Lipan Aquifer Brackish Groundwater Study

Presented at the

South Central Water Research Interest Group

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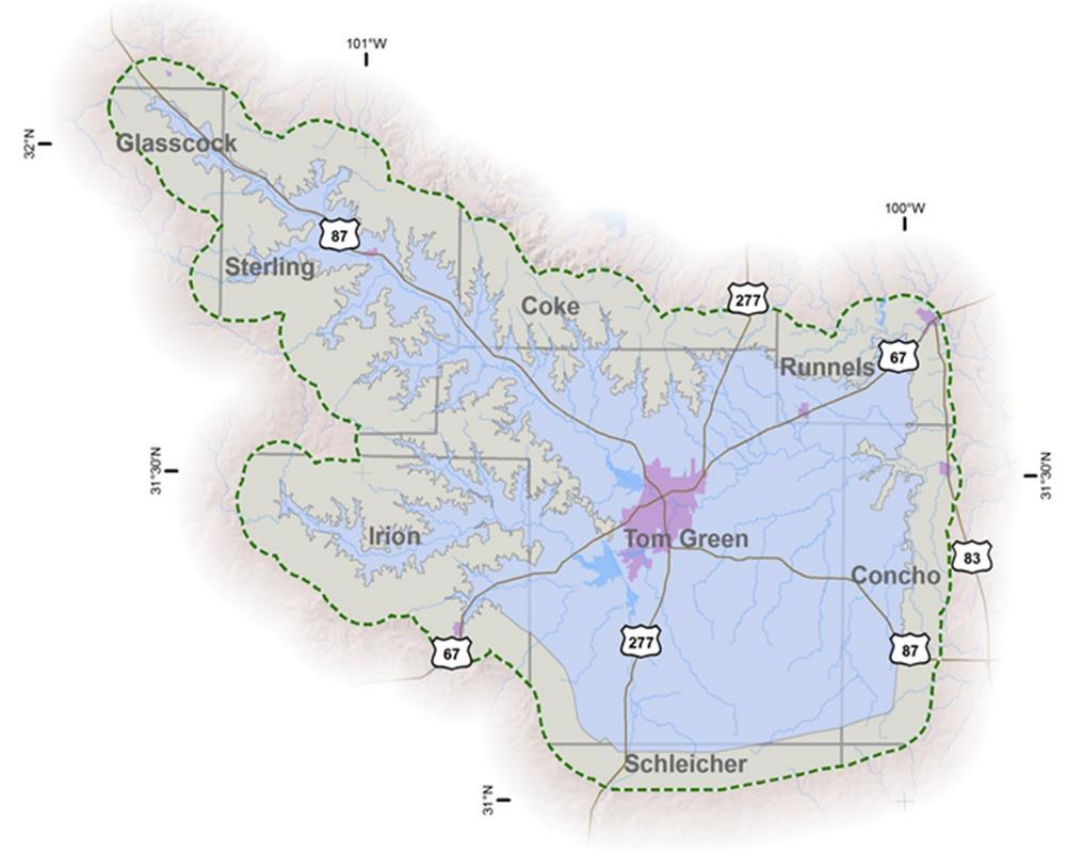
Texas Water Development Board

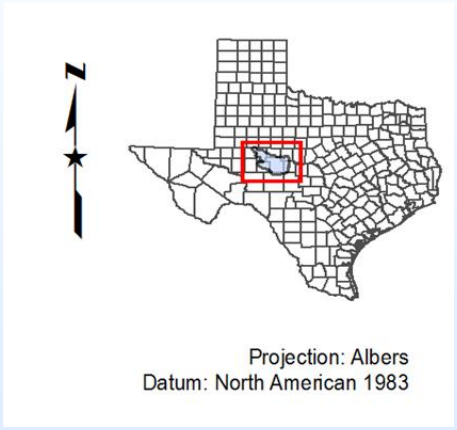
Texas Water Development Board

The following presentation is based upon professional research and analysis within the scope of the Texas Water Development Board's statutory responsibilities and priorities but, unless specifically noted, does not necessarily reflect official Board positions or decisions.

Lipan Aquifer Study Area

- Designation of the Lipan Aquifer for the report
  - Lateral extent of the TWDB-defined Lipan Aquifer with added four-mile buffer
  - Quaternary and Neogene sediments and underlying Permian formations





Salinity Classification

Saltier than fresh water, less salty than seawater

Groundwater Salinity Classification	Total Dissolved Solids Concentration (units: milligrams per liter)
Fresh	0 to 999
Slightly Saline	1,000 to 2,999
Moderately Saline	3,000 to 9,999
Very Saline	10,000 to 35,000
Brine	Greater than 35,000

← Drinking Water Limit

← Texas Aquifers Mapped Limit

← Seawater

Modified from Winslow and Kister, 1956

Data Collection

- Total of 6,995 wells evaluated
  - All from public sources
  - 2,314 from TWDB Groundwater Database (GWDB)
  - 4,287 unique to BRACS Database
  - 394 shared between BRACS and GWDB

- BRACS well sample sources
  - Abilene Geological Society published report
  - BEG paper/digital geophysical logs
  - BEG Report of Investigations 191
  - LBG Brackish GW for San Angelo study
  - LBG Lipan GAM study well data
  - RRC digital geophysical Logs
  - RRC GAU Q-log paper/digital geophysical logs
  - TCEQ PWS water wells
  - TCEQ water well images
  - TDLR digital water well reports
  - TWDB aquifer test information
  - TWDB geophysical logs
  - TWDB Groundwater Database
  - TWDB published reports
  - USGS geophysical logs

Stratigraphy (1)

- Total of 1,046 wells with 5,424 correlations used for formation mapping
- Fifteen Permian units mapped
- Ten potential water-bearing formations identified
- Other formations mapped
  - One Triassic formation (Dockum Group)
    - To be studied in future reports
  - One Cretaceous formation (Trinity Group)
    - To be studied in future reports
  - Quaternary-Neocene sediments (Leona-Ogallala)
  - Studied in order to understand the Lipan Aquifer as defined for this report

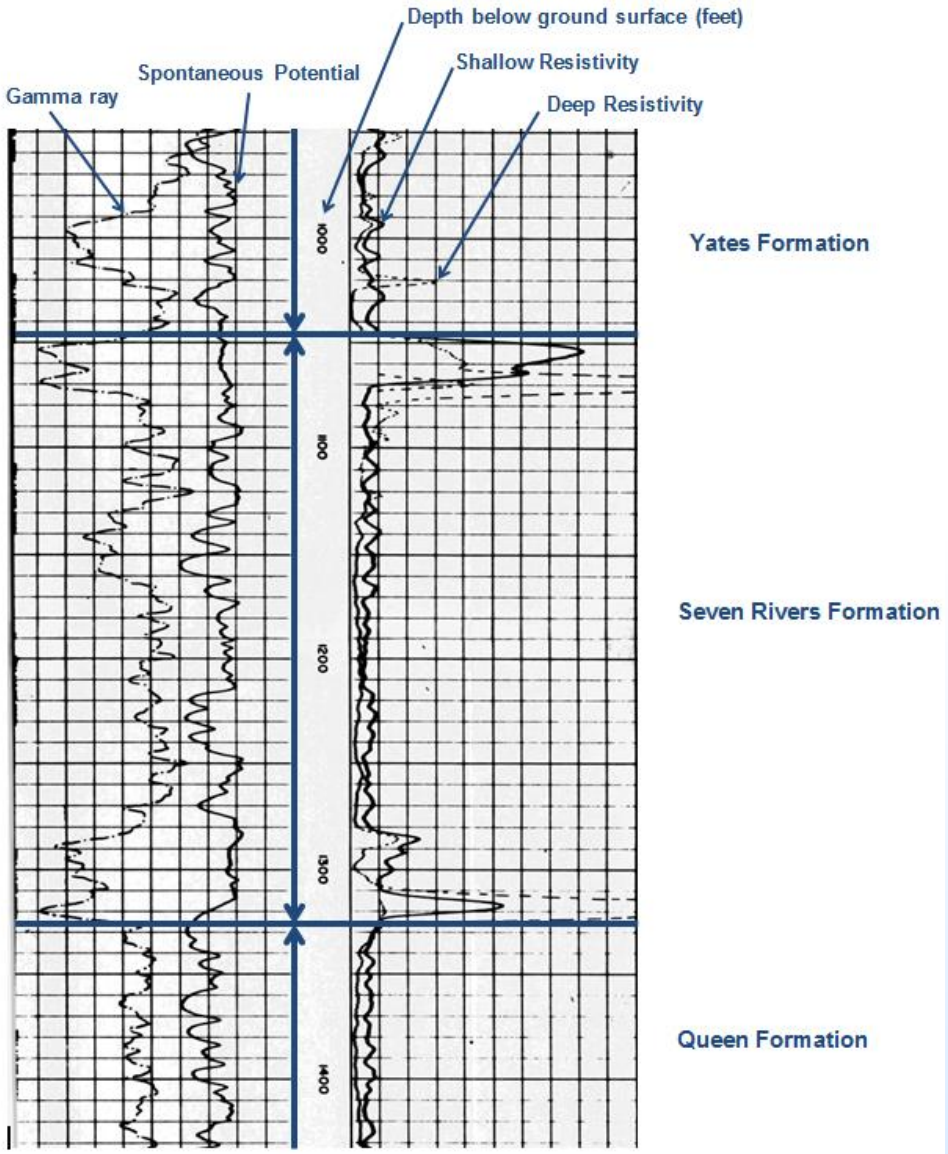
Stratigraphy (2)

Geologic period	Epoch and age (millions of years before present)	Regional series	Geologic group	Stratigraphic unit	
				Midland Basin	Eastern Shelf
Quarternary	Holocene (0.01-present)			alluvium	alluvium
	Pleistocene (2.6-0.01)			Pleistocene	Leona
Neogene (Tertiary)	Pliocene (5.33-2.6)			Pliocene	Ogallala
					unconformity
Cretaceous	Early (145.0-100.5)	Comanchean	Fredericksburg	Fredericksburg	Edwards Limestone Fort Terrett
			Trinity	Trinity Sand	Antlers Sand
					unconformity
Triassic	Upper (237.0-201.3)		Dockum	Dockum	Dockum
					unconformity
Permian	Lopingian (260-252)	Ochoan		Dewey Lake Rustler Salado Castille	Dewey Lake Rustler Salado
					unconformity
	Guadalupian (272-260)	Guadalupian	Whitehorse	Tansill Yates Seven Rivers Queen Grayburg	Tansill Yates Seven Rivers Queen Grayburg
			Pease River	San Andres	San Andres (Blaine) San Angelo
					unconformity
	Cisuralian (299-272)	Leonardian	Clear Fork	Clear Fork *undifferentiated*	Choza: Upper Choza; Tubb member Vale: Bullwagon Dolomite; Vale shale Arroyo: *Standpipe Limestone*; Arroyo
			Wichita - Albany	Wichita *undifferentiated*	Lueders

Lipan Aquifer units

- Geological units that produce water in the Lipan aquifer are highlighted.
- Geologic epochs and ages as defined by the International Commission on Stratigraphy Chronostratigraphic Chart (Gradstein and others, 2012).

Stratigraphy (3)



- Resistivity tools
  - Measures the resistivity of a formation by passing current between electrodes
  - Wider electrode spacing increases depth of formation investigation
  - May be used to determine formation water resistivity
    - Differences between shallow and deep resistivity readings
    - Proper geologic conditions are necessary
- Spontaneous potential (SP) tool
  - Measures current between electrode at surface and on the tool
  - Some factors that influence SP response are:
    - Salinity difference between borehole mud filtrate and formation water
    - Formation fluid type - water or hydrocarbon
    - Lithology – shale content decreases response
- Gamma ray tool
  - Measures naturally occurring gamma radiation
  - Typically higher in shales and clays than sands
  - Useful for determining stratigraphy
  - Not useful for salinity calculations

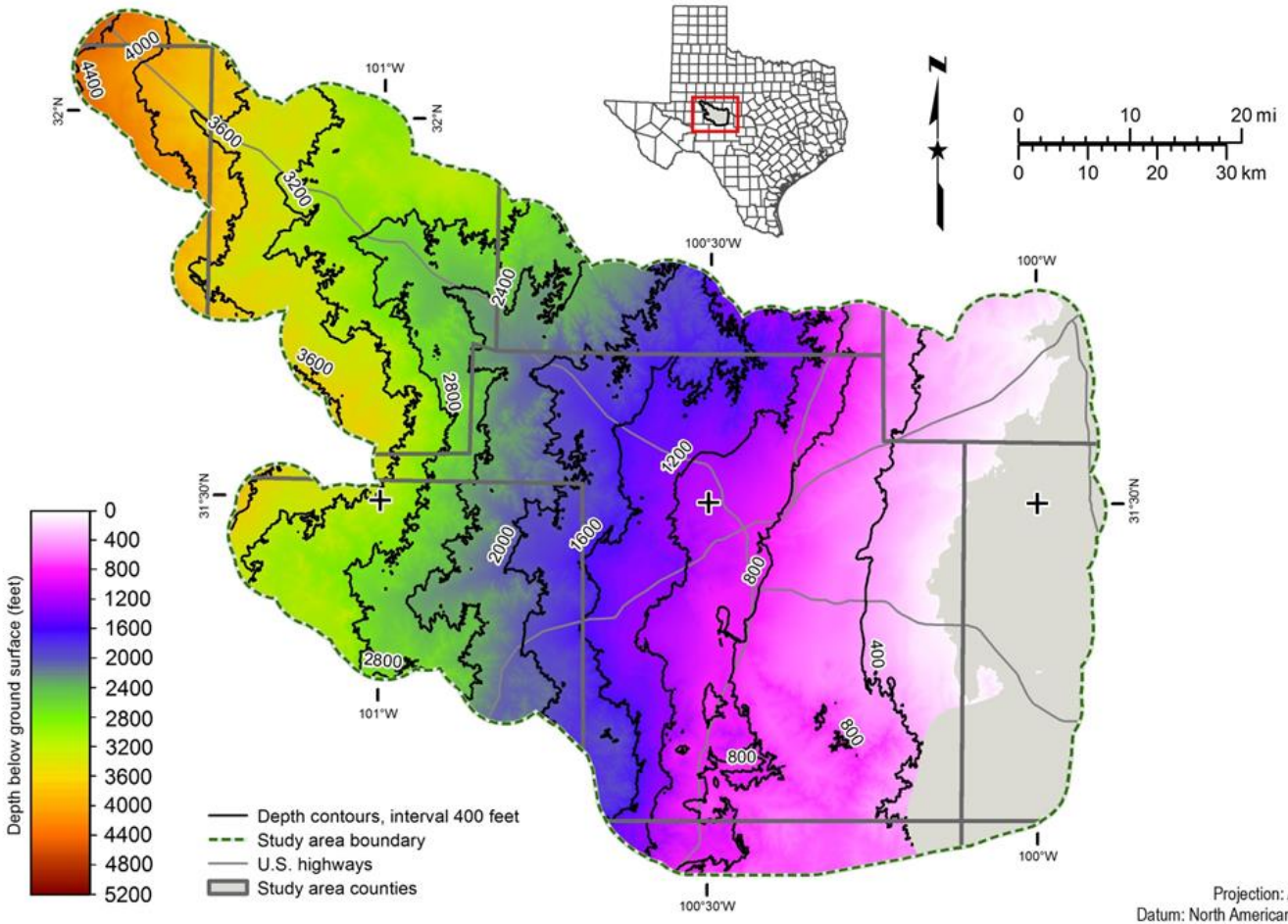
- One example of many: BRACS well ID 37978

Geologic Surface Maps

- Maps of the correlated formations:
  - Formation top depth below ground surface
  - Formation top elevation relative to mean sea level
  - Isochore (vertical formation thickness)
- Surface modeling parameters:
  - A 250 foot grid used
  - Geologic contacts from state geologic maps used at outcrops
  - 3D tools used to validate surface interactions
- Examples
  - Arroyo Formation – depth, elevation, isochore

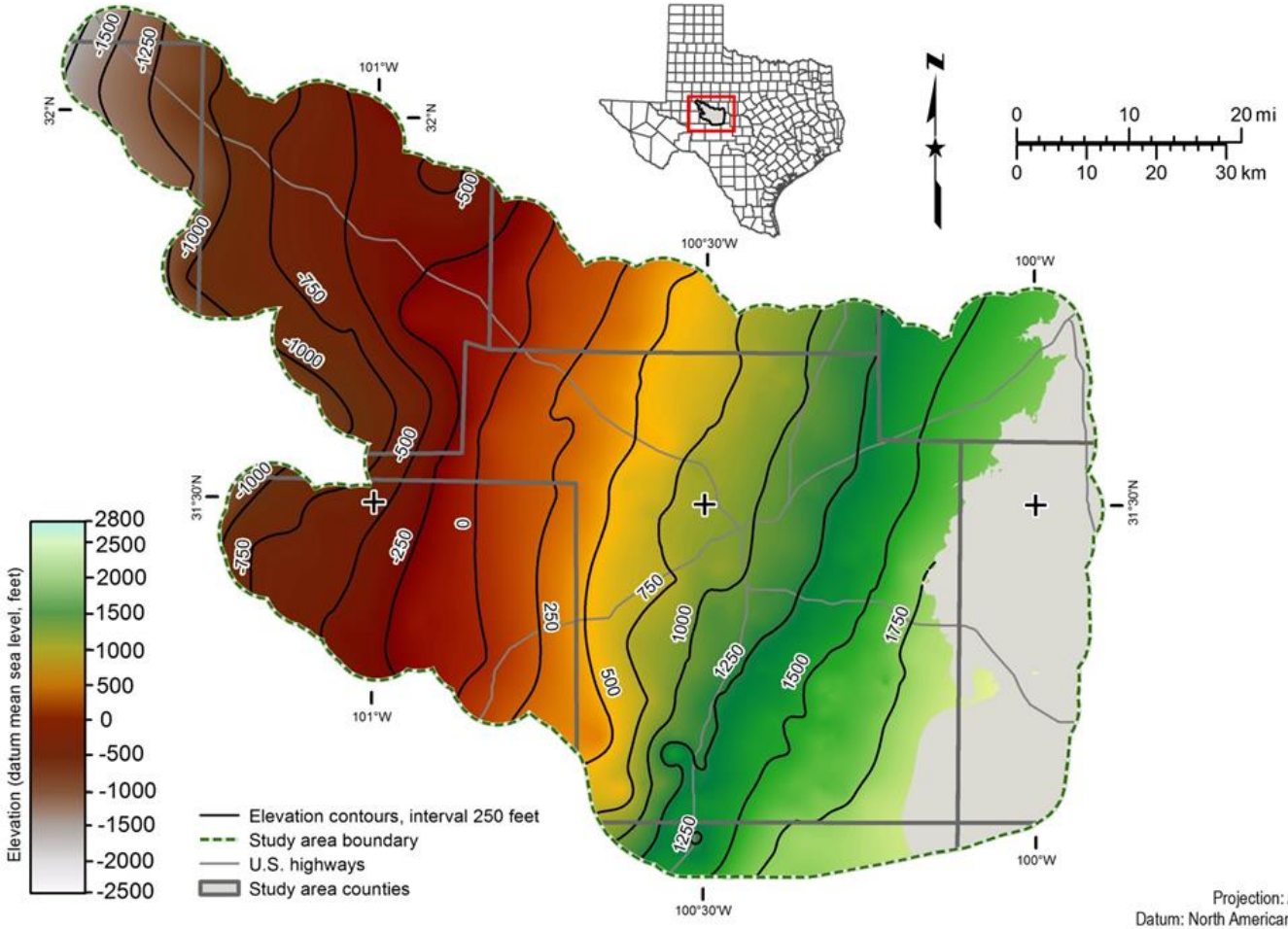
Arroyo Formation (1)

- Formation top
  - Depth in feet below ground surface
  - Gray area represents area where formation top does not exist



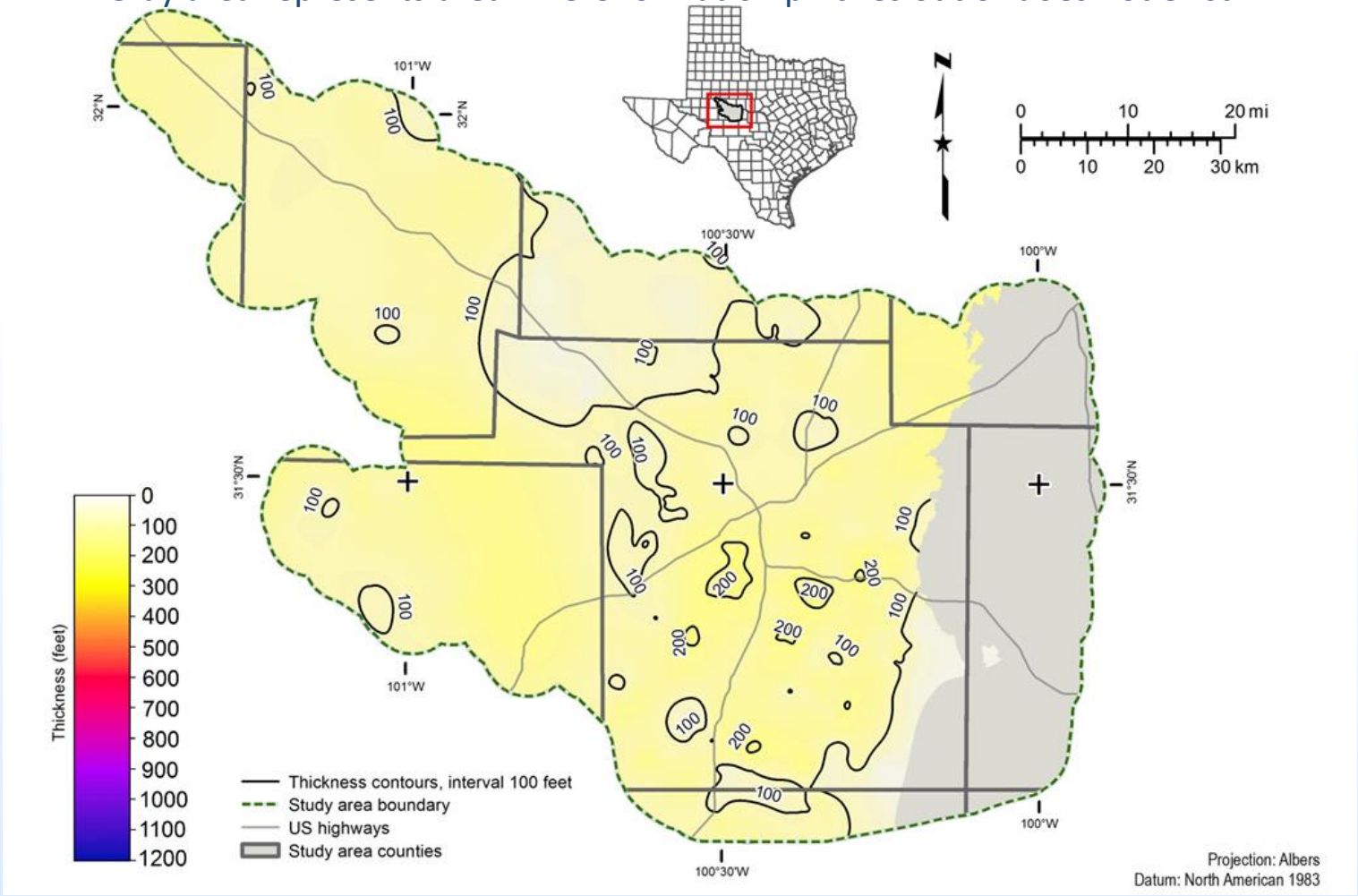
Arroyo Formation (2)

- Formation top
  - Elevation in feet above mean sea level
  - Gray area represents area where formation top does not exist



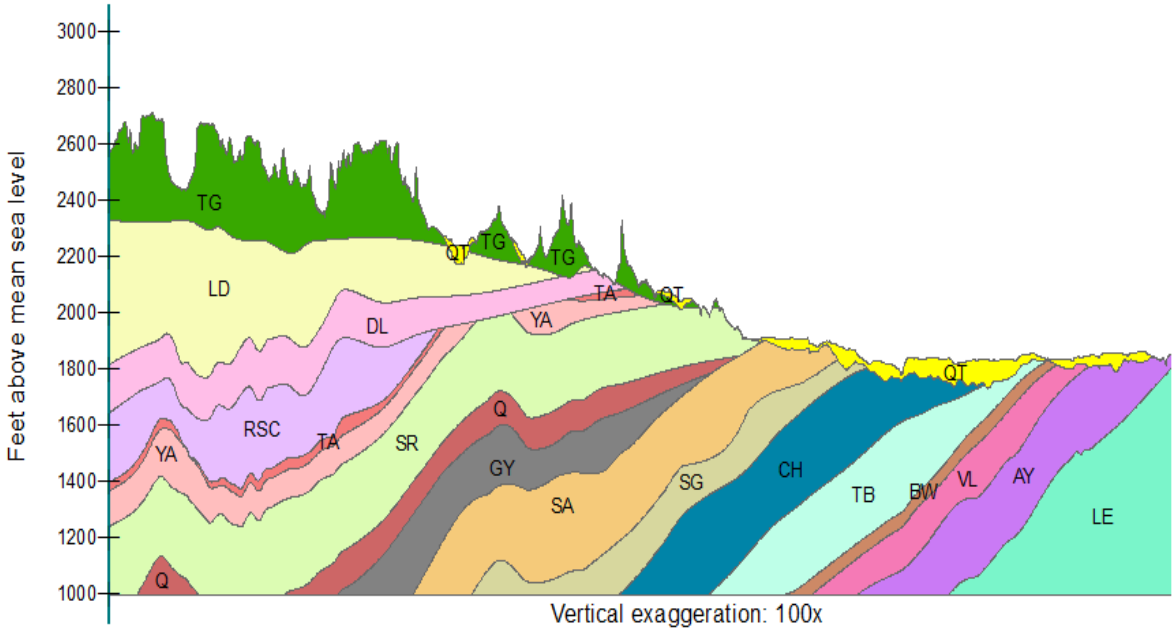
Arroyo Formation (3)

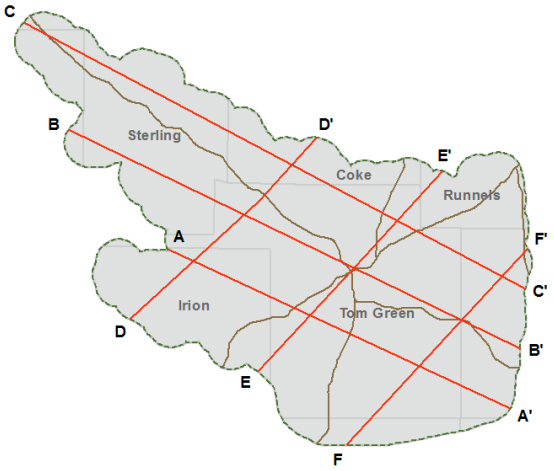
- Formation isochore
  - Vertical thickness in feet
  - Gray area represents area where formation pinches out or does not exist



Cross-section

- Six cross-sections generated
- Cross-section B-B’ shown





Aquifer codes

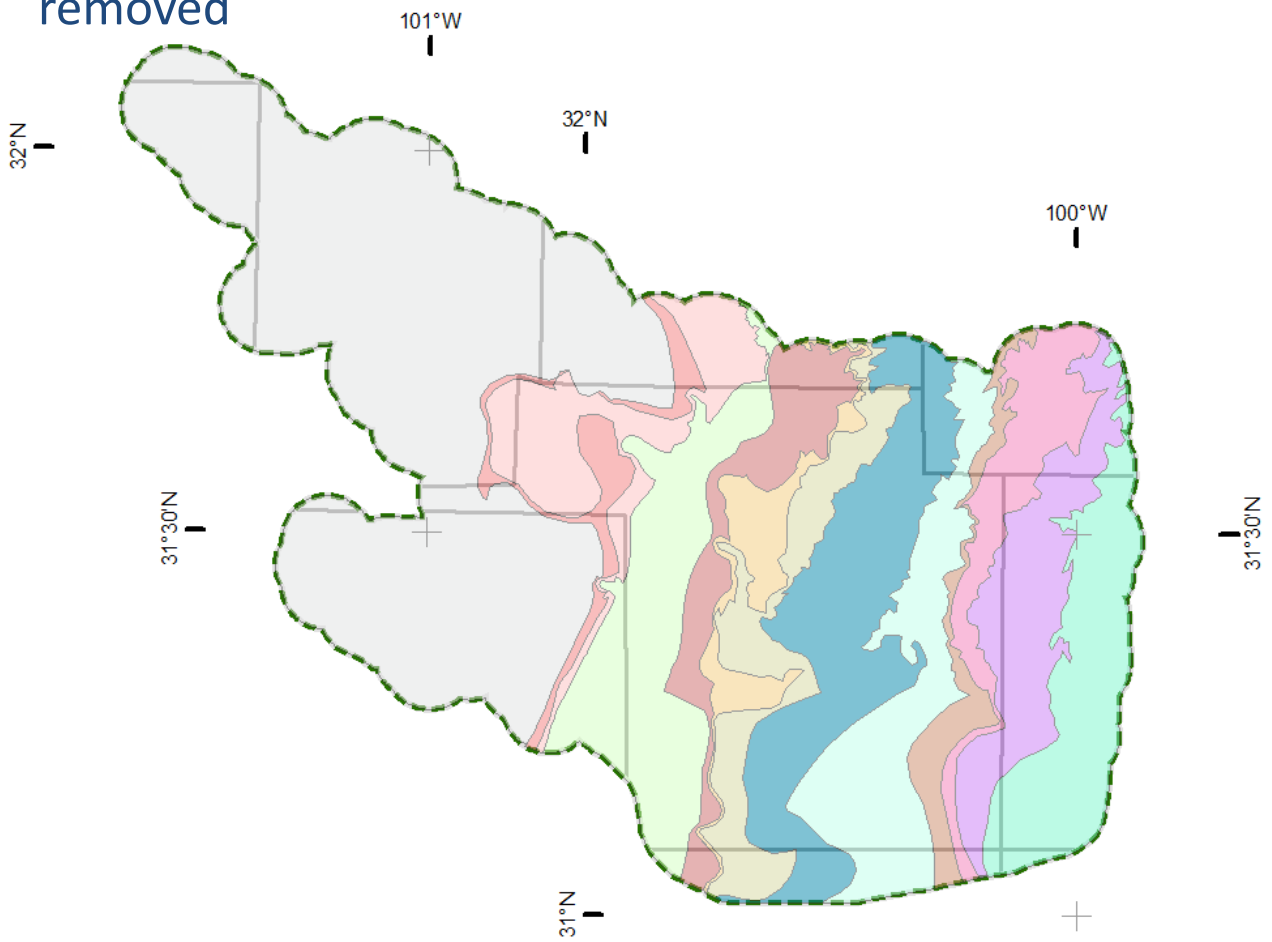
QT	TA	SA	VL
TG	YA	SG	AY
LD	SR	CH	LE
DL	Q	TB	
RSC	GY	BW	

0 10 20 mi
0 10 20 30 km

Aquifer code	Stratigraphic unit
QT	Quaternary and Neogene sediment
TG	Trinity Group
LD	Dockum Group
DL	Dewey Lake Formation
RSC	Rustler-Salado formations
TA	Tansill Formation
YA	Yates Formation
SR	Seven Rivers Formation
Q	Queen Formation
GY	Grayburg Formation
SA	San Andres Formation
SG	San Angelo Formation
CH	Upper Choza member
TB	Tubb member
BW	Bullwagon Dolomite
VL	Vale Shale member
AY	Arroyo Formation
LE	Lueders Formation and older formations

Permian subcrop areas

- Permian units surface expression if overlying units removed

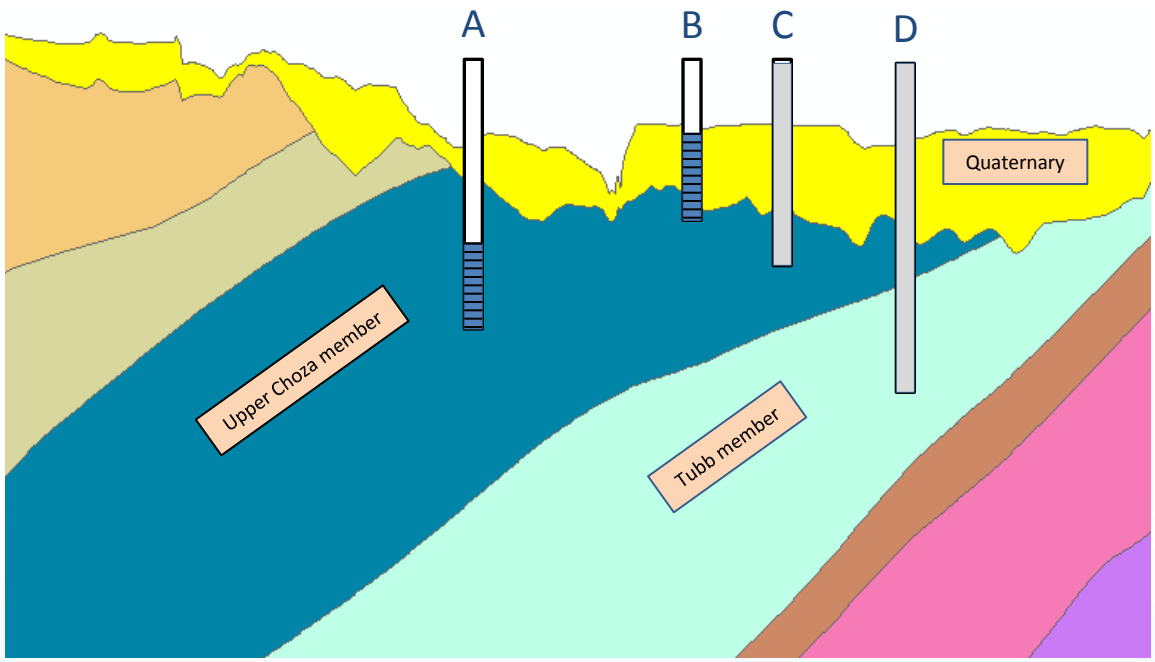


Permian subcrop

- Tansill Formation
- Yates Formation
- Seven Rivers Formation
- Queen Formation
- San Andres Formation
- San Angelo Formation
- Upper Choza member
- Tubb member
- Bullwagon Dolomite
- Vale Shale member
- Arroyo Formation
- Lueders Formation
- Non-Lipan subcrop

- Study area boundary
- Study area counties

Aquifer Determination



Scenario database designations

X denotes unknown completion

Well A: CH
Well B: QT, CH
Well C: X, QT, CH
Well D: X, QT,CH, TB

Well Completion

Screen/Open interval

Unknown

- Scenario Description
  - A: Entire completion in the Upper Choza
  - B: Completion in Upper Choza and Quaternary
  - C: Unknown well completion
    - Well depth penetrates the Quaternary and Upper Choza
  - D: Unknown well completion
    - Total depth penetrates the Quaternary, and Upper Choza and Tubb members

Aquifer Test

- Aquifer hydraulic properties summary
  - Limited to Lipan Aquifer formations
  - Single Permian completions only tabulated
  - No hydraulic conductivity or specific yield data available
  - No Queen Formation data available
  - Limited data negated productivity per formation classification

Geological unit	Property	Sample count	Min	Max	Mean
Quaternary and Neogene sediment	Well yield	24	2	750	157
	Drawdown	4	3	20	10
	Specific capacity	4	0.86	15	5
Yates Formation	Well yield	9	9	395	126
	Drawdown	3	10	15	11.7
	Specific capacity	3	6	26.3	13.1
Seven Rivers Formation	Well yield	40	2	500	54.5
	Drawdown	1	165	165	165
	Specific capacity	1	1.25	1.25	1.25
San Angelo Formation	Well yield	26	2	150	20.1
	Drawdown	2	2	12	7
	Specific capacity	2	1.17	15	8.1
Upper Choza member	Well yield	128	1	720	89
	Drawdown	11	2	60	20.4
	Specific capacity	11	0.05	75	8

Geological unit	Property	Sample count	Min	Max	Mean
Tubb member	Well yield	77	10	1,000	299
	Drawdown	7	2	30	12.1
	Specific capacity	4	16.7	106	79.2
Bullwagon Dolomite	Well yield	2	20	100	60
	Drawdown	N/A	N/A	N/A	N/A
	Specific capacity	N/A	N/A	N/A	N/A
Arroyo Formation	Well yield	65	1	1,200	148
	Drawdown	1	70	70	70
	Specific capacity	1	2.14	2.14	2.14
Lueders Formation	Well yield	25	2	400	139
	Drawdown	1	33	33	33
	Specific capacity	1	0.06	0.06	0.06

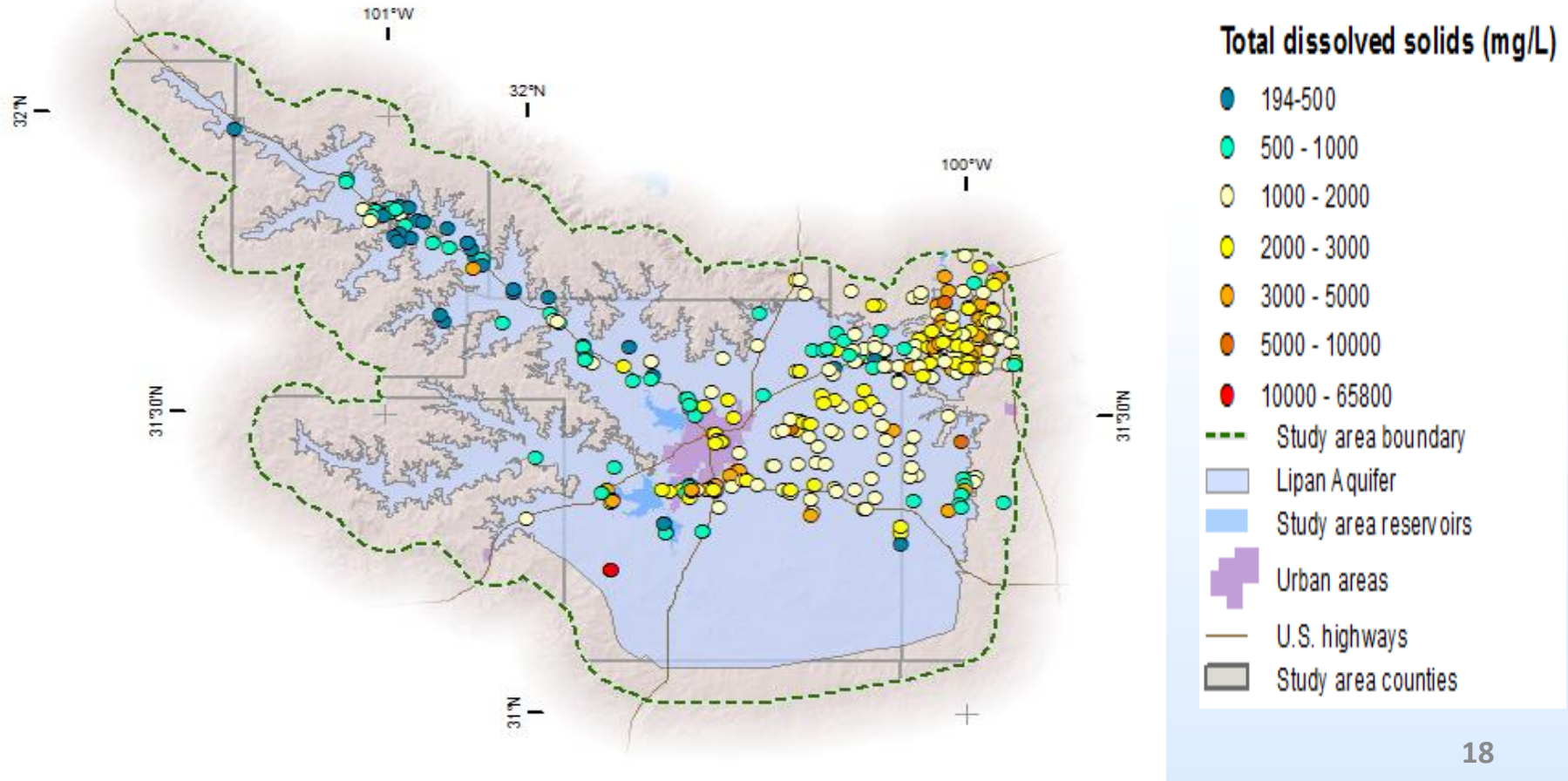
Water Quality

- Water Quality
  - Total of 1,003 samples available within study area
  - Excluded Trinity and Dockum group wells
  - Excluded wells with indeterminate completions
  - Resulting in 384 samples available for reporting
- Constituents sampled
  - Total dissolved solids (TDS)
  - Arsenic
  - Chloride
  - Iron
  - Sulfate
  - Barium
  - Radionuclides
  - Uranium
- Percent of samples exceeding, primary or secondary standard *
  - Total dissolved solids: 70%, secondary
  - Chloride: 61%, secondary
  - Iron: 11%, secondary
  - Sulfate: 39%, secondary
  - Radionuclides, gross alpha: 6%, primary

* Texas Commission on Environmental Quality Safe Drinking Water Limit

Total Dissolved Solids (TDS)

- One example of seven produced constituent maps
  - Silica tabulated due to small sample size (5)
- Mapped results from 384 samples
  - Single value above 10,000 mg/L for LBG Guyton test well at ~900 feet, BRACS ID well 51449

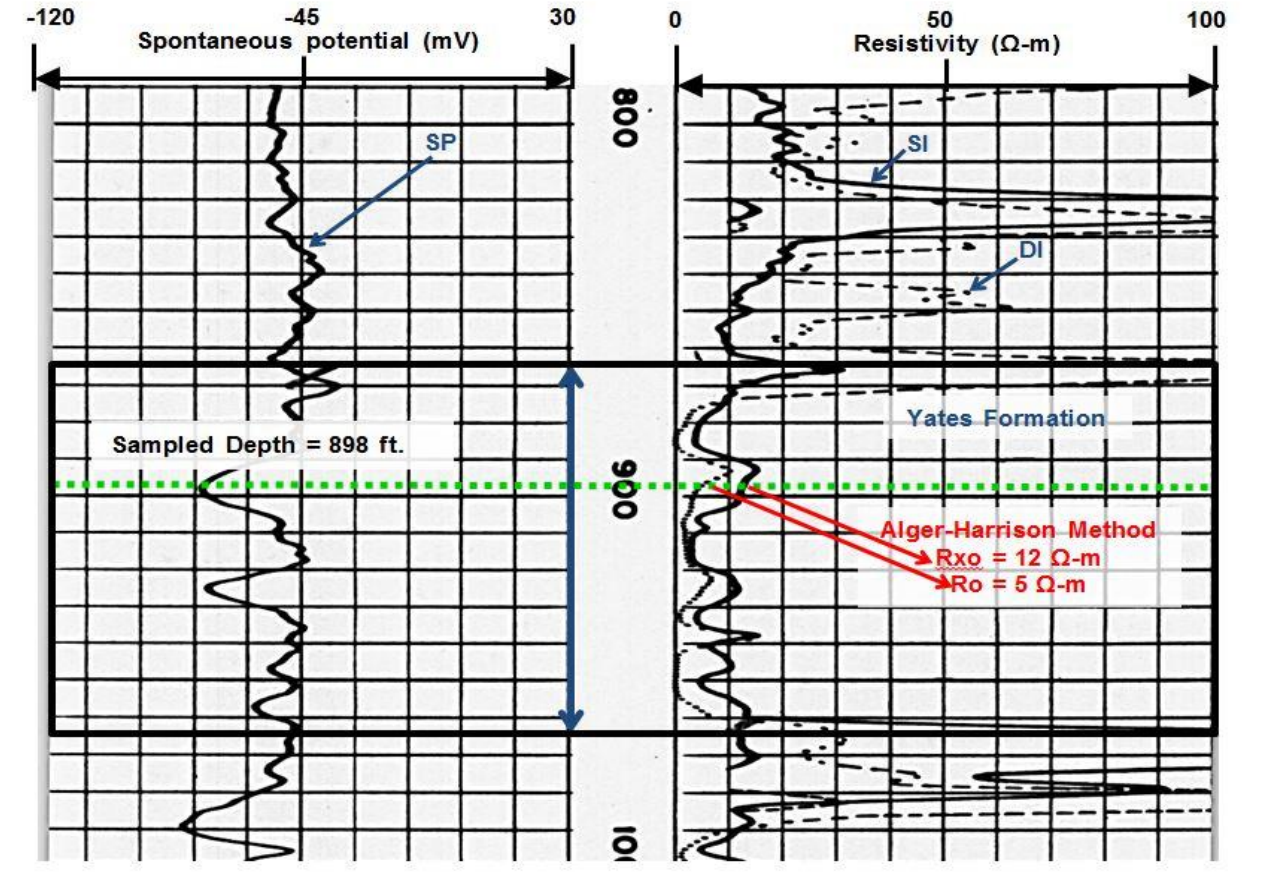


Salinity calculation

- Seven available methods defined by Estepp (1988)
  - Estimate formation water resistivity from well logs
  - TDS calculated from resistivity
  - Five methods determined on initial examination to be non-applicable
- Spontaneous Potential (SP) Method selected
  - Selected SP curve deflection is a function of formation water resistivity
  - Determined as not applicable for well-lithified shaly limestone rocks predominant at depth in the study area
- Alger-Harrison Method selected
  - Ratio of shallow and deep resistivity correlate to formation water resistivity
  - Determined as most appropriate for study area geology
  - 179 wells evaluated resulting in 771 calculated TDS values

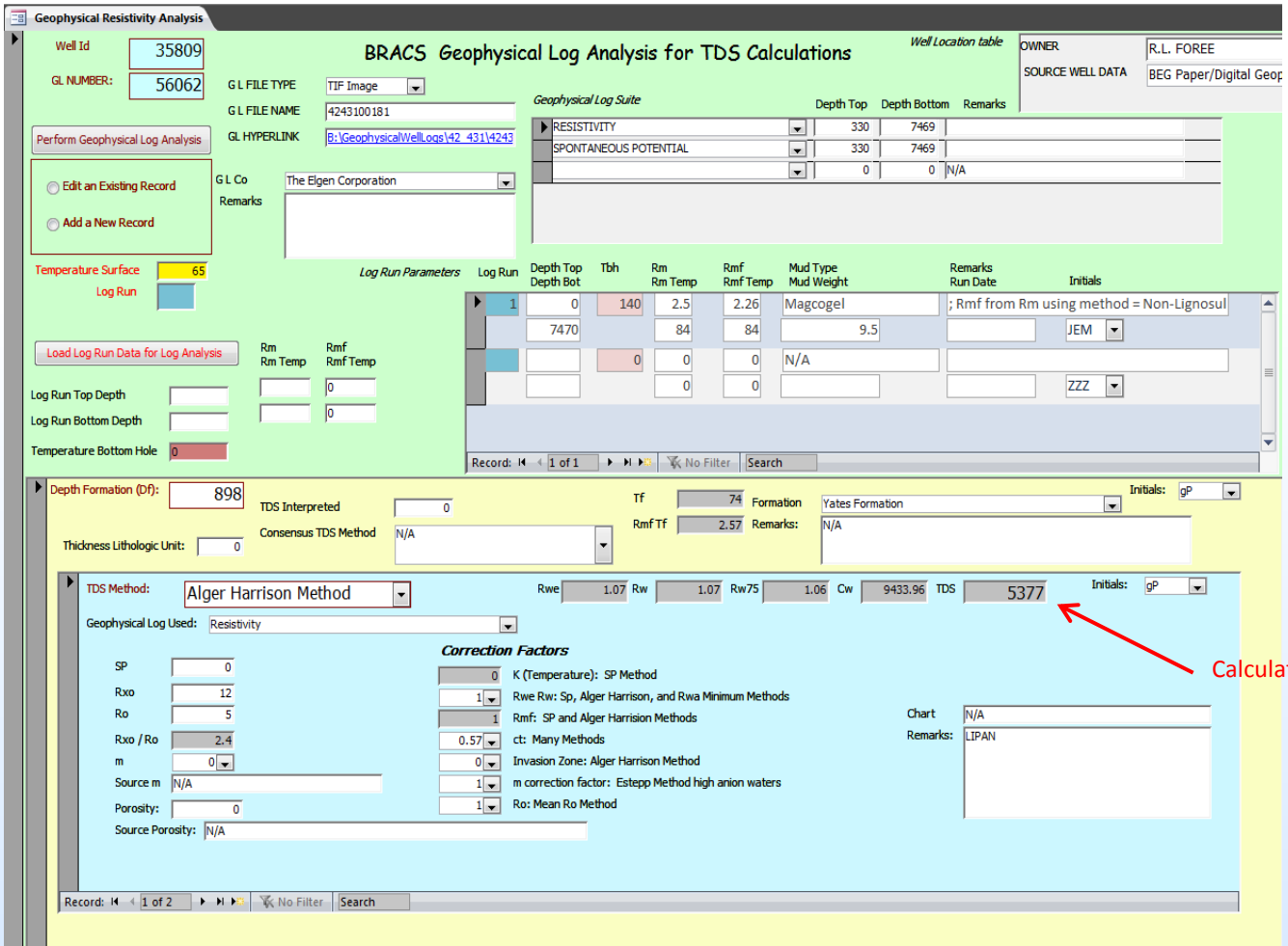
Alger-Harrison Method

- BRACS well ID 35809 example log
  - Deep formation resistivity 5 Ω-m (ohm-meter)
  - Shallow formation resistivity 12 Ω-m (ohm-meter)
  - Other required information (temperature, depths, etc.) on log header (not shown)



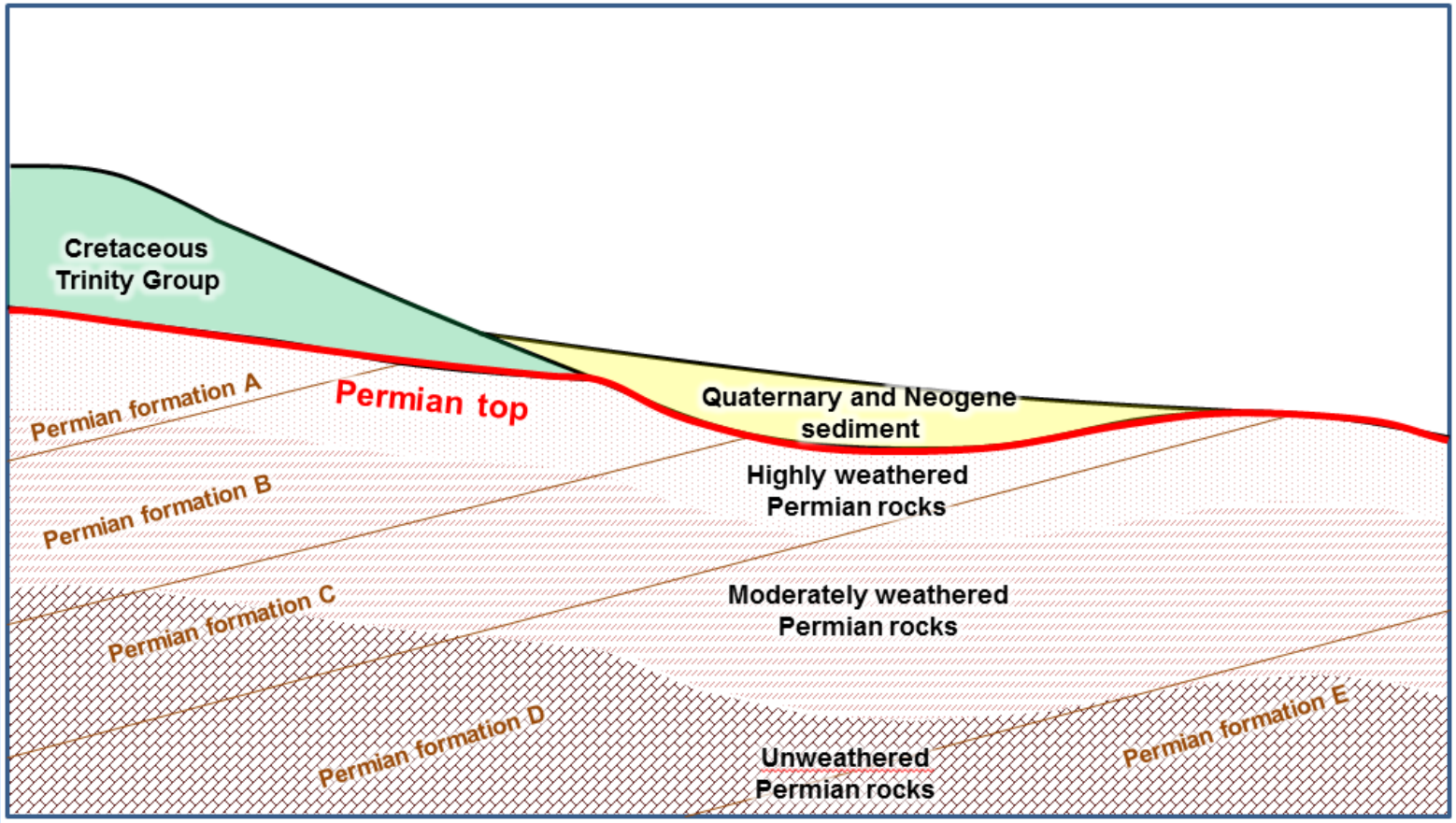
BRACS data processing

- Form entry for BRACS well identification number 35809
  - Information from log entered into BRACS database form for processing
  - Calculated interim values in gray background
  - Calculated TDS value of 5377 mg/L



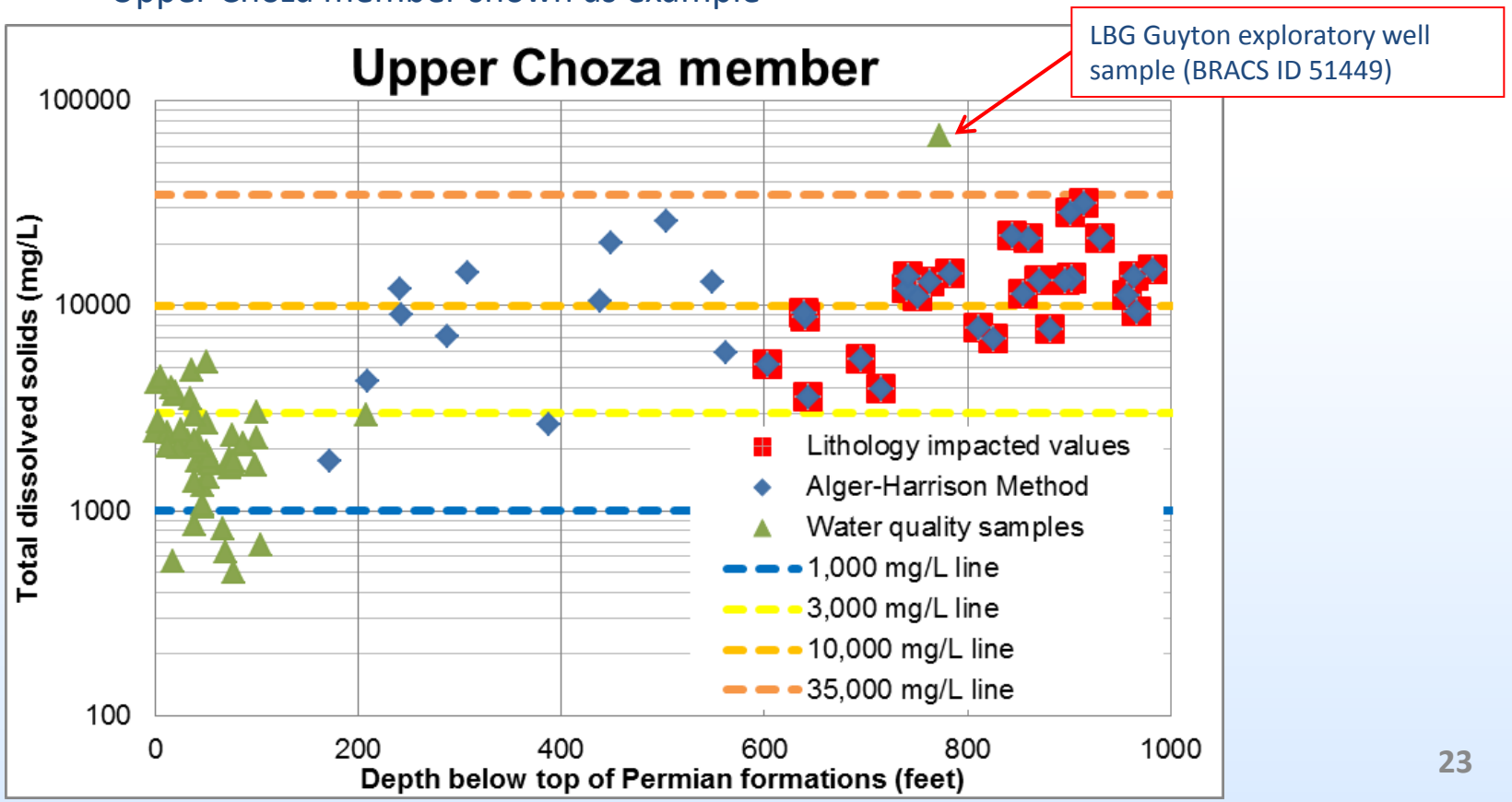
Formation Schematic

- Top of Permian formations interface (red line) is significant
- Used as basis for salinity analysis
- Weathering occurred prior to younger unit deposition
- Weathering decreases with depth relative to paleo ground surface



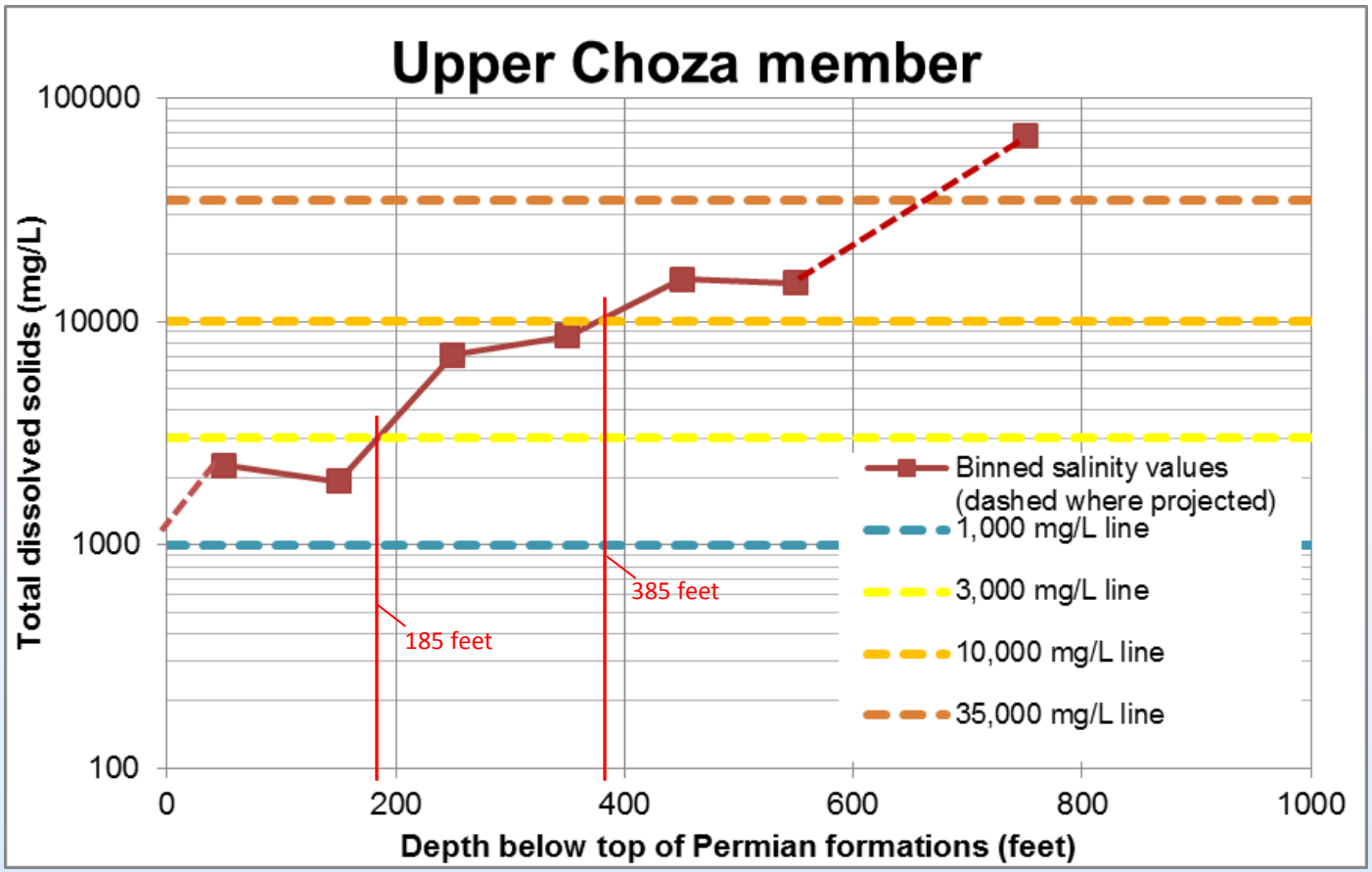
Salinity vs. depth plots

- Performed for nine Permian potential water-bearing formations
  - Combination of water quality samples and calculated values
  - Lithology impacted calculations at greater depths
  - Depth below Permian top used rather than depth below ground surface
  - Upper Choza member shown as example



Bin vs. depth plots

- Performed for nine Permian potential water-bearing formations
  - Sample values “binned” based on average TDS value within 100-foot depth increment
  - Effort to classify salinity trends with depth
  - Depth below Permian top used rather than depth below ground surface
  - Upper Choza member shown as example



Salinity zone determination

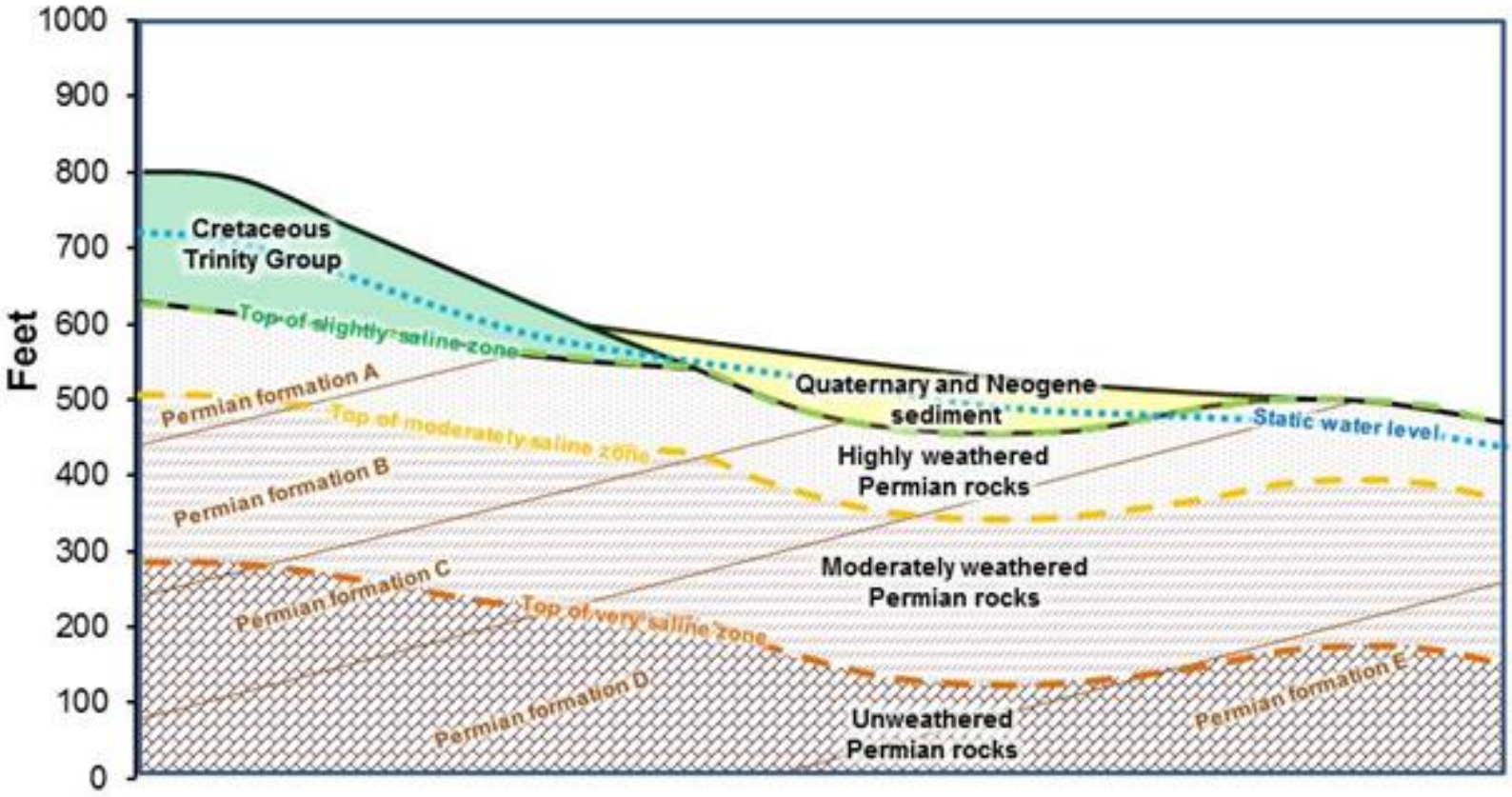
- Performed for nine Permian potential water-bearing formations
  - Bin cutoff values tabulated for all evaluated formations
  - Cutoff values averaged across formations to determine regional relationship
  - Resulting surfaces mapped and used for groundwater volume calculation
  - Depth below ground for general reference

	Depth below top of Permian (feet)	
Geological formation	**3,000 mg/L (base of slightly saline)**	**10,000 mg/L (base of moderately saline)**
Yates Formation	110	215
Seven Rivers Formation	60	315
Queen Formation	0	390
San Angelo Formation	205	445
Upper Choza member	185	385
Tubb member	150	425
Bullwagon Dolomite	115	290
Arroyo Formation	80	260
Lueders Formation	40	225
Average	**105**	**328**

Cutoff values from previous slide

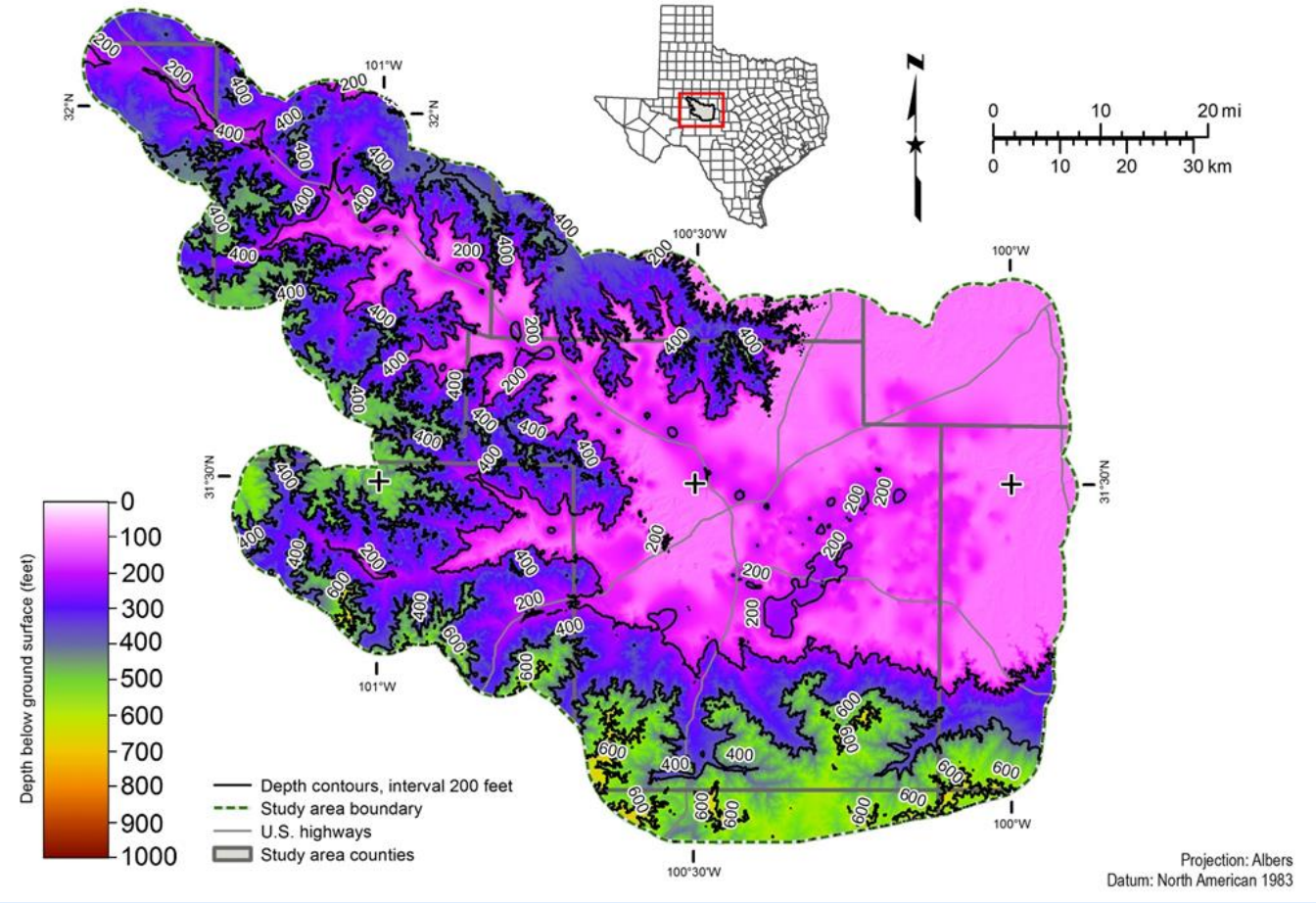
Salinity zone schematic

- Water storage top is historic static water level (since 2000)
- Fresh water primarily from formations younger than Permian
- Slightly saline water in the highly weathered Permian units
- Moderately saline water in moderately weathered Permian units
- Very saline water at greater depths



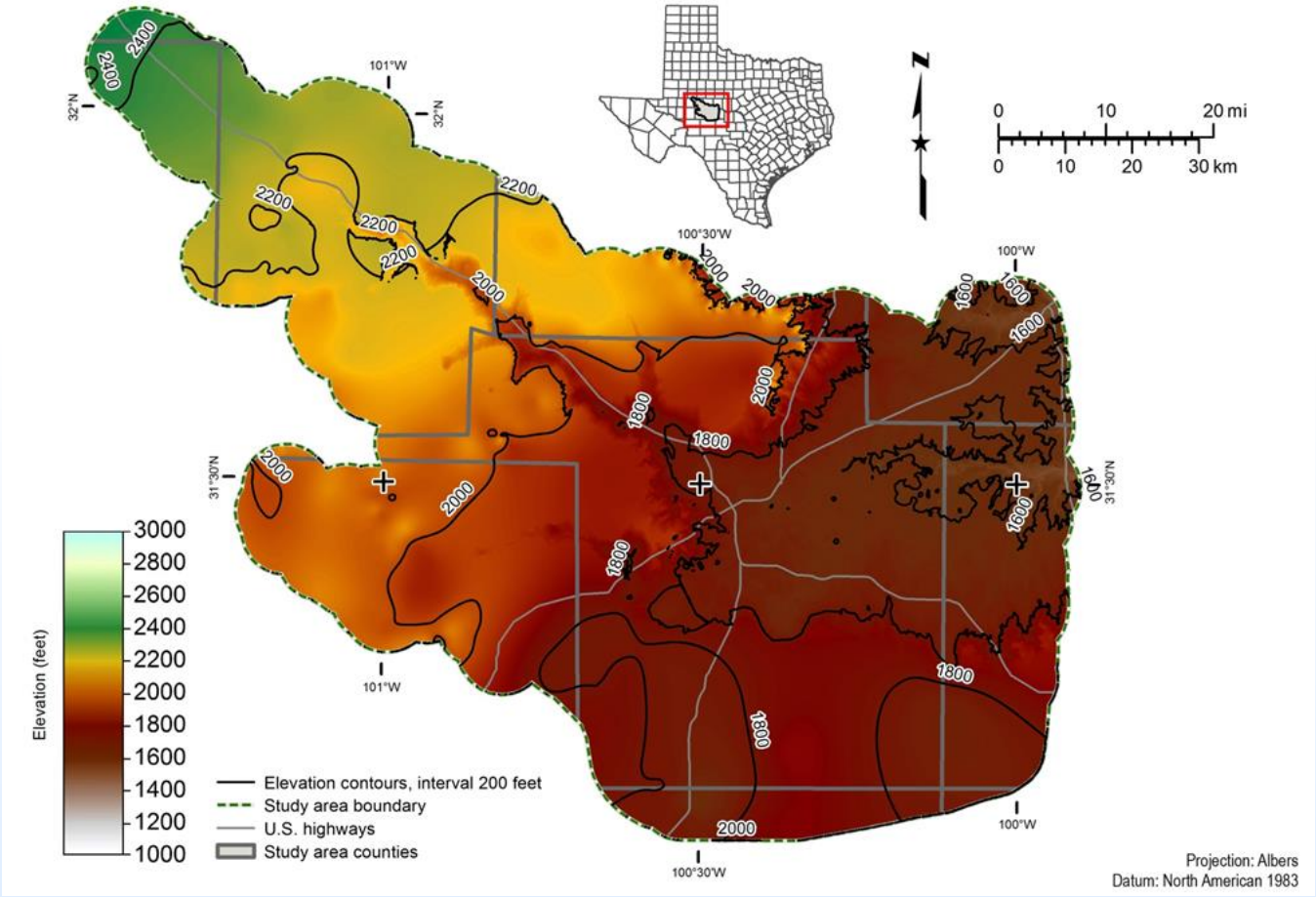
Salinity surfaces (2)

- Top of each zone mapped in feet depth below ground surface
- Moderately saline zone shown as example



Salinity surfaces (1)

- Top of each zone mapped in feet of elevation above mean sea level
- Moderately saline zone shown as example



Bulk Volume

- Total formation volume available for water storage
- Ten potential water-bearing formations shown
- Volumes in millions of cubic feet
- Fresh water isolated to Quaternary and Neogene sediments
- Volumes based on three-dimensional intersection of formation surfaces with salinity surfaces

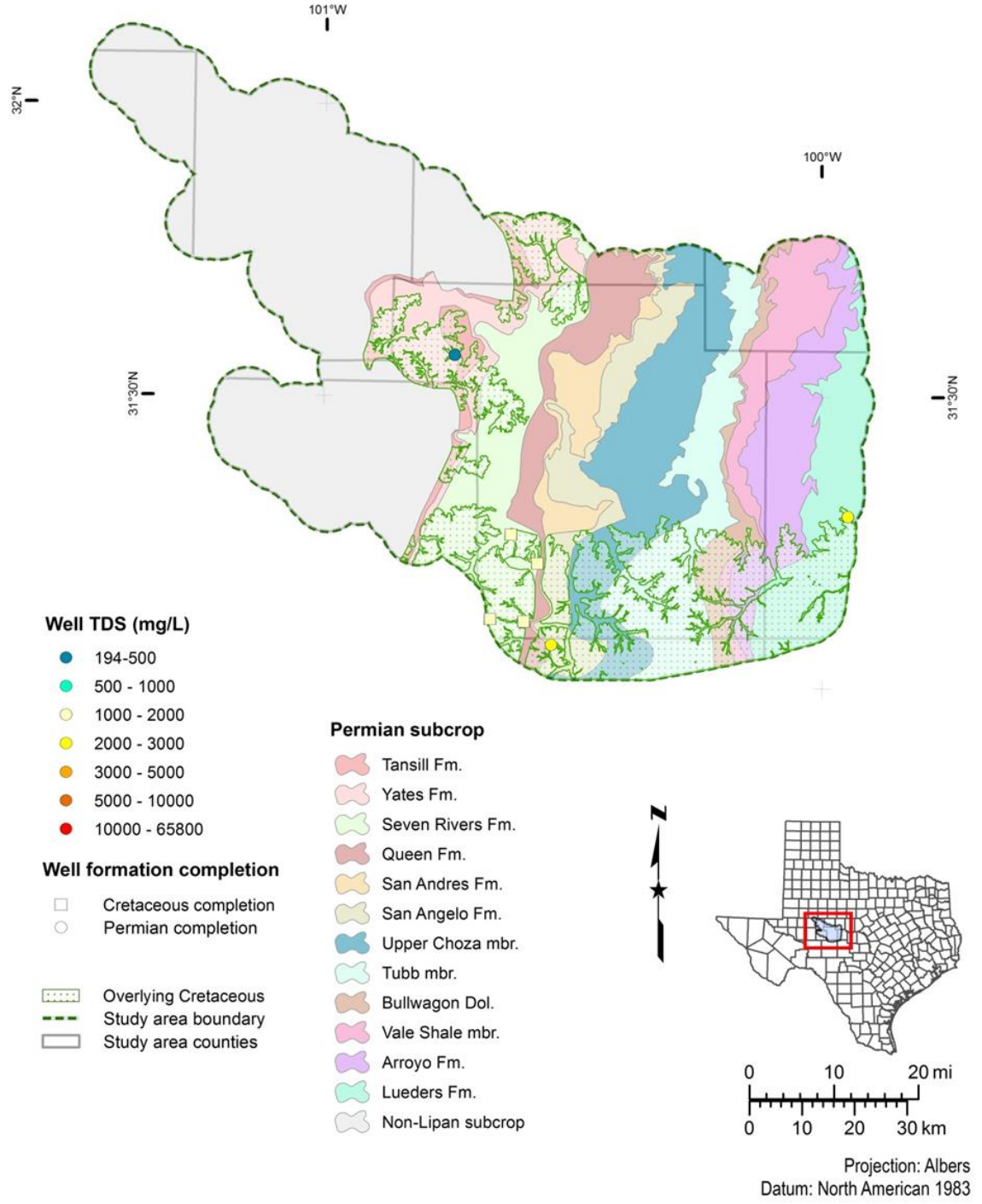
Formation	Fresh total	Fresh saturated	Slightly saline total	Slightly saline saturated	Moderately saline
Lueders Formation	0	0	1,201,942	944,447	4,073,862
Arroyo Formation	0	0	747,114	449,598	1,962,219
Bullwagon Dolomite	0	0	289,492	208,596	440,634
Tubb member	0	0	787,211	527,067	1,391,130
Upper Choza member	0	0	955,461	427,797	1,341,568
San Angelo Formation	0	0	395,581	157,029	833,100
Queen Formation	0	0	123,428	122,300	727,997
Seven Rivers Formation	0	0	1,005,388	678,368	2,192,383
Yates Formation	0	0	507,209	354,141	1,026,302
Dockum Group	0	0	2,883,943	2,027,727	3,139,185
Quaternary and Neogene Sediments	1,029,090	149,591	0	0	0

Groundwater Volume

- Top of saturated volumetric calculation is historic static water level
  - Derived from 167 wells with 14,755 records taken since January 2001
- Specific yield (volume water per bulk volume) applied (from GAM)
  - 0.05 applied to fresh and slightly saline volumes
  - 0.005 applied to moderately saline volumes
- Groundwater volumes in acre-feet
  - Very saline and brine groundwater could not be mapped
  - Because of insufficient water samples from deeper zones and the apparent failure of the method to calculate TDS from resistivity logs in consolidated Permian formations

Formation	Fresh	Slightly saline	Moderately saline
Lueders Formation	0	1,084,079	467,616
Arroyo Formation	0	516,069	225,232
Bullwagon Dolomite	0	239,435	50,578
Tubb member	0	604,992	159,680
Upper Choza member	0	491,044	153,991
San Angelo Formation	0	180,245	95,627
Queen Formation	0	140,381	83,563
Seven Rivers Formation	0	778,661	251,652
Yates Formation	0	406,499	117,804
Quaternary and Neogene sediments	171,707	0	0
Total volume	171,707	4,441,405	1,605,743

Cretaceous Overlay



- Significant area overlain by Cretaceous
  - Small percentage in the overlay area penetrate the Permian units
  - Only three of 137 wells with water quality data
  - TDS concentrations range from 384 to 2,848 mg/L

House Bill 30

- 84th Texas Legislature passed bill in 2015

TWDB directed to:

- Identify and designate local or regional brackish groundwater production zones in areas of the state with moderate to high availability and productivity of brackish groundwater that can be used to reduce the use of fresh groundwater
- Determine amount of brackish groundwater that the zone is capable of producing over 30- and 50-year period without causing a significant impact to water availability or water quality
- Recommend reasonable monitoring to observe the effects of brackish groundwater production within the zone
- Lipan Aquifer meets two exemption criteria
  - No significant hydrogeologic barrier between brackish and overlying fresh water groundwater resources
  - Significant current use of brackish water for municipal, domestic, or agricultural use

Conclusions

- Volumes of groundwater by salinity zones
  - Not all can be economically or technically recovered
  - 0.17 million acre-feet of fresh groundwater
  - 4.44 million acre-feet of slightly saline groundwater
  - 1.61 million acre-feet of moderately saline groundwater
  - Much of water-bearing Permian units overlain by Cretaceous
    - Little evidence of groundwater development in this zone
    - May present an opportunity for brackish groundwater development
- No brackish groundwater production zones identified per House Bill 30
- All data to be made public once report is published
  - Collected well data and geophysical logs
  - Calculated parameters
  - GIS files
  - Supporting database (Microsoft Access 2007 format)

Future Improvements

- Additional well information would allow for improved aquifer characterization
  - Aquifer test and water quality from all salinity zones
  - More refined groundwater modeling
    - Utilize more detail aquifer structure and water quality information
    - Better evaluate aquifer response to potential future brackish groundwater development

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