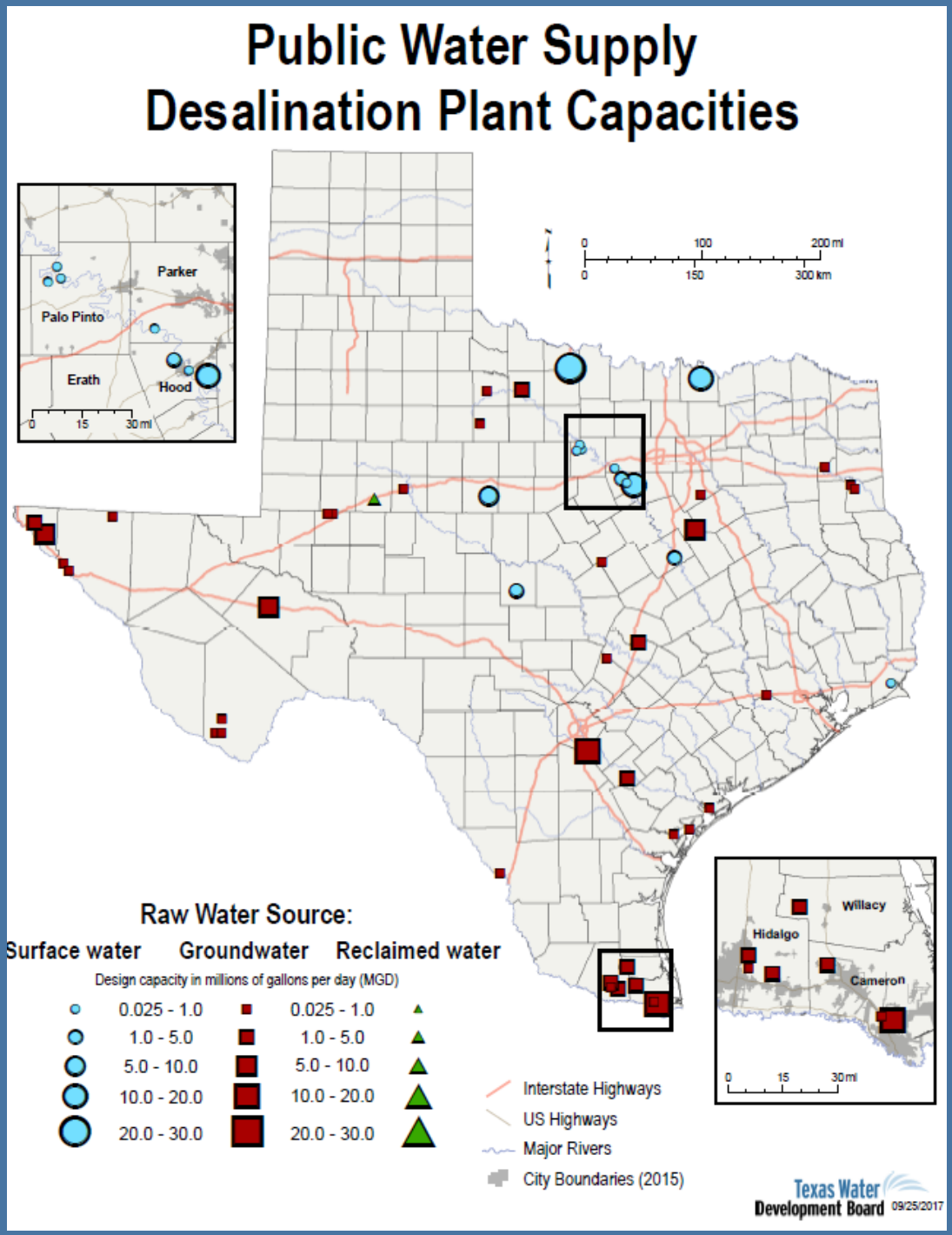
Brackish Aquifer Mapping in Texas

Ground Water Protection Council Conference, February 19, 2020

John Meyer, P.G.
Innovative Water Technologies
Texas Water Development Board

Unless specifically noted, this presentation does not necessarily reflect official Board positions or decisions

Texas Water Development Board



Estimated 2.7 billion acre-feet of brackish groundwater

32 brackish groundwater desalination plants

We have good understanding of fresh and slightly saline groundwater aquifers

The BRACS program began in 2009 to study brackish groundwater resources

So, what is brackish groundwater?

Groundwater Salinity Classification	Salinity Zone Code	Total Dissolved Solids (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

BRACKISH

PWS →

BUQ →

USDW →

← Most major / minor aquifers mapped extent

← Seawater

modified from Winslow and Kister (1956) USGS WSP 1365

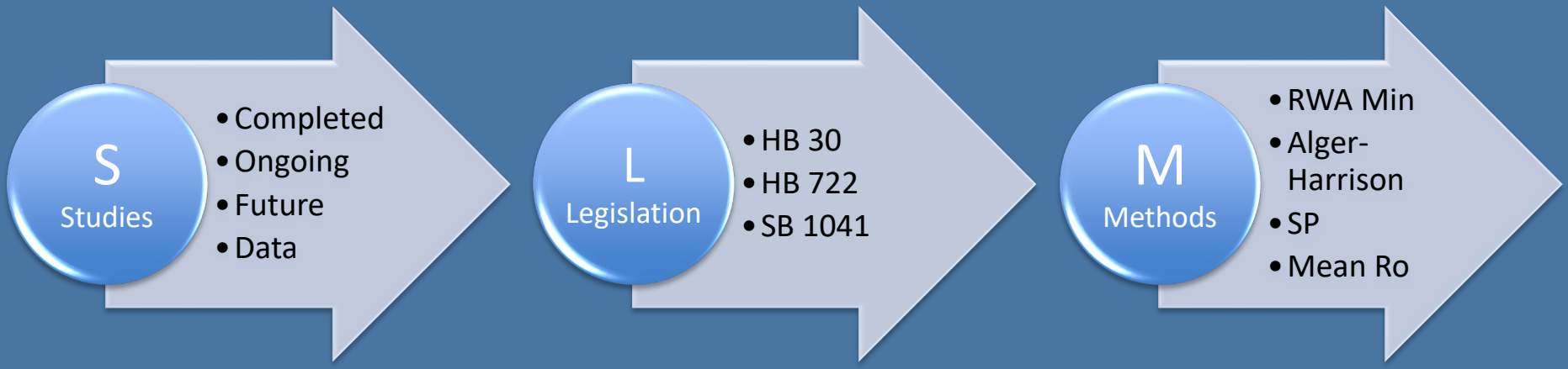
PWS: Public Water System threshold for fresh water, TX Commission on Environmental Quality

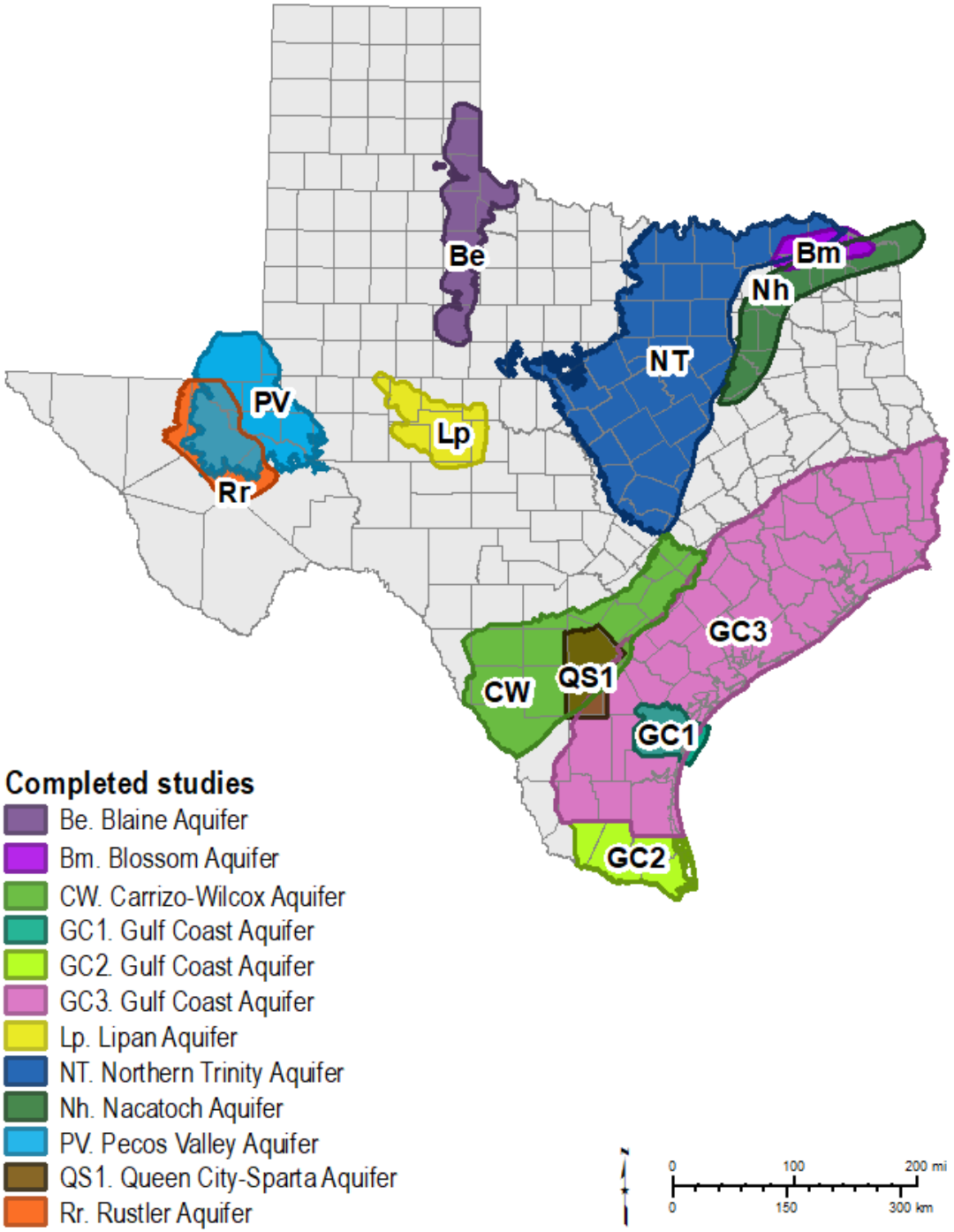
BUQ: Base Useable Quality water, TX Railroad Commission

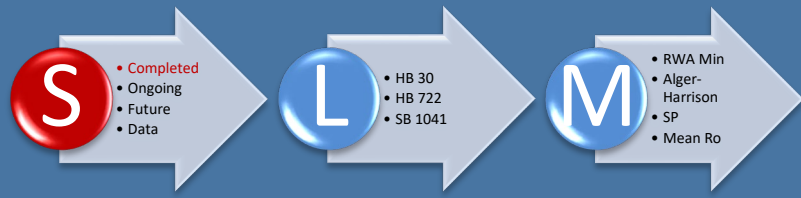
USDW: Underground Source Drinking Water, US Environmental Protection Agency

Presentation

- Status of TWDB brackish aquifer studies
- Legislation
- Methods to evaluate salinity from geophysical well logs



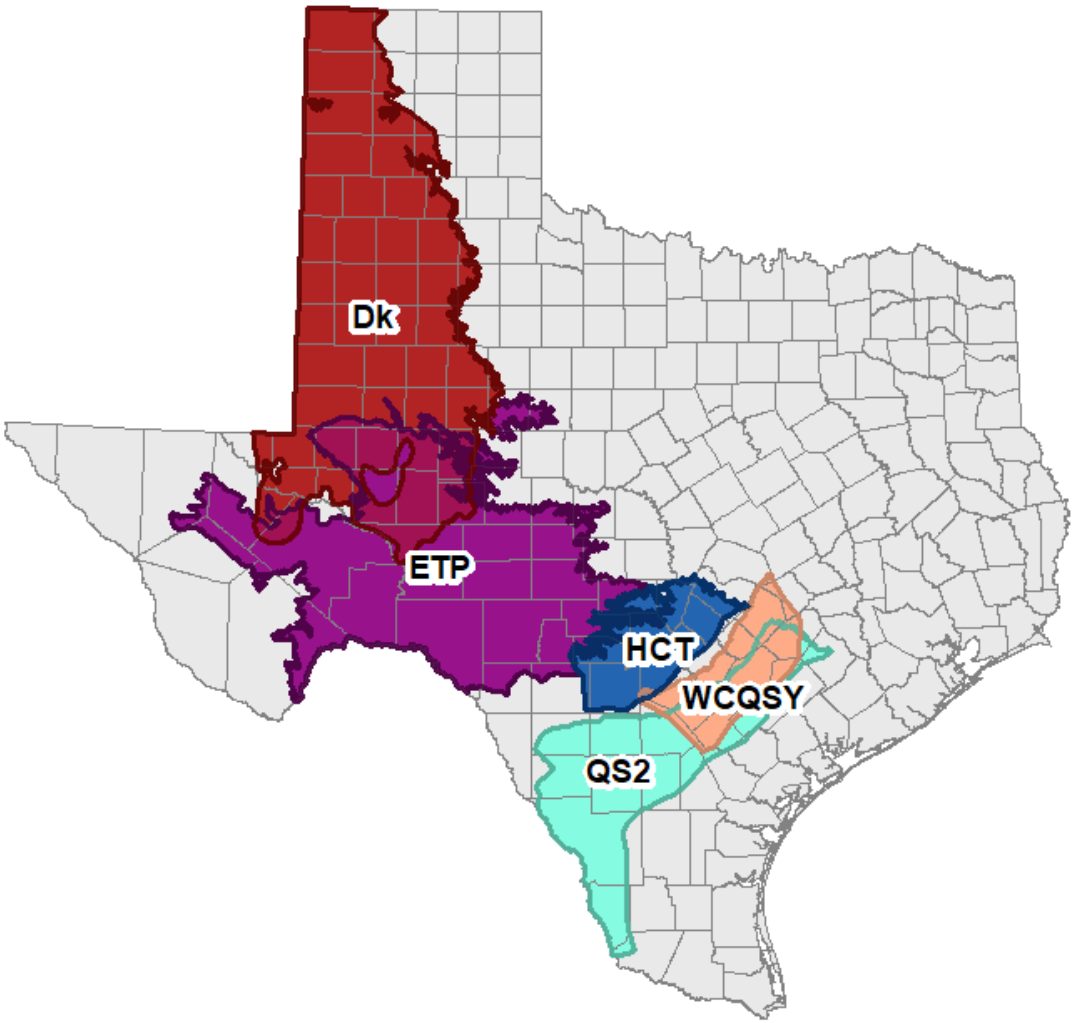




Completed studies include part or all of 11 aquifers

TWDB performed some studies

TWDB contracted other studies



Current studies

- Dk. Dockum
- ETP. Edwards-Trinity Plateau
- HCT. Hill Country Trinity
- QS2. Queen City-Sparta
- WCQSY. Wilcox, Carrizo, Queen City, Sparta, and Yegua aquifers

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Queen City - Sparta

brackish zone analysis

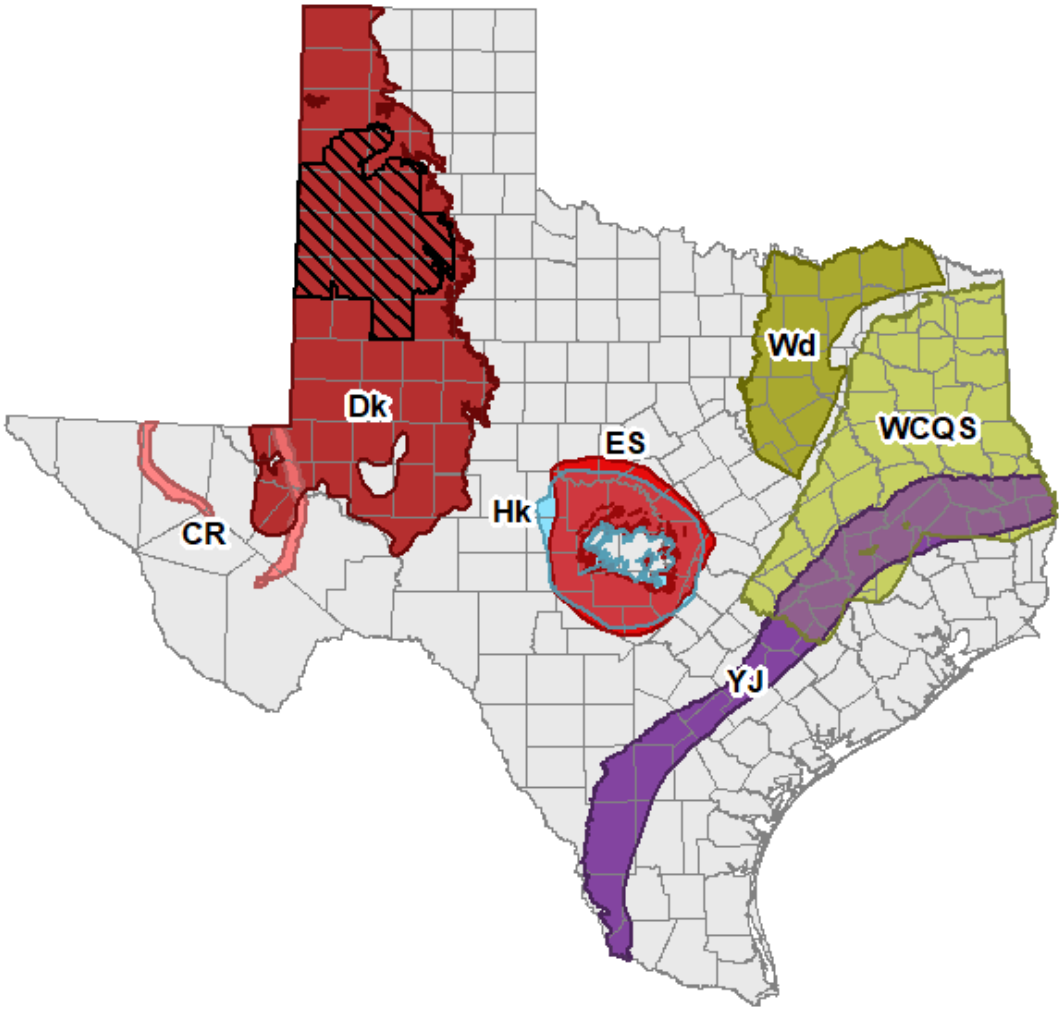
WCQSY

resource report in editing

brackish zone analysis later

Dockum

data collection only



Meets House Bill 30 criteria, eligible for zone designation

- CR. Capitan Reef Complex Aquifer
- Dk. Dockum Aquifer
- ES. Ellenburger-San Saba Aquifer
- Hk. Hickory Aquifer
- WCQS. Wilcox, Carrizo, Queen City, and Sparta aquifers
- Wd. Woodbine Aquifer
- YJ. Yegua-Jackson Aquifer
- No zones will be designated

0 100 200 mi
0 150 300 km

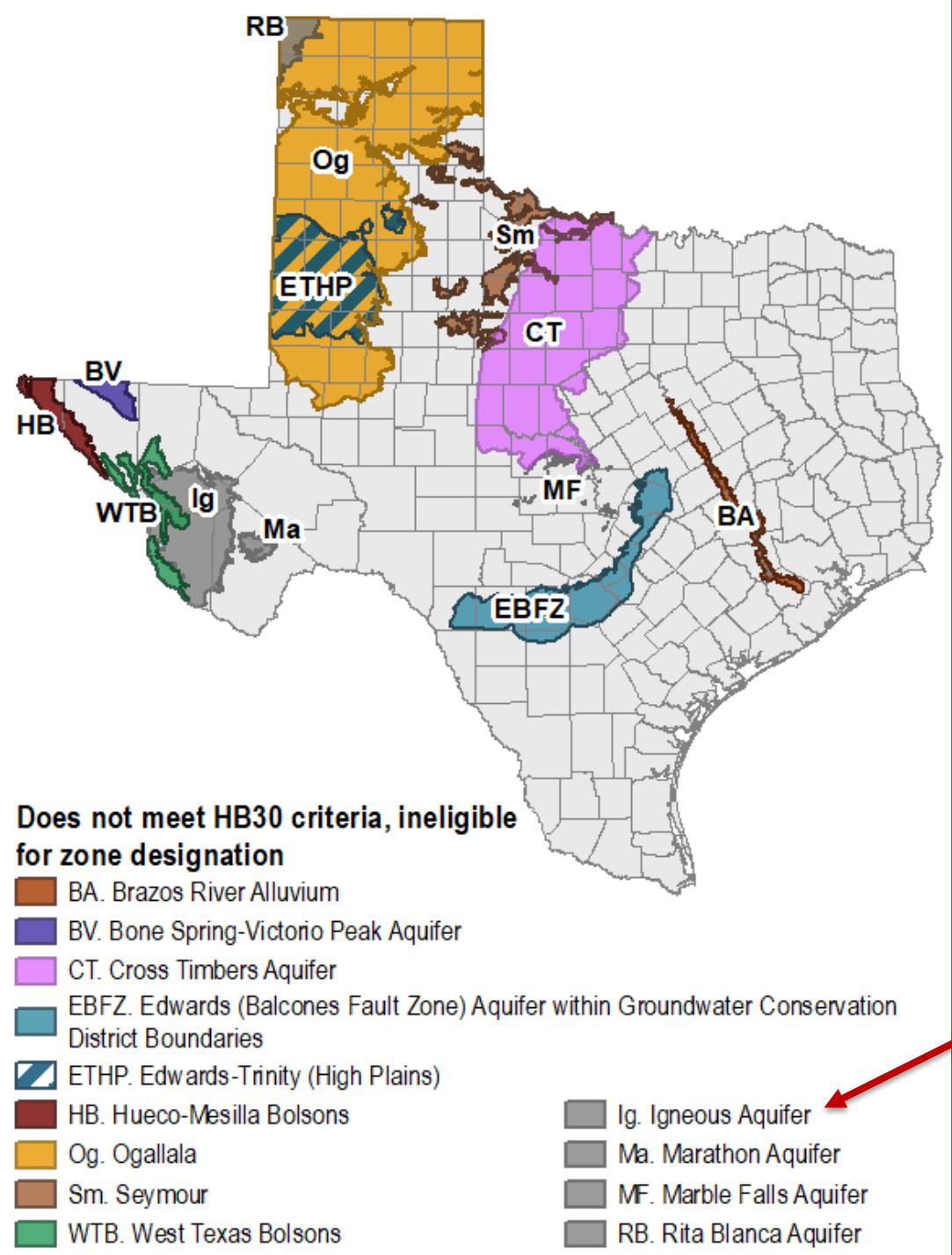
S
- Completed
- Ongoing
- Future
- Data

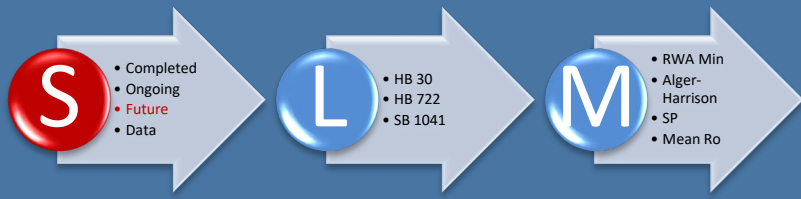
L
- HB 30
- HB 722
- SB 1041

M
- RWA Min
- Alger-Harrison
- SP
- Mean Ro

WCQS

Separate studies for the Wilcox – Carrizo and Queen City - Sparta





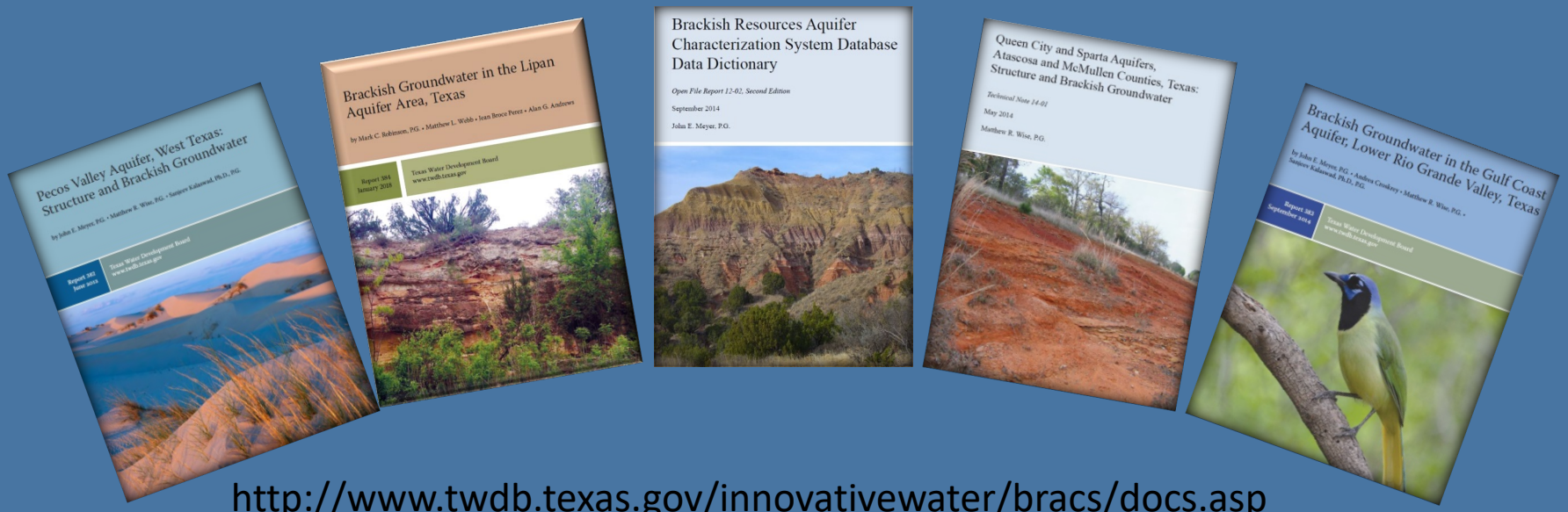
These aquifers will not meet House Bill 30 criteria and will be studied after 2032

Nine aquifers contain brackish water

Four aquifers may not have significant brackish groundwater for analysis

BRACS Data

Published reports



http://www.twdb.texas.gov/innovativewater/bracs/docs.asp

GIS datasets

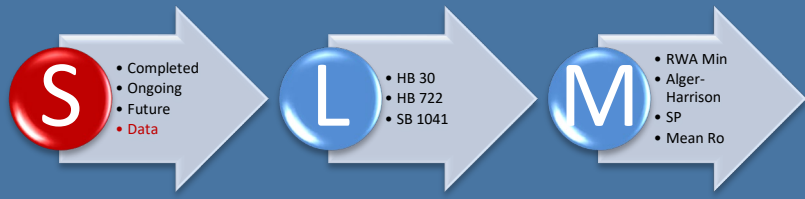
BRACS Database

Well logs

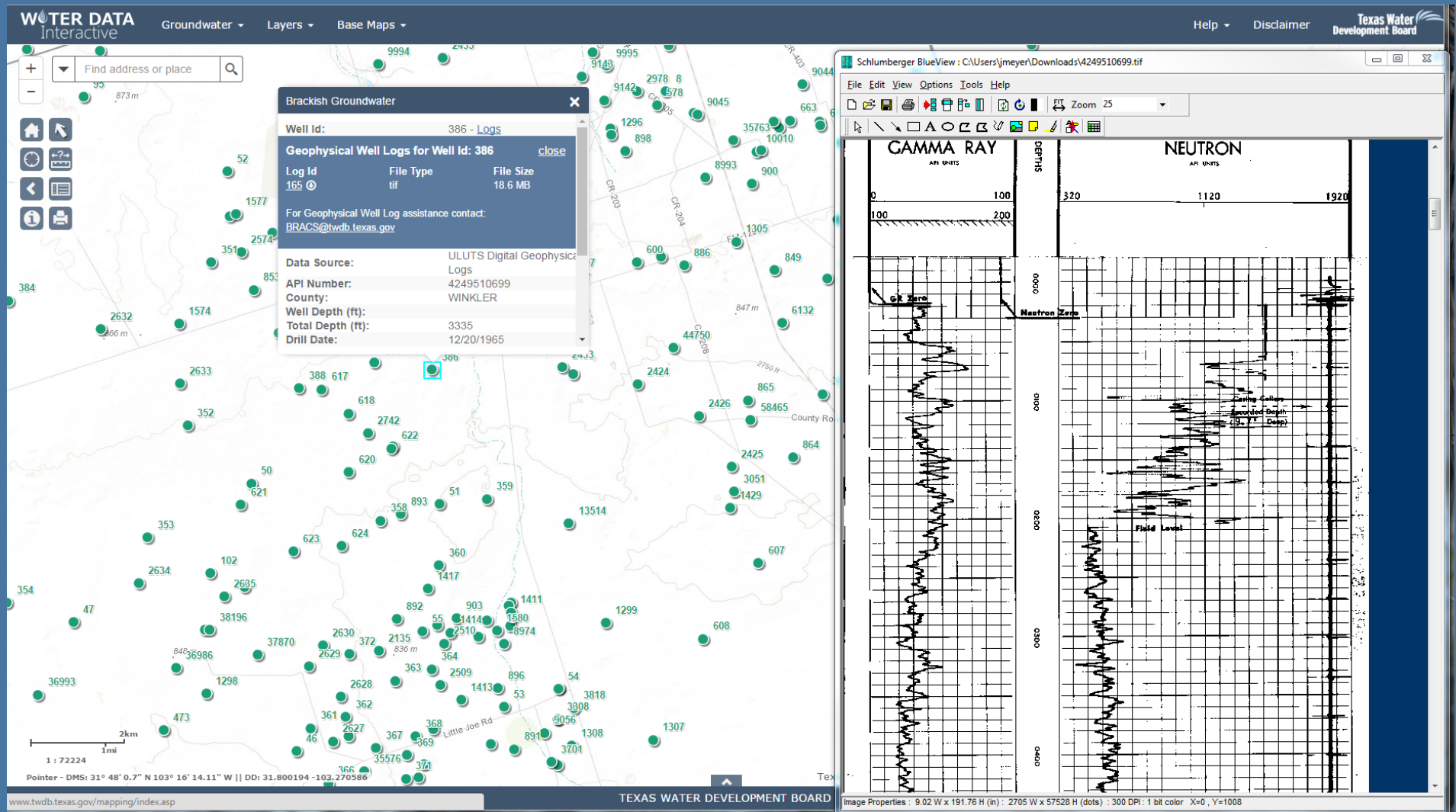
The real value is in the data:

Stakeholders can use this to evaluate potential groundwater exploration areas.

TWDB Water Data Interactive



http://www2.twdb.texas.gov/apps/waterdatainteractive/groundwaterdataviewer



Legislation

House Bill 30 (2015, 84th Texas Legislature)

- Directs TWDB to designate brackish groundwater production zones
- TWDB provides recommendations for groundwater monitoring
- Report to Legislature December 1 of every even-numbered year

House Bill 722 (2019, 86th Texas Legislature)

- Rules for permits in brackish groundwater production zones
- Groundwater Districts send permit applications to TWDB for review
- Permittees provide annual reports on water quality, levels, and production
- Groundwater Districts request TWDB to investigate 'significant impact'

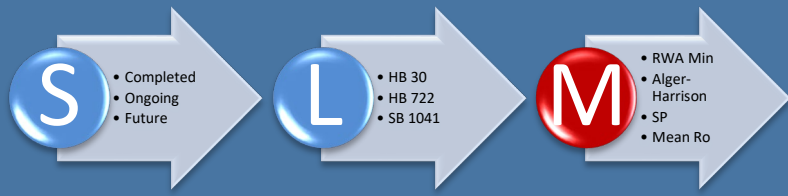
Senate Bill 1041 (2019, 86th Texas Legislature)

- extended deadline to map brackish zones to 2032

H.B. 30 Criteria for "Brackish Groundwater Production Zone"

Must have brackish water (average TDS > 1,000 mg/L)	In areas of the state with moderate to high availability and productivity
Must have hydrogeologic barriers	sufficient to prevent significant impacts to fresh water availability or quality
Cannot be within these boundaries	Edwards Aquifer within the Edwards Aquifer Authority, Barton Springs-Edwards Aquifer Conservation District, Harris-Galveston Subsidence District, and Fort Bend Subsidence District
Cannot be already in use	Brackish water already serving as a significant source of water supply for municipal, domestic, or agricultural
An area of a geologic stratum that is designated or used for wastewater injection through the use of injection wells or disposal wells permitted under Chapter 27	Class I, II, III, IV, V, VI injection wells

Geophysical Log Analysis Methods



There are many methods to evaluate geophysical logs to estimate salinity

Six popular methods are described by John Estepp (1998, *unpublished*)

John modified oilfield log analysis techniques and added corrections for temperature and water quality, and conversions from resistivity to TDS

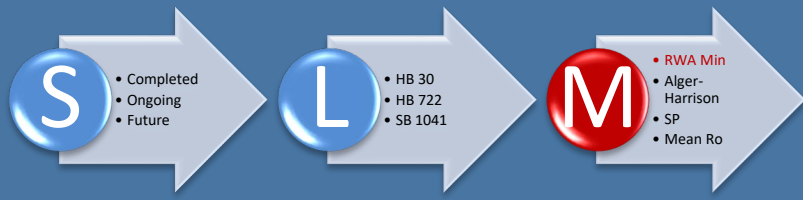
The methods are dependent upon access to logs, input parameters, and measured water quality data.

All methods require simplistic assumptions; the results are *only* estimates

Much more work needs to be done to determine input parameters

Each time we complete a study we learn more information about the method(s) as well as the aquifers

Rwa Minimum Method



Based on Archie's Equation, modified by John Estepp, P.G., and tweaked by BRACS

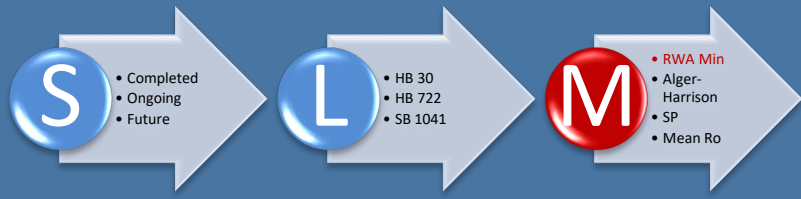
Archie's Equation simplified for groundwater is $R_w = R_o \cdot \phi^m$

where:

R_o = resistivity of the formation (units: ohm-meter)
R_w = resistivity of water (units: ohm-meter)
ϕ = porosity (units: percent)
m = cementation exponent (units: dimensionless)

Archie's does not solve for TDS, that is where John's work comes in!

Rwa Minimum Method



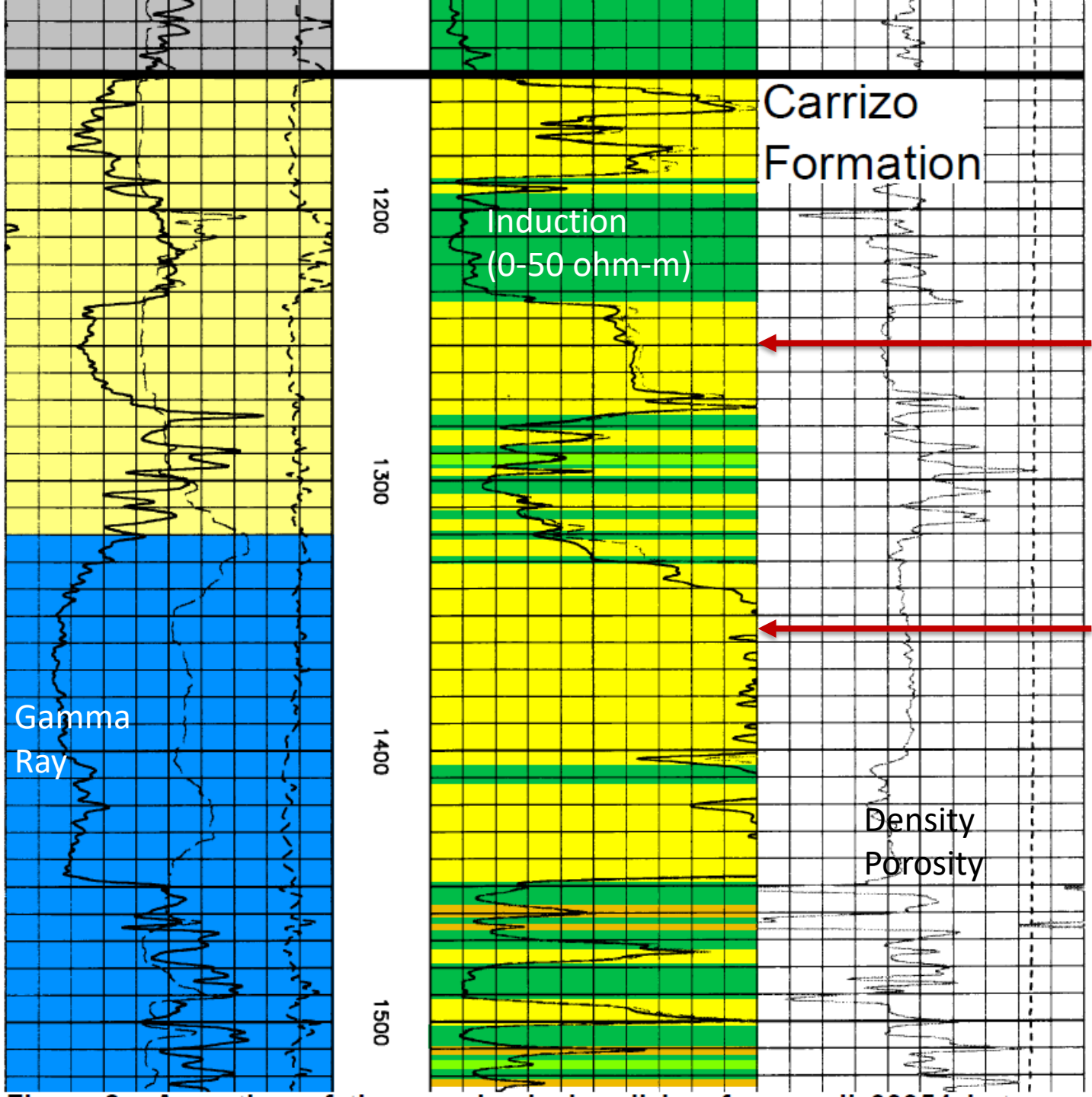
TWDB preferred method for sand and clay formations

Input parameters (challenges underlined):

- Porosity
- Temperatures (surface, bottom hole, formation being evaluated)
- Cementation ("m") factor
- ct factor (relates salinity to specific conductance)
- Water quality correction factors (address bicarbonate and sulfate)
- Deep resistivity value from log

Method fully discussed in TWDB reports (Report 383 and draft Upper Coastal Plain aquifers)

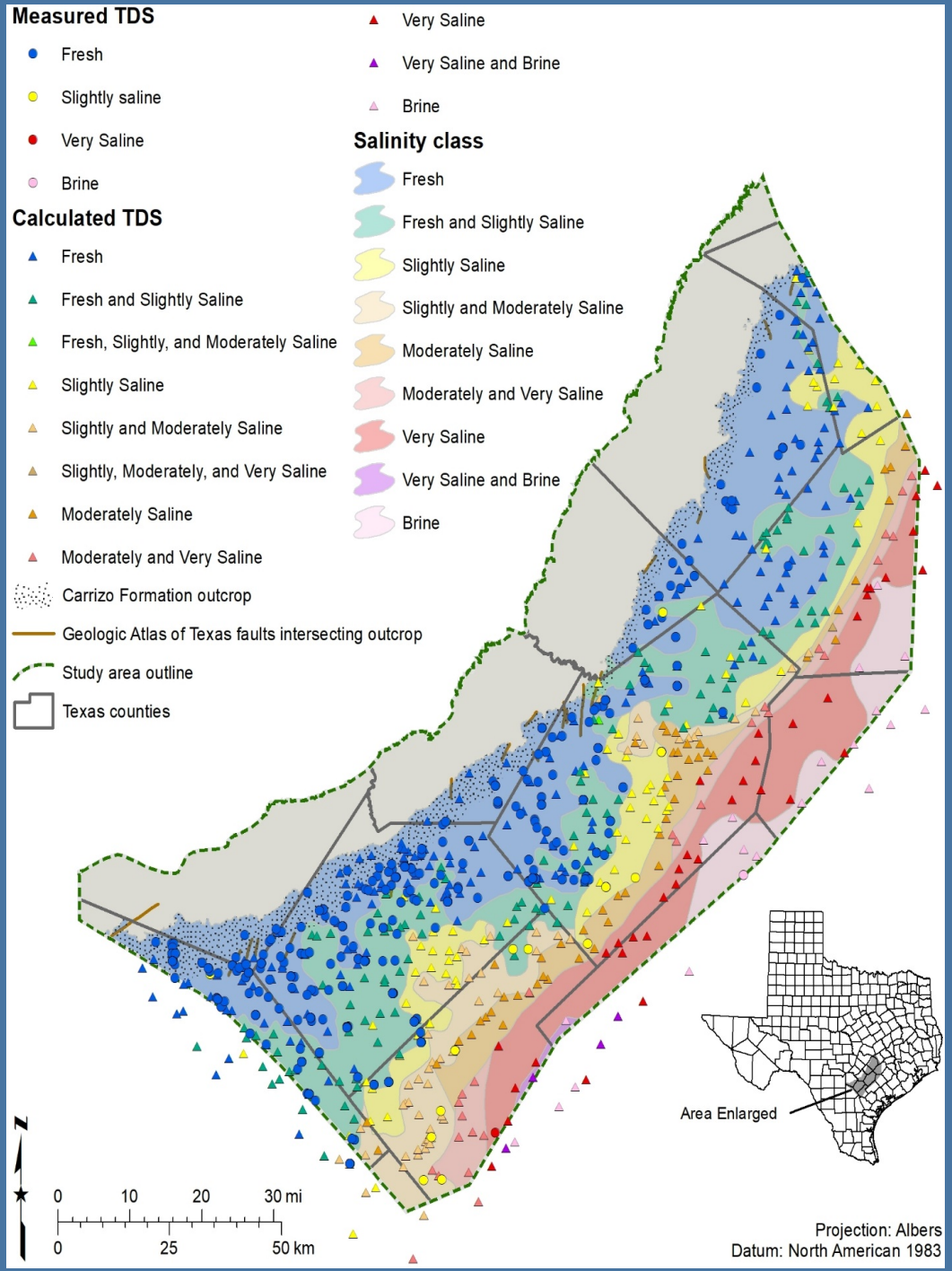
Innovative aspects of this method: water quality correction factors

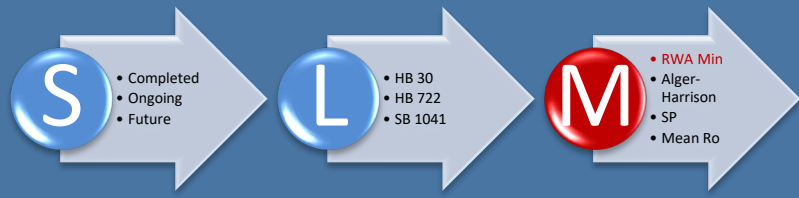


1250 ft: Ro 32 ohm-m
TDS 1188

1355 ft: Ro 50 ohm-m
TDS 812

BRACS Well 39954



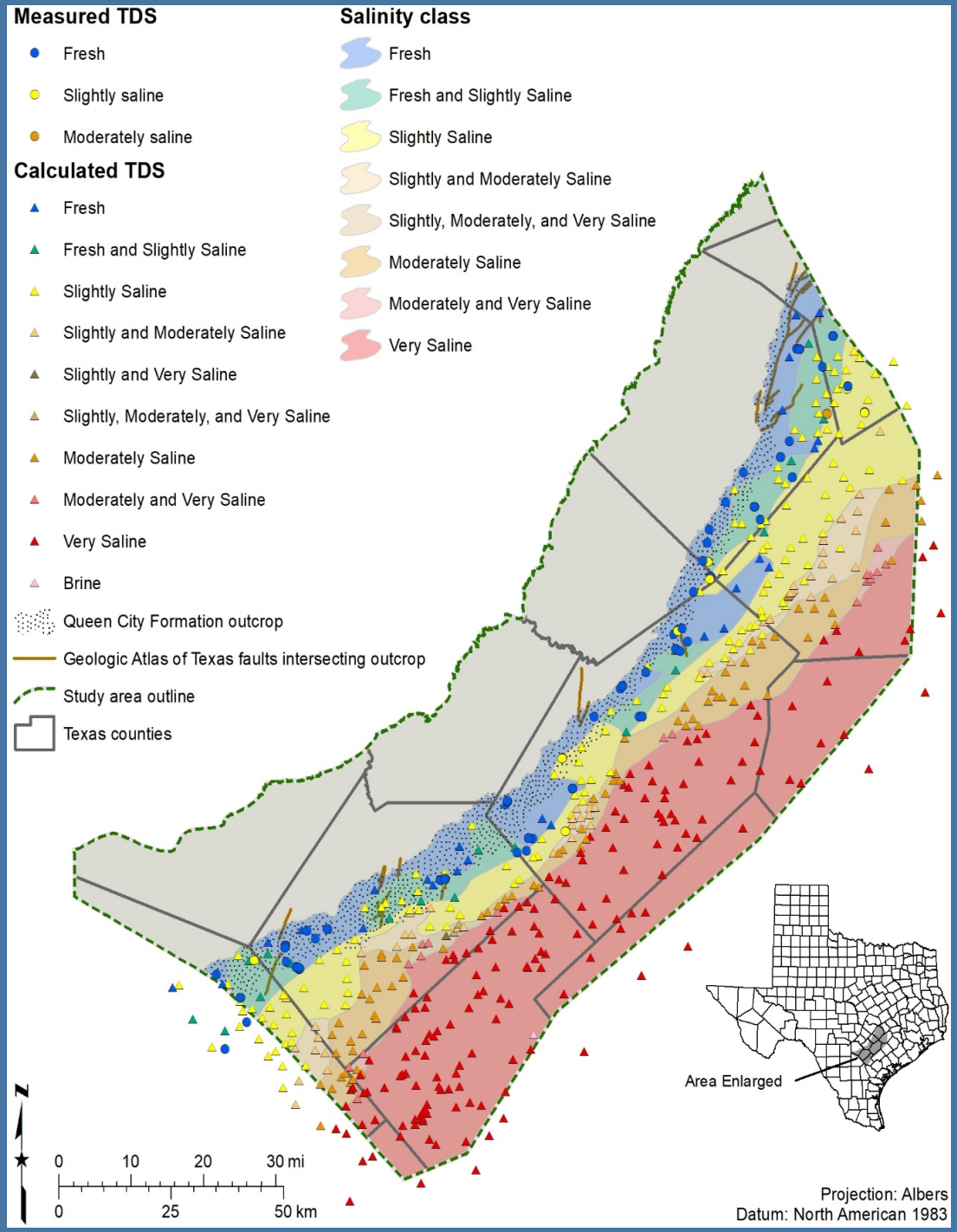


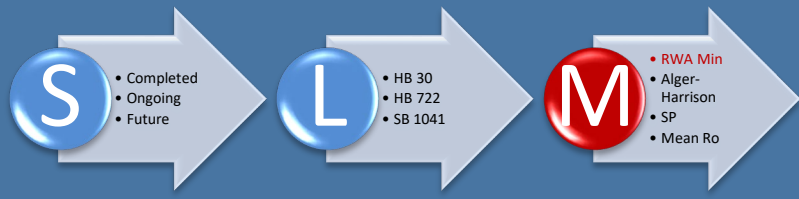
Carrizo Formation Salinity

Rwa Minimum Method

Notice the fresh water zone occurs over the outcrop and extends quite far downdip.

The distribution of salinity is complex.

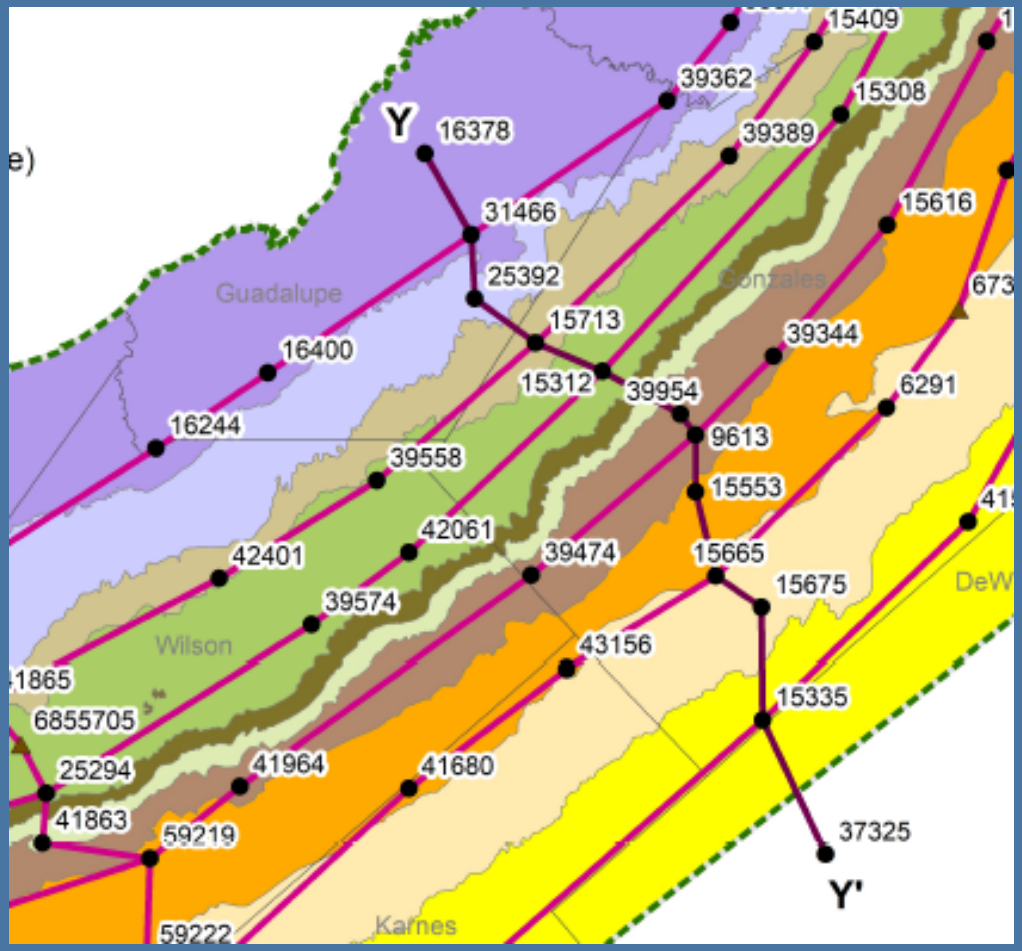


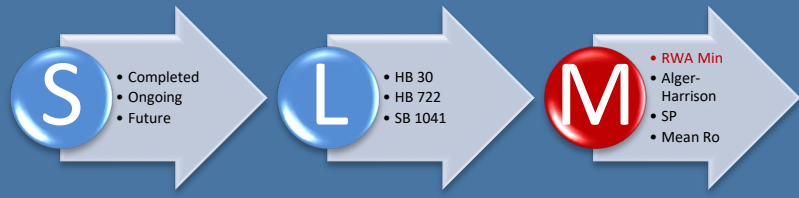


Queen City Formation Salinity

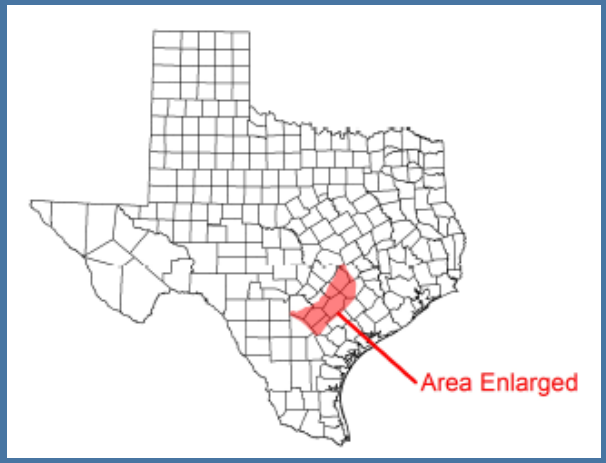
Rwa Minimum Method

Notice the fresh water zone occurs over the outcrop and immediately downdip.





Cross-section example of structural dip Y – Y'



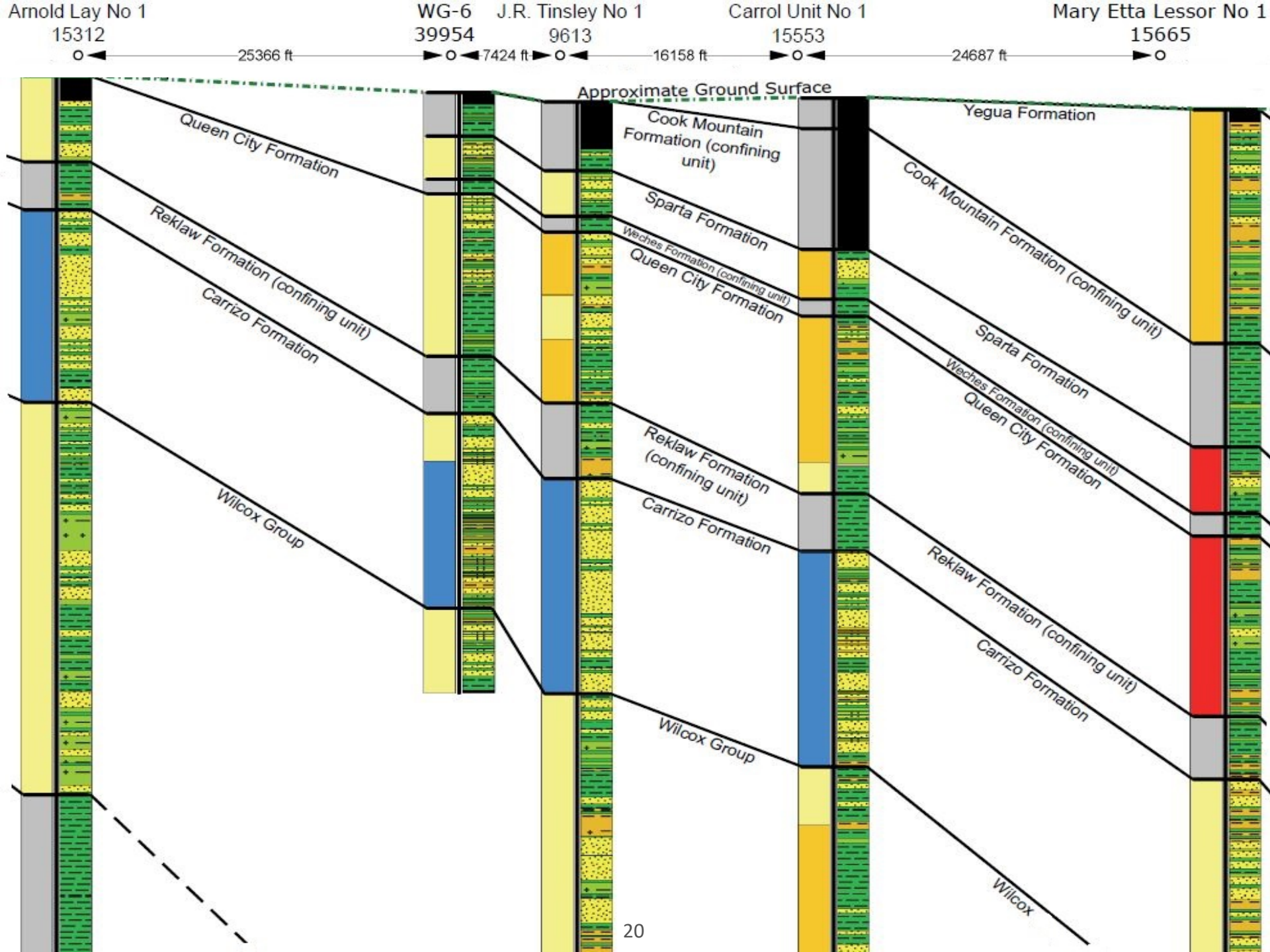
Interpreted salinity class

- Fresh (0-999 mg/L TDS)
- Slightly saline (1,000-2,999 mg/L TDS)
- Moderately saline (3,000-9,999 mg/L TDS)
- Very saline (10,000-34,999 mg/L TDS)
- TDS analysis not performed

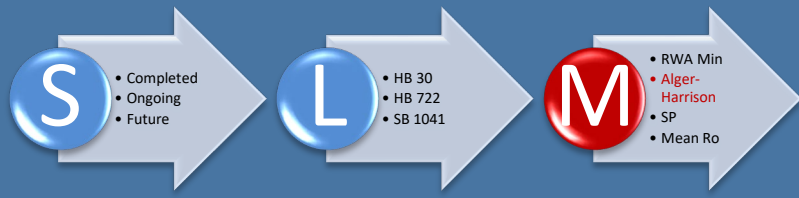
Total Dissolved Solids (TDS) are measured in milligrams per liter (mg/L)

Lithology interpretation

- Sand
- Sand with clay
- Clay with sand
- Clay
- Coal
- Unknown
- Log interpretation not conducted
- No log available for interpretation


Arnold Lay No 1
15312
WG-6
39954
J.R. Tinsley No 1
9613
Carrol Unit No 1
15553
Mary Etta Lessor No 1
15665
25366 ft
7424 ft
16158 ft
24687 ft
Approximate Ground Surface
Queen City Formation
Reklaw Formation (confining unit)
Carrizo Formation
Wilcox Group
Cook Mountain Formation (confining unit)
Sparta Formation
Weches Formation (confining unit)
Queen City Formation
Reklaw Formation (confining unit)
Carrizo Formation
Wilcox Group
Yegua Formation
Cook Mountain Formation (confining unit)
Sparta Formation
Weches Formation (confining unit)
Queen City Formation
Reklaw Formation (confining unit)
Carrizo Formation
Wilcox

Alger-Harrison Method



Based on the ratio of shallow and deep resistivity tools

- assumes deep resistivity is based on native groundwater
- assumes shallow resistivity is based on mud filtrate invasion

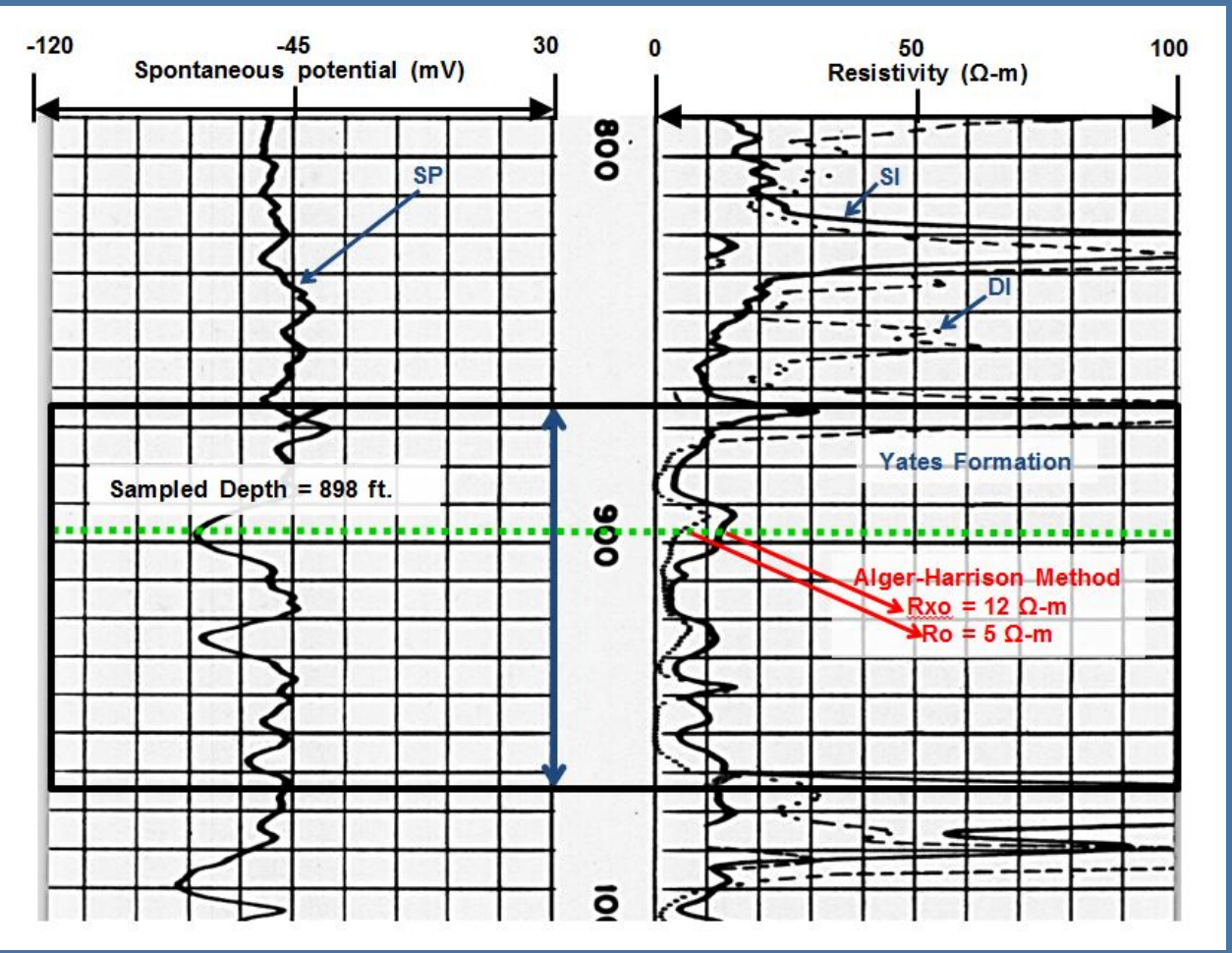
Method modified by John Estepp, P.G.

Requires

- shallow and deep resistivity tools
- mud filtrate resistivity
- temperatures (surface, bottom hole, formation being evaluated)
- ct factor (relates salinity to specific conductance)
- Corrections for mud type and resistivity tool type

Method fully discussed in TWDB Report 384 (Lipan Aquifer) and will be applied to the Hill Country and Plateau Trinity formations

Alger-Harrison Method



Yates Formation

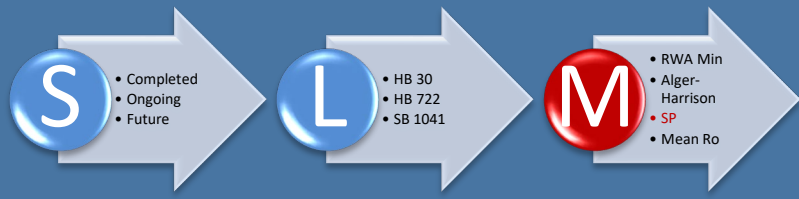
deep resistivity
Ro = 5 ohm-meters

Shallow resistivity
Rxo = 12 ohm-meters

TDS estimated 5,377 mg/L

BRACS Well 35809

SP Method



The SP Method is based on the spontaneous potential tool

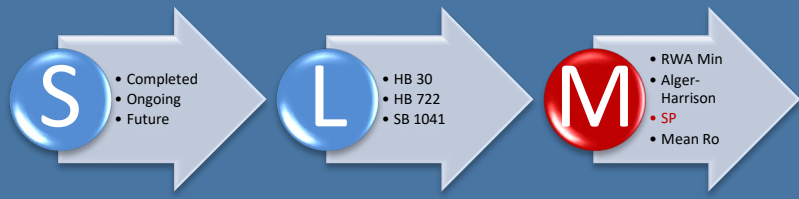
Requires thick uniform bed to obtain maximum SP curve deflection

Method modified by John Estepp, P.G.

Requires

- SP tool
- mud filtrate resistivity
- temperatures (surface, bottom hole, formation being evaluated)
- ct factor (relates salinity to specific conductance)
- Corrections for mud type
- Water quality correction for groundwater less than 3,000 mg/L TDS

SP Method



$R_{we} = 10^{[SSP = K(Log\ Rmf\_Tf)/K]}$

Where

R_{we} = resistivity water equivalent

SSP = Static SP response

R_{mf_Tf} = Resistivity mud filtrate at temperature of formation

K = Constant = 61 = $0.133T_f$

SP Method

TWDB has not been successful in using this method as compared to other authors.

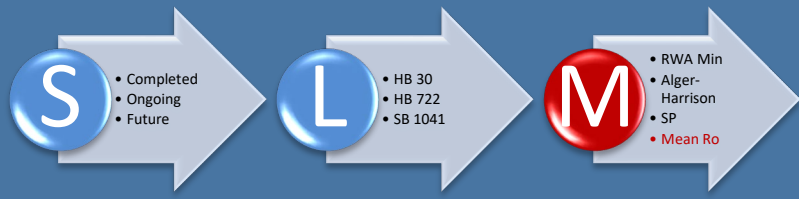
The method is based on high salinity sodium chloride groundwater for oil field applications … the mixed cation – anion groundwater in aquifers may be one problem

It will not work unless there is a significant difference between native groundwater and mud filtrate resistivity

It does not seem to work in carbonate aquifers, as discovered in our Lipan Aquifer study.

Formation clay and mud filtrate invasion has a negative impact on the results

Mean Ro Method



Based on an empirical relationship between formation resistivity and TDS

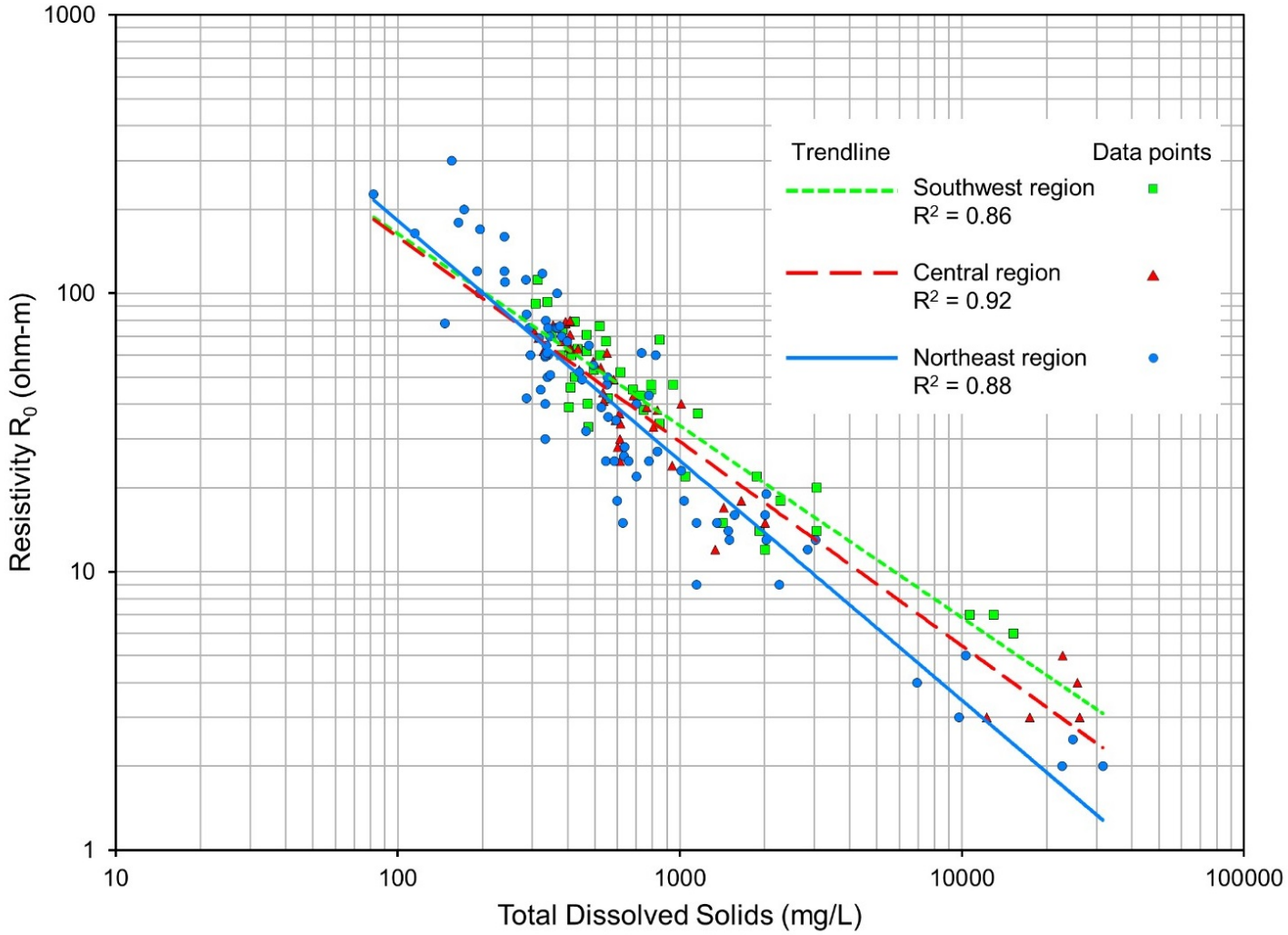
Assumes Ro is proportional to TDS *if* lithology, porosity, pore structure, and cementation exponent of Archie's equation are constant … this is a big IF

This method is designed as a quick look assessment

Two of our contractors used this approach for the Gulf Coast and the Carrizo-Wilcox aquifers … primarily due to time constraints

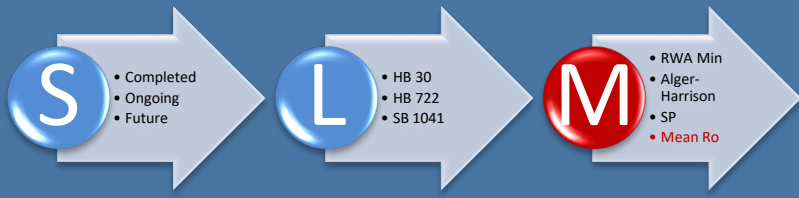
The method worked reasonably well in the 0 – 3,000 mg/L TDS range where there were measured water quality samples

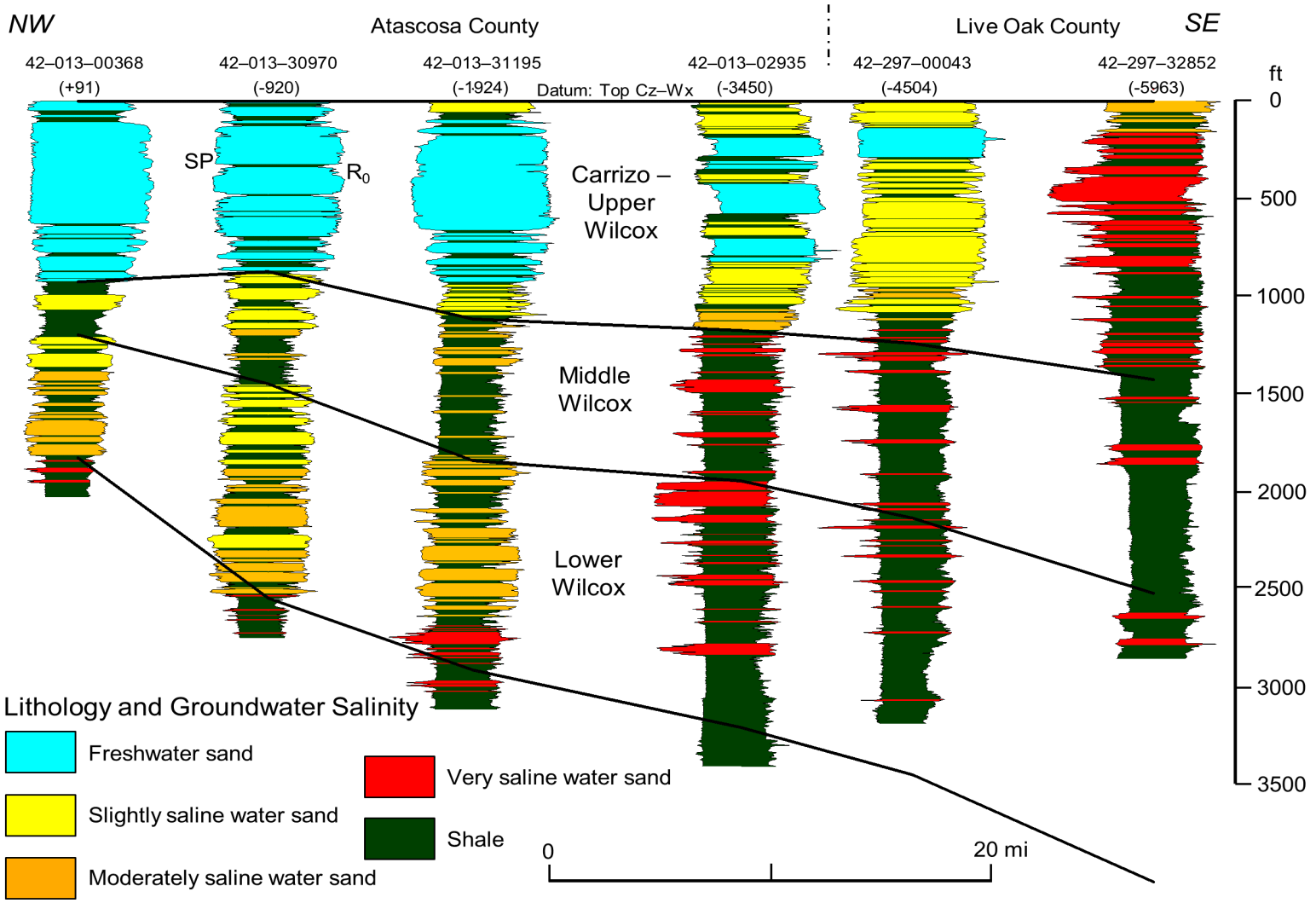
Higher salinity calculations required other methods.



Salinity Classification	Total Dissolved Solids (mg/L)	R_0 Cut-offs (ohm-m)
Freshwater	< 1,000	> 20
Slightly saline water	1,000 – 3,000	9 – 20
Moderately saline water	3,000 – 10,000	4 – 9
Very saline water	10,000 – 35,000	2 – 4
Brine	> 35,000	< 2

Mean Ro Method





Conclusions

Log analysis is critical to mapping salinity of groundwater

Future TWDB contracts will focus on log parameters

Carbonate rocks are especially tricky, and we have a lot of those aquifers!

Several agencies are dependent on these techniques for resource mapping, protection, and permitting

TWDB meets regularly with RRC, TCEQ, BEG, and USGS technical staff to discuss data and techniques

Questions

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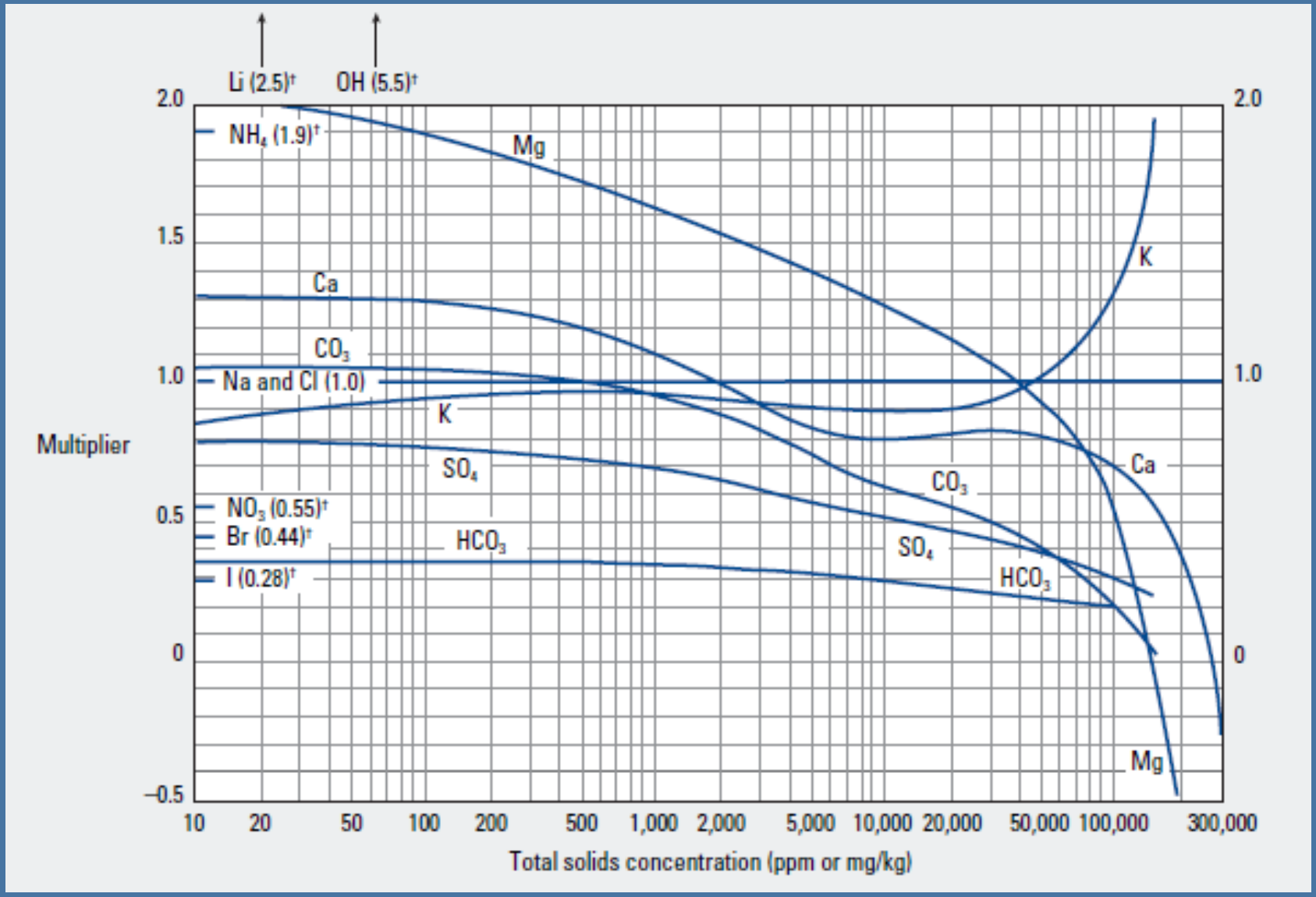
Extra slides



Schlumberger Chart GEN 8 (now Gen 4)

Used to determine NaCl equivalent solutions