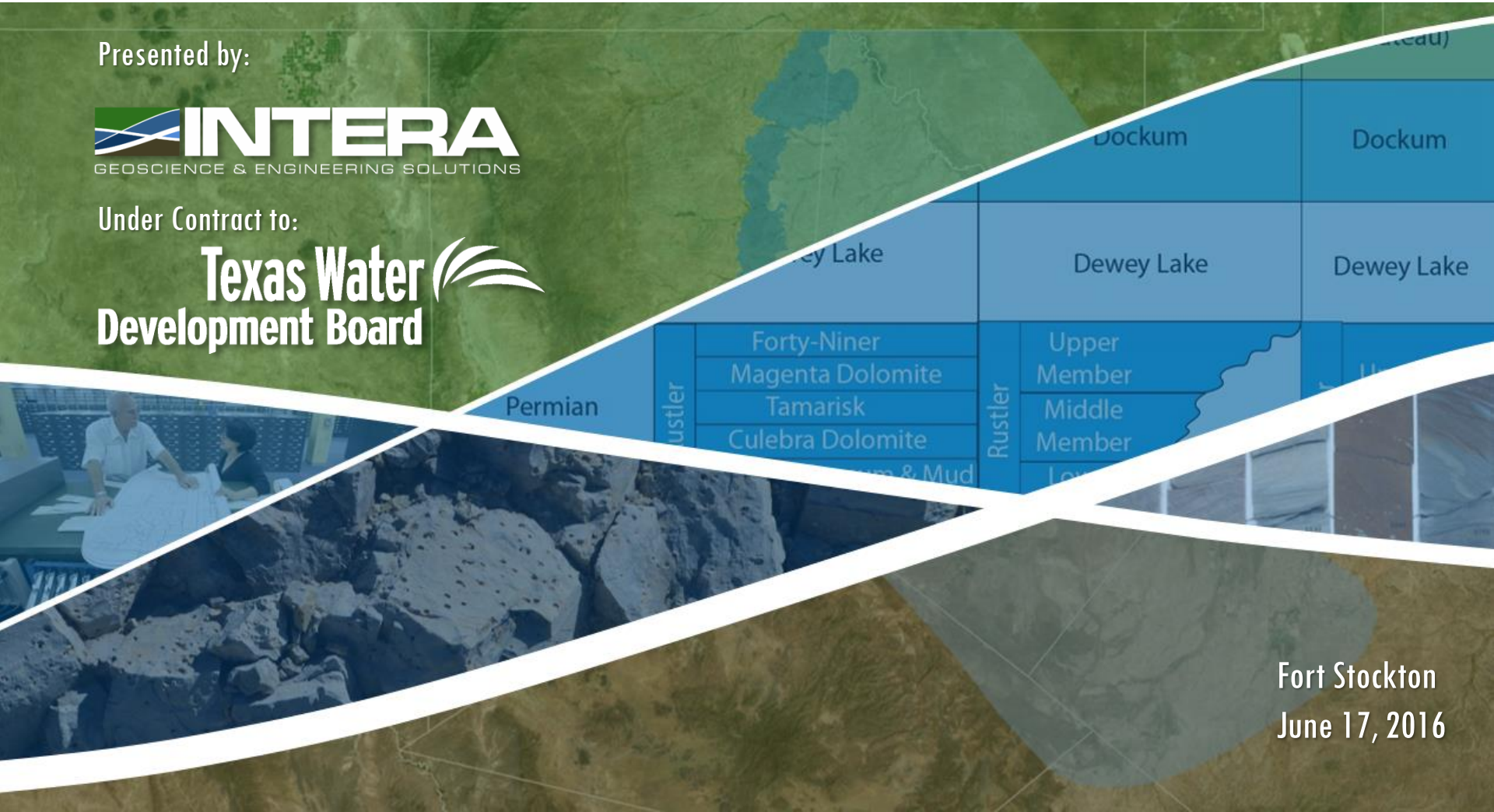
Study of Brackish Aquifers in Texas –
PROJECT #3- RUSTLER AQUIFER
STAKEHOLDER ADVISORY MEETING #2



Details

- Study of Brackish Aquifers in Texas- Project No. 3 Rustler Aquifer
  - TWDB Contract # 1600011949
- Project authors:
  - Project Management, Hydrogeology, Log Analysis, Structure and Stratigraphy
    - Van Kelley and Daniel Lupton (INTERA Geoscience and Engineering)
  - Structure and Stratigraphy
    - Dennis W. Powers (Independent Consultant)
  - Well Log Interpretation
    - Carlos Torres-Verdin (Professor and Endowed Chair at the UT-Austin Petroleum and Geosystems Engineering Department)

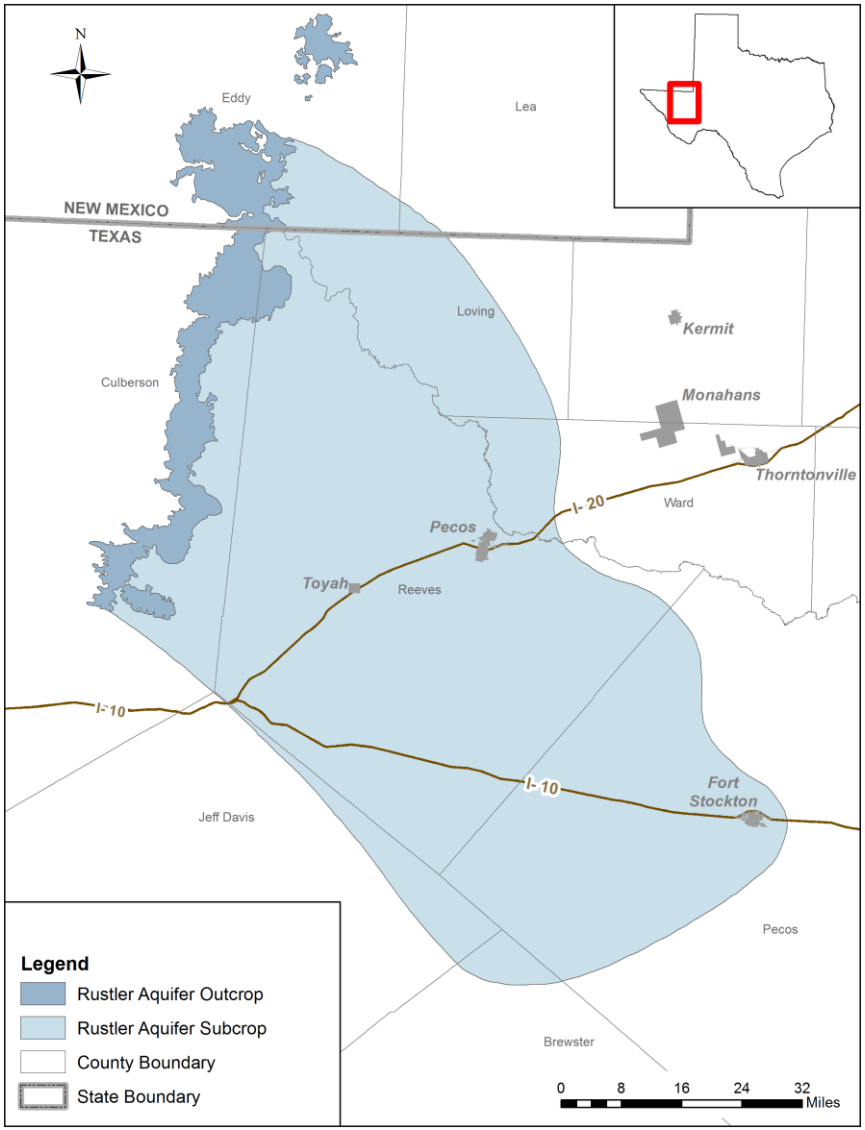
House Bill 30 (HB 30)

- In 2015, the 84th Texas Legislature passed House Bill 30, directing the Texas Water Development Board (TWDB) to conduct studies to identify and designate brackish groundwater production zones in four aquifers and to report to the legislature by December 1, 2016.
- The four aquifers include: part of the Carrizo-Wilcox Aquifer, the Gulf Coast Aquifers, the Blaine Aquifer, and the Rustler Aquifer.
- The full text of House Bill 30, and all other materials related to it's implementation, are available on the TWDB House Bill 30 website: http://www.twdb.texas.gov/innovativewater/bracs/HB30.asp

House Bill 30 (Summary)

- HB 30 Criteria for brackish groundwater production zones in the Rustler Aquifer:
  - Groundwater that is >1,000 mg/L TDS
  - Groundwater that is separated by hydrogeologic barriers sufficient to prevent significant impacts to water with a TDS ≤1,000 mg/L
  - Areas that are not serving as a significant source of water supply for municipal, domestic, or agricultural purposes at time of designation
  - Areas that are not 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

Study Area Location Map



- Project area is based the TWDB Groundwater Availability Model (GAM) Extent of the Rustler Formation
  - Outcrop in the updip portion
  - Large offsetting fault in SW
  - TX/NM border to the north
  - An approximate 5,000 mg/L TDS cutoff

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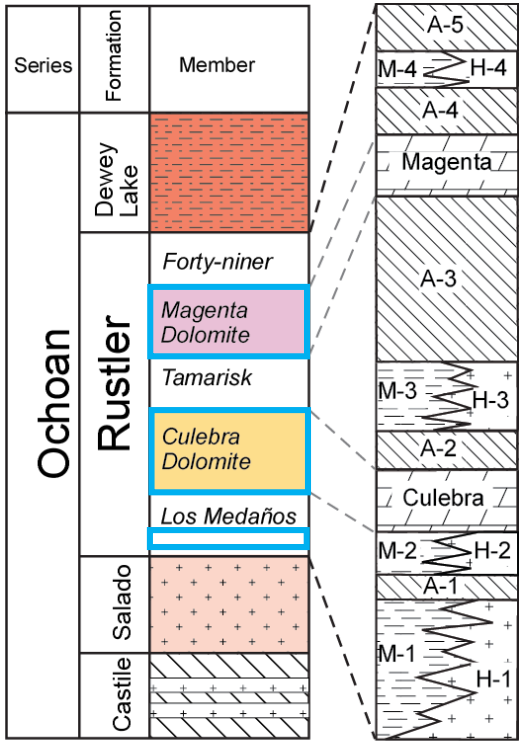
General Project Tasks

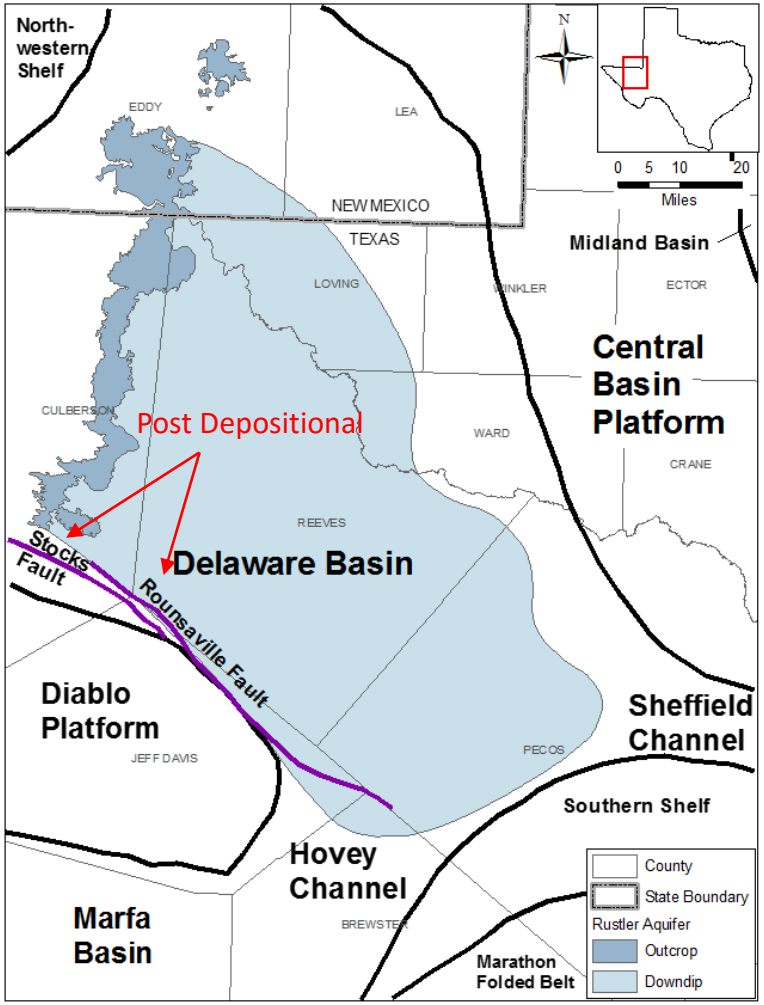
- Primary Objective is to understand the occurrence and distribution of brackish groundwater in the Rustler Aquifer
- To accomplish this we have:
  - Defined structure, stratigraphy, lithology and apparent porosity of the Rustler Formation using mainly geophysical logs
  - Evaluated all available water quality data from water wells and oil and gas wells against the structural top and bottom of the Rustler
  - Built upon existing, and developed new, techniques in well log analysis to supplement the sampled water quality data with calculated water quality from resistivity logs
  - Delineate Potential Production Areas (PPAs) and gather stakeholder feedback to aid the TWDB in designating Brackish Groundwater Production Zones



Upper Permian
Delaware Basin

Geology of the Rustler Aquifer (Structure)

Structure at time of deposition



System	Culberson and Reeves Counties, TX	Pecos County, TX/ Glass Mountains	Central Basin Platform
Quaternary/ Tertiary	Pecos Alluvium	Alluvium / Volcanics	Alluvium
Cretaceous	Edwards-Trinity	Edwards-Trinity	Edwards-Trinity
Triassic	Dockum	Dockum	Dockum
Permian	Dewey Lake	Dewey Lake	Dewey Lake
	Rustler: Forty-Niner, Magenta Dolomite, Tamarisk, Culebra Dolomite, Lower Gypsum & Mud, Siltstone	Rustler: Upper Member, Middle Member, Lower Member / Tessey Limestone	Rustler: Upper Member, Basal Member
	Salado	Salado	Salado

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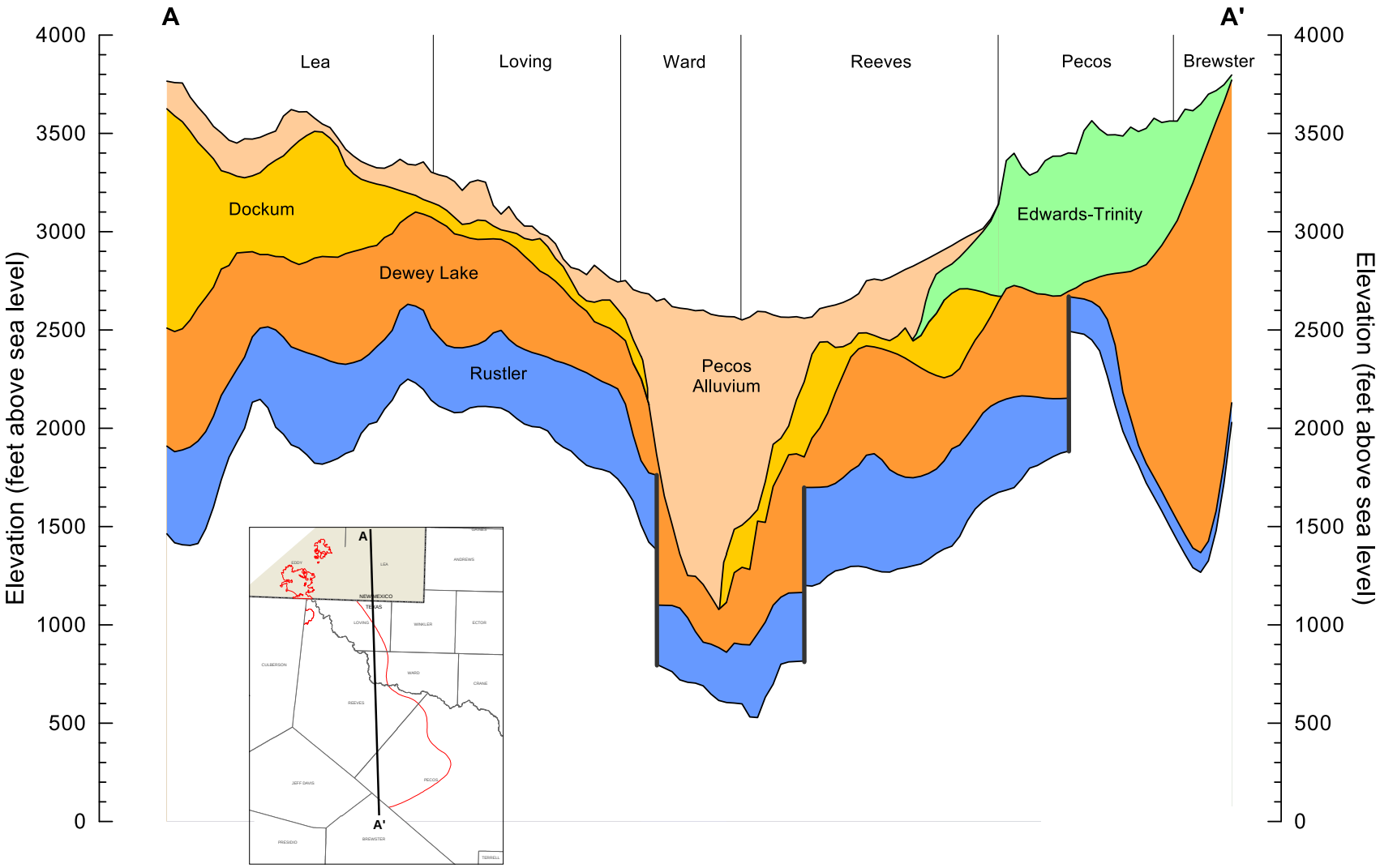

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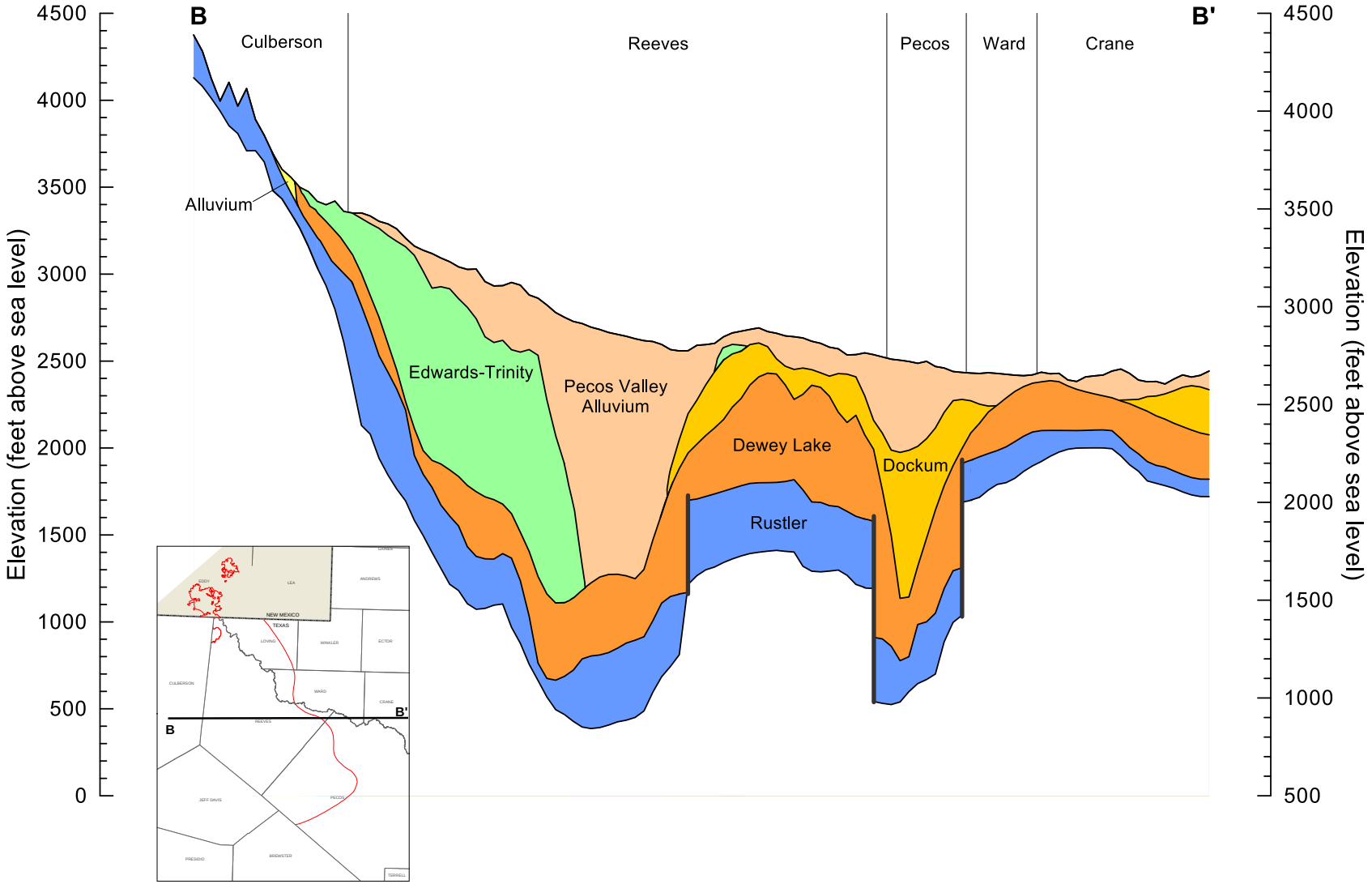

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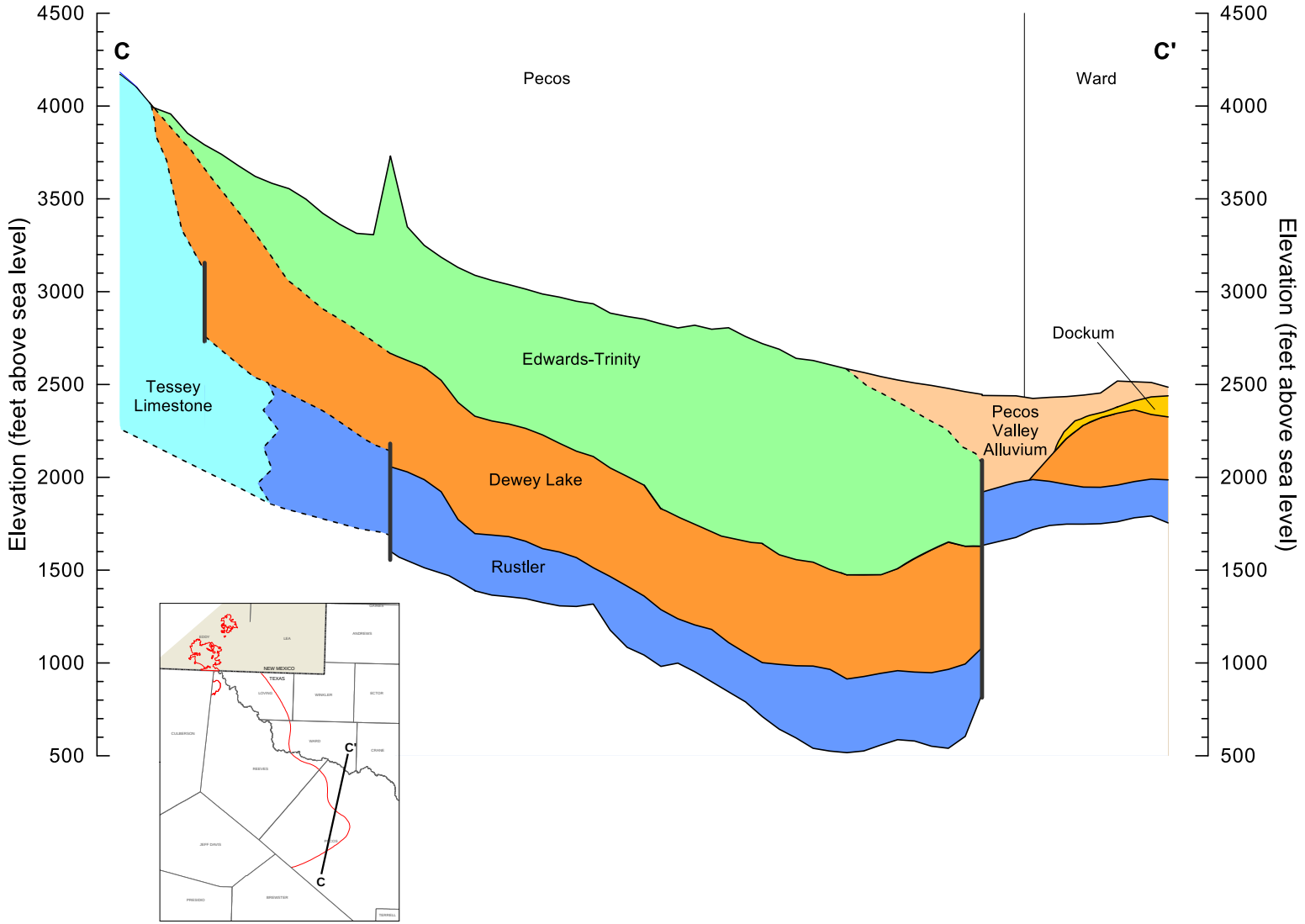
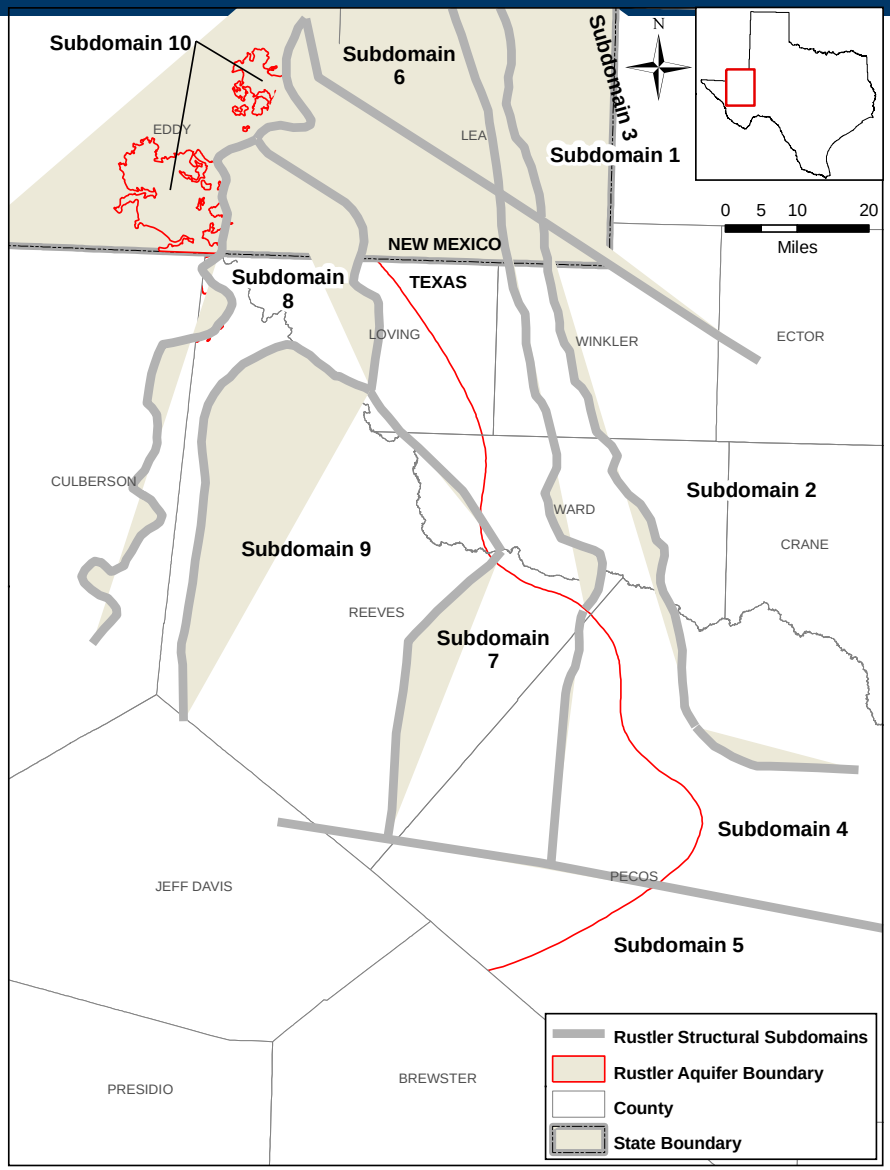


Geology of the Rustler Aquifer (Structure)

- Used structural subdomains developed by Ewing and other 2012 to account for the structural heterogeneity in the study area
- Subdomain 10: Rustler outcrop and potentially cavernous porosity
- Subdomain 8: Transition from outcrop into the Pecos-Loving Trough
- Subdomain 9: Pecos-Loving Trough
- Subdomain 7: Structural High relative to the two troughs
- Subdomain 4: Monument Draw Trough
- Subdomain 5: Tessey outcrop and potentially cavernous porosity



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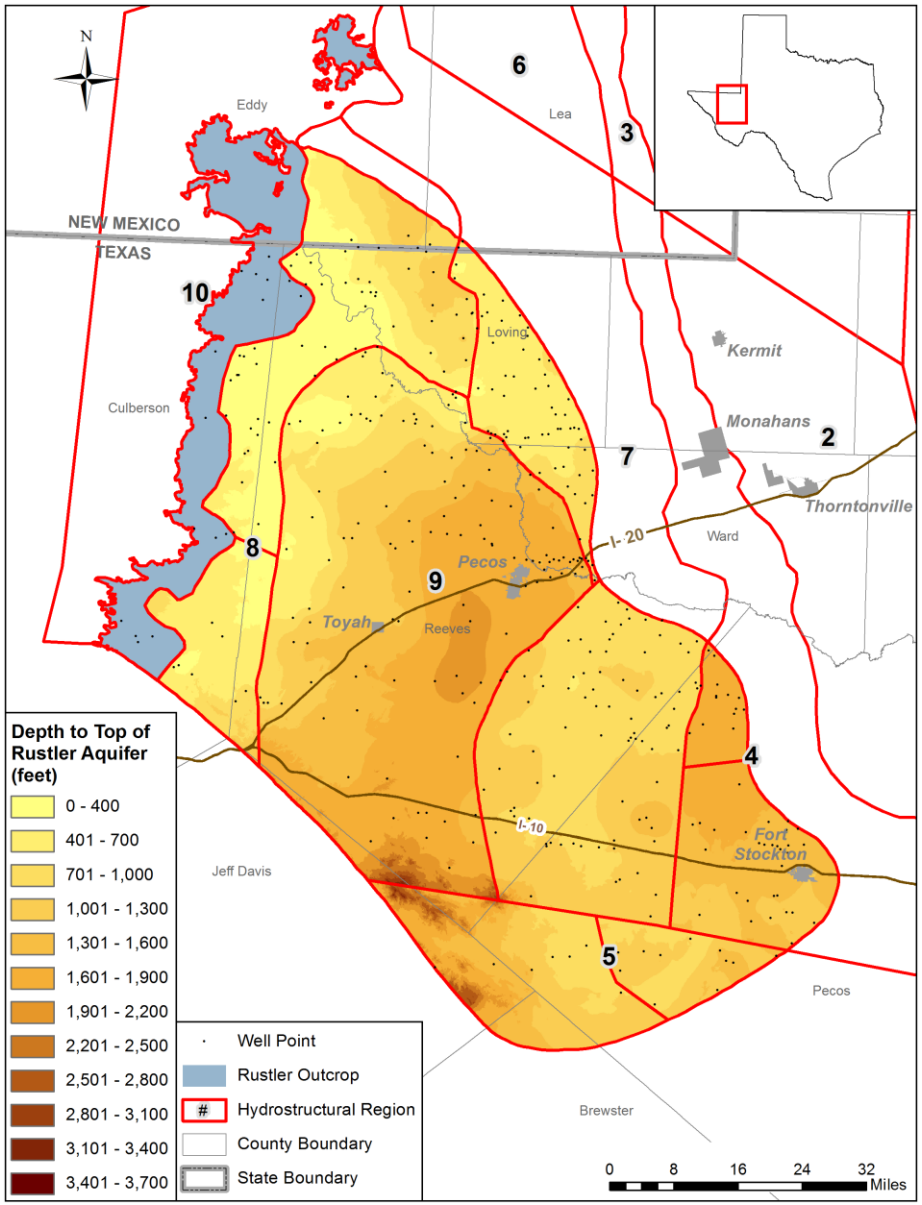

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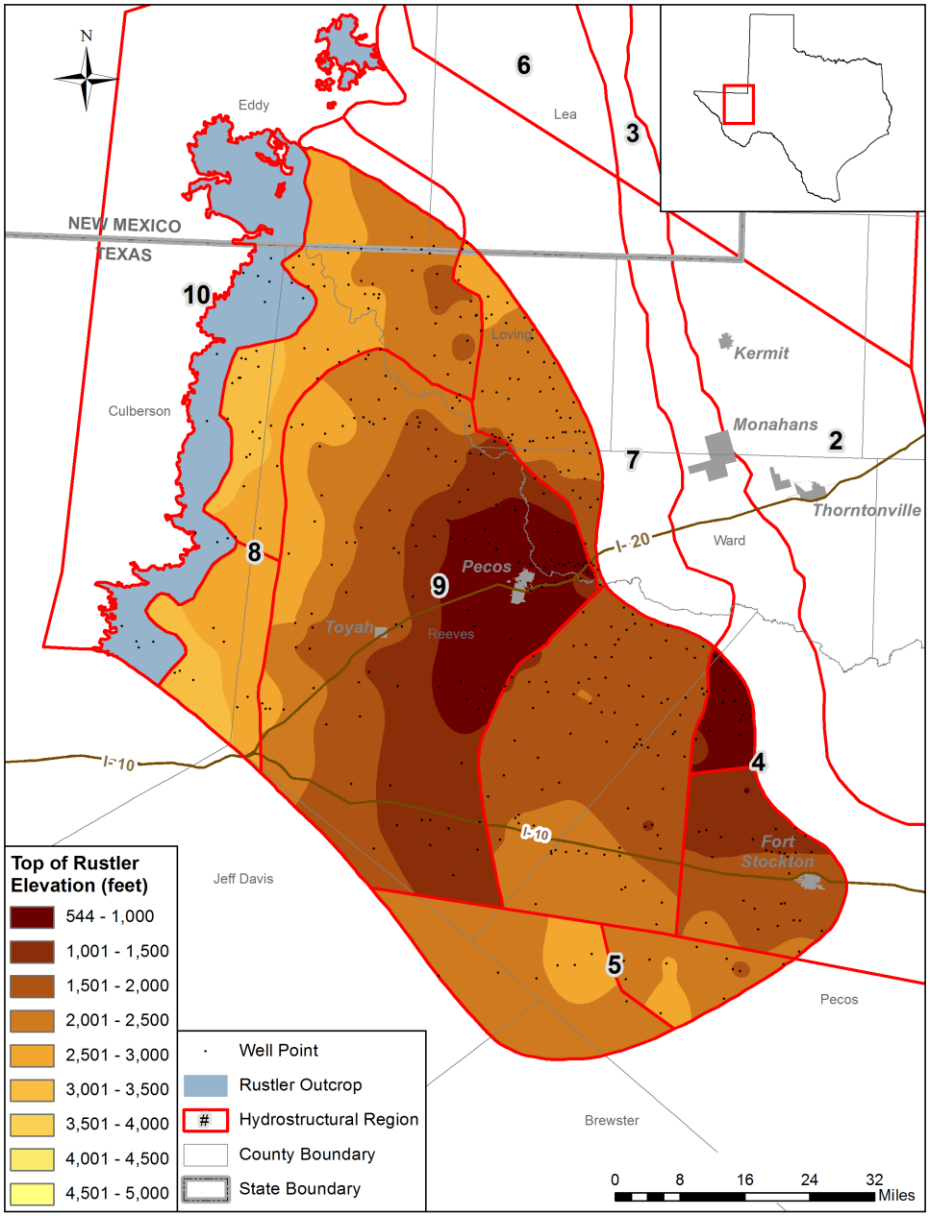

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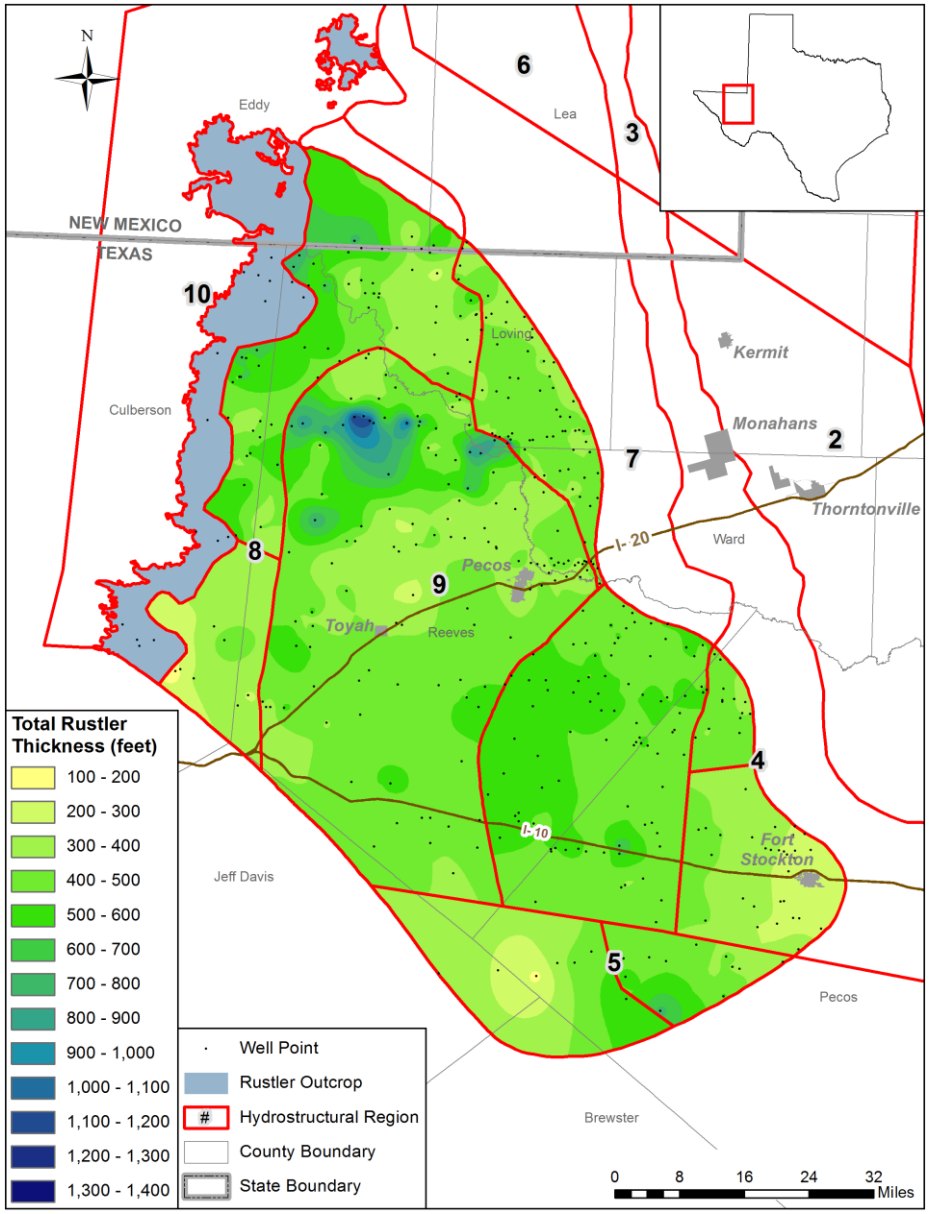
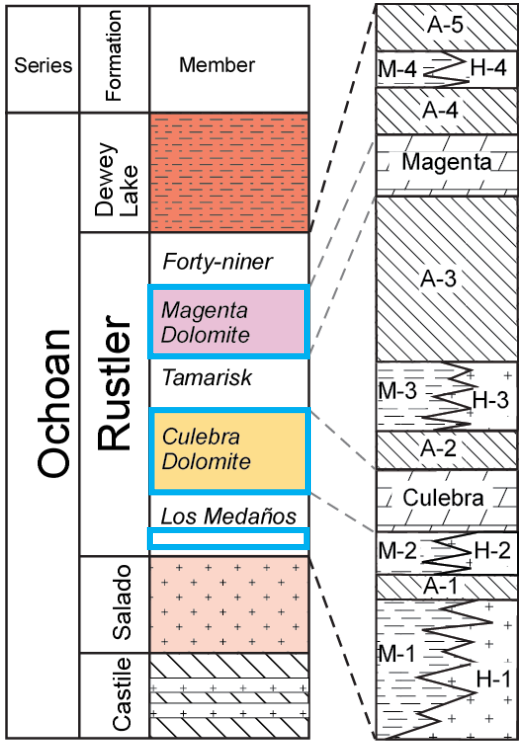
Geology of the Rustler Aquifer (Structure)



Geology of the Rustler Aquifer (Stratigraphy)

- The Rustler Formation is a complex distribution of anhydrites, halites, mudstones, dolomites and limestones
- Various factors influence the distribution of the member and submember units:
  - Paleodepositional environments
  - Post-depositional processes associated with the erosion of the Rustler
  - Collapse and subsequent karstification

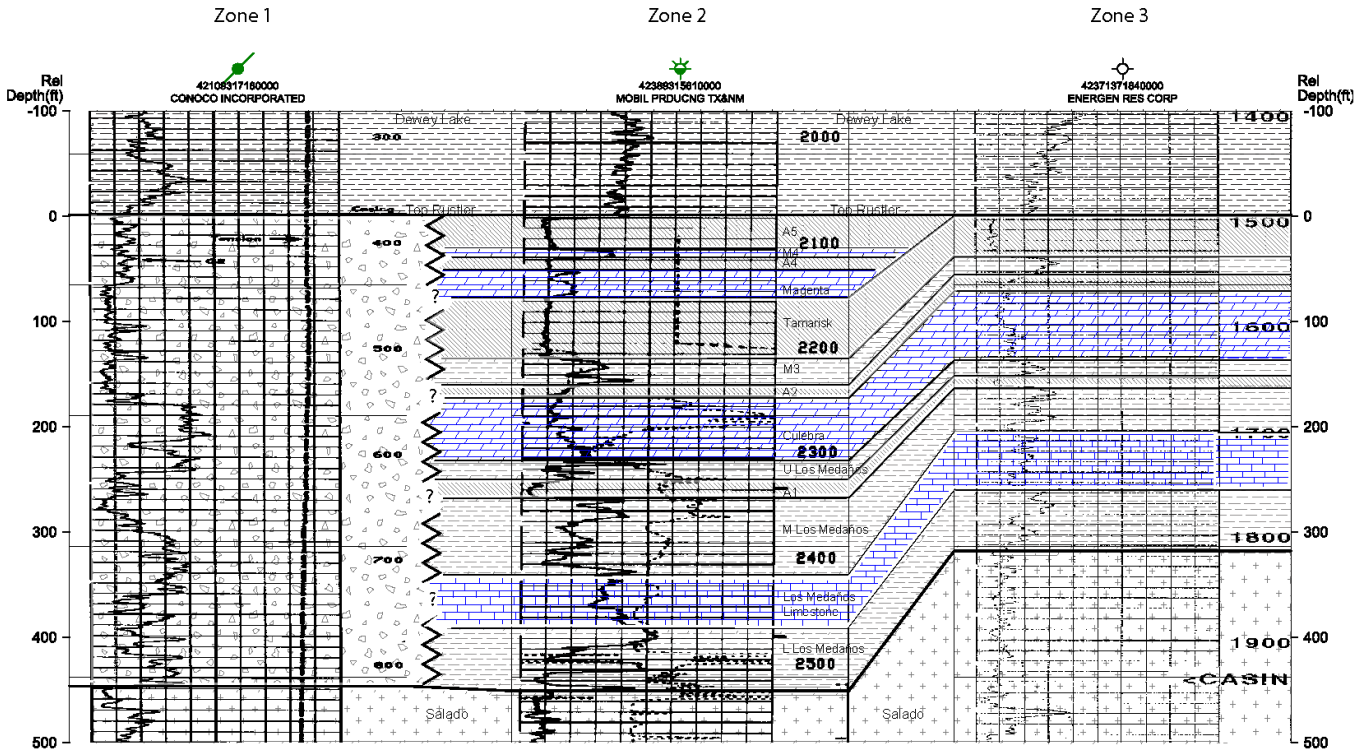


Upper Permian
Delaware Basin

Geology of the Rustler Aquifer (Stratigraphy)

- Rustler stratigraphy distributed according to primary lithologic makeup

1. Collapse
2. Full section of member units
3. Missing A5 through Magenta



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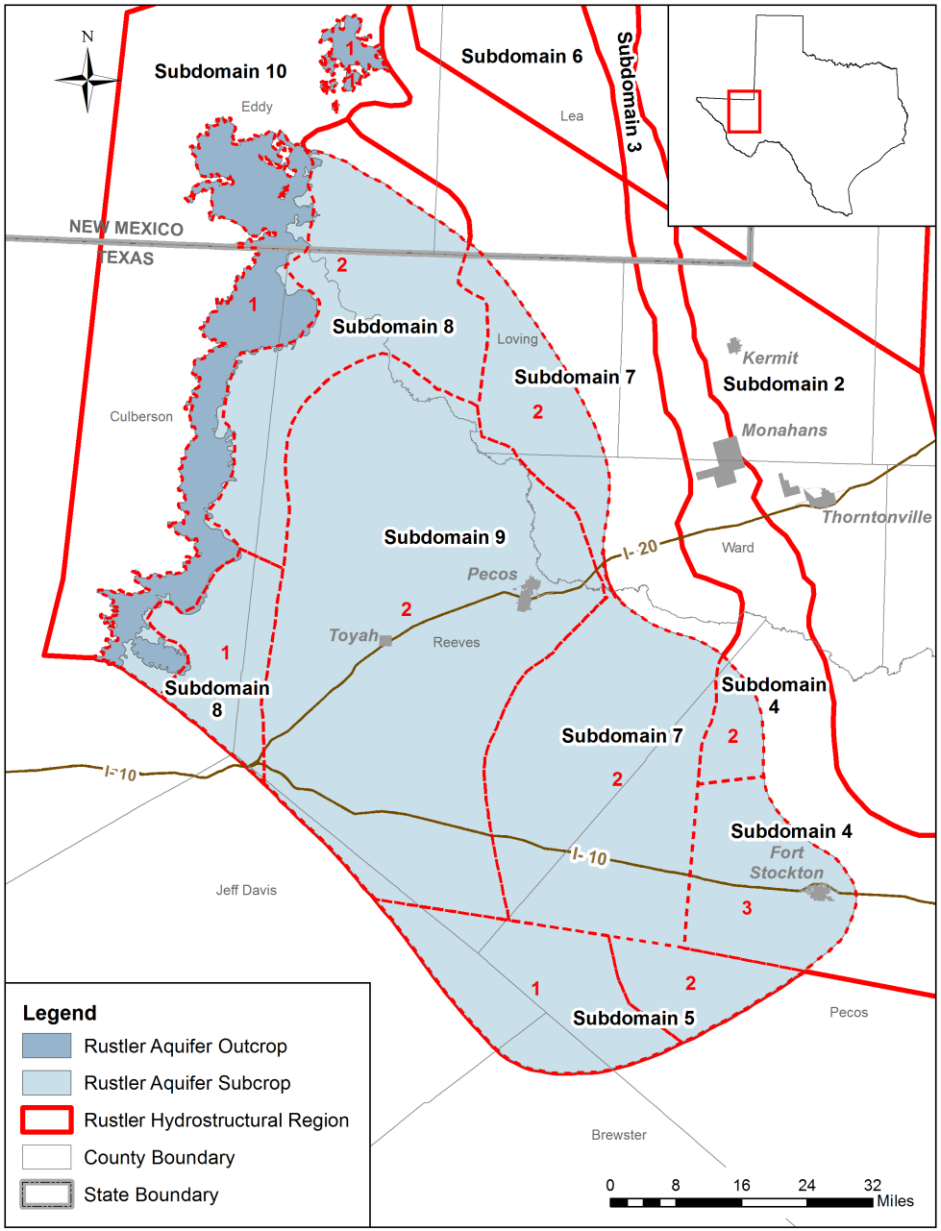

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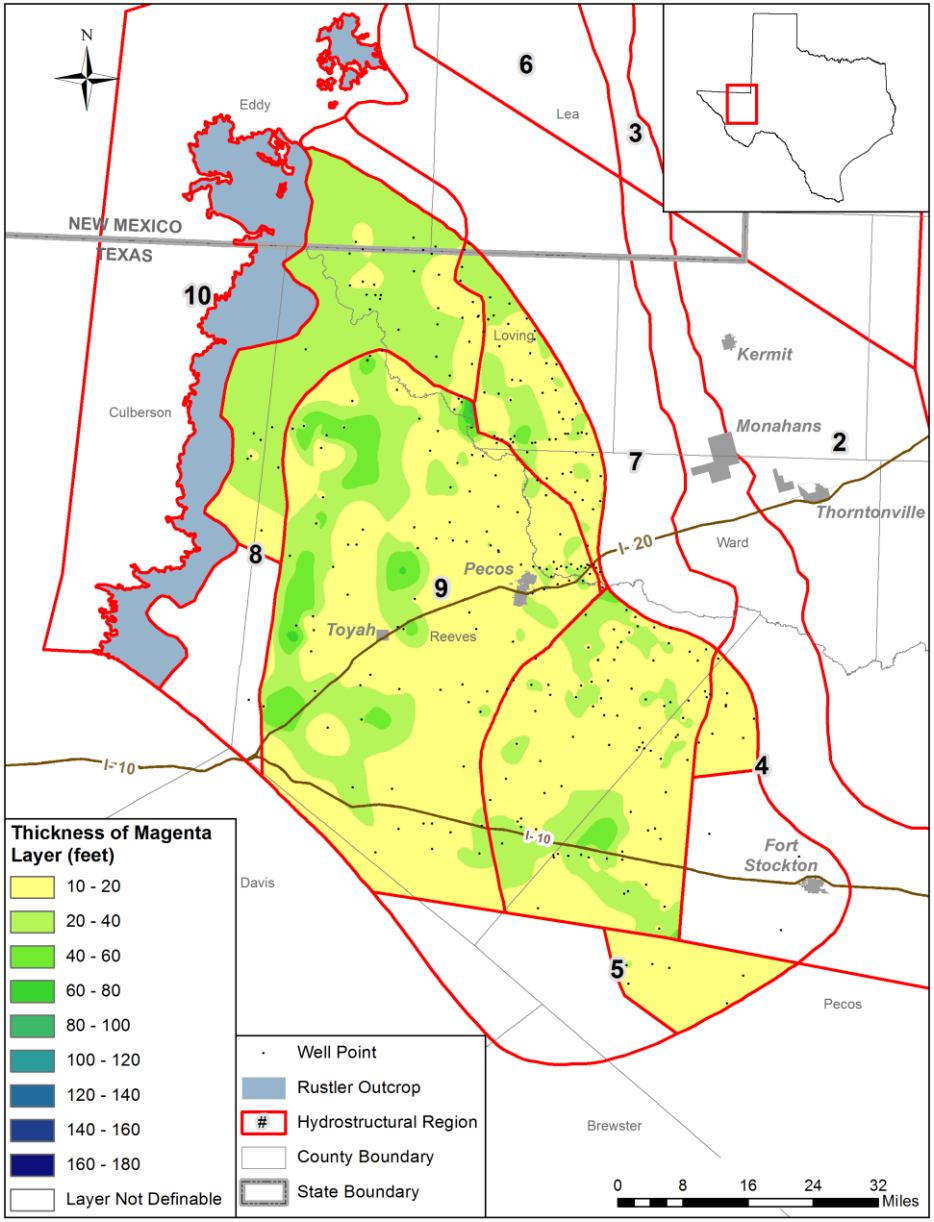

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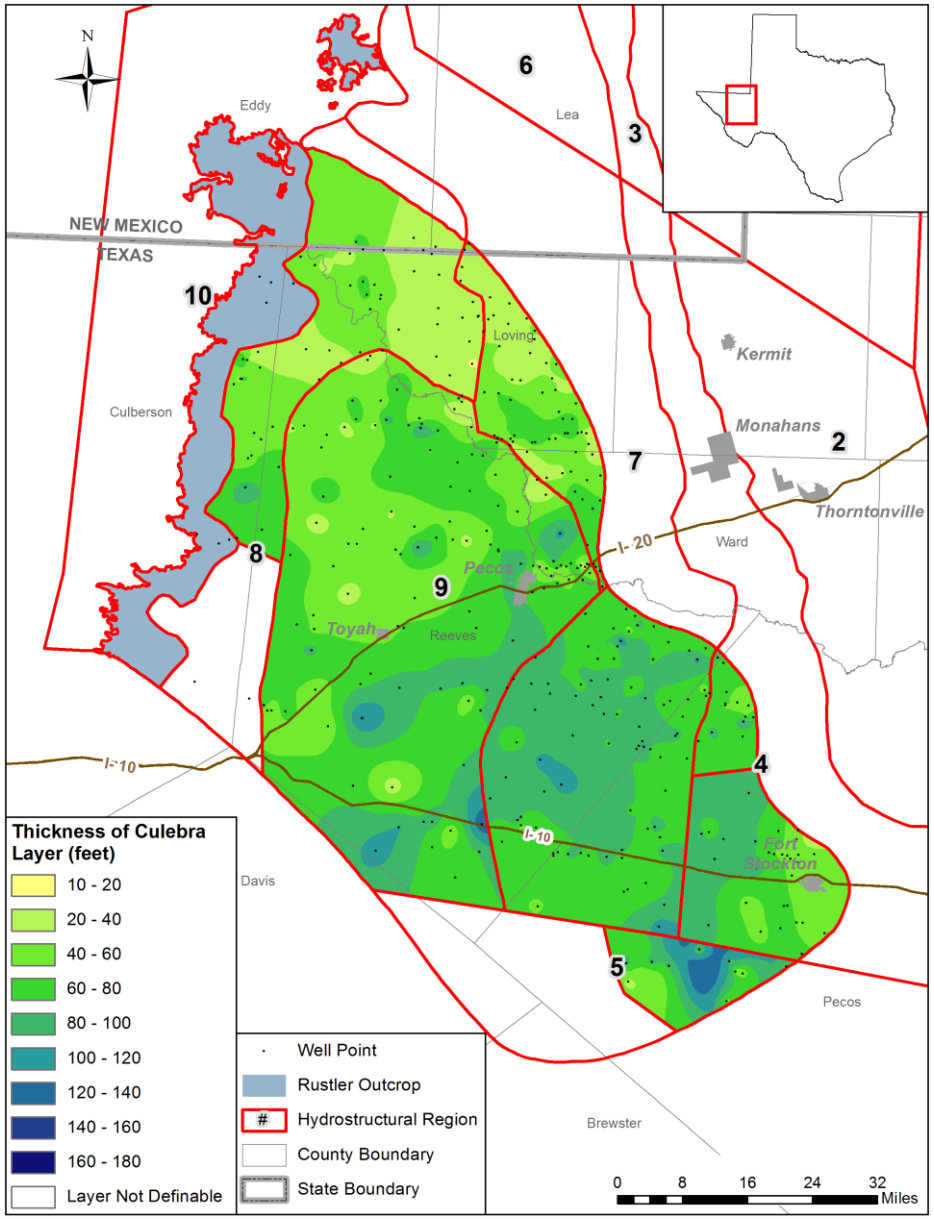

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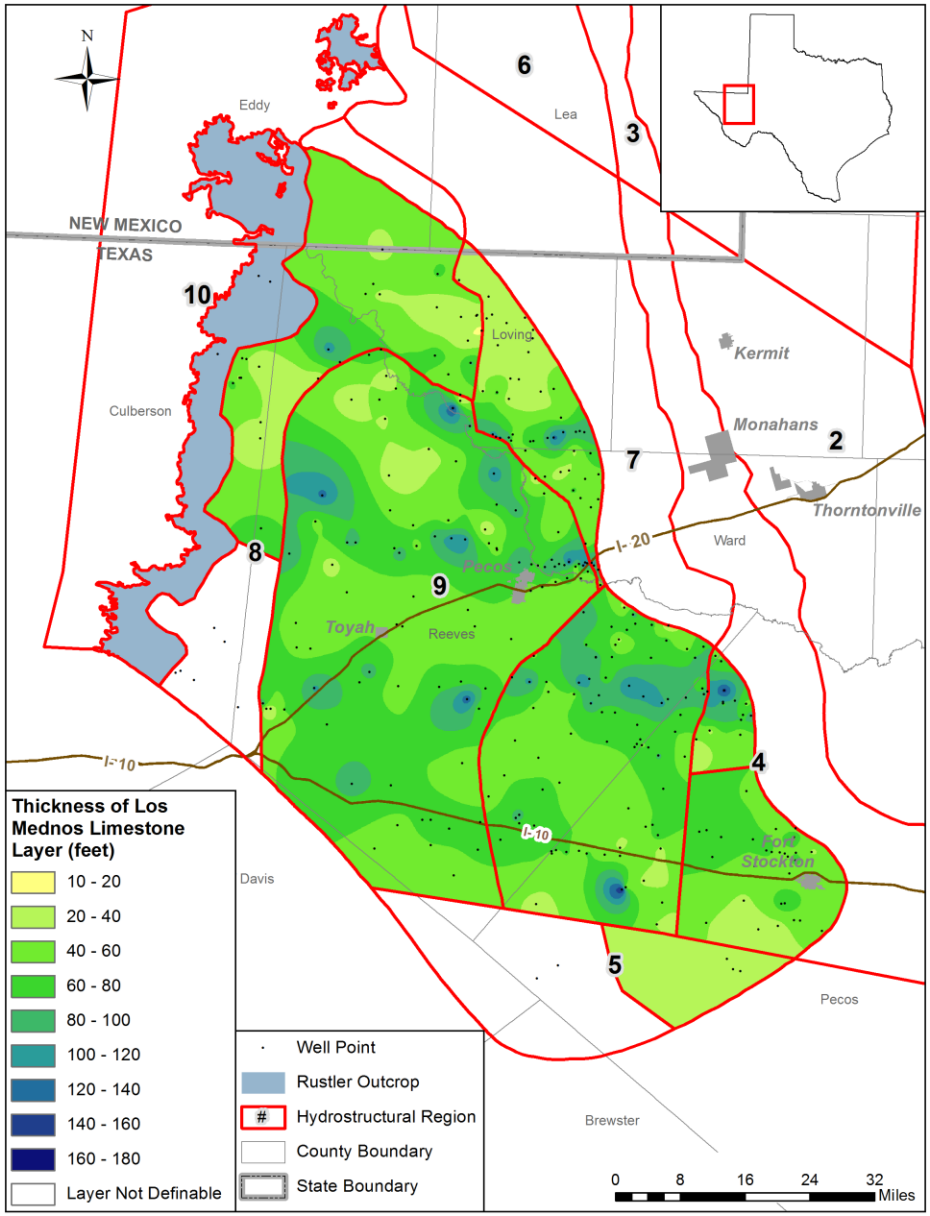

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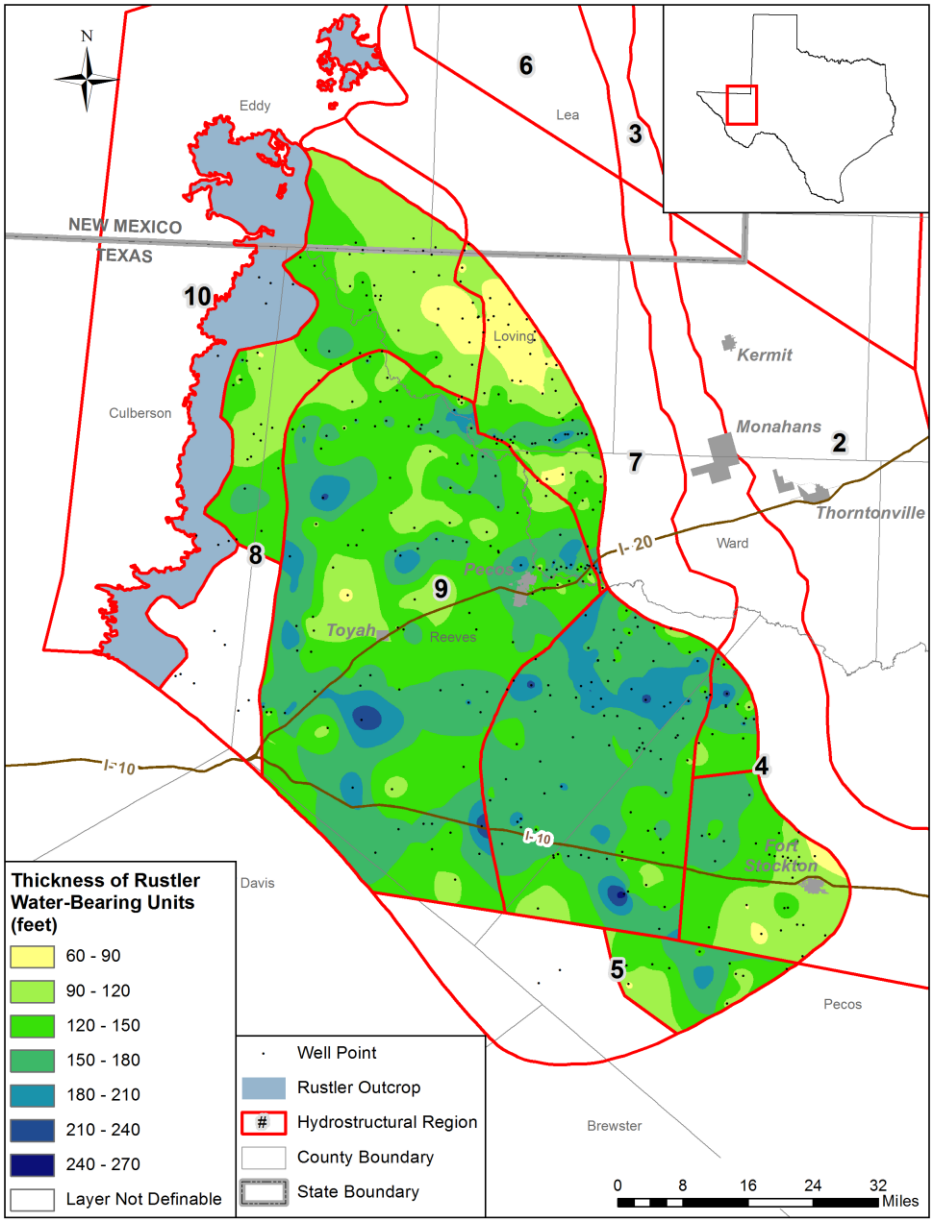
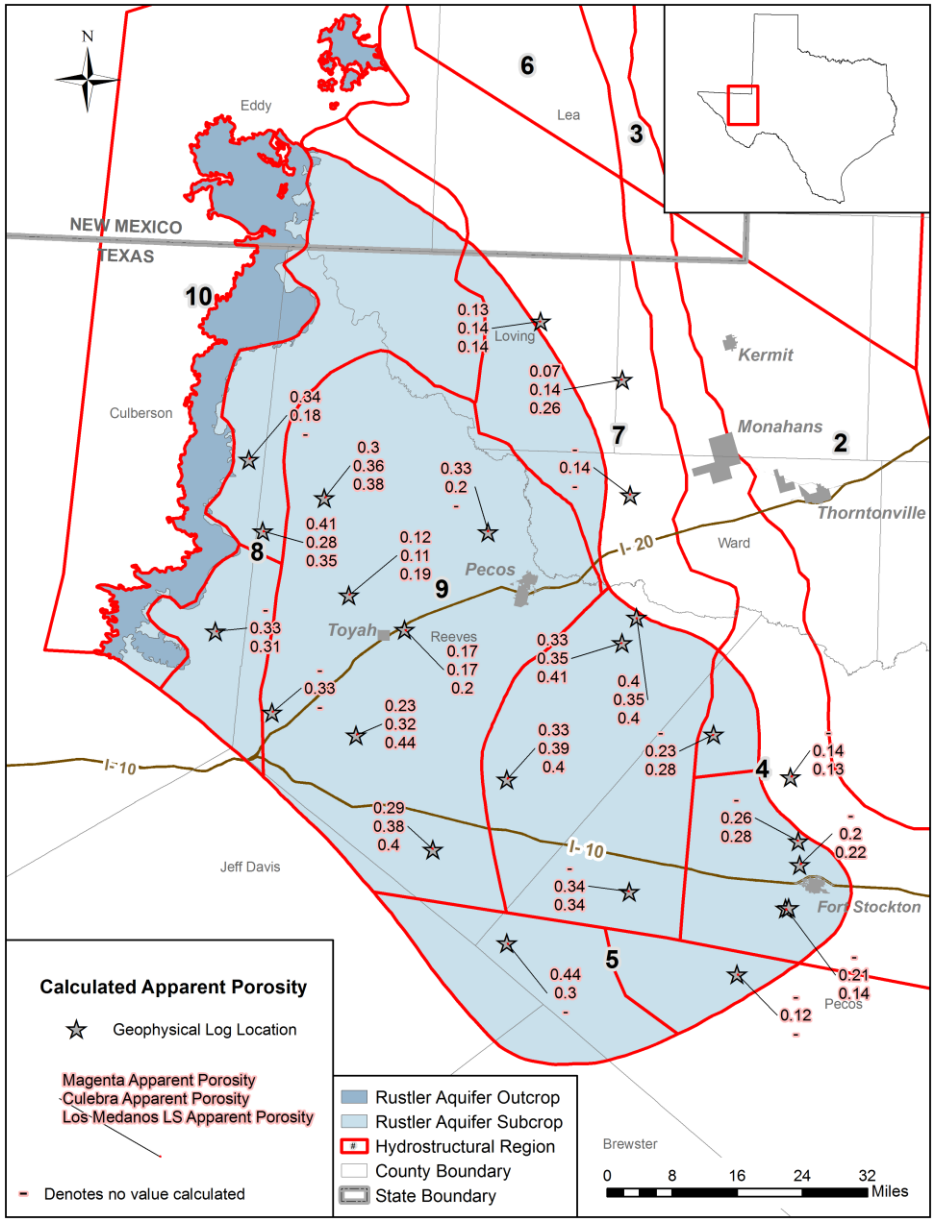


Geology of the Rustler Aquifer (Porosity)

- Assumed porosity calculations made using neutron and acoustic porosity logs
- All of the gamma logs needed to be "balanced" in order to appropriately calibrate each of the porosity measurements over the dolomite and limestone water bearing units
- Porosity values will be used for water quality and volumetric calculations



Brackish Groundwater

Saltier than fresh water, less salty than seawater

Groundwater Salinity Classification	Salinity Zone Code	Total Dissolved Solids Concentration (units: milligrams per liter)
Fresh	FR	0 to 1,000
Slightly Saline	SS	1,000 to 3,000
Moderately Saline	MS	3,000 to 10,000
Very Saline	VS	10,000 to 35,000
Brine	BR	Greater than 35,000

← Drinking Water Limit

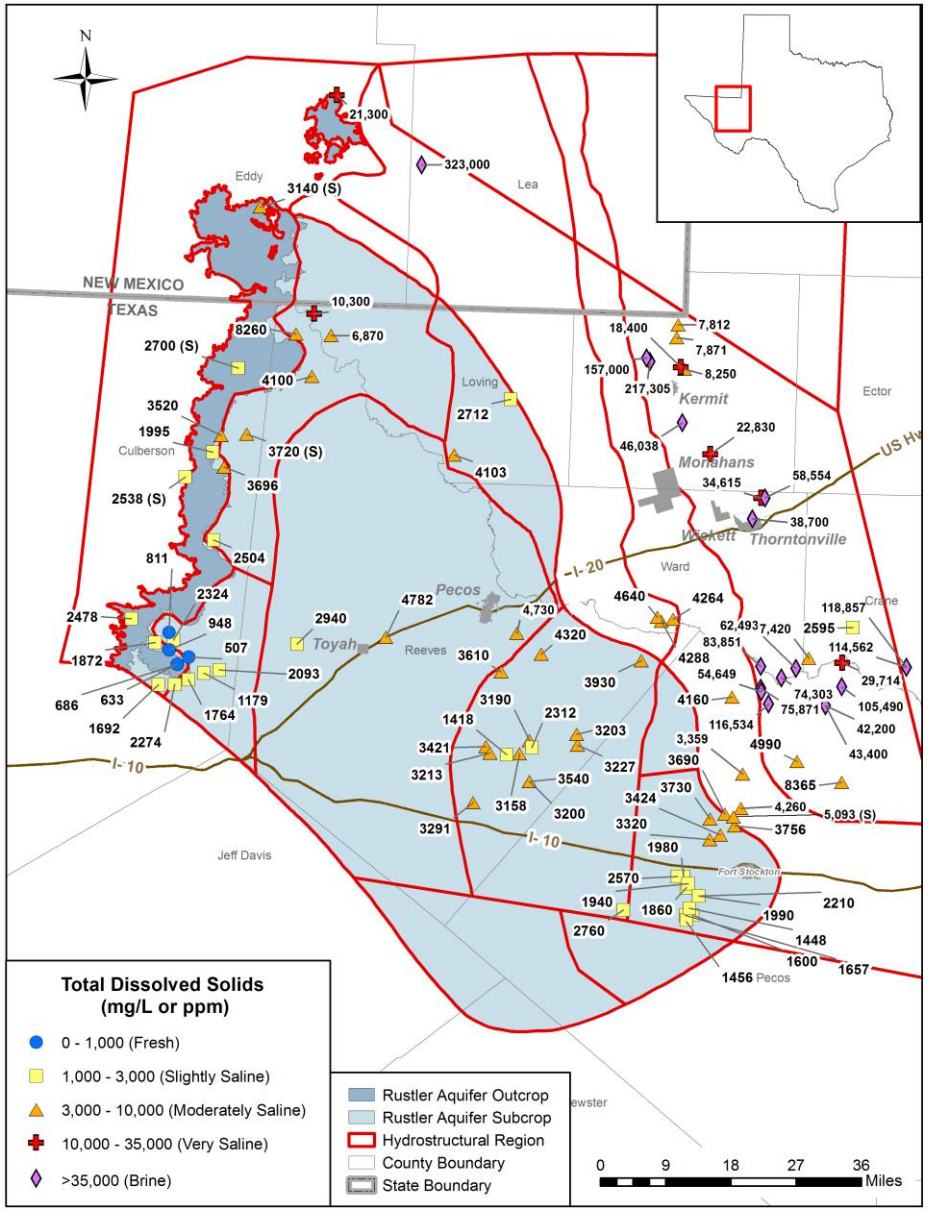
← Major/Minor Aquifer (Texas) Mapped Limit

← Seawater

Modified from Winslow and Kister, 1956

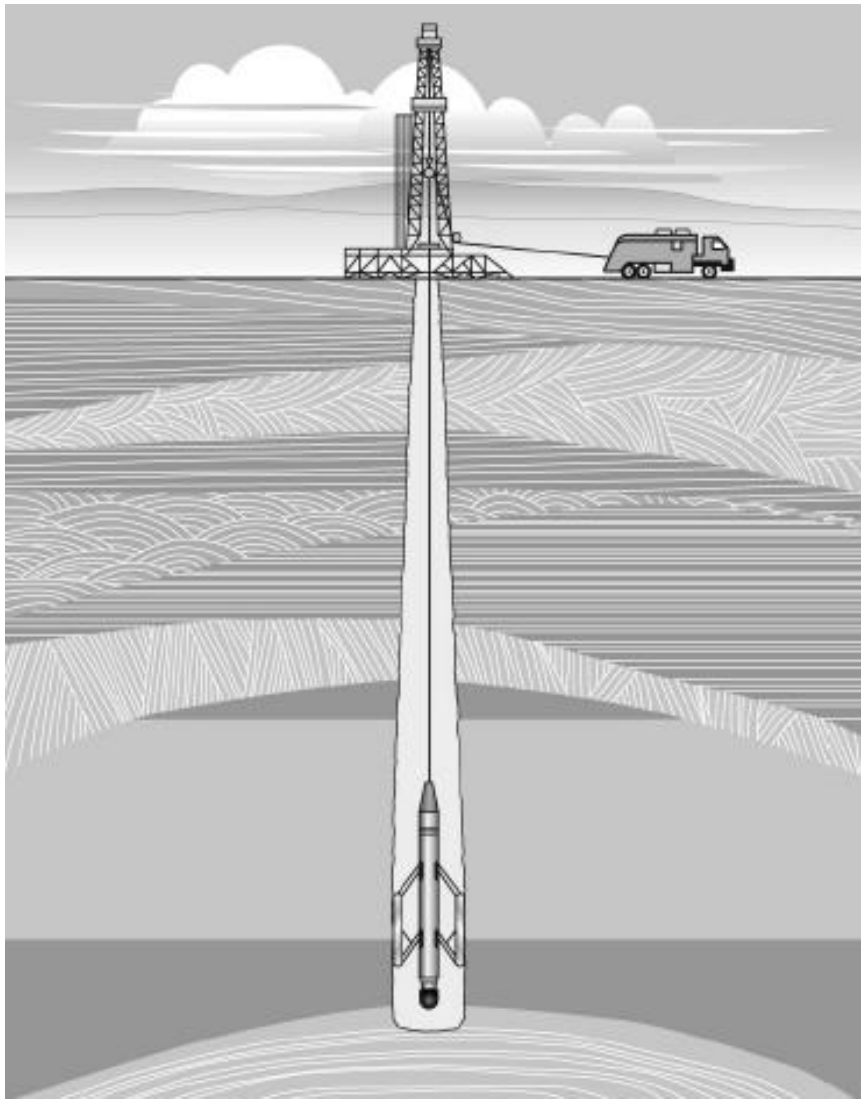
Water Quality (Sampled)

- In general, approximately 95% of the sampled water quality is in excess of 1,000 mg/L TDS
- Values below 1,000 mg/L occur exclusively in the southern portion of the Rustler outcrop in Culberson County
- Increasing trend in TDS from southwest to northeast
- Exception is possible freshening from the Glass Mountains (Tessey outcrop)



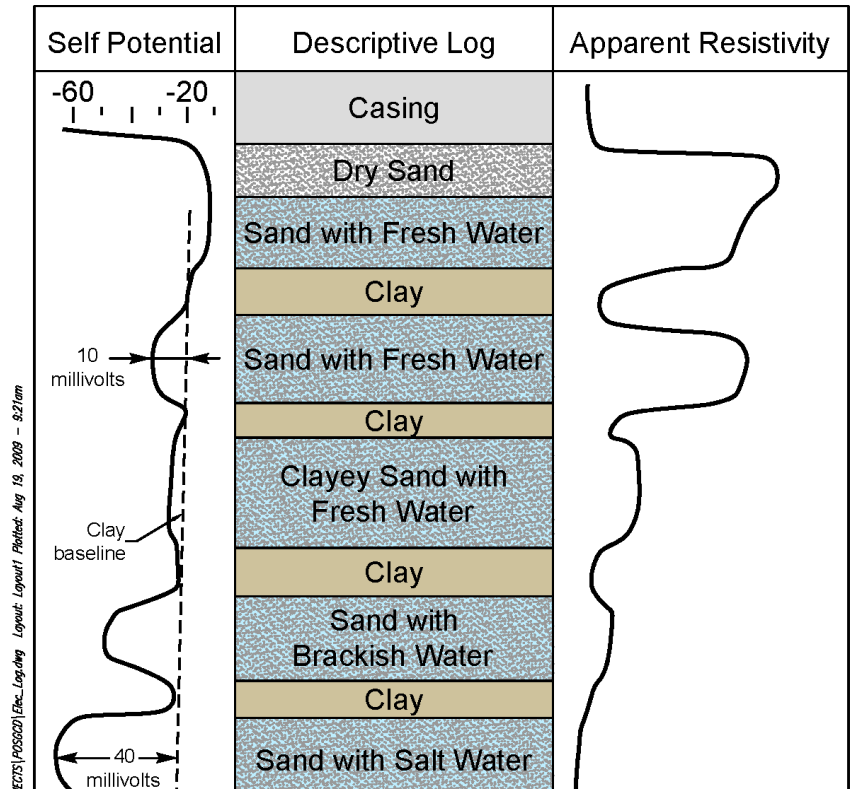
Calculation of WQ from Logs

- What is a geophysical log?
  - A record vs depth of variations of measurements of a specific physical property.
  - A record of the characteristics of the rock material penetrated by the borehole.
  - Most commonly used by scientists and engineers within the oil and gas and mining industries to characterize geologic formations

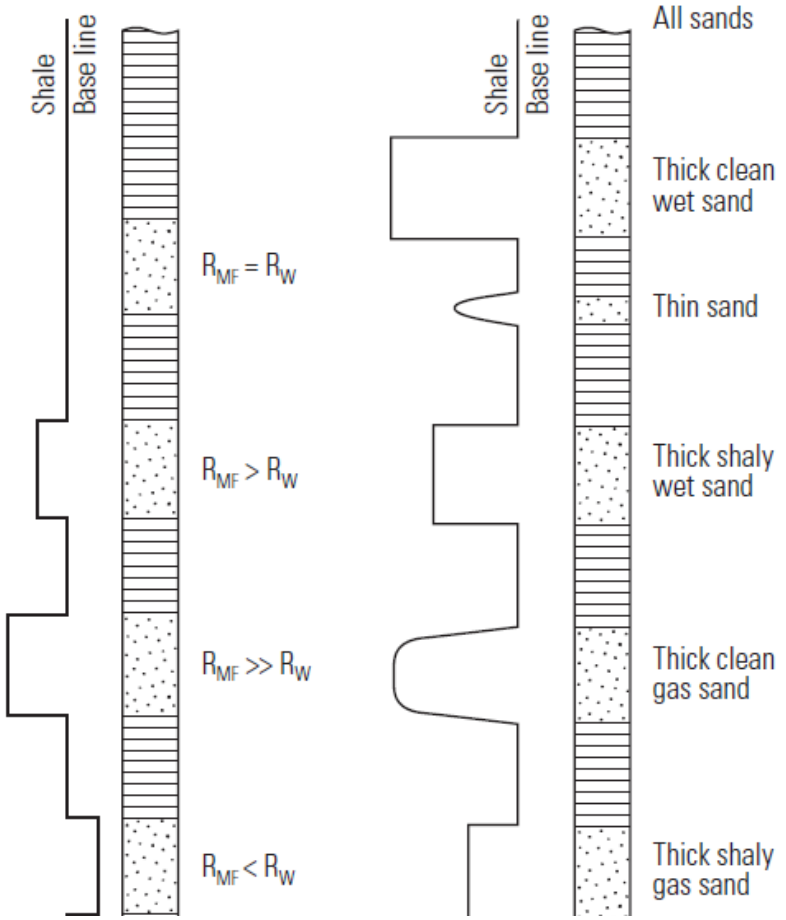


Calculation of WQ from Logs

- Spontaneous Potential (SP) Log- Measures the relative electric potential developed between the fluid within the borehole and the fluid within the formation



Groundwater based analysis (Young et al., 2012)

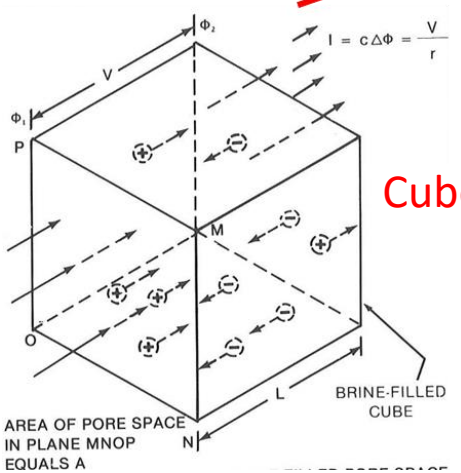


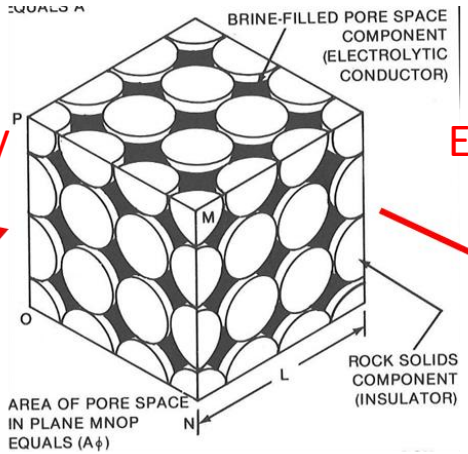
Oil/Gas based analysis (Asquith, 1982)

Calculation of WQ from Logs

- Resistivity Log- measures the rock's resistance, in ohm-meters, to the flow of an electric current
  - Major question is: How to parse out R_w from R_t in 100% water saturated formation

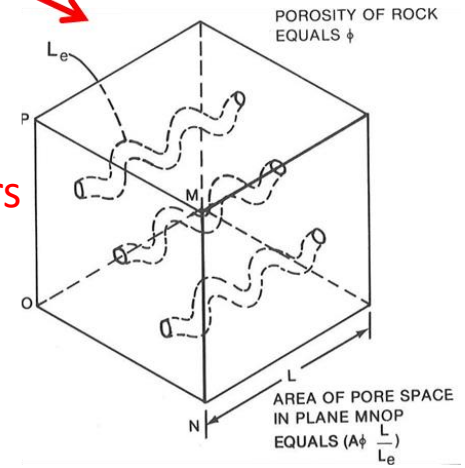
Brine filled cube: conductance related to intrinsic conductivity and cube dimensions





Cube filled with electrical insulators

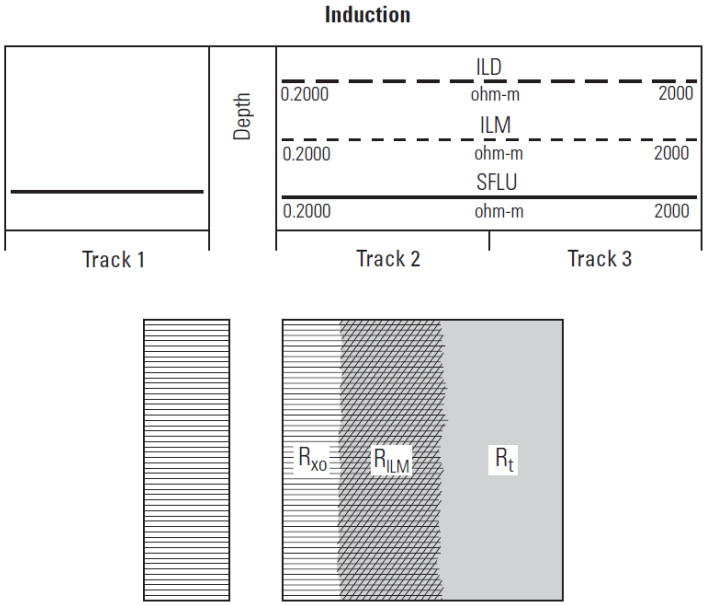
Electric charges are only conducted through tortuous paths of brine filled pore space

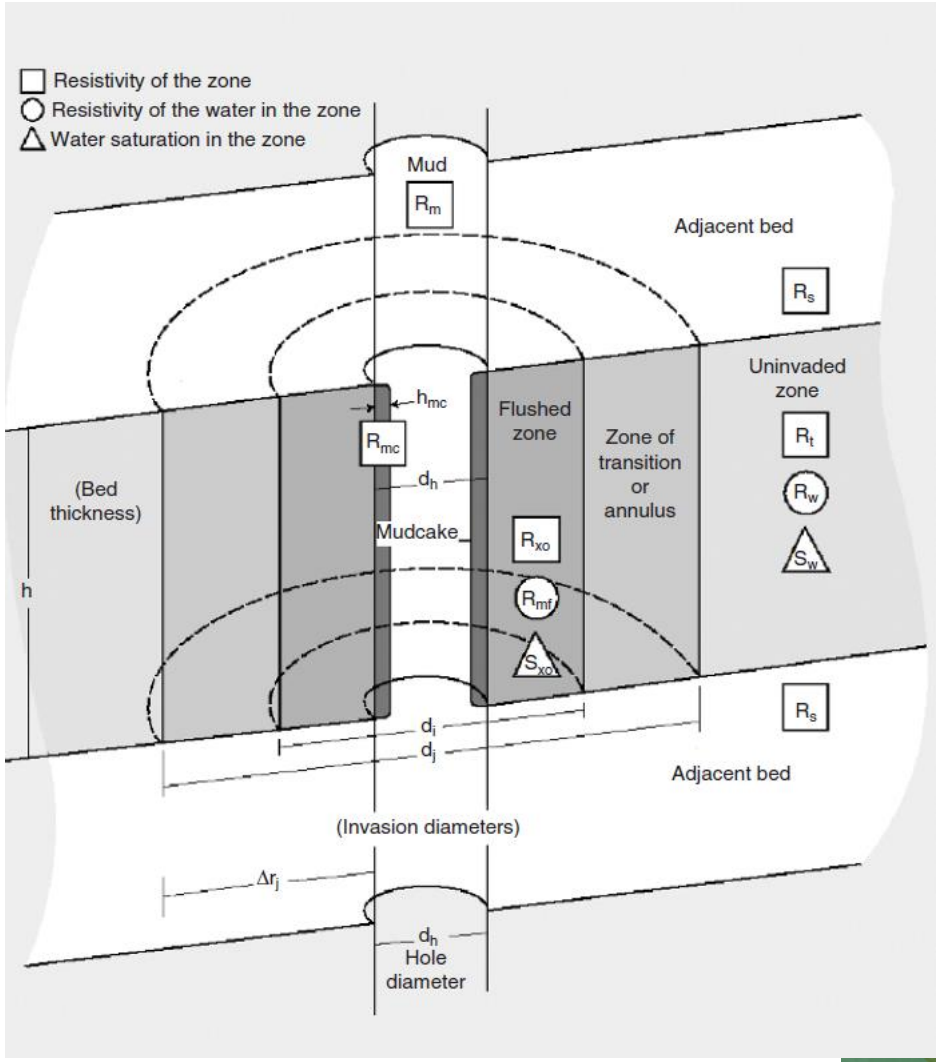


(Jorden and Campbell, 1986)

Calculation of WQ from Logs

- Different resistivity tools have different depths of investigation





Calculation of WQ from Logs

- What we know:
  - IF the water chemistry of a water sample can be approximated, a relationship between the resistivity, as taken from a geophysical log, can be related to the water quality using the following equation:

$$C_w = \frac{10{,}000}{\Phi^m \, x \, R_o}$$

$$TDS = C_w \, x \, ct$$

Where:

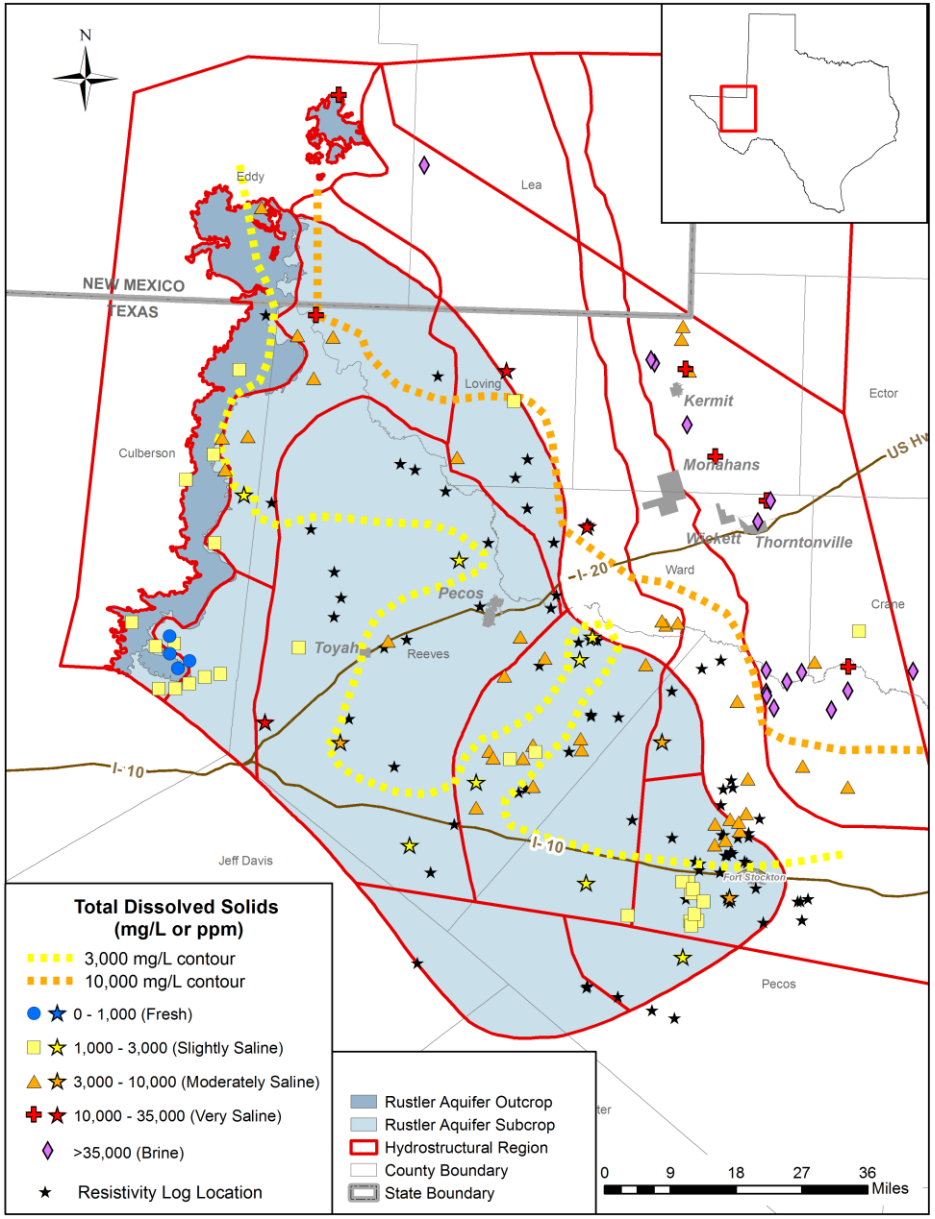
- C_w = specific conductance in µmhos/cm
- Φ = porosity
- m = the cementation exponent
- R_o = resistivity of water equivalent
- TDS = Total Dissolved Solids in milligrams per Liter
- ct = Rustler specific correction factor derived from sampled water quality data

Calculation of WQ from Logs

- Calculations of water quality complicated by the following factors:
  - Resistivity logs run through the Rustler are sparse, older in age and lack definition
  - Drillers typically used high salinity/high weight mud when drilling through the Rustler Formation which resulted in significant invasion
  - Rustler is a complex series of interbedded mudstones, anhydrites, dolomites and limestones all requiring specific correction factors
- Complexities associated with water quality calculations necessitated the assistance of a professional well log analyst/formation evaluation expert/petrophysicist
- Created a technique to correct resistivity logs run through the Rustler Formation so that the resistivity signature is more reflective of the water chemistry within the water bearing units
- Technique was developed using 17 “key wells” and will subsequently be applied to other resistivity logs in the study area to supplement sampled water quality data

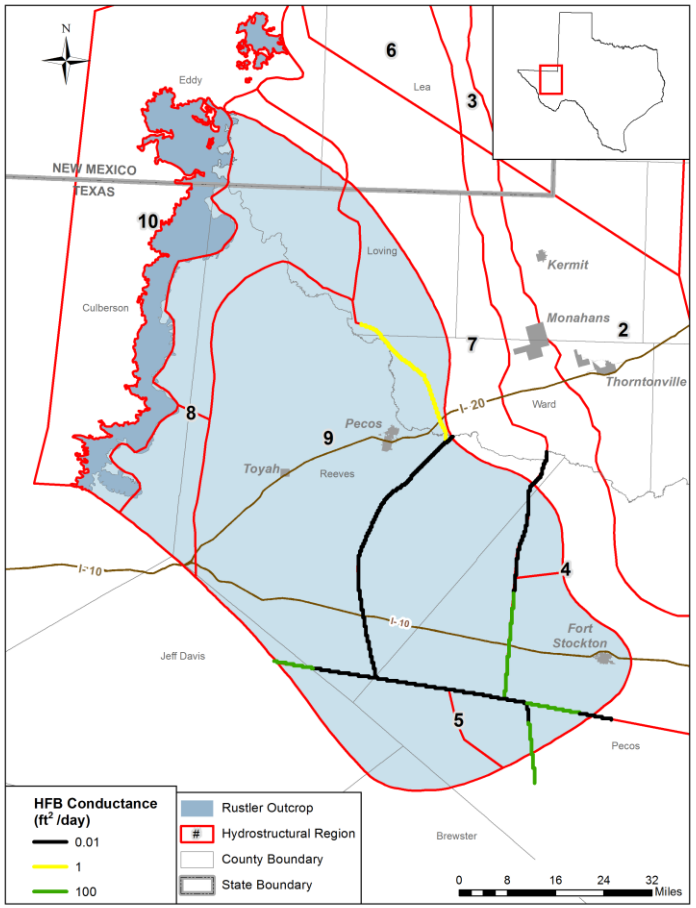
Water Quality (Calculated)

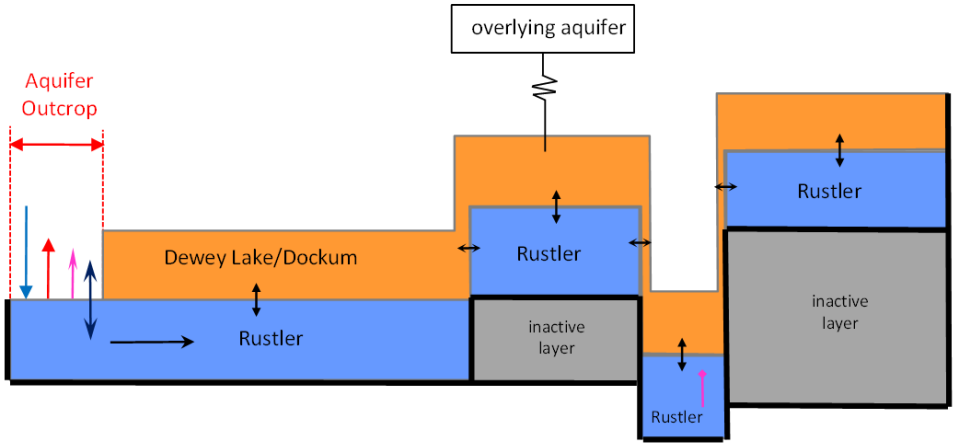
- Worked with Dr. Torres-Verdin to develop a technique to calculate water quality from resistivity curves specifically in the Rustler
- Calculations of water quality were made specifically on the dolomite and limestone water bearing units
- Calculations were made irrespective of geographic location



Hydraulic Barriers

- Vertical Hydraulic Barriers:
  - Except in outcrop areas, Rustler is overlain be the Dewey Lake Red Beds
  - Rustler is underlain over its extent by evaporites of either the Salado or Castile Formation
- Horizontal Hydraulic Barriers:
  - Significant offset through faulting results complete separation





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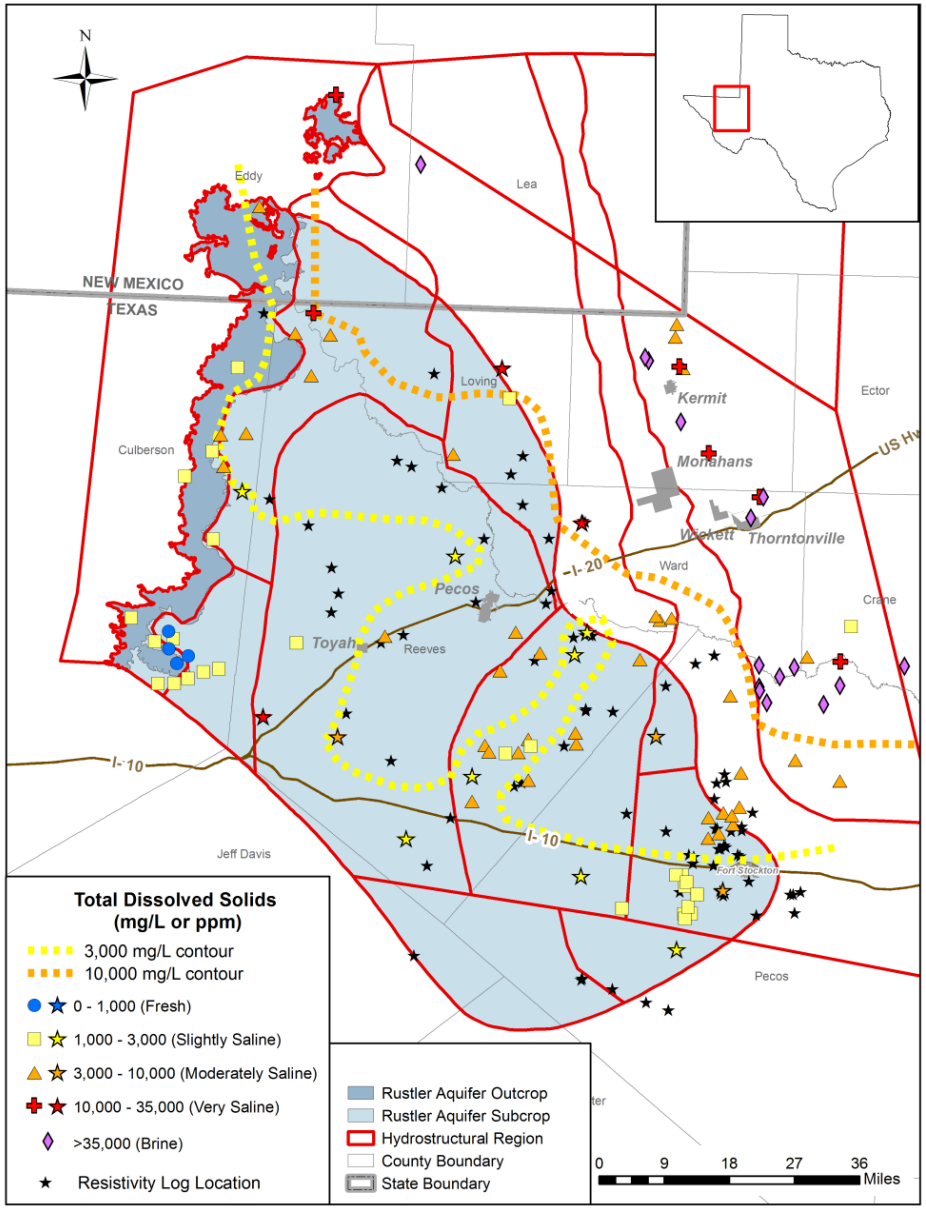
List of Criteria for Exclusion from PPA

- ≤1,000 mg/L TDS
- Are separated by hydrogeologic barriers sufficient to prevent significant impacts to water availability of zones with a TDS at or less than 1,000 mg/L
- Are not located in:
  - an aquifer, subdivision of an aquifer, or geologic stratum that:
    - has TDS more than 1,000 mg/L; and is serving as a significant source of water supply for municipal, domestic, or agricultural purposes at time of designation
    - An area of geologic stratum that is designated or used for wastewater injection through the use of injection wells or disposal wells permitted under Chapter 27

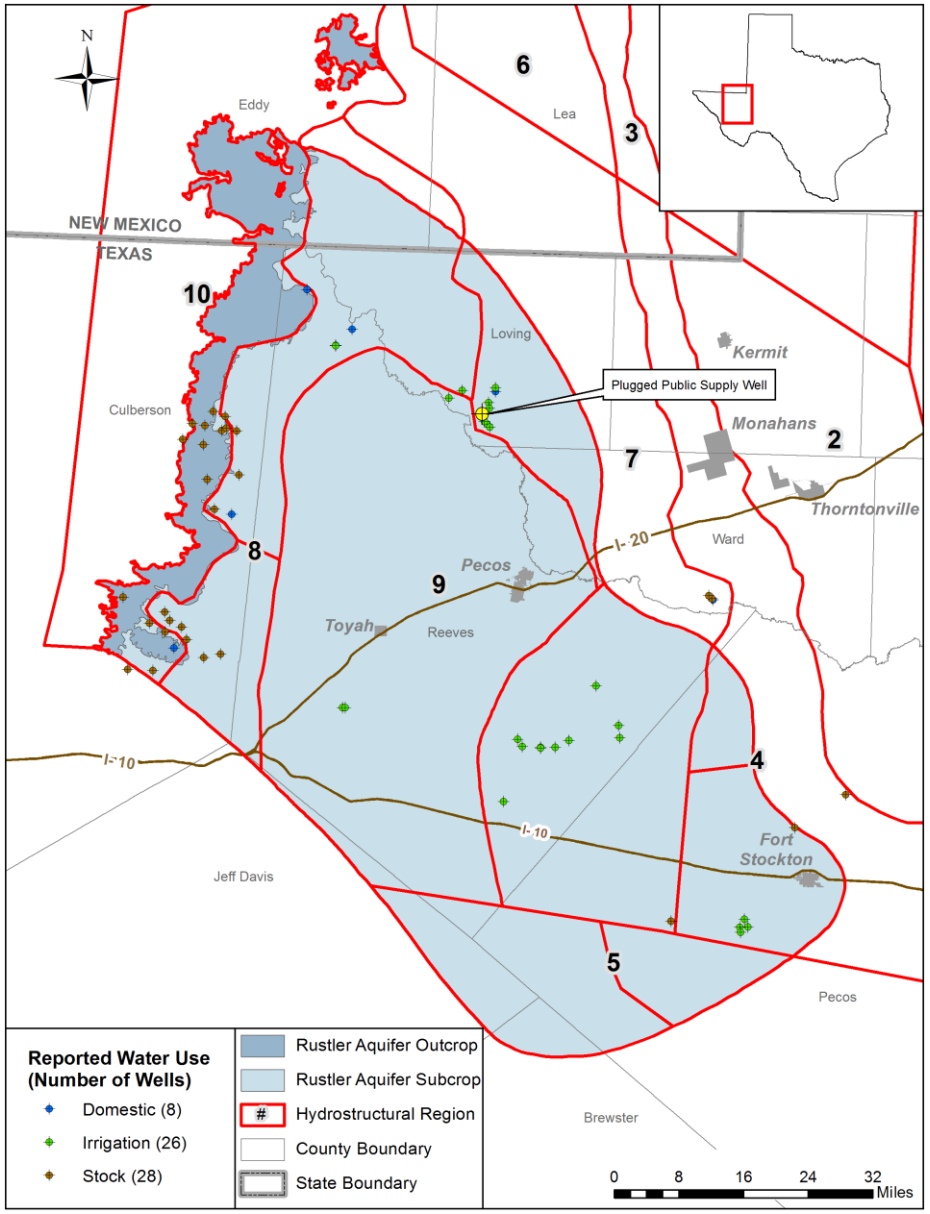
TDS > 1,000mg/L

- Majority of sampled water quality values in excess of 1,000 mg/L with the exception occurring in the southern portion of the outcrop
- Areas where TDS > 1,000 mg/L but there are no other groundwater resource options



Not significant source of water supply

- Sampled all water wells with screen and or total depth data to the top and base of the Rustler Aquifer
- Criteria in HB 30 specifies consideration for **municipal**, **domestic** or **agricultural**
- One municipal well drilled in Loving County but was subsequently plugged
- Majority of applicable wells are irrigation and stock
- Rest are domestic



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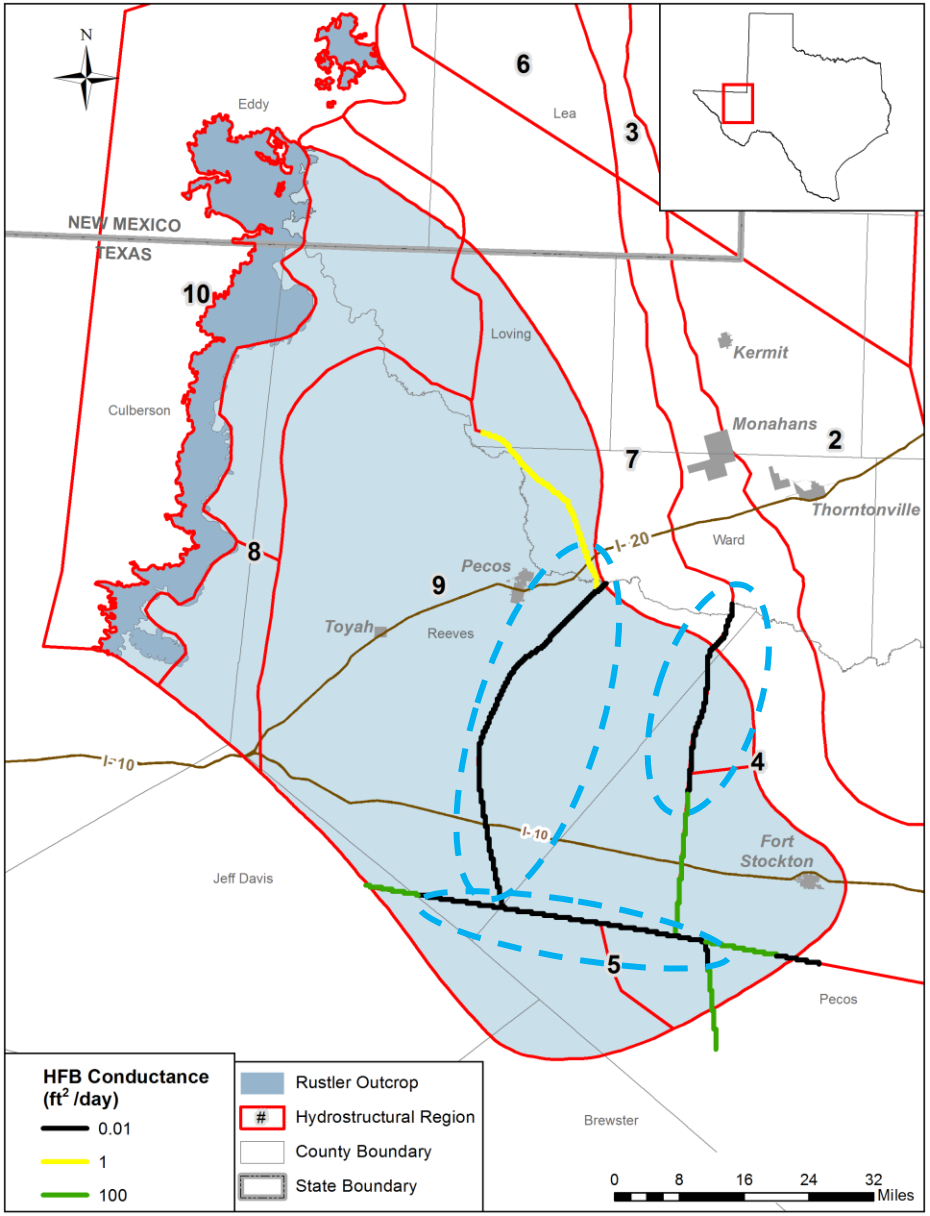
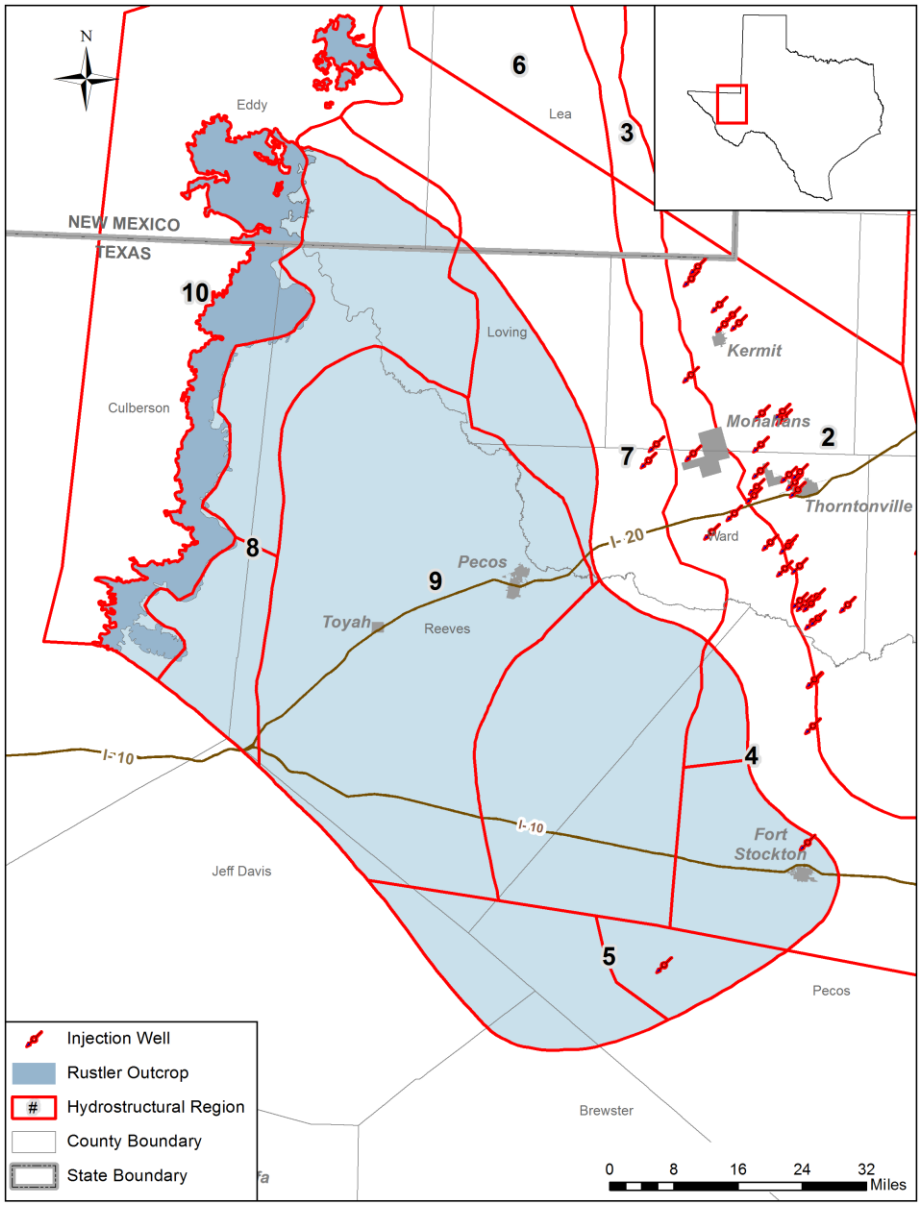


Designated or used for wastewater injection

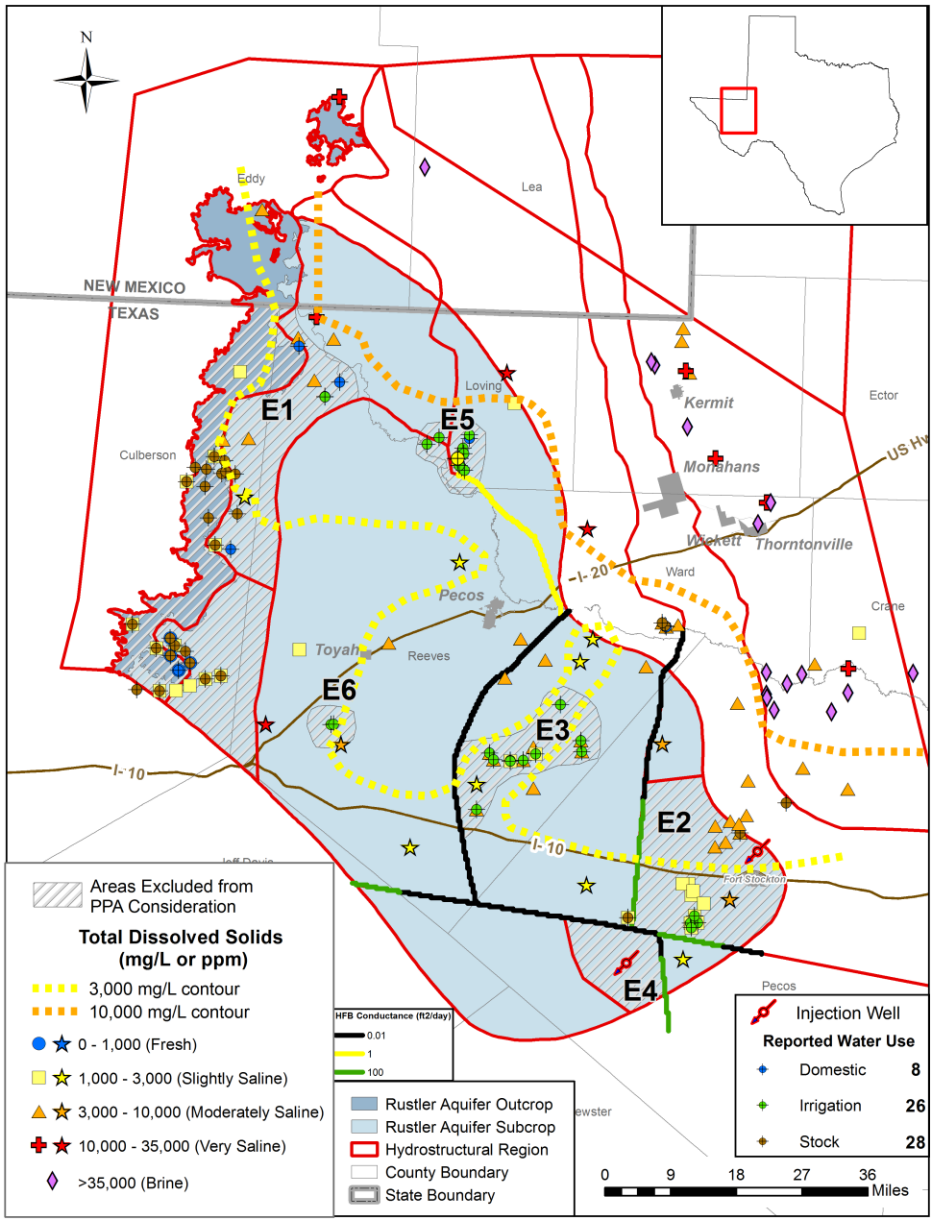
- Two wells exist in the study area
- Injection well 2.5 miles north of Fort Stockton is a brine mining well and while it is permitted over the Rustler, is likely mining the Salado
- Injection well southwest of Fort Stockton is in the Oates Field which has approximately 30 oil and gas wells producing from the Rustler Formation
- While there is only one injection well designated, it is possible that there are additional wells permitted for injection but not in the dataset used



Designation of Exclusion Zones

- Based on criteria designated in HB 30
  6 Exclusion Zones were designated
- Majority of exclusion was because of **KNOWN** existing use
- If you believe you have a Rustler well, contact TWDB
- We don't have a good source for current use status either

Exclusion Zone #	Water Quality < 1,000	Significant Use and/or Limited Alternatives	Injection Wells
1			
2			
3			
4			
5			
6			



Designation of Exclusion Zones

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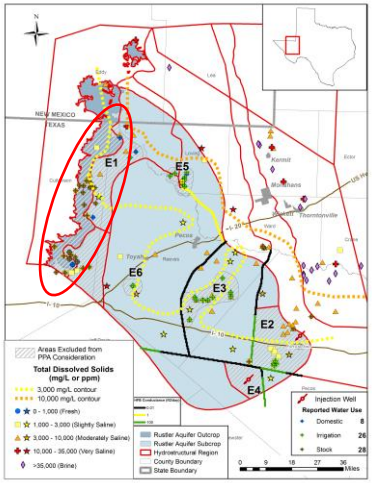
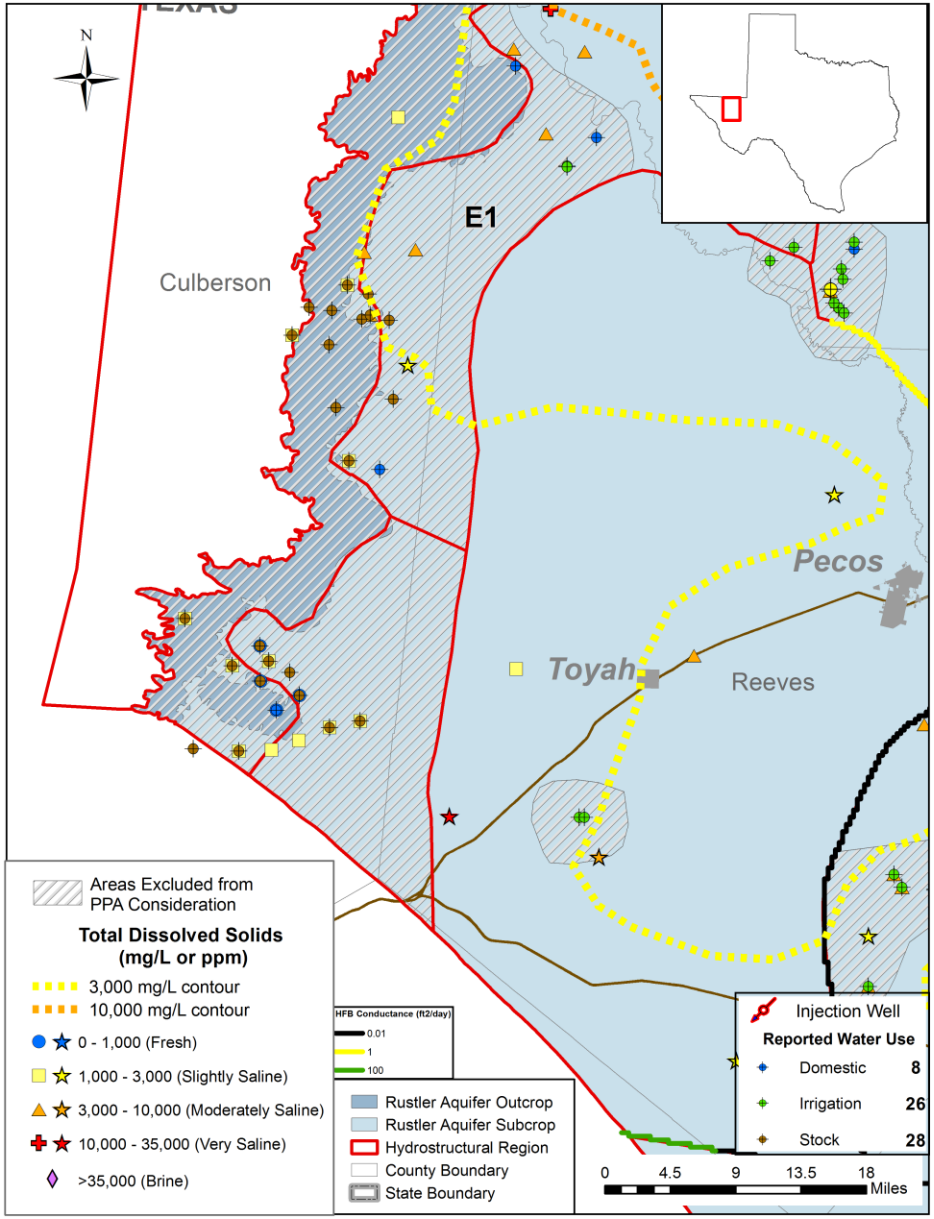
Exclusion Zone #	Water Quality < 1,000	Significant Use and/or Limited Alternatives	Injection Wells
1	X	X	-
2			
3			
4			
5			
6			

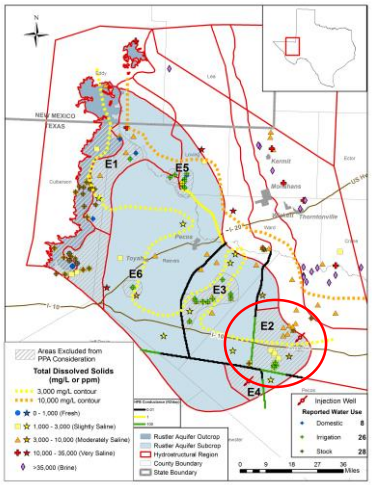


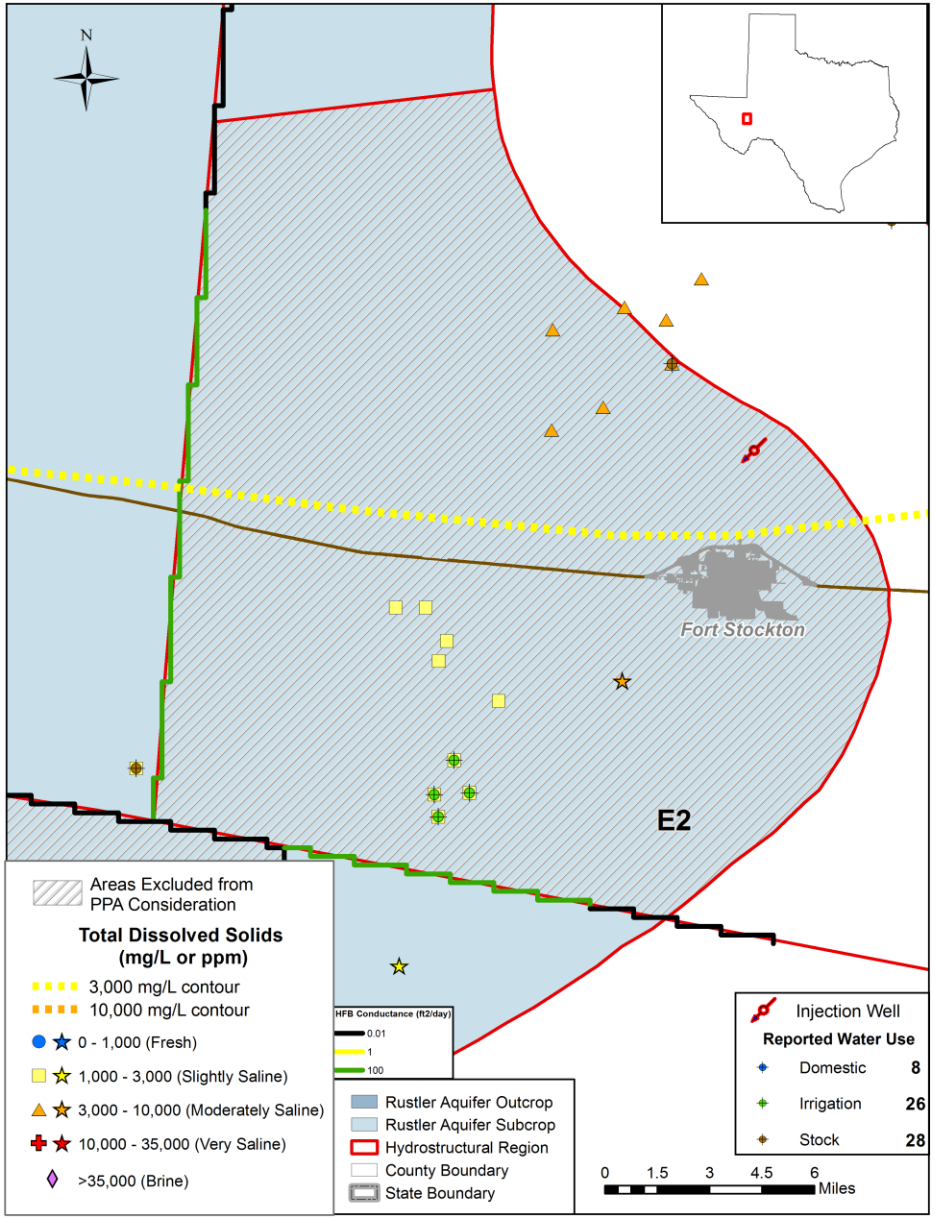


Designation of Exclusion Zones

- Based on criteria designated in HB 30
  6 Exclusion Zones were designated

Exclusion Zone #	Water Quality < 1,000	Significant Use and/or Limited Alternatives	Injection Wells
1			
2	-	X	-
3			
4			
5			
6			

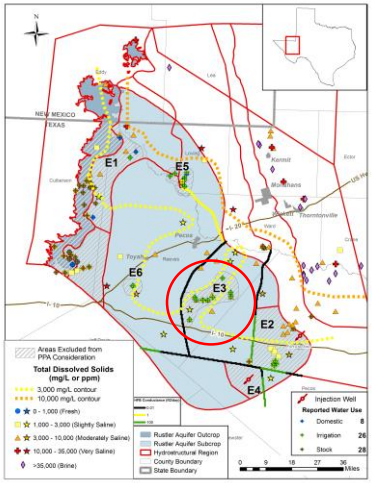


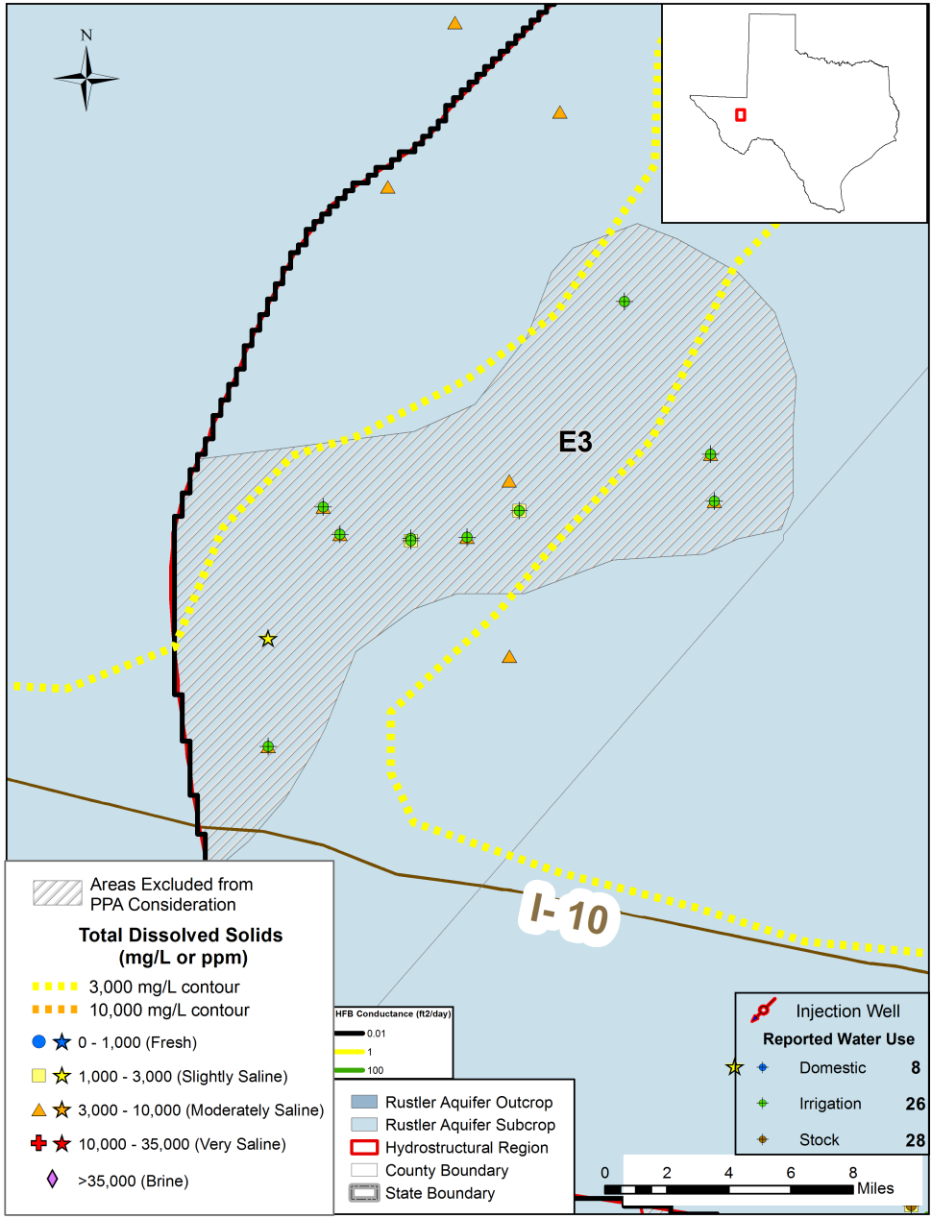


Designation of Exclusion Zones

- Based on criteria designated in HB 30
  6 Exclusion Zones were designated

Exclusion Zone #	Water Quality < 1,000	Significant Use and/or Limited Alternatives	Injection Wells
1			
2			
3	-	X	-
4			
5			
6			

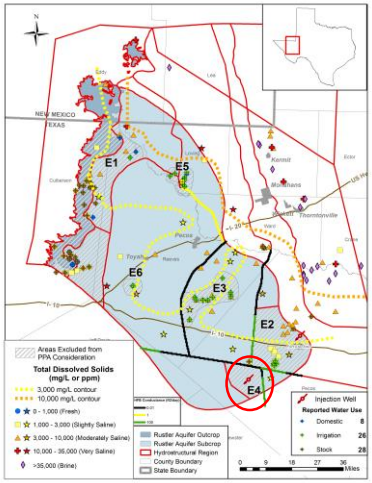


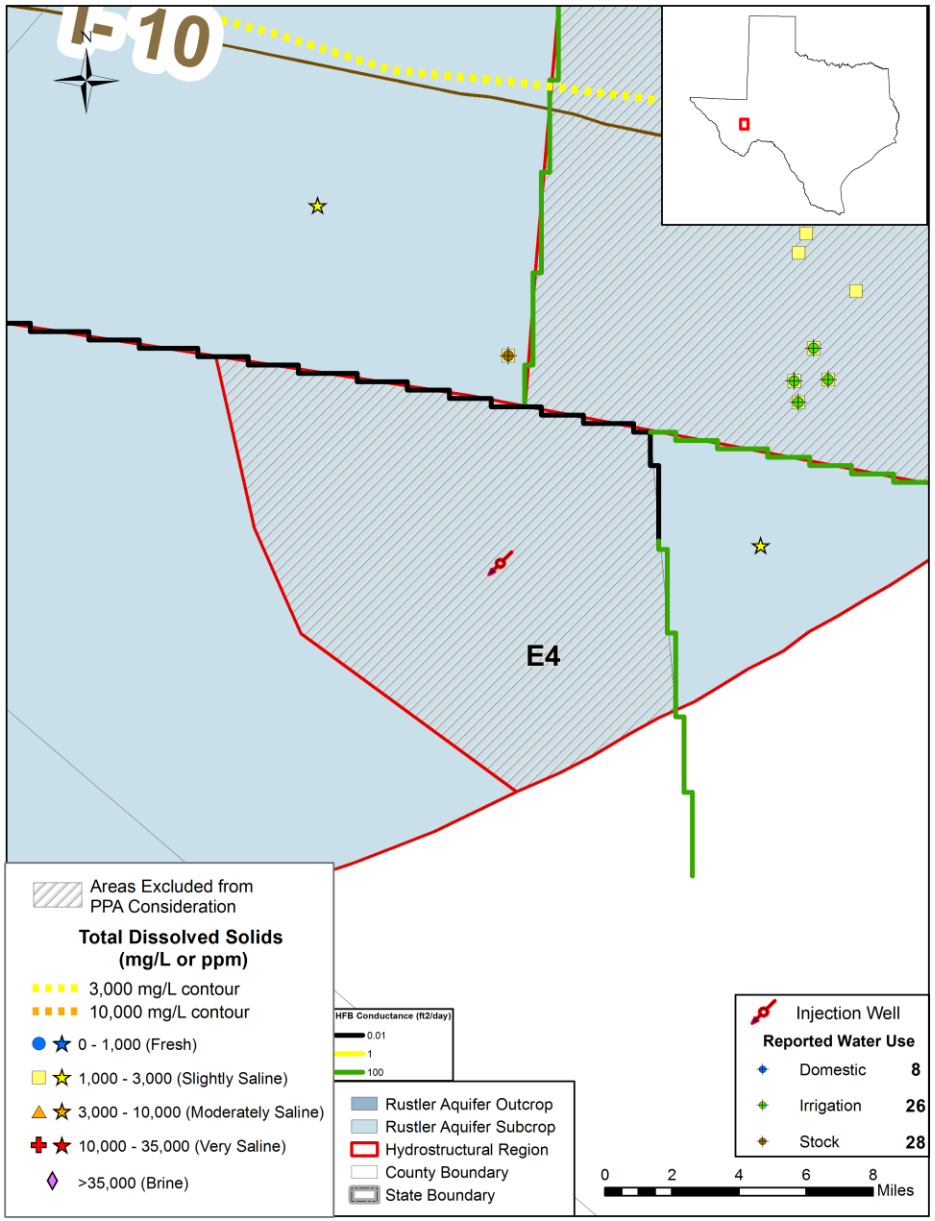


Designation of Exclusion Zones

- Based on criteria designated in HB 30
  6 Exclusion Zones were designated

Exclusion Zone #	Water Quality < 1,000	Significant Use and/or Limited Alternatives	Injection Wells
1			
2			
3			
4	-	-	X
5			
6			

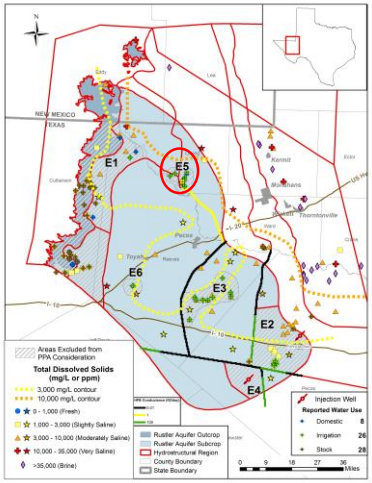


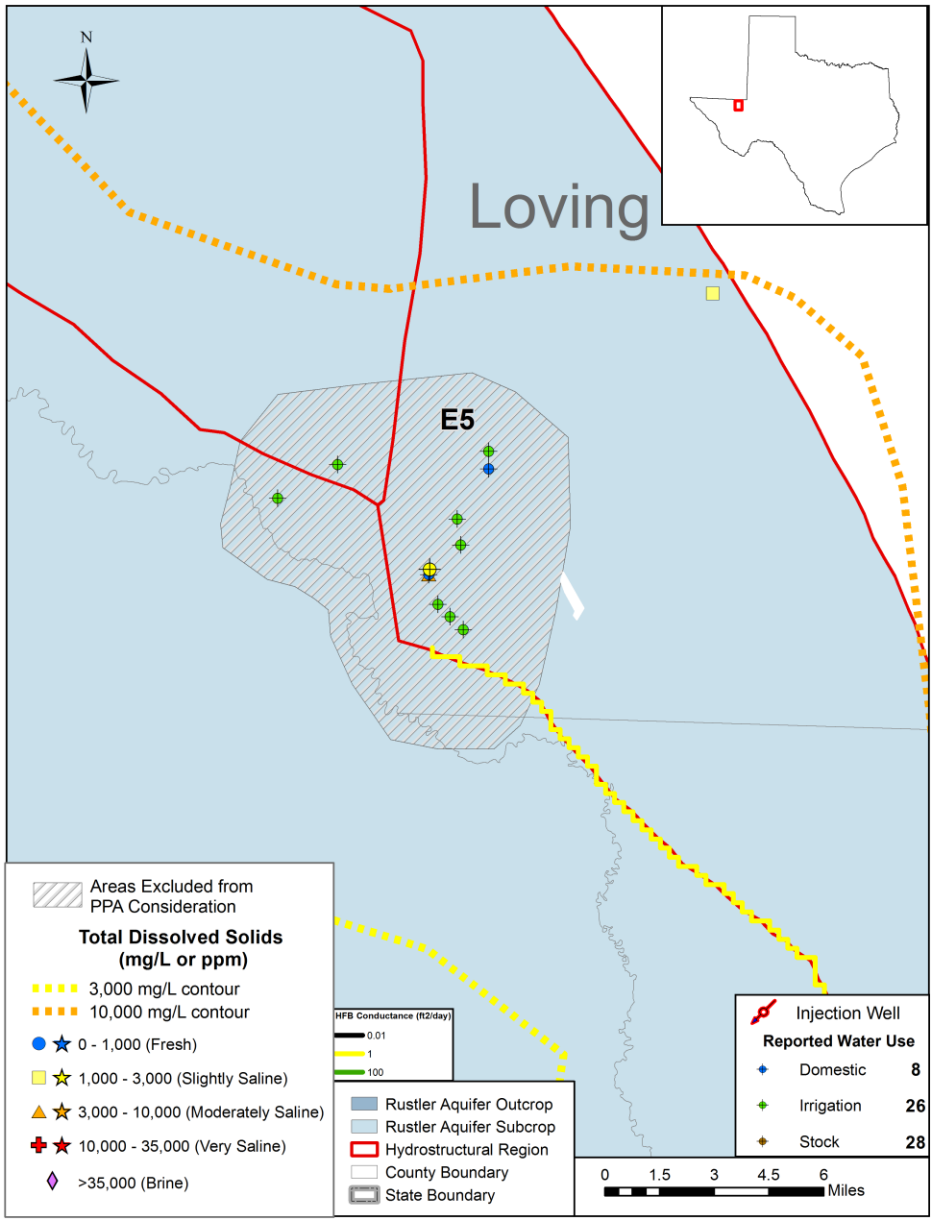


Designation of Exclusion Zones

- Based on criteria designated in HB 30
  6 Exclusion Zones were designated

Exclusion Zone #	Water Quality < 1,000	Significant Use and/or Limited Alternatives	Hydraulic Barriers
1			
2			
3			
4			
5	-	X	-
6			

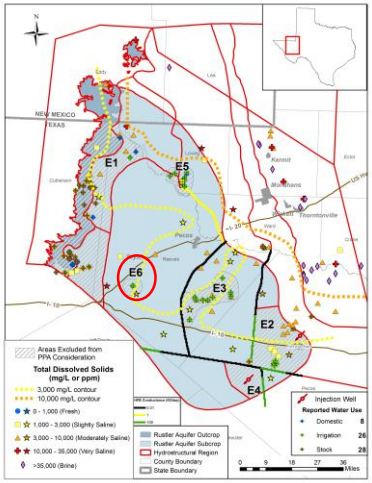


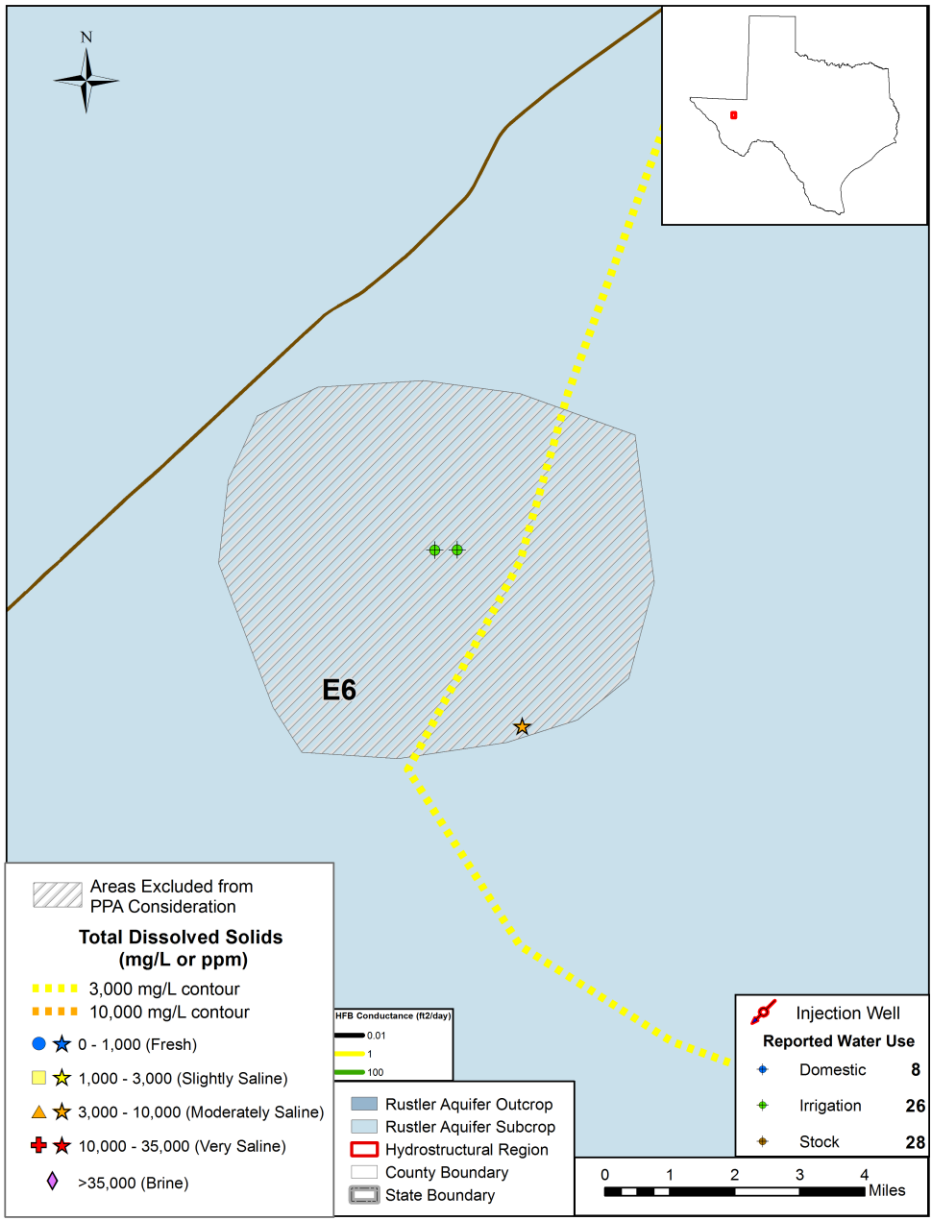


Designation of Exclusion Zones

- Based on criteria designated in HB 30
  6 Exclusion Zones were designated

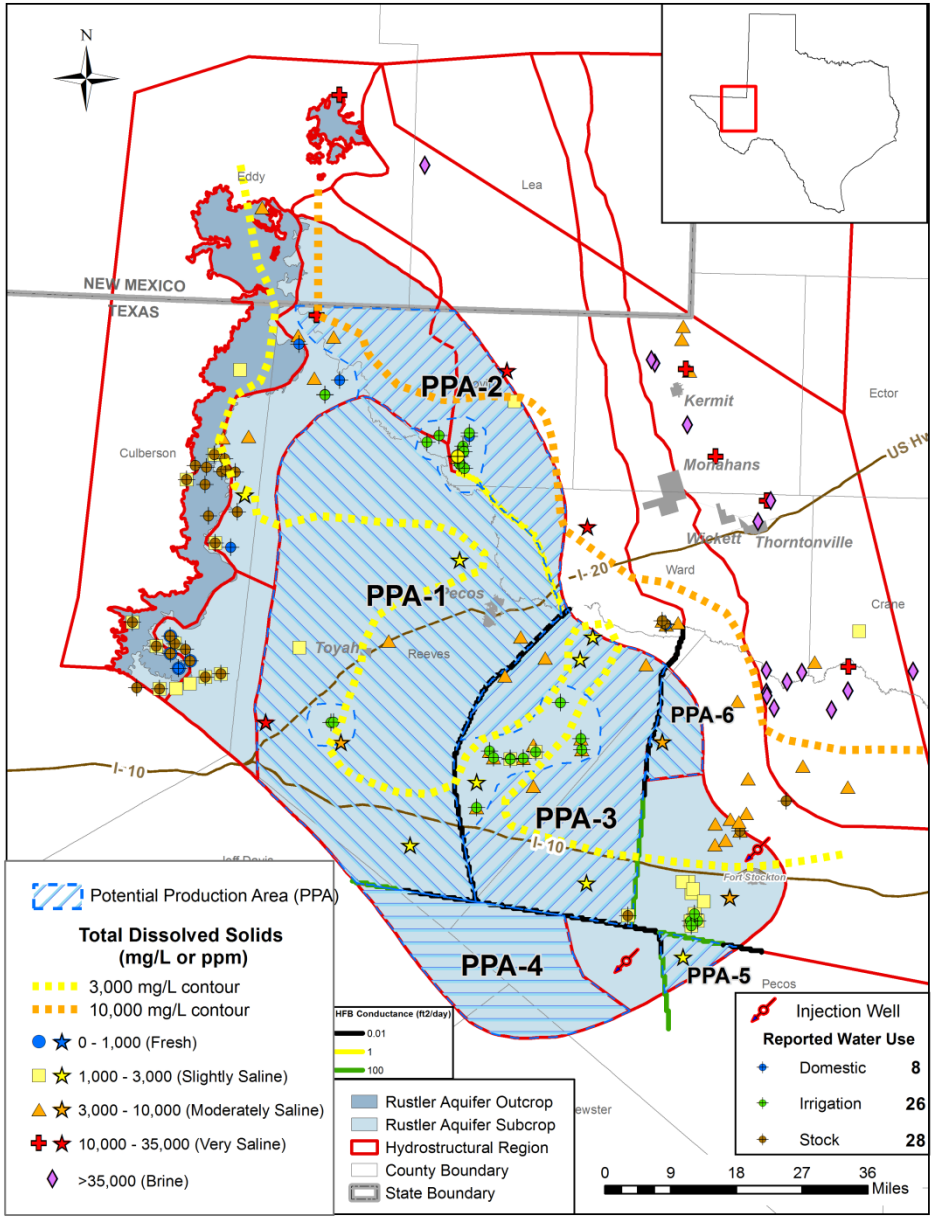
Exclusion Zone #	Water Quality < 1,000	Significant Use and/or Limited Alternatives	Injection Wells
1			
2			
3			
4			
5			
6	-	X	-





Draft Potential Production Areas

- There have been 6 Potential Production Areas (PPAs) identified.
- These designations are DRAFT
- After receiving feedback, INTERA will meet with the TWDB and the TWDB will determine which PPAs to analyze for volumetrics and potential impact to users in excluded areas
- The TWDB will ultimately define the Brackish Groundwater Production Zones in their report to the State Legislature submitted December 1, 2016



Public Comments and Next Steps

The delineation of potential production areas presented today are draft and open to public comment:

- This presentation will be publicly available at the TWDB Rustler Aquifer BRACS website
  - Stakeholders will receive an email when it is posted
  - Stakeholders should have their comments to the TWDB by August 1st
- The Final Report will be delivered to the TWDB by August 31st
  - Stakeholders will receive an email when the Final Report is posted to the website and will be encouraged to provide comments
- Brackish Groundwater Production Zones will be designated by the TWDB at a public board meeting in the fall
  - Stakeholders will receive an email with the meeting date, time, and location
- The biennial report to the Texas Legislature will be approved at a public board meeting in the fall
  - Stakeholders will receive an email with the meeting date, time, and location


INTERA
GEOSCIENCE & ENGINEERING SOLUTIONS