Please Pass the Salt:

Using Oil Fields for the Disposal of Concentrate

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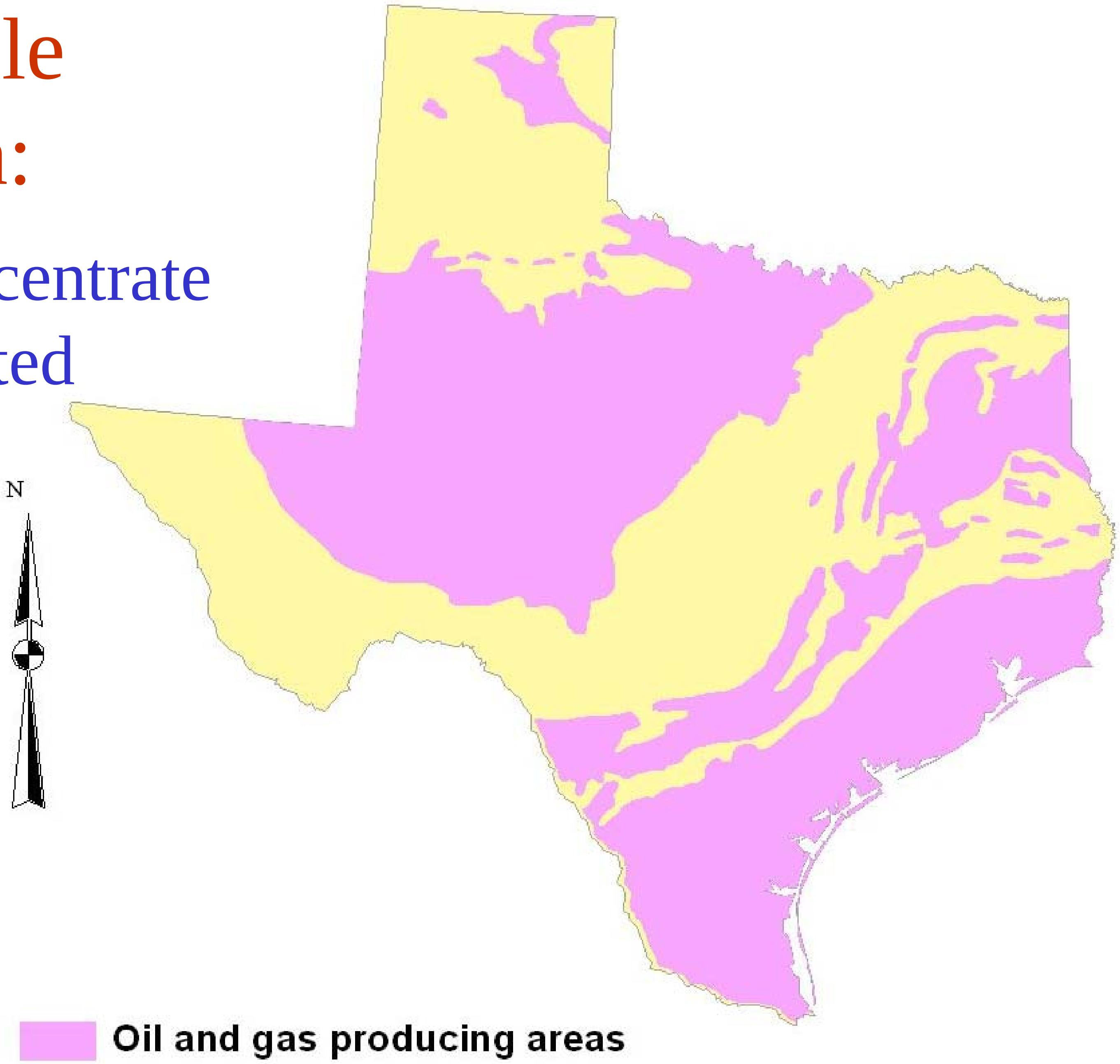
Bureau of Reclamation

The problem:

- Communities interested in desalination need a cost-effective and safe solution for disposing of concentrate.

A possible solution:

- Inject concentrate into depleted oil fields.

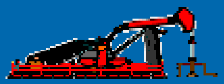


Goal of the project:

To develop the scientific foundation upon which we can support recommended policy change to allow an easier approval path for permitting concentrate injection wells in oil fields.

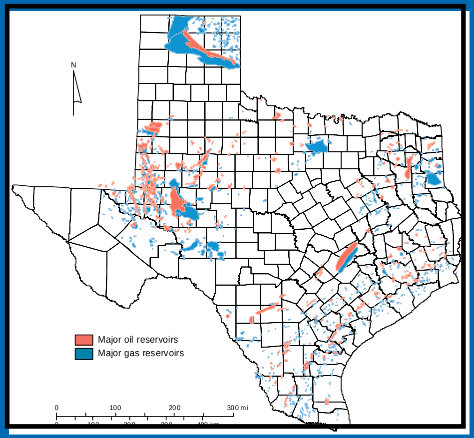
- Show location of oil fields across state that may be potential injection sites.
- Show through physical and geochemical modeling that oil fields can accept concentrate.
- Make a recommendation on how to streamline permitting.

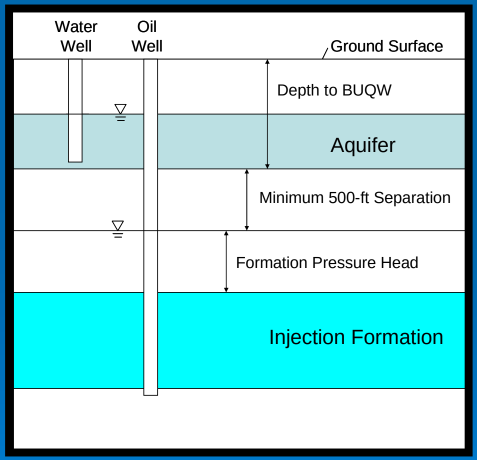
TECHNICAL APPROACH

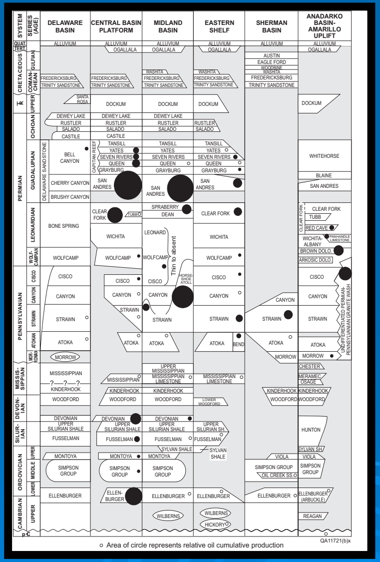


- Identify depleted oil and gas fields
- Historical perspective on fluid injection in oil and gas fields in Texas
- Characteristics of analysis areas
- Characteristics of concentrates
- Formation damage
  - Scaling
  - Clay sensitivity
- Formation damage control
- Injection rates

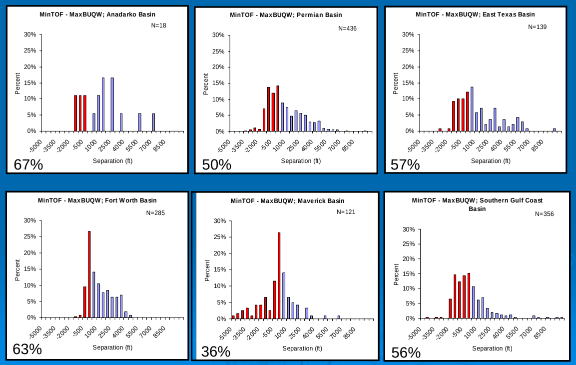
IDENTIFY DEPLETED OIL AND GAS FIELDS







Pressure Depletion and AOR

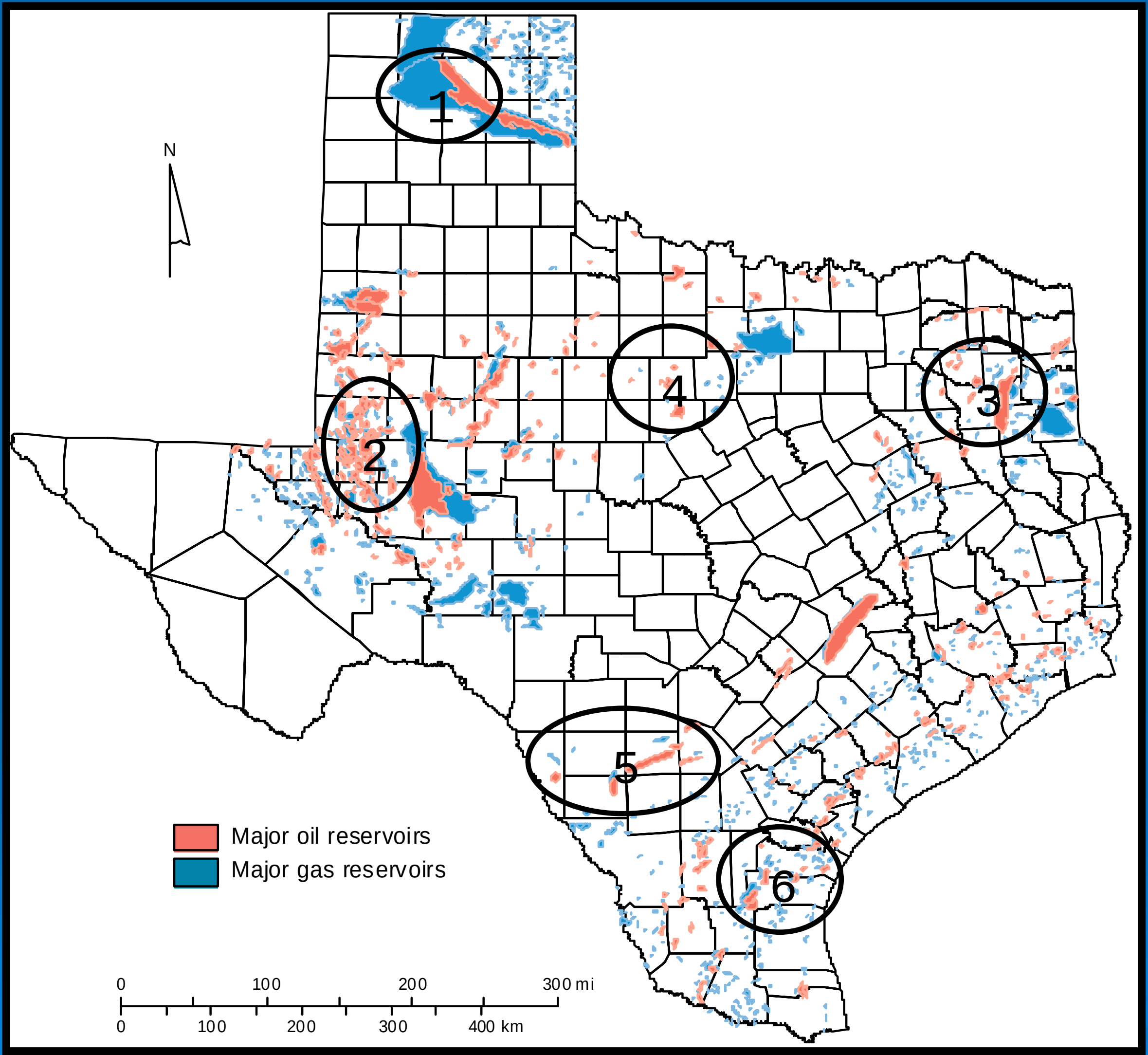


% values represent percentage of fields candidates for a AOR variance

Why Do We Care about Pressure Depletion?

- Create opportunity to inject fluid with little risk of exceeding maximum pressure that can be sustained by reservoir
- Simplify Area of Review Process
- Field production history guarantees surface infrastructure needed to move around fluids

Major Oil and Gas Reservoirs



Analysis Areas

1 Anadarko

2 Permian

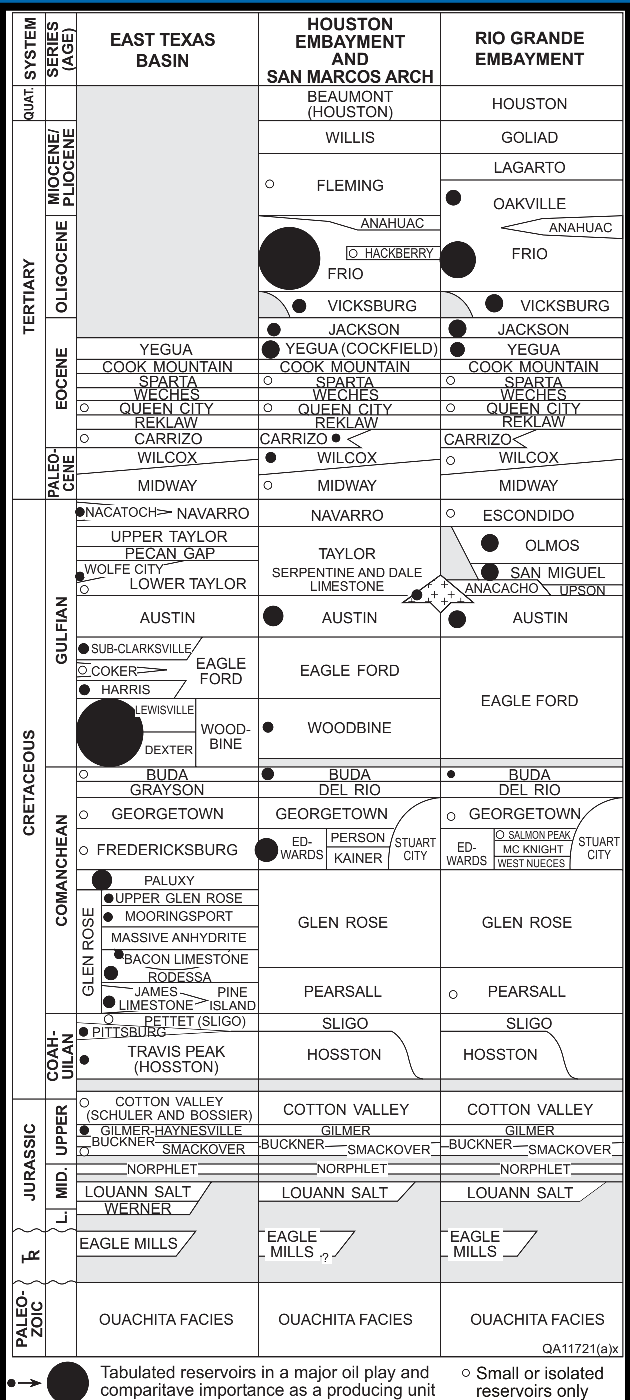
3 East Texas

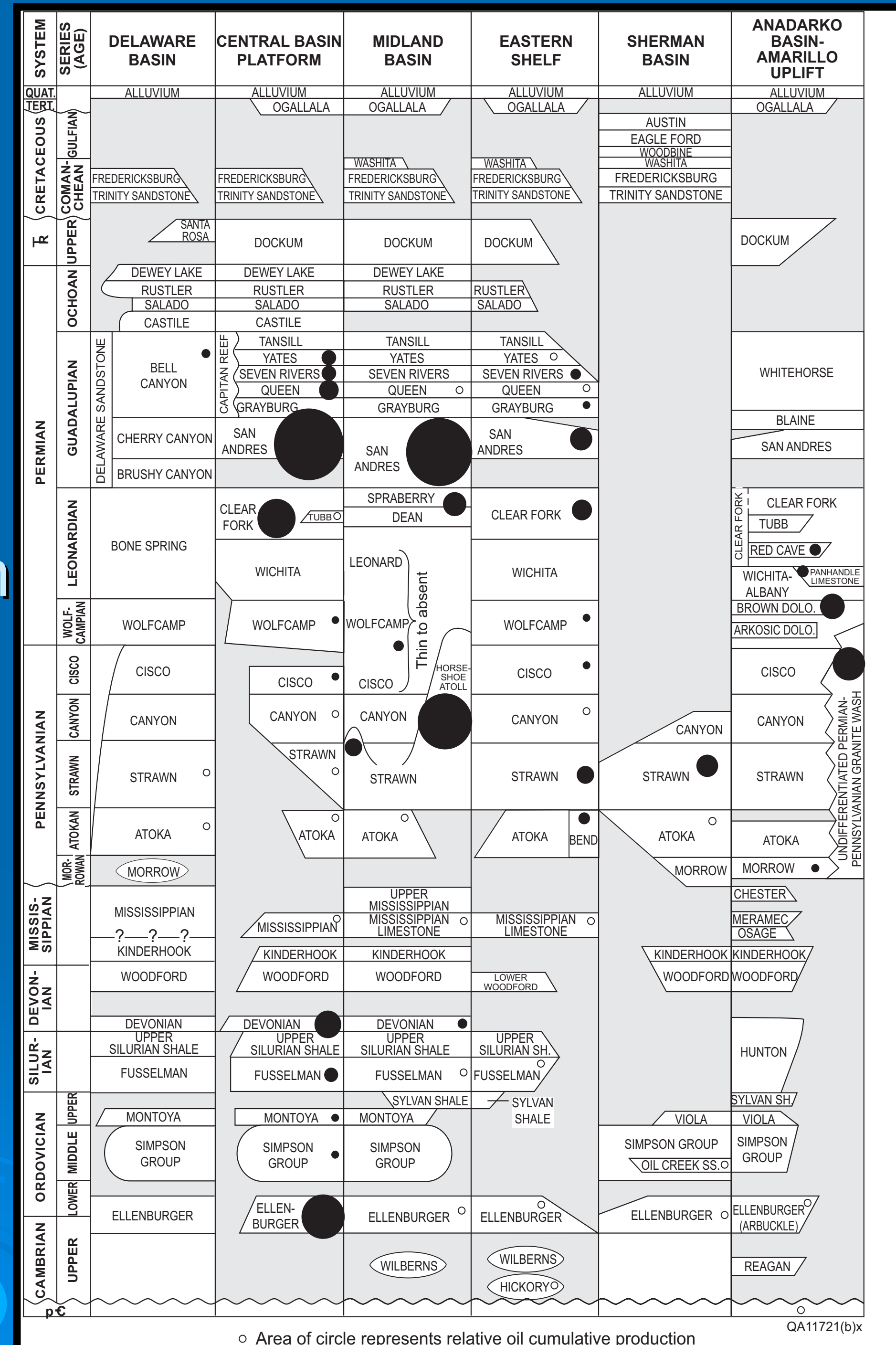
4 Fort Worth

5 Maverick

6 Southern Gulf Coast

Selected Strati-graphic Columns in Texas with Oil Production

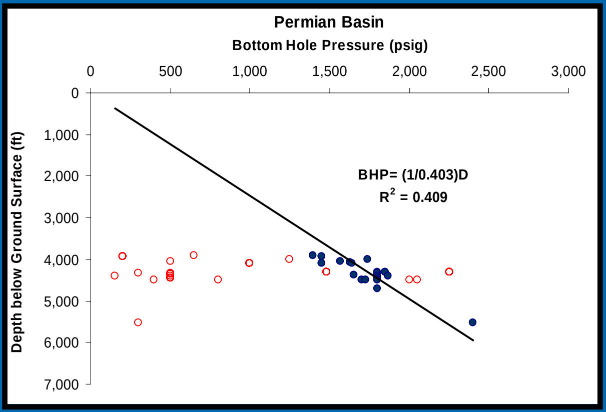


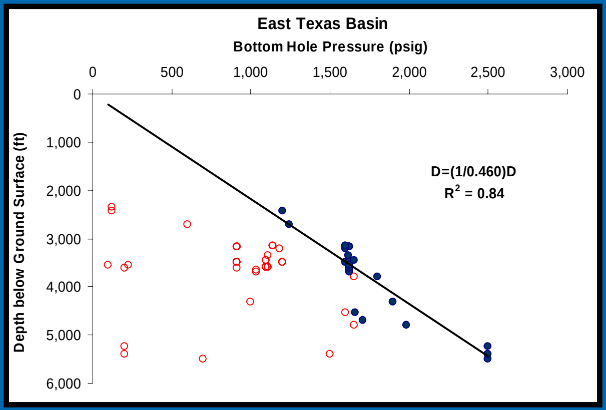


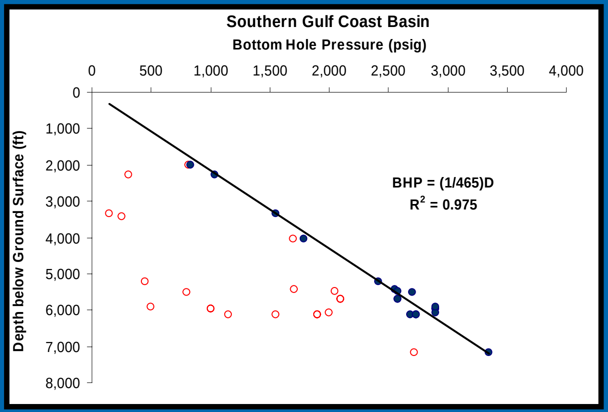
Target Formations

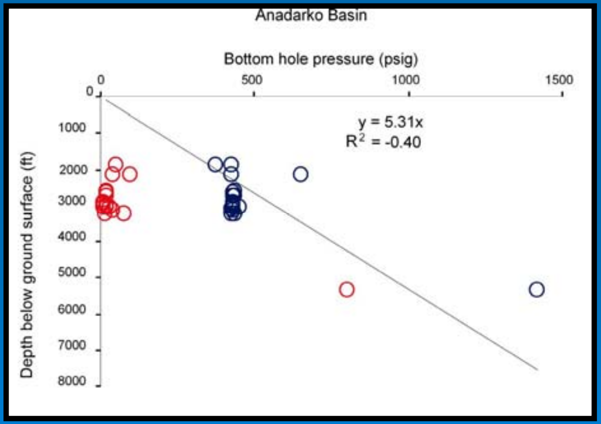
- Anadarko B.:
  Granite Wash Fm.
- Fort Worth B.:
  Atoka Fm.
- Permian B.:
  San Andres Fm.
- Maverick B.:
  San Miguel/Olmos Fm.
- East Texas B.:
  Woodbine Fm.
- Southern Gulf Coast B.:
  Frio Fm.

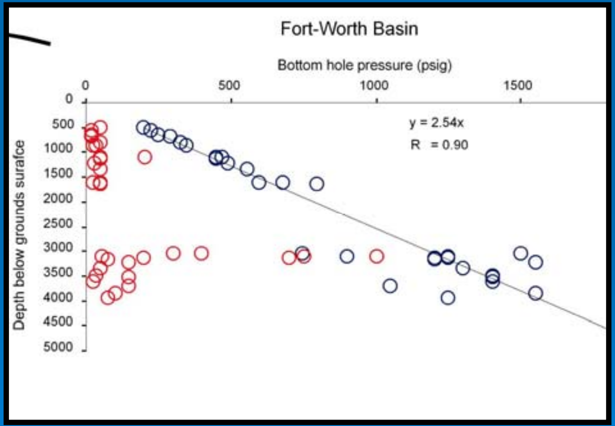
Pressure-depleted Fields

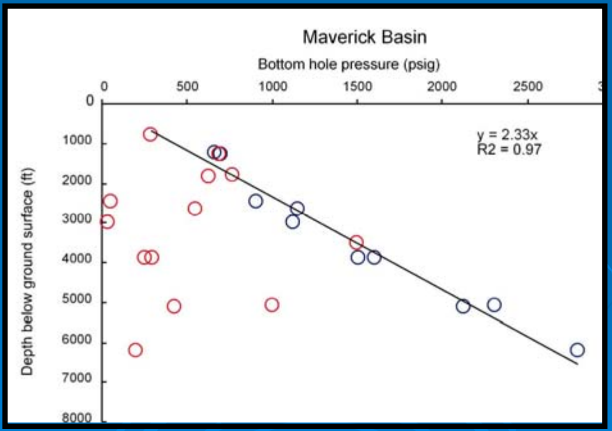




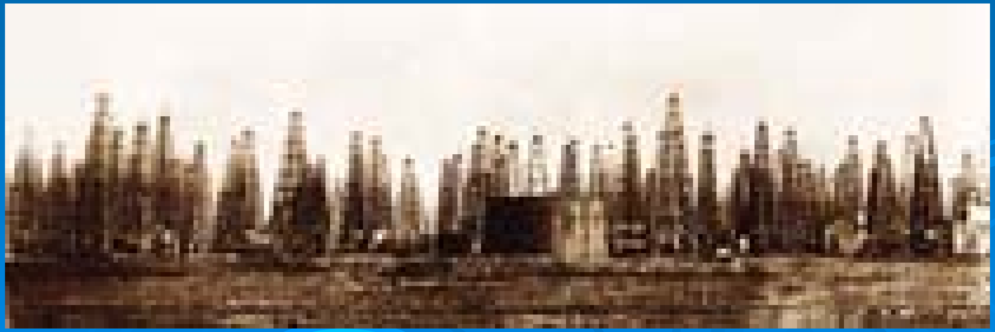






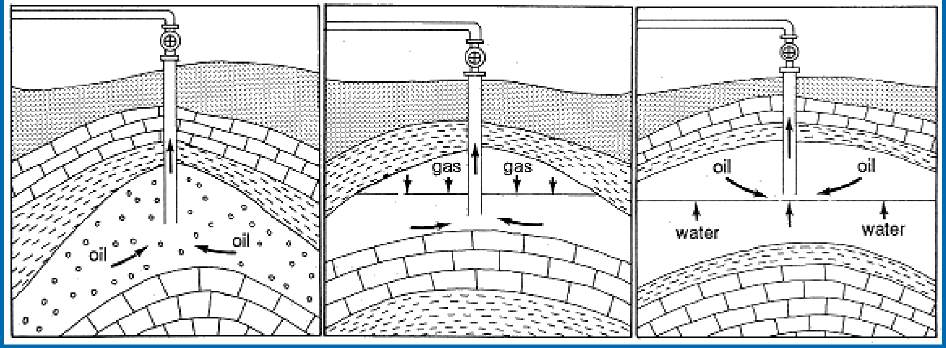


HISTORICAL PERSPECTIVE ON OIL AND GAS FIELDS IN TEXAS



Water Injection in Oil&Gas Fields

- Reservoir drive mechanisms in oil&gas fields:
  - Water drive
  - Gas cap drive
  - Solution gas drive

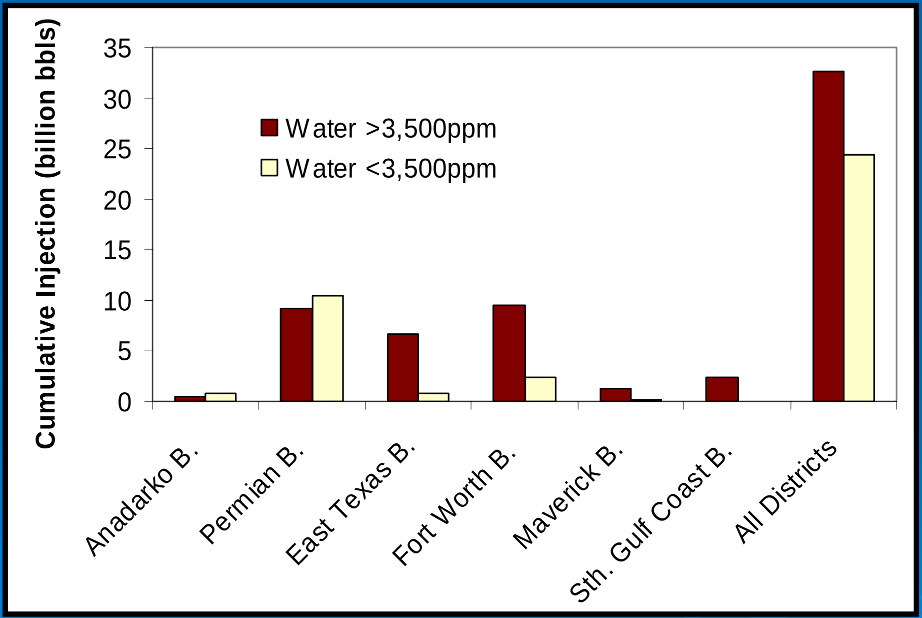


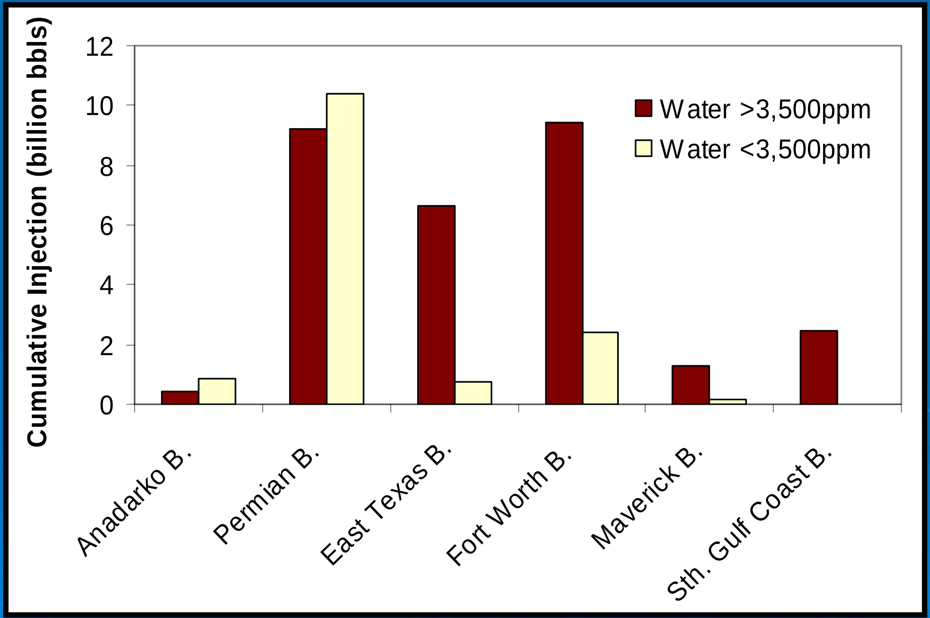
- Pressure maintenance and waterflooding with fresh, brackish, or produced waters
- Fresh water needs no treatment before injection
- Fresh water reduces or eliminates scaling in pipes but could generate downhole scaling and/or fine plugging

Source for figure: http://www.kgs.ukans.edu/Publications/Oil

Injection Historical Data

- Data compilation up to 1982

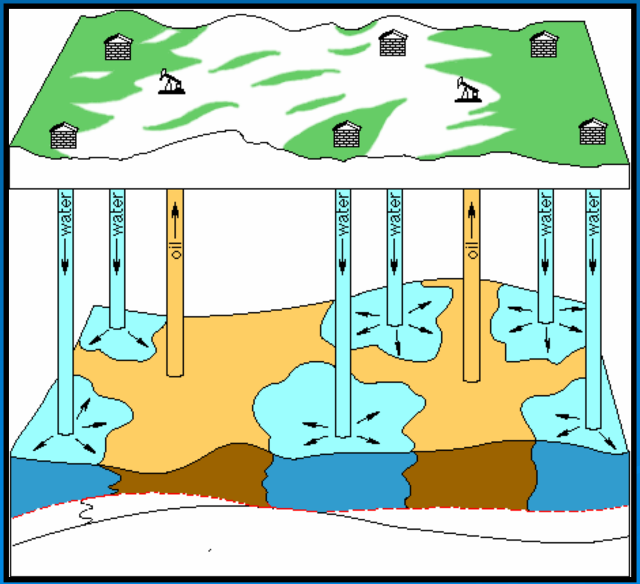


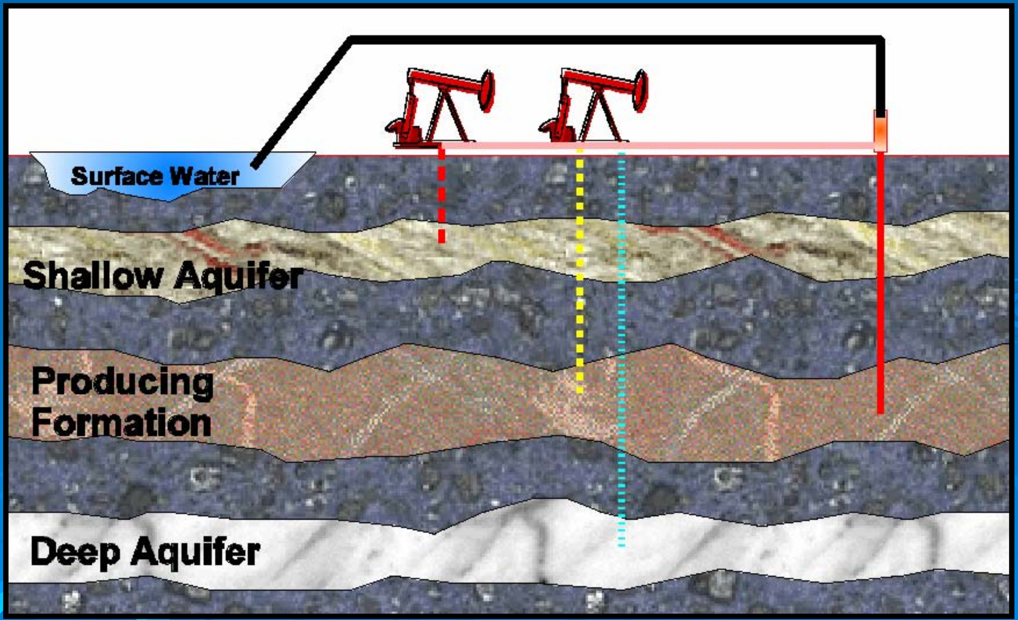


From RRC database (1982) – last year with data compilation

Conclusions

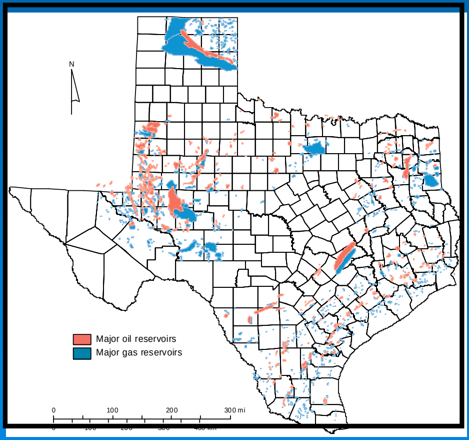
- Oil and Gas industry in Texas has an extensive experience with fluid injection
- Fluids include fresh, brackish and saline waters

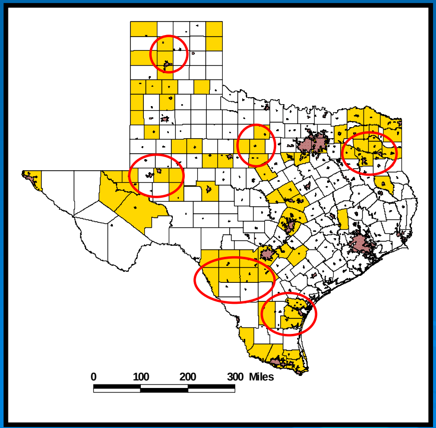


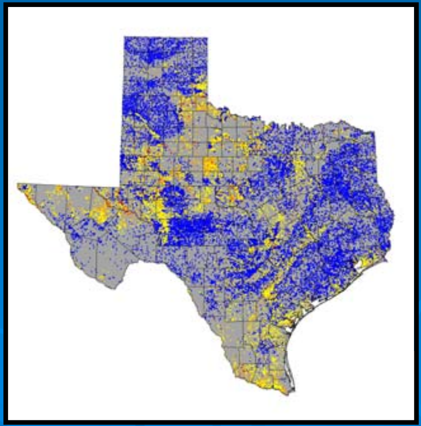
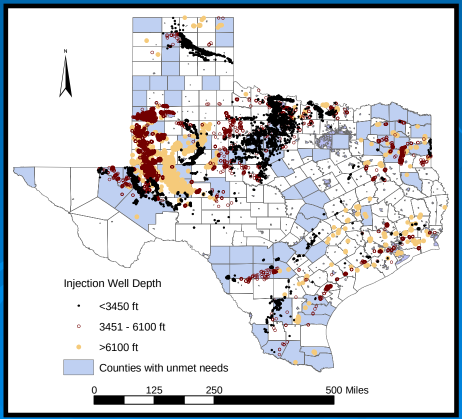


Source: Hycal.com

SELECT ANALYSIS AREAS



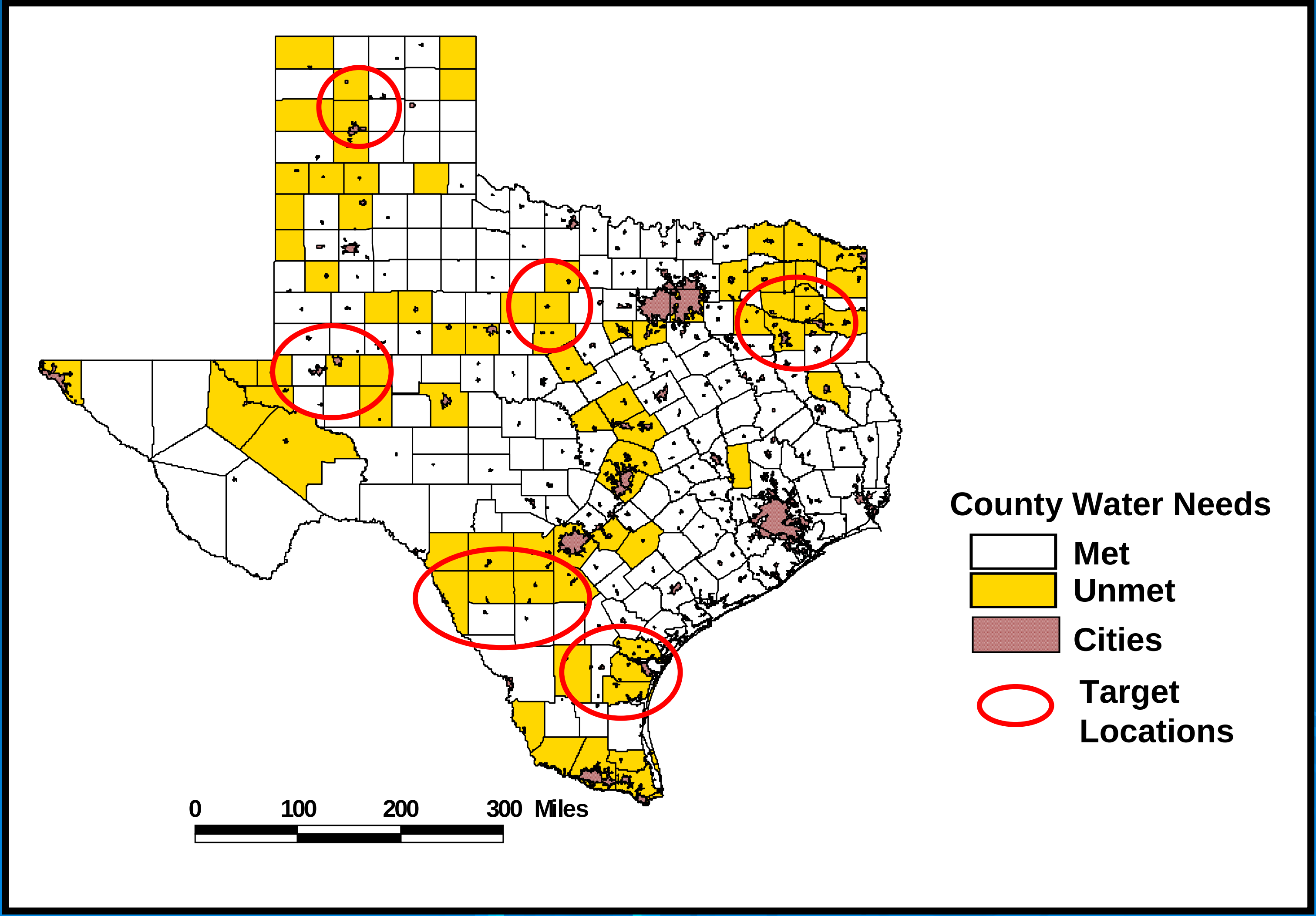


Analysis Area Selection Criteria

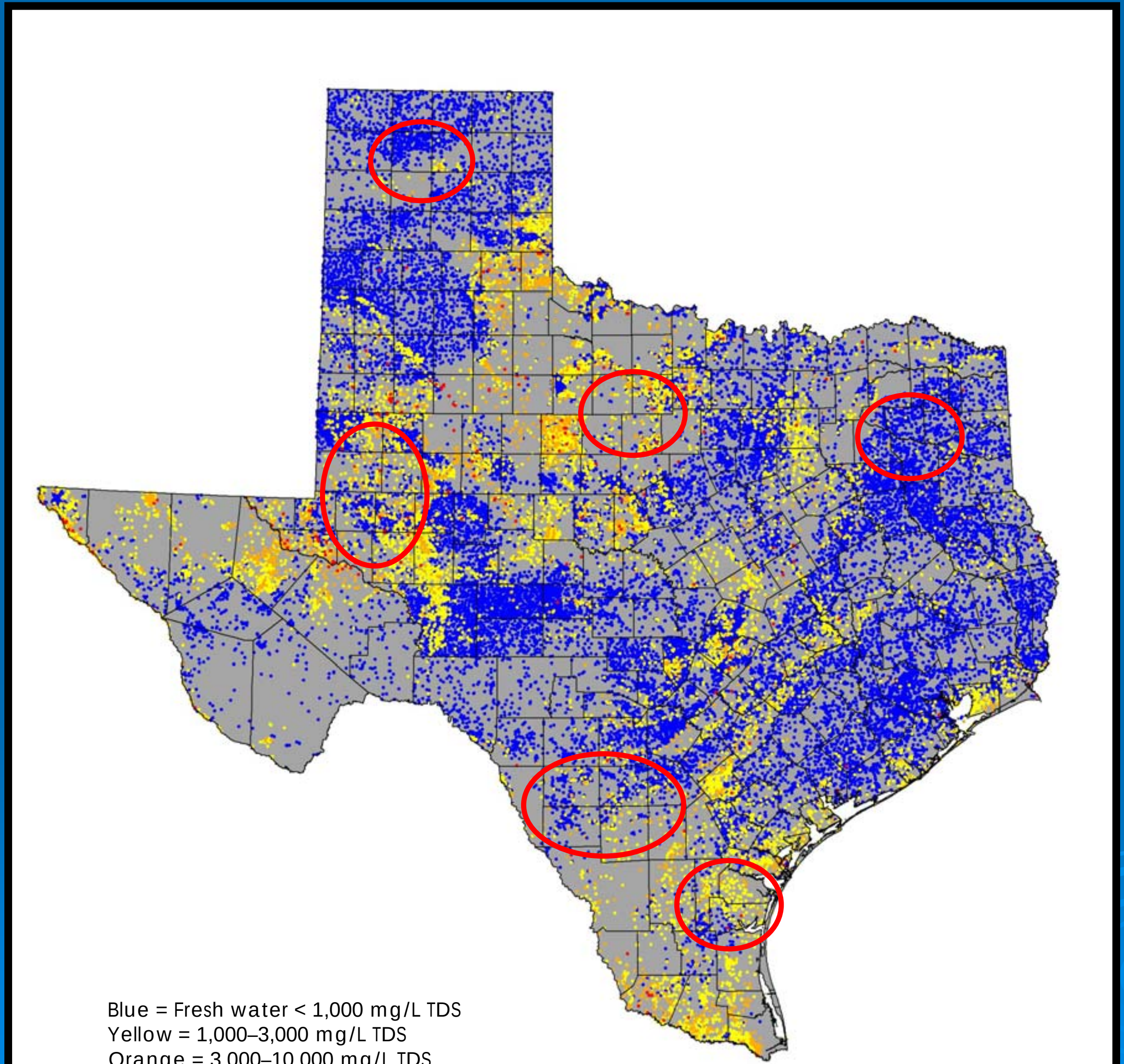
- Counties with depleted oil/gas fields
- Counties with a predicted shortfall of water supply over the next 50 years
- Counties with brackish ground water resources
- Counties with injection wells not too deep

County Water Needs



Source: TWDB, 2002 Water for Texas

Water Quality of Shallow Groundwater

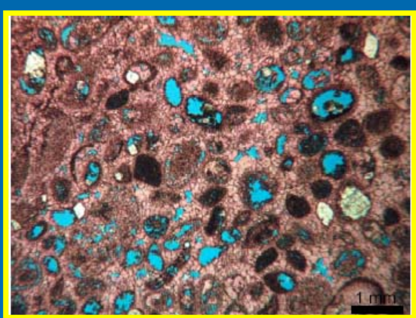


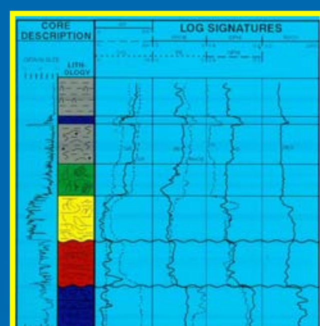
From LBJ Guyton Associates (2003)

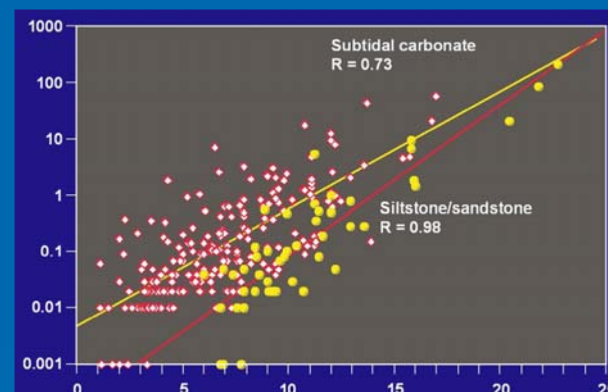
Target Brackish Water Sources

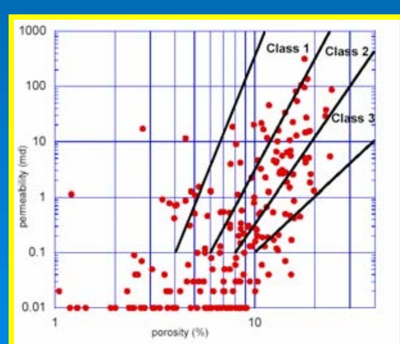
- Anadarko B.:
  - Ogallala Aq.
  - Dockum Aq.
- Permian B.:
  - Ogallala Aq.
  - Dockum Aq.
- East Texas B.:
  - Carrizo-Wilcox Aq.
- Fort Worth B.:
  - Trinity Aq.
- Maverick B.:
  - Carrizo-Wilcox Aq.
- Southern Gulf Coast B.:
  - Gulf Coast Aq.

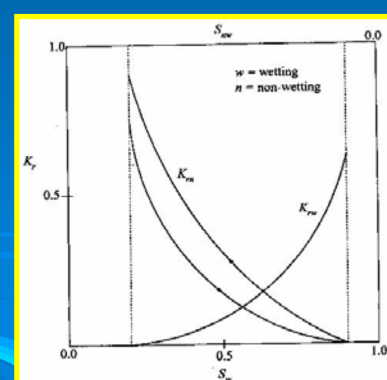
CHARACTERISTICS
OF
ANALYSIS AREAS

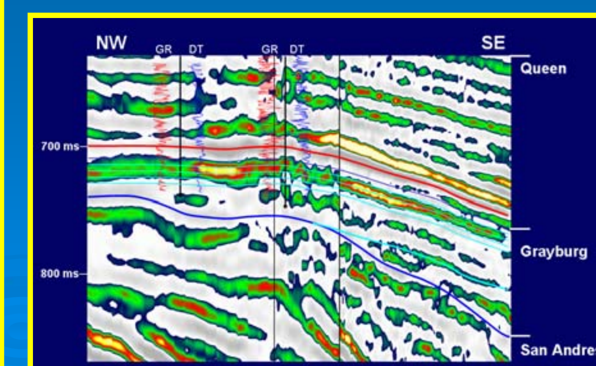












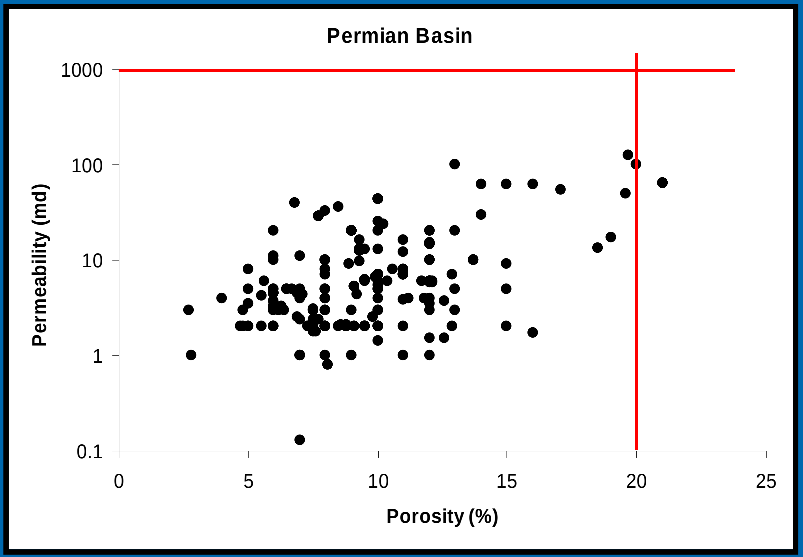
Important Parameters

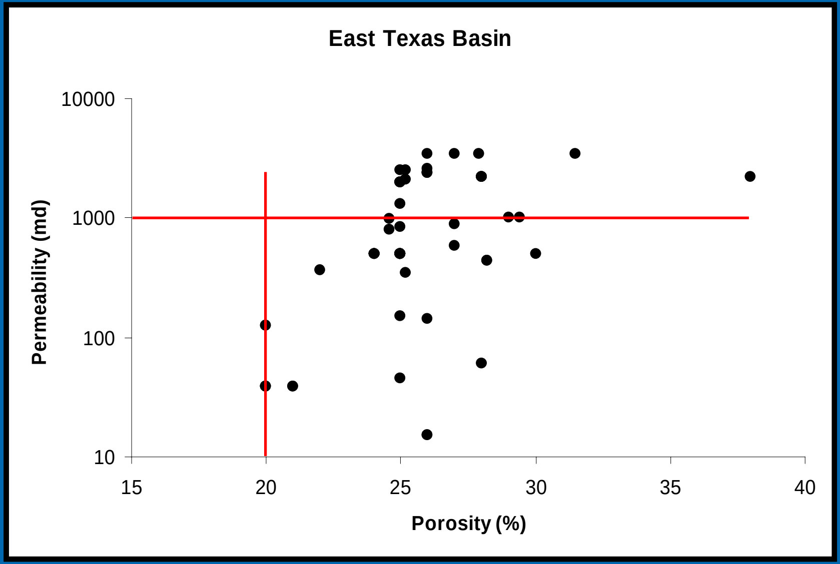
- Lithology/Mineralogy:
  - Rock type
  - Mineral in contact with flowing fluids
  - Clay content and nature
- Formation water composition
- Flow properties:
  - Porosity, permeability
  - Other fluid present (relative permeability)
- Field characteristics
  - Pay thickness
  - Geothermal gradient
  - Average pressure and depth

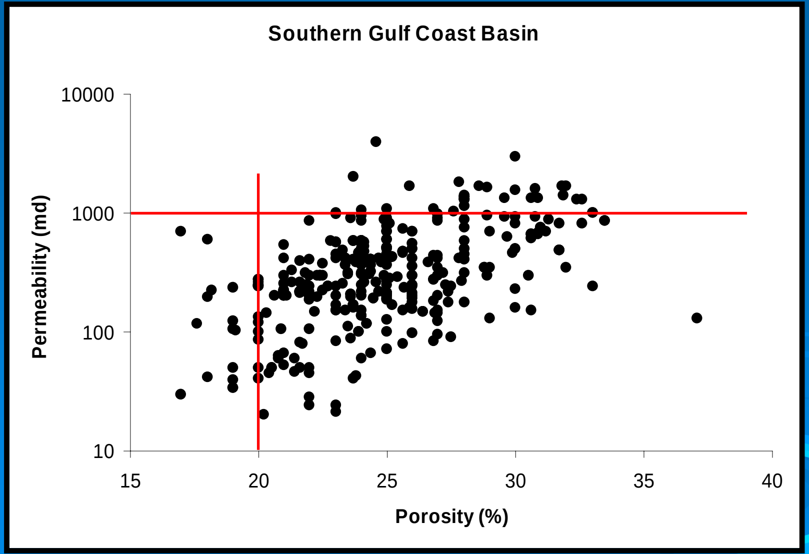
Mineralogical Characteristics of Analysis Areas

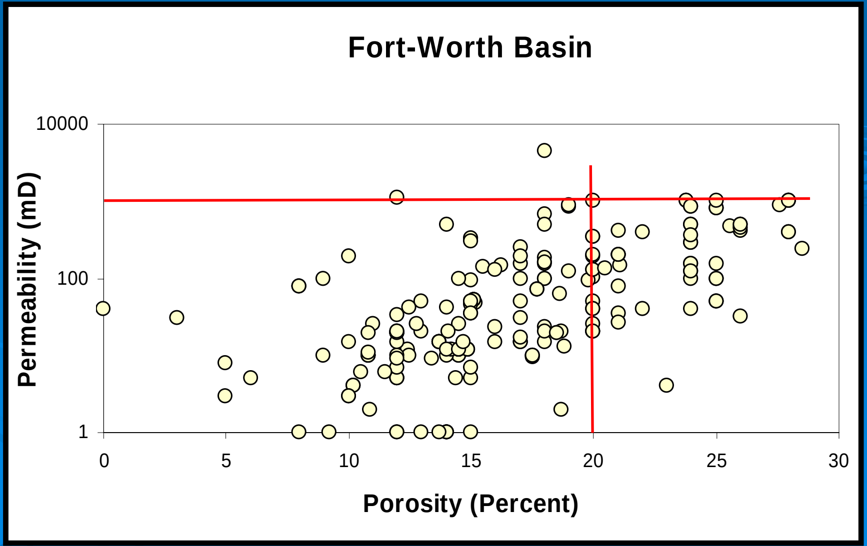
Basin	Rock Type	Important Minerals
Anadarko	Silico-clastic	Feldspars, quartz, clays
Permian	Carbonate	Calcite, dolomite
East Texas	Silico-clastic	Feldspars, quartz, clays
Fort Worth	Silico-clastic	Quartz, feldspars
Maverick	Silico-clastic	Quartz, feldspars
S. Gulf Coast	Silico-clastic	Feldspars, quartz, clays

Porosity/Permeability of Analysis Areas







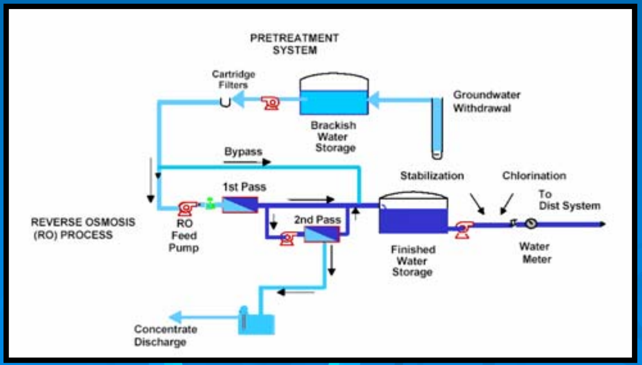


Median and Range of Porosity/Permeability

Basin	Porosity (%)	Permeability (mD)
Anadarko	~12 (4 - 20)	~20 (6 – 65)
Permian	~9.3 (<3 - >20)	~5 (1 - >100)
East Texas	~25 (20 - >35)	~500 (15 - >3,000)
Fort Worth	~14.5 (6 – 28)	~20 (1 - >1,000
Maverick	~25 (19 -32)	~30 (3 - >2,000)
S. Gulf Coast	~25 (<15 - >35)	~305 (20 - >1,000)

CHARACTERISTICS OF CONCENTRATES

2 MGD Oceanside, CA RO Installation



From R.W. Beck

12 MGD Sarasota, FL EDR plant

Concentrate

- Most feed water TDS between 1,000 and 3,000 mg/L
- Concentration factor of 4 (all ions have the same rejection rate)
- Closed system (no equilibration with CO_2)
- Two cases:
  - Addition of antiscalant
  - Addition of antiscalant and sulfuric acid to a pH=6
- Difficulty in obtaining minor element (Si, Fe, Ba, Sr) concentrations

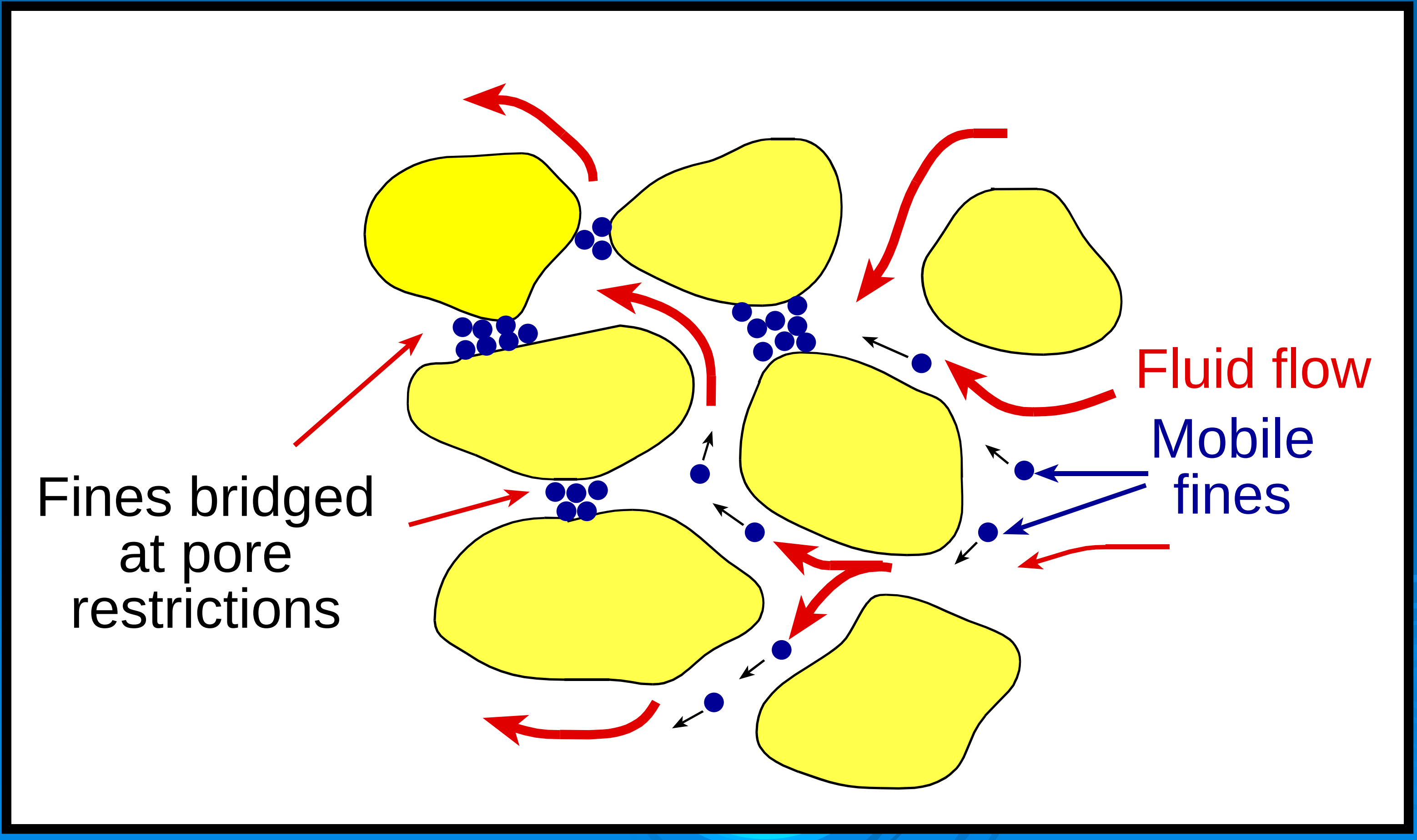
FORMATION DAMAGE

Formation Damage Definitions

- A condition that occurs when barriers to flow develop in the near-wellbore region. Results in lower than expected production rate from (or injection rate into)
- Any process causing a reduction in the natural inherent productivity or injectivity of a producing or injection well

Mechanical Formation Damage

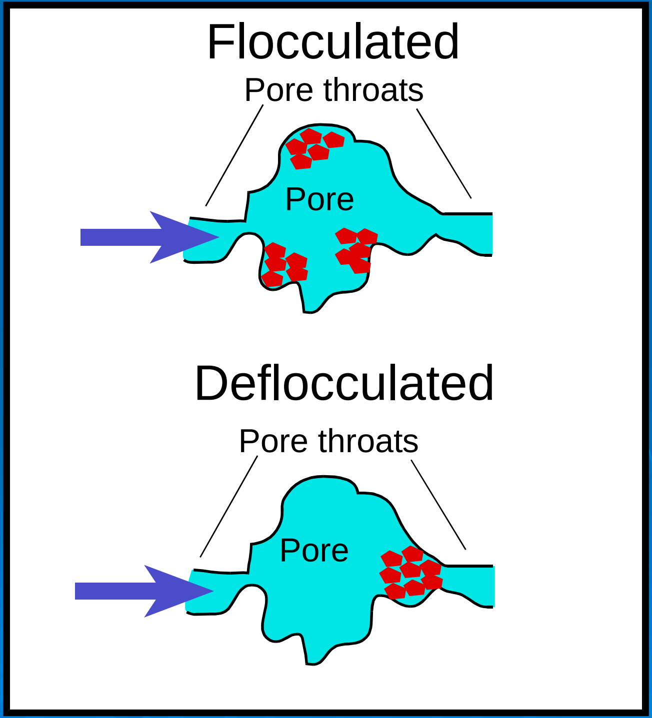
- Origin: injected suspended solids, formation fine migration plugging pore throats



Mod. From Michael Dixon
OMNI Laboratories, Inc.

Chemical Formation Damage

- Origin1: deflocculation of clays, swelling of clays due to chemical changes (pH, ionic makeup)
- Origin2: formation of scales due to mixing of incompatible water and change in environmental conditions



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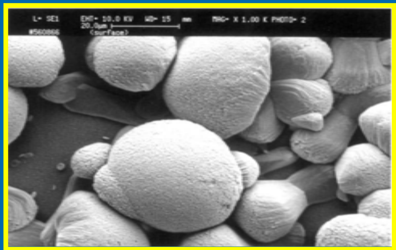
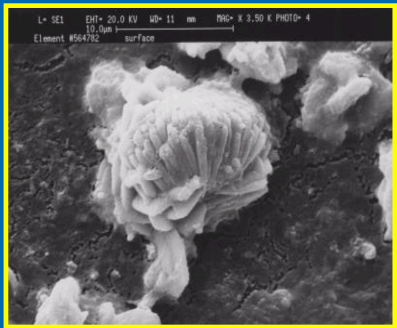
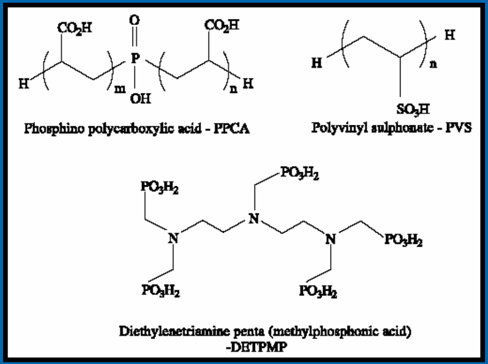
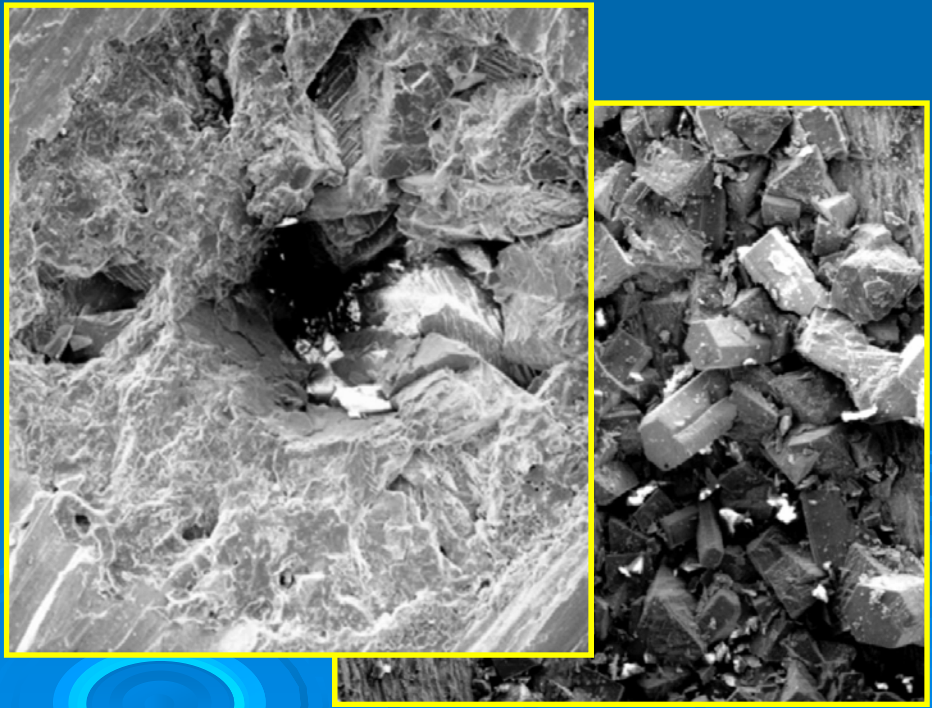




UCLA, Cohen et al

SCALING





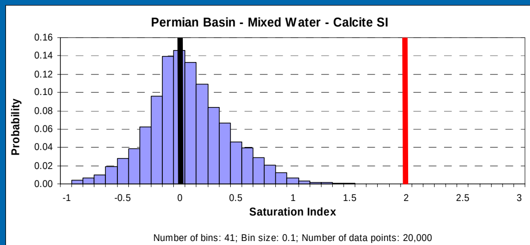
What is scaling?

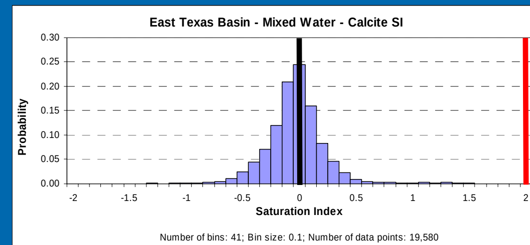
- Precipitation of minerals in the wellbore or in the formation.
- Calcite, gypsum, barite, silica (iron oxides, brucite, siderite, anhydrite, strontianite)
- Term also applies to corrosion products
- Fluid injection is typically less scale-prone than production

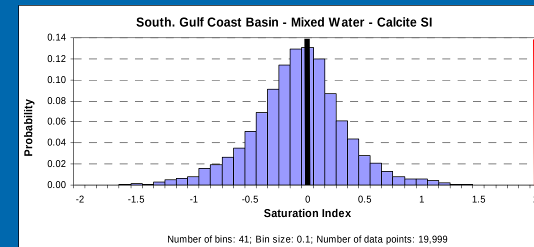
Approach

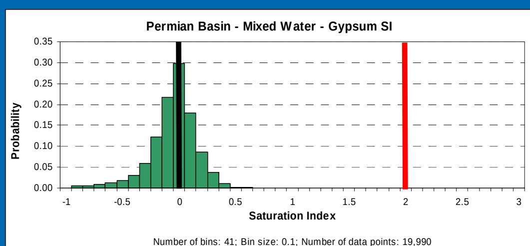
- Compute concentrate composition with the USGS geochemical code PHREEQC using standard industry pretreatment and a factor of 4
- Mix in different proportions concentrate with formation water with the USGS geochemical code SOLMINEQ (able to handle high salinity fluids)
- Choose randomly 2x5,000 samples to mix
- Analyze statistically (histograms) saturation index for relevant minerals of resulting combinations
- Determine the fraction of mixing combinations above the *SI* threshold beyond which antiscalants are not effective

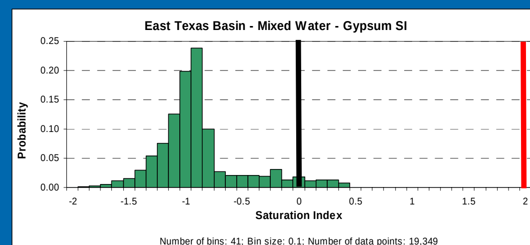
Examples of *SI* Histograms

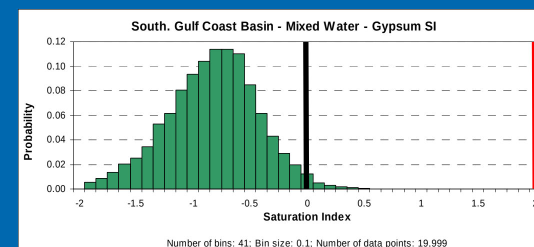


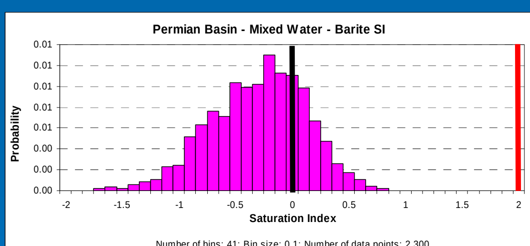


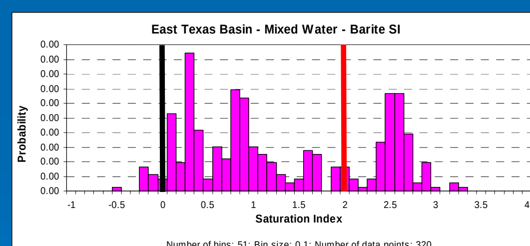


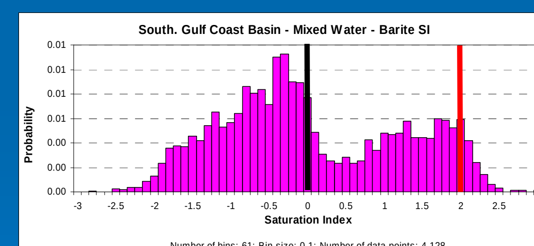


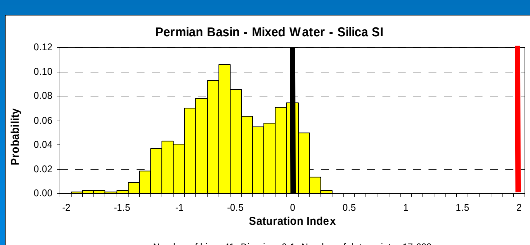


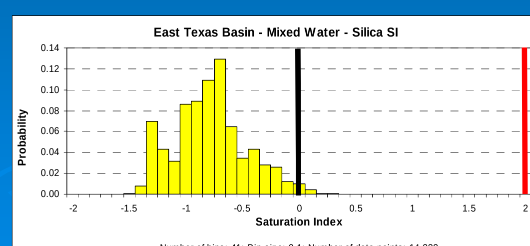


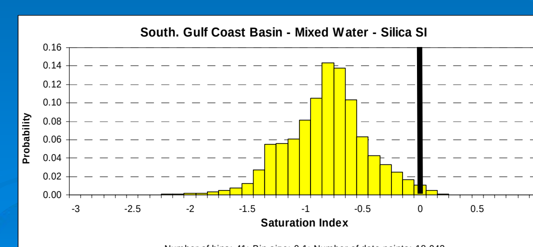






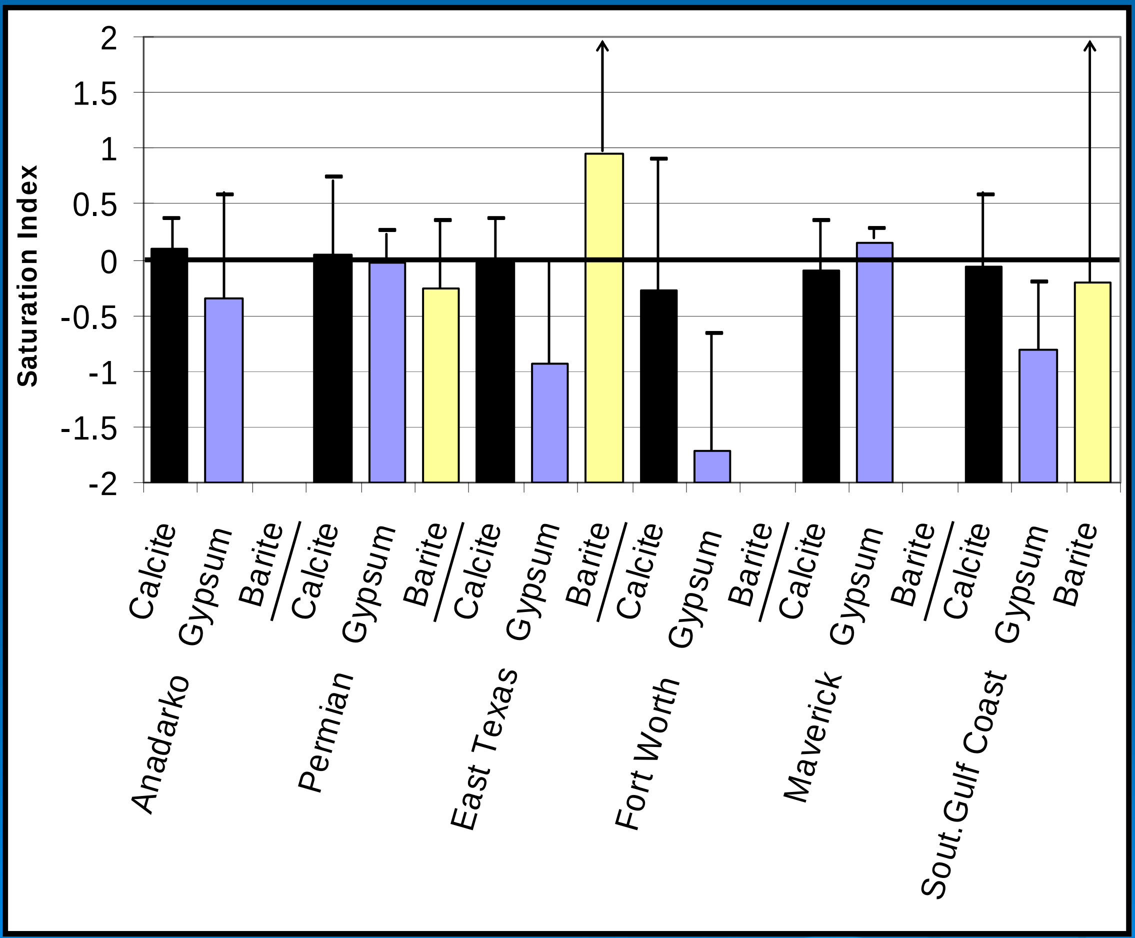






With acidified concentrate

Summary of *SI*'s of Mixing Combinations



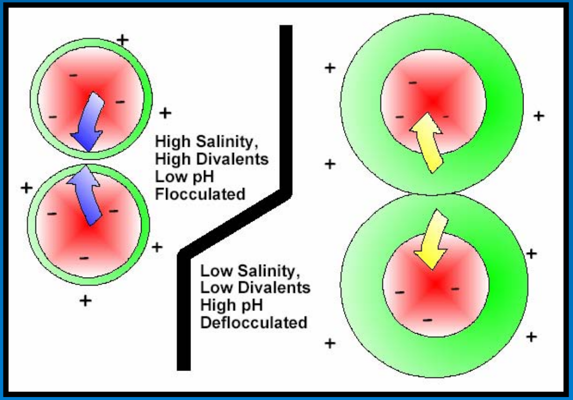
Median and 95th percentile
With acidified concentrate

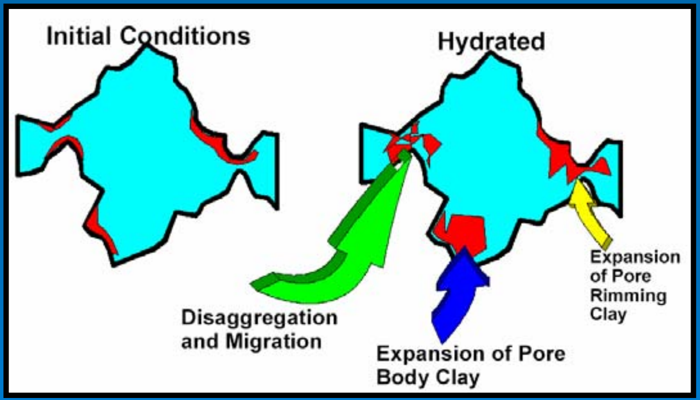
- Most *SI* are <1 including amorphous (colloidal) silica
- Barite may be a problem locally (*SI* is also higher because of H_2SO_4)

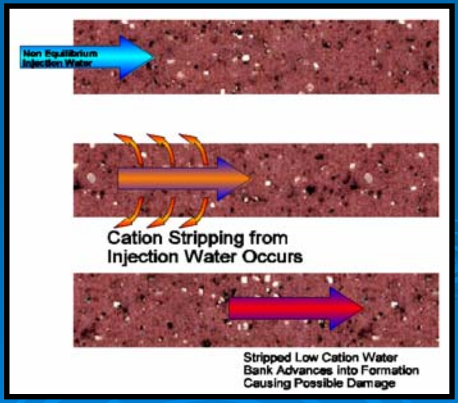
Scaling Discussion

- Previous results assume thorough mixing between concentrate and formation water
- This is conservative because mixing is likely to be less than thorough owing to ~piston flow of concentrate displacing formation water

CLAY SENSITIVITY



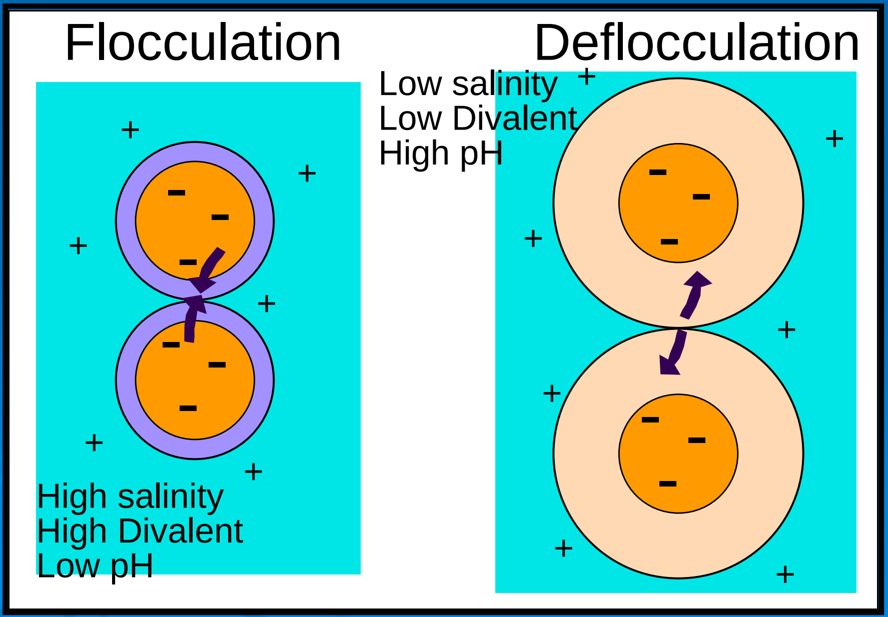




Source: hycal.com

What is Clay Sensitivity?

- Clay sensitivity is due to the ability of clays to exchange ions with surroundings and/or to absorb water (swelling)
- A change in environmental conditions (ionic makeup, salinity, pH) may also disperse clay particles (deflocculation)
- Before injection, two questions need to be answered:
  - Is there any clay?
  - What type of clay?

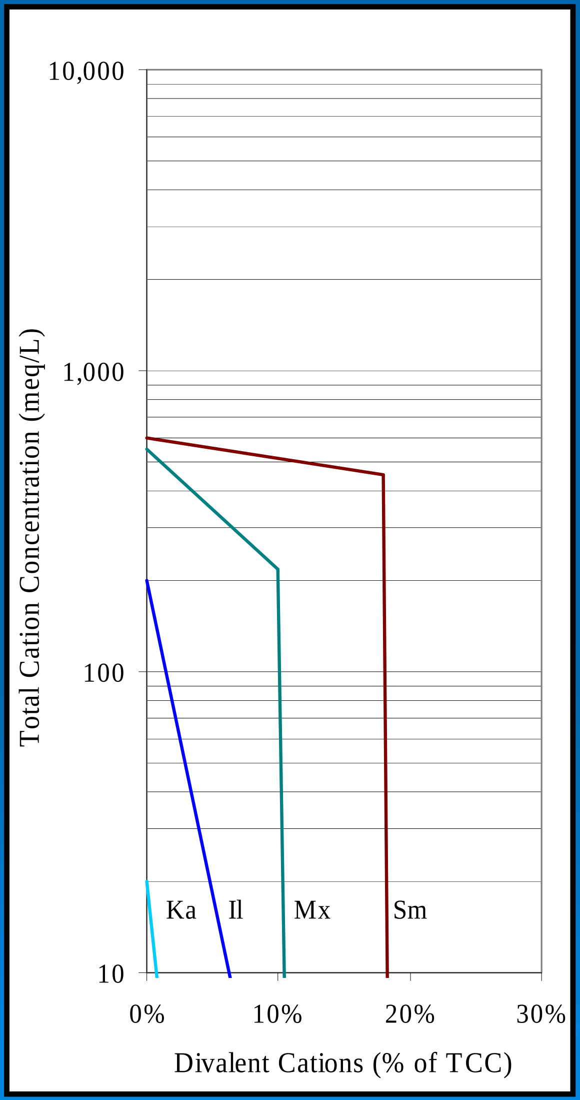


Mod. From Michael Dixon OMNI Laboratories, Inc.

Clay Types in Analysis Areas

Basin	**Clay Abundance**	**Clay Type**
Anadarko		Chlorite, illite , kaolinite
Permian	Rare	Kaolinite
East Texas	Common	Smectite, illite, chlorite, kaolinite
Fort Worth		Chlorite, illite, kaolinite
Maverick	Abundant	Mx-layer illite-smectite, chlorite, kaolinite
S. Gulf Coast	Abundant	Mx-layer illite-smectite, smectites, kaolinite

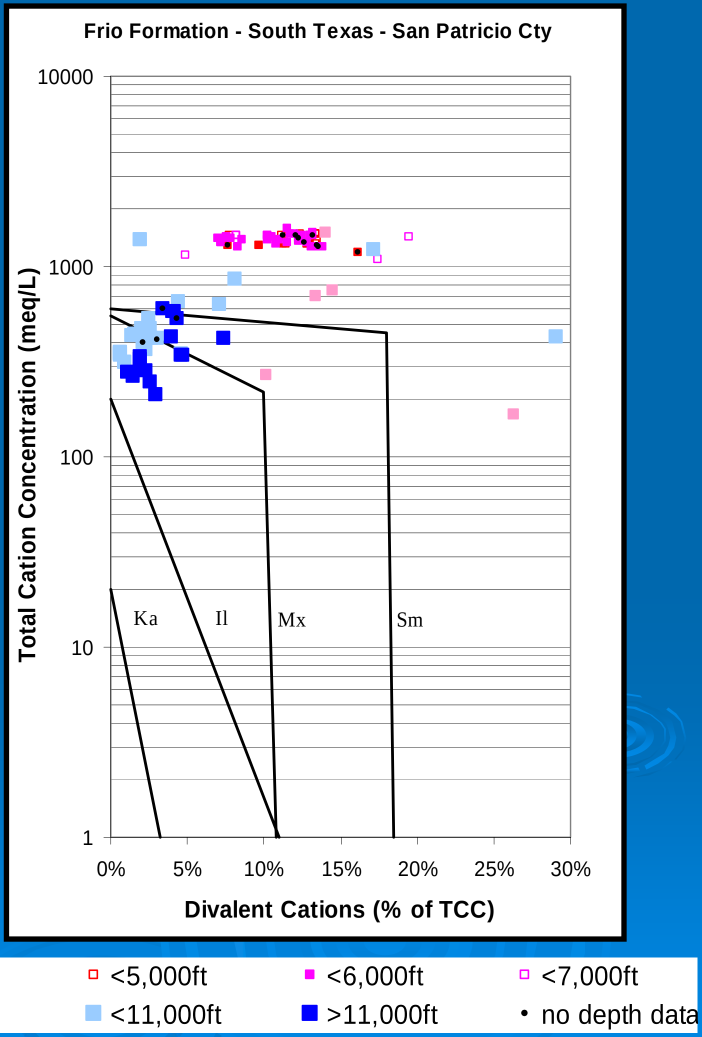
Clay Sensitivity Principles



Ka=kaolinite
Il=illite
Mx=mixed layers;
Sm=smectite
TCC=Total Cation Conc.

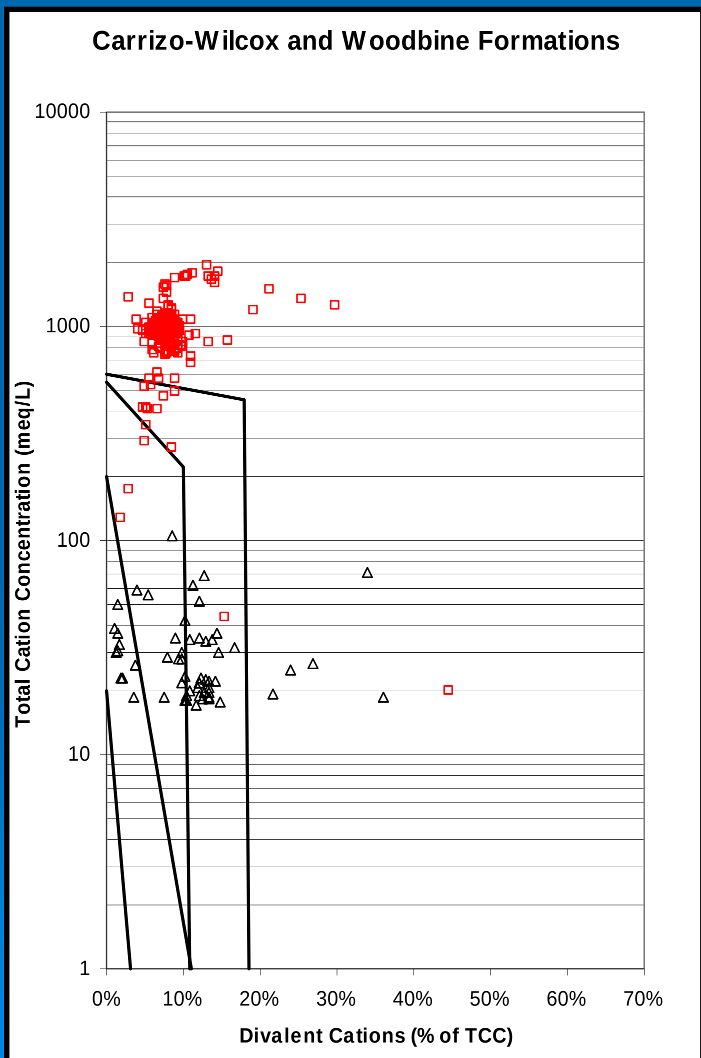
Any water inside the delineated domain will deflocculate the corresponding clay at equlibrium.

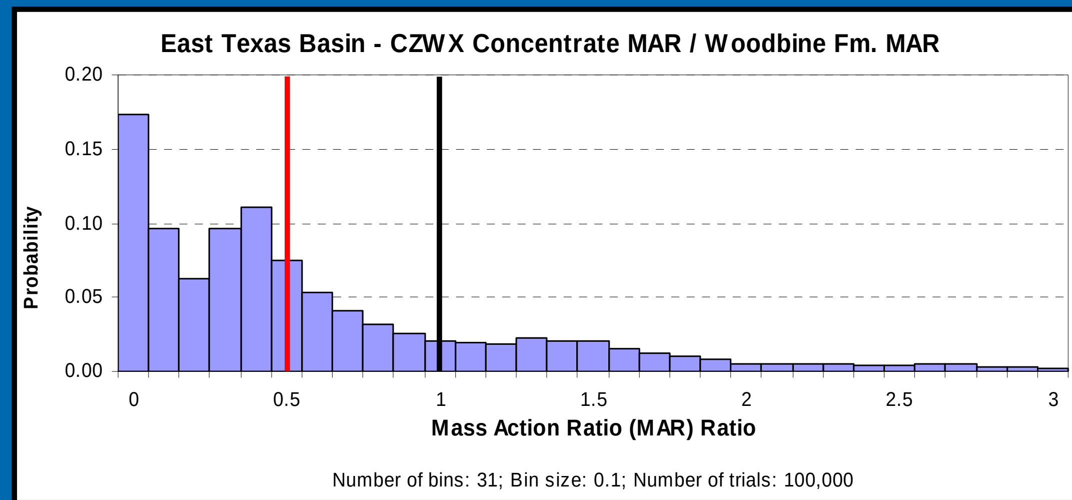
Possible cation stripping and deflocculation in the transient stage



Plot mod. from Scheuerman and Bergersen, 1990, SPE Paper No. 18461

MAR Study: East TX B. Analysis A.



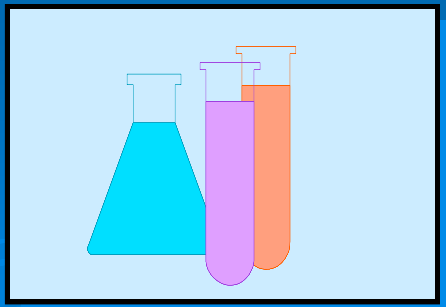


MAR Ratio =

$\{[Na]^2/[Ca]\}_{conc} / \{[Na]^2/[Ca]\}_{form}$

If MAR Ratio <0.5, problems are expected for smectite clay

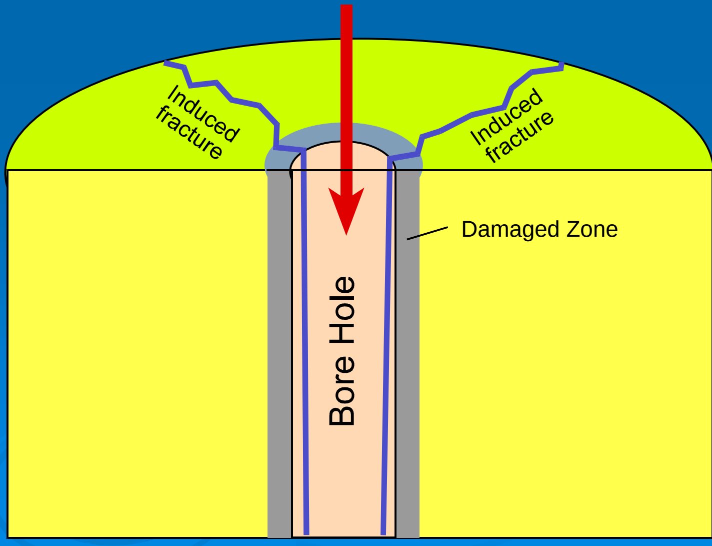
FORMATION DAMAGE CONTROL



Chemical and Physical Solutions

- Matrix acidizing by HCl, H_2SO_4 (both for carbonates), HF (for silicates), organic acids
- Treatment with KOH and NaOH (for calcium sulfate)
- $CaCl_2$ brine treatment (to limit clay sensitivity). NaCl and KCl. Clay stabilizers that bind clays to the substrate

- Hydraulic fracturing
- Heat treatment (?)



Mod. From Michael Dixon, OMNI Laboratories, Inc.

Operational Solutions

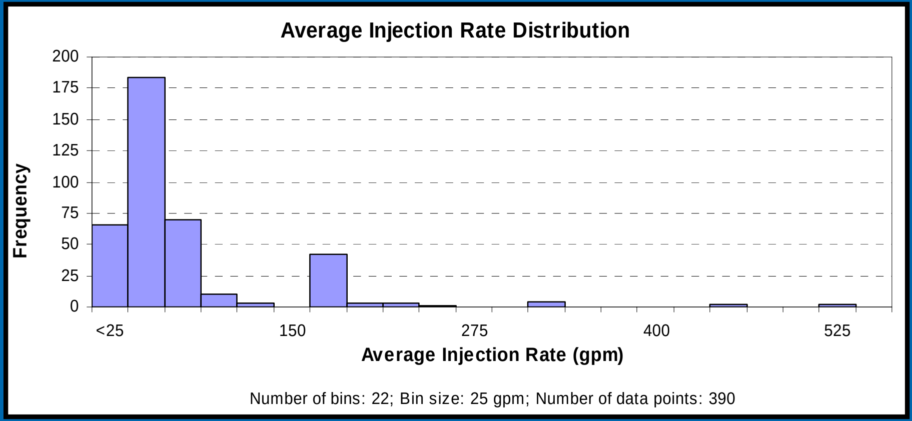
- Surface treatment to remove suspended solids
- Lower flow rate, increase perforation density
- Gradual change in salinity to avoid salinity shock
- Injection of a buffer solution
- Oxygen scavengers, antiscalant

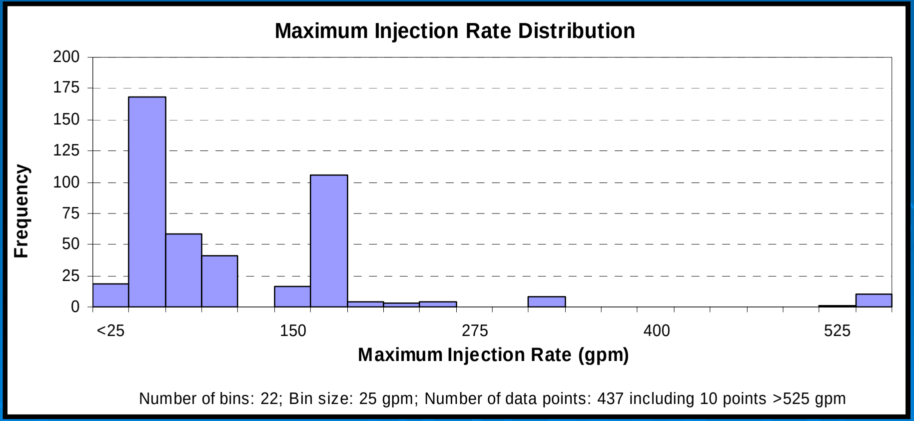
INJECTION RATES

Injection Rate Issues

- Maximum injection rate controls number of wells needed
- Injection rate is dependent on formation parameters:

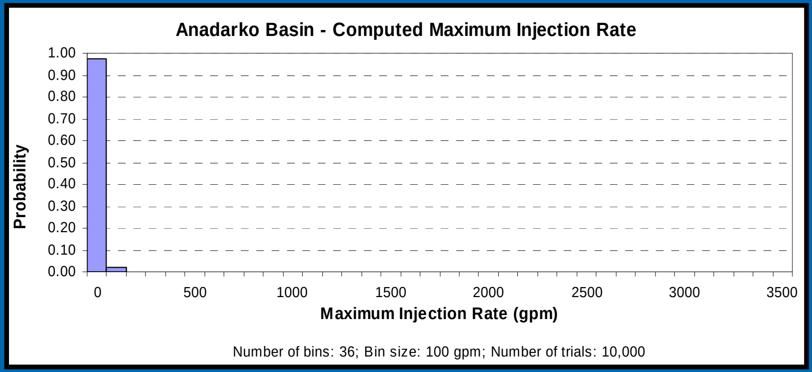
$$\Delta P = \frac{Q\mu}{4\pi k b} \ln\left(\frac{2.25kt}{\phi c \mu r^2}\right)$$



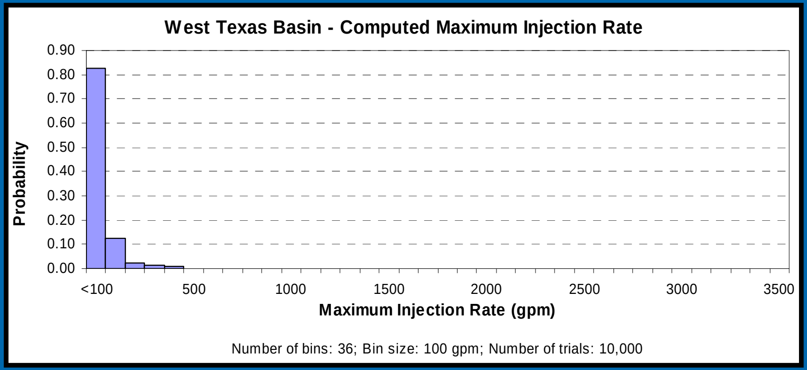


(Limited sampling of injection wells)

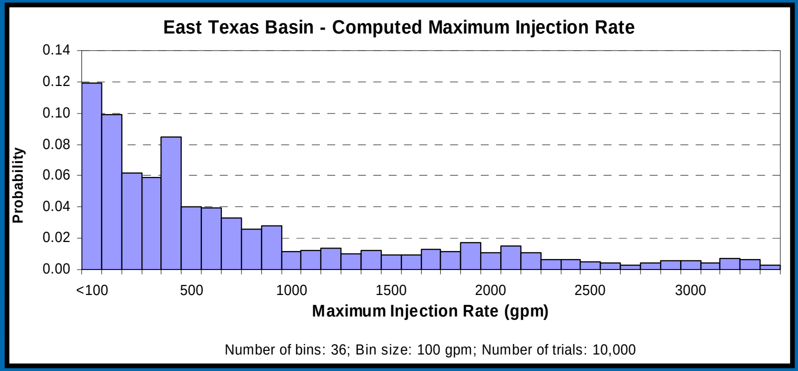
Computed Injection Rates



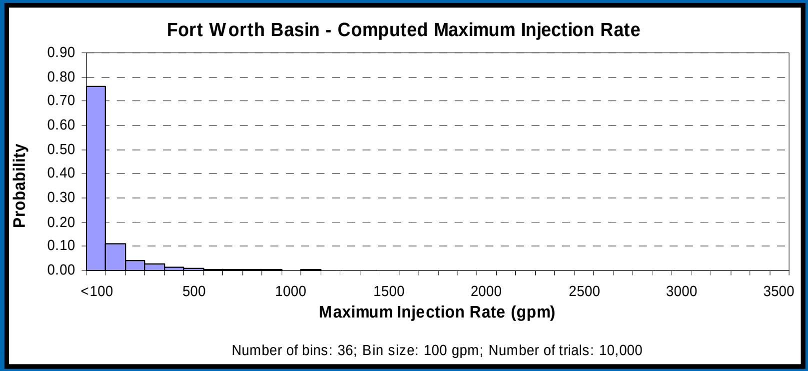
median = 7.3 gpm; 95th = 23 gpm



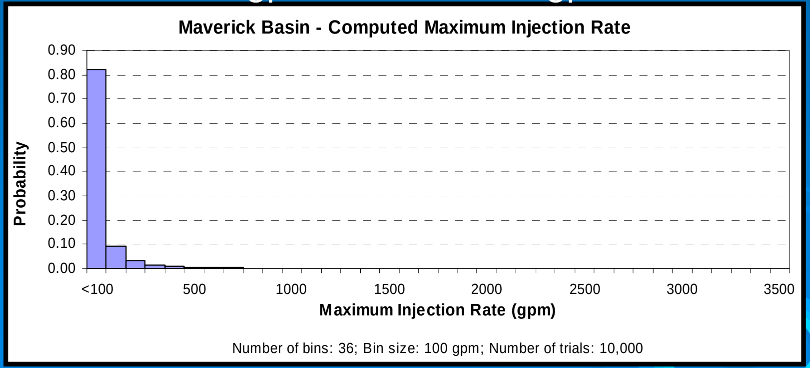
median = 13.2 gpm; 95th = 153 gpm



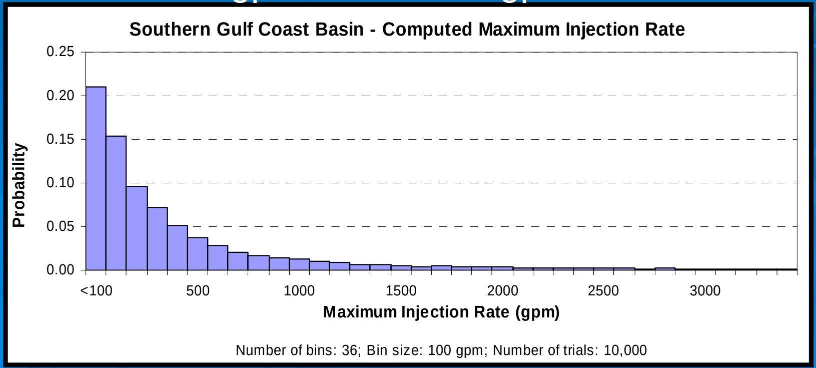
median = 466 gpm; 95th = 3,347 gpm



median = 9.8 gpm; 95th = 376 gpm



median = 6.3 gpm; 95th = 270 gpm



median = 278 gpm; 95th = 9,038 gpm

Injection Rate Conclusions

- 1 MGD of concentrate:
  - Is equivalent to 695 gpm
  - Would require a couple of wells in the eastern half of the state in recent formations
  - Would require one or several well clusters in the paleozoic formations
- Injection rate can be augmented by screening the pay thickness and stimulating the well

Summary of Technical Conclusions

- A significant fraction of the wells would qualify for a variance of AOR
- Scaling can be mitigated with standard approaches (acidification, antiscalant)
- Clay sensitivity may be a local issue for several fields. It could be dealt with but at a price
- Multiple wells/well clusters are needed to accommodate concentrate output of a typical plant

Policy procedures:

- Met with RRC and TCEQ
- Met with EPA Region 6 and headquarters
- Talked with other states about their solutions
- Researched permitting and permitting options

Current permitting process:

- History
- Class I
- Class II
- Class V

Possible permitting paths:

- Non-hazardous Class I
- Class II
- Class V
- Dual-permitted wells
- General permit, Class I
- Special Class I
- Change Federal regulations

Conclusions