Spatial and Temporal Variabilty in Produced Water in Texas: Implications for Management

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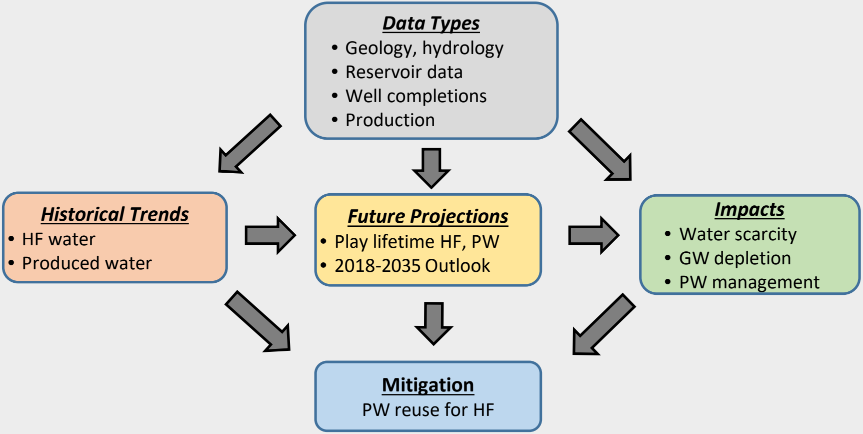
Texas Groundwater Protection Committee

Basic Questions

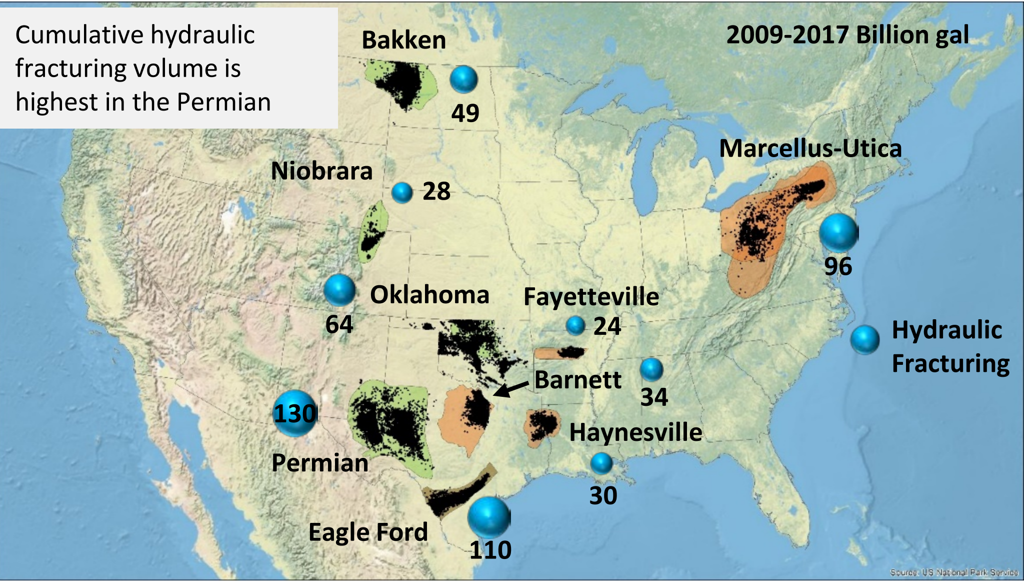
1. How much water is used for hydraulic fracturing (source and quality of water)?
2. How much water is produced with oil and gas and how is it managed?
3. What is the quality of produced water?
4. Can we reuse produced water for hydraulic fracturing?
5. Can we treat produced water for use in other sectors?

Work Flow

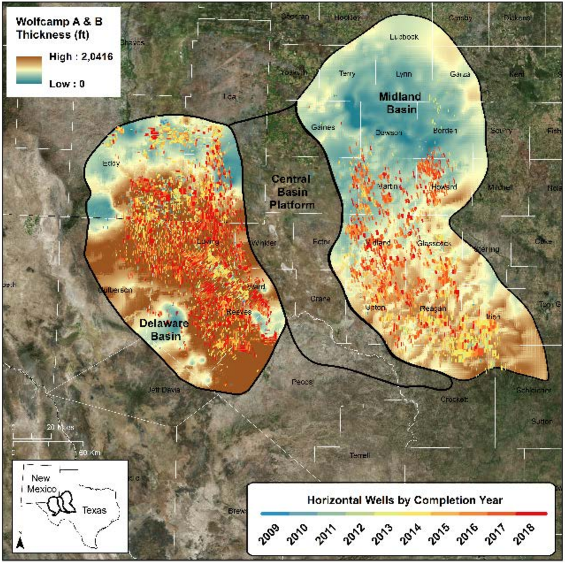

Data Types
• Geology, hydrology
• Reservoir data
• Well completions
• Production
Historical Trends
• HF water
• Produced water
Future Projections
• Play lifetime HF, PW
• 2018-2035 Outlook
Impacts
• Water scarcity
• GW depletion
• PW management
Mitigation
PW reuse for HF

Water Use for Hydraulic Fracturing

Cumulative hydraulic fracturing volume is highest in the Permian

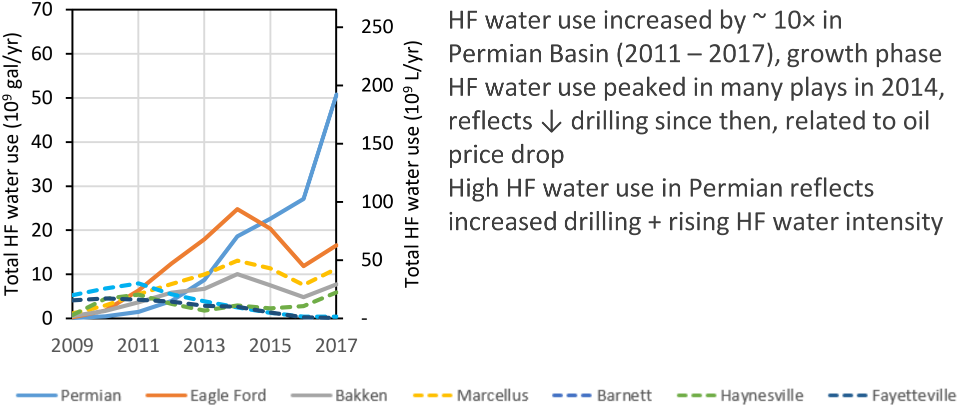


Thickness and Drilling in Primary Producing Intervals in Permian Basin



Thickness of Wolfcamp A & B units in Midland and Delaware basins in the Permian Basin and horizontal wells by year.

Total Water Use for Hydraulic Fracturing by Play



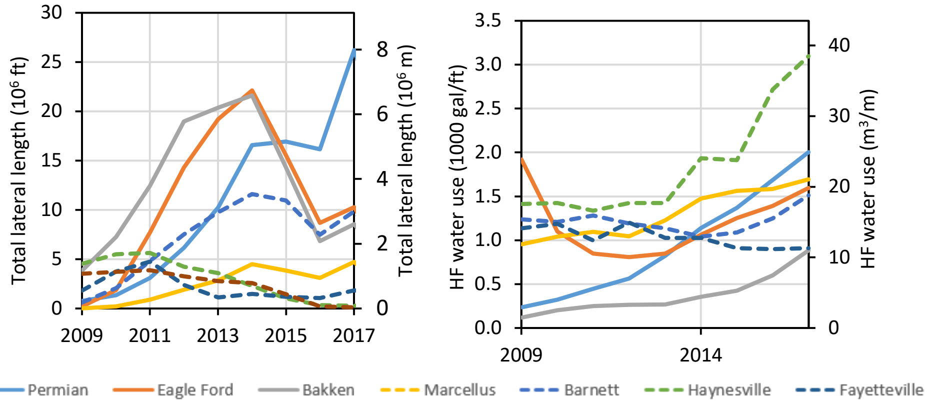
HF water use increased by ~ 10× in Permian Basin (2011 – 2017), growth phase

HF water use peaked in many plays in 2014, reflects ↓ drilling since then, related to oil price drop

High HF water use in Permian reflects increased drilling + rising HF water intensity

Total Lateral Length Drilled

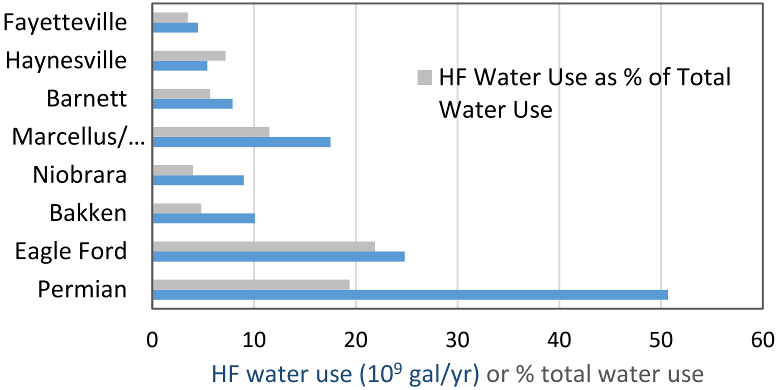
HF water use/foot of lateral



Lateral length drilled peaked in 207 in Permian and 2014 in many other plays

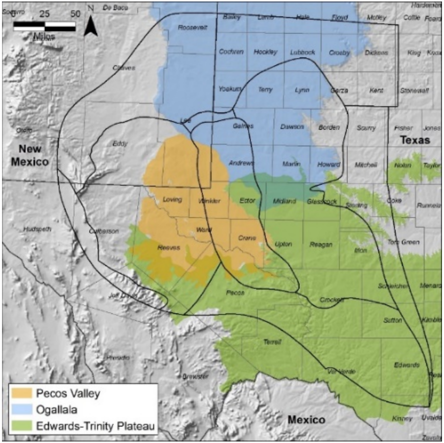
HF water use/foot of lateral in Permian increased by 4× 2011 – 2017; ~300%

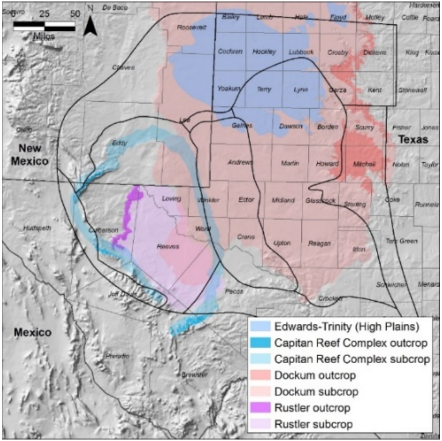
Water use for Hydraulic Fracturing as a % of Total Water Use in the Play



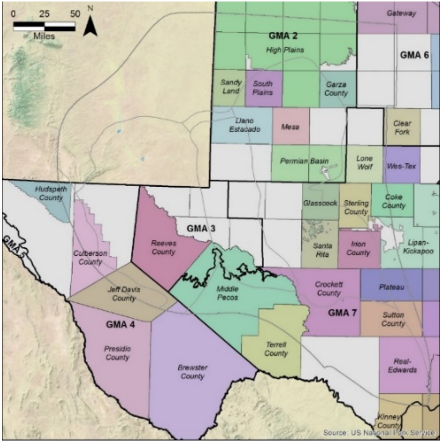
Water use (WU) for hydraulic fracturing (HF, maximum annual) ranges from 4% to 22% of total water use (TWU; USGS 2015) in play areas, excluding mining.

Major and Minor Aquifers in the Permian Basin

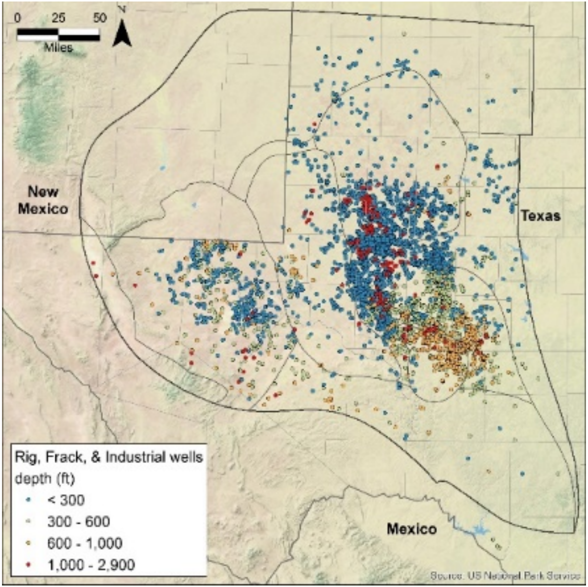




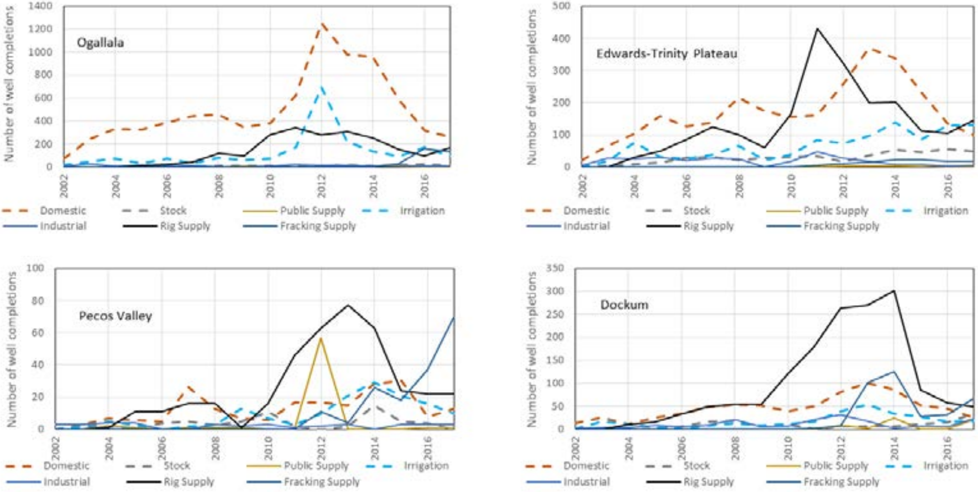
Groundwater Management

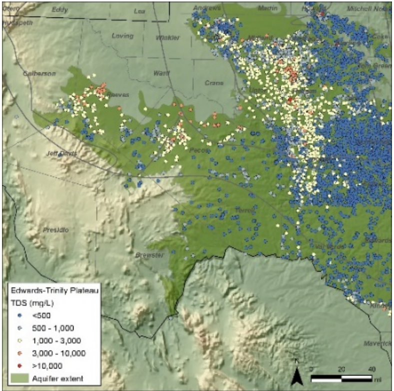


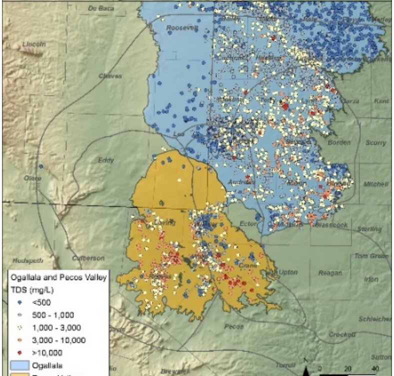
Depth of Rig, Frack, and Industrial Wells



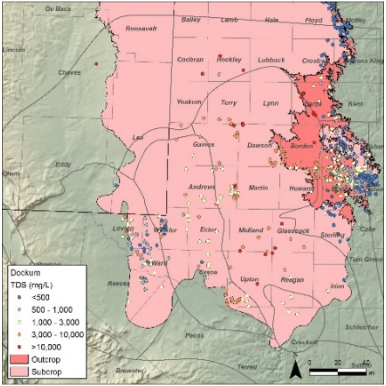
Number of Wells drilled to supply Hydraulic Fracturing by Aquifer







Groundwater Quality



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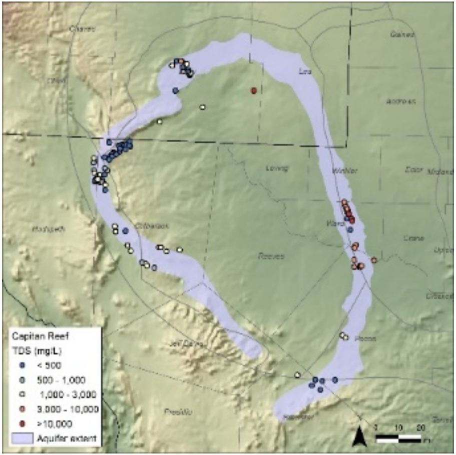
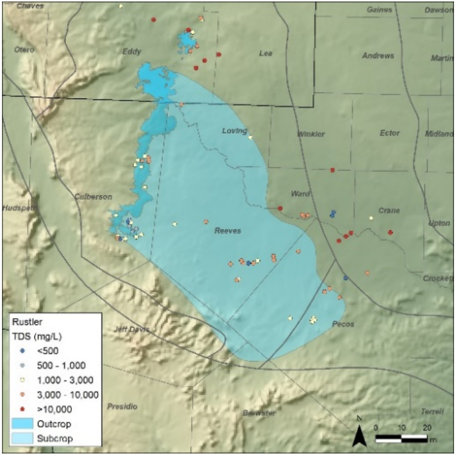
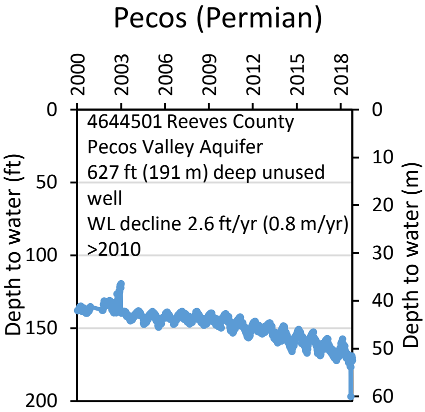
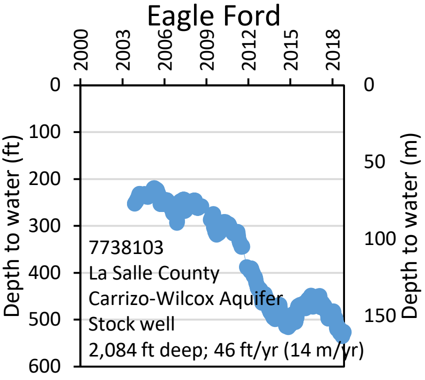




Impacts of Groundwater Pumping on Groundwater Levels





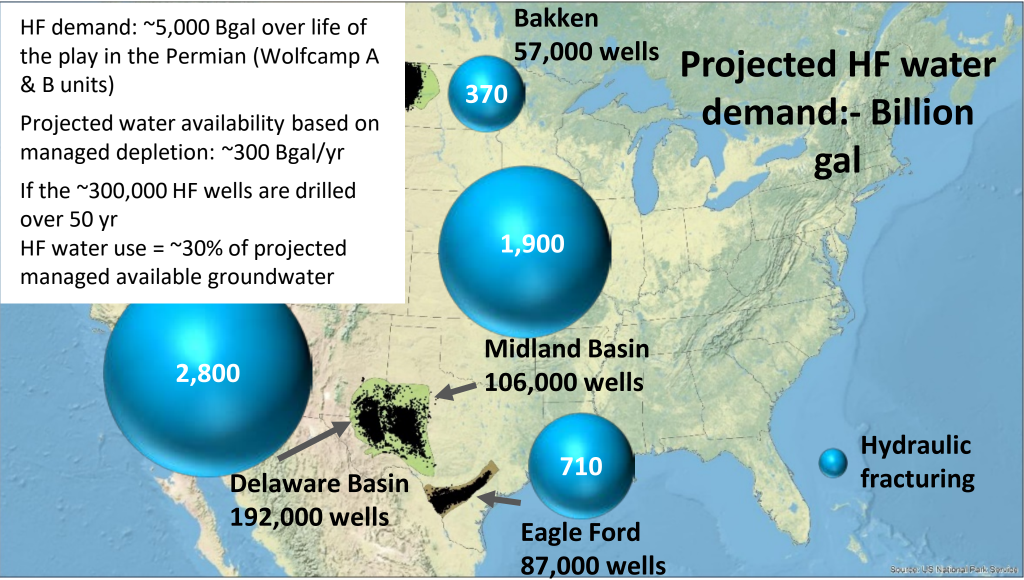
GW declines in the Delaware Basin could impact surface water.
Large GW declines in the western portion of the Eagle Ford play.

HF demand: ~5,000 Bgal over life of the play in the Permian (Wolfcamp A & B units)

Projected water availability based on managed depletion: ~300 Bgal/yr

If the ~300,000 HF wells are drilled over 50 yr

HF water use = ~30% of projected managed available groundwater



Basic Questions

1. How much water is used for hydraulic fracturing (source and quality of water)?
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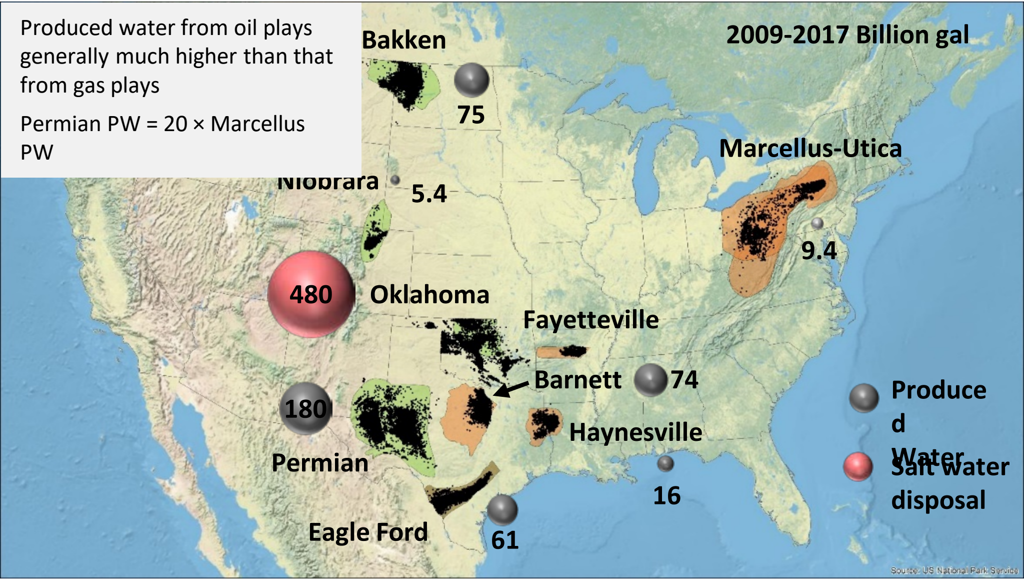
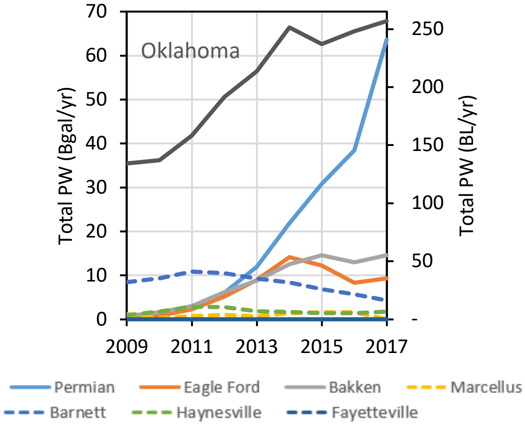
Produced water from oil plays generally much higher than that from gas plays

Permian PW = 20 × Marcellus PW



Produced Water Volume in Plays

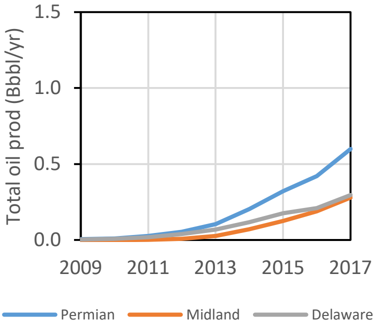


PW volume ↑ 30 times in Permian Basin (2011 – 2017)

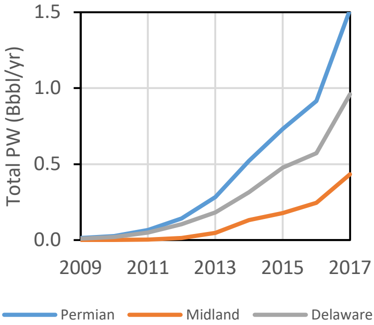
Oil plays produce much more water than gas plays

Permian Basin

Total Oil Production



Total Produced Water



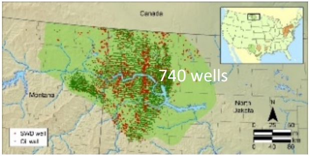
Oil production in Midland and Delaware Basins are similar

PW in Delaware Basin = ~2× that in Midland Basin in 2017

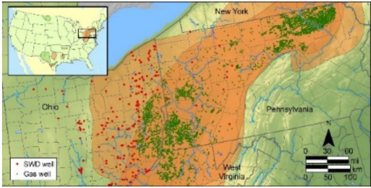
PW in Delaware Basin = 3 × oil production (2017)

Produced water is mostly managed using Saltwater Disposal Wells

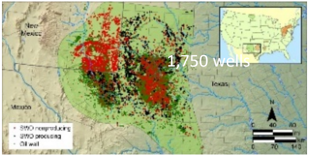
Bakken



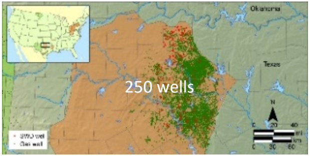
Marcellus/Utica



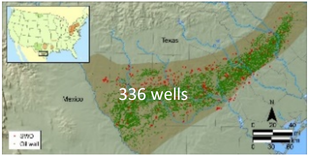
Permian



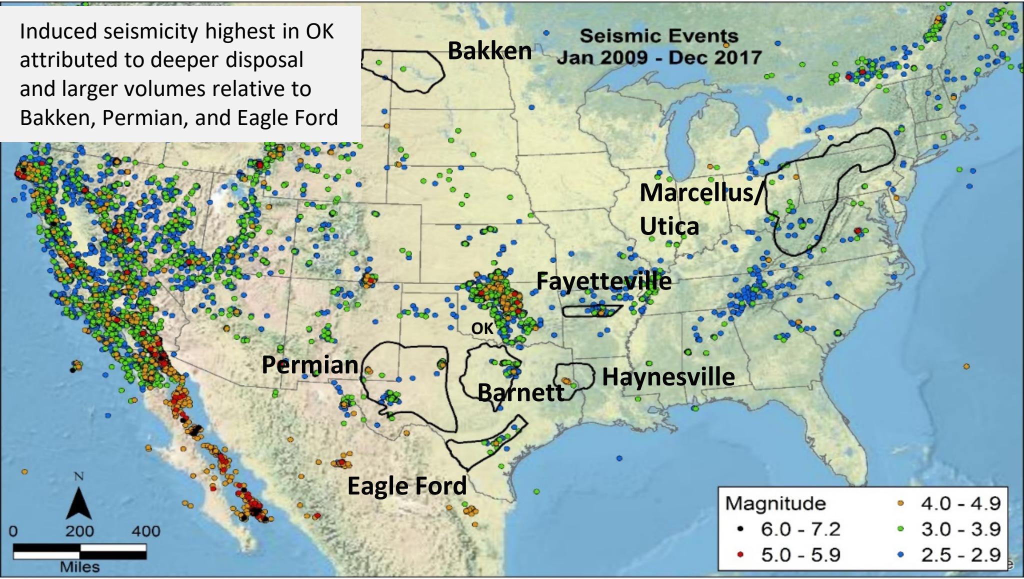
Haynesville



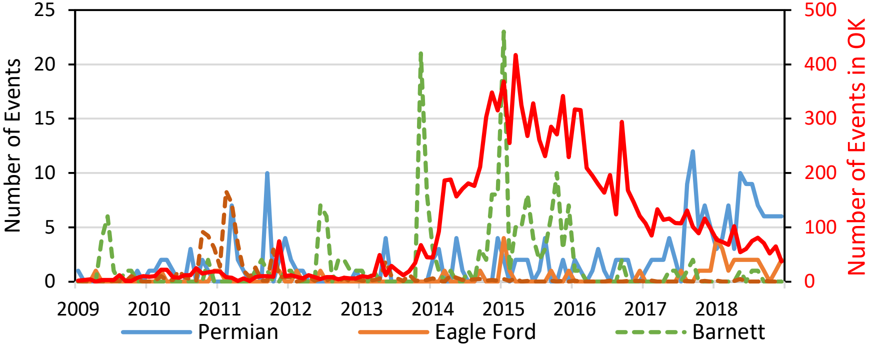
Eagle Ford



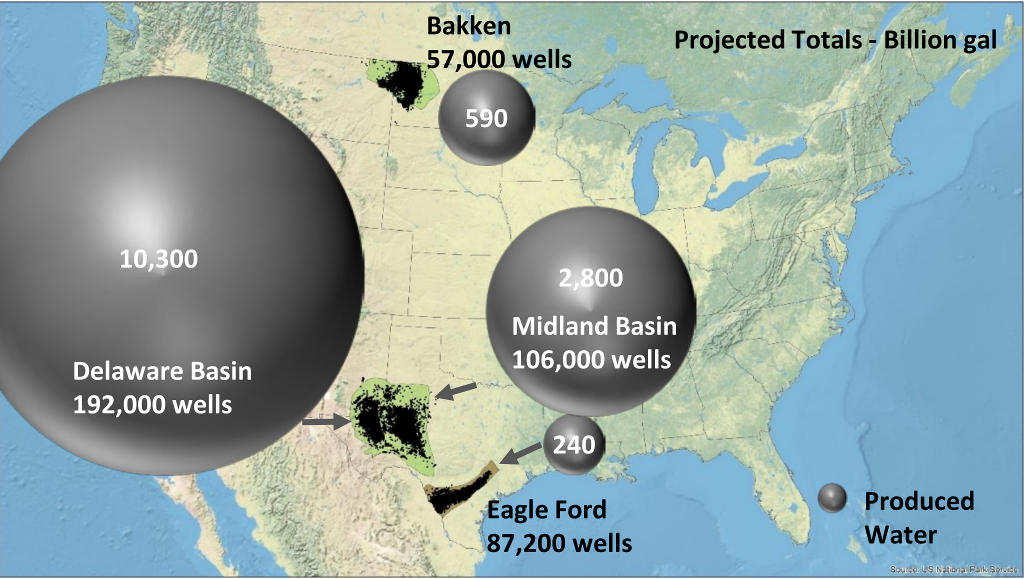
Induced seismicity highest in OK attributed to deeper disposal and larger volumes relative to Bakken, Permian, and Eagle Ford



Earthquake Events ≥ Magnitude 2 (monthly data; USGS Source)



Seismicity increasing in the Permian and Eagle Ford plays


Projected Totals - Billion gal
Bakken
57,000 wells
590
10,300
Delaware Basin
192,000 wells
2,800
Midland Basin
106,000 wells
240
Eagle Ford
87,200 wells
Produced
Water
Source: US National Park Service

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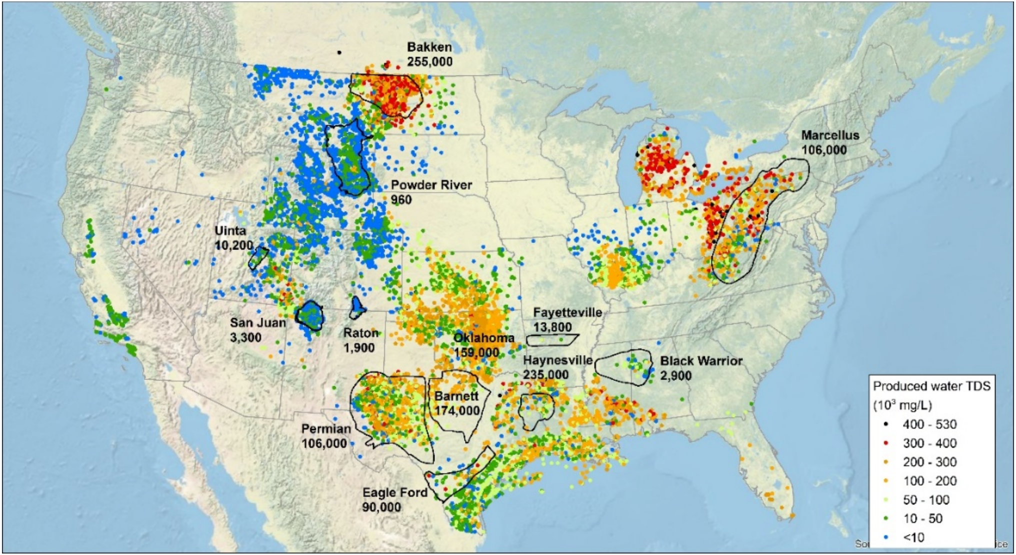
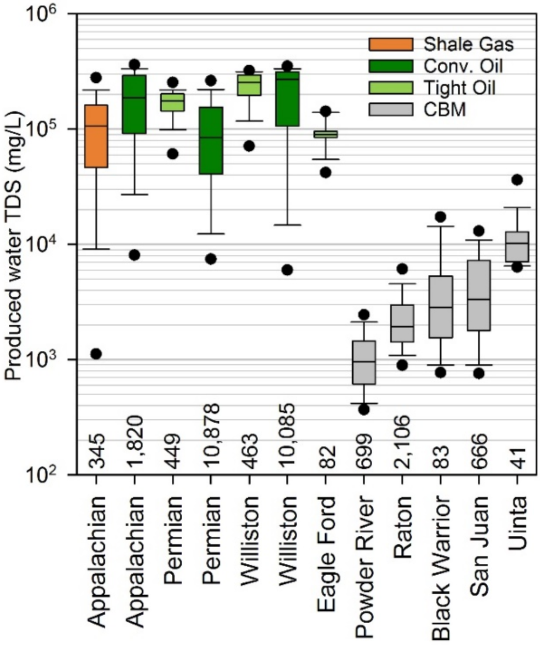
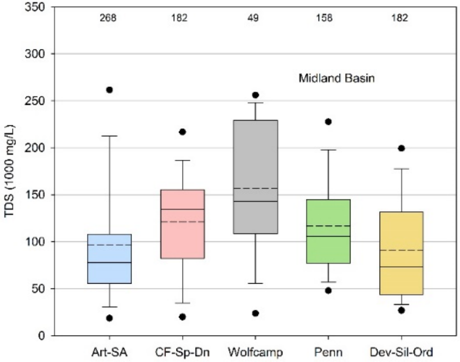
Produced Water Quality (USGS)

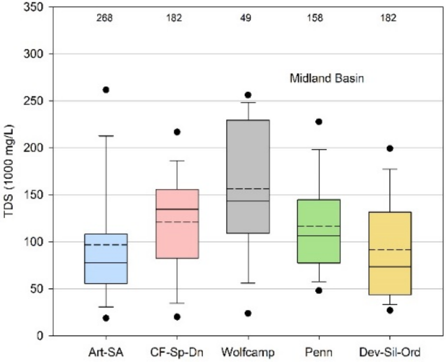


Variability in Produced Water Quality among Plays



Quality of Produced Water in the Permian Basin





Difficulties of Analyzing Produced Water

- Flowback and produced waters have complex matrices, high salinity, many waters exceeding seawater salinity
- These waters contain inorganic and organic chemicals from formation waters in addition to chemical additives from hydraulic fracturing, naturally occurring radioactive materials, and heavy metals
- Common analytical approaches for surface water and groundwater are not suitable for flowback and produced waters
- Oetjen et al., 2017

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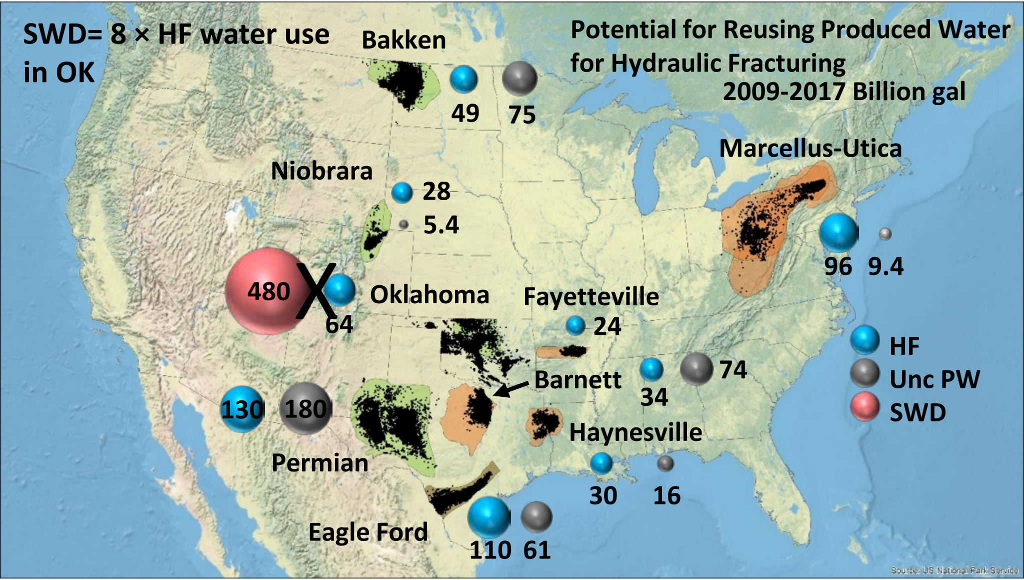
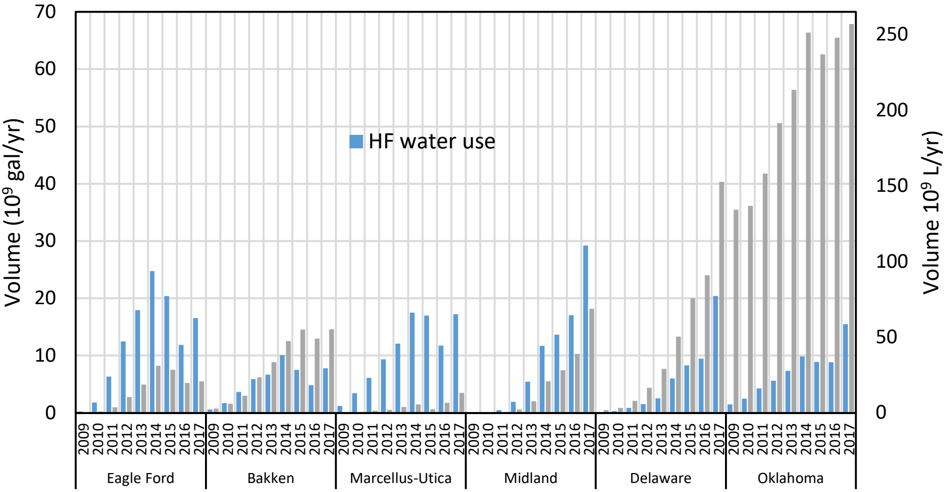

SWD= 8 × HF water use
in OK
Bakken
Potential for Reusing Produced Water
for Hydraulic Fracturing
2009-2017 Billion gal
49
75
Marcellus-Utica
Niobrara
28
5.4
96
9.4
480
64
Oklahoma
Fayetteville
24
HF
Unc PW
SWD
74
Barnett
34
130
180
Haynesville
Permian
30
16
Eagle Ford
110
61
Source: US National Park Service

Temporal Variations in PW to HF Ratios by Play



HF > PW

PW ↑ rel to HF

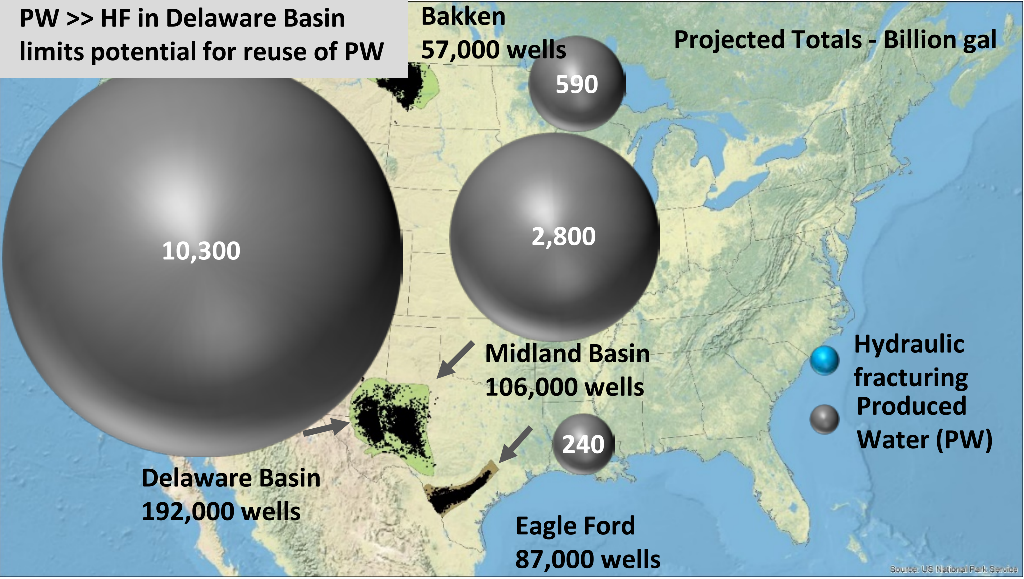
HF >> PW

HF > PW

PW = 2 HF 2016

PW>>HF

PW >> HF in Delaware Basin limits potential for reuse of PW



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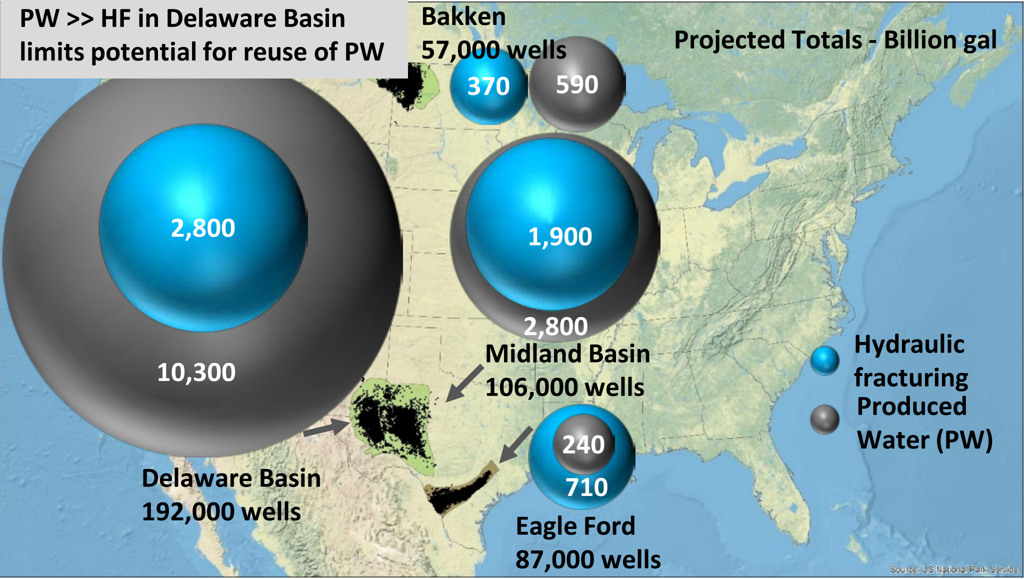

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Water requirements for different sectors

- Potable water, EPA regulations for major, trace, and organic constituents
- Primary inorganic standards of concern: Fl (4 mg/L), $Ra^{226}+Ra^{228}$ combined (5 pico Curies, pCi/L), and U (30 ug/L).
- Secondary inorganic standards of concern: TDS (500 mg/L), Cl (250 mg/L), SO_4 (250 mg/L), Fl (2 mg/L), and Fe (0.3 mg/L)
- These regulations were developed considering general surface water and groundwater quality but do not include regulations for many of the potentially harmful constituents in flowback and produced water

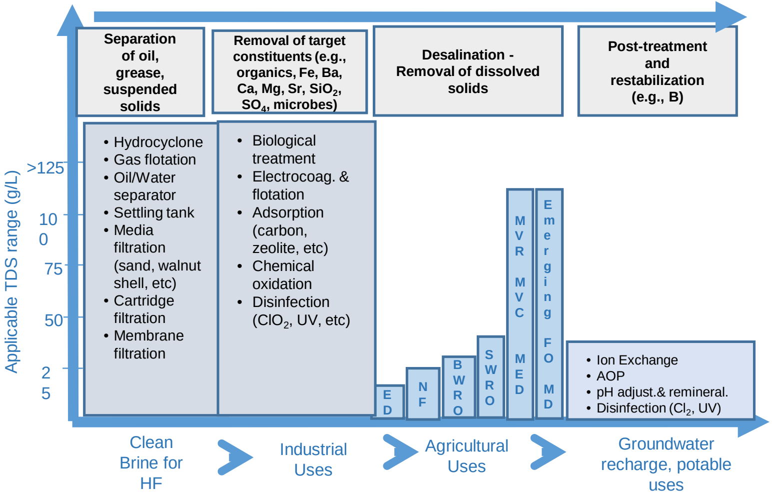
Water Quality Requirements for Agriculture

- **Livestock watering**: TDS up to 10,000 mg/L
- Elements of potential concern: arsenic (As; 0.2 mg/L), boron (B; 5.0 mg/L), and fluoride (2.0 mg/L). NORMs also an issue.
- **Irrigation:**
- TDS: <175 mg/L (excellent, Class 1); 175–525 mg/L (good, Class 2), 525–1,400 mg/L (permissible with leaching, Class 3), and 1,400–2,100 mg/L (doubtful, particularly for sensitive plants (Class 4)
- Sodium Adsorption Ratio: $SAR = \frac{Na^{+}}{\sqrt{[Ca^{+2}]+[Mg^{+2}]/2}}$
- SARs > 3 require additional flushing; SARs > 13 can degrade soil structure
- SARs from USGS database: 0.7 – 28.5 (water samples from conventional reservoirs)
- SARs in Williston Basin ~15 – 16.
- Boron (B) is also an issue: B tolerance varies with crop type: wheat (0.75 – 1.0 mg/L), sorghum and alfalfa (4 – 6 mg/L), and cotton (6 – 15 mg/L)

Reduction in Total Dissolved Solids in Produced Water

- Reverse Osmosis can remove TDS in waters with TDS up to 47,000 mg/L
- Remove up to 99% NaCl; Si and B require additional treatment, can remove radionuclides, pretreatment recommended for removal of organics and scale, recovery 30 – 60%
- Thermal approaches can be used with water up to 300,000 mg/L TDS
- Thermal distillation can be used with any level of TDS, (heat and evaporate feedwater followed by condensation of pure water)
  - 100% rejection of Na, SiO_2, B, and heavy metals.
  - Multistage Flash Distillation (< 40,000 mg/L TDS; recovery 10 – 20%, scale inhibitors and acids, no biocides required [high T])
  - Multiple Effect Distillation (MED) (scaling issues, 20 – 35% recovery)
  - Vapor Compression Distillation (VCD) (can be used with TDS > 40,000; can be used as crystallizer resulting in zero liquid discharge)
  - High energy requirements (waste heat available)

PW treatment costs increase with higher salinity in PW and product water quality improvement

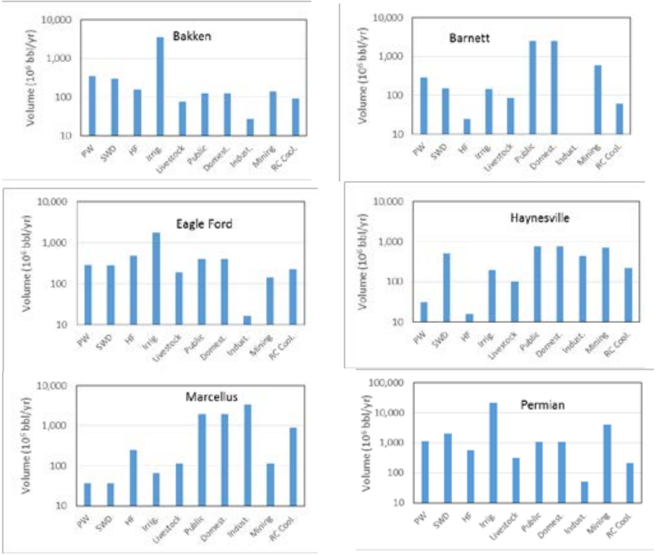


Treatment Options for Produced Water

- Fit for purpose treatment
- Minimal treatment for HF because of changes in HF water quality requirements (filtering, TSS, biocides, Fe, Mn)
- Desalination plants (Marcellus, interest in Permian Basin)
- Use of high quality PW for irrigation (CBM, CA)

Salt from Concentrate

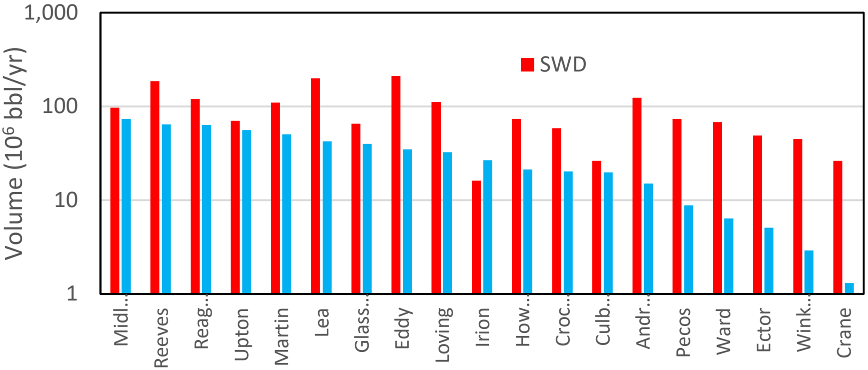
- Permian Basin Example
- $273x10^6$ m^3 of SWD
- 100,000 mg/L TDS = 100 kg salt/m^3 of water
- Density of NaCl 2170 kg/m^3
- 100 (kg salt/m^3) / 2170 (kg salt/m^3 of salt) x $273x10^6$ m^3 SWD
- 12.6×10^6 m^3 salt in 2015
- 10,300 acre feet of salt in 2015



Comparison of Water Supplies from Produced Water with Water Demand in Different Sectors

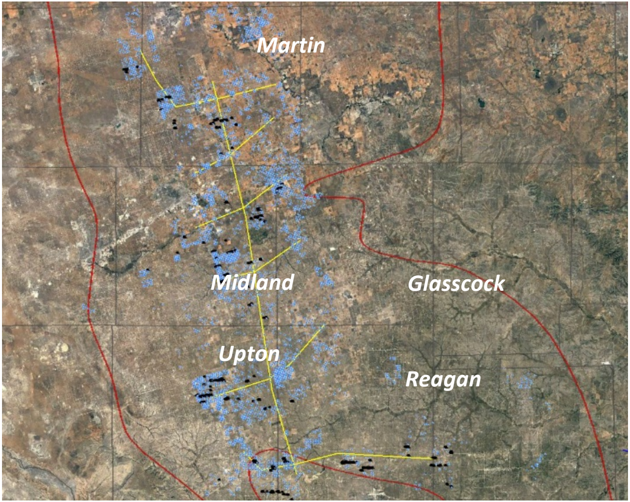
barrel = 0.16 m^3

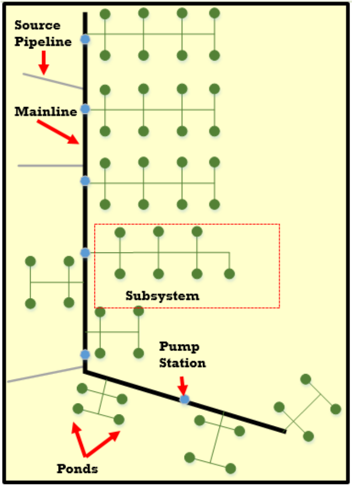
Comparison between Produced Water Supply versus Water Demand for Hydraulic Fracturing: Permian Basin (2015 data)



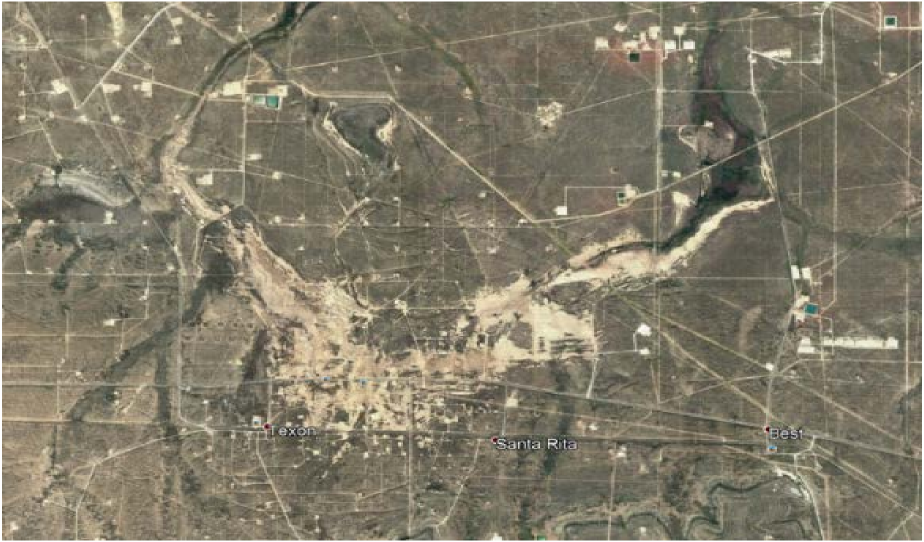
Produced water supply is based on volumes disposed in salt water disposal wells (SWD)
HF: hydraulic fracturing water demand

Infrastructure to store and transport produced water

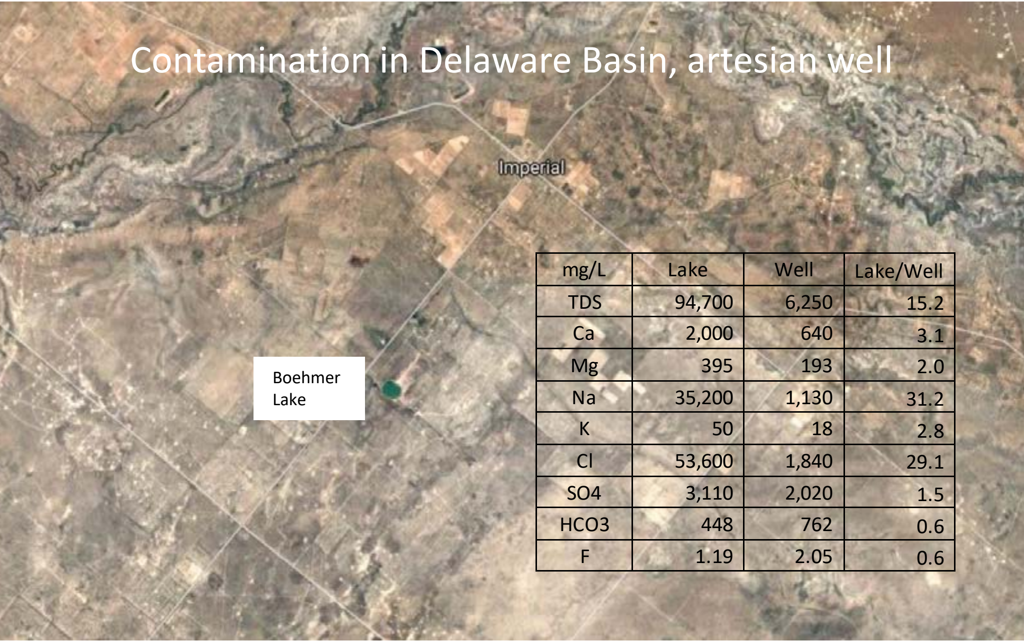




Contamination from Produced Water (Texon Scar)

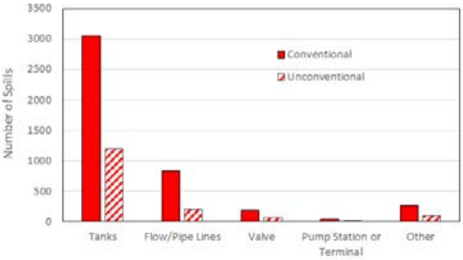


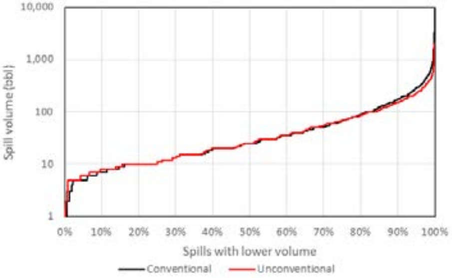
Contamination in Delaware Basin, artesian well

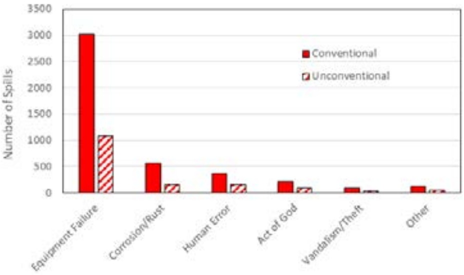


mg/L	Lake	Well	Lake/Well
TDS	94,700	6,250	15.2
Ca	2,000	640	3.1
Mg	395	193	2.0
Na	35,200	1,130	31.2
K	50	18	2.8
Cl	53,600	1,840	29.1
SO4	3,110	2,020	1.5
HCO3	448	762	0.6
F	1.19	2.05	0.6

Spills in Permian







Main Conclusions

1. How much water is used for hydraulic fracturing (source and quality of w
20% of water in the Permian and Eagle Ford plays, increasing volumes being
stabilizing recently. Fresh and brackish GW. No reports on reuse/recycling.
2. How much water is produced with oil and gas and how is it managed?
Permian: 14 bbl water/bbl oil (conventional), ~ 3 bbl water/bbl oil (unconver
Mostly managed using EORI for conventonal reservoirs and SWD for unconve
reservoirs.
3. What is the quality of produced water?
Variable: Permian highest salinity in shallow zone near salt deposits, higerh d
depth.
4. Can we reuse produced water for hydraulic fracturing?
Yes, in most plays. Delaware Basin and some others produce more water tha
for hydraulic fracturing.
5. Can we treat produced water for use in other sectors?
Yes, high salinity will require thermal distillation. Lot of salt generated.

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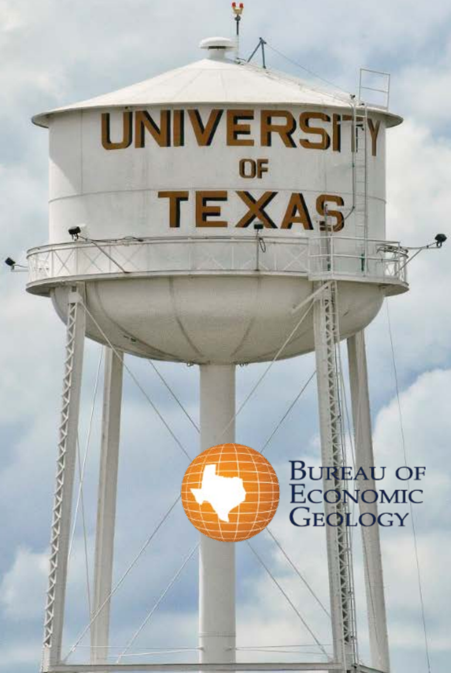

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