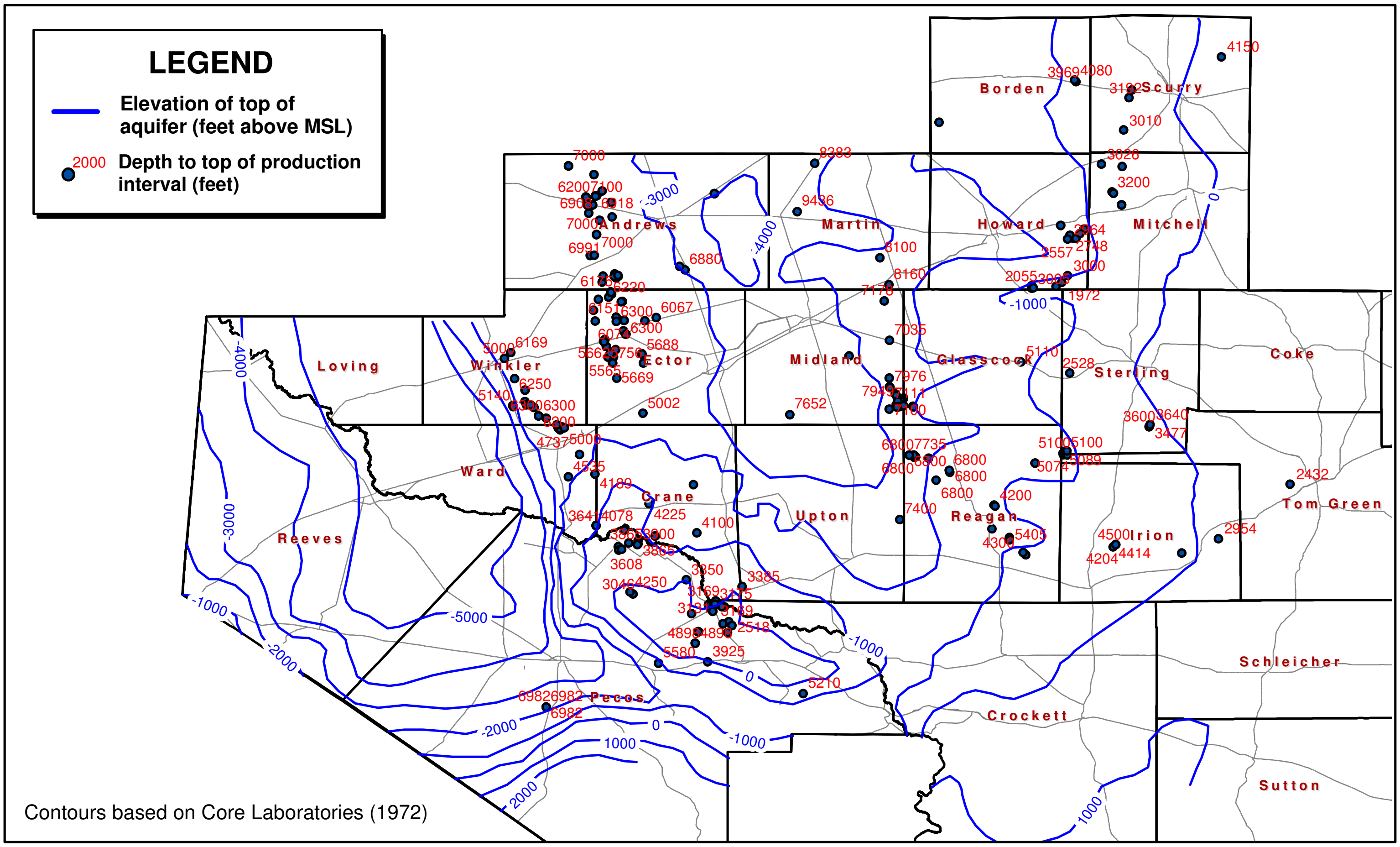


Figure 20a - Depth to the top of the Clear Fork-Wichita Aquifer

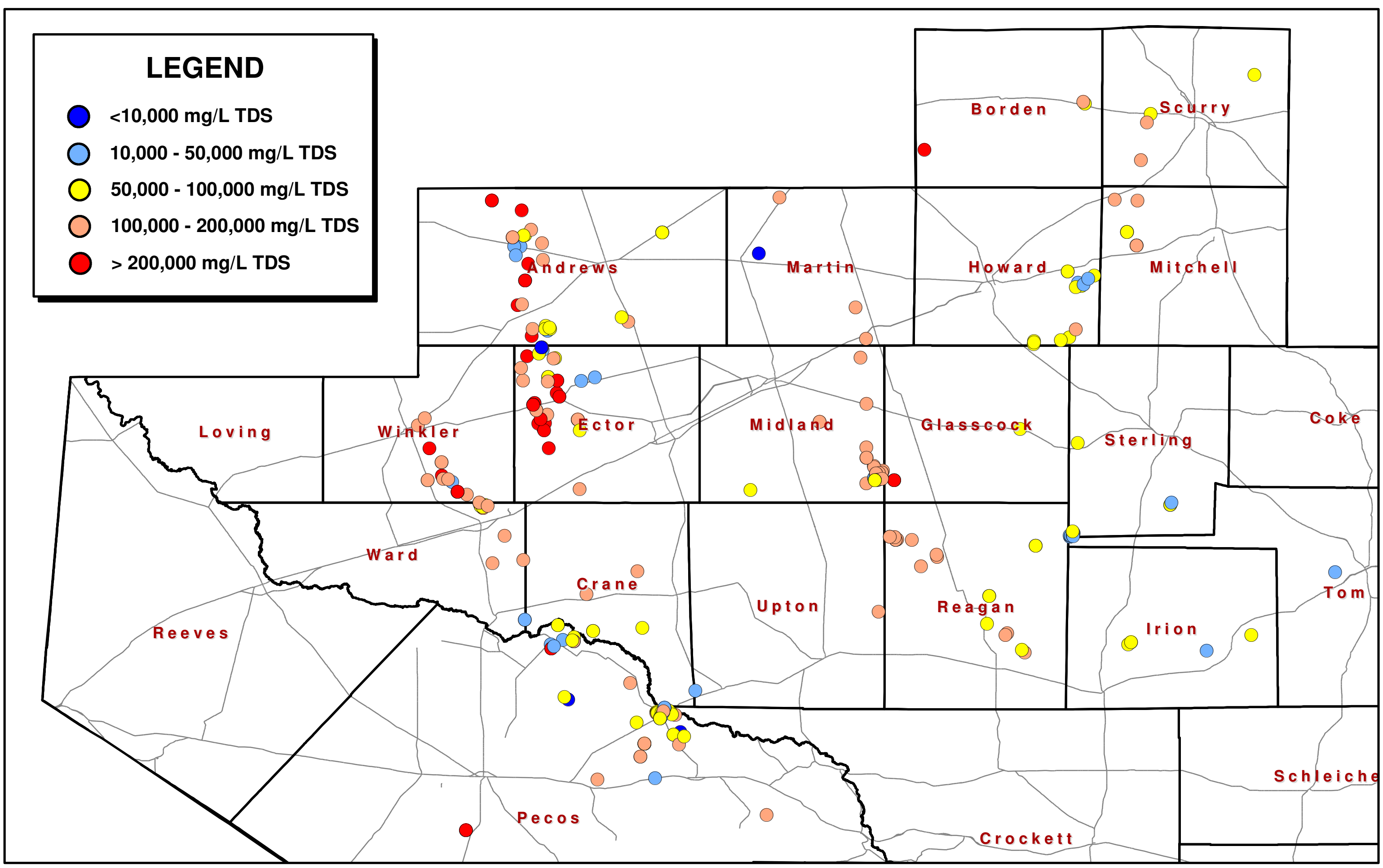


Figure 20b - Produced water quality in oil and gas wells in the Clear Fork-Wichita Aquifer

Leonard (Clear Fork-Wichita) Aquifer - The Leonard Series is a Permian-age unit located throughout much of West Texas. This series contains several well-known formations/groups, including the Spraberry Formation, the Clear Fork Group, the Victorio Peak and Bone Springs Formations, the upper Wichita (or Wichita-Albany) Group, and the Leuders Group, among others. A map of the elevation of the top of the Leonard aquifer is shown in Figure 20a, which is the structure of the top of the Clear Fork Group (Core Laboratories, 1972). Depth to the top of production intervals of oil and gas wells in the Leonard (also shown in Figure 20a) indicates a maximum depth of approximately 8,000 feet, and less than 5,000 feet in most of the region.

The individual units that make up the Leonard aquifer are quite variable from area to area, but generally consist of limestone, shale, sandstone, and anhydrite. Productivities and aquifer characteristics vary with the formations (Core Laboratories, 1972). The Clear Fork Group, which consists of the Choza, Vale, and Arroyo Formations in north-central Texas, is 1,200 to 1,500 feet thick and produces fresh to slightly saline water to wells where these rocks outcrop or are found in the shallow subsurface. Groundwater is produced from the Clear Fork Group in Coke, Runnels, and Coleman Counties, nearly all from wells less than 200 feet deep. In addition, the Lipan aquifer located in Tom Green, Runnels, and Concho Counties (described above in Section 2) includes water in the upper portions of the Choza, Bullwagon, and Vale Formations.

The Clear Fork and Wichita Groups are the principal aquifers in the Leonard Series, and productivity is generally high where these aquifers are present. Relatively low water productiveness occurs throughout most of the rest of the region where the undifferentiated Leonard units exists.

Water produced from the Clear Fork is generally slightly to moderately saline, although fresh water is produced in some areas. Salinities from produced waters from the Leonard aquifer vary widely (as shown in Figure 20b) ranging from less than 5,000 mg/L to over 300,000 mg/L.

The Leonard aquifer may be considered a potential brackish or saline water source for parts of Region F where it is encountered at depths of less than 5,000 feet. Salinities are high in much of the region, but are lower in some areas.

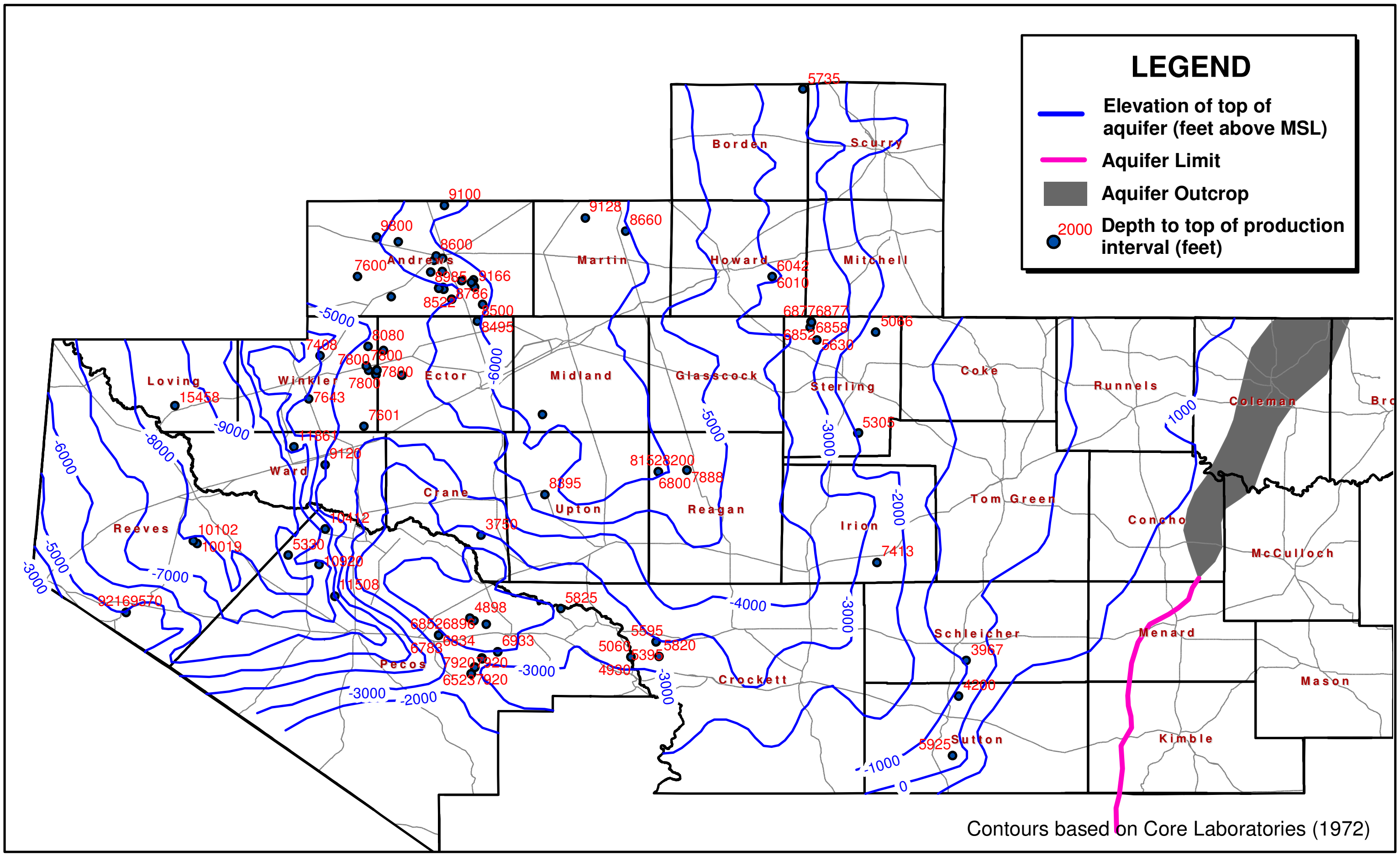


Figure 21a - Depth to the top of the Wolfcamp Aquifer

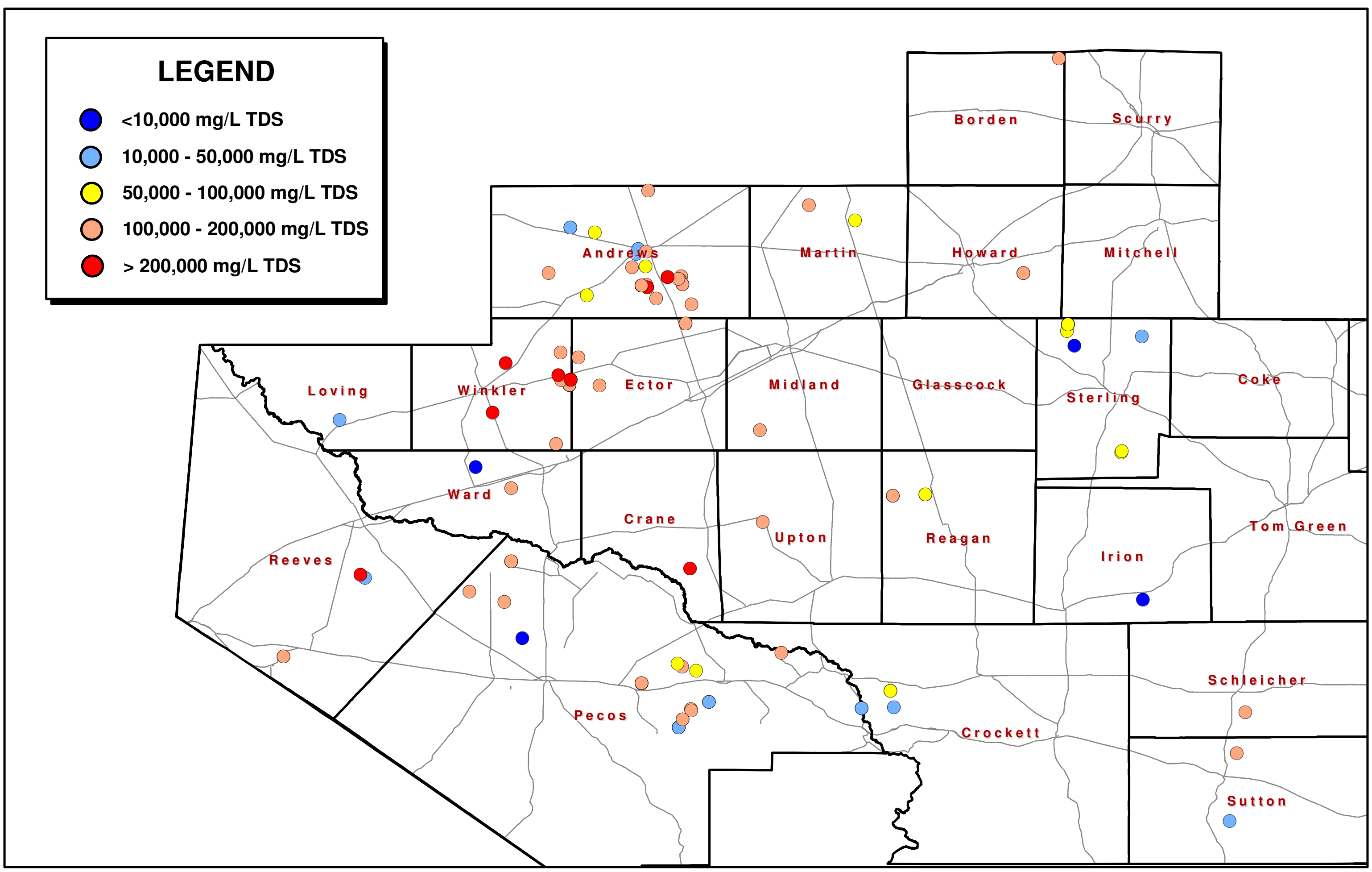


Figure 21b - Produced water quality in oil and gas wells in the Wolfcamp Aquifer

Wolfcamp (Coleman Junction) Aquifer - The Wolfcamp Series is the oldest of the Permian-aged units in West Texas, and is comprised of several formations, including most importantly in the eastern Region F area, the Coleman-Junction. The Wolfcamp Series is the thickest of any of the Paleozoic sequences in West Texas, reaching a maximum thickness of 14,000 feet in the Delaware Basin and Val Verde Trough in West Texas (Core Laboratories, 1972). From its outcrop in Concho and Coleman Counties, the formations dip into the subsurface, and are present throughout the western half of the state, including most of Region F. The elevation of the top of the Wolfcamp is shown in Figure 21a, along with depths to the top of production intervals for oil and gas wells in the region. The depths indicated on wells in this figure may be misleading, because they may not be at the top of the Wolfcamp and, as noted above, the Wolfcamp can be extremely thick in parts of the region, and therefore this depth may be significantly different than the true top of the aquifer.

Because the Wolfcamp is so widespread and so thick, the units contained within it have a wide range of lithologies and hydrologic properties. Porosities ranging from 5 to more than 25 percent, and permeabilities range from 1 millidarcy to more than 1 darcy (Core Laboratories, 1972). This also results in highly variable water quality. As with most other hydrocarbon-producing units in the region, salinities are highly variable on a regional basis (Figure 21b) ranging from lower salinities (less than 50,000 mg/L) to more than 300,000 mg/L TDS.

The Wolfcamp may be considered as a potential saline water source for Region F. It is very widespread throughout much of the region, and may contain significant quantities of saline groundwater. As with the other deeper, typically hydrocarbon-producing units being evaluated, site-specific studies should be conducted to determine the water quality and nature of the aquifer due to the variability in aquifer properties and formation water quality throughout the extent of the aquifer.

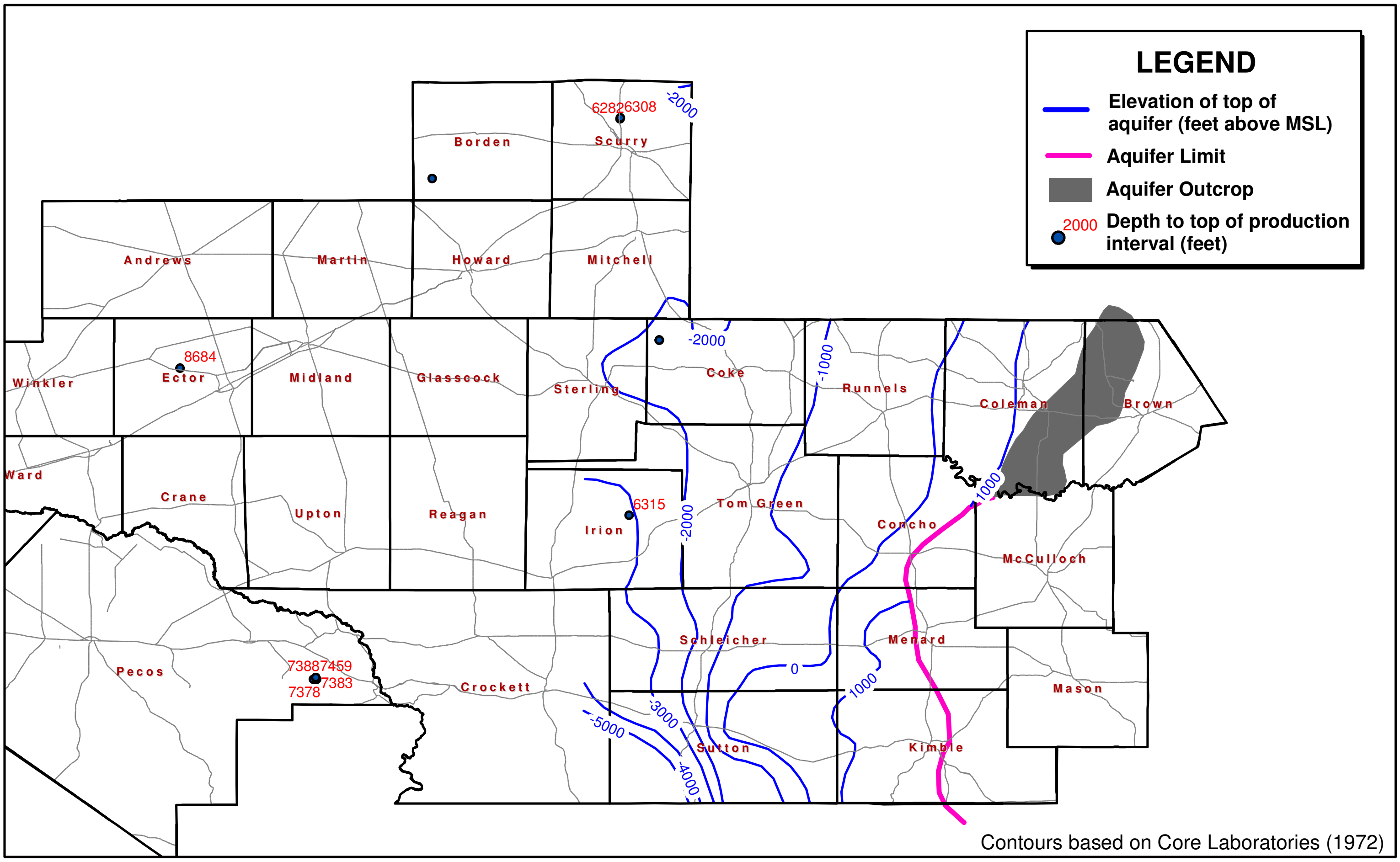


Figure 22a - Depth to the top of the Cisco Aquifer

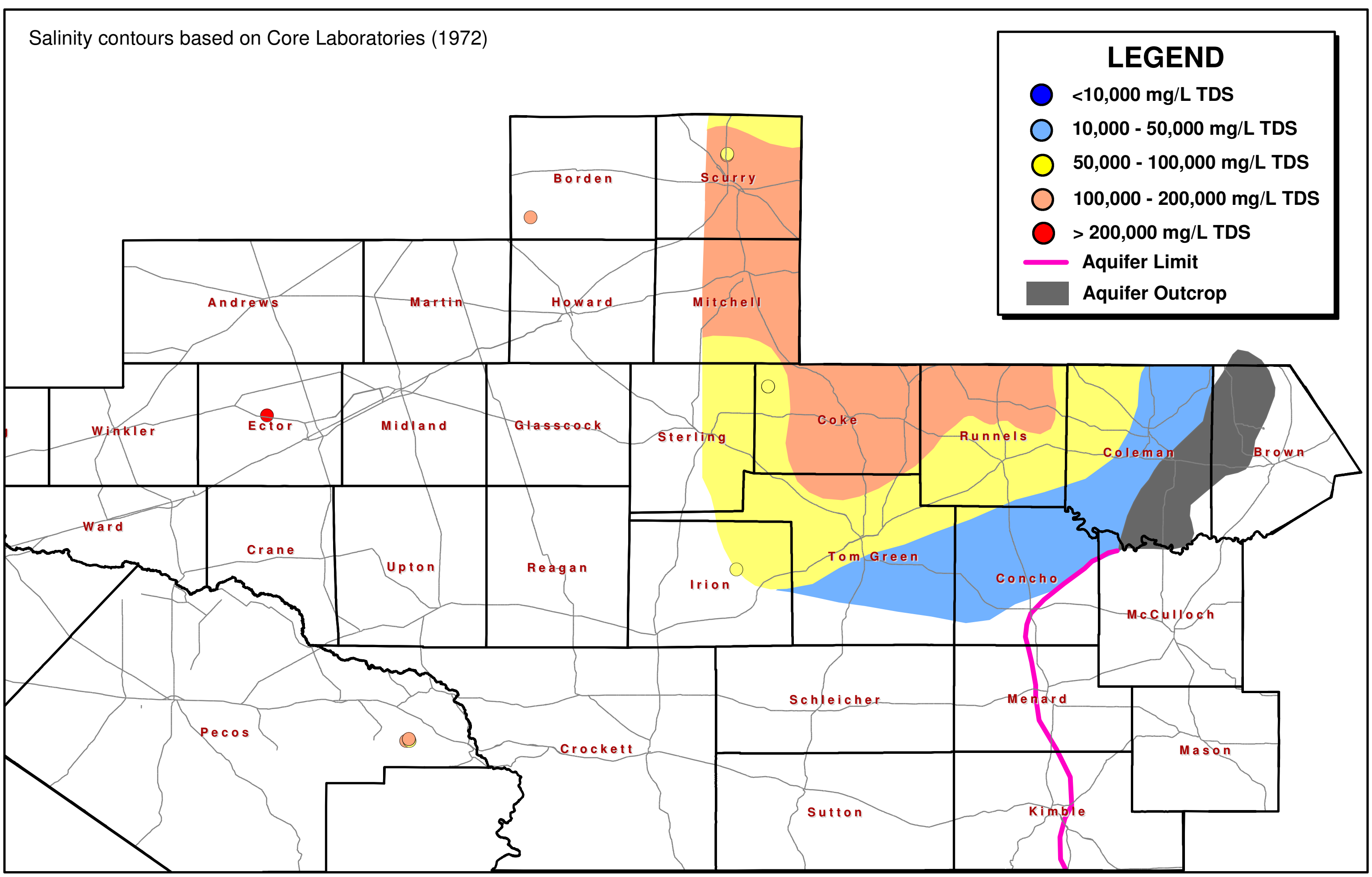


Figure 22b - Produced water quality in oil and gas wells in the Cisco Aquifer

3.2 Pennsylvanian-age Aquifers

Cisco Aquifer – The Cisco Group is the uppermost Pennsylvanian aged unit present in Central Texas. The Cisco Group outcrops in a 15 to 20 mile band in Concho, McCulloch, and Coleman Counties and rapidly dips into the subsurface away from the Llano Uplift area. The elevation of the top of the Cisco Group is shown in Figure 22a, along with depths to the top of production intervals in oil and gas wells producing from the Cisco.

The Cisco Group contains both the Thrifty and Graham Formations and is comprised of shales, sandstones, conglomerates, limestones, and coal beds. It is approximately 1,000 feet thick away from the outcrop, however net sand is only 10 to 15 percent of the total thickness. Porosities average 12 to 22 percent, and permeabilities range from 10 to 350 millidarcies (Core Laboratories, 1972).

The Cisco Group provides fresh to moderately saline water to wells in Coleman and Brown Counties, in and near where it outcrops. Of the water wells in the Region F area that are included in the TWDB database, just over half produce fresh water, with most of the remainder producing slightly saline (1,000-3,000 mg/L TDS) groundwater. A majority of these wells are less than 200 feet deep. In the downdip areas, salinities of produced water from the Cisco are shown in Figure 22b and have TDS ranging from 50,000 to 200,000 mg/L.

Because the Cisco produces groundwater with relatively low salinities, it may be considered a potential source of saline water within Region F, particularly in the eastern half of the region where the aquifer is found at shallower depths.

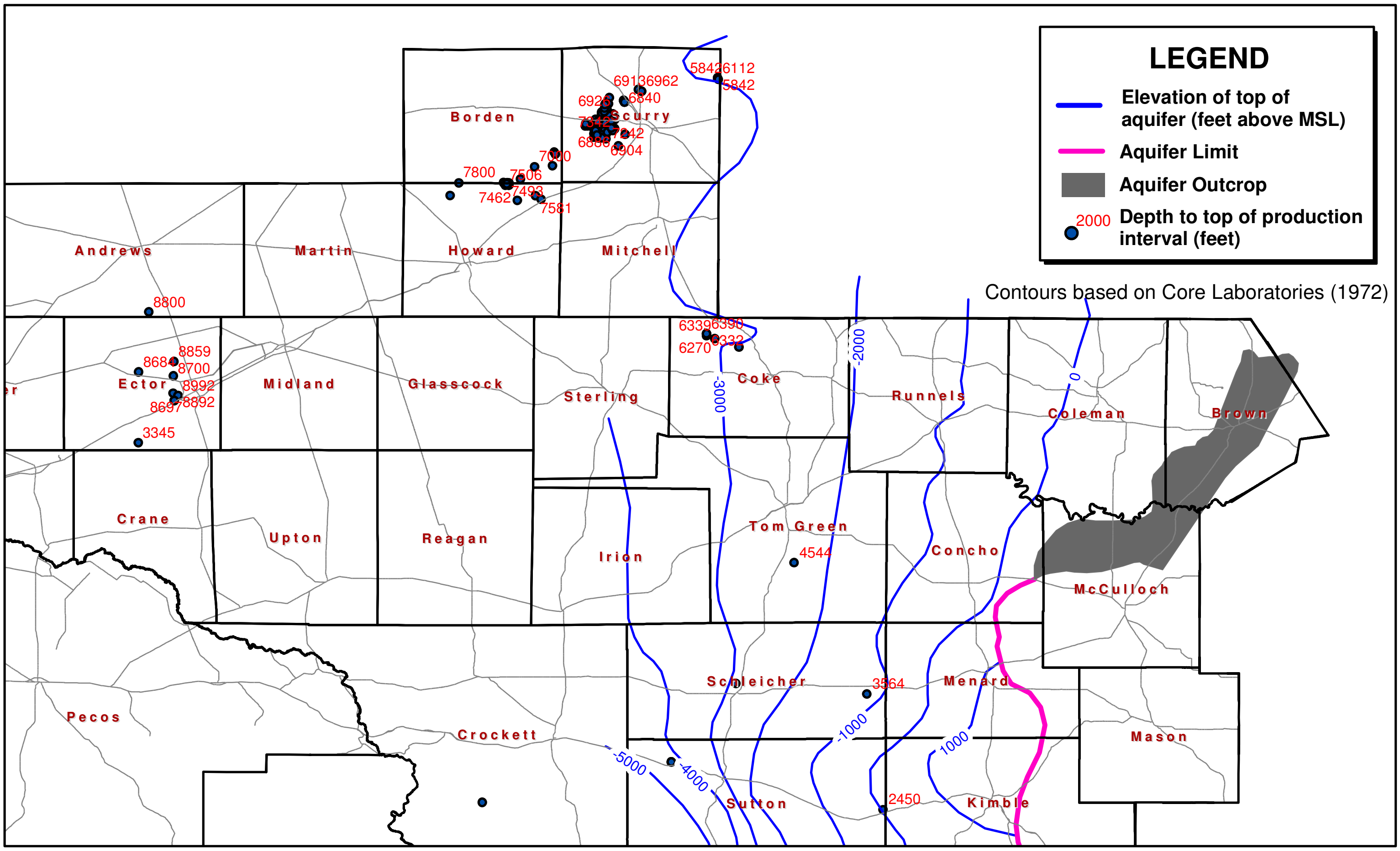


Figure 23a - Depth to the top of the Canyon Aquifer

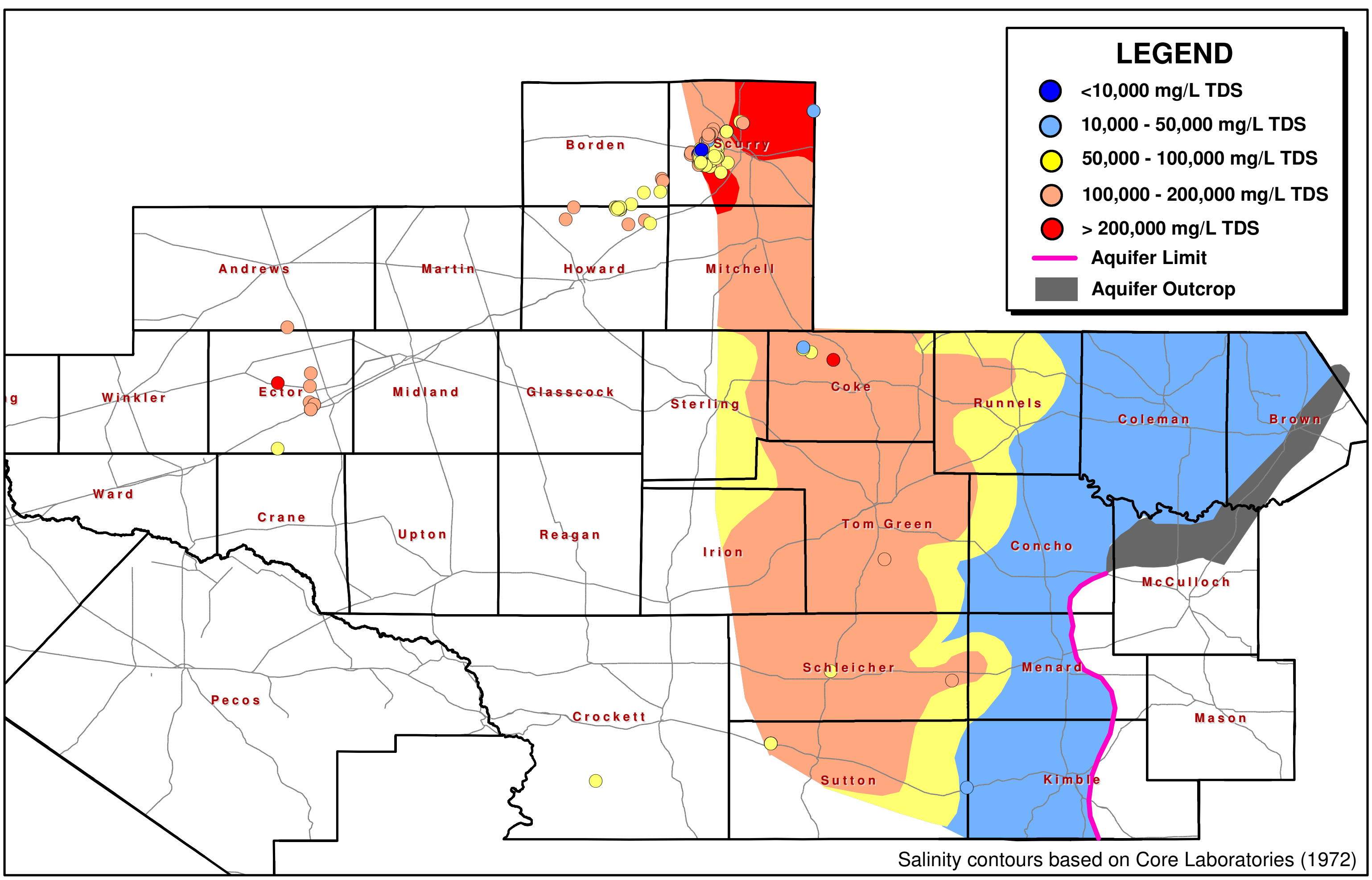


Figure 23b - Produced water quality in oil and gas wells in the Canyon Aquifer

<u>Canyon Aquifer</u> – The Pennsylvanian-age Canyon Group is located stratigraphically below the Cisco and includes four formations; the Palo Pinto, Graford, Brad, and Caddo Creek. The Canyon Group outcrops west and north of the Llano Uplift in Brown and McCulloch Counties, and, as with the Cisco, rapidly dips into the subsurface, occurring at depths of 3,000 feet within 50 miles of the outcrop, and much greater depths throughout the rest of Region F. The elevation of the top of the Canyon in the eastern to central portion of Region F is shown in Figure 23a. Depths to the upper zone of oil and gas wells from the Canyon are also included for the western portion of the region. These data show that depths to the top of production zones are 6,000 to 9,000 feet in the western half of the region. Porosities of the thick limestone beds in the Canyon range from 5 to 25 percent, and the porosity of the reef facies may be as high as thirty percent locally. Permeabilities range from 1 to over 500 millidarcies (Core Laboratories, 1972).

The Canyon provides some fresh but mostly slightly- to moderately-saline water to wells that are less than 400 feet deep in and near the outcrop area. In downdip areas, limited quality data from Canyon produced water suggests a wide range of salinity, ranging from less than 10,000 mg/L to greater than 200,000 mg/L (Figure 23b). As with other deeper, hydrocarbon-producing formations, the salinity of formation water may be more variable on a regional basis than the contours shown in Figure 23b suggest. Because the Canyon produces groundwater with relatively low salinities in the eastern third of the region where the aquifer is found at depths of less than 5,000 feet, it may be a potential source of saline water in this area.

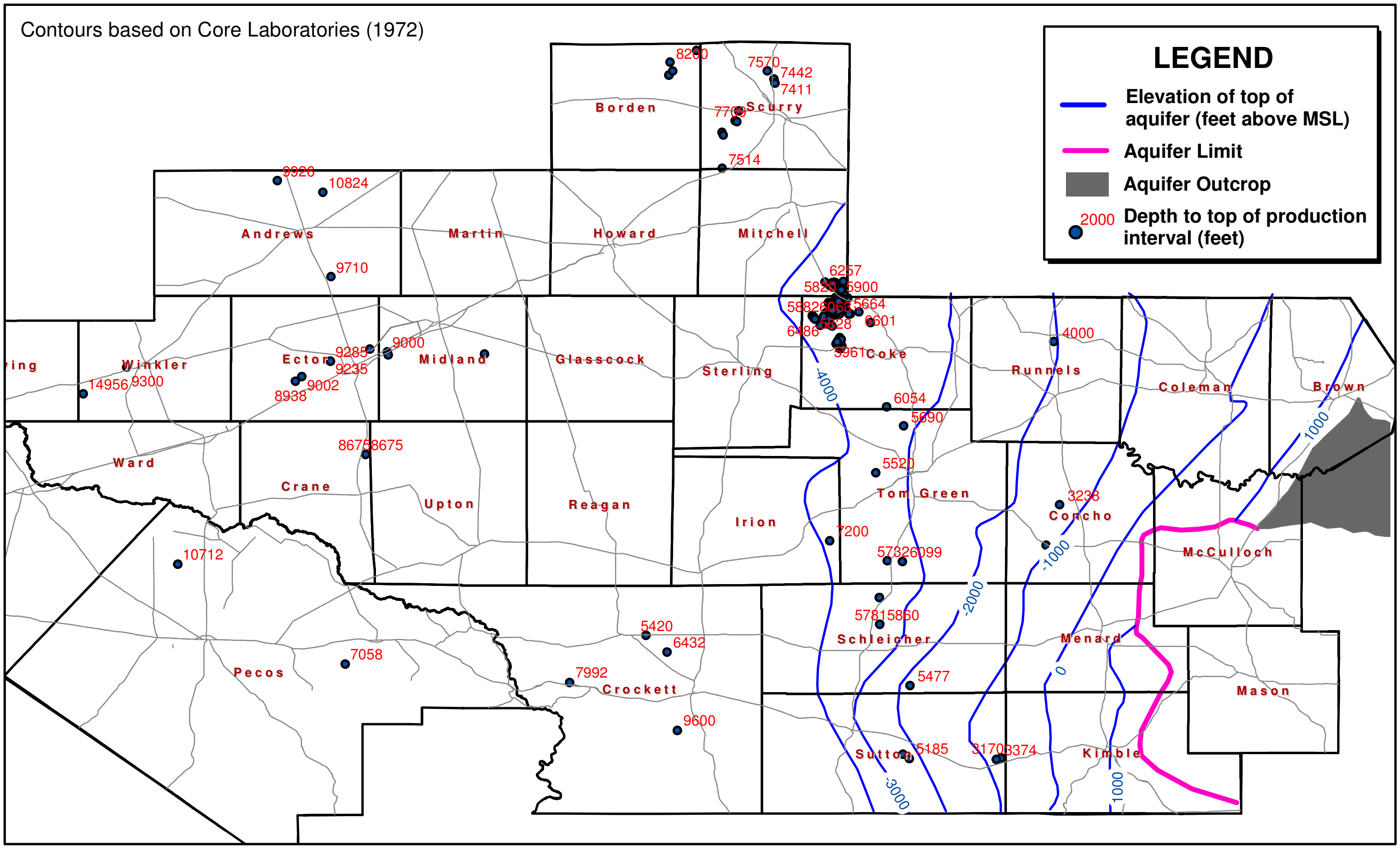


Figure 24a - Depth to the top of the Strawn Aquifer

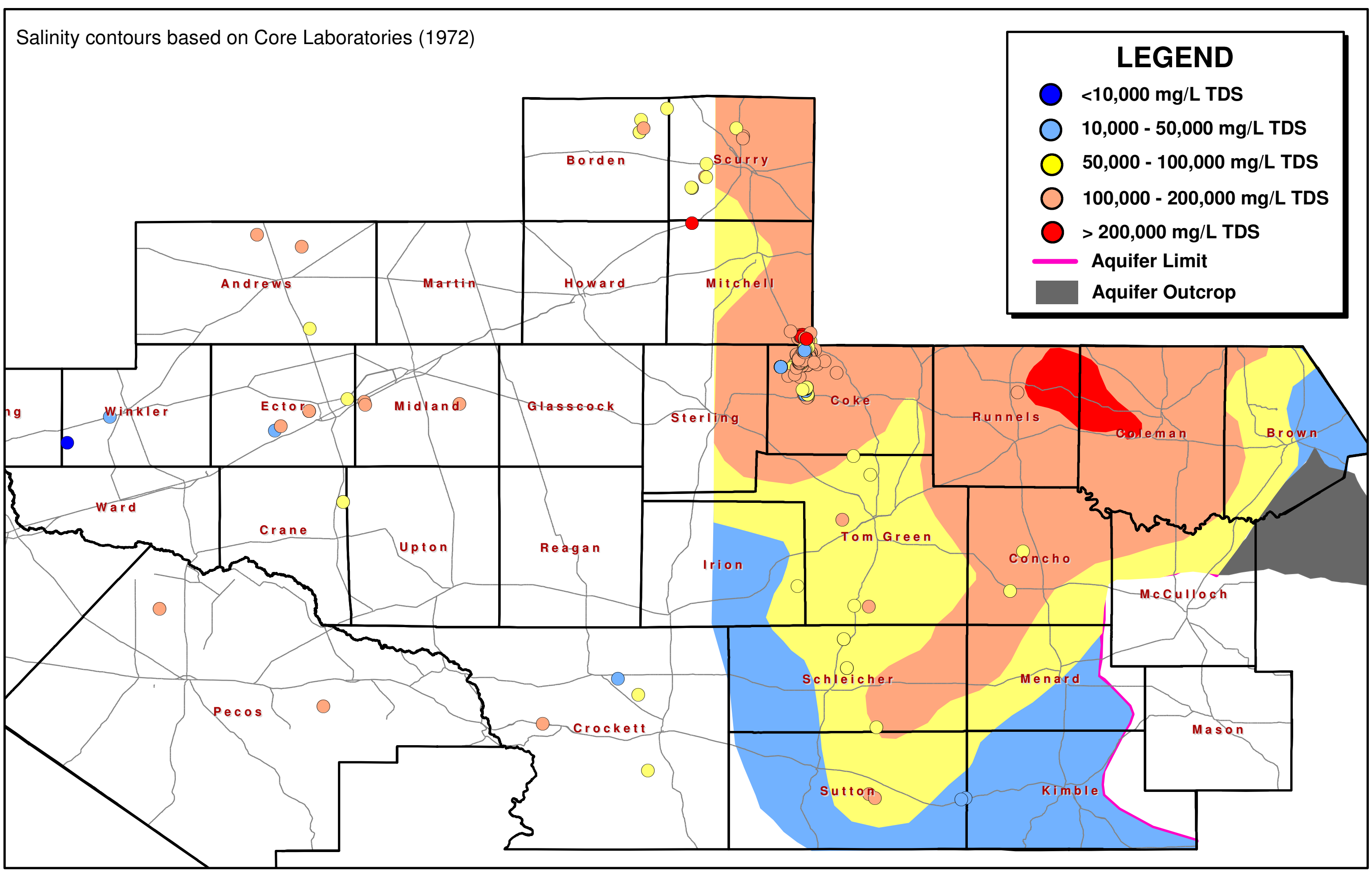


Figure 24b - Produced water quality in oil and gas wells in the Strawn Aquifer

Strawn Aquifer – The Strawn Group, located stratigraphically below the Canyon, is a Pennsylvanian aged unit found throughout Region F, and includes the Lone Camp, Millsap Lake, and Kickapoo Creek Formations. The Strawn Group outcrops in a very wide area immediately north of the Llano Uplift, including the extreme western portions of McCulloch and Brown Counties of Region F. The elevation of the top of the Strawn Group is shown in Figure 24a. As with the other Pennsylvanian-aged units, the Strawn rapidly dips into the subsurface away from the Llano Uplift, occurring at significant depths throughout much of the Region F area. Only in the easternmost counties in the planning area does the Strawn occur at depths of less than 5,000 feet. The Strawn Group consists of sandstones, shales, conglomerates, and limestones, and due to the variations in rock types, porosities and permeabilities are highly variable, with porosity ranges of 5 to 20 percent and permeability ranges of 5 to over 500 millidarcies (Core Laboratories, 1972).

The Strawn provides fresh to slightly saline water to numerous wells in and near the outcrop area in Brown County, and to some wells in the extreme northeastern corner of McCulloch County. The depths of these wells are generally less than 250 feet, although some wells are as deep as 500 feet. The Strawn is also a significant hydrocarbon-producing formation, and quality data of produced water is available from this unit in its western extent (Figure 24b). Produced formation water in the western extent of the Strawn is highly saline, with TDS concentrations of over 200,000 mg/L being common. A trend toward lower salinity (<50,000 mg/L) occurs in the aquifer's southeasterly extent.

Because of the depth to the Strawn aquifer, this aquifer may be a potential brackish or saline water source primarily in the eastern third of Region F. Salinities in this area tend to be high, but are lower than many other hydrocarbon-producing units in the region.

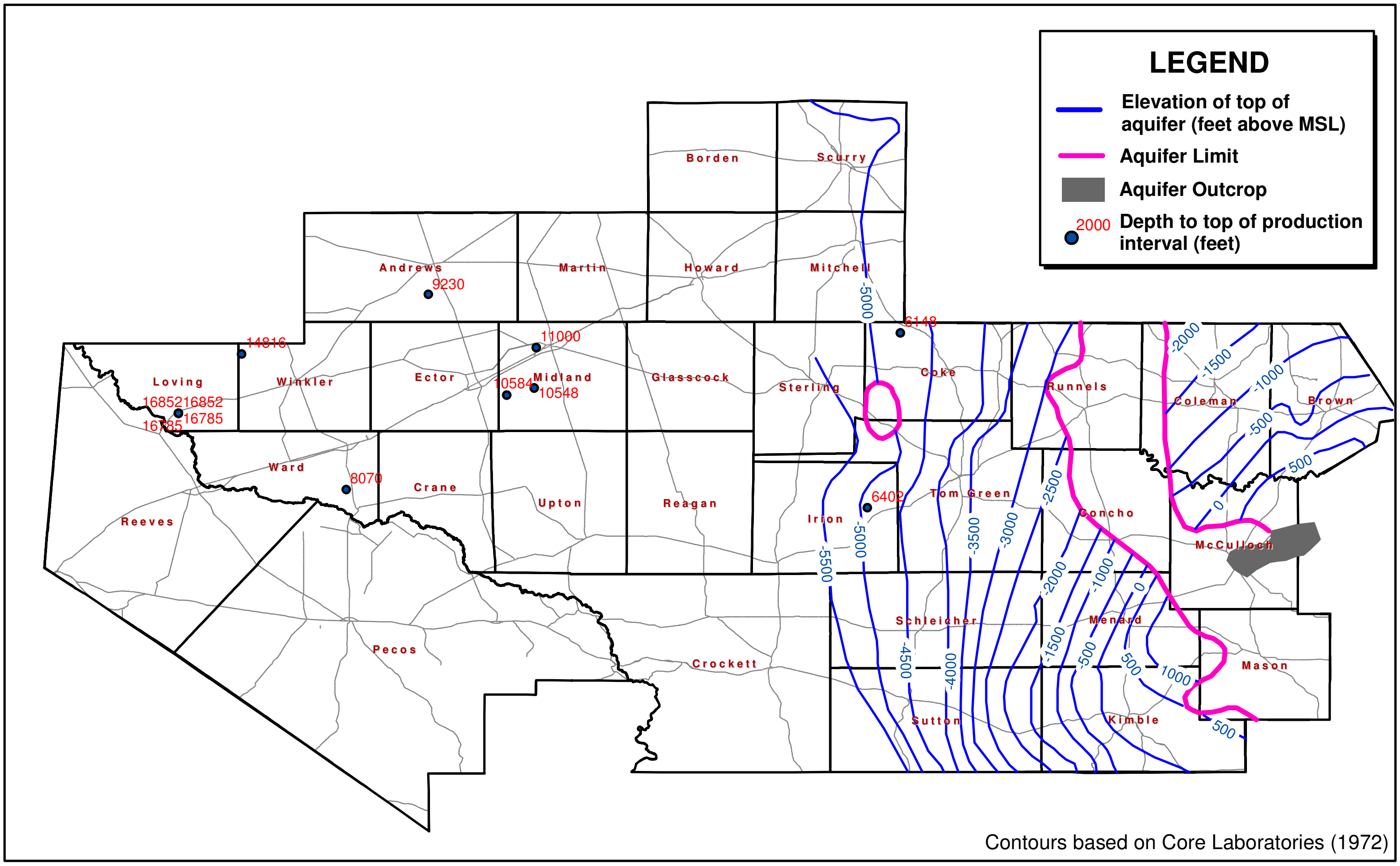


Figure 25a - Depth to the top of the Bend Aquifer

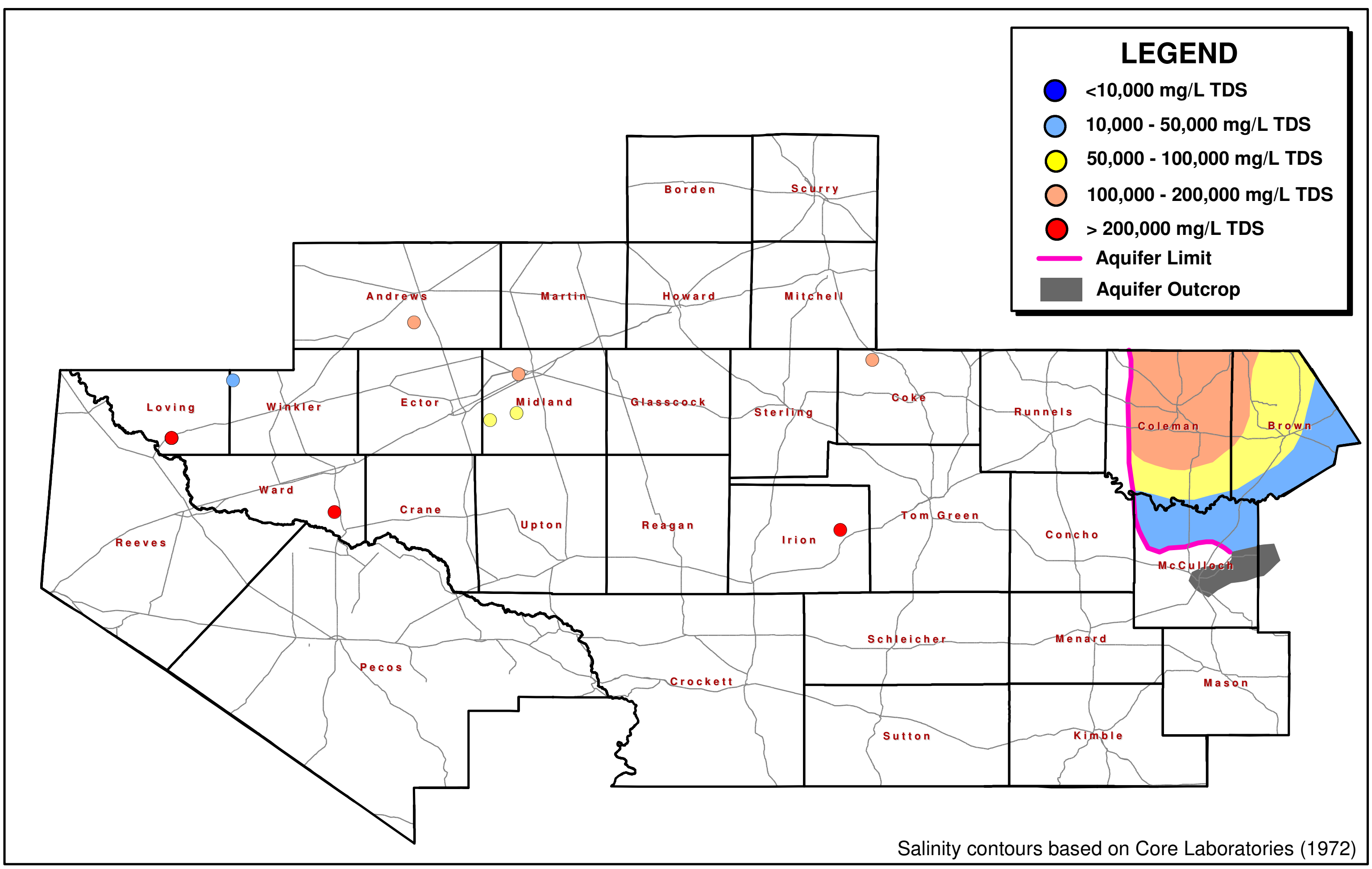


Figure 25b - Produced water quality in oil and gas wells in the Bend Aquifer

Bend Aquifer - The Bend Group is the oldest and deepest of four major Pennsylvanian aged units that are present throughout much of the Region F area, and is located stratigraphically below the Strawn. The Bend Group includes the Morrow and Atoka Formations in West Texas, and consists of shales, limestones, conglomerates, and thin sandstones. The formations crop out in the Llano Uplift area in the far eastern portion of the Region F, and dip rapidly into the subsurface, as shown in Figure 25a. Depths of wells producing from the Bend aquifer in the western portion of Region F exceed 15,000 feet. Permeabilities ranging from 5 to 600 millidarcies and porosities of 10 to 20 percent occur primarily coarse-grained sands and conglomerates (Core Laboratories, 1972).

Very few produced water data from Bend aquifer oil and gas wells are available, but those that are indicate that salinities range from 25,000 to 300,000 mg/L. In its eastern extent, salinity in the Bend aquifer ranges from 50,000 to 200,000 mg/L, with a slight decrease in salinity toward the south. Figure 25b shows the interpreted salinity contours of the Bend in the Llano Uplift area, plus additional quality data in the western region. Because the Bend aquifer is very thin, highly saline, and deep throughout much of the Region F area, it is not considered to be a good source of saline water.

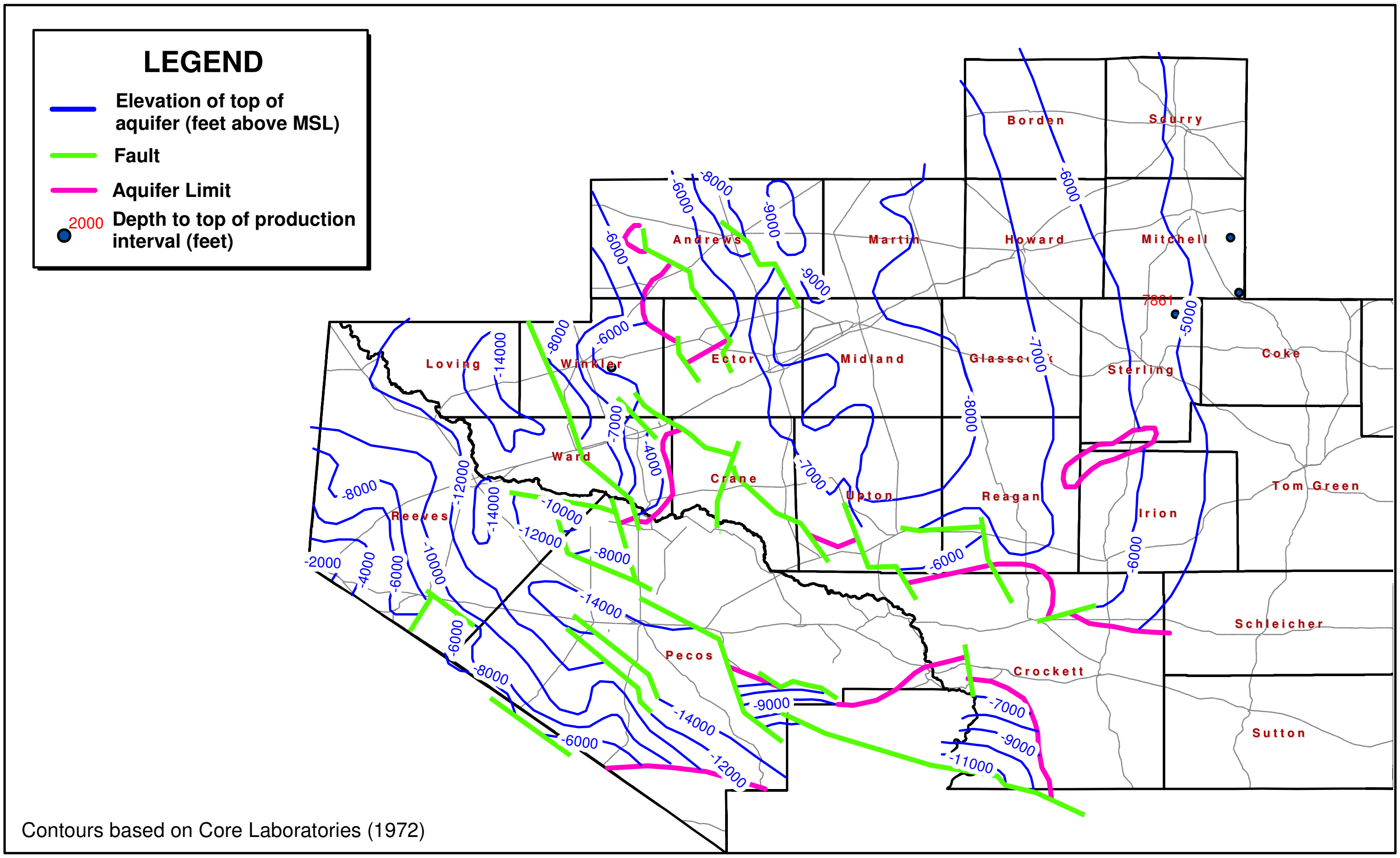


Figure 26a - Depth to the top of the Mississippian Aquifer

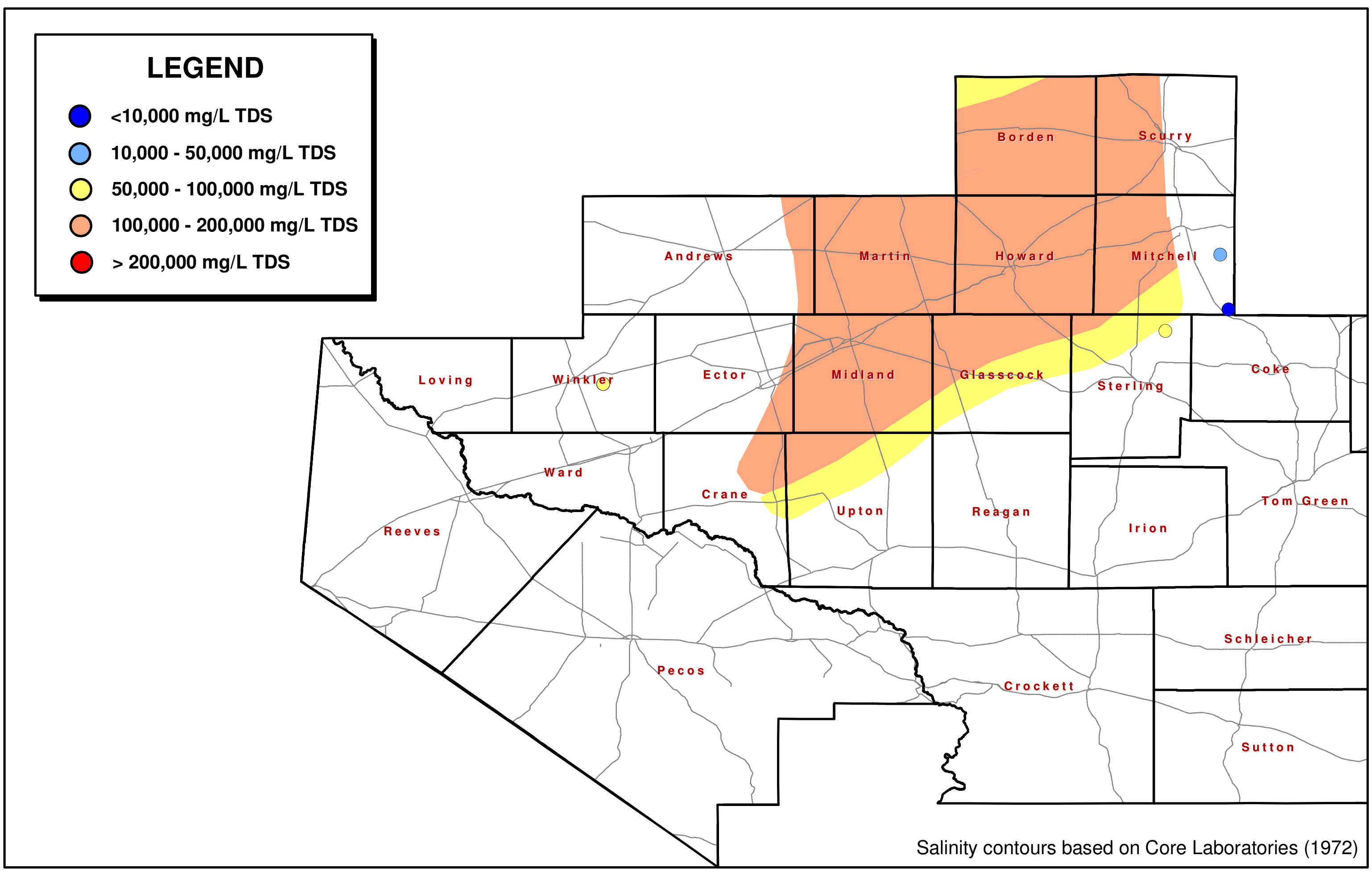


Figure 26b - Produced water quality in oil and gas wells in the Mississippian Aquifer

3.3 Mississippian through Ordovician-age Aquifers

Mississippian Aquifer - The Mississippian aquifer is present throughout much of West Texas. The elevation of the top of the Mississippian aquifer in the Region F area is shown in Figure 26a and varies from 4,000 to more than 15,000 feet below sea level, and is more than 5,000 feet below land surface throughout the Region F area.

The Mississippian aquifer consists mainly of limestone and siliceous limestone. Productivity data indicate porosities of 8 to 12 percent and permeabilities of 10 to 50 millidarcies (Core Laboratories, 1972). Very few salinity data exist on water present in the Mississippian aquifer. However, the data that are available indicate a TDS range of 50,000 to 150,000 mg/L. Figure 26b shows the interpreted salinity contours of produced water quality. However, as with other deep, hydrocarbon-producing formations in the region, it is likely that formation water quality in the Mississippian aquifer is much more variable than the contours might suggest.

Due to the depth to the Mississippian aquifer, and the very high TDS of water produced from them, this aquifer is not considered to be practical saline or brackish groundwater source for the purposes of this study.

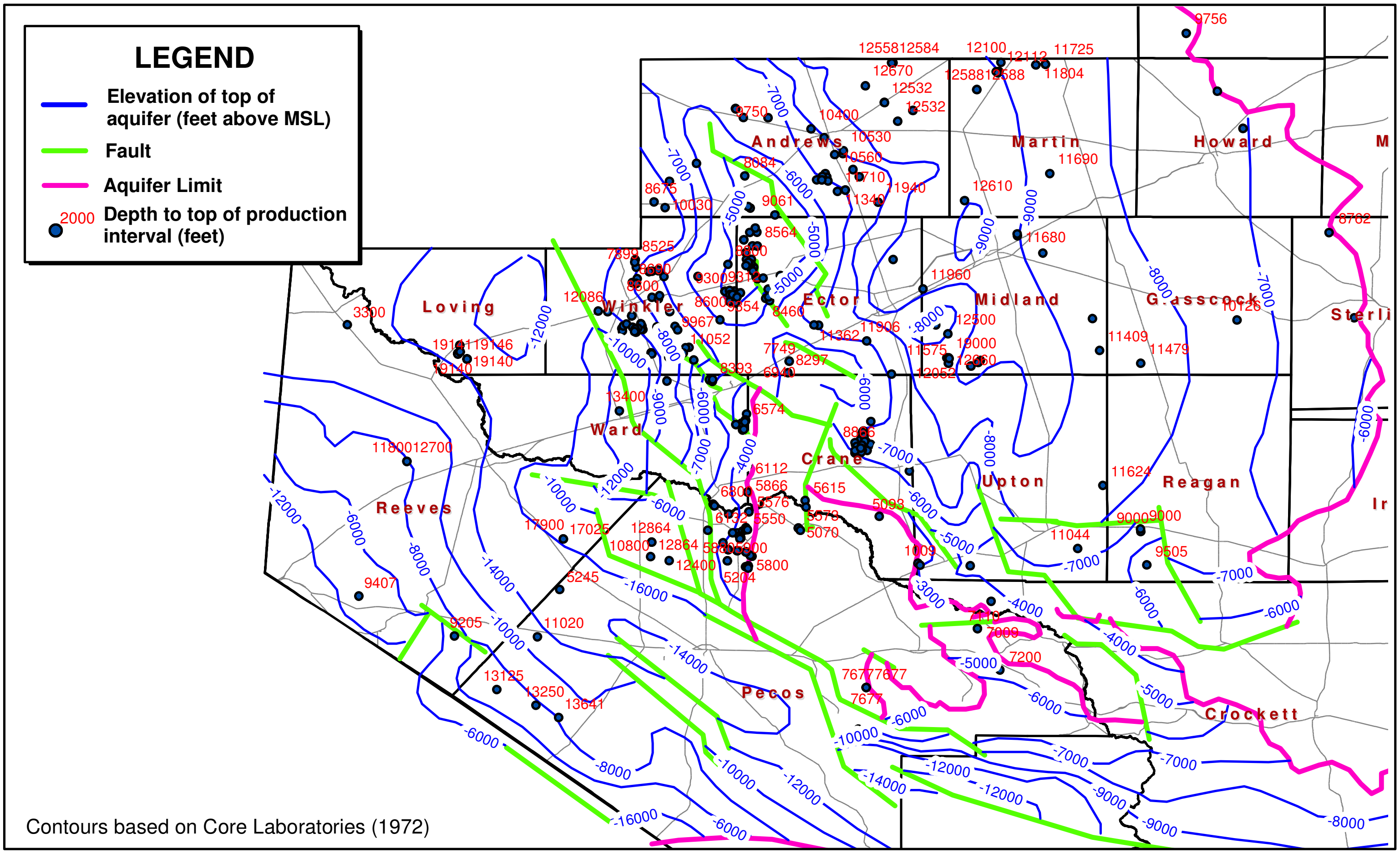


Figure 27a - Depth to the top of the Siluro-Devonian Aquifer

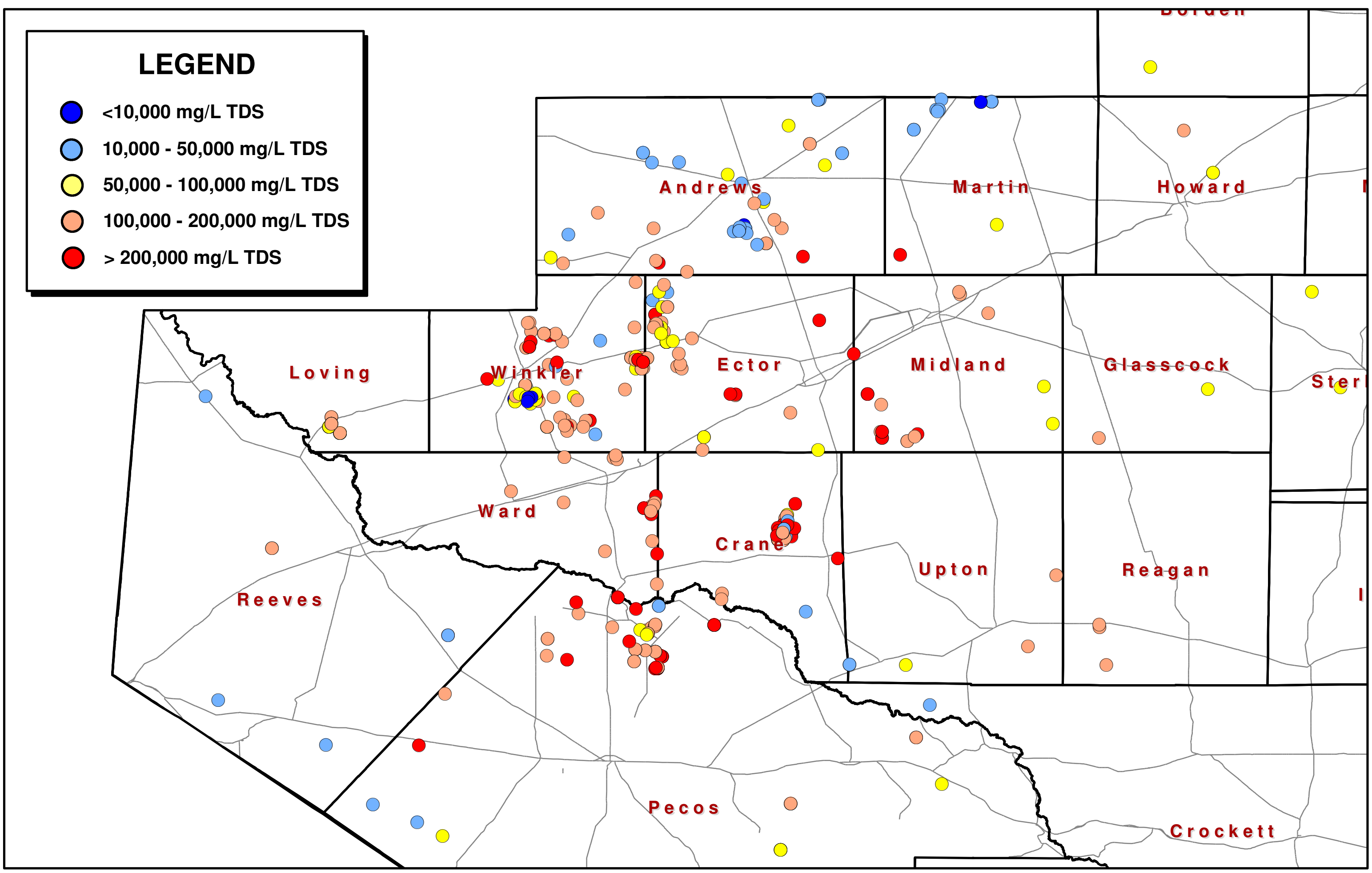


Figure 27b - Produced water quality in oil and gas wells in the Siluro-Devonian Aquifer

Siluro-Devonian Aquifer - Located under portions of West Texas, the Siluro-Devonian aquifer occurs at depths of greater than 5,000 feet in most of the areas where it is present in the region. The Silurian-age Fusselman Formation and the Devonian Limestone are the predominate units associated with this deep aquifer system. Figure 27a shows the elevation of the top of this aquifer in the Region F area.

The Siluro-Devonian aquifer consists mainly of limestone and chert. Porosities range from 5 to 10 percent, and permeabilities vary significantly, from less than 10 to greater than 100 millidarcies (Core Laboratories, 1972).

Figure 27b shows water quality of produced water from oil and gas wells, mostly for the Fusselman Formation. These analyses show high TDS ranging from 40,000 to more than 300,000 mg/L, with a large percentage being over 100,000 mg/L. Because of the depth to this aquifer, and the very high TDS of water produced from it, the Siluro-Devonian aquifer is considered to be a poor choice as a saline or brackish groundwater source for the purposes of this study.

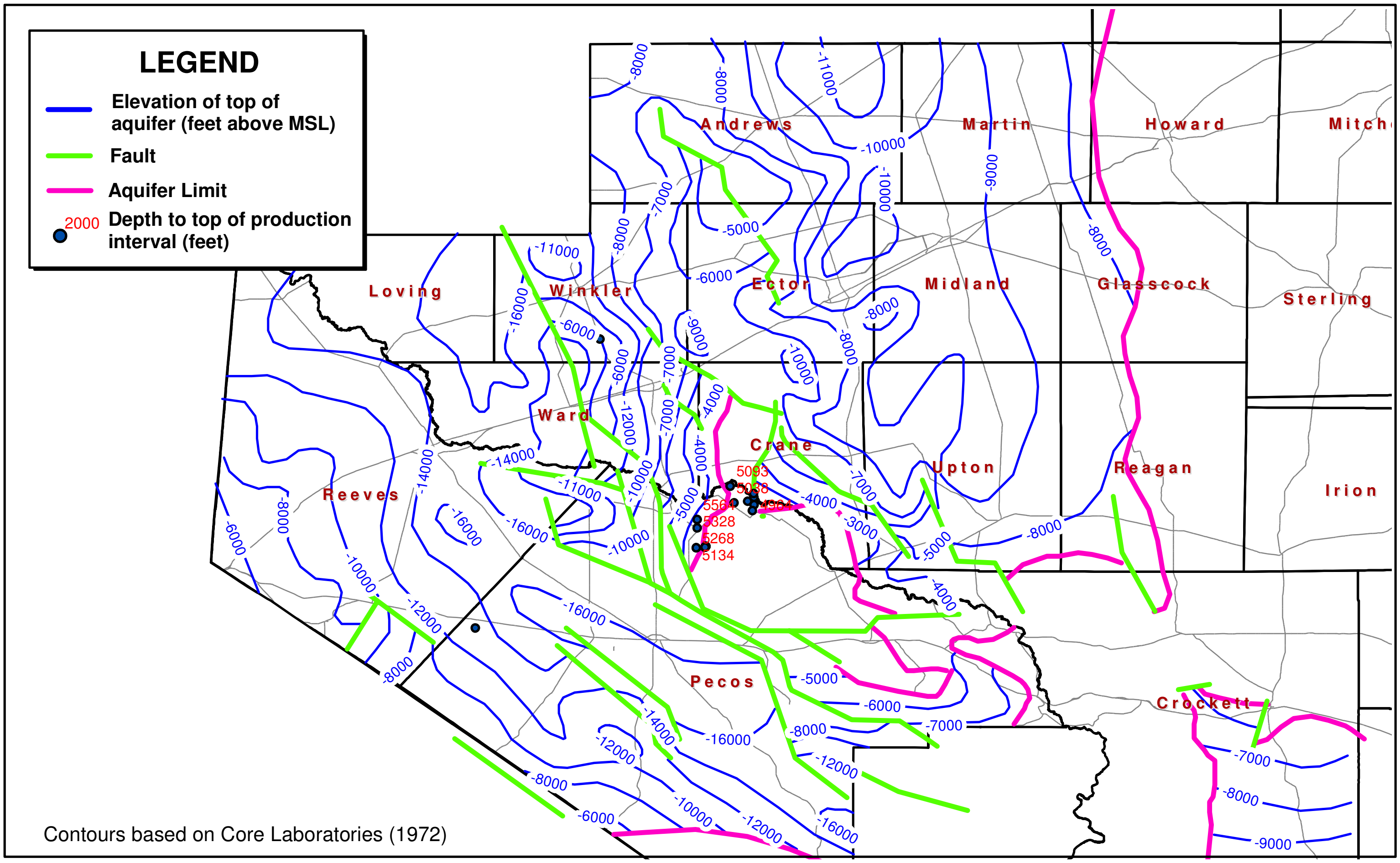


Figure 28a - Depth to the top of the Montoya Aquifer

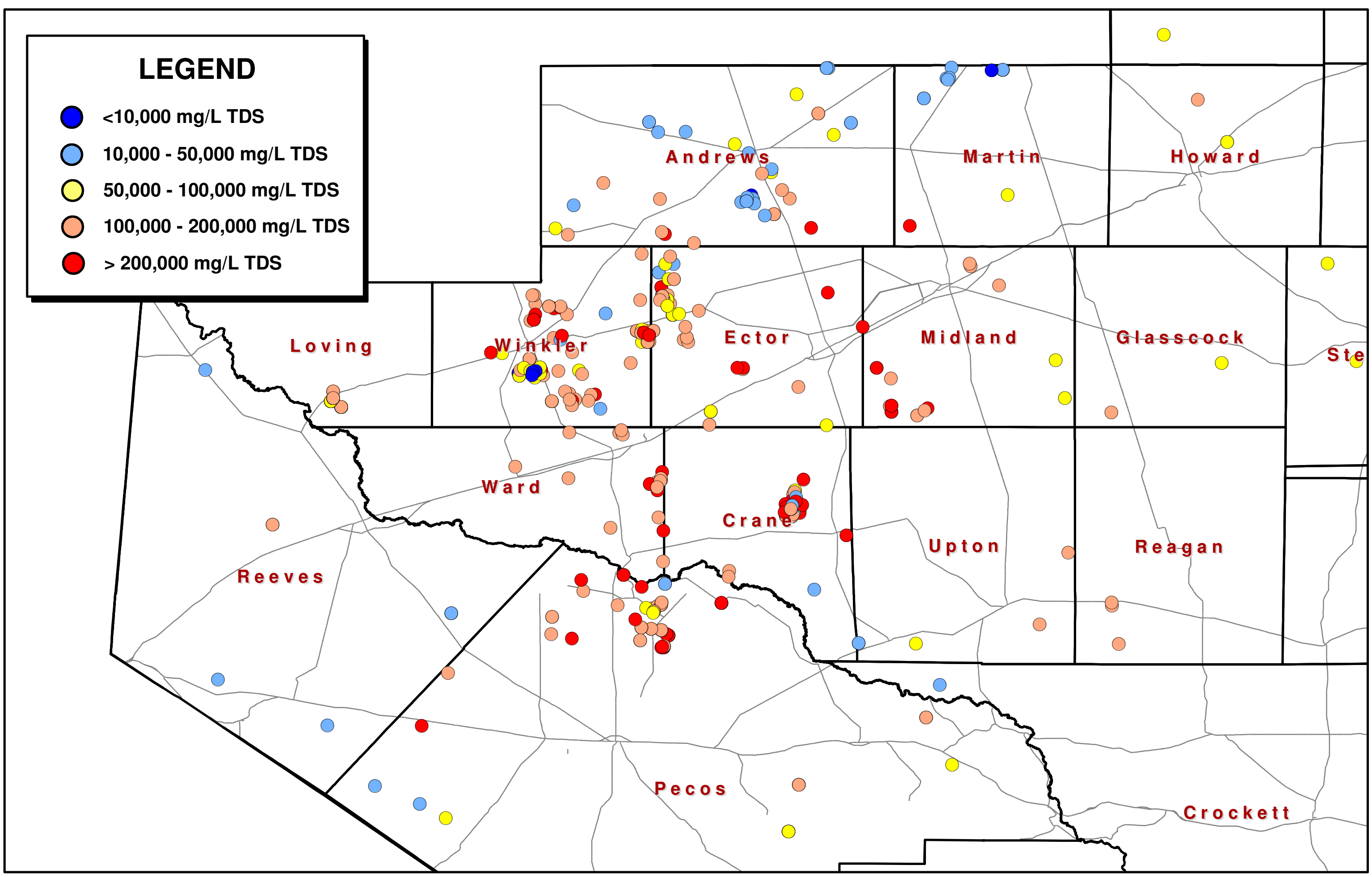


Figure 28b - Produced water quality in oil and gas wells in the Simpson and Montoya Aquifers

Simpson-Montoya Aquifer - The hydrocarbon producing Simpson and overlying Montoya Formations of Ordovician age are found at depths of greater than 5,000 feet throughout most the Region F area. Figure 28a shows the top of the Montoya formation in the Region F area. The Simpson aquifer consists mainly of shale with thin sandstone and limestone beds, and the Montoya consists mainly of dolomite, limestone, and chert. Productivity data for the Simpson are scarce, and porosities and permeabilities vary too much to give a meaningful assessment of their ranges. Productivity and rock property data for the Montoya indicate porosities range from 5 to 10 percent and permeabilities average 10 millidarcies (Core Laboratories, 1972).

Figure 28b shows the total dissolved solids concentrations for waters from both the Simpson and Montoya aquifers. Analytical data of the produced water from both formations indicate total dissolved solids concentrations of greater than 100,000 mg/L. Water quality of produced waters from the Simpson and Montoya Formations indicates that the TDS magnitude of the Montoya is between 40,000 and 150,000 mg/L, and of the Simpson is 50,000 to 200,000 mg/L (very few data exist for the Simpson).

Because of the depth to these formations and the very high TDS of water produced from them, neither the Simpson nor the Montoya aquifers are considered to be practical saline or brackish groundwater sources for the purposes of desalination.

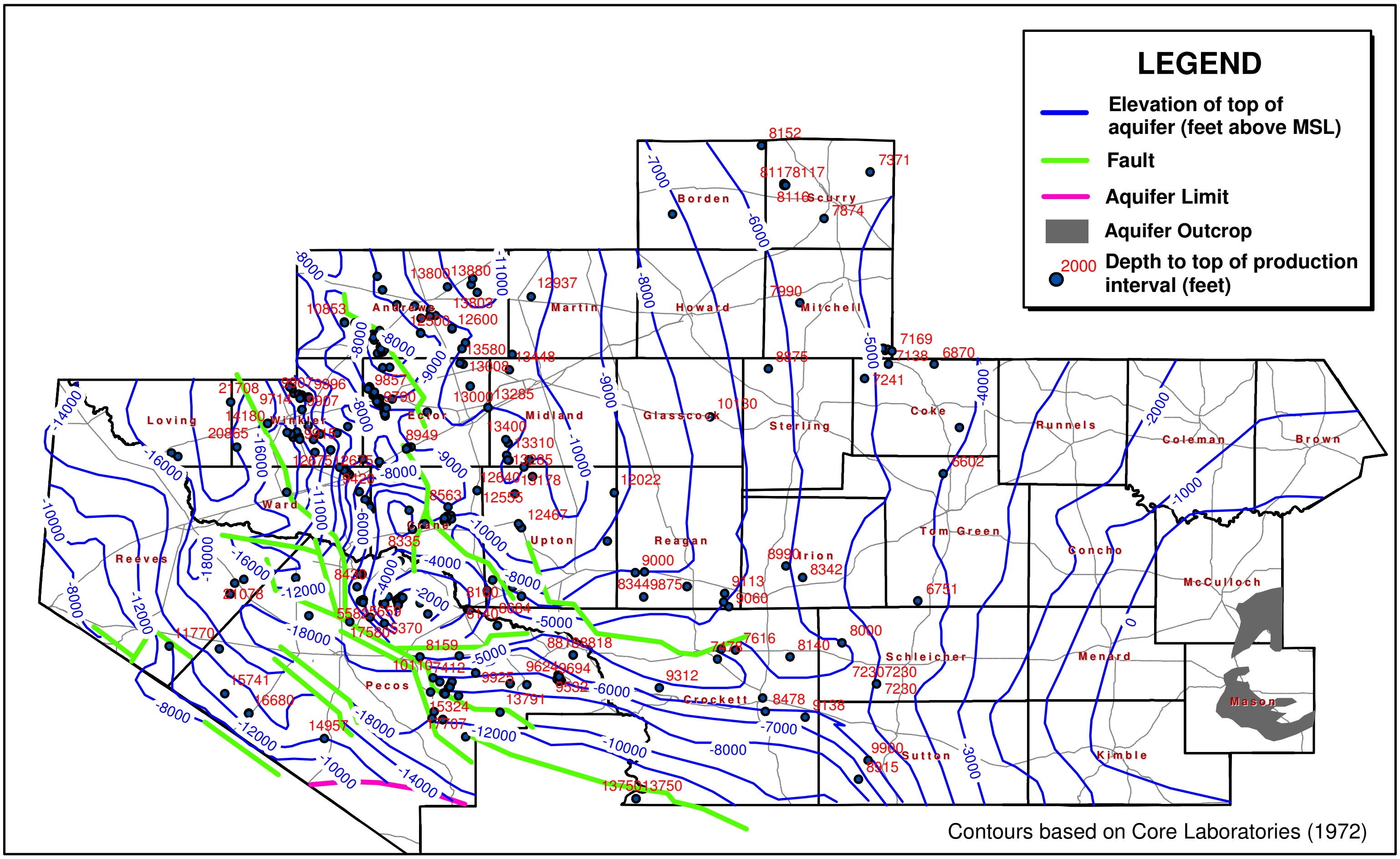


Figure 29a - Depth to the top of the Ellenburger Aquifer

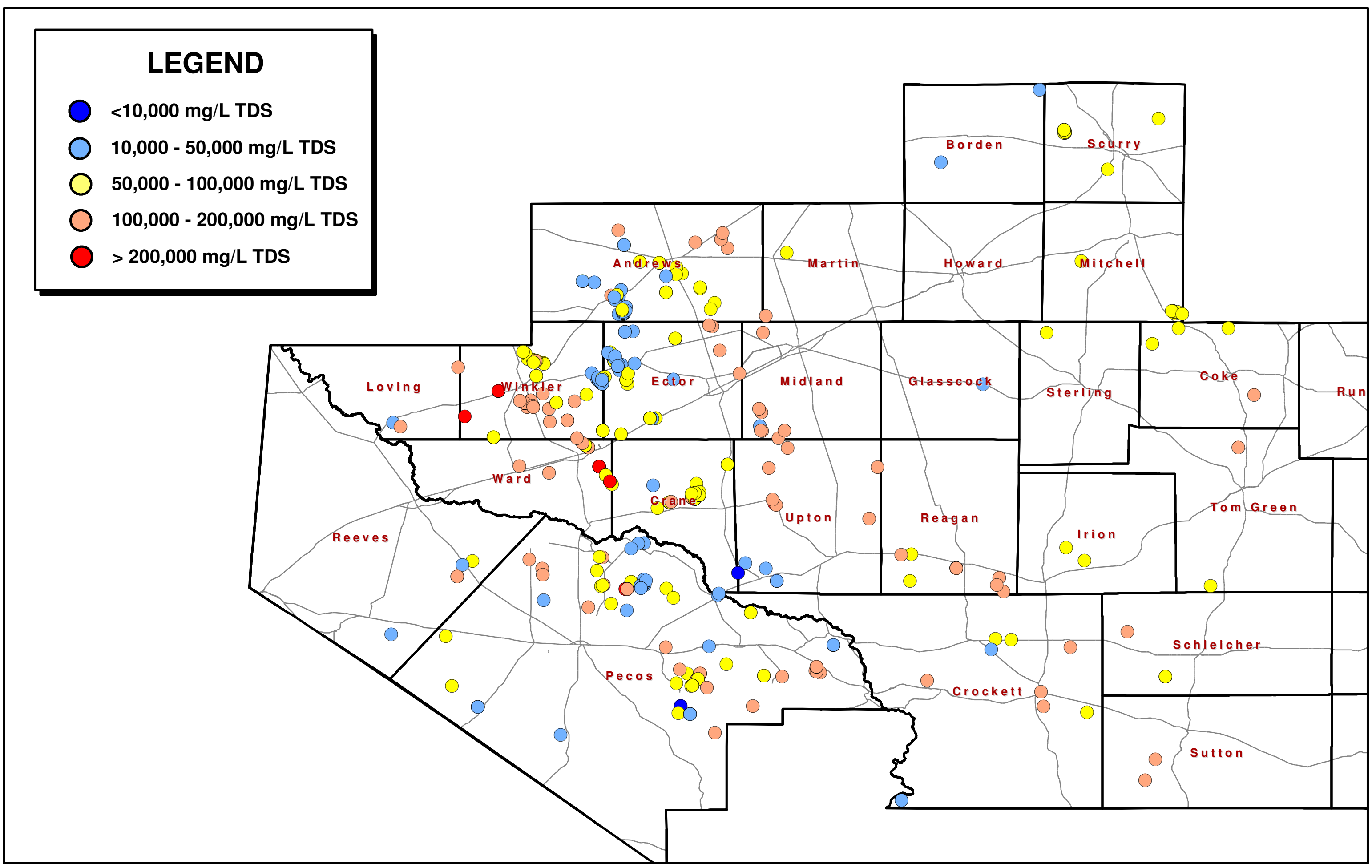


Figure 29b - Produced water quality in oil and gas wells in the Ellenburger Aquifer

Ellenburger Aquifer- The Ellenburger is a prolific hydrocarbon-producing unit and is the most widespread of all of the aquifers in the state. The elevation of the top of the Ellenburger is shown in Figure 29a, which shows that it occurs at depths that are likely too great to be considered a viable brackish or saline water source for water-supply purposes in most of the region. Only in the eastern third of Region F is the formation found at depths of less than 5,000 feet, where this formation is considered the Ellenburger-San Saba aquifer, as described above in Section 2.

As with the Ellenburger-San Saba aquifer described above, the Ellenburger throughout the rest of its extent in Region F consists mainly of dolomite and limestone. It is up to 4,000 feet thick, although it typically has thicknesses of up to 1,700 feet in the Midland and Delaware basins (TWDB, 1972). Productivities from the Ellenburger vary significantly. In general, porosities range from 2 to 12 percent and permeabilities range from 0.1 to 200 millidarcies (TWDB, 1972)

Figure 29b shows the salinity of produced water from the Ellenburger. These data vary enough to indicate that no definitive salinity trend exists on a regional basis, but some areas do contain produced waters with less than 50,000 mg/L TDS. However, this figure also shows that if the Ellenburger is to be considered a potential source of brackish or saline water, a site-specific investigation must be conducted to determine the properties and hydrochemistry of the formation.

Summary- Many of the deeper, hydrocarbon-producing formations present throughout most of Region F have brackish to saline groundwater resources available. Most of the data available for these units are from oil and gas wells producing from the deeper zones of these formations, which typically have highly variable, and usually very high, salinities. In addition, the productivities of these units from a water-supply perspective is unknown, as all of the available data are from oil and gas wells, and the units are highly variable in rock properties and productivities. It is possible that some of these deeper formations could be used as a brackish or saline groundwater resource on a very limited, site-specific basis, but this would not be expected to be typical.

However, many of these formations outcrop in the eastern third of Region F, and it is likely that some of them have the potential to produce adequate quantities of brackish groundwater from shallow to intermediate depth wells (less than 3,000 feet) in this portion of the region, so that they may be considered a potential source of brackish to saline groundwater. Because the data was not available to evaluate the updip portions of these aquifers, the potential for their use must be evaluated on a site-specific basis.

4.0 Oil-Field Produced Water

The Region F water-planning group has identified oil-field produced water as a potential source of brackish or saline water. However, from a water-supply perspective, in particular from a regional water-supply perspective, this is not a source of water that can be considered. While the potential exists for the desalination of oil-field produced water to become a very useful technology, several issues exist with oil-field produced water that limit it's use as a water supply for the purposes of regional water planning, as described below.

The first and foremost problem with oil-field produced water from a regional water supply perspective is the volume that is produced. This technology is mainly being evaluated as an economic alternative to the current methods of disposal for a by-product of hydrocarbon production (i.e. produced water), in particular when the cost of hauling the water is considered. This alternative also produces fresh water, but the economics of the technology are not as a new water supply, but as an alternative to current disposal methods. Volumes are low, similar to what a windmill might produce, and if this water has to then be hauled in order to move it to meet a demand, it becomes economically unfeasible (David Burnett, personal communication, 2004). Currently the fresh water by-product of this desalination is being considered for use in livestock ponds/tanks, discharge into intermittent streams, or for use in habitat restoration. If a demand exists for this water it is likely that it is for a demand that was created due to the water being available, rather than to meet an existing demand.

In addition, the current technology for on-site desalination of oil-field produced water has an upper limit of between 35,000 and 50,000 mg/L TDS, which significantly limits the applicability of this technology in the Region F area. As described in Section 3 above, the geochemistry of formation waters in the deeper, hydrocarbon-producing units in the Region F area are highly variable, but generally contain groundwater with greater than 50,000 mg/L TDS. Although this technology would be applicable for some produced-water in some locations, the limit on the TDS that can be treated also make it a poor choice for water-supply purposes.

5.0 Desalination Cost Analysis

The economics of constructing and operating a desalination facility must be considered when justifying its process over other more conventional water-supply alternatives. Cost estimates must be considered for all the various engineering aspects including source water acquisition (well field), supply distribution (pipeline), plant construction, operations and maintenance including energy cost, and concentrate disposal. Improved membrane technology is increasing the efficiency and effectiveness of the desalination process thus continuing to drive down the overall cost. In general, it is less expensive to desalinate lower TDS groundwater than higher TDS groundwater because of the reduction in energy requirements.

This section provides a basic overview of these costs. Estimates of the cost to desalinate brackish groundwater were given in the TWDB Brackish Groundwater Report (LBG-Guyton, 2003). In addition, the TWDB commissioned a desalination cost analysis study By HDR Engineering in 2000, which provides an overview of desalination technologies and summarizes the process selection for desalination, including water quality, treatment objectives, and costs (HDR, 2000). For a more complete discussion of the costs associated with desalination, interest should be directed to these original reports.

5.1 Total Capital Cost

Current cost information indicates that the total cost of brackish groundwater desalination can range from \$1.5/Kgal to \$2.75/Kgal (Figure 30, after HDR 2000). These figures represent the total treated water costs for brackish groundwater desalination for plant capacities up to 15 million gallons per day (MGD), without consideration of TDS concentration in source water supply. The total treated water costs are the sum of the amortized capital costs and the operation and maintenance (O&M) costs, but do not include the source-water supply and concentrate disposal. This figure clearly shows an economy of scale in the total treatment cost, with larger capacity plants having significantly lower unit rate than smaller capacity plants. Due to the rapid changes in treatment technology, cost estimates that are over two or three years old may be higher than current costs. Because of current technology advances, Figure 30 should be used

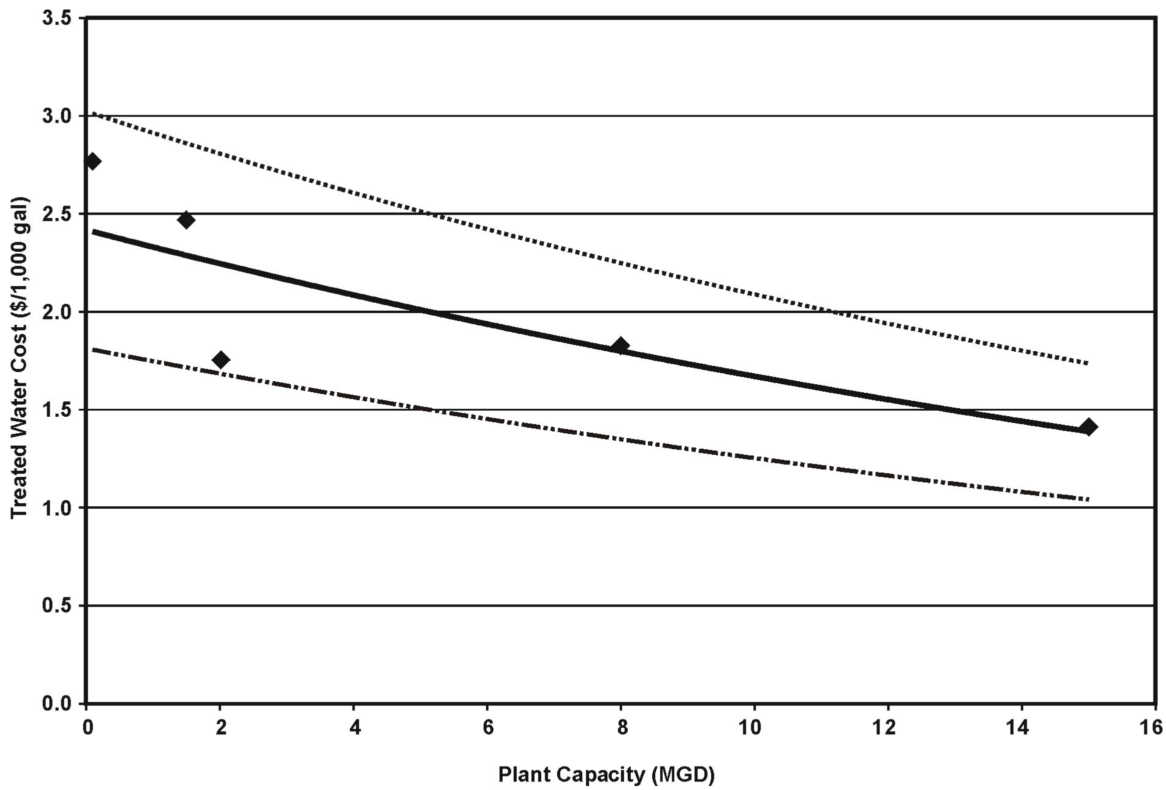


Figure 30 - Total Treatment Cost for Brackish Groundwater Desalination (after HDR and others, 2000)

only as a guideline, as recent data and projections indicate that costs for desalination are decreasing as technology develops. In addition, site-specific conditions can greatly increase or reduce projected costs.

5.2 Operation and Maintenance

Figure 31 (after HDR 2000) illustrates the estimated O&M costs associated with brackish groundwater desalination ranging from $0.60 to $1.60. This estimate includes the cost of personnel, chemicals, power, membrane parts replacement, concentrate disposal, and other costs. As with capital costs, O&M costs show a significant economy of scale. The report indicates that variations in O&M costs may reflect source-water quality such as TDS concentration.

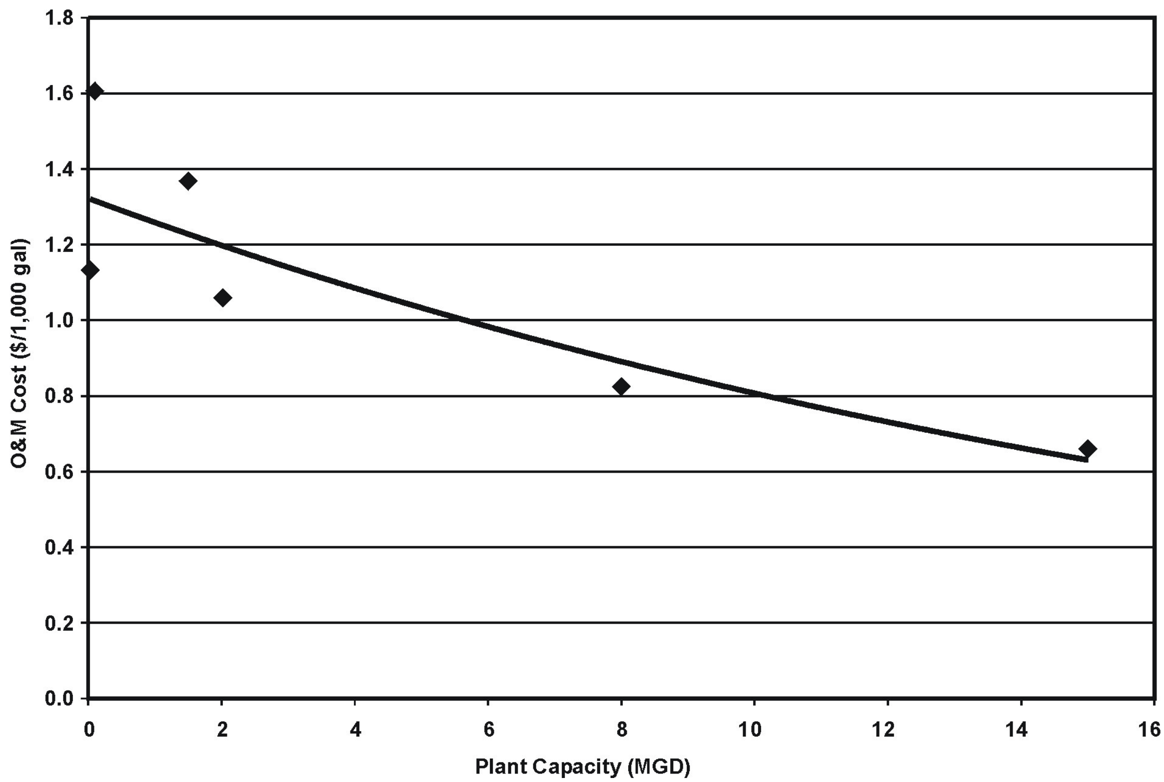


Figure 31 - O&M Costs for Brackish Groundwater Desalination
(after HDR and others, 2000)

5.3 Energy

Energy required to force brackish groundwater through the membranes is one of the most significant cost factors for desalination. As a general rule, the higher the salt content of the water being treated, the higher the pressure required for feed pumping. Compared to desalination of seawater, pressure requirements for brackish water (i.e., less than 10000 mg/L TDS) are significantly lower. Technological advances in membranes make it possible for TDS to be removed at much lower pressures than just a few years ago. There is generally no economy gained regarding energy costs with larger production facilities.

5.4 Pretreatment

Reverse osmosis systems may require pretreatment of the water being treated to adjust pH and prevent salt scaling, and to remove particulates that might foul, clog or damage membranes. As with capital and O&M expenses, there is an economy of scale in the construction and O&M costs for the pretreatment systems. Pretreatment costs are generally higher for surface water (brackish lakes and seawater) than for brackish groundwater because of the need for pretreatment filtration.

5.5 Source Water Wells

Well costs for brackish groundwater supply are shown in Table 2 (LBG-Guyton, 2003). These cost relationships are general in nature and are meant to be used only in the broad context of this report. The cost relationships assume construction methods required for public water supply wells, including carbon steel surface casing and pipe-based, stainless steel, and wire-wrap screen, and that wells would be gravel-packed in the screen sections and the surface casing cemented to their total depth. In addition, the cost estimates include the cost of drilling, completion, well development, well testing, pump (set at 300 feet below ground surface), motor, motor controls, column pipe, installation and mobilization. Not included in these cost estimates are engineering, contingency, financial and legal services, land costs, or permits. In addition, these cost relationships will not apply to wells producing from deep, typically hydrocarbon-producing formations that are also described in this report.

Table 2. Estimated Well Costs for Brackish Water Production Wells		
Well Diameter (inches)	**Typical Production Range (gpm)**	**Estimated Cost (2002 $)** a=production rate (gpm), b= well depth (feet)
6	25-150	7000 + 68a + 60b
8	150-300	10000 + 65a + 140b
10	300-500	15000 + 63a + 180b
12	500-800	20000 + 60a + 225b
16	800-2000	22000 + 60a + 320b

5.6 Concentrate Disposal

Concentrate disposal methods and processes are a critical element in the overall cost of the desalination process, and is a major decision in designing and planning the overall desalination strategy. The ability to estimate the quantity and quality of the concentrate stream allows proper selection of the disposal process and subsequent regulatory permitting.

Table 3 (after HDR, 2000) summarizes the potential advantages and constraints for different types of brine disposal. It is difficult to estimate generic disposal cost relationships because the costs vary significantly between projects, locations, and the disposal method selected. Prior to project implementation, a thorough review of pertinent regulations regarding brine disposal and associated water quality issues should be completed to ensure that proposed brine disposal methods and cost estimates are appropriate for planning purposes.

Table 3. Concentrate Disposal Options Summary (after HDR and others, 2000)		
Disposal Option	**Advantages**	**Disadvantages**
Direct surface water discharge	• Low up front cost	• Requires available receiving water body • Future regulations may restrict

		• Monitoring program
Pre-discharge mixing	• Low to medium up front cost	• Requires adequate mixing source • Monitoring program
Municipal wastewater system	• Low cost (if co-located) • Additional source for reclaimed water	• Higher wastewater treatment costs • Impacts to treatment process
Deep well injection	• Can handle large volumes • May be available to inland plants	• Difficult permitting • High cost up front • Costs vary due to many site-specific circumstances
Land application	• Best suited for small facilities	• Difficult to site
Evaporation ponds	• Relatively easy to design and construct • Low maintenance, little equipment required • Low cost for small volumes	• Require large tracts of land • Require clay or synthetic liners, which increase cost • Little to no economy of scale

6.0 Conclusions

Additional supplies of water in Region F may be obtained from the desalination of existing brackish or saline water sources. Because very little, if any, surface water in the region is available, subsurface, groundwater from a variety of aquifers should be evaluated to meet desalination supply needs. The technology for the desalination of brackish or saline water is improving, and the costs for desalination are continuing to decrease, meaning more and more brackish or saline groundwater supplies may become economically feasible to use as a water supply to meet regional water demands.

Table 4 provides a summary of the brackish and saline groundwater potential for all of the major and minor aquifers as well as the deeper, hydrocarbon-producing formations in Region F. Many of the major and minor aquifers in the region have significant potential to produce brackish groundwater for water-supply purposes, and contain millions of acre-feet of brackish groundwater, as indicated in the table.

Although extensive brackish and saline water resources are available in the deep, typically hydrocarbon-producing units throughout Region F, for the most part these are not potential water supplies for meeting regional water demands. Many of these units are found deep in the subsurface, at depths too great to be economically feasible as a water supply. These formations typically produce groundwater with highly variable, and generally very high, salinities. Productivities of wells from these formations from a water-supply perspective are unknown, as most of the data available are from oil and gas wells. However, it is unlikely that most of these formations can produce the quantities of water at rates sufficient enough to be considered a potential water supply, especially in the downdip portions of these units.

It should be noted that most of the deeper, hydrocarbon-producing formations do have some potential to produce brackish groundwater at reasonable rates from shallower depths in and near where they outcrop, which for many of these units is in the eastern third of the region. However, data was not available for most of these formations in these areas, and therefore the descriptions in Table 4 may not indicate the potential for these units in these areas. If areas in or near the outcrop area of any of these deeper units are to be targeted, additional data and study on a site-specific basis will be required.

Oil-field produced water with relatively lower salinities (less than 50,000 mg/L) have the potential to be treated on-site to create a fresh water source. However, due to the low productivity rates this source cannot be considered a viable water supply from a regional water planning perspective.

7.0 References

Core Laboratories, 1972, A Survey of the Subsurface Saline Water of Texas, Texas Water Development Board Report 157, October, 1972; 113 pp.

HDR Engineering Inc., Water Resources Associates, Malcolm Pirnie Inc., and PB Water, 2000, Desalination for Texas Water Supply. Part A: Membrane Technologies and Costs. Part B: Economic Importance of Siting Factors for Seawater Desalination

LBG-Guyton Associates, 2003, Brackish Groundwater Manual for Texas Regional Water Planning Groups, contract report prepared for the Texas Water Development Board, February, 2003, 188 pp.

Table 4- Summary of Brackish to Saline Groundwater Availability				
Aquifer	***Depth***	***Productivity***	***Salinity***	***Potential for Brackish Resource****
Cenozoic Pecos Alluvium	Shallow to Intermediate	High	Fresh to Brackish	Good
Ogallala	Shallow	High	Fresh to Brackish	Good
Edwards-Trinity (Plateau)	Shallow	Low to Moderate	Fresh to Brackish	Moderate
Trinity	Shallow	Low	Fresh to Brackish	Poor
Rustler	Intermediate to Deep	Low to High	Brackish to Saline	Moderate to Poor
Capitan Reef	Intermediate to Deep	High	Brackish to Saline	Moderate
Dockum	Shallow to Intermediate	Low to Moderate	Fresh to Saline	Moderate
Blaine	Shallow to Deep	Unknown	Fresh to Saline	Unknown
Whitehorse-Artesia	Shallow to Deep	Low to Moderate	Fresh to Saline	Moderate
Lipan	Shallow	Moderate	Fresh to Brackish	Moderate to Good
Hickory	Shallow to Deep	Moderate	Fresh to Saline	Moderate to Good
Ellenburger-San Saba-Marble Falls	Shallow to Deep	Moderate	Fresh to Saline	Moderate to Good
Guadalupe (Delaware Mtn.)	Intermediate to Deep	Unknown	Saline	Poor
Guadalupe (Whitehorse-Artesia)	Shallow to Deep	Unknown	Brackish to Saline	Poor to Moderate
Guadalupe (San Andres)	Intermediate to Deep	Unknown	Brackish to Saline	Poor to Moderate
Leonard (Clear Fork-Wichita)	Intermediate to Deep	Unknown	Saline	Poor

Wolfcamp	Shallow to Deep	Unknown	Brackish to Saline	Moderate to Poor
Cisco	Shallow to Deep	Unknown	Saline	Poor
Canyon	Shallow to Deep	Unknown	Saline	Poor
Strawn	Shallow to Deep	Unknown	Saline	Poor
Bend	Shallow to Deep	Unknown	Saline	Poor
Mississippian	Deep	Unknown	Saline	Poor
Siluro-Devonian	Deep	Unknown	Saline	Poor
Simpson-Montoya	Deep	Unknown	Saline	Poor
Ellenburger**	Deep	Unknown	Saline	Poor

*- Note: The potential ratings follow these general guidelines:

Good = Shallow to intermediate depth + high to moderate productivity + brackish quality
Moderate = Intermediate depth or moderate productivity
Poor = Deep depth or low productivity or saline quality

**- Note: Ellenburger characteristics do not include the area included in the "Ellenburger-San Saba-Marble Falls" area.