Study of Brackish Aquifers in Texas – Project No. 4 –Trinity Aquifer

TWDB Contract No. 1600011950

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GEOSCIENCE & ENGINEERING SOLUTIONS

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Project Details

- Study of Brackish Aquifers in Texas – Project No. 4 –Trinity Aquifer
  - TWDB Contract No. 1600011950

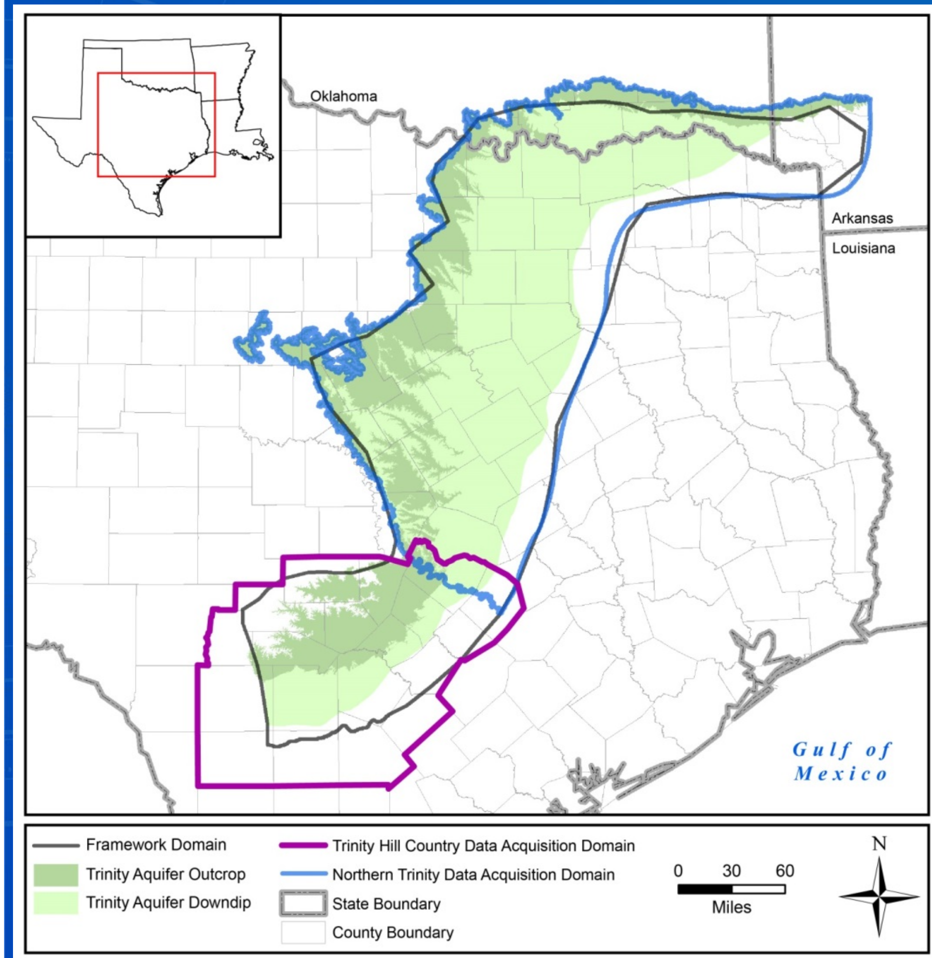
Project Authors:

- Leanne Stepchinski (SwRI)
  - Project management, hydrogeology
- Ronald Green (SwRI)
  - Hydrogeology
- Paul Bertetti (SwRI)
  - Geochemistry
- Ronald McGinnis (SwRI)
  - Structure and stratigraphy, log interpretation
- Nathaniel Toll (SwRI)
  - Hydrogeology, groundwater modelling
- Daniel Lupton (INTERA, Inc.)
  - Hydrogeology, log analysis, structure and stratigraphy, geochemistry
- Neil Deeds (INTERA, Inc.)
  - Hydrogeology, log analysis, structure and stratigraphy, geochemistry
- Beth Fratesi (SwRI)
  - Hydrogeology, groundwater modelling
- Rebecca Nunu (SwRI)
- Kirk Gulliver (SwRI)

Project Objectives

- Evaluate the fresh, brackish, and saline groundwater resources of the Trinity Aquifer
- The project team has:
  - Evaluated all groundwater and geophysical log data available in the study area
  - Developed a technical approach for estimating total dissolved solids (TDS) from geophysical logs
  - Delineated fresh, brackish, and saline groundwater both vertically and horizontally in the aquifers of the project area
  - Developed a stratigraphic framework model with available structural, stratigraphic, and lithologic data
  - Delineated Potential Production Areas (PPAs)

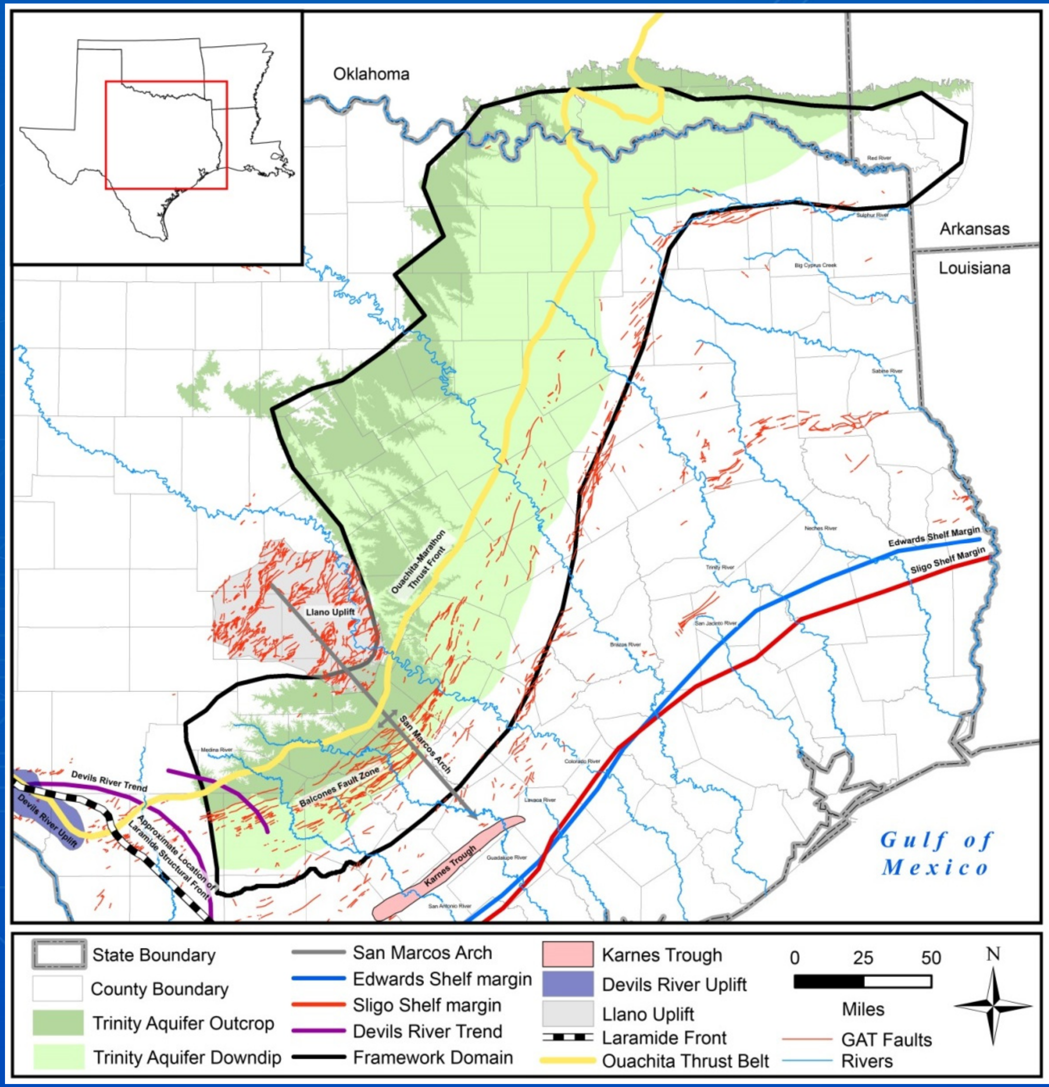
Geology of the Trinity Aquifer



Period	Age	Age M.Y.	Group	North Formation[1]	Central Formation[1]	South Formation[1]	Hill Country Formation[2]	This Study Formations
				Grayson Marl	Buda	Buda	Buda	
					Del Rio	Del Rio	Del Rio	
				Mainstreet				
	Cenomanian			Pawpaw				NA
			Washita	Weno	Georgetown	Georgetown	Georgetown	
				Denton				
				Duck Creek				
				Fort Worth				
		97.0		Kiamichi	Kiamichi	Kiamichi		
Cretaceous			Fredericksburg	Goodland	Edwards	Edwards	Edwards	NA
	Albian				Comanche Peak	Comanche Peak		
				Walnut Clay	Walnut Clay	Walnut Clay		
					Paluxy	Paluxy	Glen Rose Upper	Paluxy
		112.0			Glen Rose	Glen Rose	Glen Rose Lower	Glen Rose
	Aptian				Twin Mountains: Hensell	Travis Peak: Hensell	Hensell	Hensell
			Trinity	Antlers		Travis Peak: Pearsall	Cow Creek	
					Twin Mountains: Pearsall	Travis Peak: Cow Creek	Hammett	Pearsall
						Travis Peak: Hammett		
						Travis Peak: Sligo	Sligo	
		124.5			Twin Mountains: Hosston	Travis Peak: Hosston	Hosston	Hosston
	Pre-Aptian	145.0						
Jurassic	Tithonian			Permian	Permian	Permian	Pre-Cretaceous Undifferentiated	Pre-Cretaceous Undifferentiated

[1]Northern Trinity Aquifer GAM
[2]Hill Country Aquifer GAM

Depositional and Tectonic Setting of the Trinity Aquifer



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Hill Country Trinity Geologic Framework

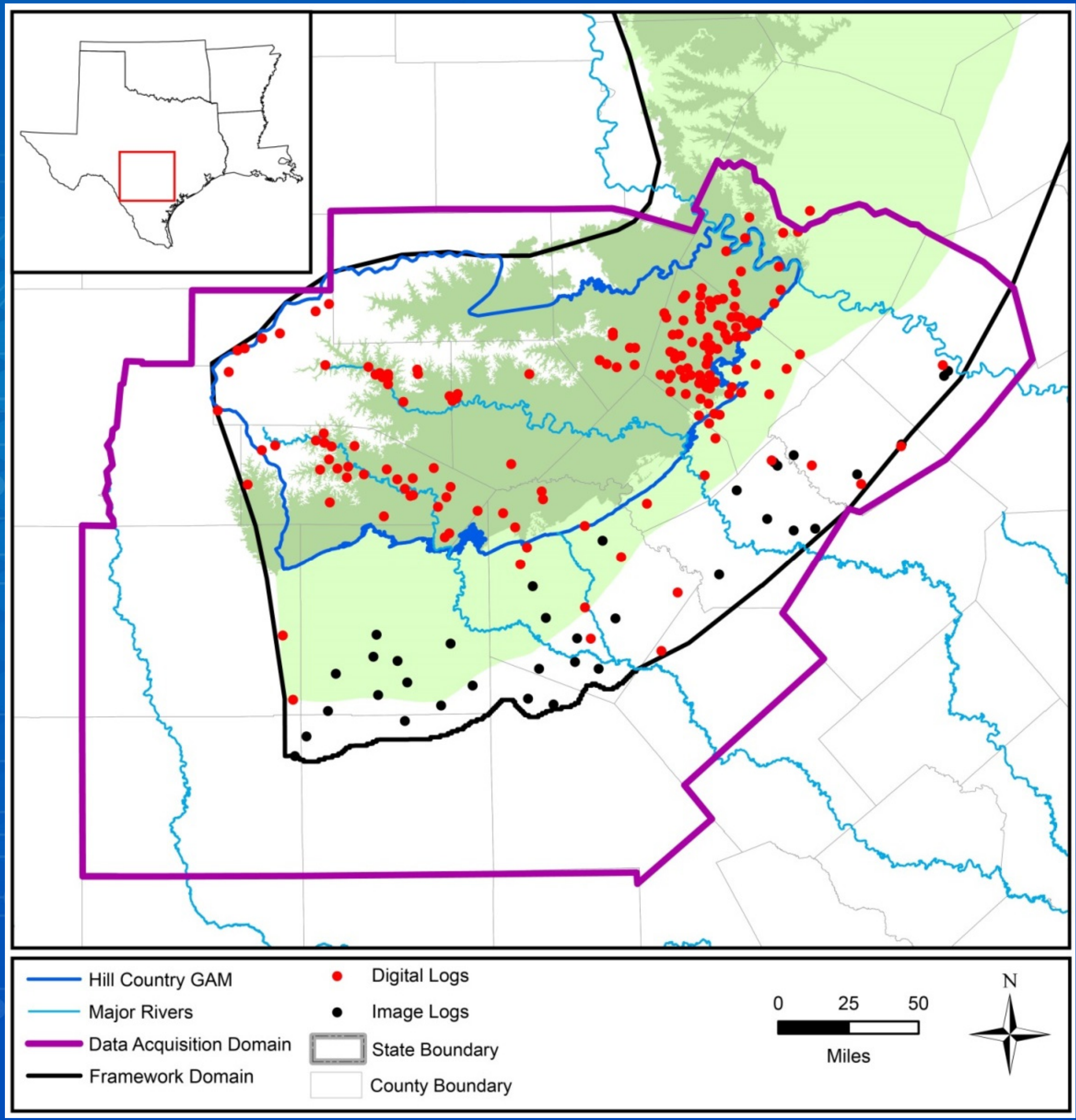
The existing groundwater availability model (GAM) for the Hill Country Trinity Aquifer was not appropriate for use in this application. Therefore, the project team took the following steps to create the geologic framework:

- Build Well Log Database
  - Literature, BRACS, Type Wells, IHS Enerdeq, and IHS GCS
- Interpret Geologic Units
  - Original work for this study
  - Lithology interpreted from geophysical well logs:
    - 7 wells for lithology – sand/shale/carbonate at 5 ft frequency
  - 7 stratigraphic horizons
- Incorporate fault model into framework
  - 126 normal faults that cut all 7 layers
  - Average fault dip is 70° (range is 42-89°)
- Correlate Offset on Stratigraphic Surfaces
  - Original work for this study
- Map Layer Thicknesses and Compositions
  - Structure, isopach, net sandstone maps

Hill Country Trinity Aquifer Geologic Framework

Used to build the geologic framework:

- 62 wells with depth registered image logs
- 176 wells with digitized logs
- This task is in continual development as new data become available.

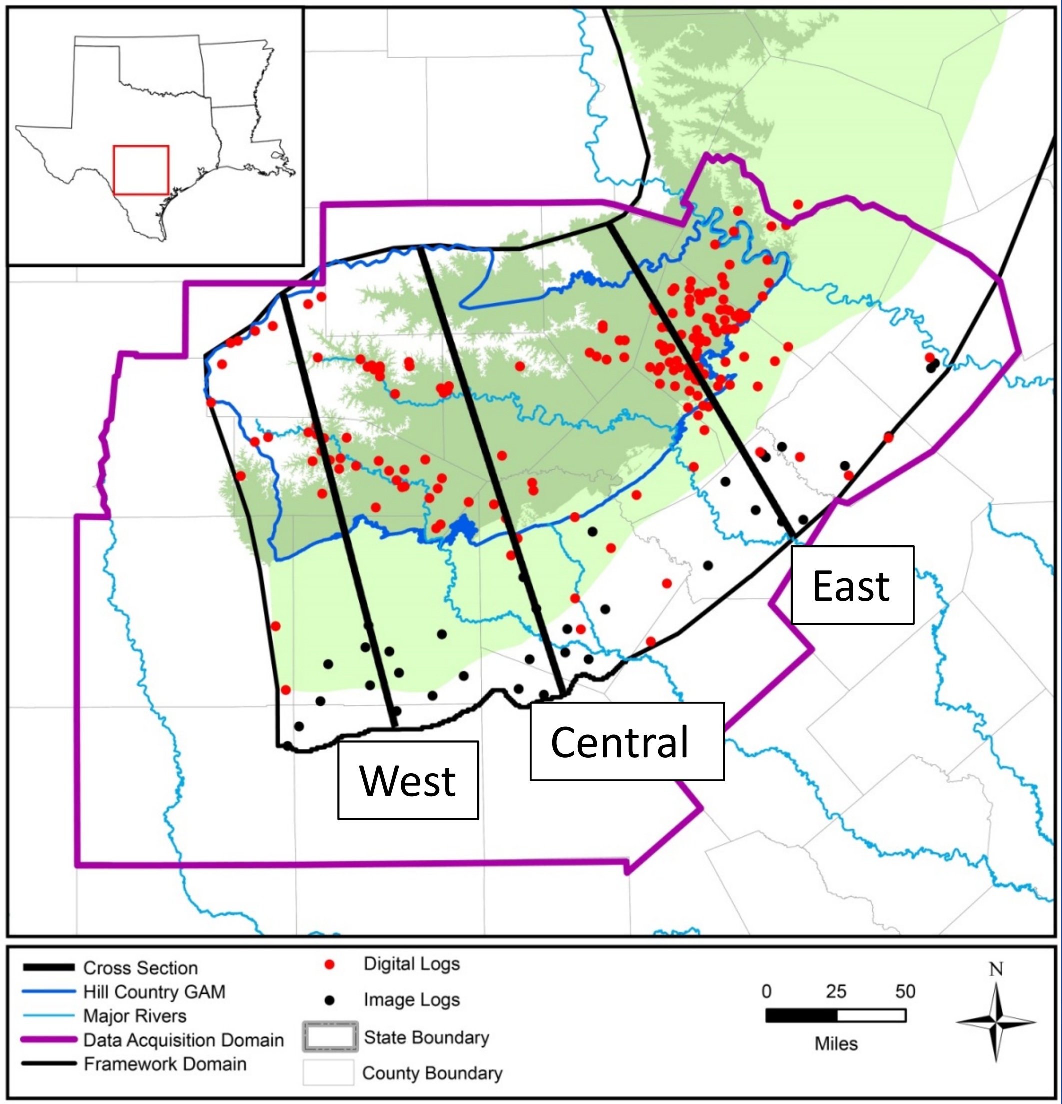


Hill Country Trinity Aquifer Geologic Framework

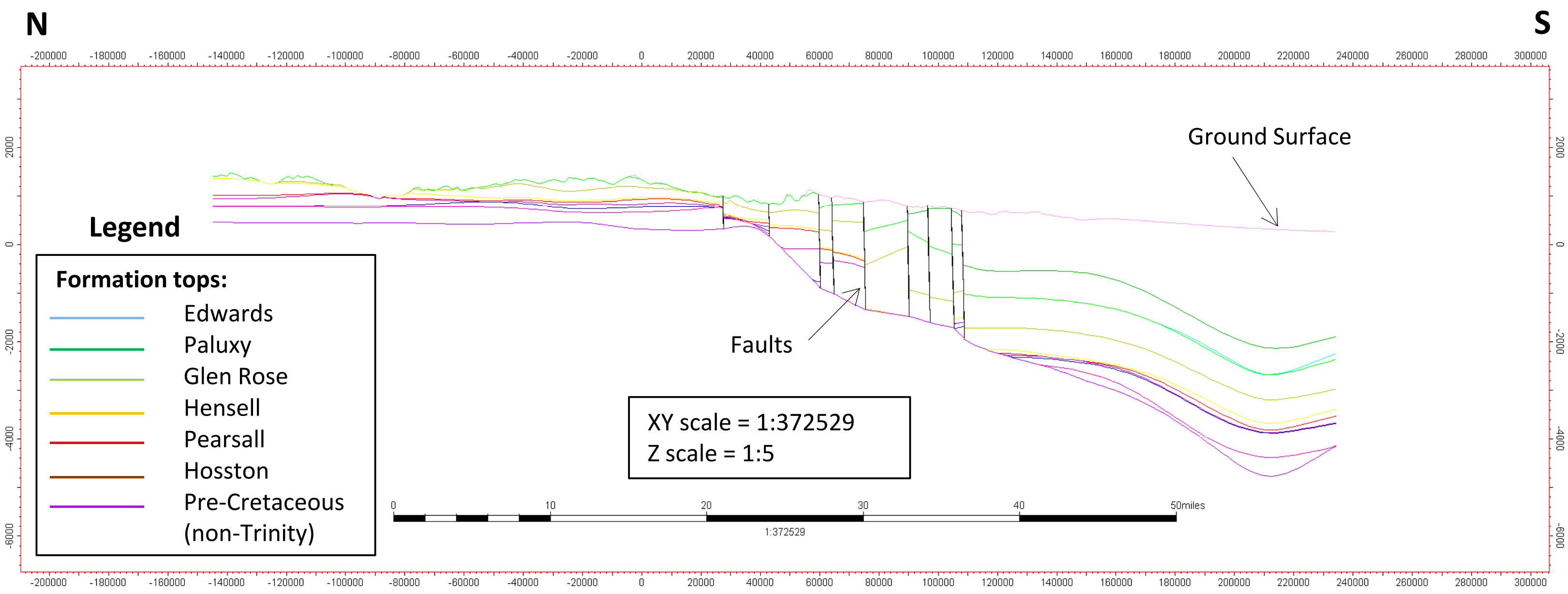
East Cross-Section

Central Cross-Section

West Cross-Section

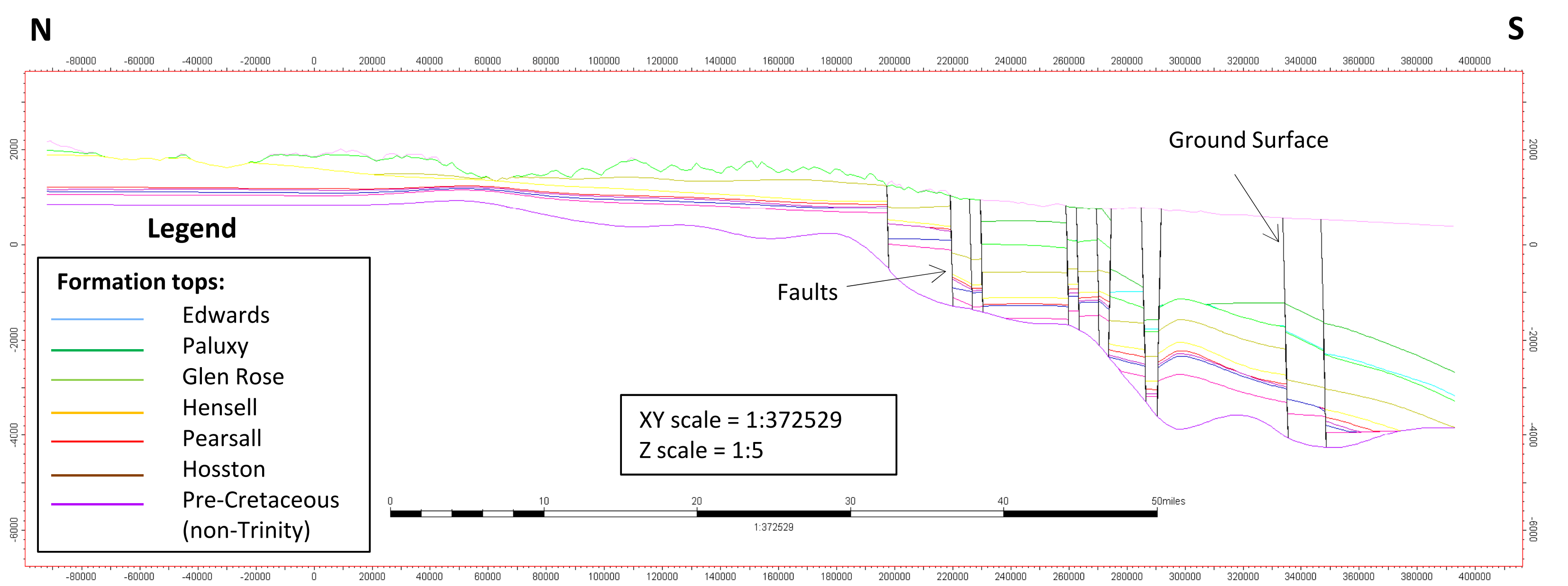


Hill Country Trinity Aquifer - East Stratigraphic Section



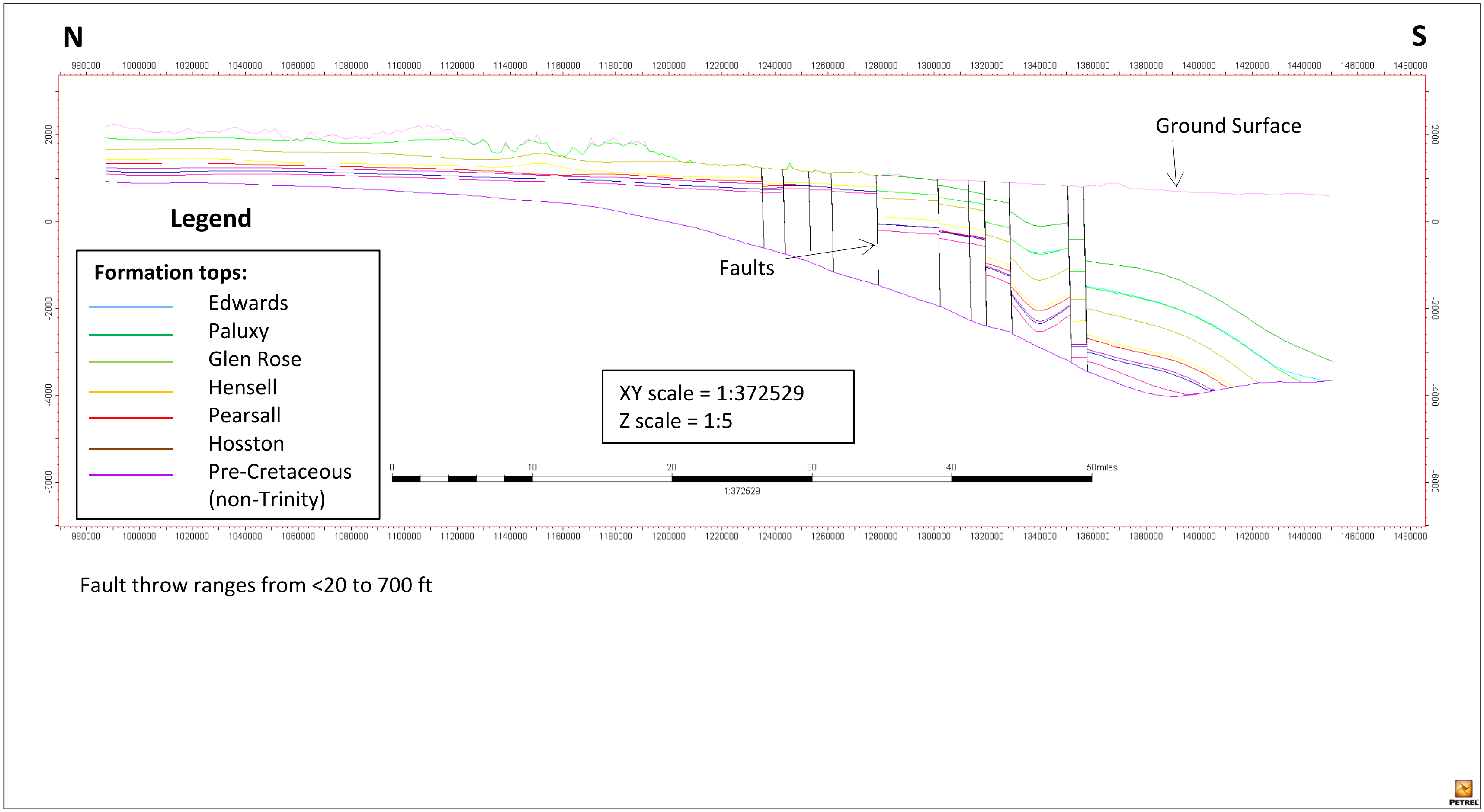
Fault throw ranges from <20 to 1000 ft

Hill Country Trinity Aquifer – Central Stratigraphic Section



Fault throw ranges from <20 to 950 ft

Hill Country Trinity Aquifer – West Stratigraphic Section



Fault throw ranges from <20 to 700 ft

Northern Trinity GAM Hydrostratigraphy Work Flow (Kelley and others, 2014)

Build Well Log Database
- BRACS, BEG, TCEQ PWS, Q-logs, commercial sources

Correlate Stratigraphic Surfaces
- Original work but built off of previous studies

Interpret Lithologies from Well Logs
- Vertical record of interbedded lithologies – 5 to 10 foot scale

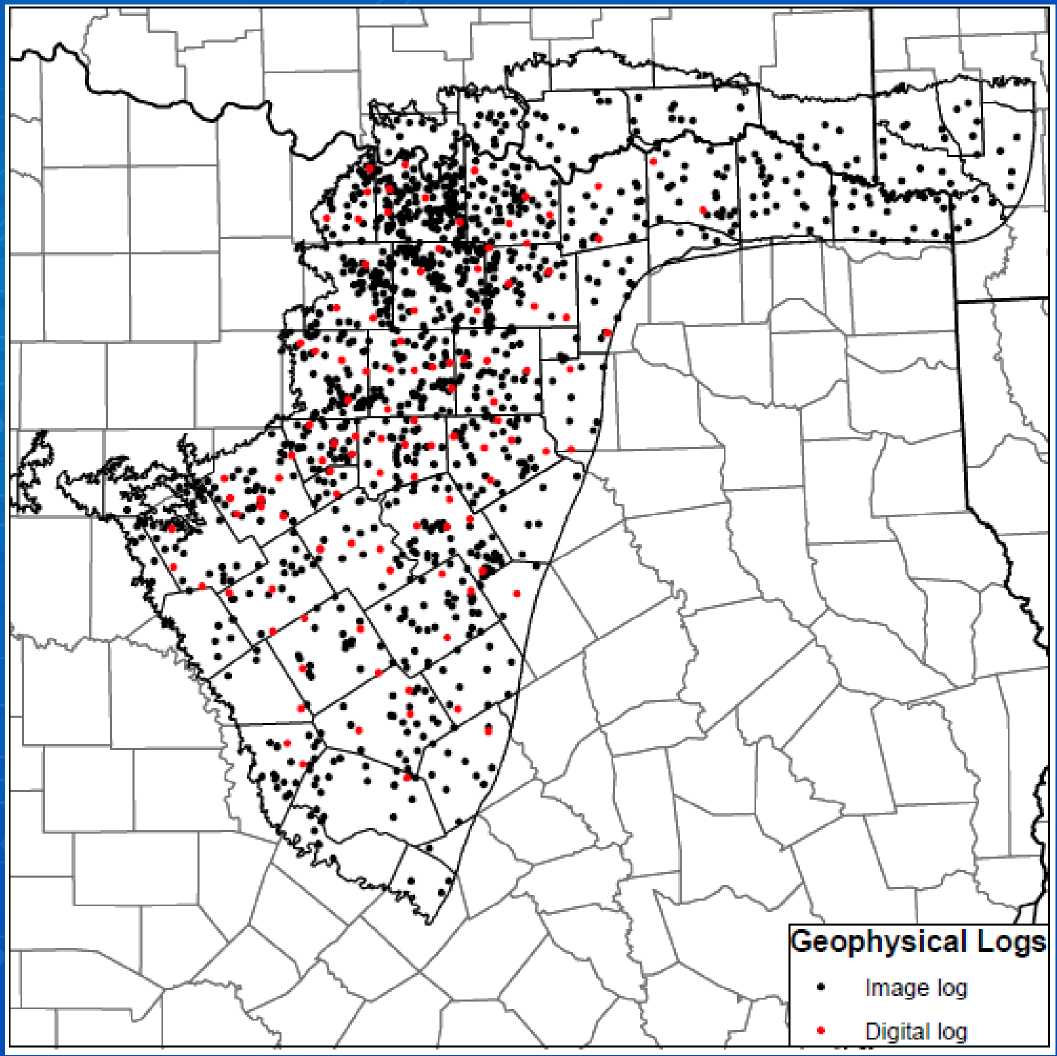
Map Layer Thicknesses and Compositions
- Structure, isopach, net sandstone maps

Interpret Depositional Environments
- Enhance predictability between wells – informs properties

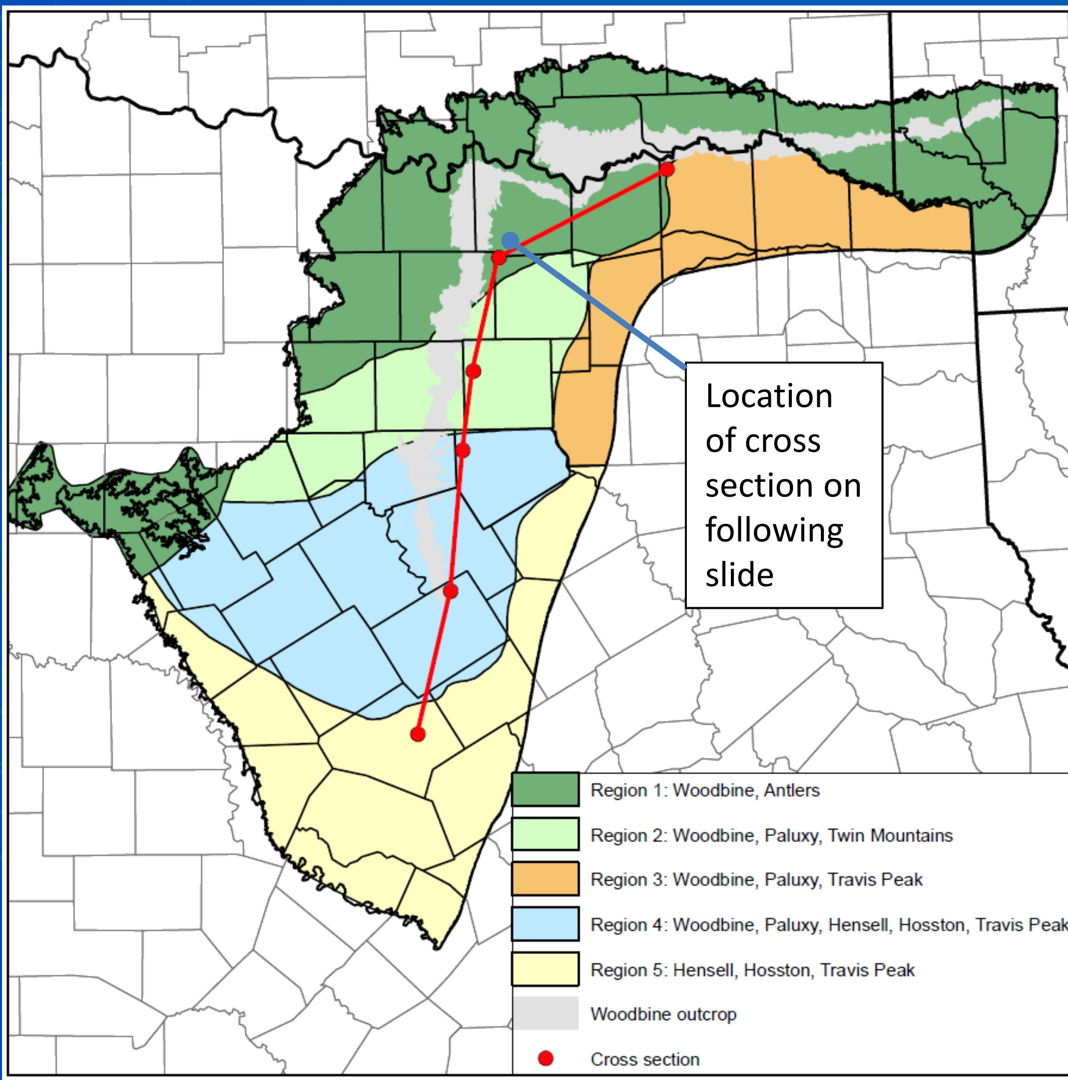
Build Well Log Database (Kelley and others, 2014)

The well log database for the Northern Trinity Aquifer GAM utilized:

- 1193 wells with depth registered image logs
- 109 wells with digitized logs



Correlate Stratigraphic Surfaces (Kelley and others, 2014)



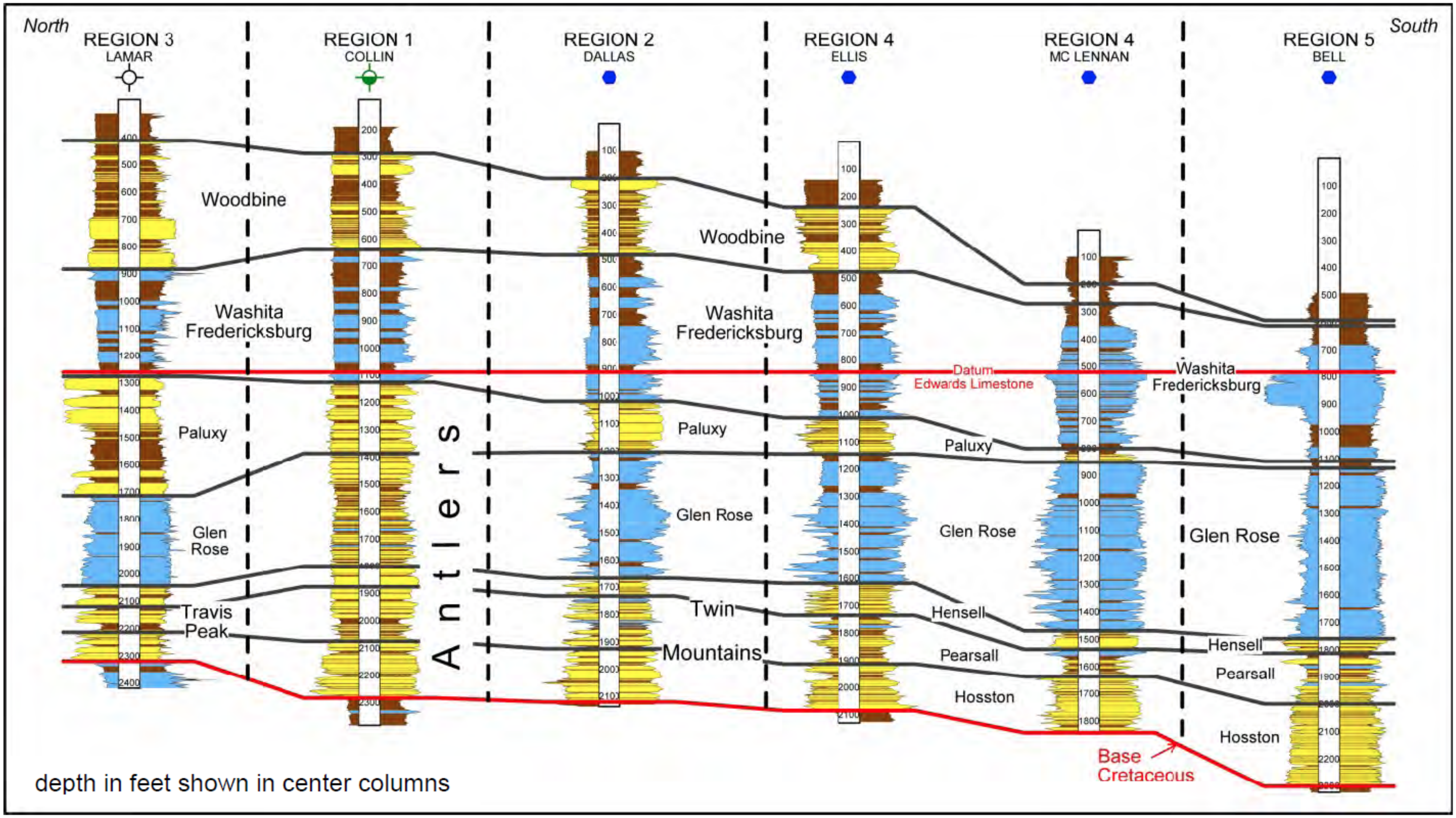
Stratigraphic surfaces define the tops and bottoms of the formations

These correspond to the tops and bottoms of the PPAs for each formation

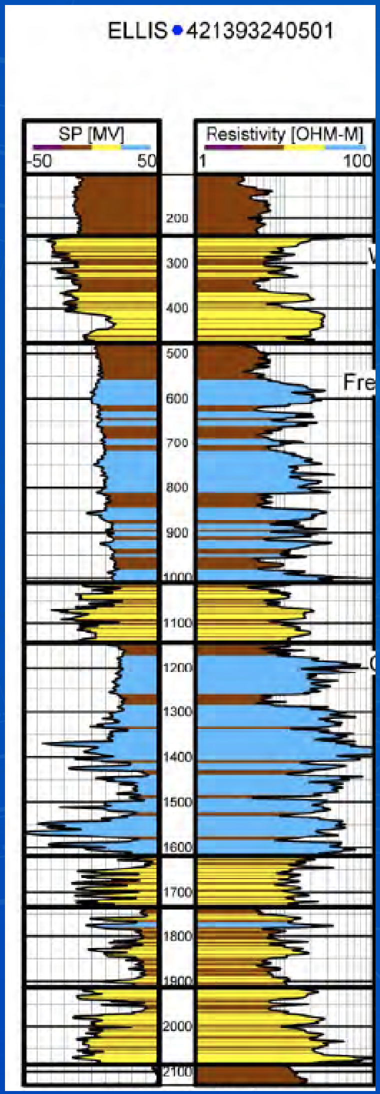
Model Terminology	Region 1	Region 2	Region 3	Region 4	Region 5
Woodbine Aquifer	Woodbine	Woodbine	Woodbine	Woodbine	Woodbine (no sand)
Washita/ Fredericksburg Groups	Washita/ Fredericksburg	Washita/ Fredericksburg	Washita/ Fredericksburg	Washita/ Fredericksburg	Washita/ Fredericksburg
Paluxy Aquifer	Antlers	Paluxy	Paluxy	Paluxy	Paluxy (no sand)
Glen Rose Formation	Antlers	Glen Rose	Glen Rose	Glen Rose	Glen Rose
Hensell Aquifer	Antlers	Twin Mountains	Travis Peak	Hensell/ Travis Peak	Hensell/ Travis Peak
Pearsall Formation	Antlers	Twin Mountains	Travis Peak	Pearsall/ Sligo	Pearsall/ Sligo
Hosston Aquifer	Antlers	Twin Mountains	Travis Peak	Hosston/ Travis Peak	Hosston/ Travis Peak

yellow = sandstone aquifers

Correlate Stratigraphic Surfaces (Kelley and others, 2014)



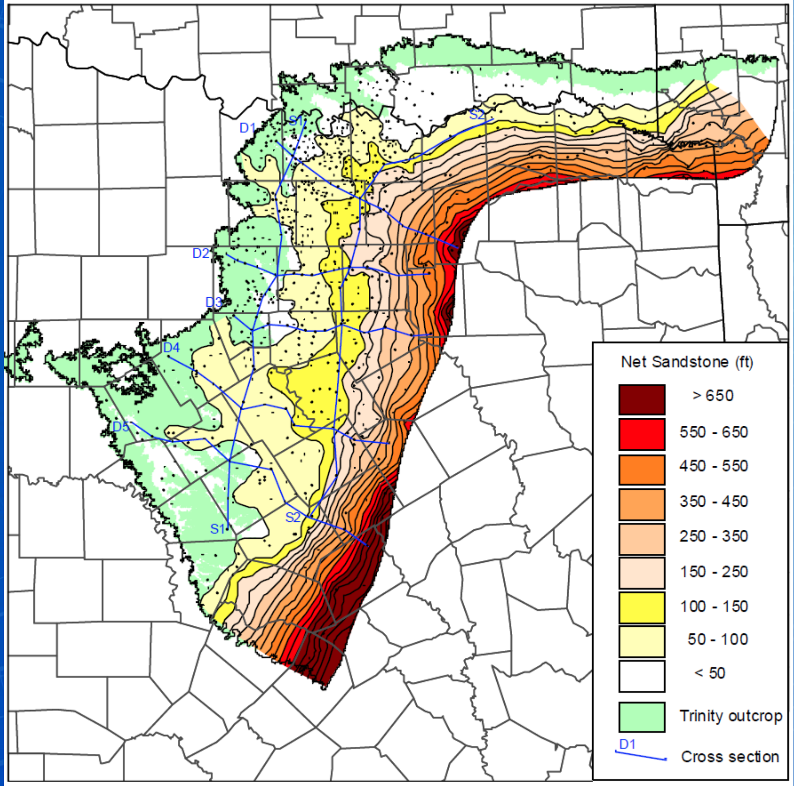
Interpret Lithologies from Well Logs (Kelley and others, 2014)



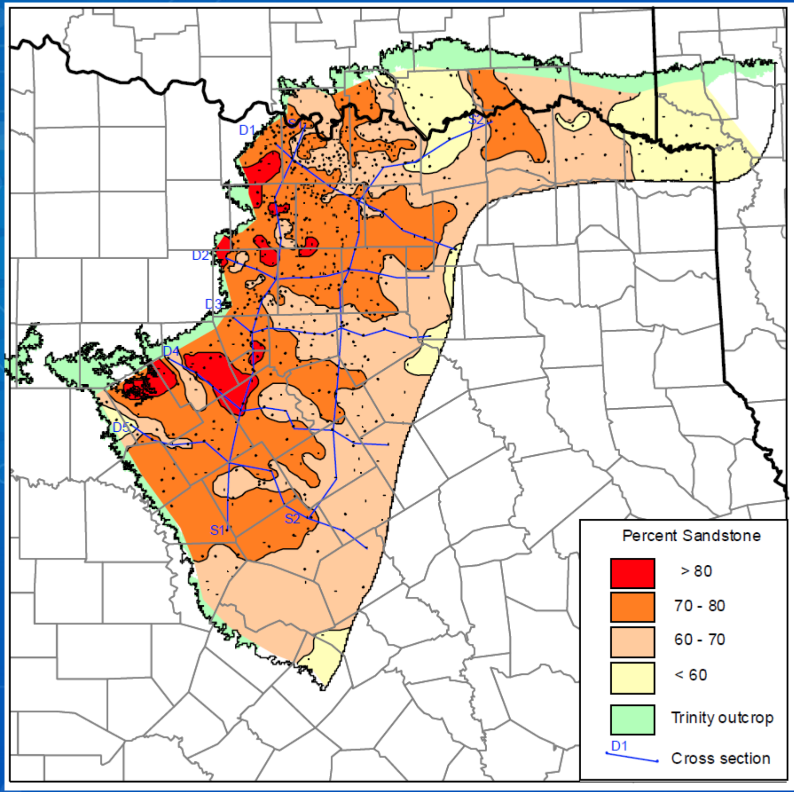
- Lithologic interpretations were made on 988 of the 1,302 available geophysical logs
- Lithologies were separated into sand, shale and limestone based on specific geophysical signatures
- Lithologic picks made on a sub- 5 ft basis
- Lithology may be used in calculations of brackish groundwater volumes
  - Volumes counted in sands/limestones only

Map Layer Thicknesses and Compositions (Kelley and others, 2014)

Net Sandstone Maps



Percent Sandstone Maps



Sand percent/fraction may be used in the calculation of brackish groundwater volumes

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Brackish Water Quality

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 (between Fresh and Slightly Saline)

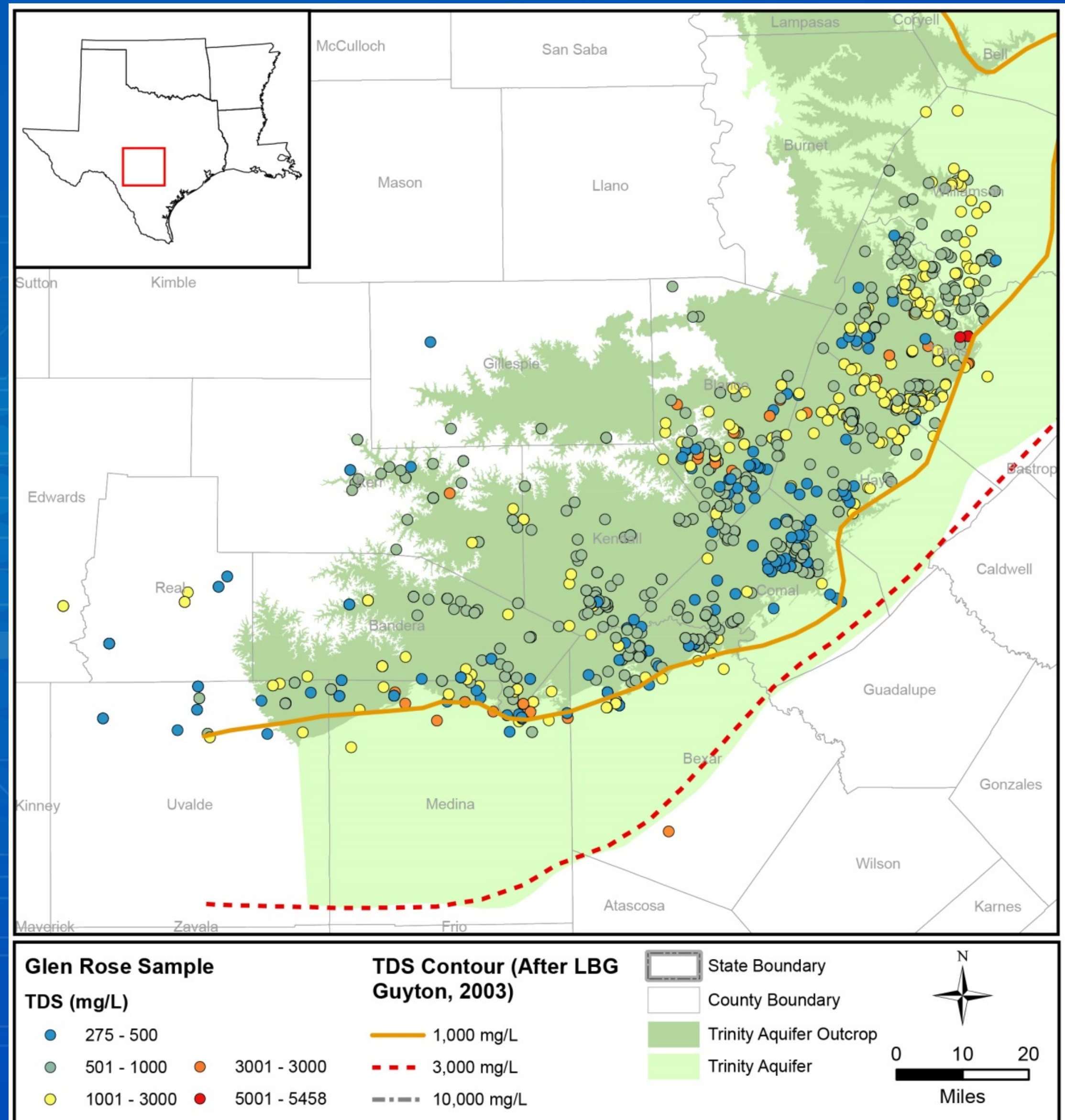
← Major/Minor Aquifer (Texas) Mapped Limit (between Slightly Saline and Moderately Saline)

← Seawater (between Very Saline and Brine)

Modified from Winslow and Kister, 1956

Water Quality

- Available water quality data from various sources were used to identify data gaps and potential production areas



Water Quality

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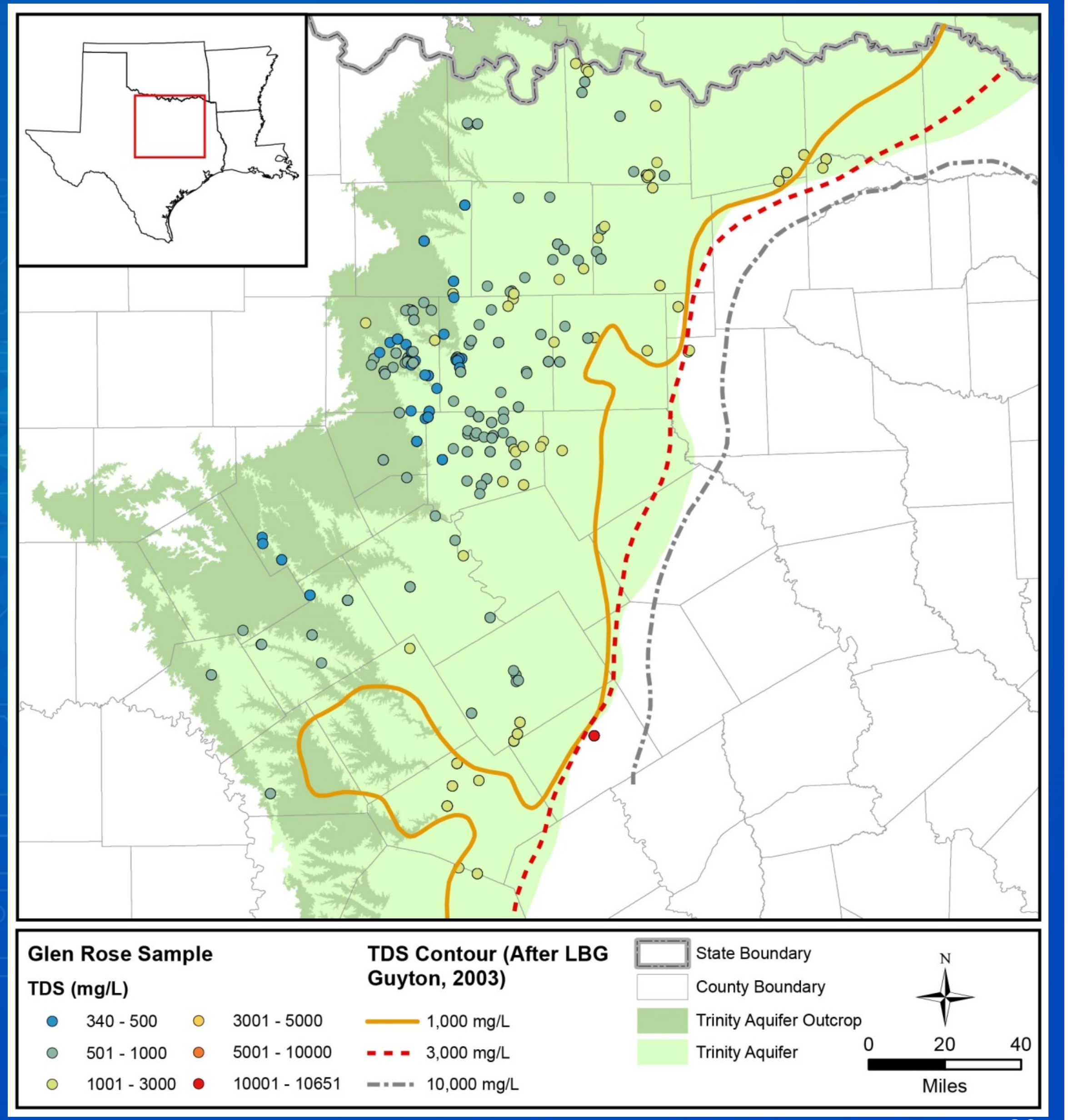

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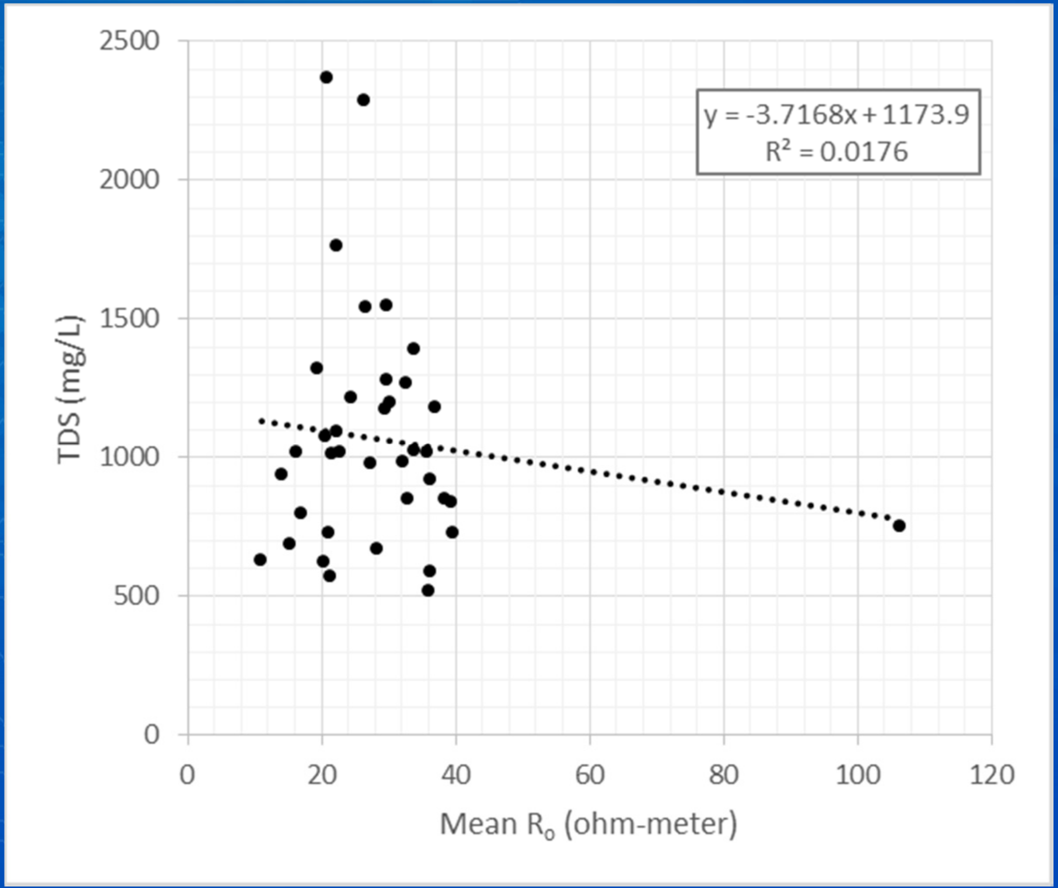
Estimating Water Quality

- Methods primarily rely on use of data collected from borehole geophysical logs to estimate water quality
- The methods rely on conversions of groundwater resistivity to conductivity and then to TDS
- Several methods are available
  - Empirical relationships between log data and TDS for many wells
  - Techniques that calculate TDS using single log data
- Limitations in the availability of borehole data reduced the number of methods
  - For example, very small number of well logs with porosity data prevented implementation of some techniques

Estimating Water Quality

- Empirical methods examined were not useful

- Poor correlation observed for plot of Mean R_o and TDS in Hosston Formation wells



Estimating Water Quality

- Alger-Harrison (1989) or resistivity ratio methods are most suitable
- Requires resistivity values of mud filtrate (R_{mf}) from the log header and deep (R_t) and shallow resistivities (R_{xo}) from the borehole data
- Some advantages
  - The method does not require calculation of formation temperatures
  - The method minimizes the effect of surface conductance
- Disadvantages
  - Often requires adjustments of resistivity values due to tool differences
  - Values must be adjusted for influence of variable chemistry

Alger-Harrison Method

- Alger and Harrison (1989) extended the work of Archie (1942) to produce the relationship

$$R_w = \frac{R_{mf} \times R_t}{R_{xo}}$$

For a 100% water saturated formation

Where:

R_w = resistivity (ohm-m) of the water

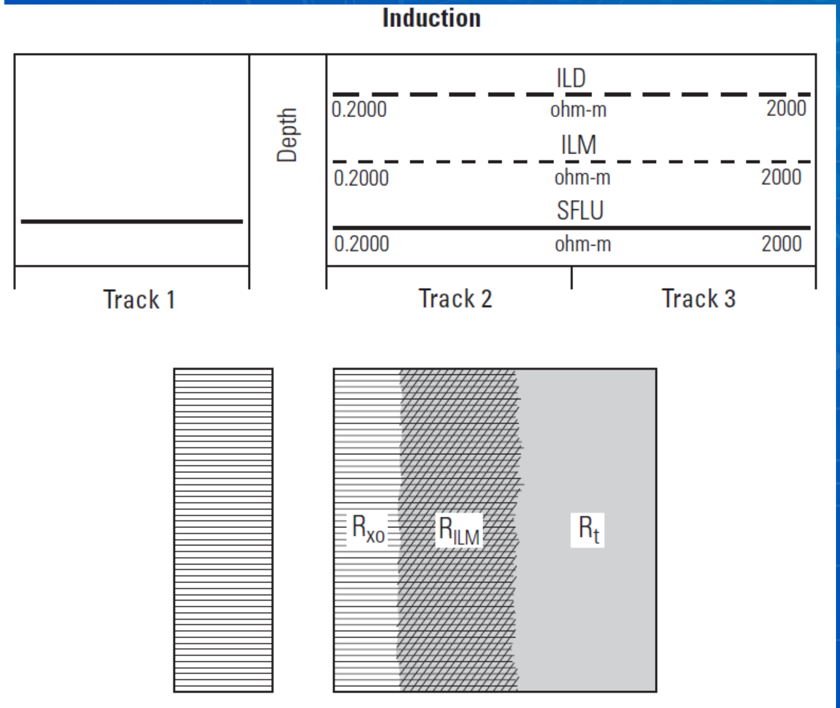
R_{mf} = resistivity of mud filtrate

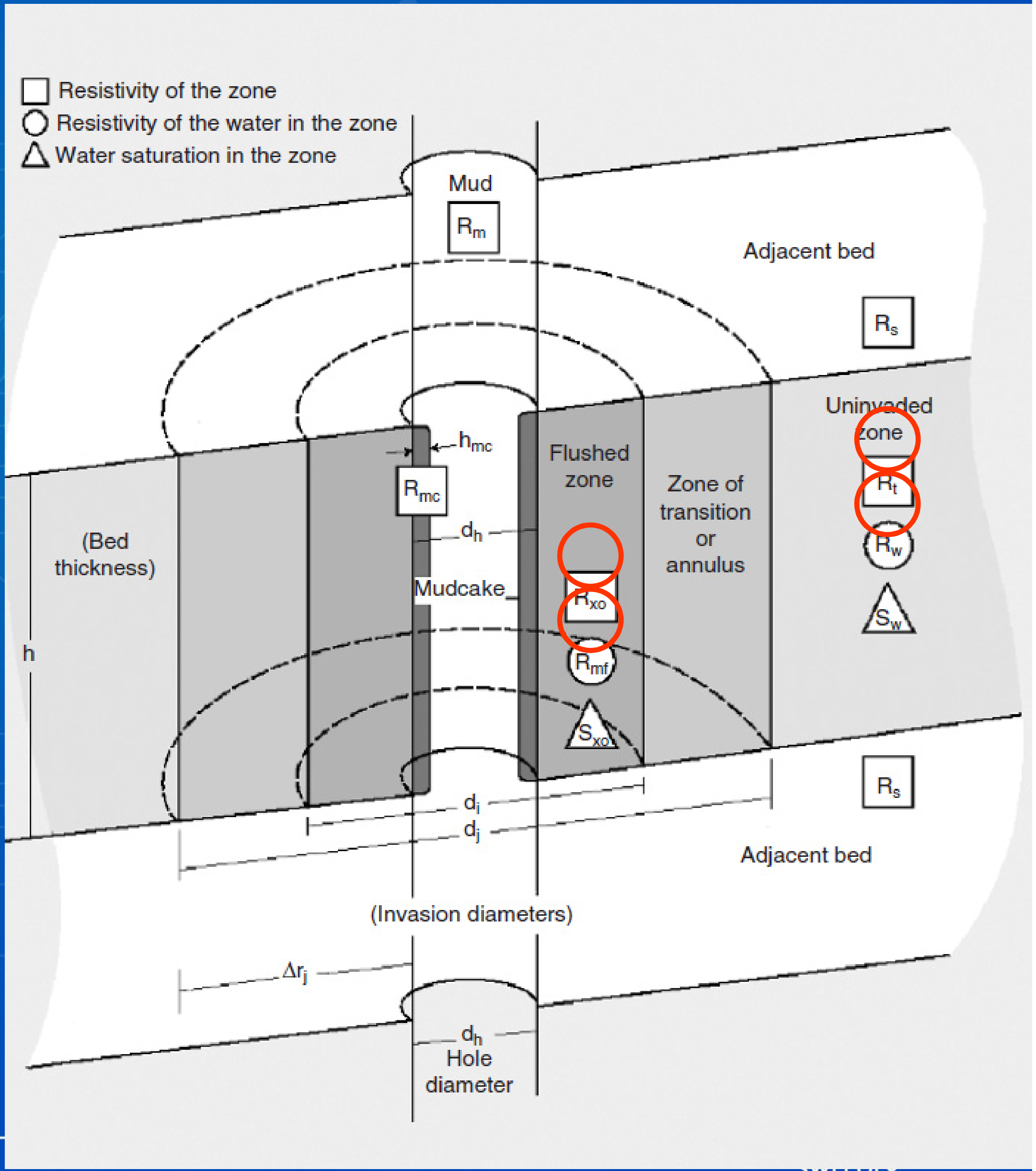
R_t = resistivity of the formation or deep resistivity

R_{xo} = resistivity of the shallow or invaded zone

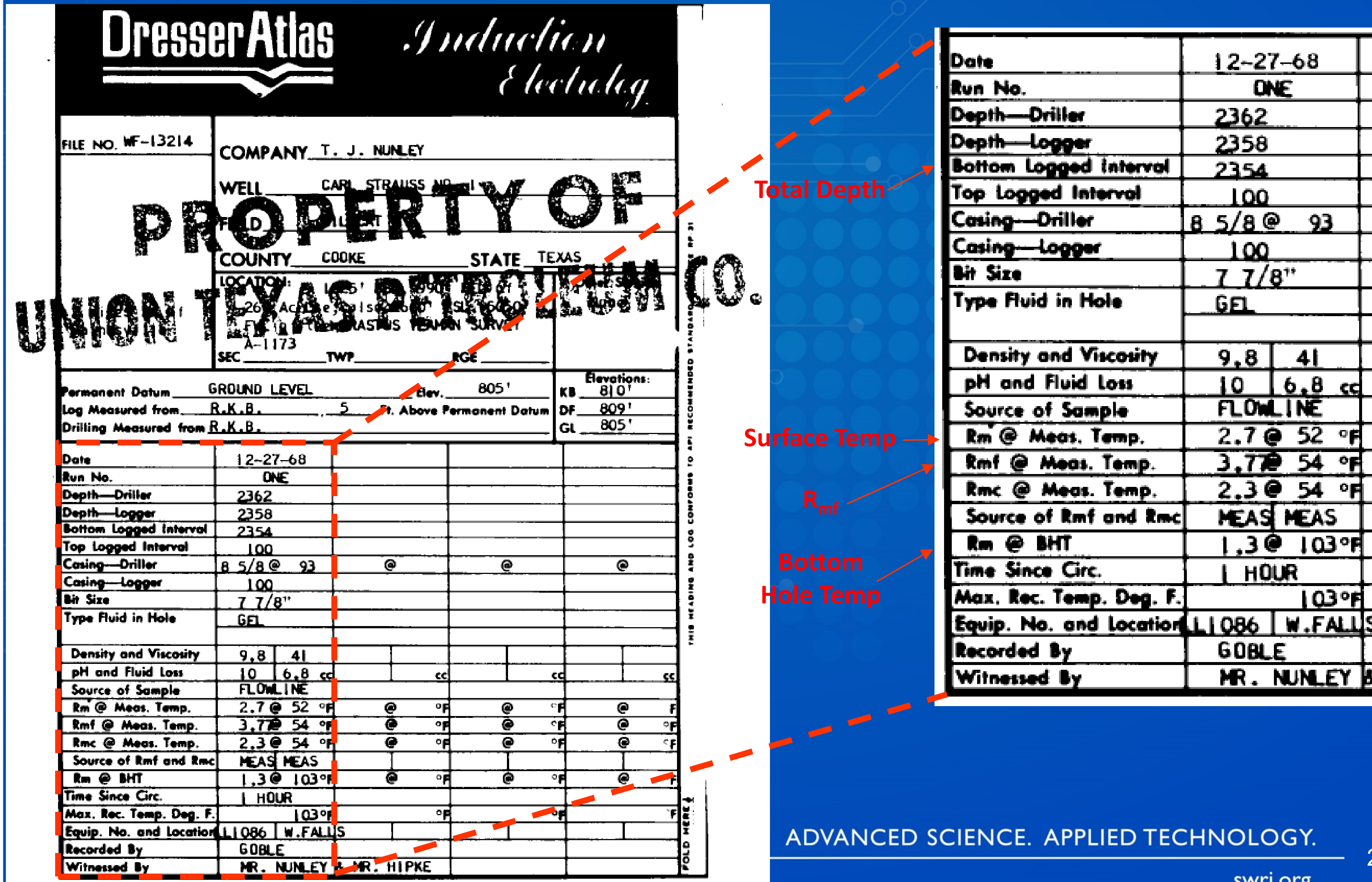
Alger-Harrison Method

- Different resistivity tools have different depths of invasion



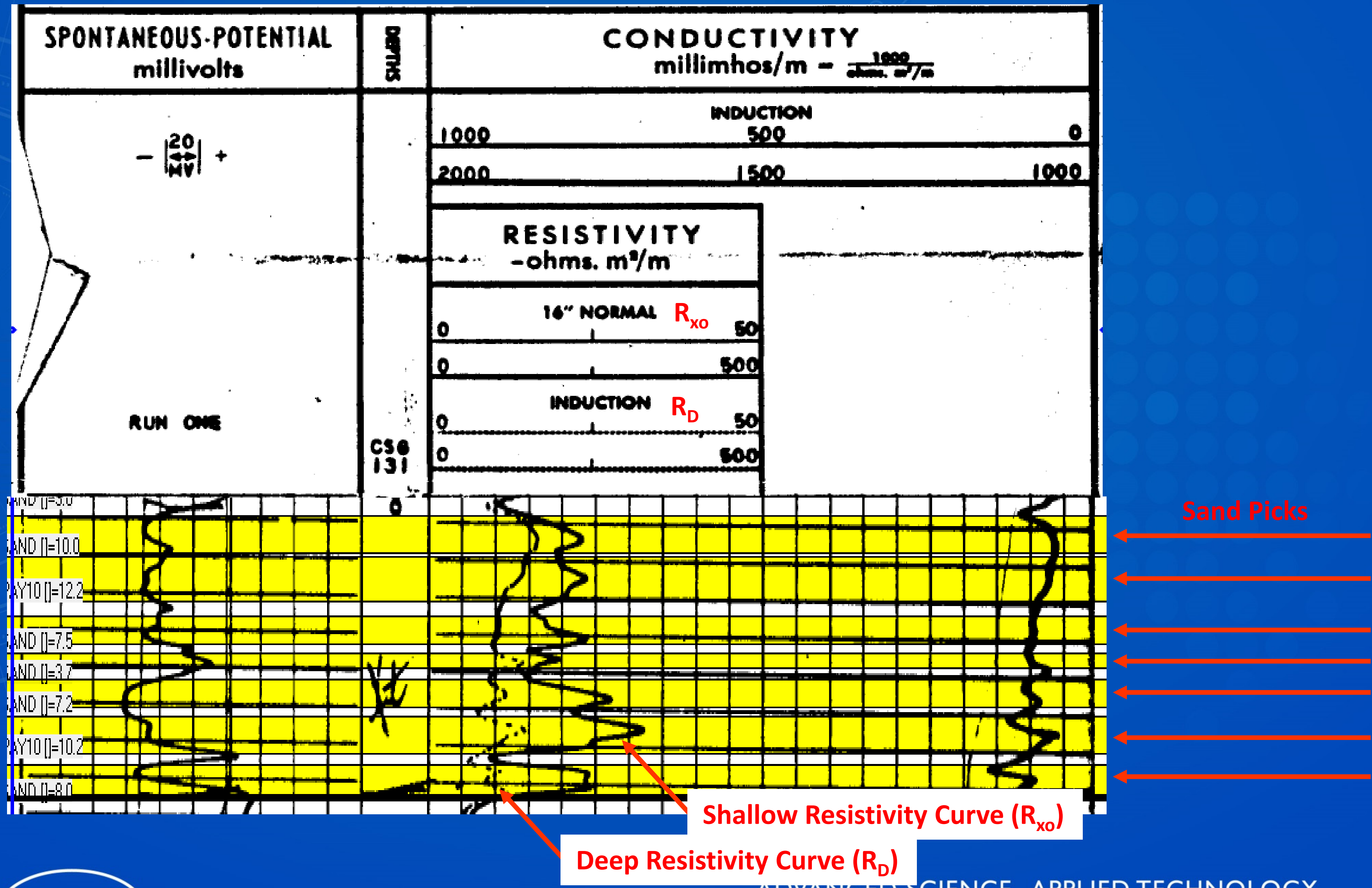


Alger-Harrison Method

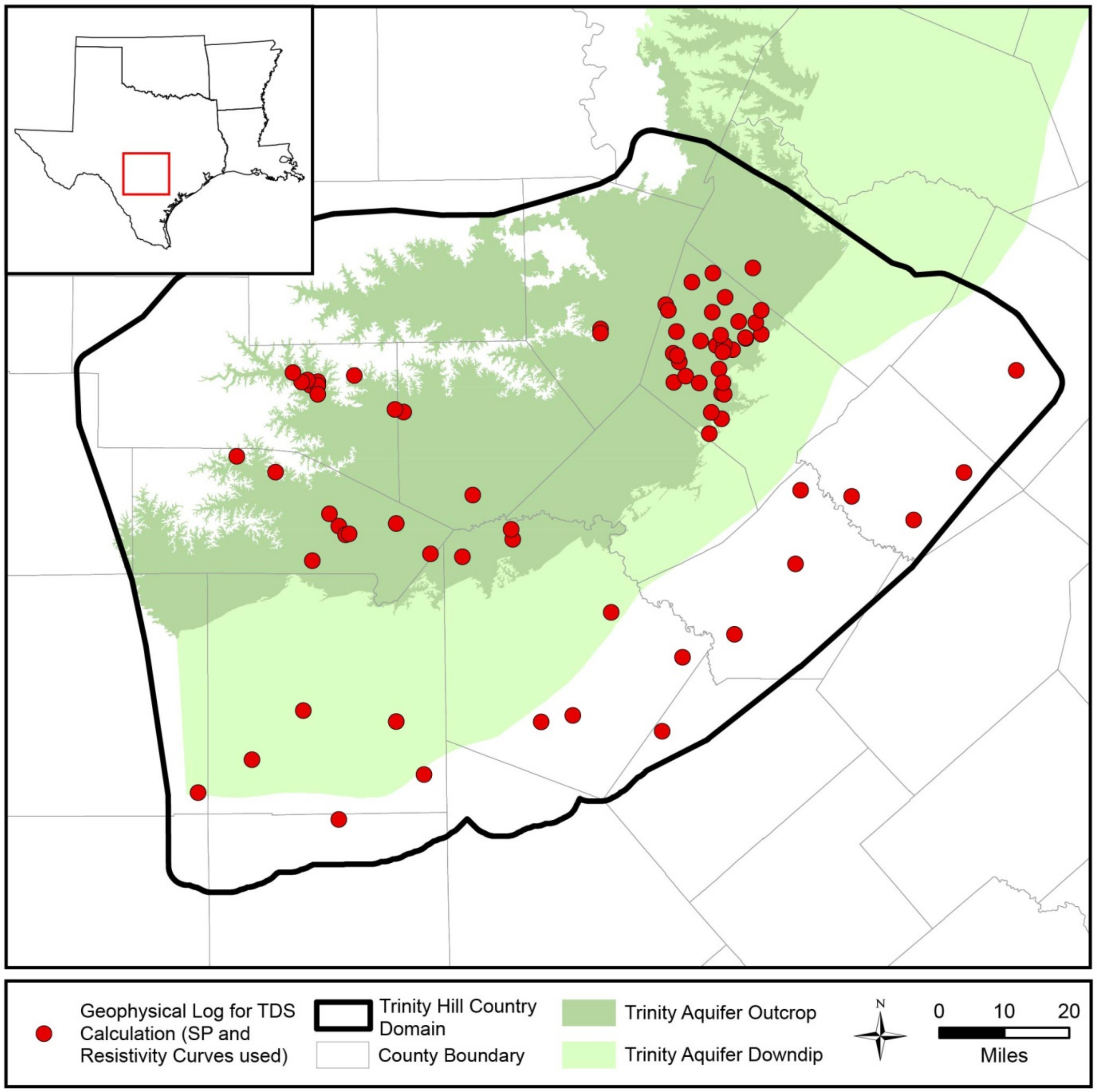


Date	12-27-68
Run No.	ONE
Depth—Driller	2362
Depth—Logger	2358
Bottom Logged Interval	2354
Top Logged Interval	100
Casing—Driller	8 5/8 @ 93
Casing—Logger	100
Bit Size	7 7/8"
Type Fluid in Hole	GEL
Density and Viscosity	9.8 | 41
pH and Fluid Loss	10 | 6.8 cc
Source of Sample	FLOWLINE
Rm @ Meas. Temp.	2.7 @ 52 °F
Rmf @ Meas. Temp.	3.7 @ 54 °F
Rmc @ Meas. Temp.	2.3 @ 54 °F
Source of Rmf and Rmc	MEAS | MEAS
Rm @ BHT	1.3 @ 103 °F
Time Since Circ.	1 HOUR
Max. Rec. Temp. Deg. F.	103 °F
Equip. No. and Location	L1086 | W.FALLS
Recorded By	GOBLE
Witnessed By	MR. NUNLEY & MR. HIPKE

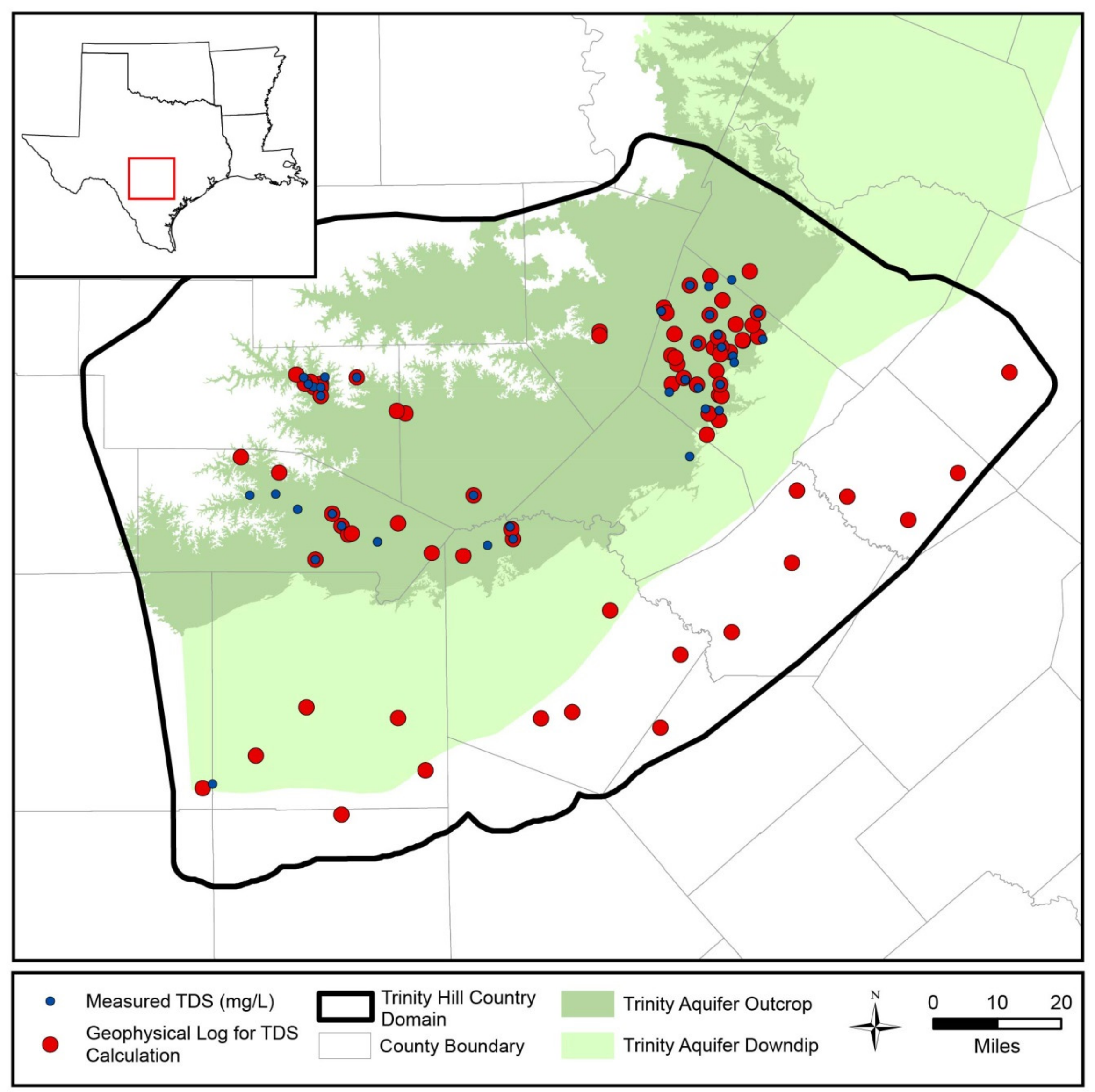
Alger-Harrison Method



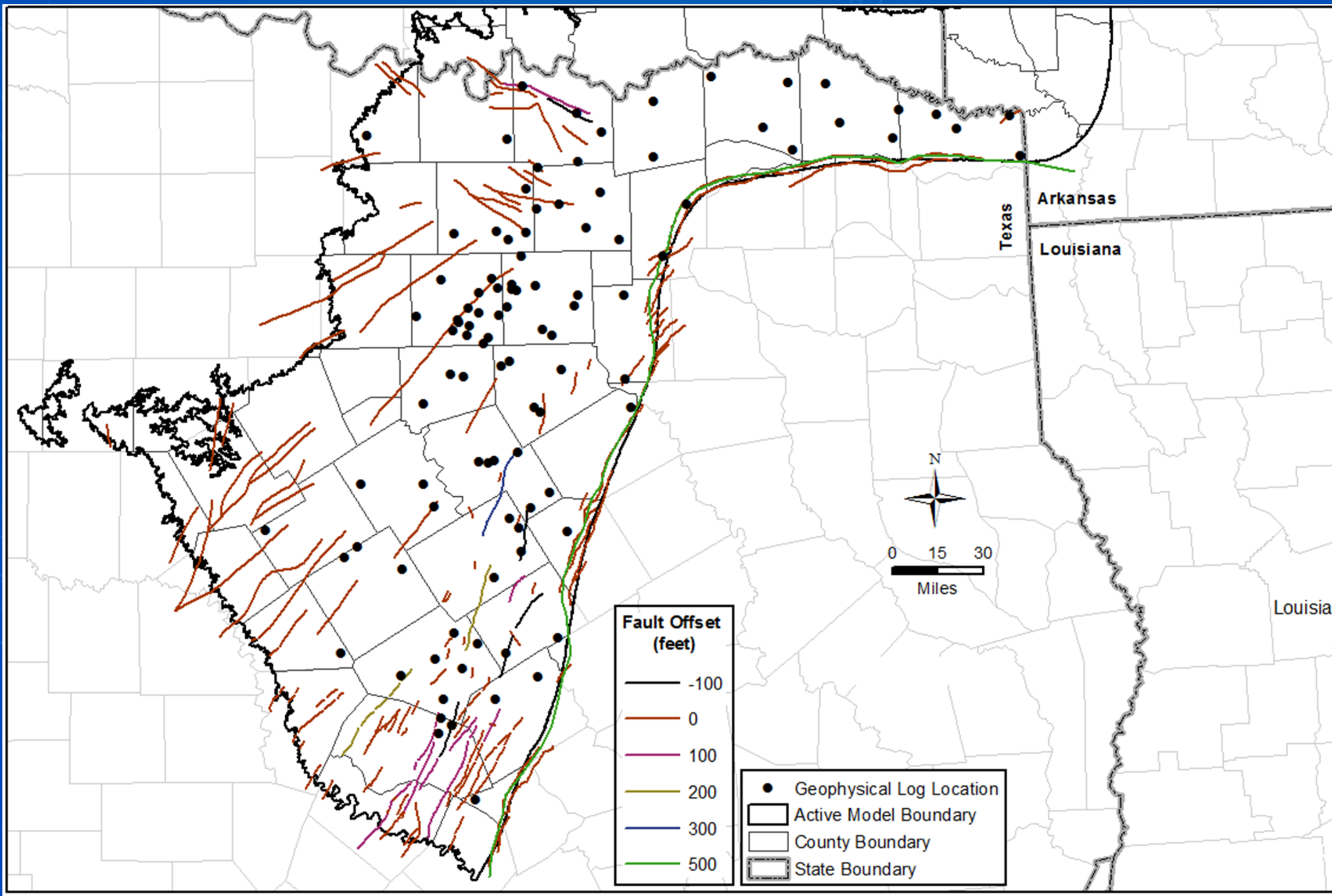
Locations of Geophysical Logs Anticipated for use in TDS Calculations (Hill Country Trinity Aquifer)



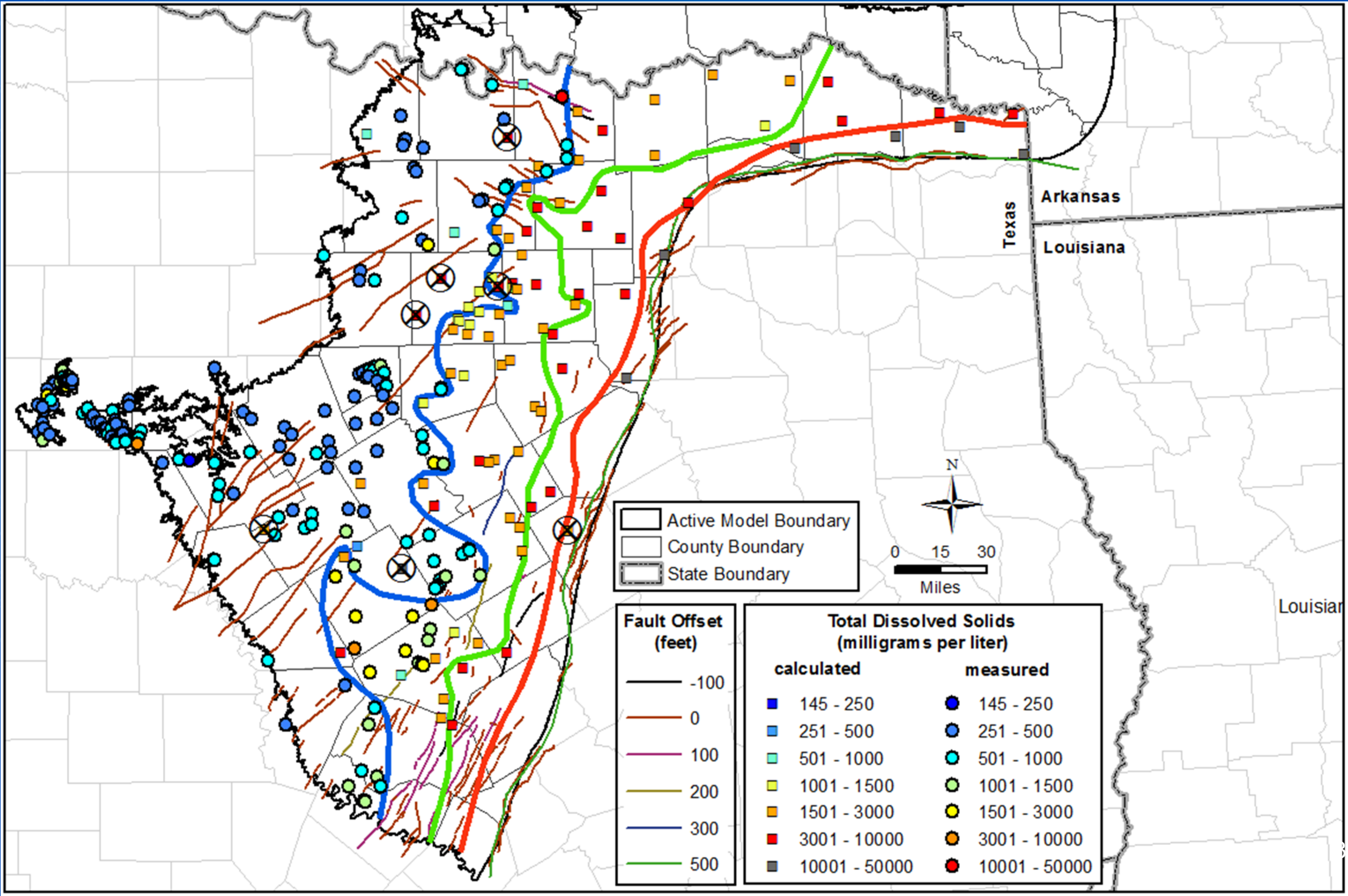
Locations of Wells with Water Quality Data and Wells with Logs to be used in Calculating TDS (Hill Country Trinity Aquifer)



Geophysical Log Locations Used for TDS Calculations
(Northern Trinity Aquifer)



Example Calculated TDS (Northern Trinity Aquifer): Hensell Aquifer



Potential Production Areas

- House Bill 30 required the identification of potential brackish groundwater production zones.
- Potential production zones are zones that could yield significant quantities of brackish water for 30-50 years or more without impacting fresh water sources.
- The bill prescribed certain criteria the production zones must meet.

(5) identification and designation of local or regional brackish groundwater production zones in areas of the state with moderate to high availability and productivity of brackish groundwater that can be used to reduce the use of fresh groundwater and that:

Excerpt H.B. No. 30

Potential Production Areas

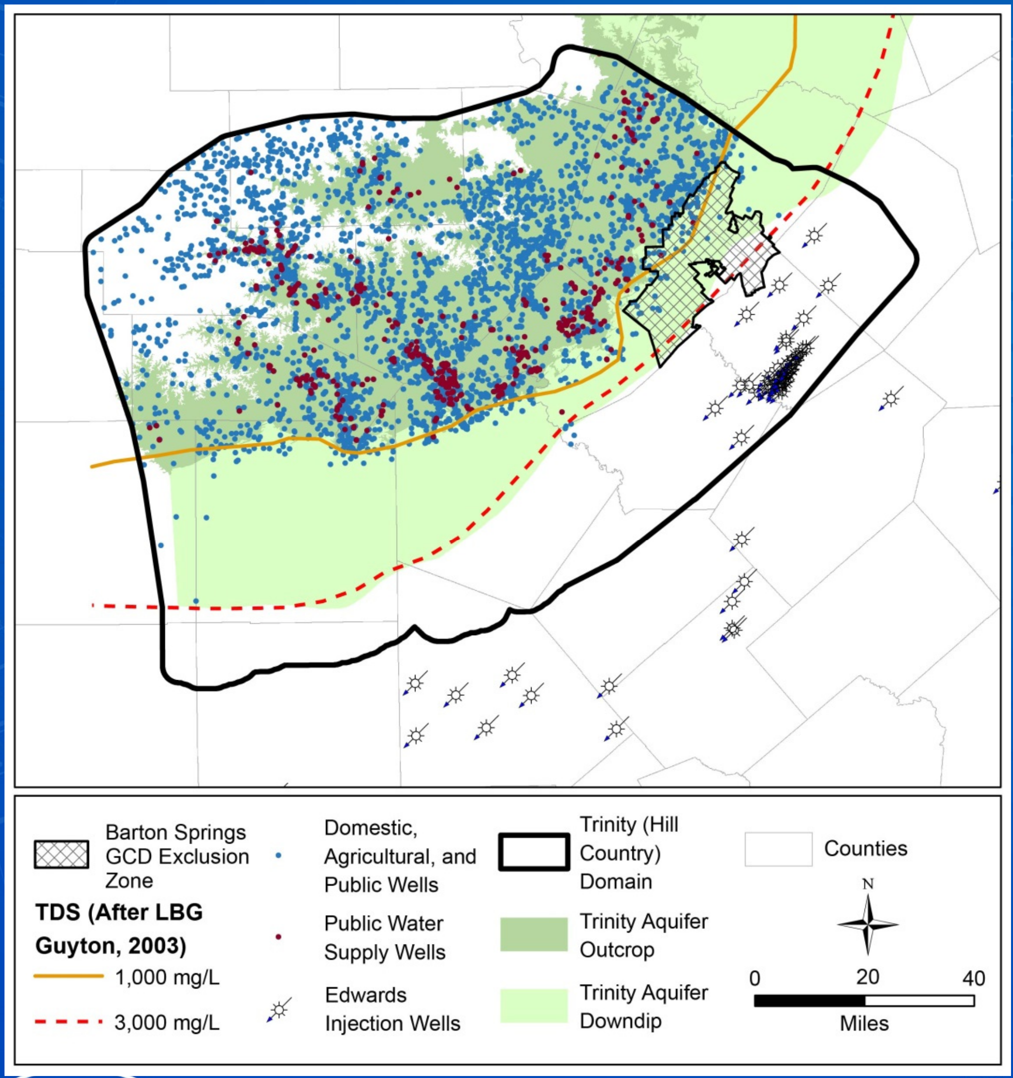
- Exclusion criteria enumerated in H.B. No. 30
  - Separation by hydrogeologic barriers to prevent impacts on water availability and water quality in fresh groundwater sources
  - Not located in the Edwards Aquifer under the jurisdiction of the Edwards Aquifer Authority
  - Not in the boundaries of:
    - Barton Springs-Edwards Aquifer Conservation District
    - Harris-Galveston
    - Fort Bend Subsidence District
  - Not in a brackish groundwater source that is already in use by municipal, domestic, or agriculture entities
  - Not in a geologic stratum designated or used for wastewater injection through the use of injection wells

Potential Production Areas

- How exclusion criteria were applied in practice for the Trinity Aquifer
  - A 3 mile buffer is extended around wells identified from public sources with screened intervals in the Trinity Aquifer or fresh water aquifers hydraulically connected to the Trinity Aquifer
  - A 15 mile buffer extended around injection wells identified in the Texas RRC database with screened intervals in the Trinity Aquifer or fresh water aquifers hydraulically connected to the Trinity Aquifer
  - Exclude brackish portions of the Trinity Aquifer hydraulically connected to fresh water aquifers
    - e.g. Exclude the Glen Rose and Lower Trinity where the Edwards Balcones Fault Zone aquifer is present, south of the Colorado River

PPAs for the Hill Country Trinity

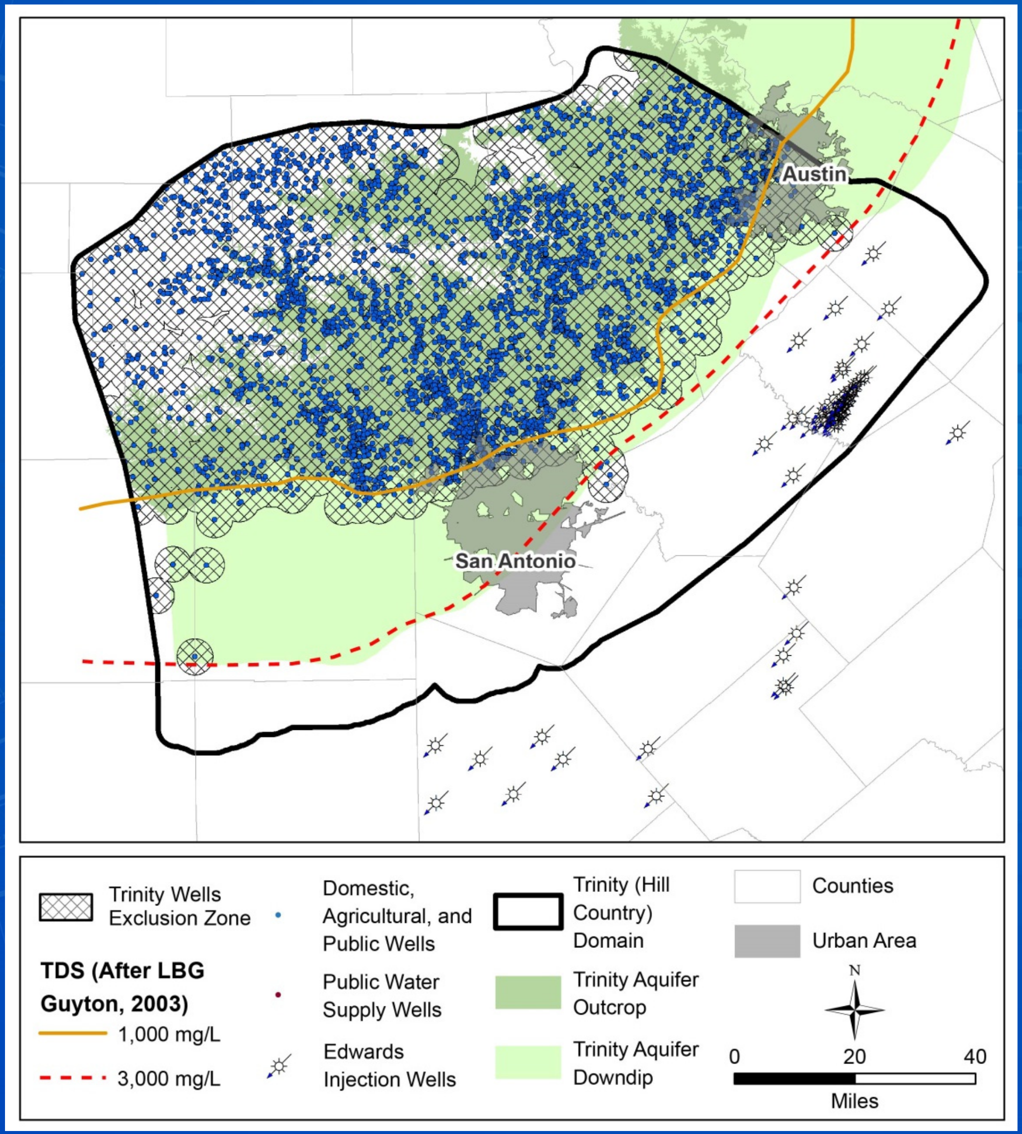
Exclusion Process (Barton Springs-Edwards Conservation District)



H.B. 30 excludes:

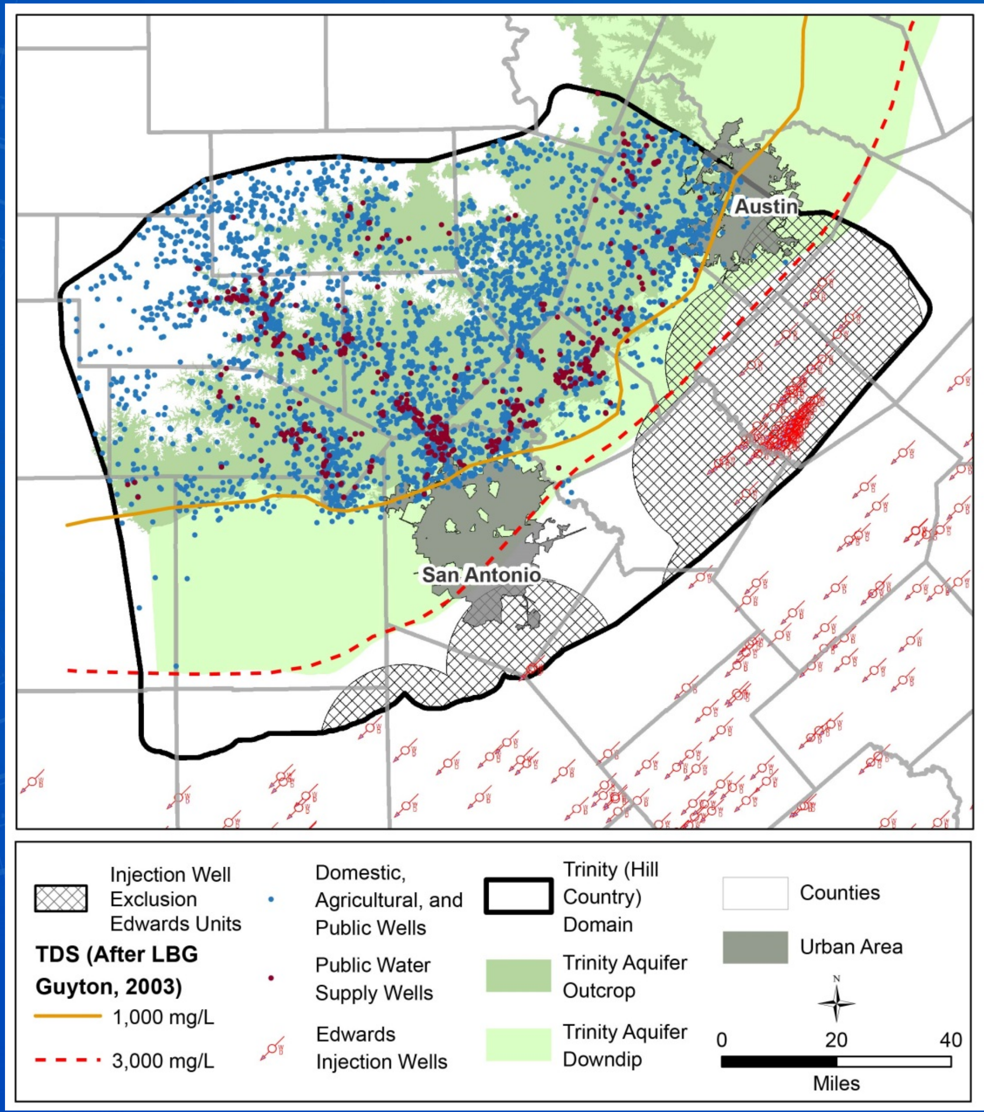
- Barton Springs-Edwards Aquifer Conservation District
- Harris-Galveston
- Fort Bend Subsidence District

Exclusion Process (Existing Water Sources)



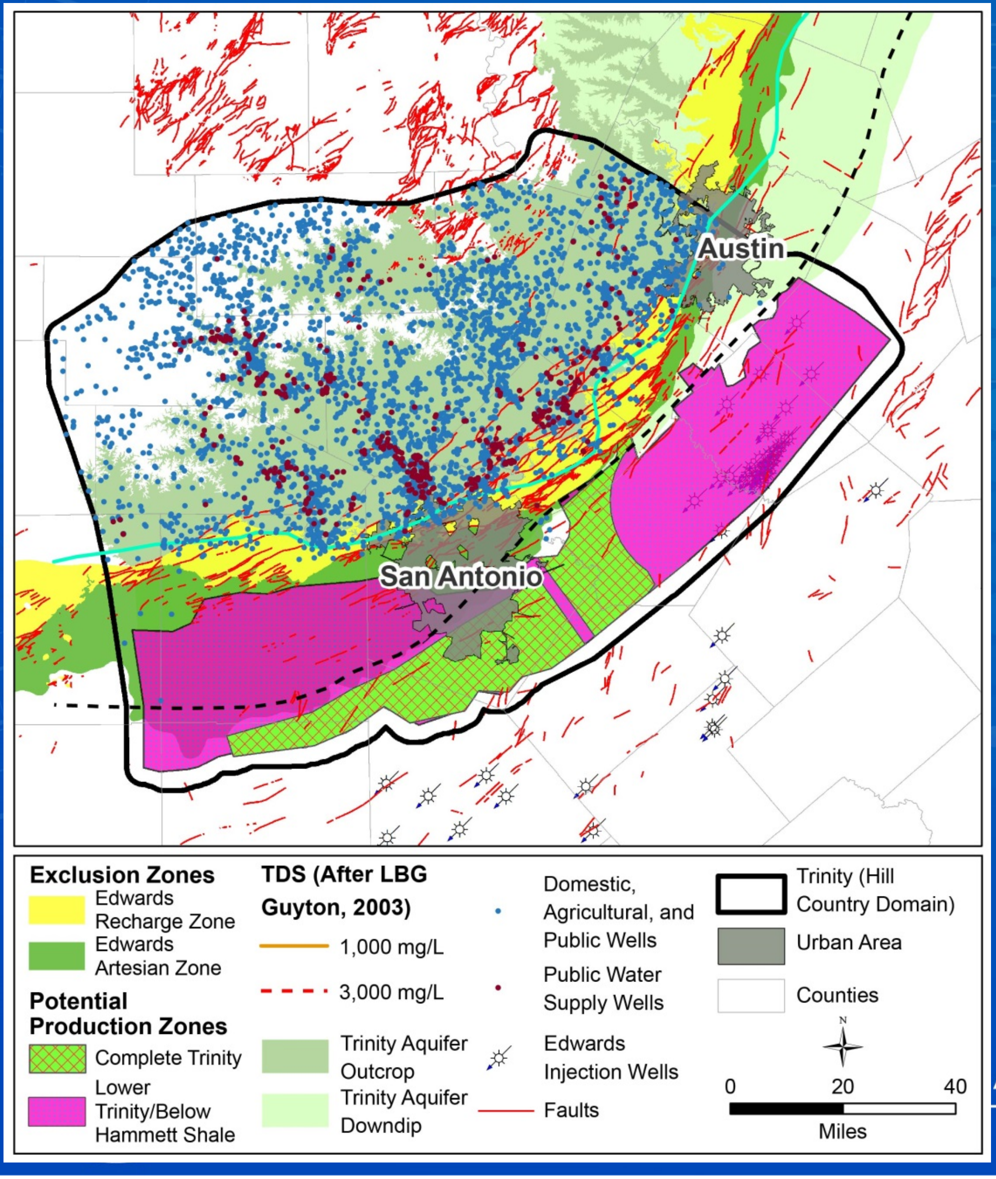
- Separation by hydrogeologic barriers to prevent impacts to on water availability and water quality in fresh groundwater sources
- Exclusion of areas of brackish water already being used
- 3 mile buffer exclusion zone around all domestic, livestock, and public supply wells in the Trinity aquifer

Exclusion Process (Wastewater Injection)



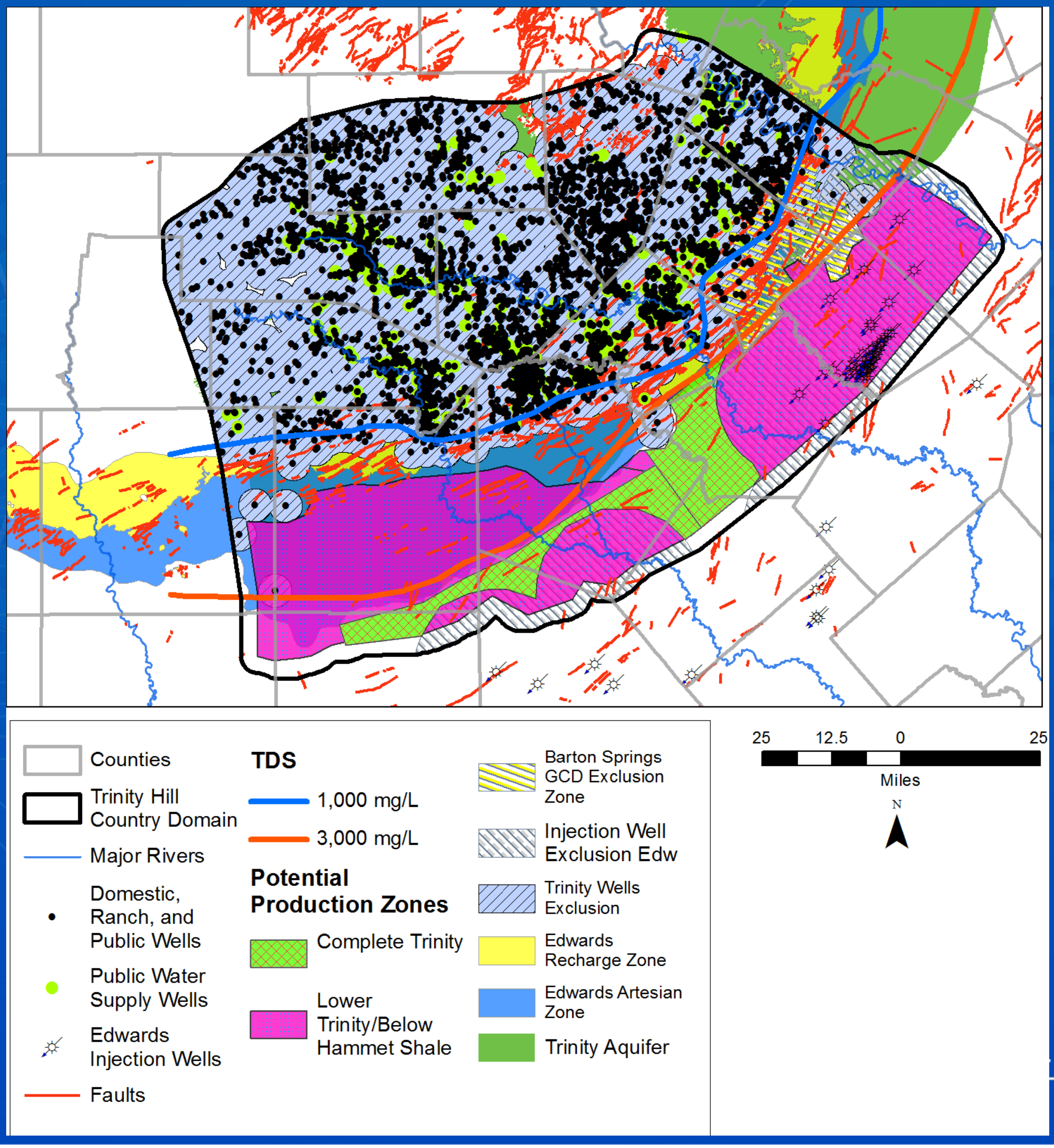
Not in a geologic stratum designated or used for wastewater injection through the use of injection wells

Exclusion Process (Upper Trinity Excluded Under Edwards Aquifer)

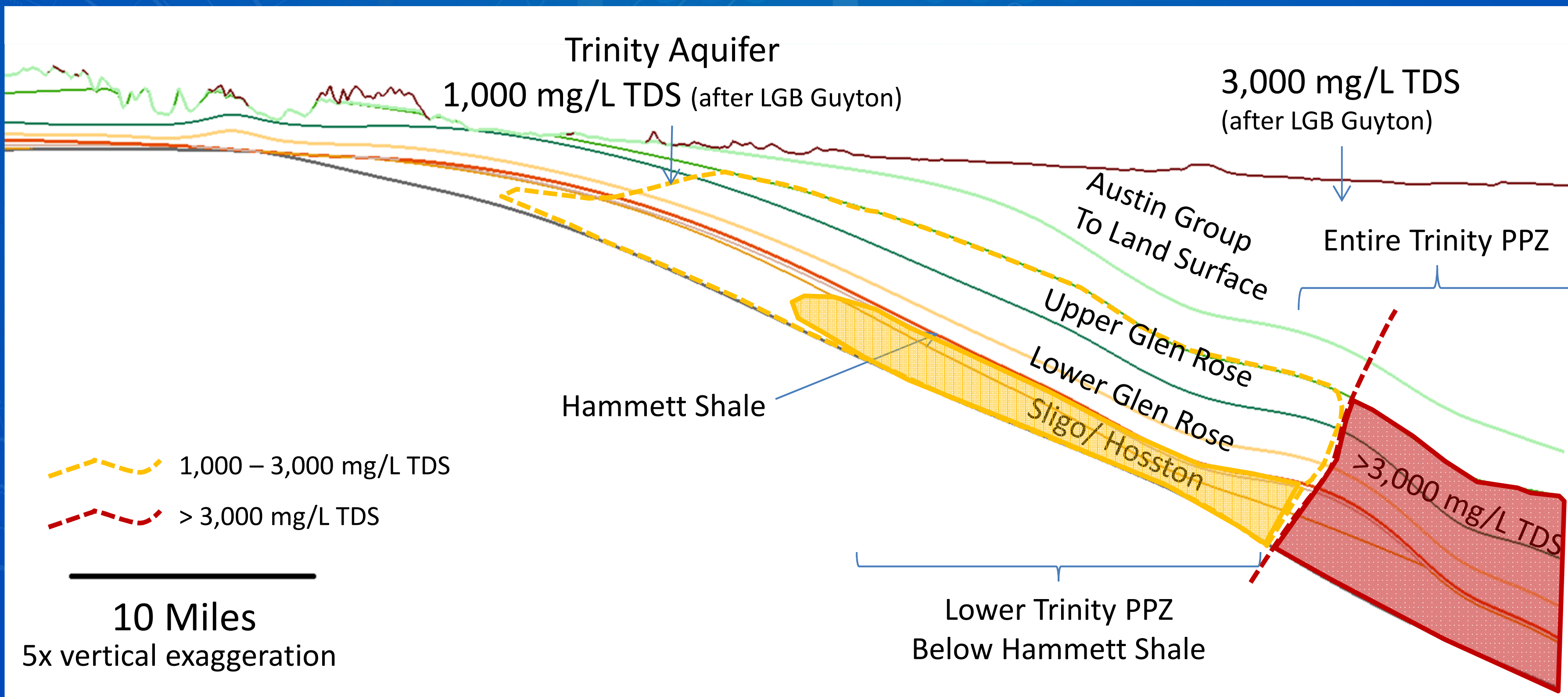


- Although the Trinity Aquifer is below the Edwards Aquifer, there is insufficient hydraulic barrier between the Upper Trinity and the Edwards Aquifer
- Balcones Fault Zone disrupts hydraulic barriers that are present and offsets units such that brackish zones may be in communication with the Edwards Aquifer

Draft Potential Production Areas (Hill Country Trinity study area)



Draft Potential Production Areas (Hill Country Trinity study area) Hydrostratigraphic Schematic Section



PPAs for the Northern Trinity

PPA Delineation Strategy: Hydraulic Barriers

- Horizontal barriers
  - Mexia Talco fault zone downzip is coincident with study boundary
  - Updip faults cannot be demonstrated to be barriers to flow (most have small throw compared to unit thickness)
- Vertical barriers
  - No true confining units (all formations have wells)
  - Areas where clays are more prevalent, but no evidence of regional confining nature
- Primary "barrier" is distance

PPA Delineation Strategy: Productive Areas

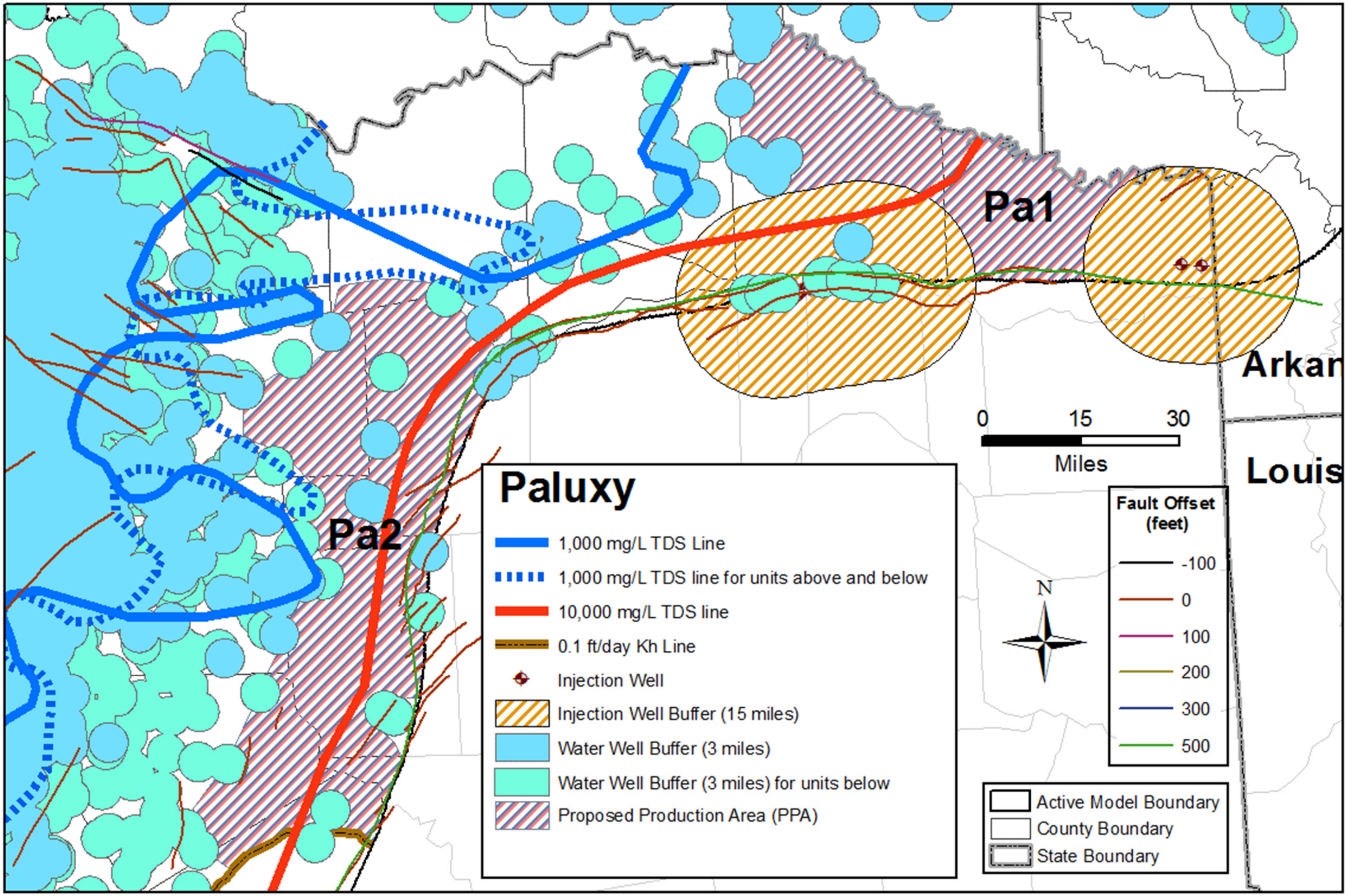
- Horizontal hydraulic conductivity conceptualized as decreasing with depth
- Cutoff for “productive” set at 0.1 ft/d, based on calibrated groundwater model
- For most formations, this occurs near the Mexia-Talco fault zone (or not at all, i.e. Kh > 0.1 throughout)
- Glen Rose and Hosston are not affected

PPA Delineation Strategy: Exclusion Zones

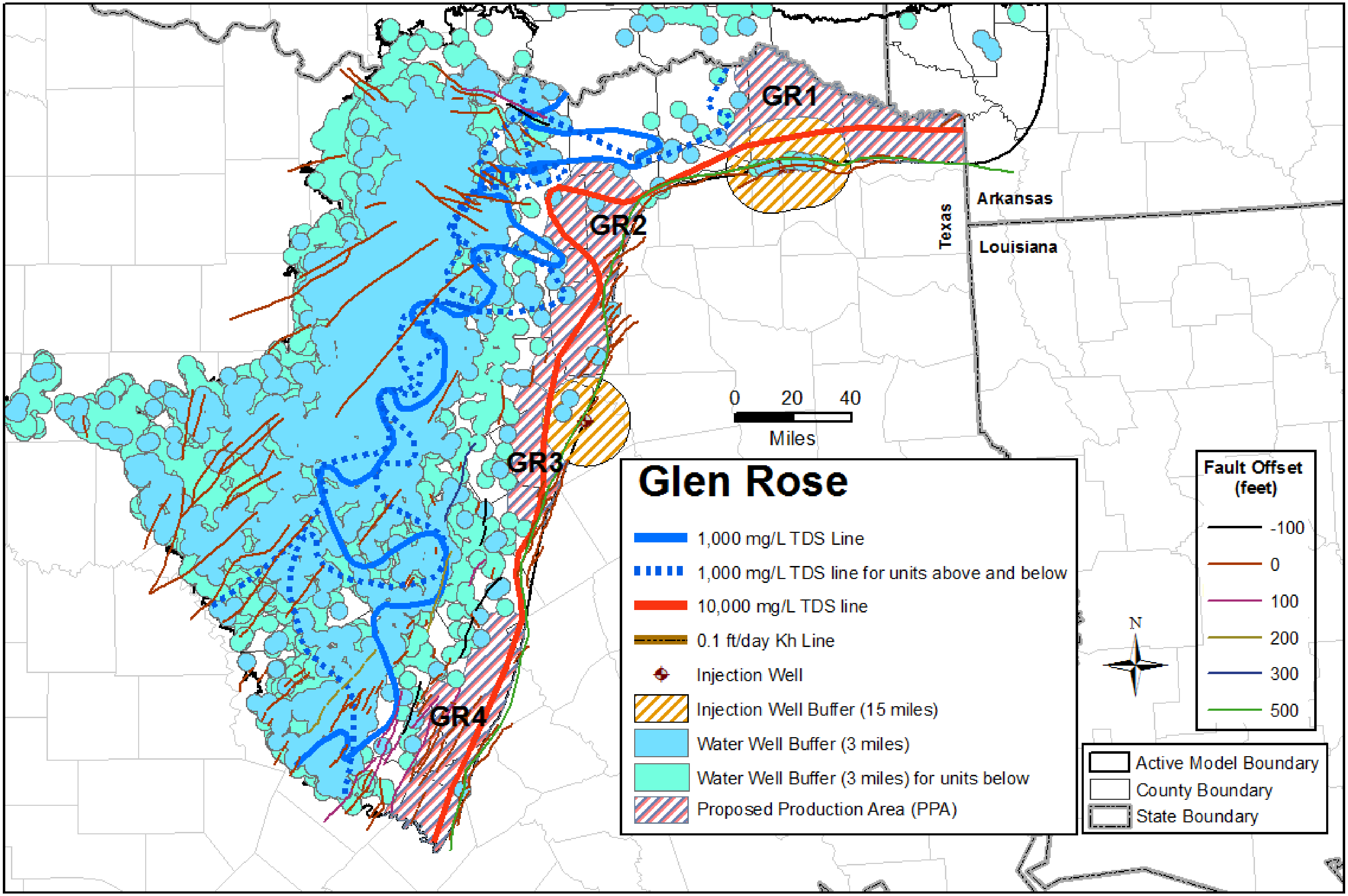
- Fresh water
  - In formation of interest
  - In formations immediately above and below (due to lack of vertical barriers)
- Existing water wells
  - Buffered with a three mile radius
  - Well TD in formation of interest
  - Well TD in any deeper formation (i.e. if the well penetrates the formation, we exclude) due to typical long multi-completed nature of wells in the region
- Disposal wells (15 mile radius)

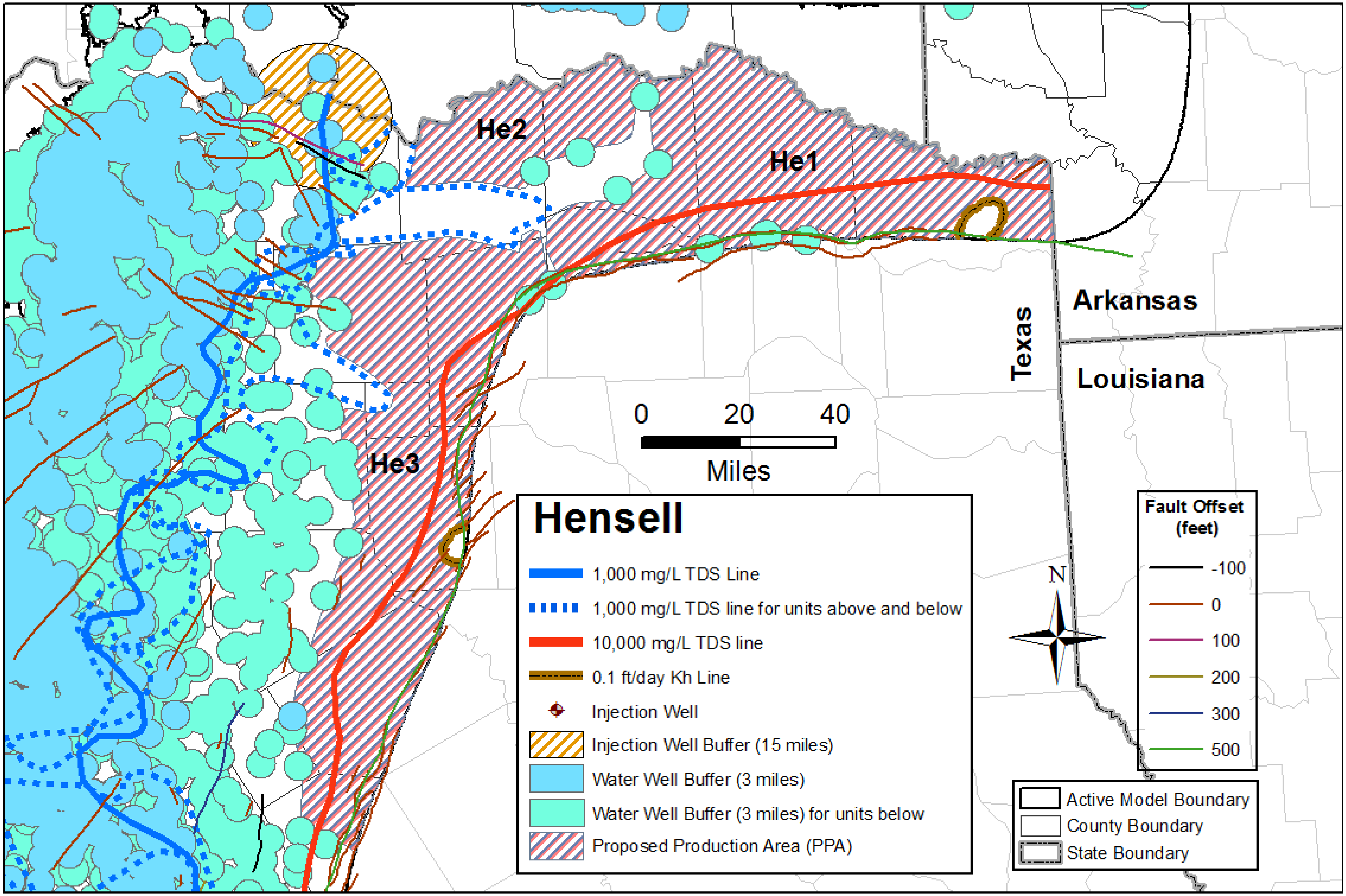
PPA Delineation Strategy: Approach

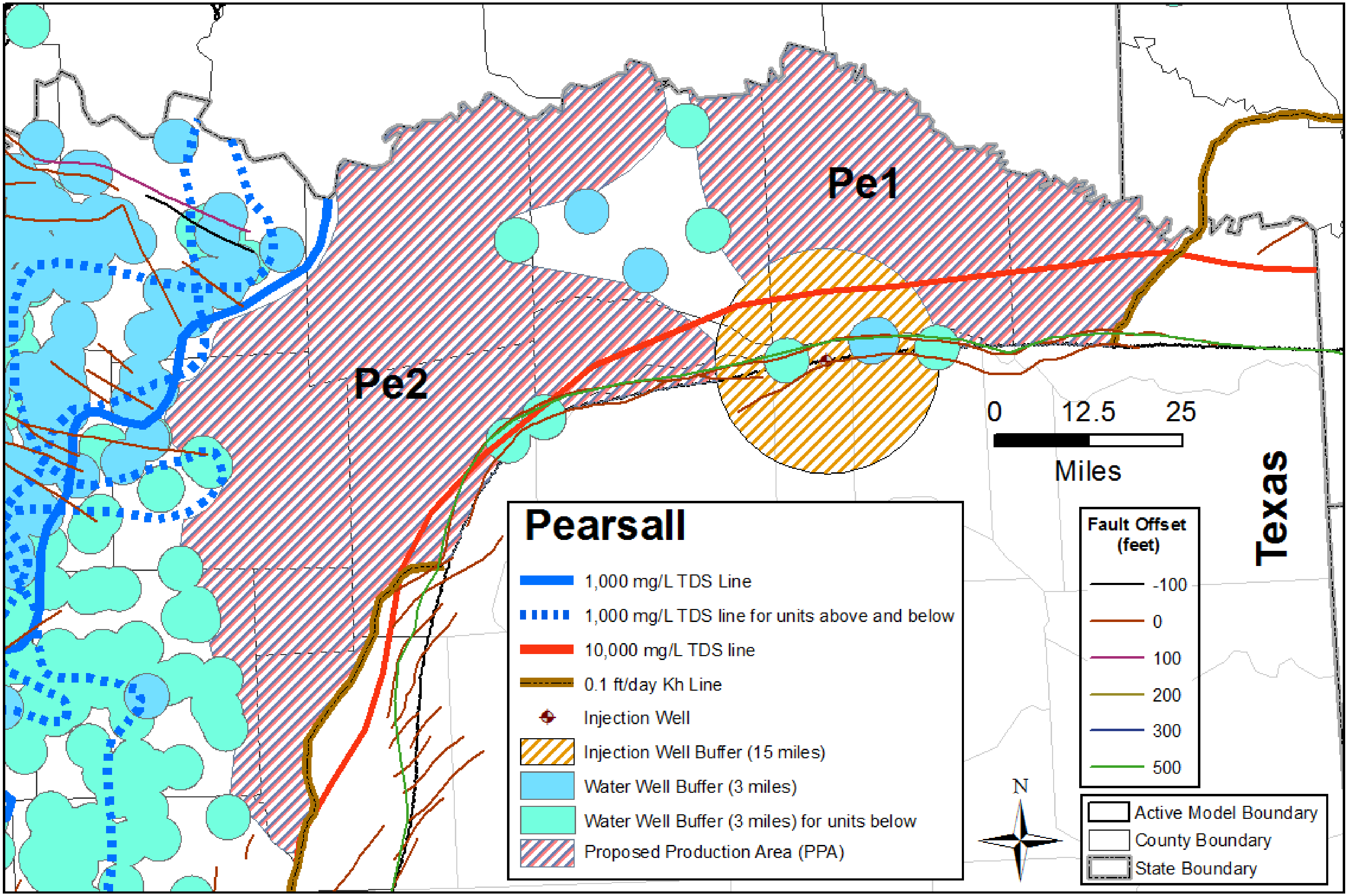
- PPAs delineated per-formation (no lumping Twin-Mountain, Travis Peak, Antlers)
  - Consistent with water quality estimates
  - Easier to aggregate than split at a later date
- Overlay exclusion zones
- Drew PPAs manually
  - Tried to keep them relatively contiguous
  - Included regions near exclusions zones, assume modeling will sort out viability based on impacts

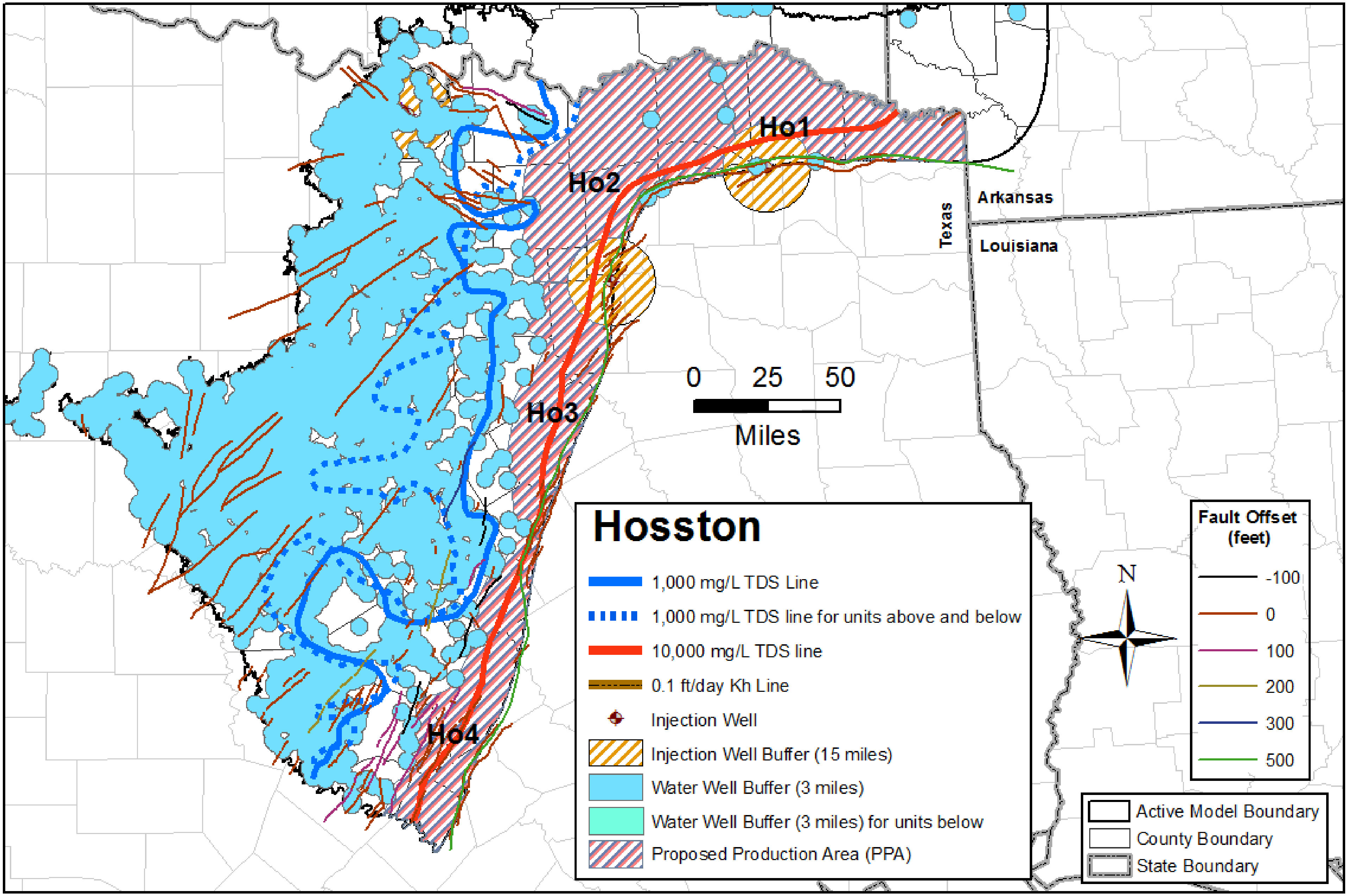


Pa1
Pa2
Arkan
Louis
0 15 30
Miles
N
Paluxy
1,000 mg/L TDS Line
1,000 mg/L TDS line for units above and below
10,000 mg/L TDS line
0.1 ft/day Kh Line
Injection Well
Injection Well Buffer (15 miles)
Water Well Buffer (3 miles)
Water Well Buffer (3 miles) for units below
Proposed Production Area (PPA)
Fault Offset (feet)
-100
0
100
200
300
500
Active Model Boundary
County Boundary
State Boundary


GR1
GR2
GR3
GR4
Arkansas
Texas
Louisiana
0 20 40
Miles
Glen Rose
1,000 mg/L TDS Line
1,000 mg/L TDS line for units above and below
10,000 mg/L TDS line
0.1 ft/day Kh Line
Injection Well
Injection Well Buffer (15 miles)
Water Well Buffer (3 miles)
Water Well Buffer (3 miles) for units below
Proposed Production Area (PPA)
N
Fault Offset (feet)
-100
0
100
200
300
500
Active Model Boundary
County Boundary
State Boundary


He2
He1
He3
Arkansas
Texas
Louisiana
0
20
40
Miles
Hensell
1,000 mg/L TDS Line
1,000 mg/L TDS line for units above and below
10,000 mg/L TDS line
0.1 ft/day Kh Line
Injection Well
Injection Well Buffer (15 miles)
Water Well Buffer (3 miles)
Water Well Buffer (3 miles) for units below
Proposed Production Area (PPA)
N
Fault Offset (feet)
-100
0
100
200
300
500
Active Model Boundary
County Boundary
State Boundary


Pe1
Pe2
0
12.5
25
Miles
Texas
Pearsall
1,000 mg/L TDS Line
1,000 mg/L TDS line for units above and below
10,000 mg/L TDS line
0.1 ft/day Kh Line
Injection Well
Injection Well Buffer (15 miles)
Water Well Buffer (3 miles)
Water Well Buffer (3 miles) for units below
Proposed Production Area (PPA)
Fault Offset (feet)
-100
0
100
200
300
500
N
Active Model Boundary
County Boundary
State Boundary

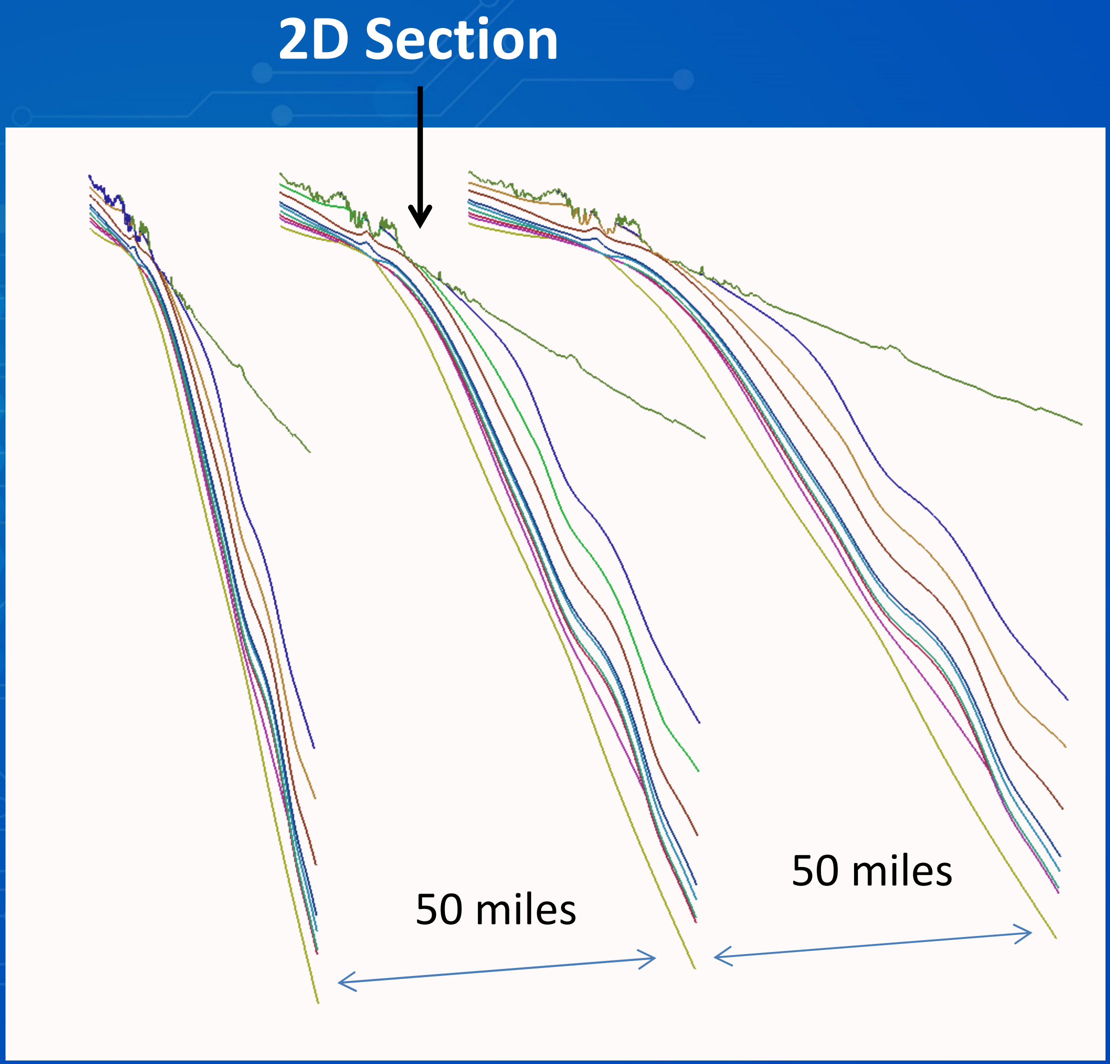

Ho1
Ho2
Ho3
Ho4
Arkansas
Texas
Louisiana
0 25 50
Miles
Hosston
1,000 mg/L TDS Line
1,000 mg/L TDS line for units above and below
10,000 mg/L TDS line
0.1 ft/day Kh Line
Injection Well
Injection Well Buffer (15 miles)
Water Well Buffer (3 miles)
Water Well Buffer (3 miles) for units below
Proposed Production Area (PPA)
N
Fault Offset (feet)
-100
0
100
200
300
500
Active Model Boundary
County Boundary
State Boundary

Modeling Strategy for the Hill Country Portion of the Trinity Aquifer

- Modeling underway to estimate the sustainable rates of extraction of brackish water that may be maintained for 30 and 50 years of production in potential production areas.
- No groundwater availability model (GAM) exists with appropriate extent
- Psuedo 3D models are being created in MODFLOW-USG for three vertical sections that intersect the potential production areas
- Hydraulic Parameters will be based on the parameters available in the Hill Country GAM and from published literature
- Well fields will be simulated at several total rates to determine sustainable yields for each potential production area

Modeling Strategy for the Hill Country Portion of the Trinity

- Construct simplified vertical 2D cross-section one model grid cell thick
- Extrude vertical cross-section 50 repeat 50 times on either side of section
- The result is a pseudo 3-D model for the area of interest



Modeling Approach: Northern Trinity Aquifer

- NTWGAM (Kelley and others, 2014) will be used
- Baseline simulation will be GMA-8 DFC (Run10)
  - Drawdown will be calculated by comparing baseline simulation head surface to "with project" head surface
  - Drawdown will be evaluated at 30 and 50 years
- One or more wellfields will be simulated in each PPA
  - Maximum rate will depend on conductivity at location of wellfield
  - Limit will be based on maximum drawdown (500 feet or top of aquifer)
  - Three rates will be simulated (low, medium, max) at each location
- In addition to drawdown, particle tracking will be performed to determine induced movement at fresh water 1,000 mg/L line

Public Comments and Next Steps

- The draft Potential Production Areas are open to public comment
  - This presentation will be publically available on the TWDB Trinity Aquifer BRACS website
  - Stakeholders should have their comments to TWDB by May 19, 2017
- Groundwater modeling will be performed for each PPA
- Draft report will be provided to TWDB by May 31, 2017 for review and comments
- The Final Report will be delivered to TWDB by August 31, 2017
- Brackish Groundwater Production Zones will be designated by TWDB in a public board meeting later this year

Contact Information

- Leanne Stepchinski (SwRI Project Manager)
  - 210.522.5140
  - Leanne.Stepchinski@swri.org

- Mark Robinson (TWDB Contract Manager)
  - (512) 463-7657
  - Mark.Robinson@twdb.texas.gov

- All public comments should be directed to Mark Robinson
  - Mark.Robinson@twdb.texas.gov