# Lipan Aquifer
# Brackish Groundwater Study

# WTGS 2017 Symposium

*September 27, 2017*

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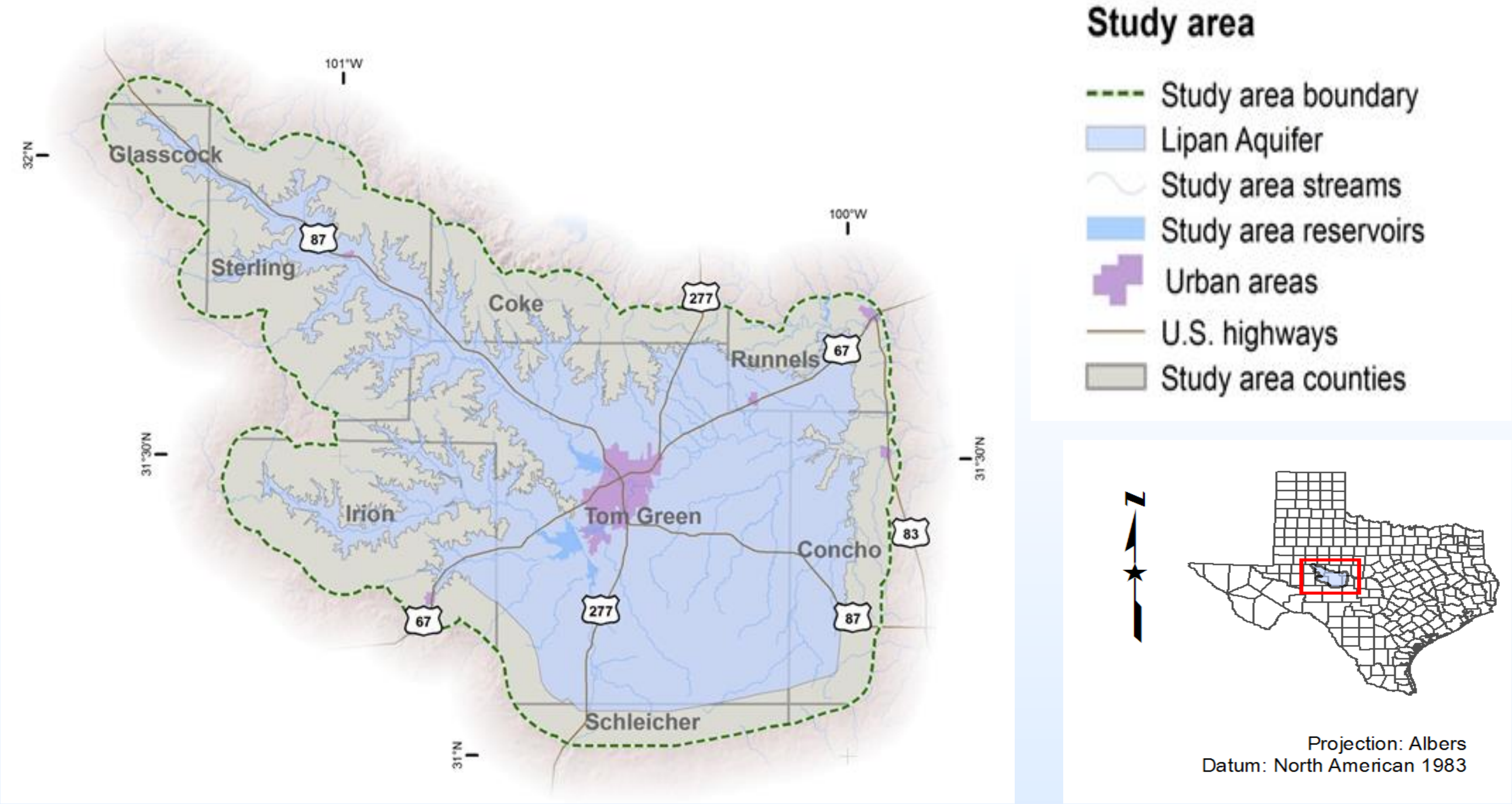
*Innovative Water Technologies*

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.

# 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 (between Fresh and Slightly Saline)

← Texas Aquifers Mapped Limit (between Slightly Saline and Moderately Saline)

← Seawater (between Very Saline and Brine)

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

# Geophysical logging tools

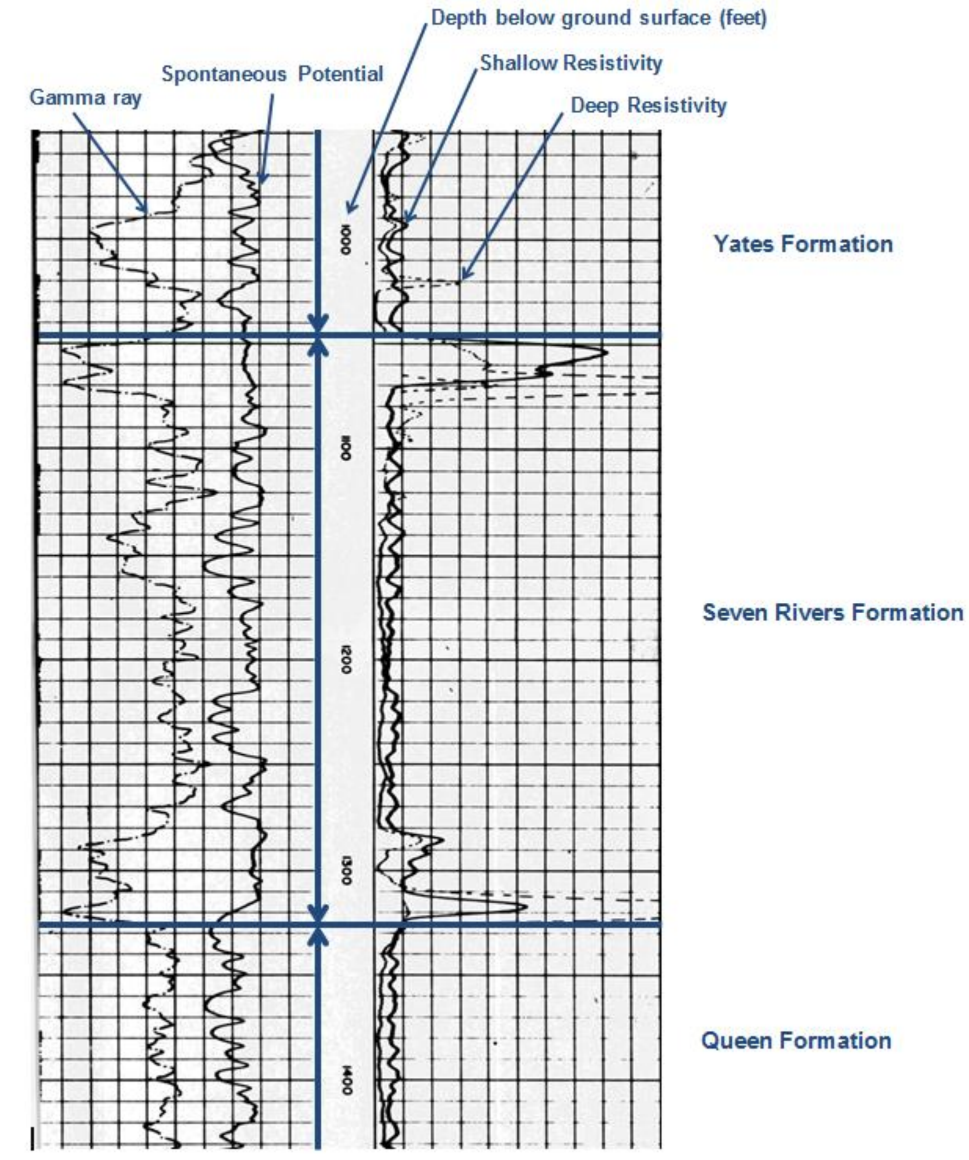
- Resistivity tools
  - Measures the resistivity of a formation by passing current between electrodes
  - Wider electrode spacing increases depth of formation investigation
  - Can be used to determine formation water resistivity
    - Differences between shallow and deep resistivity readings
    - Proper 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

# Stratigraphy (1)

- Total of 1,046 wells with 5,424 picks used for formation mapping
- Fifteen Permian units mapped
- Ten potential water-bearing formations identified
- Other formations mapped
  - One Triassic formation (Dockum Group)
  - One Cretaceous formation (Trinity Group)
  - Referenced only as applicable to Lipan Aquifer as defined in report
  - To be studied in future reports

# Stratigraphy (2)

- One example of many
  - BRACS well ID 37978



# Stratigraphy (3)

| Geologic period | Epoch and age (millions of years before present) | Regional series | Geologic group | Stratigraphic unit: Midland Basin | Stratigraphic unit: Eastern Shelf |
|---|---|---|---|---|---|
| Quaternary | 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<br>Trinity | Fredericksburg<br>Trinity Sand | Edwards Limestone<br>Fort Terrett<br>Antlers Sand |
| | | | | | *unconformity* |
| Triassic | Upper (237.0-201.3) | | Dockum | Dockum | Dockum |
| | | | | | *unconformity* |
| Permian | Lopingian (260-252) | Ochoan | | Dewey Lake<br>Rustler<br>Salado<br>Castille | Dewey Lake<br>Rustler<br>Salado |
| | | | | | *unconformity* |
| | Guadalupian (272-260) | Guadalupian | Whitehorse | Tansill<br>Yates<br>Seven Rivers<br>Queen<br>Grayburg | Tansill<br>Yates<br>Seven Rivers<br>Queen<br>Grayburg |
| | | | Pease River | San Andres | San Andres (Blaine)<br>San Angelo |
| | | | | | *unconformity* |
| | Cisuralian (299-272) | Leonardian | Clear Fork | Clear Fork *undifferentiated* | Choza: Upper Choza<br>Tubb member<br>Vale: Bullwagon Dolomite<br>Vale shale<br>Arroyo: *Standpipe Limestone*<br>Arroyo |
| | | | Wichita - Albany | Wichita *undifferentiated* | Lueders |

Lipan Aquifer units

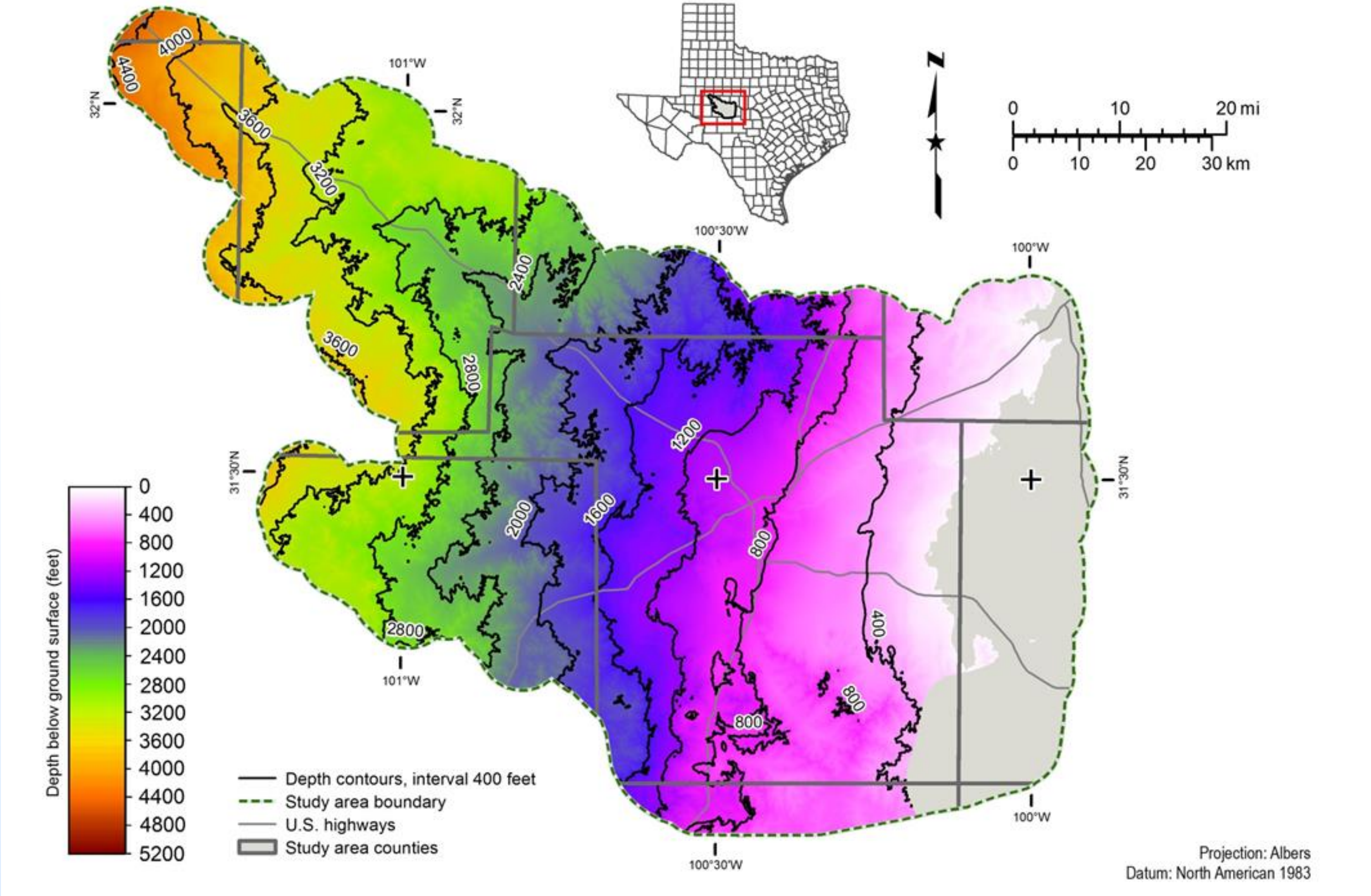
- Geological units that produce water in the Lipan aquifer are highlighted.
- Geologic epochs and ages as defined by the International Commission on Stratigraphy Chronostratigraphic Chart (Gradstein and others, 2012).

# Surface Maps

- Total of 50 maps of formation surfaces generated
  - Ground elevation
  - Formation top depth below ground surface
  - Formation top elevation relative to mean sea level
  - Isochore (vertical formation thickness)
  - Arroyo Formation examples shown in following slides
- Total of five salinity surfaces generated
  - Top of moderately saline groundwater zone shown later in the presentation

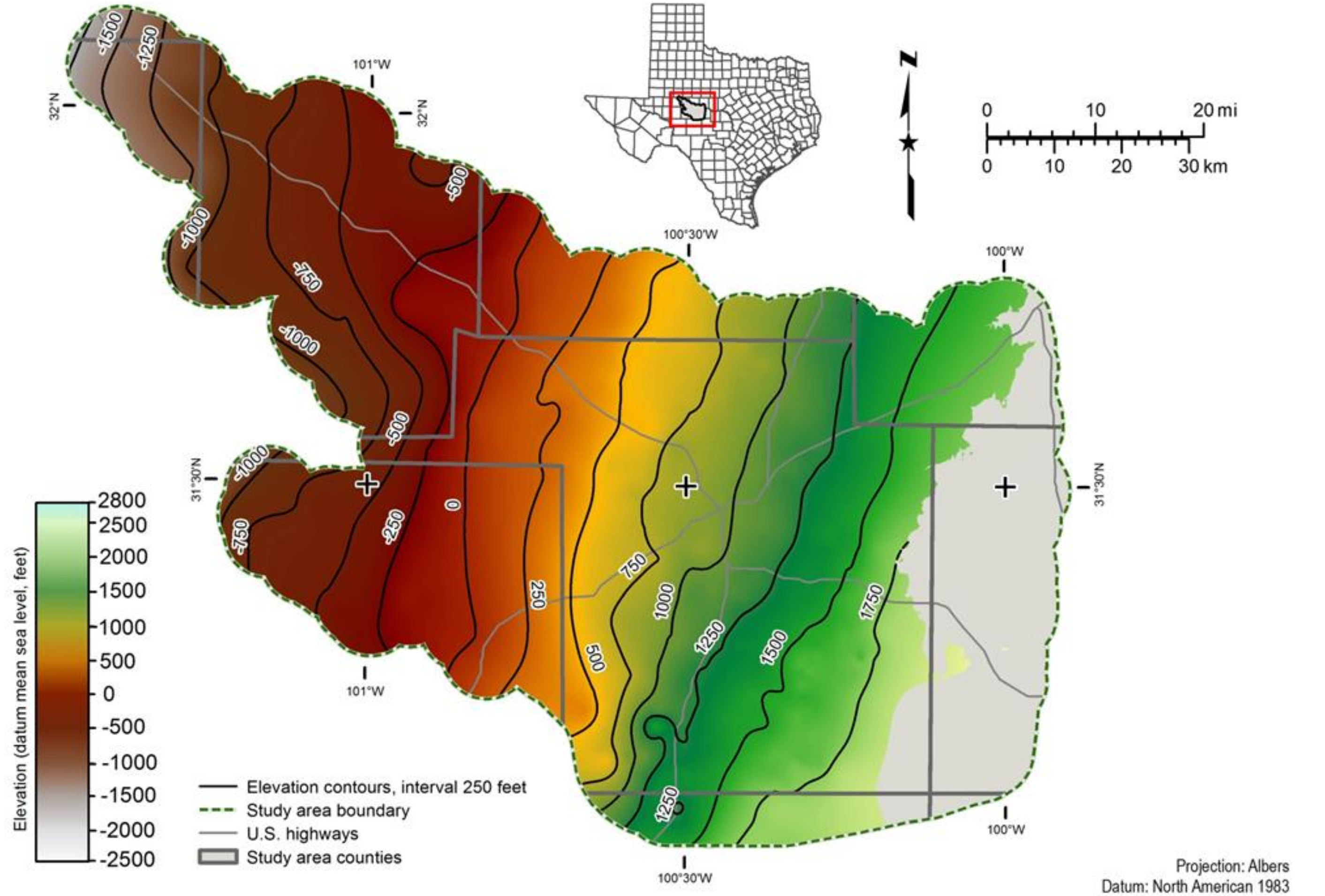
# Arroyo Formation (1)

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



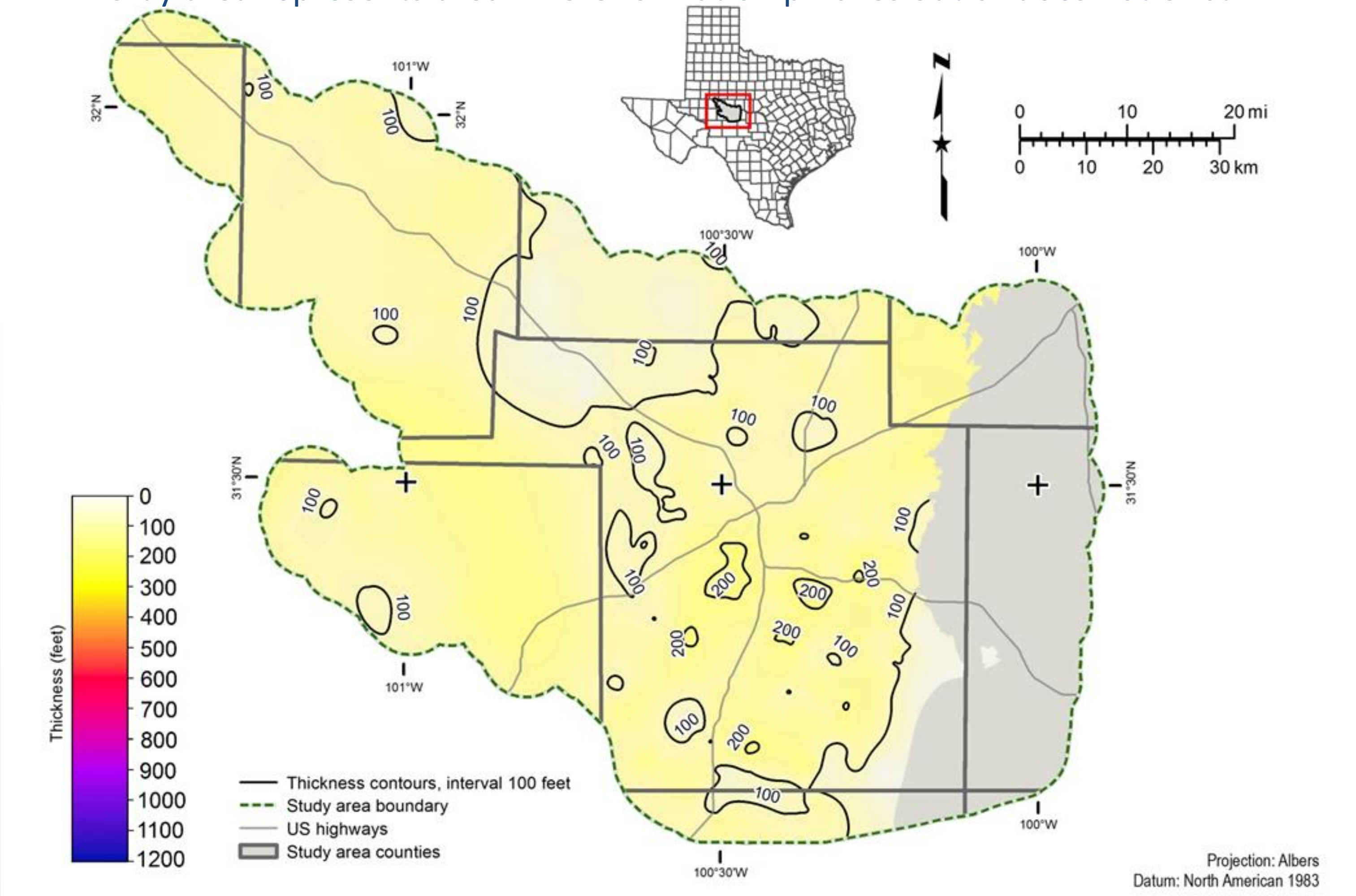
# Arroyo Formation (2)

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



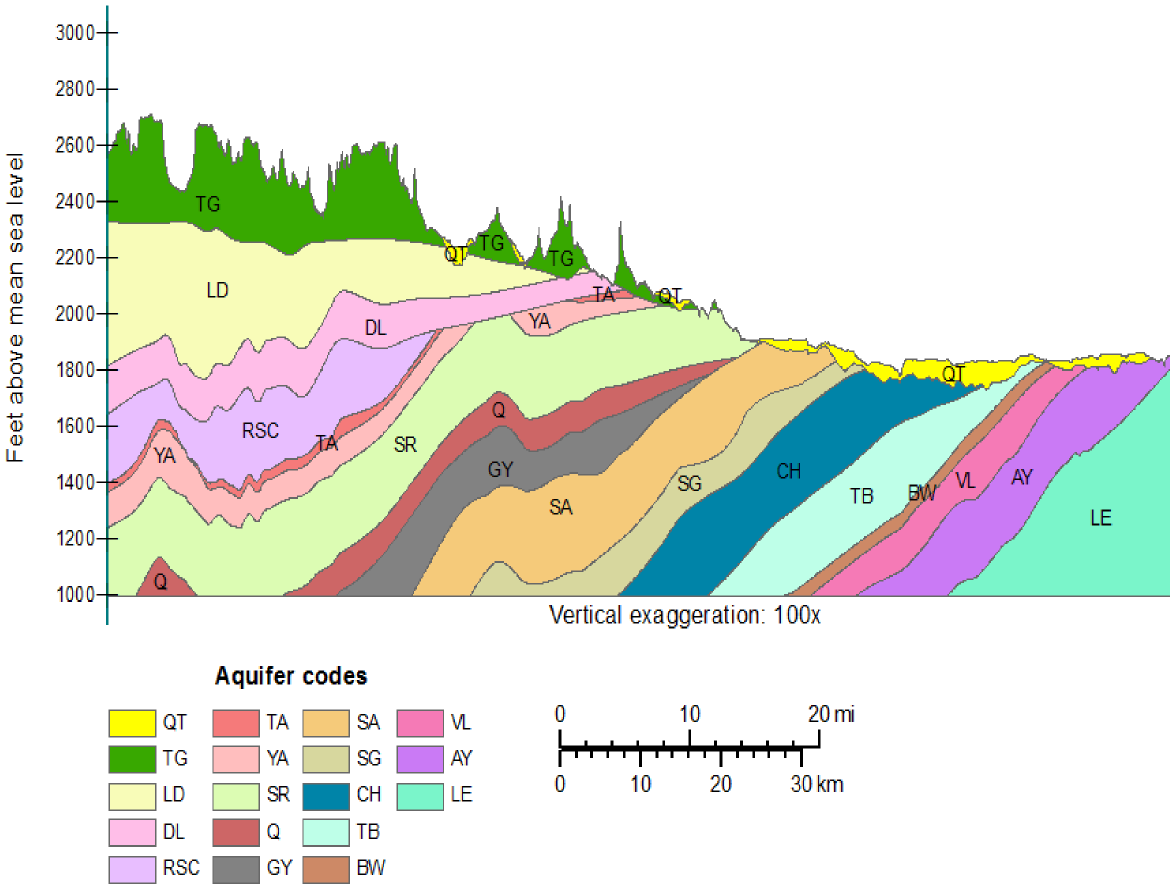
# Arroyo Formation (3)

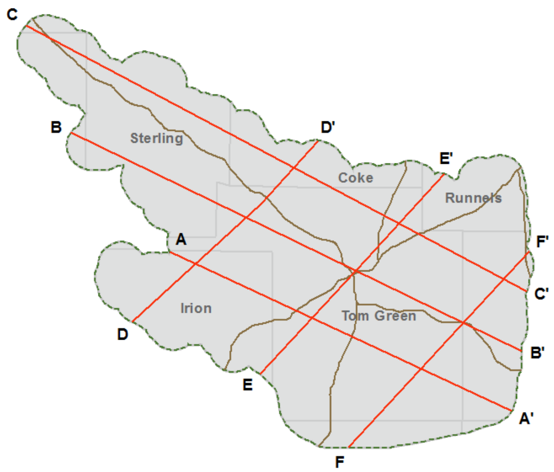
- Formation isochore
  - Vertical thickness in feet
  - Gray area represents area where formation pinches out or does not exist



# Cross-section

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

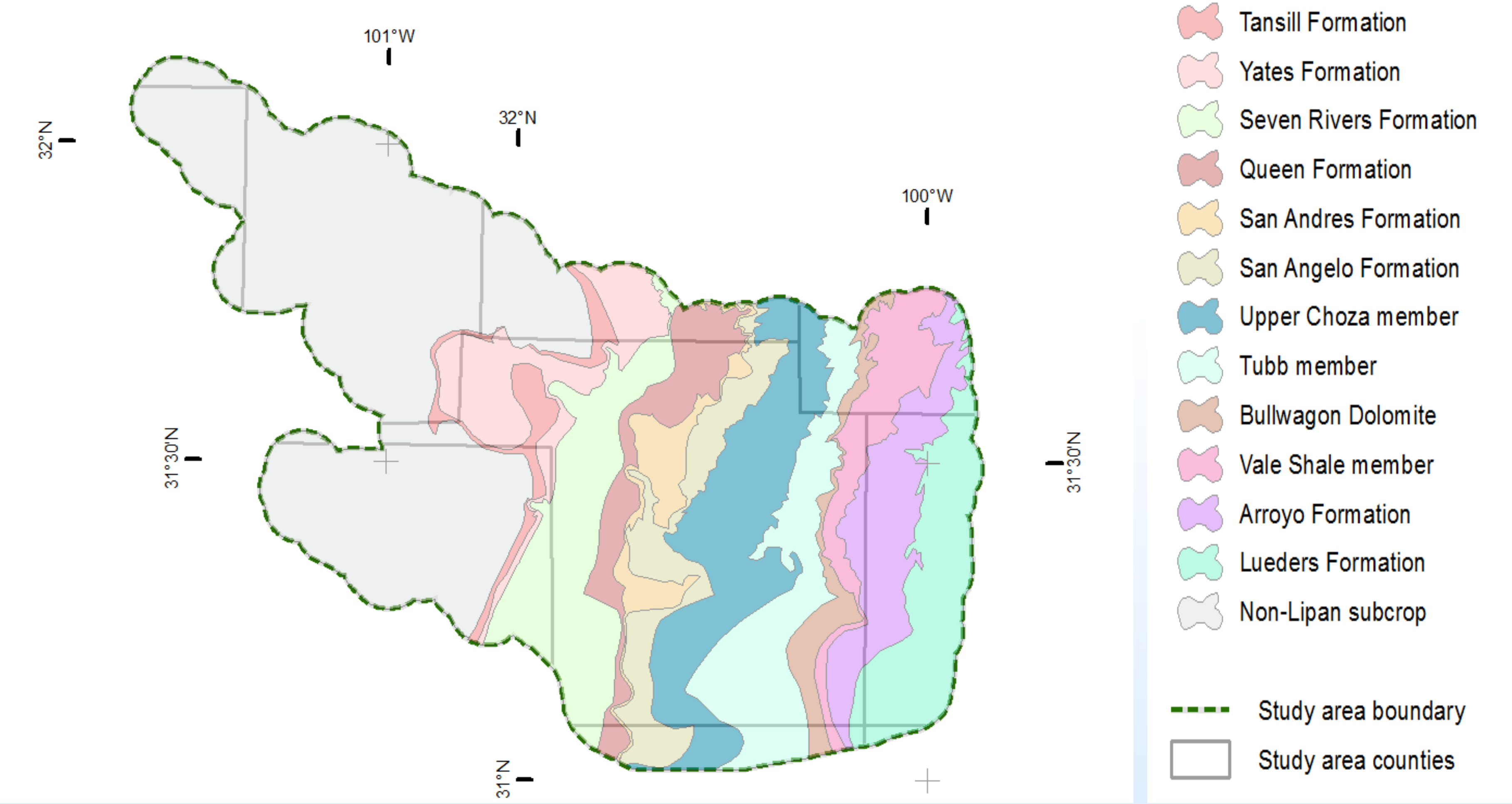


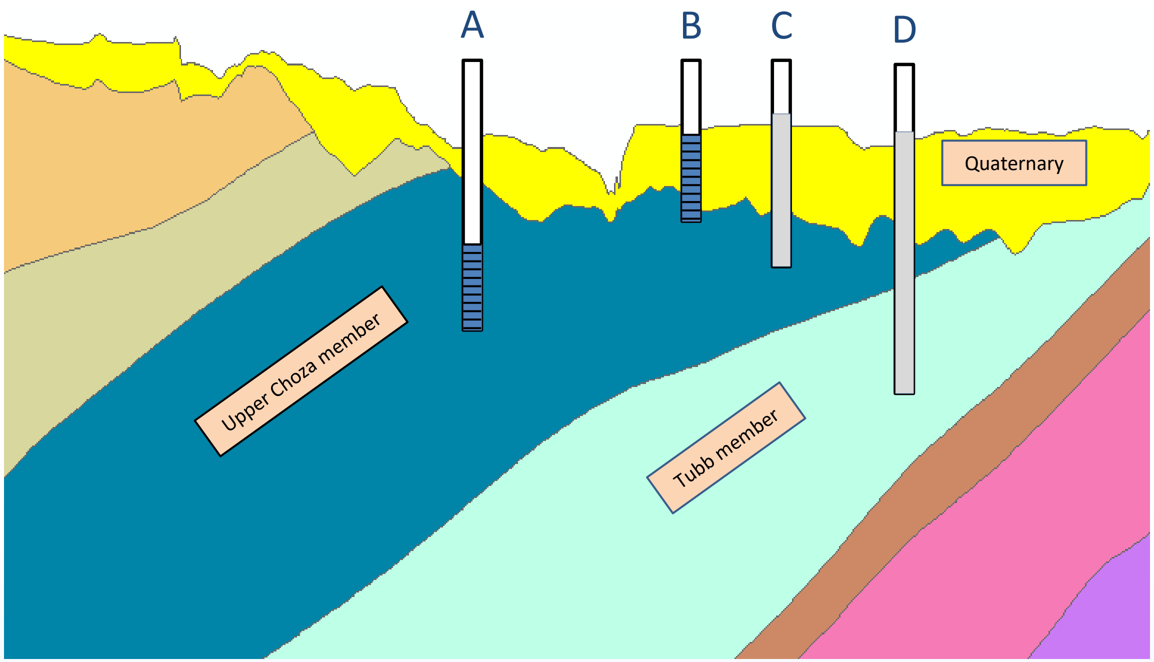

| Aquifer code | Stratigraphic unit |
|---|---|
| QT | Quaternary and Neogene sediment |
| TG | Trinity Group |
| LD | Dockum Group |
| DL | Dewey Lake Formation |
| RSC | Rustler-Salado formations |
| TA | Tansill Formation |
| YA | Yates Formation |
| SR | Seven Rivers Formation |
| Q | Queen Formation |
| 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 expression if overlying units removed



# 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 |

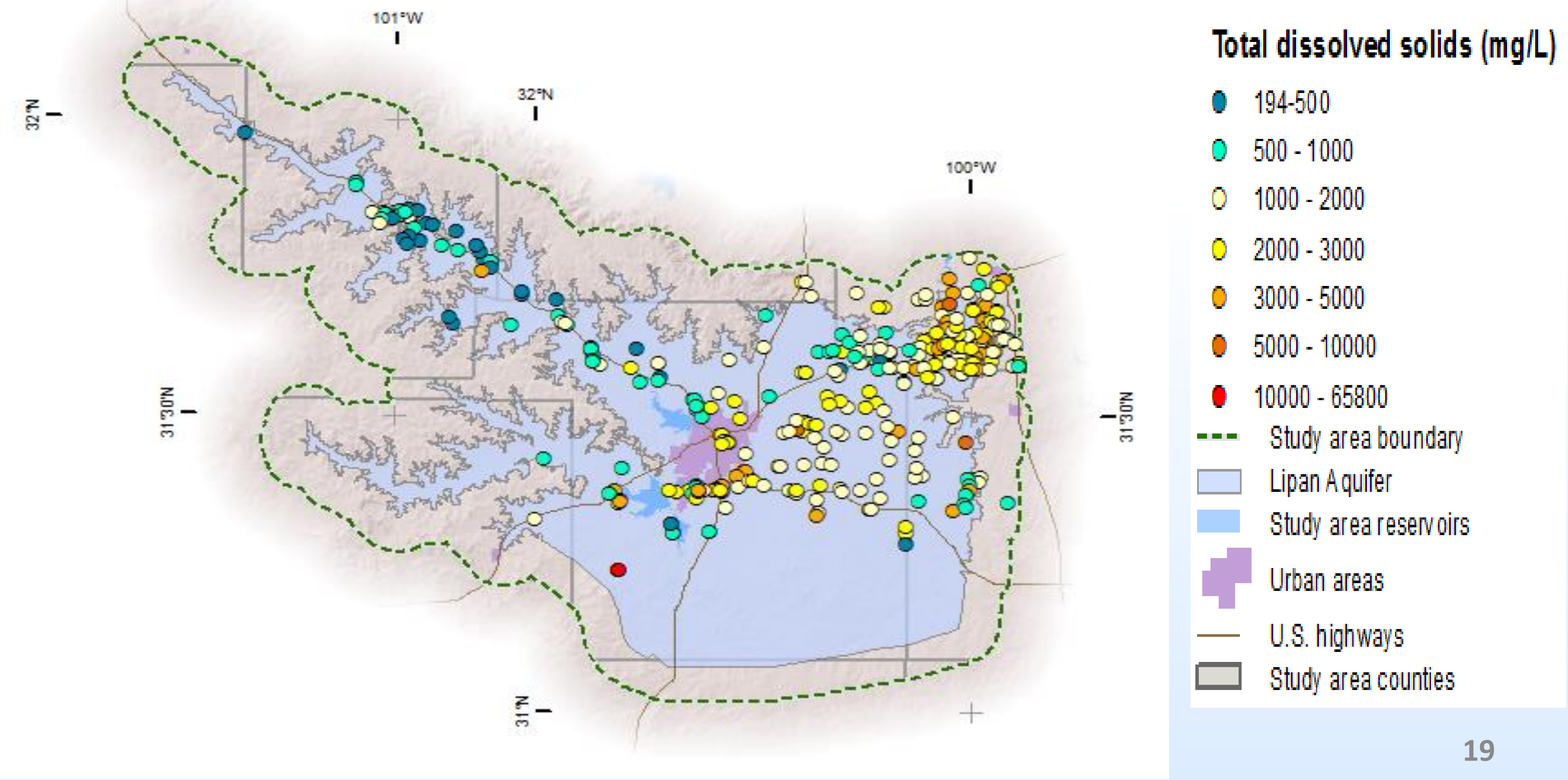
# Water Quality

- 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

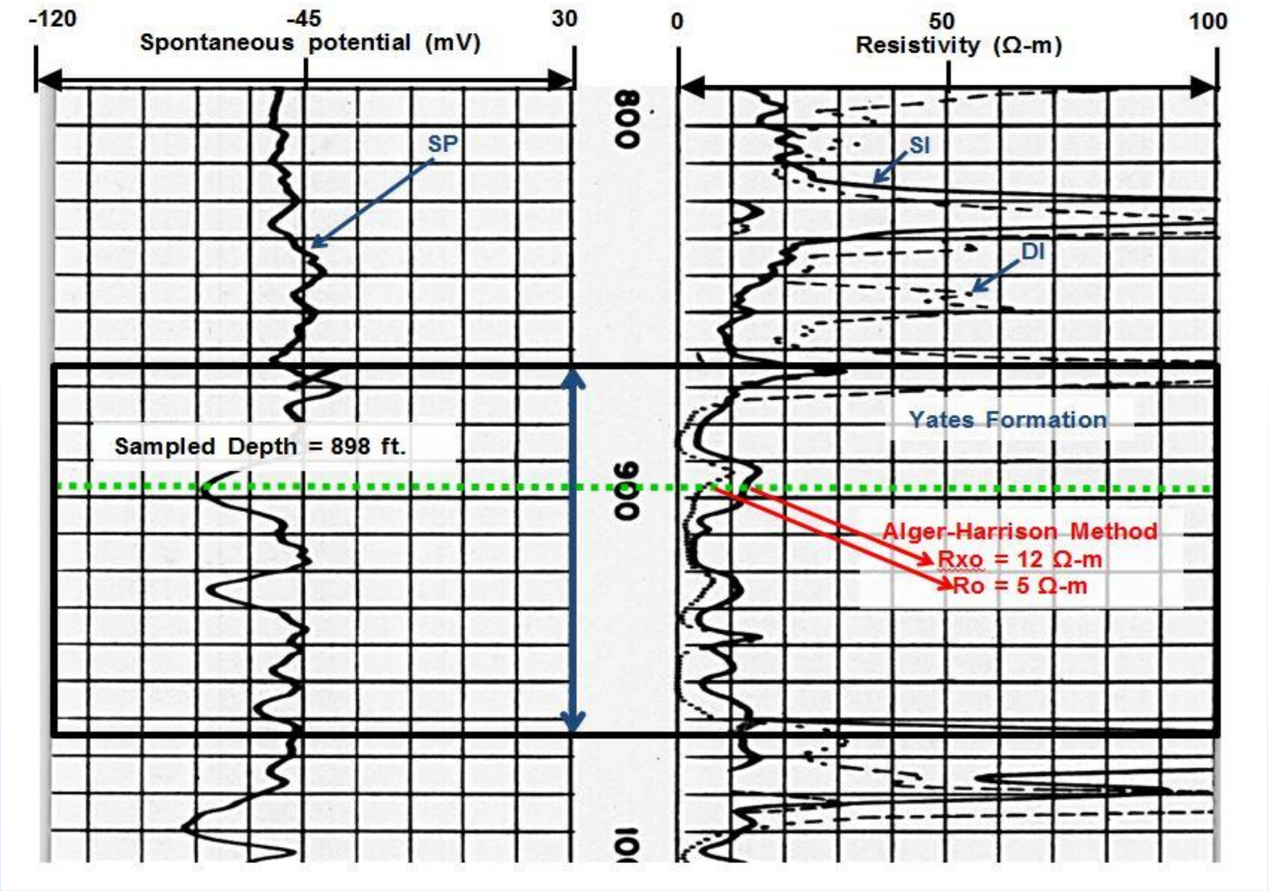


# Salinity calculation

- 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 resistivities correlate to formation water resistivity
  - Determined as most appropriate for study area geology
  - 179 wells evaluated resulting in 771 calculated TDS values

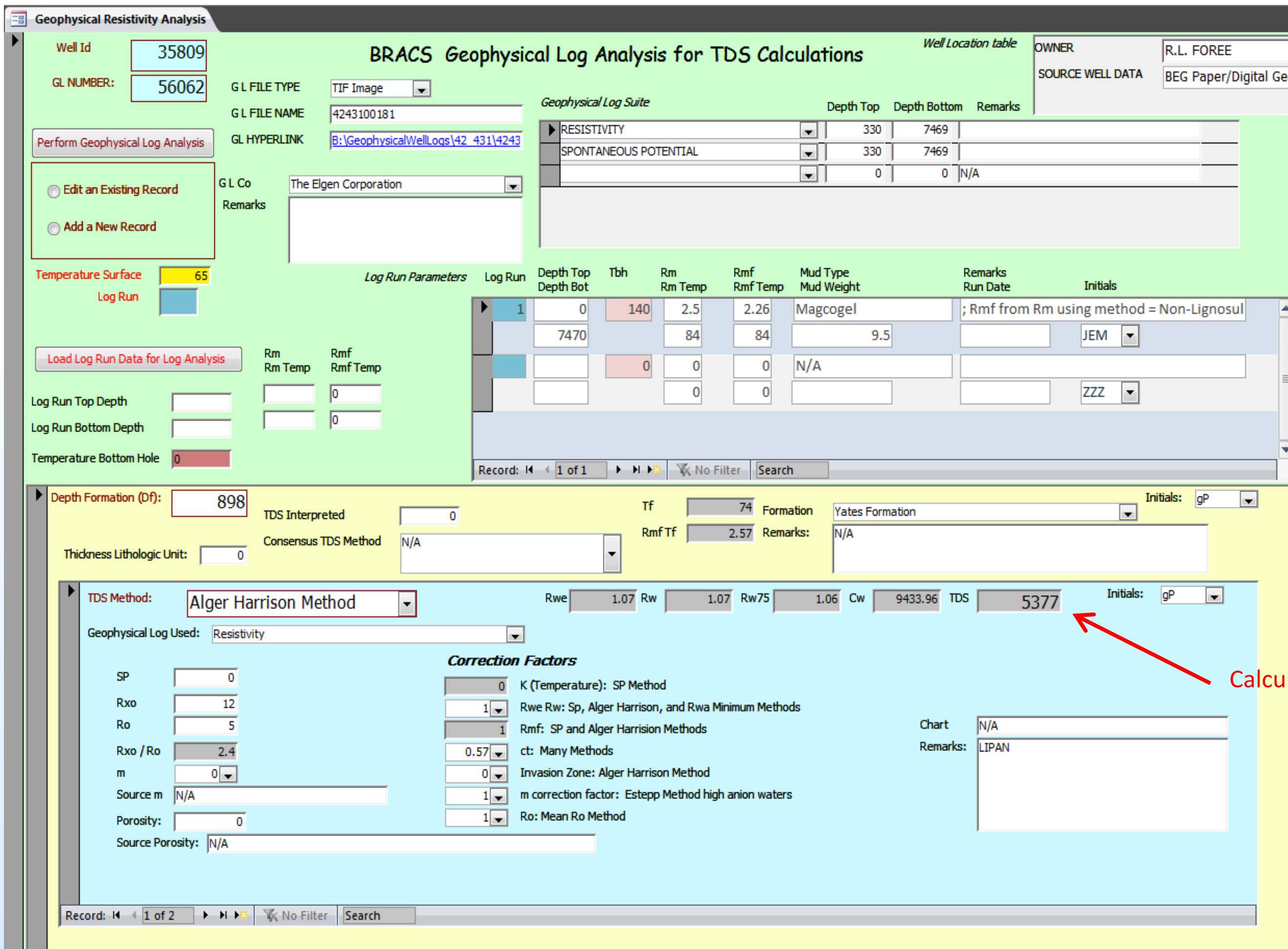
# Alger-Harrison Method

- 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, Rm, Rmf, etc.) on log header (not shown)



# BRACS data processing

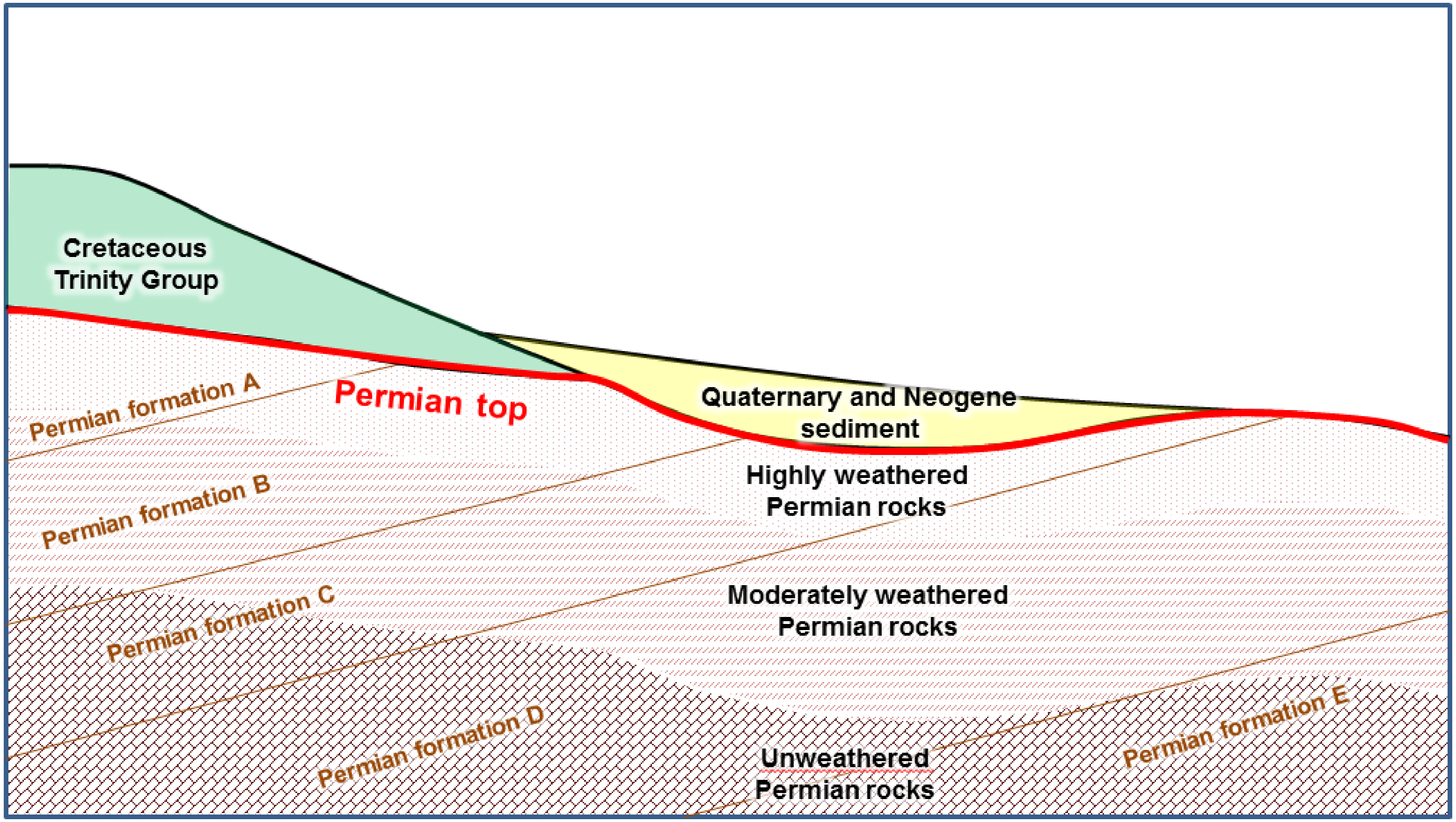
- Form entry for BRACS well identification number 35809
  - Information from log entered into BRACS database form for processing
  - Calculated interim values in gray background
  - Calculated TDS value of 5377 mg/L




Calculated TDS

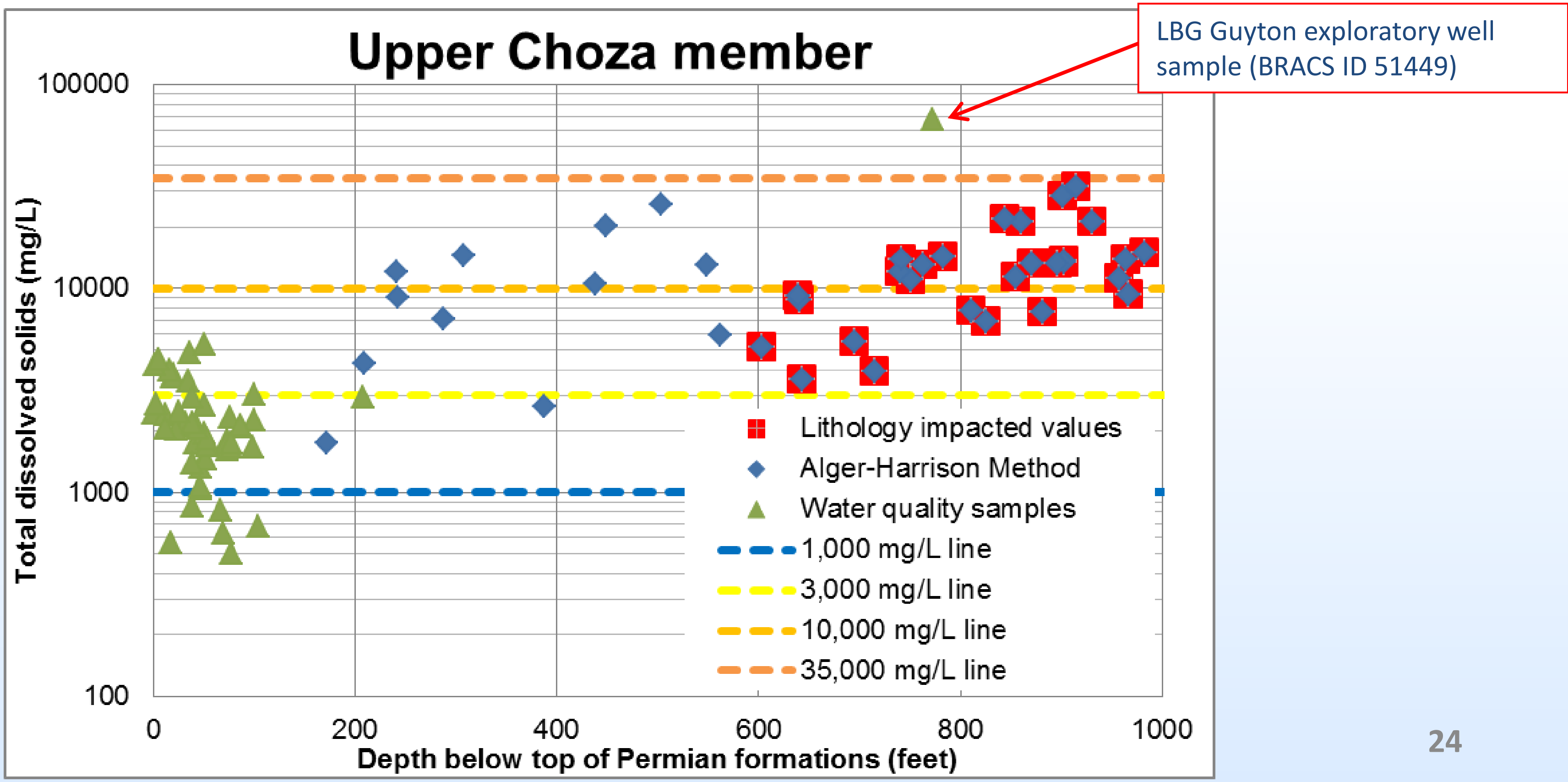
# Formation Schematic

- Top of Permian formations interface (red line) is significant
- Used as basis for salinity analysis
- Weathering prior to younger unit deposition
- Weathered rock differs from deeper formation zones



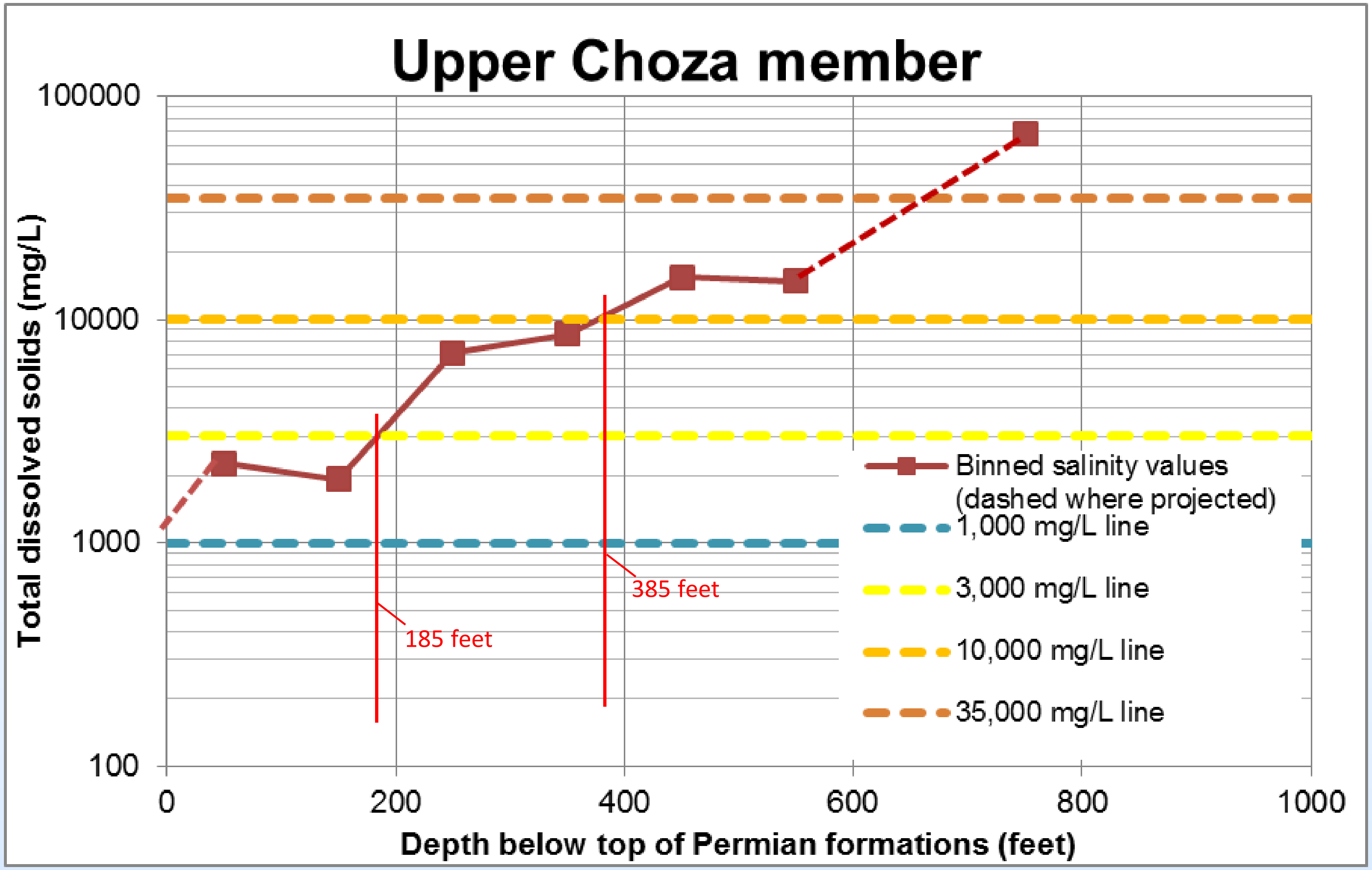
# Salinity vs. depth plots

- 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 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 incremental
  - Effort to classify salinity trends with depth
  - Depth below Permian top used rather than depth below surface
  - Upper Choza member shown as example



# Salinity zone determination

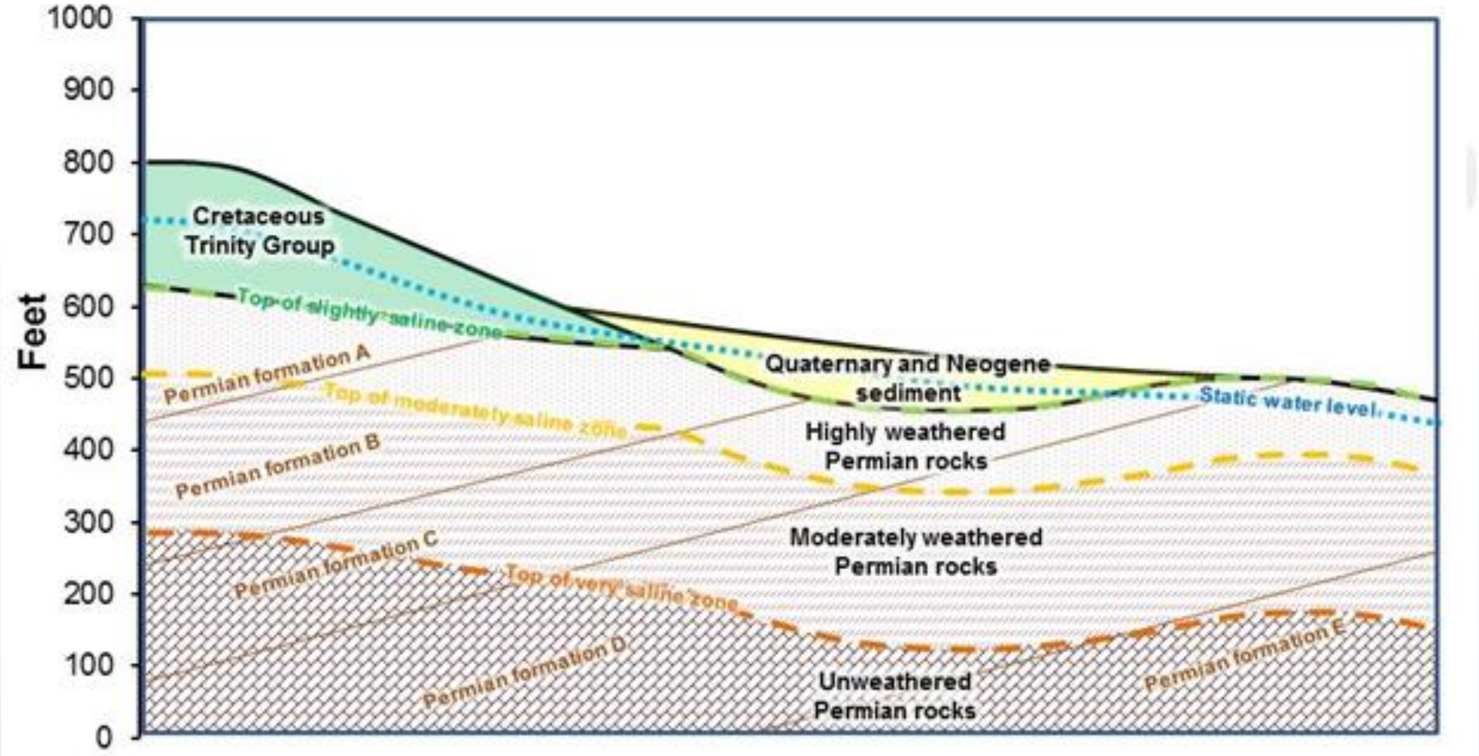
- Performed for nine Permian potential water-bearing formations
  - Bin cutoff values tabulated for all evaluated formations
  - Cutoff values averaged across formations to determine regional relationship
  - Resulting surfaces mapped and used for groundwater volume calculation
  - Depth below ground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

| | Depth below ground (feet) | | Depth below top of Permian (feet) | |
|---|---|---|---|---|
| **Geological formation** | **3,000 mg/L** | **10,000 mg/L** | **3,000 mg/L** | **10,000 mg/L** |
| Yates Formation | 190 | 390 | 110 | 215 |
| Seven Rivers Formation | 150 | 500 | 60 | 315 |
| Queen Formation | 0 | 660 | 0 | 390 |
| San Angelo Formation | 160 | 370 | 205 | 445 |
| Upper Choza member | 190 | 310 | 185 | 385 |
| Tubb member | 270 | 330 | 150 | 425 |
| Bullwagon Dolomite | 190 | 240 | 115 | 290 |
| Arroyo Formation | 180 | 240 | 80 | 260 |
| Lueders Formation | 150 | 220 | 40 | 225 |
| **Average** | **164** | **362** | **105** | **328** |

Cutoff values from previous slide

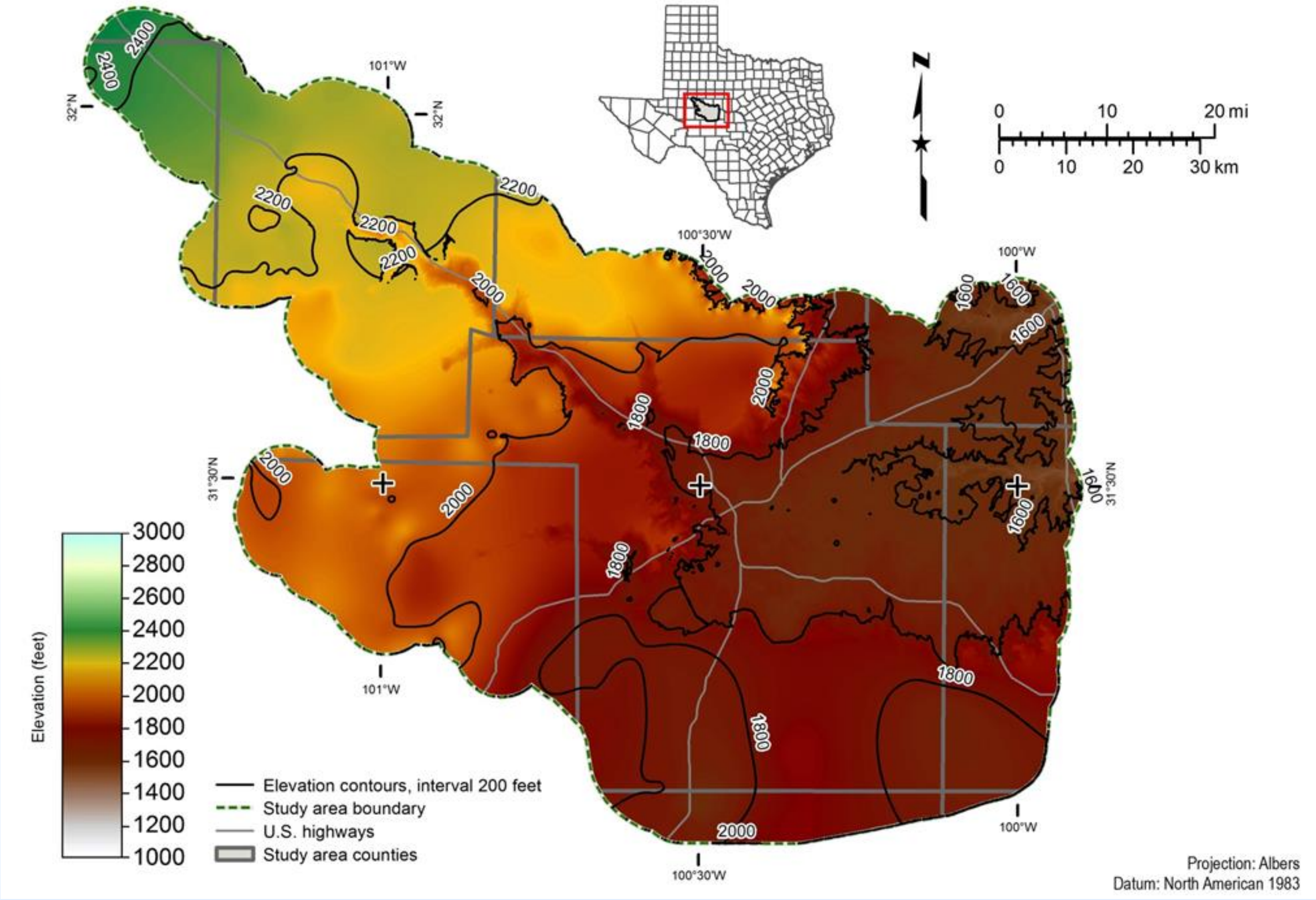
# Salinity zone schematic

- Water storage top is historical static water level
- Fresh water in 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



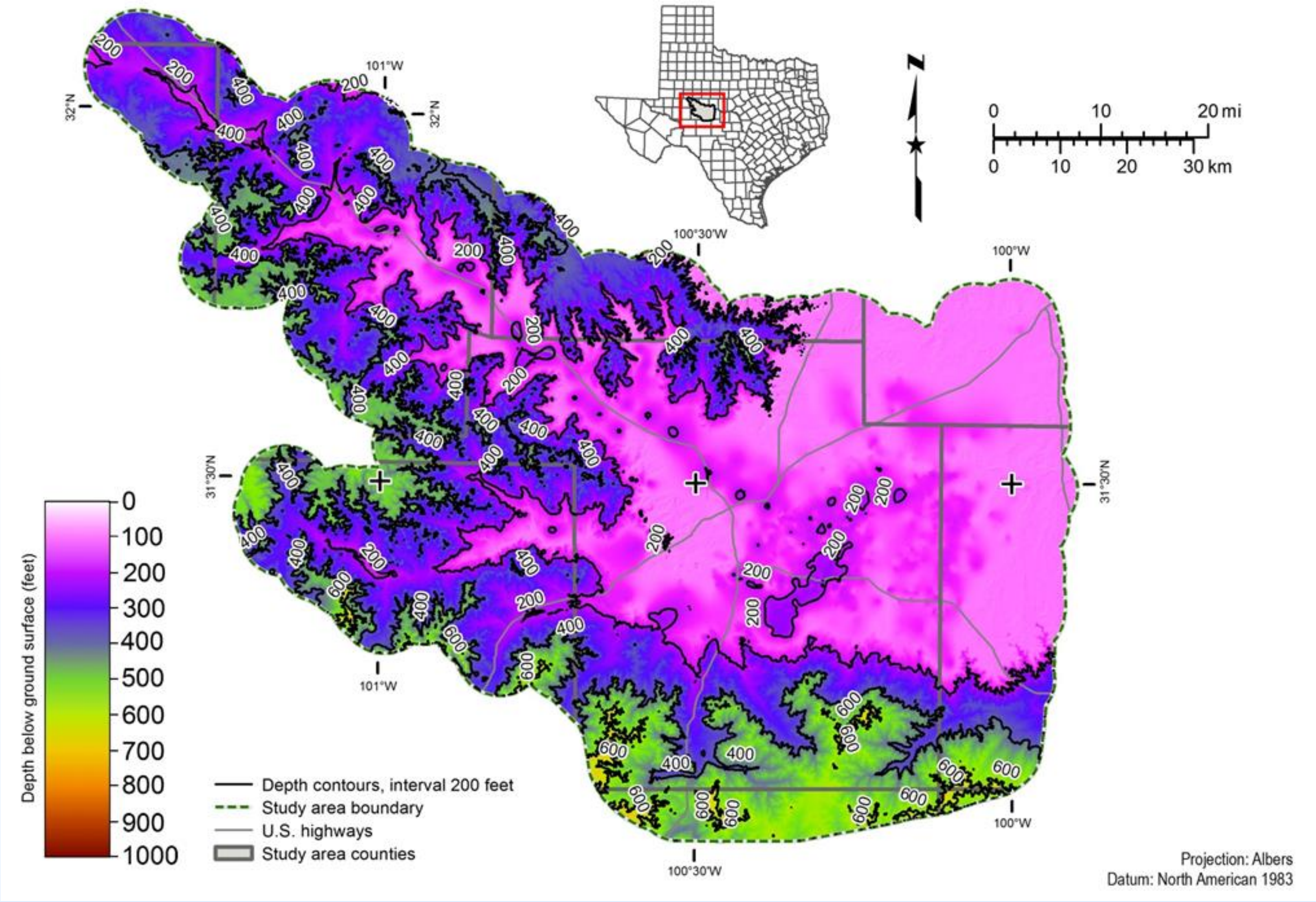
# Salinity surfaces (1)

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



# Salinity surfaces (2)

- Top of each zone mapped in feet depth below ground surface
- 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 |

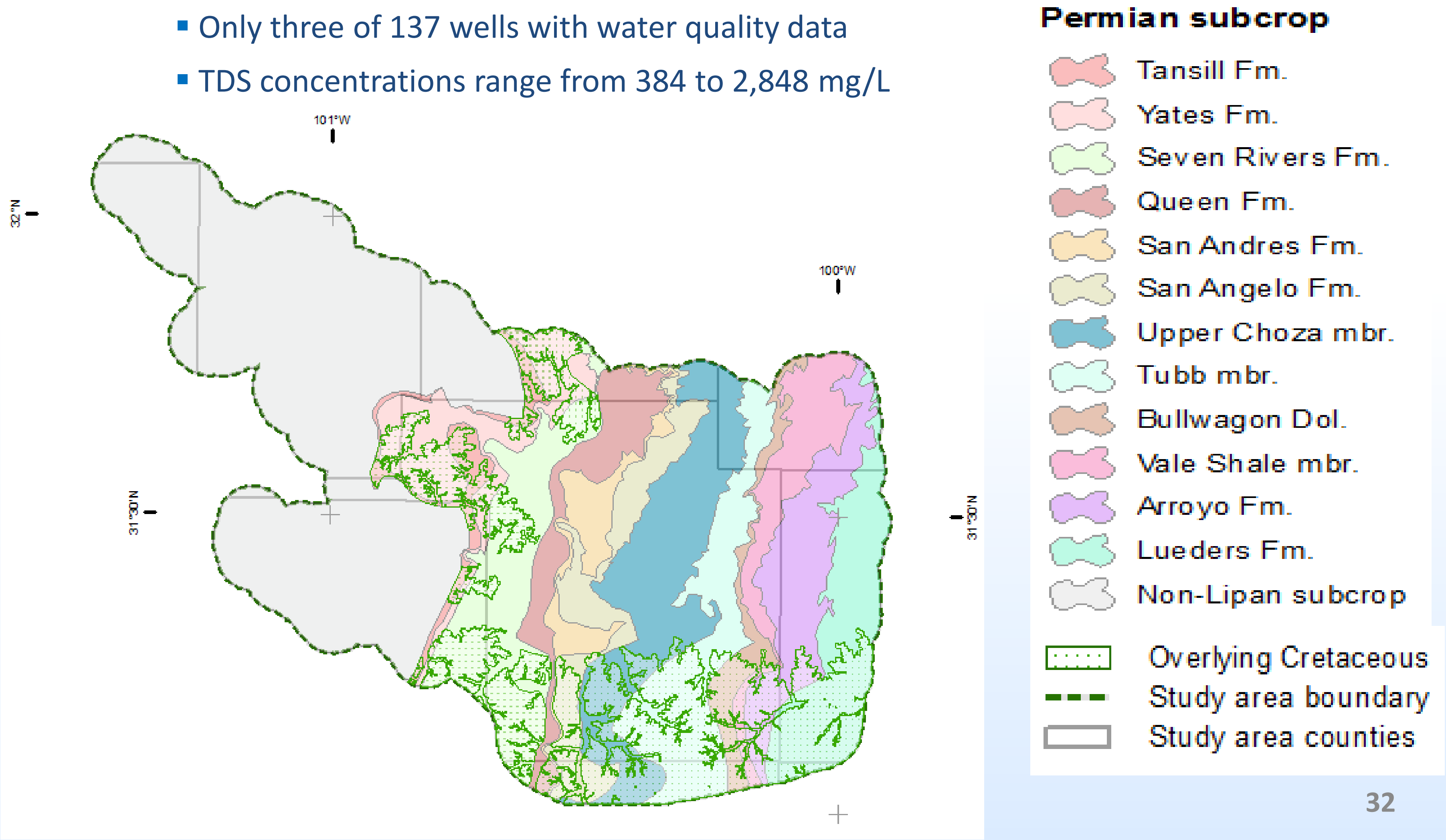
# Groundwater Volume

- 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
  - 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 were not mapped
  - Due to lack of data and lithology impacted effects on salinity calculations

| 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



# Brackish Groundwater Production Zones

- 84th Texas Legislature passed House Bill 30 in 2015

TWDB is directed to:

  - Identify and designate brackish groundwater production zones in all major and minor aquifers.
  - Determine the volumes of groundwater that a brackish groundwater production zone can produce over 30-year and 50-year periods without causing significant impact to water availability or water quality.
  - Work with groundwater conservation districts and stakeholders.
  - Make recommendations on reasonable monitoring to observe the effects of brackish groundwater production within the zone.
  - Provide a summary of brackish groundwater production zone designations in the biennial report due December 1 of each even-numbered year.
  - By December 1, 2016, identify and designate brackish groundwater production zones for four specified aquifers.
  - By December 1, 2022, identify and designate brackish groundwater production zones for rest of the state.

# House Bill 30 exclusion areas

- House Bill 30 also excluded certain areas from designation:
  - The Edwards (Balcones Fault Zone) Aquifer located within the jurisdiction of the Edwards Aquifer Authority.
  - Areas within the boundaries of the Barton Springs-Edwards Aquifer Conservation District, the Harris-Galveston Subsidence District, and the Fort Bend Subsidence District.
  - Aquifers, subdivisions of aquifers, or geologic strata that have an average total dissolved solids concentration of more than 1,000 milligrams per liter and serve as a significant source of water supply for municipal, domestic, or agricultural purposes.
  - Geologic formations that are designated or used for wastewater injection through the use of injection or disposal wells permitted under Texas Water Code Chapter 27
- **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
    - Perhaps variable density modeling
    - To evaluate effect of slightly saline  development on higher salinity zones

Texas Water Development Board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