USING ELECTRIC LOGS TO ESTIMATE SALINITY AND RESOURCES OF FRESH AND BRACKISH GROUNDWATER

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ELECTRIC LOGS

- Borehole measurements of electrical properties versus depth
- Commonly run in both oil and gas wells and water wells
- Respond to variations in both pore-fluid composition and rock properties
- Can be used to estimate groundwater salinity where rock properties are relatively constant
- Graphically display variations in **Spontaneous Potential (SP)** and **Resistivity** with depth

LOG TYPES

SP log records relative difference in electrical potential

- Positive SP – groundwater salinity < borehole fluid salinity
- Neutral SP – groundwater salinity = borehole fluid salinity
- Negative SP – groundwater salinity > borehole fluid salinity
- **Qualitative indicator of groundwater salinity**

Resistivity log records resistance to an induced current

- High resistivity – low salinity groundwater
- Low resistivity – high salinity groundwater
- **Quantitative indicator of groundwater salinity**

Distinguishing Lithology from Groundwater salinity

- Works best in simple sand/mud sequences
- Mud and shale – neutral SP and low resistivity
- Sand and sandstone – groundwater salinity effects

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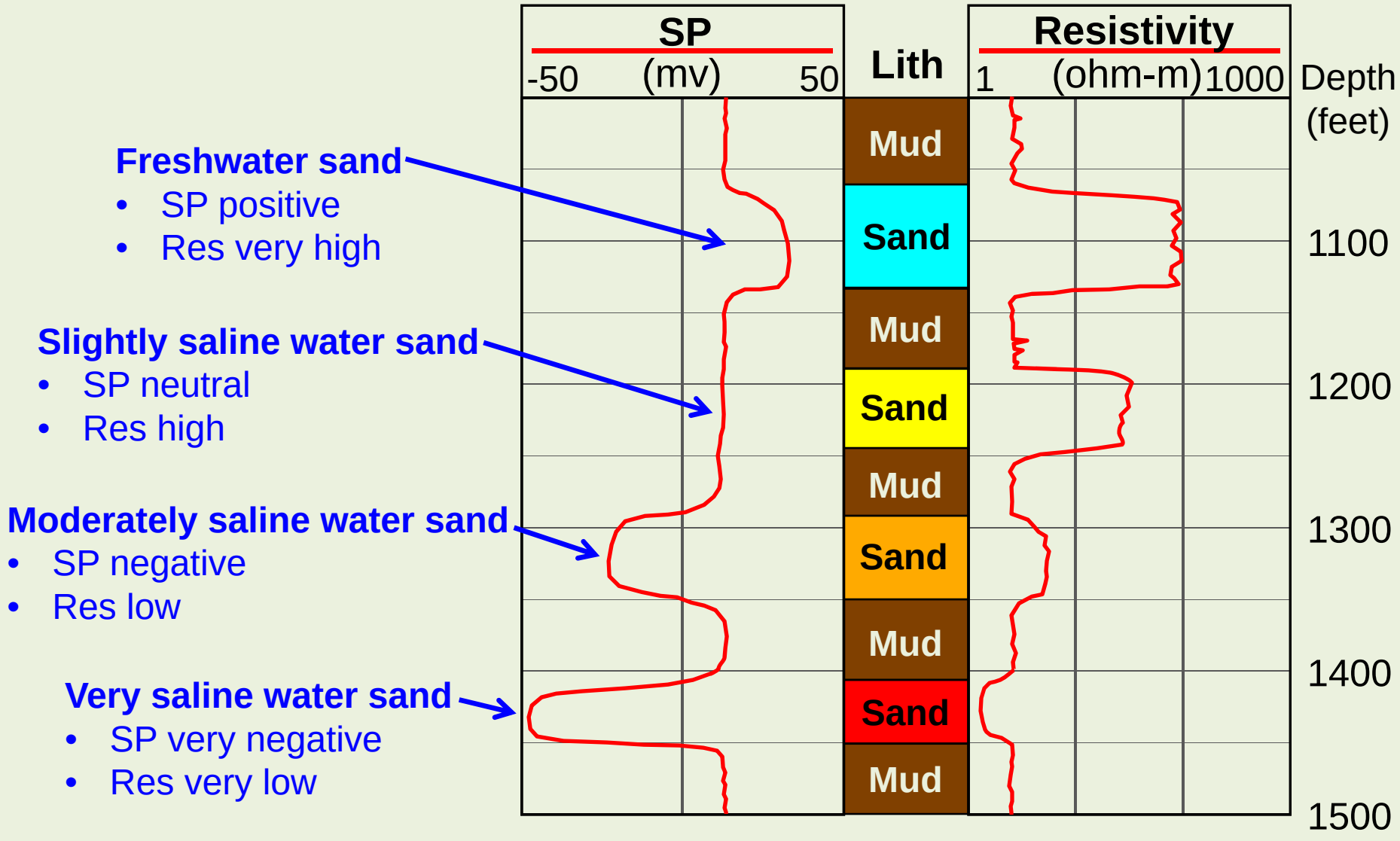
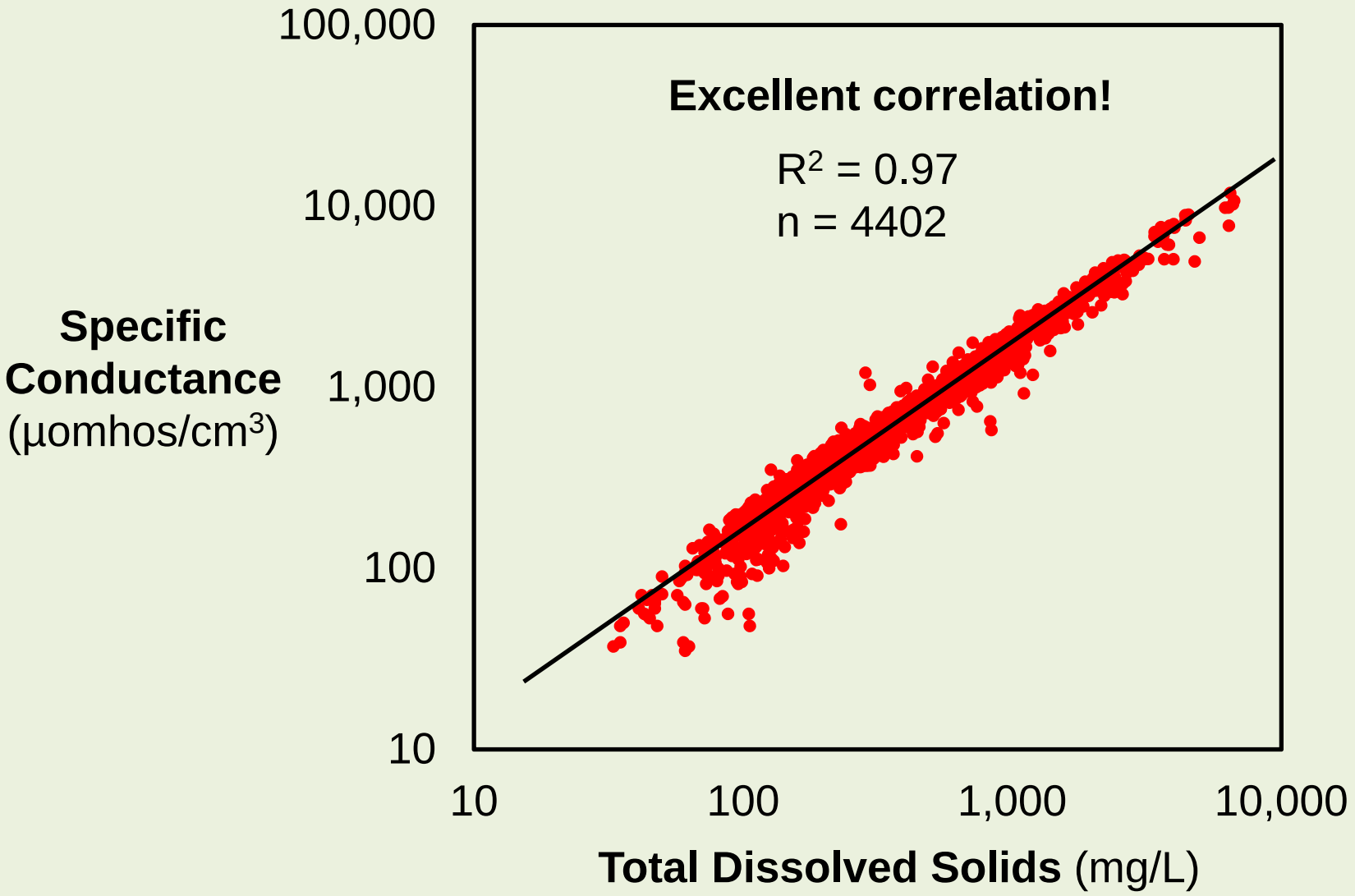
Electric Log Response to Groundwater Salinity



Quantifying the Resistivity / Salinity Relationship

Conductivity of Groundwater Samples

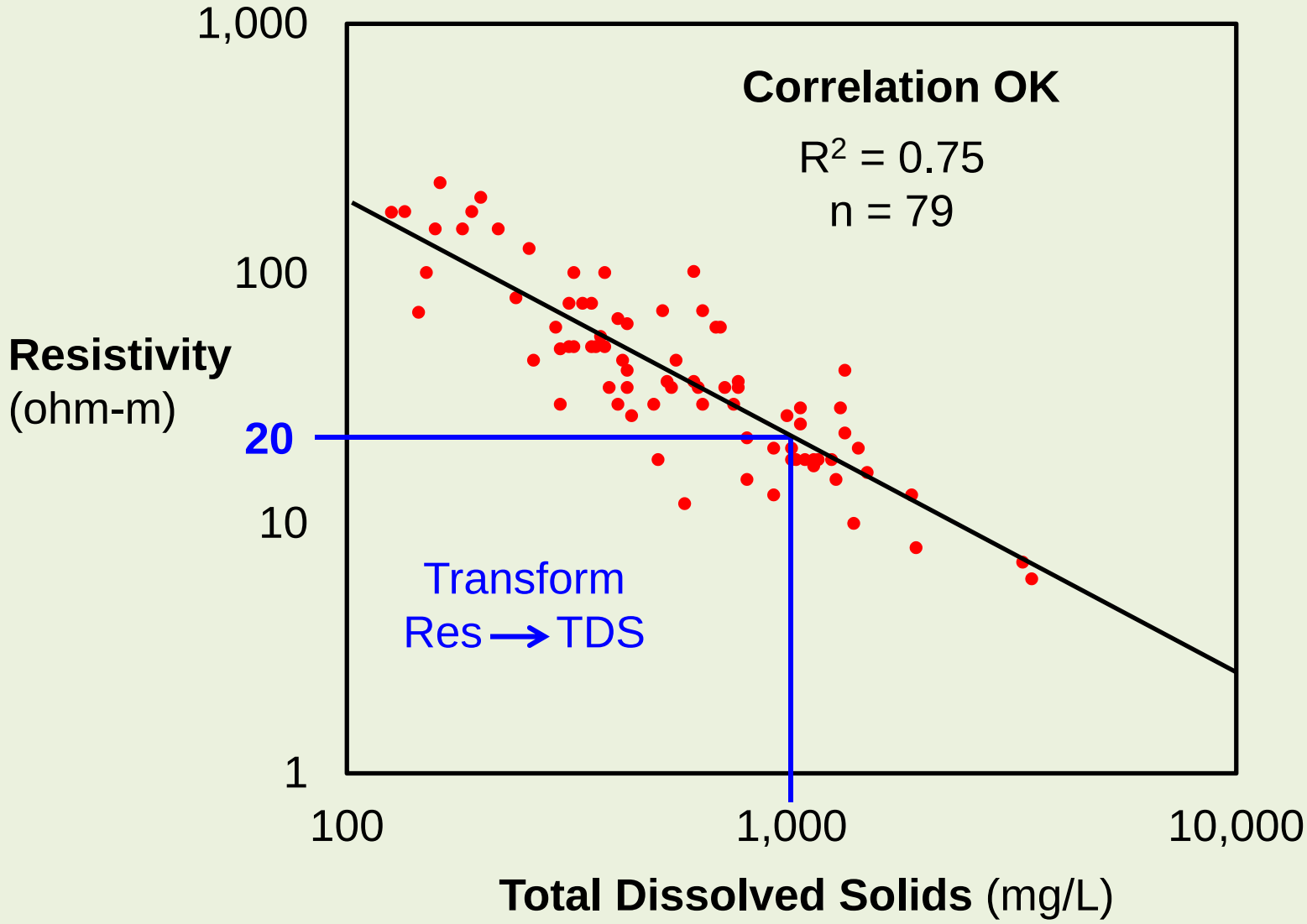


$$\text{Resistivity} = \frac{10{,}000}{\text{Specific Conductance}}$$

Specific Conductance measured in groundwater sample at surface – no lithology effects

Resistivity influenced by borehole environment, lithology, etc. (correlation with TDS not as good)

Quantifying the Resistivity / Salinity Relationship
Empirical Data from Carrizo-Wilcox Aquifer



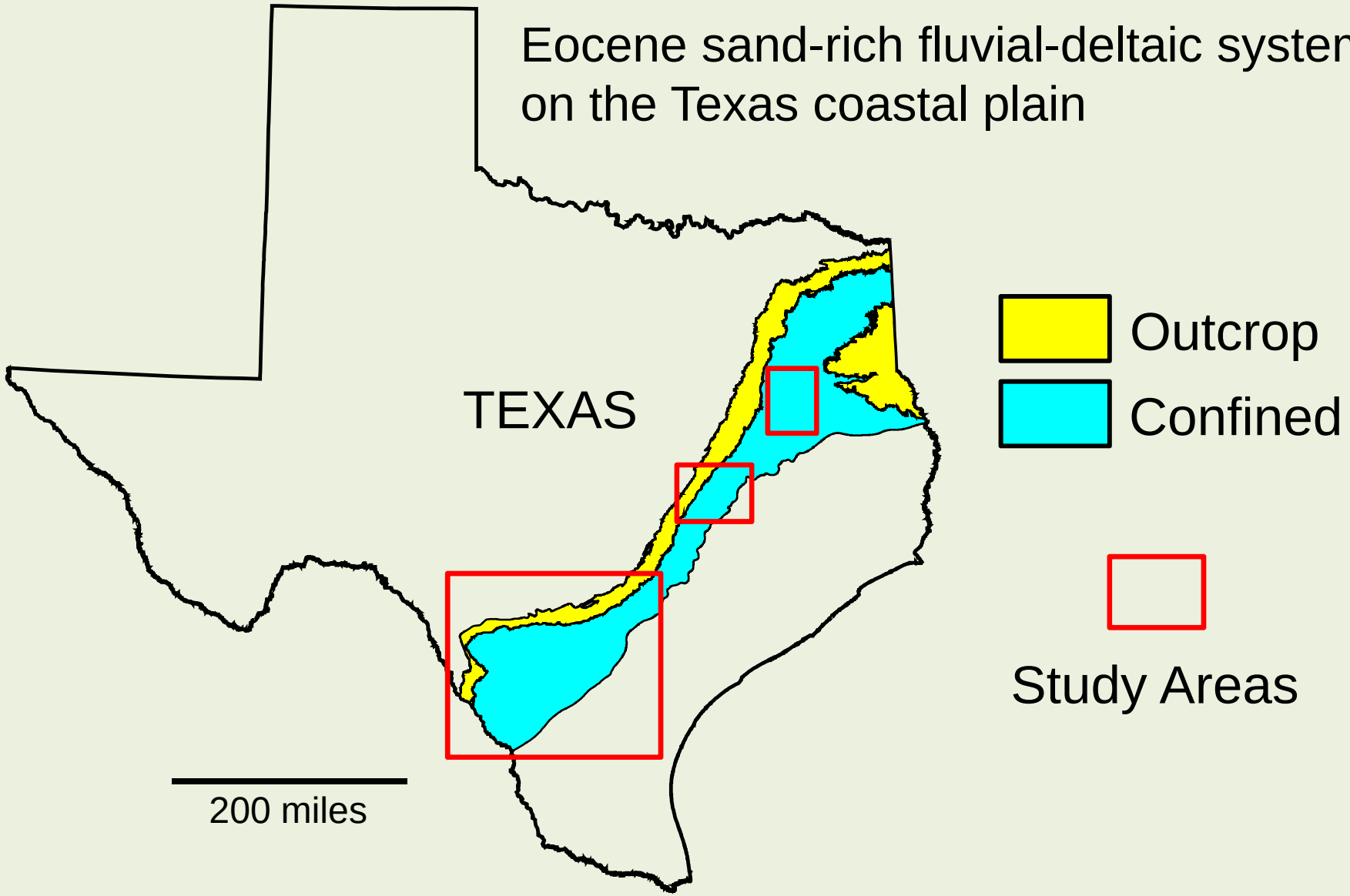
Quantifying the Resistivity / Salinity Relationship

Resistivity Cut-offs for Carrizo-Wilcox Aquifer

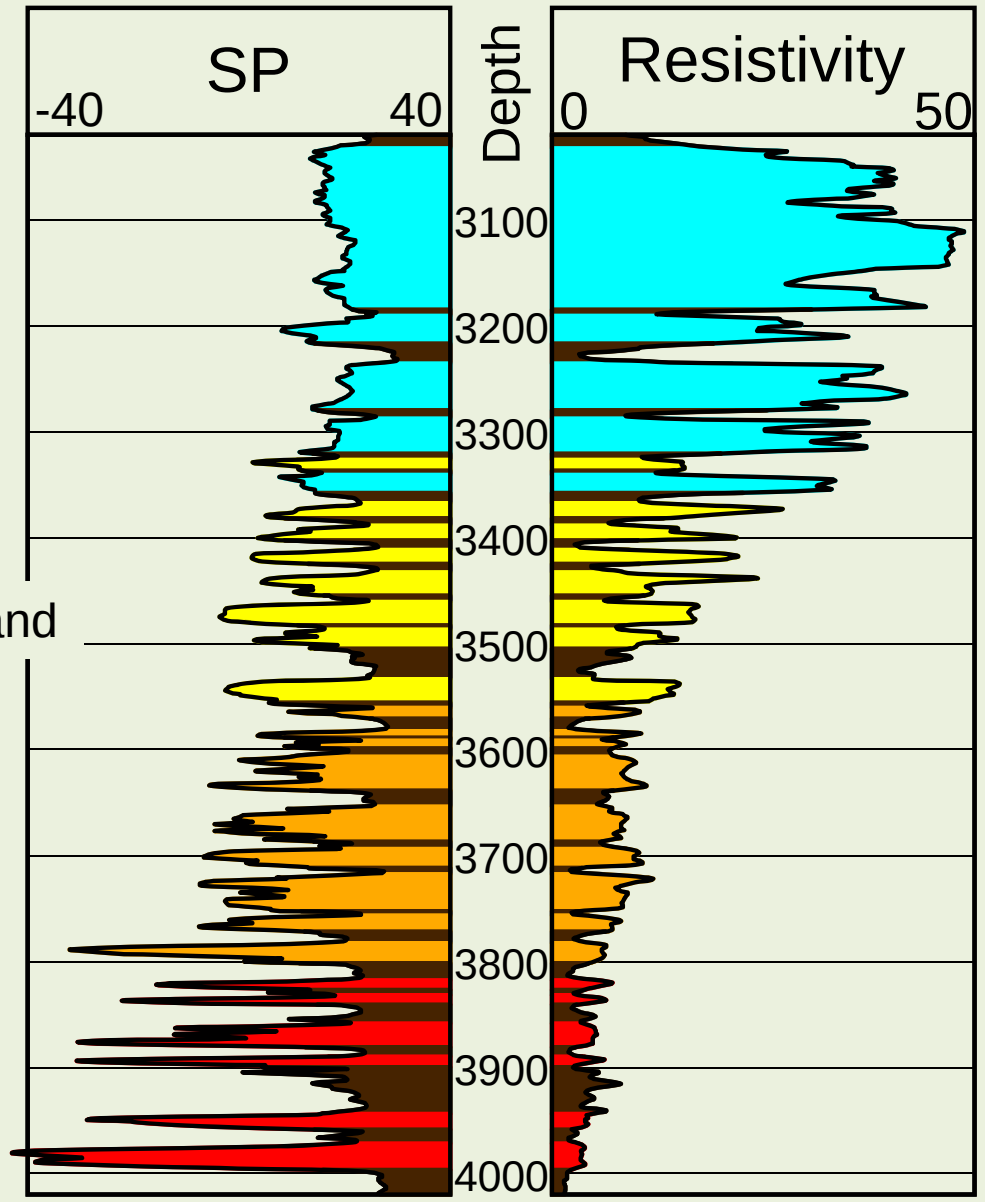
Salinity Classification	Total Dissolved Solids (mg/L)	Typical Resistivity Cut-offs (ohm-m)*
Freshwater	< 1,000	> 20
Slightly saline water	1,000 – 3,000	10 – 20
Moderately saline water	3,000 – 10,000	5 – 10
Very saline water	> 10,000	< 5

* Resistivity cut-offs vary with location, depth, lithology, water chemistry, etc.

CARRIZO-WILCOX AQUIFER



Carrizo-Wilcox Electric Log example showing groundwater salinity increase with depth



- Freshwater sand
- Slightly saline water sand
- Moderately saline water sand
- Very saline water sand
- Shale

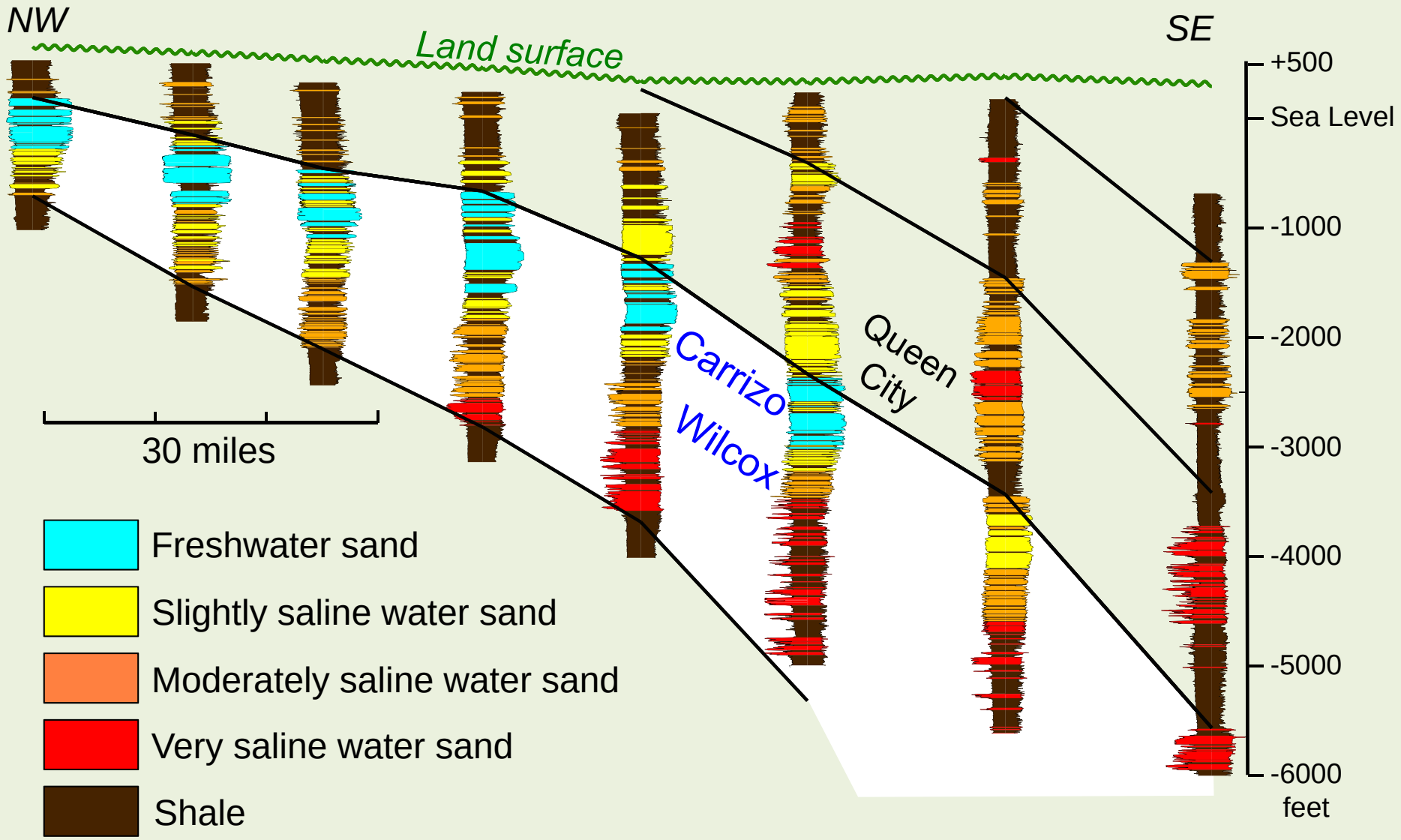
Log trends with depth:

SP – increasing negative

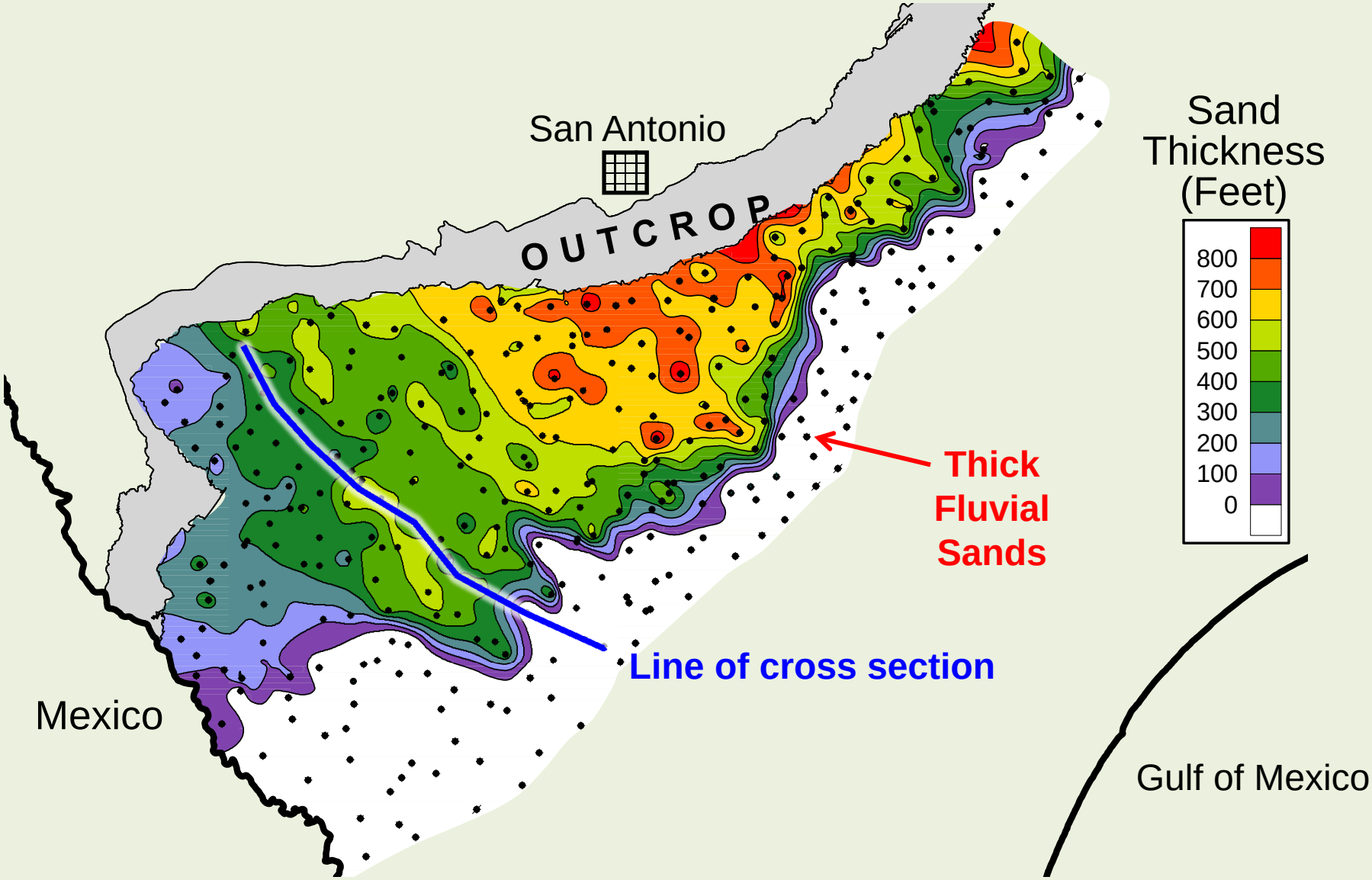
Res – decreasing

South Texas Carrizo-Wilcox Cross Section

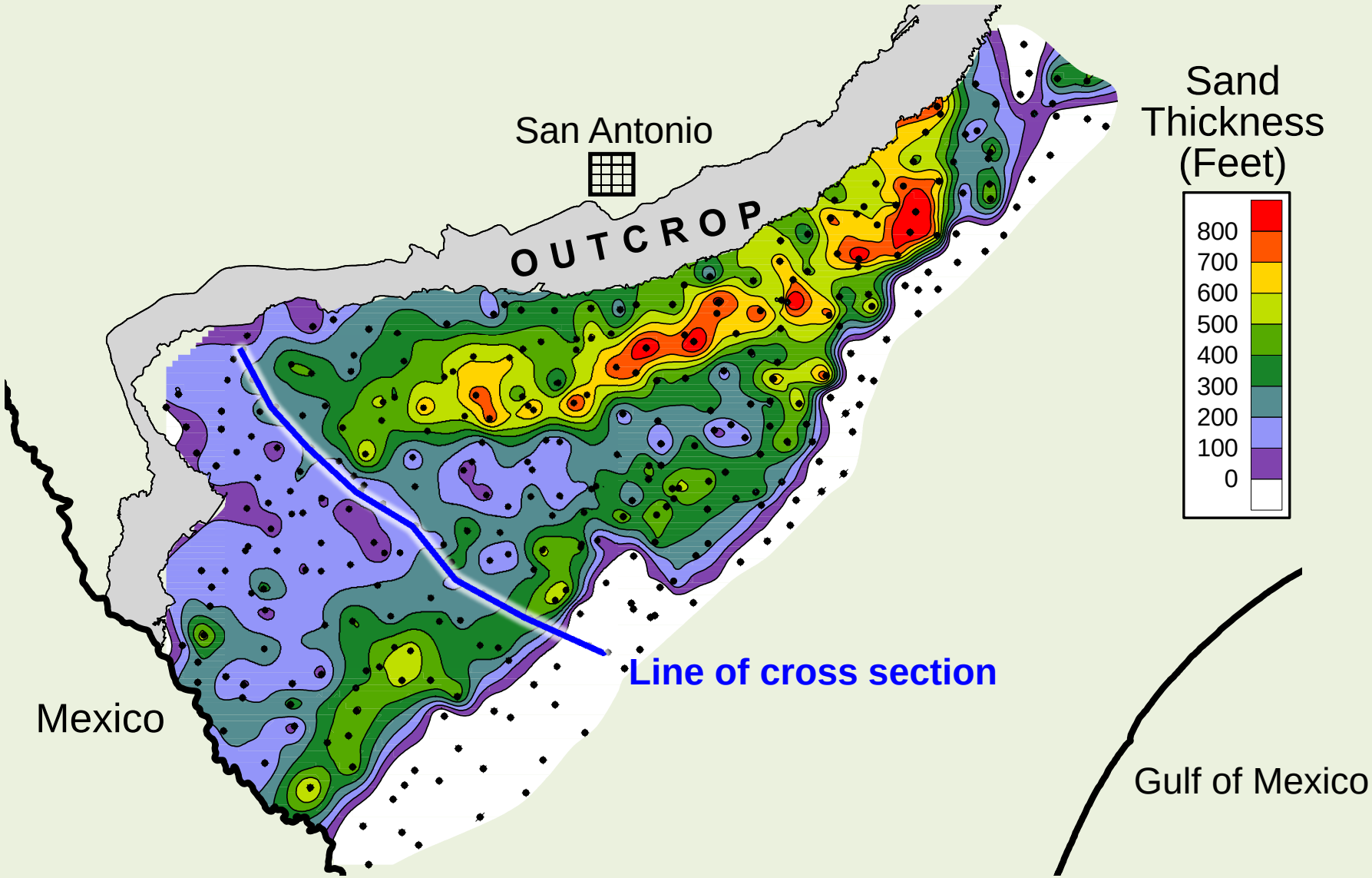
Vertical lithology/salinity profiles + stratigraphic correlation between wells



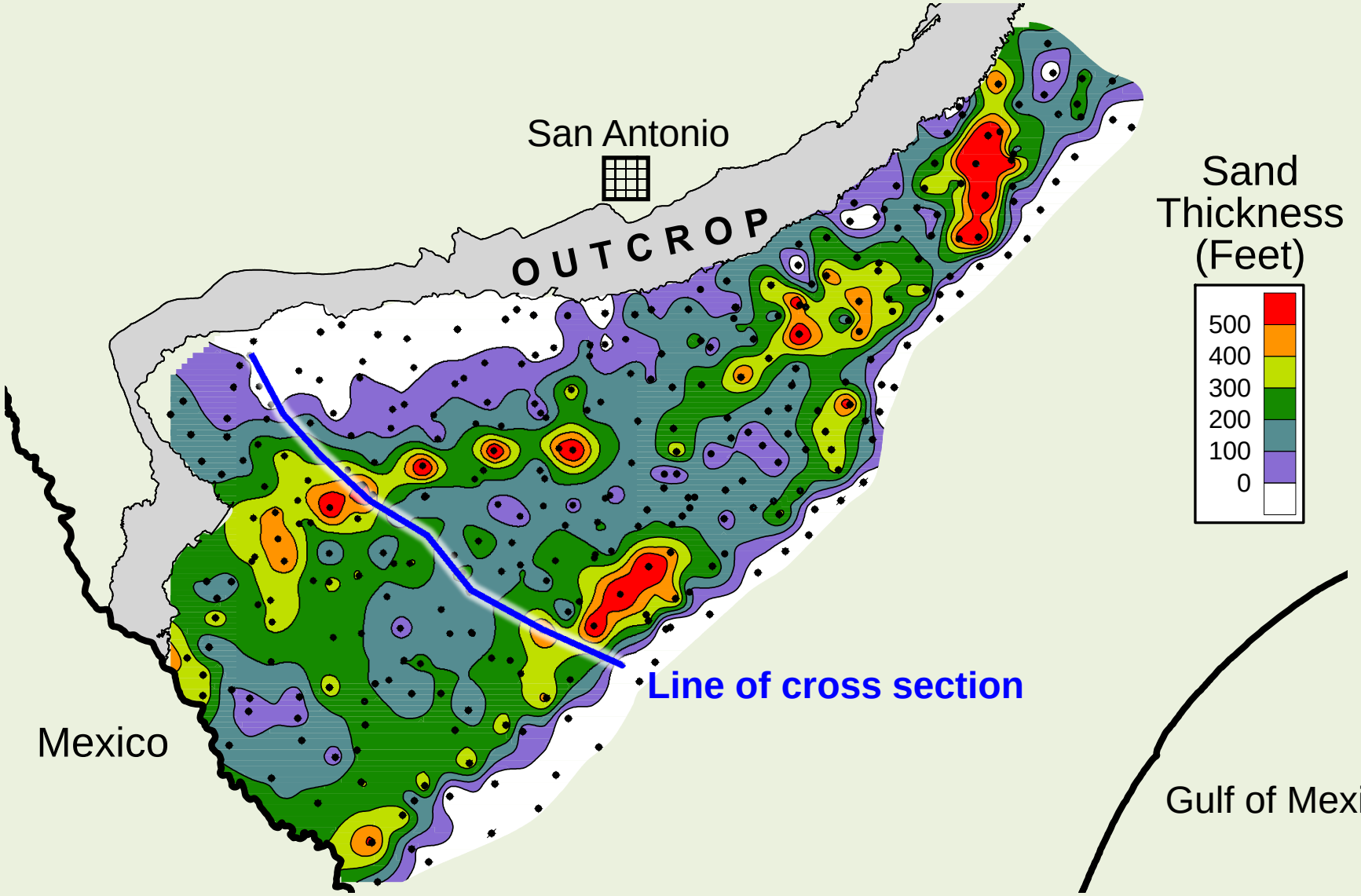
CARRIZO-WILCOX NET FRESHWATER SANDSTONE



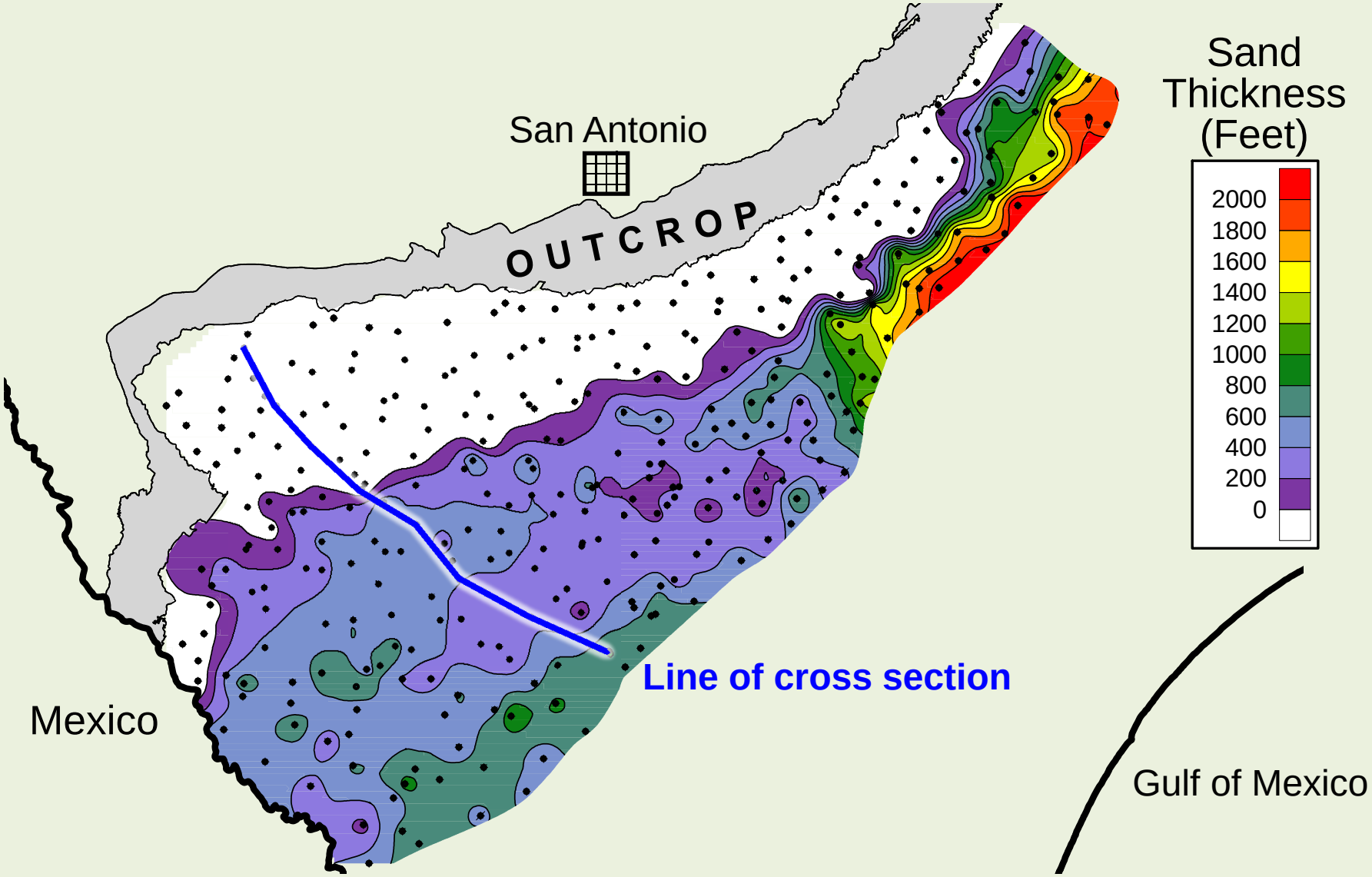
CARRIZO-WILCOX NET
SLIGHTLY SALINE WATER SANDSTONE



CARRIZO-WILCOX NET
MODERATELY SALINE WATER SANDSTONE



CARRIZO-WILCOX NET
VERY SALINE WATER SANDSTONE



ESTIMATING BRACKISH GROUNDWATER RESOURCES

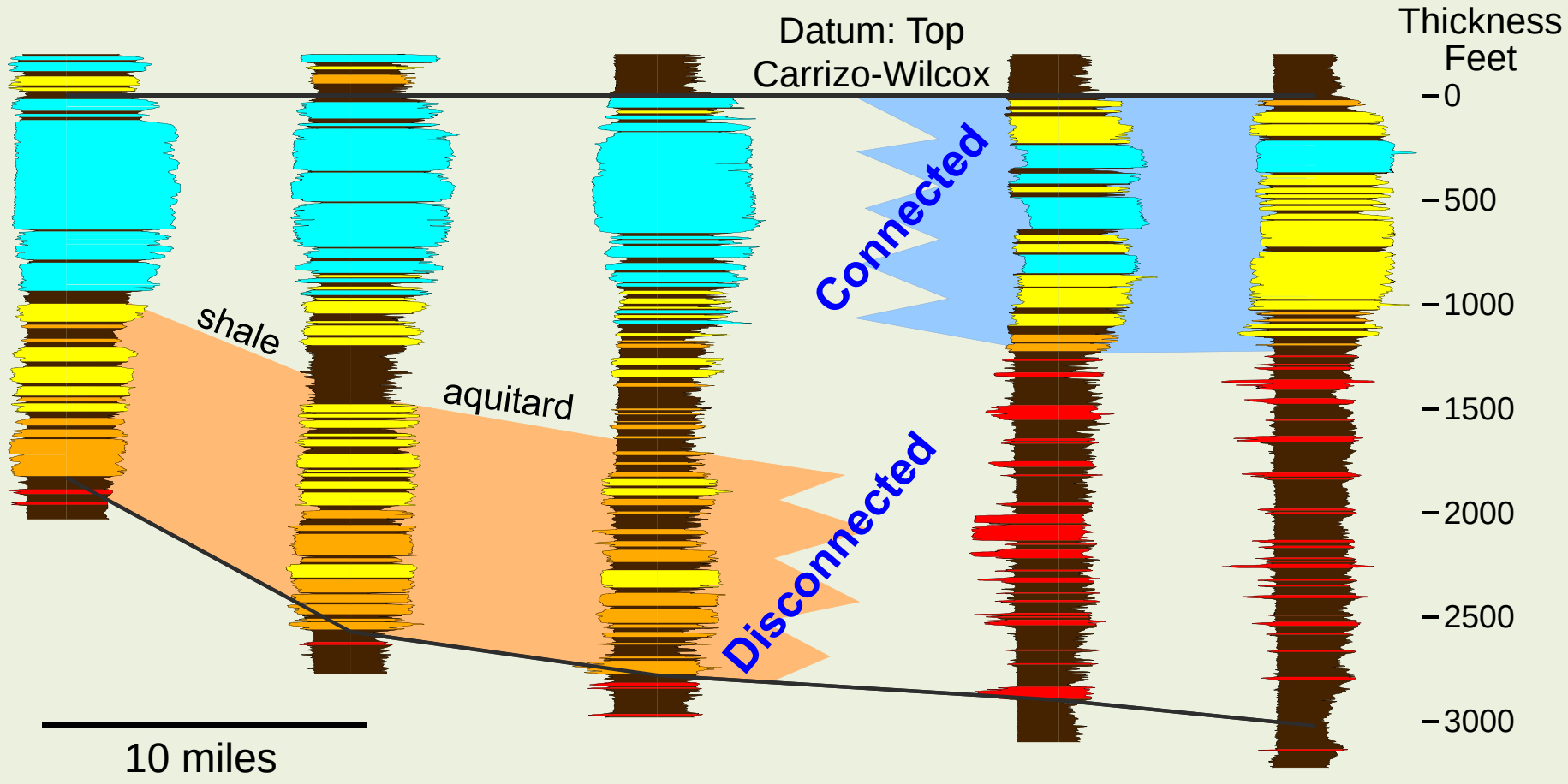
Slightly saline + moderately saline = brackish groundwater

Protecting the freshwater resource by distinguishing flow systems

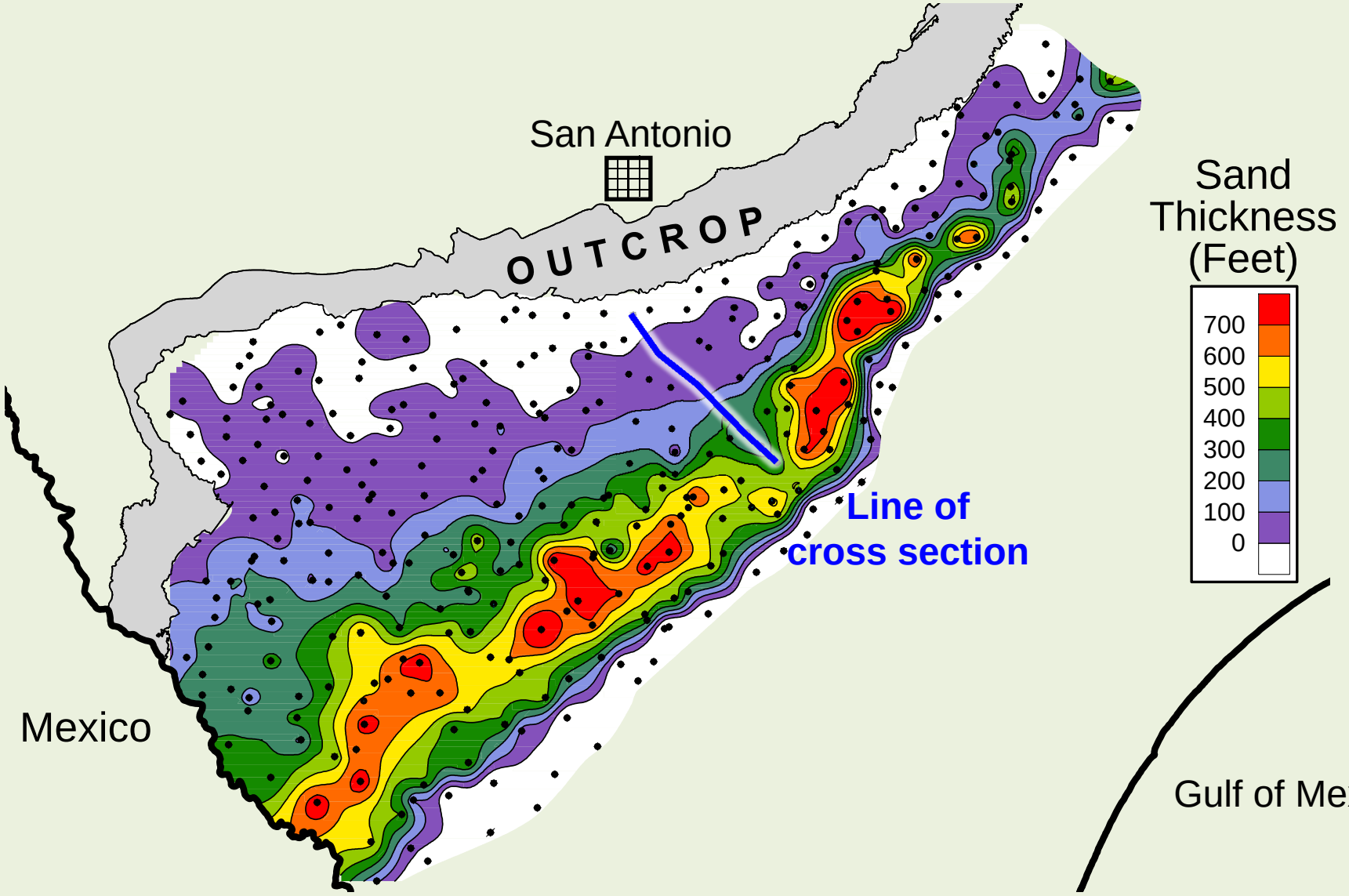
- Freshwater flow system = freshwater + brackish water in laterally continuous sandstones (**connected brackish groundwater**)
- Brackish water flow system = brackish water vertically separated from freshwater by shales (**disconnected brackish groundwater**)

Separate volumetrics for connected vs disconnected brackish groundwater

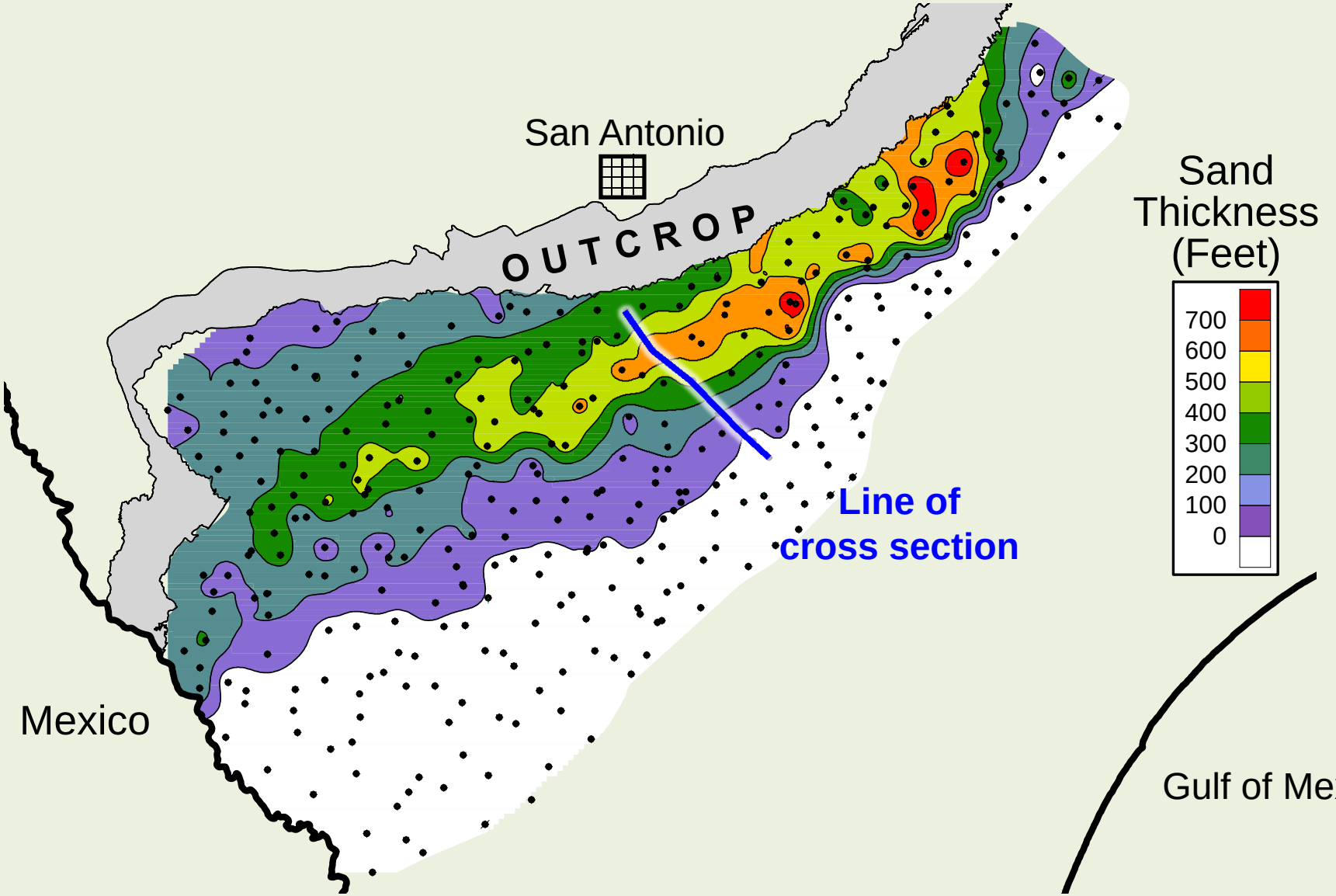
Carrizo-Wilcox Stratigraphic Cross Section Showing Connected and Disconnected Brackish Groundwater



CARRIZO-WILCOX NET CONNECTED BRACKISH WATER SANDSTONE



CARRIZO-WILCOX NET DISCONNECTED BRACKISH WATER SANDSTONE



VOLUMETRIC ANALYSIS OF GROUNDWATER IN THE CARRIZO-WILCOX AQUIFER IN SOUTH TEXAS

Groundwater volume = sandstone volume * porosity

Sandstone volume = area * thickness (from net sand maps)

Porosity = 0.20 (estimated from petrographic studies)

Groundwater volume and storativity used to estimate resource

GROUNDWATER VOLUMES
CARRIZO-WILCOX AQUIFER IN SOUTH TEXAS

FLOW SYSTEM	GROUNDWATER VOLUME 10^6 acre-feet (km^3)
Freshwater	458 (565)
Connected brackish water	94 (116)
Disconnected brackish water	600 (740)

CONCLUSIONS

- Electric logs record both lithology and groundwater salinity for continuous vertical sections through the aquifer (not just point source measurements)
- Methodology works best in simple sandstone/shale aquifer systems
- Empirical data (groundwater chemical analyses) are used to calibrate resistivity logs
- Electric logs are analyzed spatially to map aquifer thickness and to estimate volumes of fresh and brackish groundwater
- Electric-log-based stratigraphic analysis used to distinguish connected versus disconnected flow systems