Evaluation of Produced Water Reuse within and outside the Energy Sector

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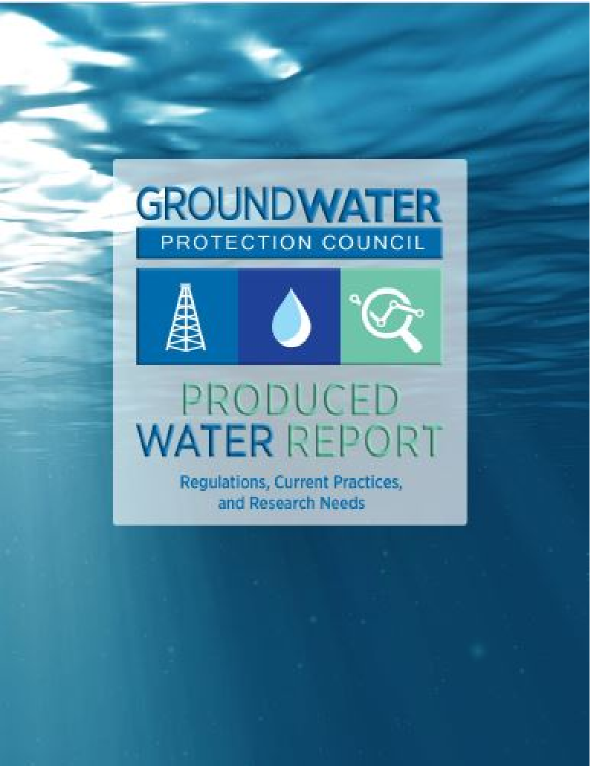

Module 2: Produced Water **Reuse in Unconventional** Oil and Gas Operations

Module 3: Produced Water Reuse and Research Needs **Outside Oil and Gas Operations**

Environmental Science & Technology

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Will Water Issues Constrain Oil and Gas Production in the U.S.? YES

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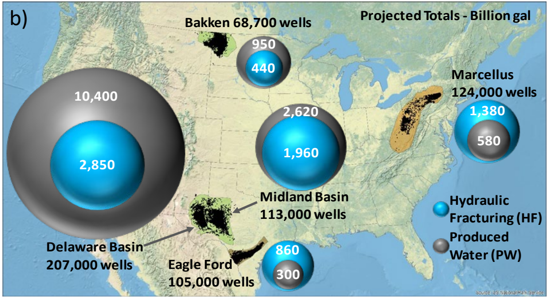
KEYWORDS hydraulic fracturing, produced water, unconventional oil and gas, tight oil, shale oil, water reuse/recycling

Abstract:

Rapid growth in U.S. unconventional oil and gas made energy more available and affordable globally, but brought environmental concerns, especially related to water. We analyzed water-related sustainability of energy extraction focusing on: (a) meeting rapidly rising water demand for hydraulic fracturing (HF), and (b) managing rapidly growing volumes of water co-produced with oil and gas (produced water, PW). We analyzed historical (2009–2017) HF water and PW volumes in ~73,000 wells and projected future water volumes in major U.S. unconventional oil (semiarid regions) and gas (humid regions) plays. Results show a marked increase in HF water use, depleting groundwater in some semiarid regions (e.g. by ≤58 ft [18 m]/yr in Eagle Ford). PW from oil reservoirs (e.g. Permian) is ~15× higher than that from gas reservoirs (Marcellus). Water issues related to both HF water demand and PW supplies may be partially mitigated by closing the loop through reusing PW for HF of new wells. However, projected PW volumes exceed HF water demand in semiarid Bakken (2.1×) and Permian Midland (1.3×) and Delaware (3.7×) oil plays, with the Delaware accounting for ~50% of projected U.S. oil production. Therefore, water issues could constrain future energy production, particularly in semiarid oil plays.

- PW from oil reservoirs >> than that from gas reservoirs
Permian PW = 50× Marcellus PW
- Reuse PW for HF
- Projected PW volumes = ~ 4× HF water demand in the Delaware



ELSEVIER
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In Press, Journal Pre-proof

Can we beneficially reuse produced water from oil and gas extraction in the U.S.?

Bridget R. Scanlon [a], Robert C. Reedy [a], Pei Xu [b], Mark Engle [c], J.P. Nicot [a], David Yoxtheimer [d], Qian Yang [a], Svetlana Ikonnikova [a]

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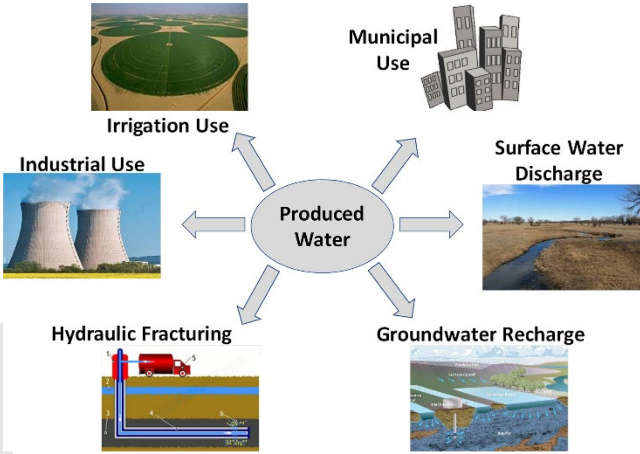
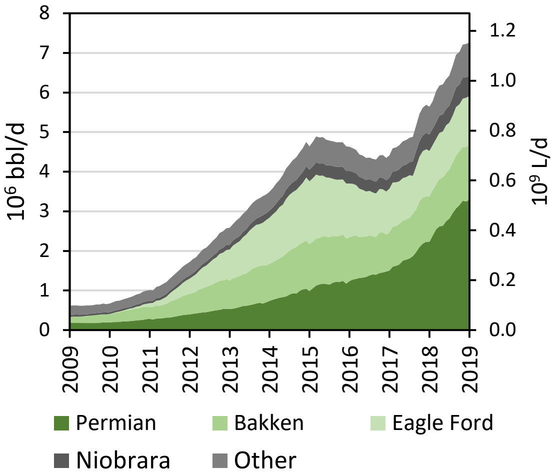
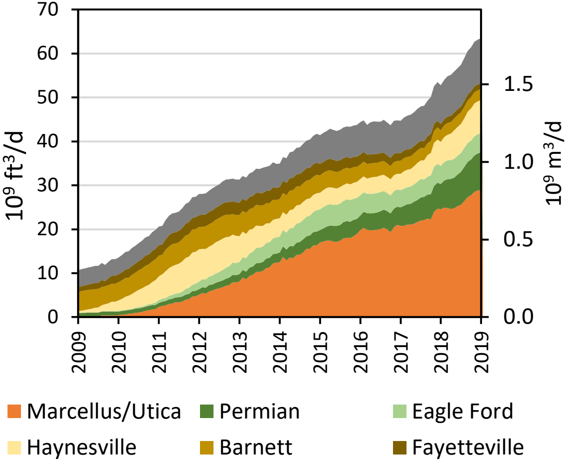


Highlights

- Irrigation demand exceeds produced water (PW) volumes by 5× in the U.S.
- PW volumes would not substantially alleviate overall water scarcity.
- PW quality is variable with salinity up to 7 that of seawater.
- Intensive treatment is required for PW use outside of energy.
- Knowledge gaps related to PW quality preclude reuse outside of energy.

U.S. ~20% of global total production in oil and gas
Unconventional production: 60% of U.S. oil and 70% of U.S. natural gas

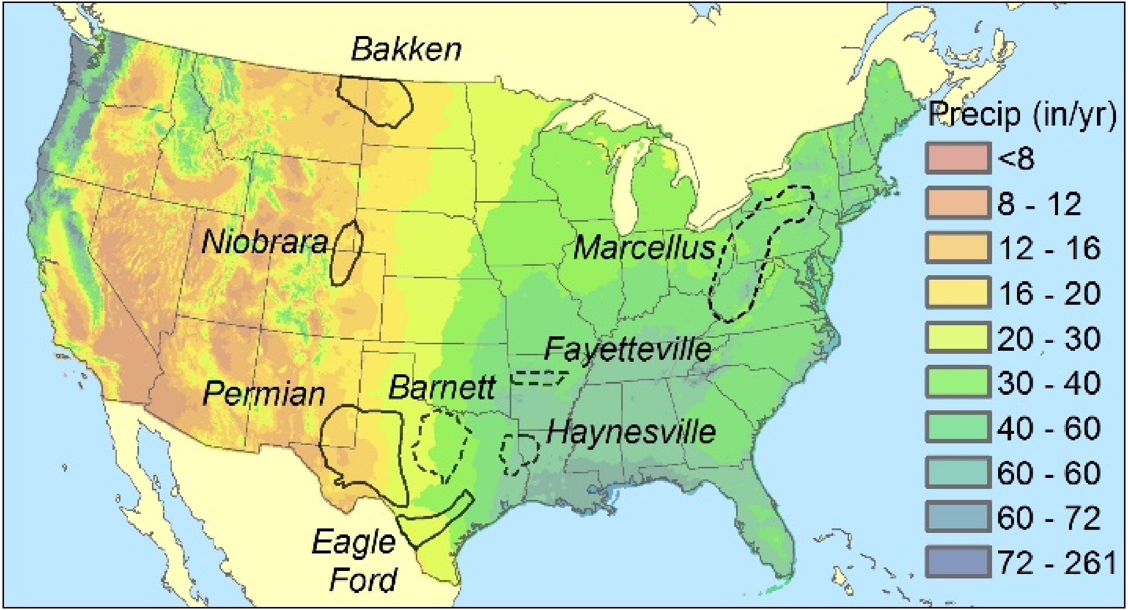




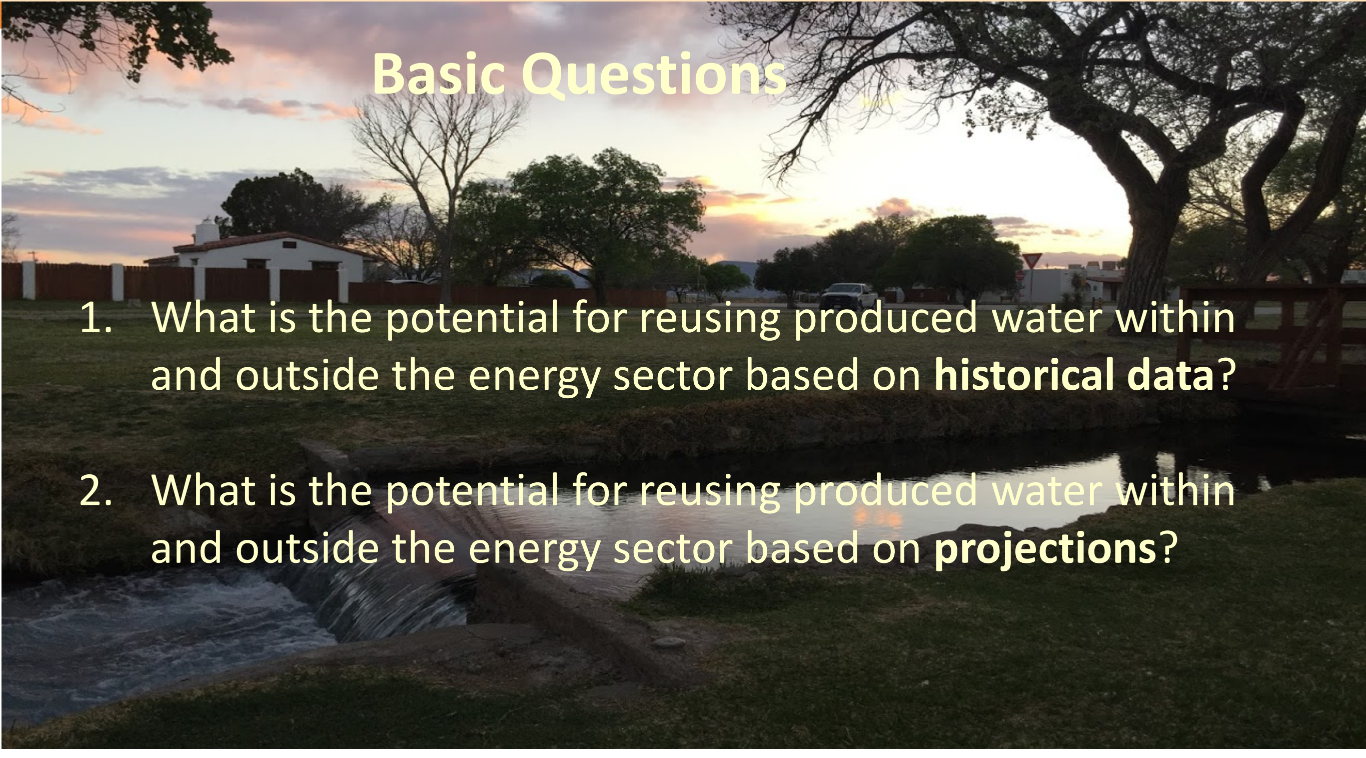
Scanlon et al., ES&T, 2020

Oil plays in semiarid regions

Gas plays in humid regions



Scanlon et al., ES&T, 2020

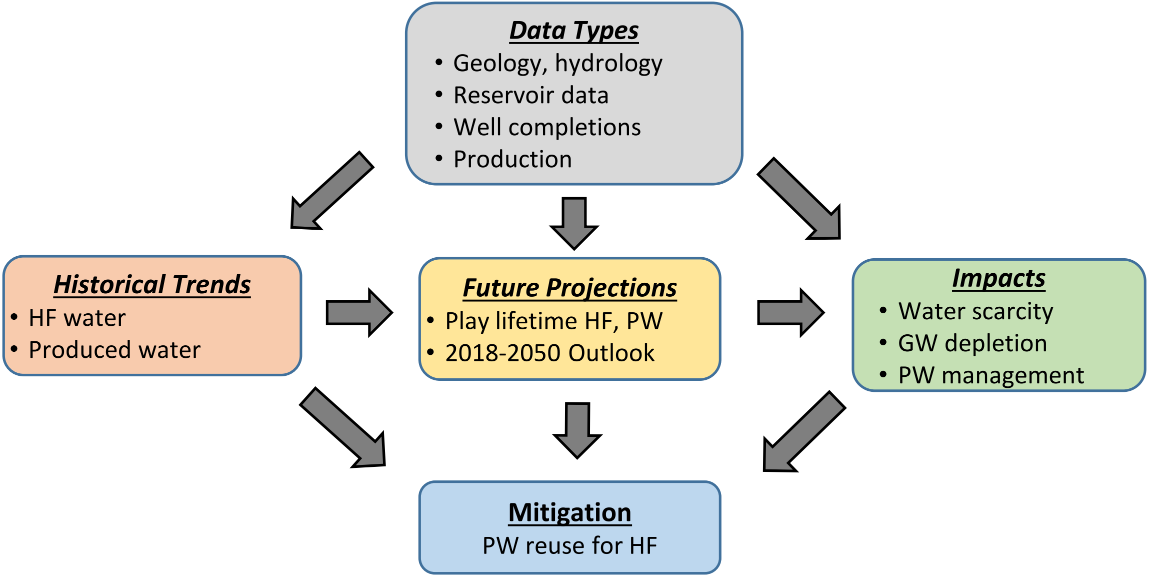


Basic Questions

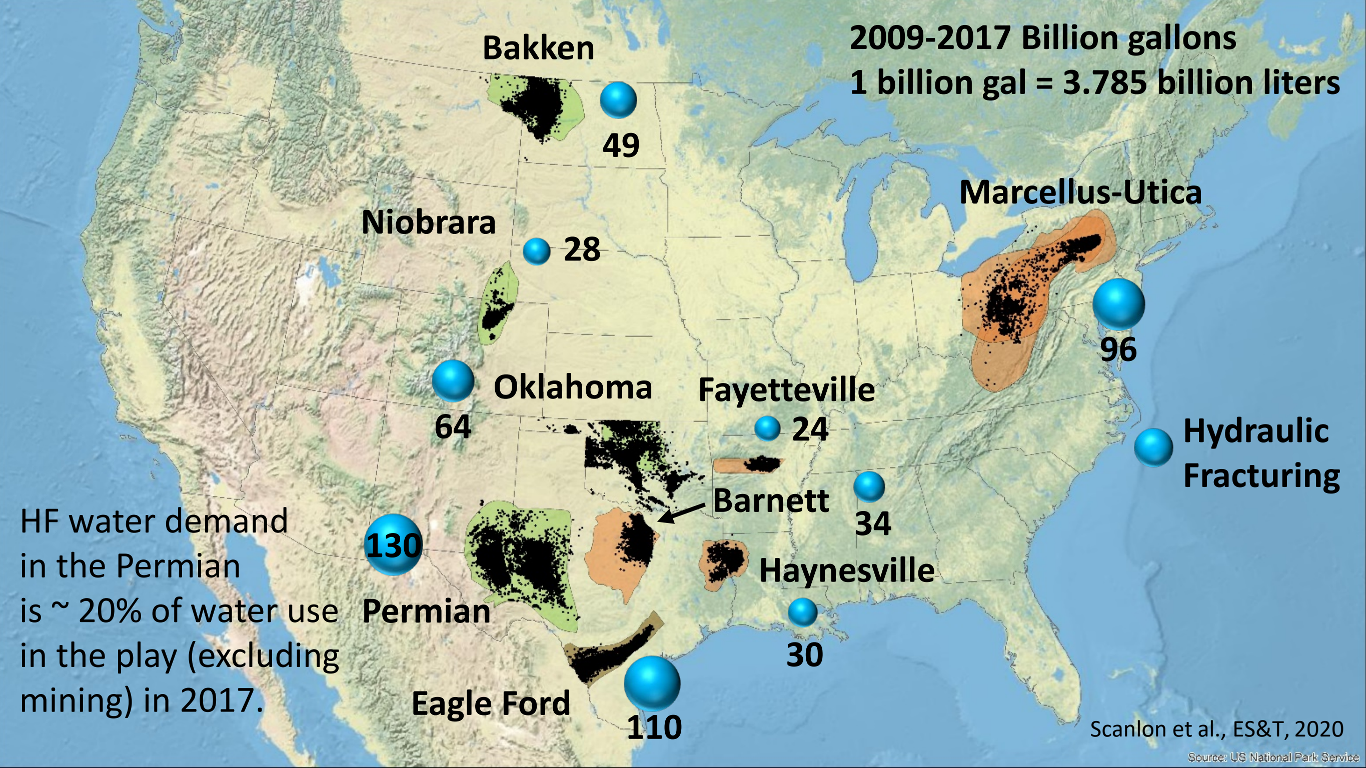
1. What is the potential for reusing produced water within and outside the energy sector based on **historical data**?

2. What is the potential for reusing produced water within and outside the energy sector based on **projections**?

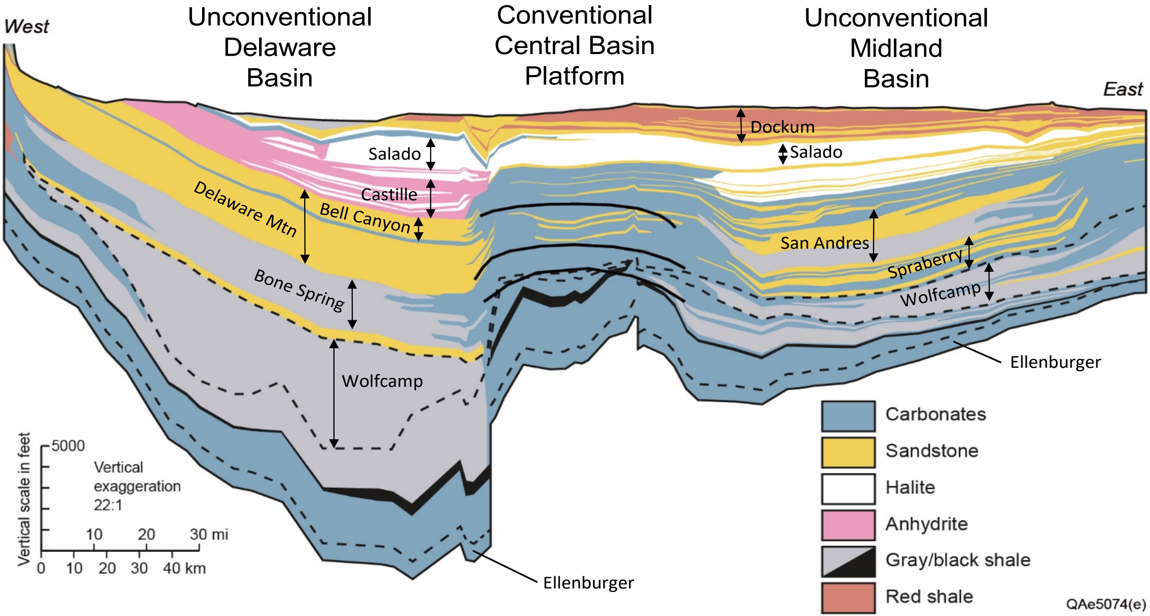
Work Flow



Scanlon et al., ES&T, 2020


2009-2017 Billion gallons
1 billion gal = 3.785 billion liters
Bakken
49
Niobrara
28
Oklahoma
64
Fayetteville
24
Marcellus-Utica
96
Hydraulic
Fracturing
Barnett
34
Haynesville
30
Permian
130
Eagle Ford
110
HF water demand
in the Permian
is ~ 20% of water use
in the play (excluding
mining) in 2017.
Scanlon et al., ES&T, 2020
Source: US National Park Service

Permian Basin

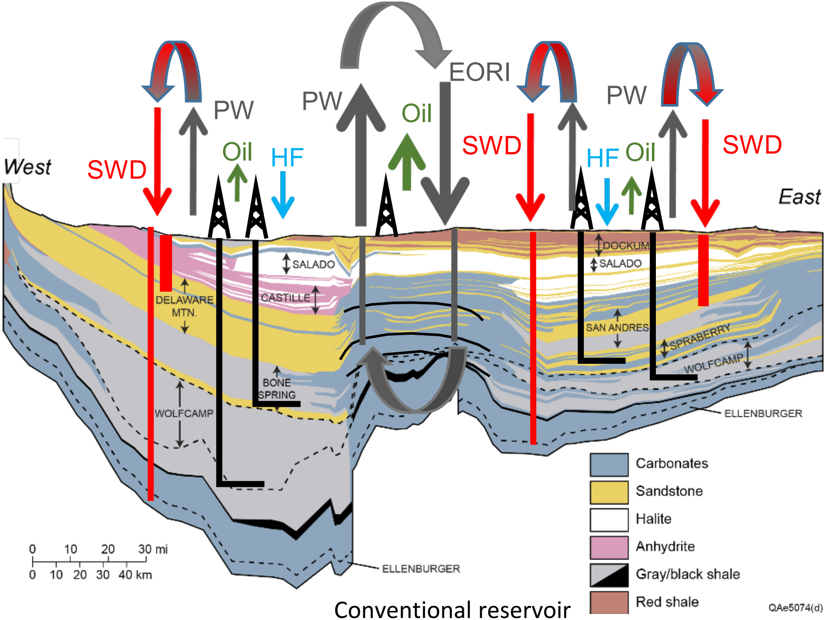


Permian basin

Unconventional
Delaware Basin

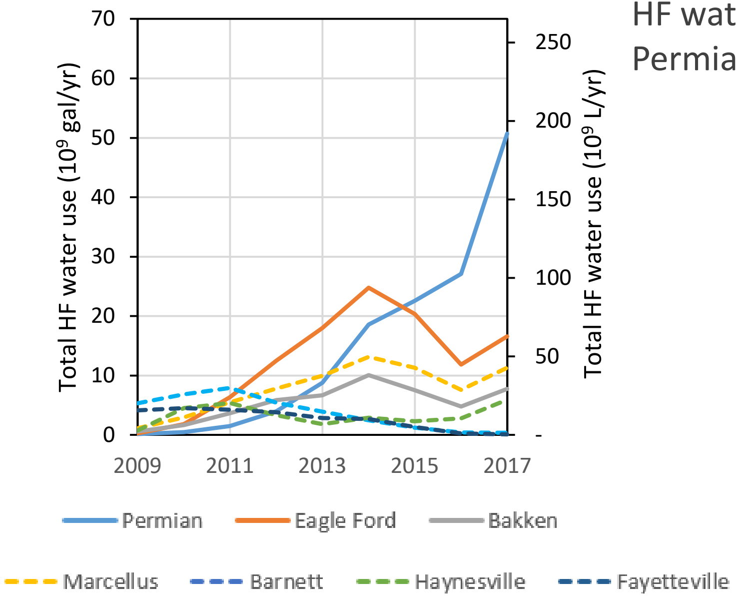
Conventional
Central Basin Platform

Unconventional
Midland Basin



Conventional reservoir
Big recycle loop

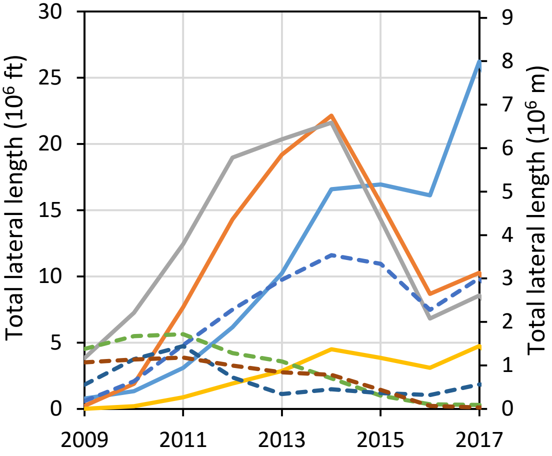
Total Water Use for Hydraulic Fracturing by Play



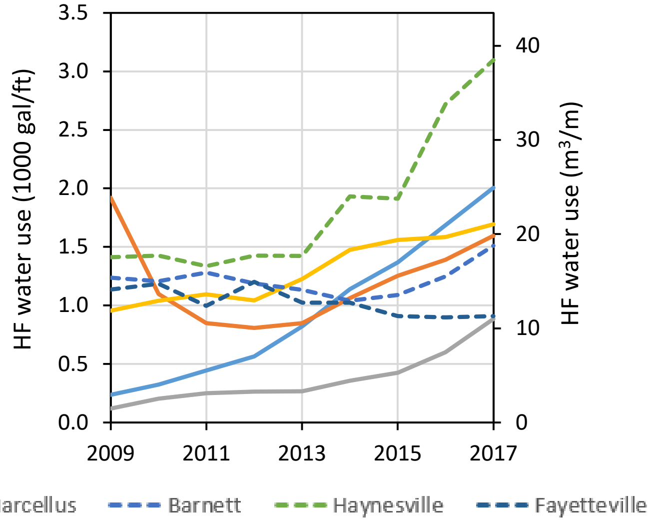
HF water use increased by ~ 10× in Permian Basin (2011 – 2017)

Scanlon et al., ES&T, 2020

Total Lateral Length Drilled = 4 x Earth's circumference



HF water use/foot of lateral

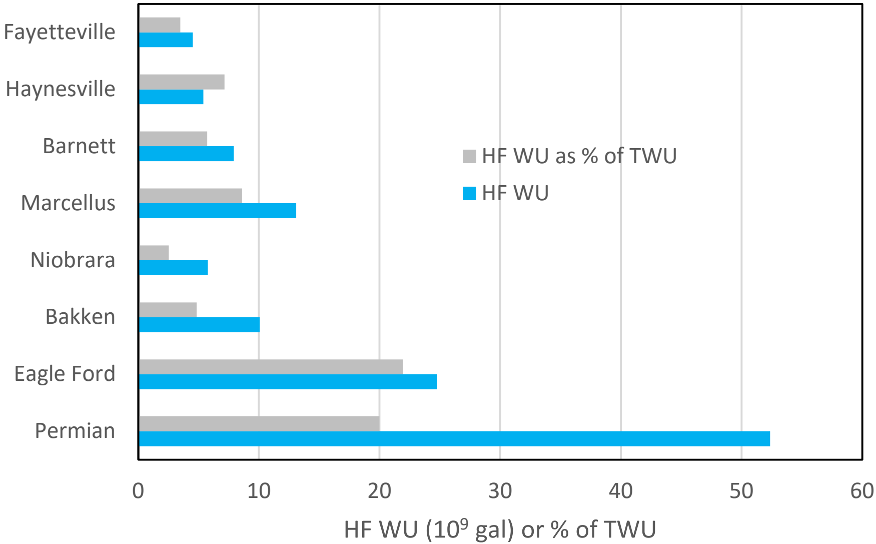


Lateral length drilled peaked in 2017 in Permian and 2014 in many other plays

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

Scanlon et al., ES&T, 2020

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

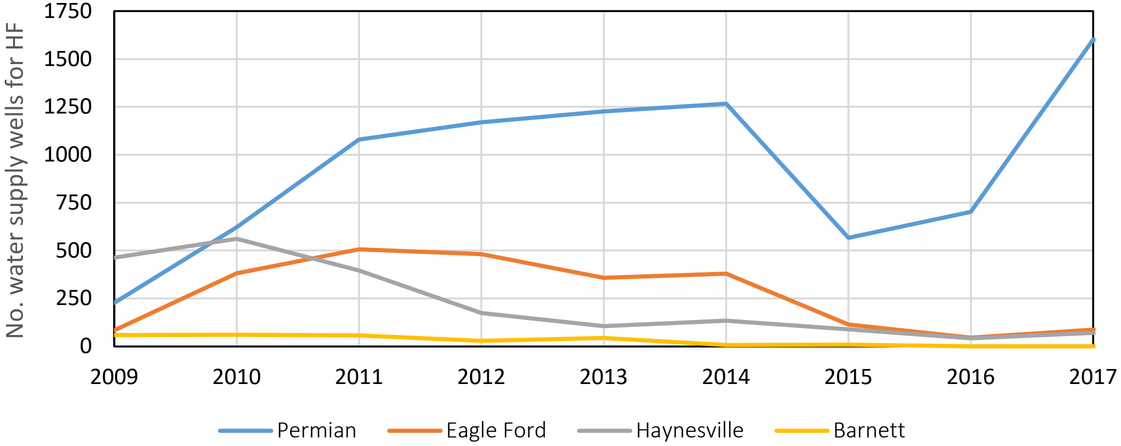


HF water use (maximum annual): 3% to 22% of total non-mining water use (TWU; USGS 2015).

HF water use in the Permian = 20% of water use in the play.

Scanlon et al., ES&T, 2020

Number of Water Wells Drilled to Supply Water for Hydraulic Fracturing

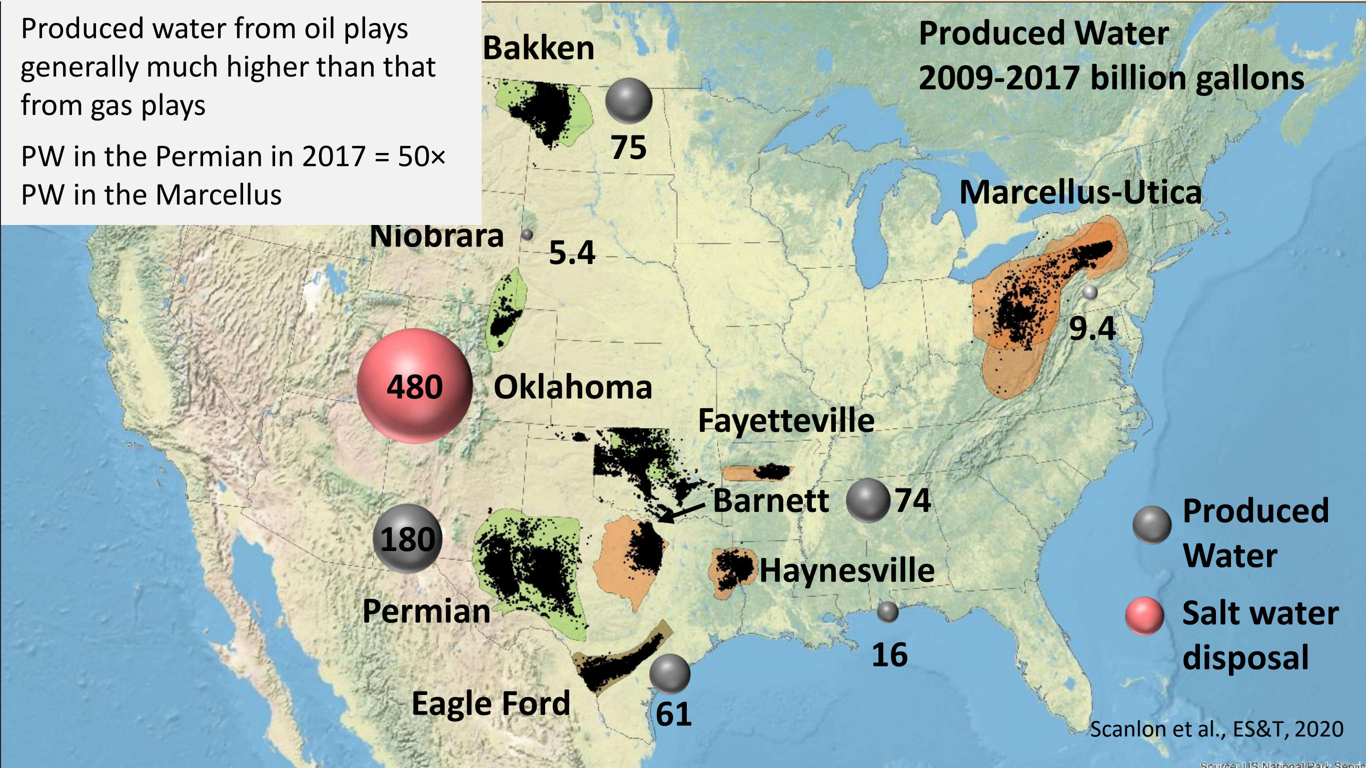


Total: 8,500 wells in the Permian; 2,500 wells in the Eagle Ford

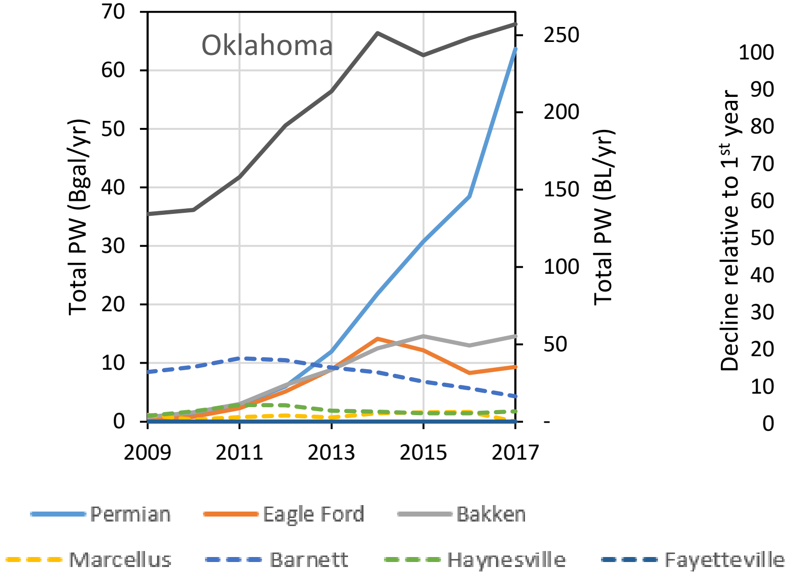
Scanlon et al., ES&T, 2020

Produced water from oil plays generally much higher than that from gas plays

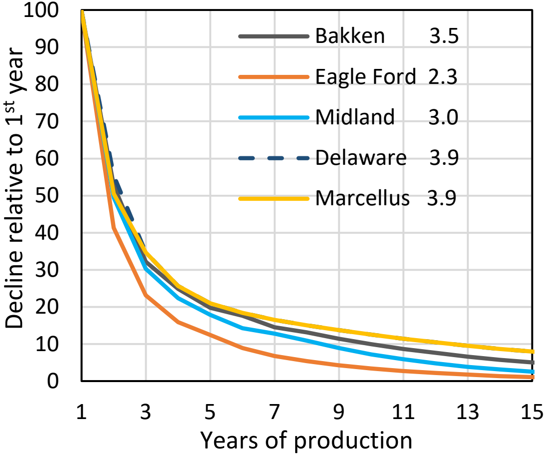
PW in the Permian in 2017 = 50× PW in the Marcellus



Produced Water Volume in Plays



Decline Curves for Produced Water



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

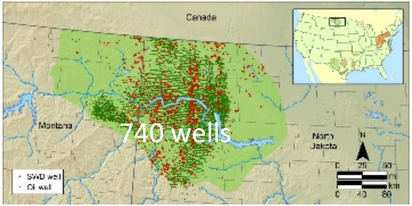
Oil plays produce much more water than gas plays

Need to keep drilling wells to maintain production

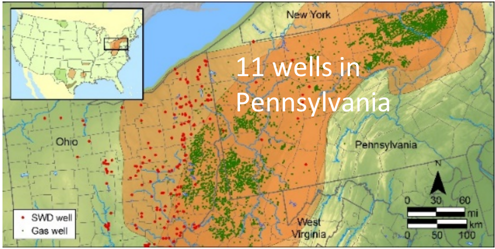
Scanlon et al., ES&T, 2020

Produced water is mostly managed using Saltwater Disposal Wells

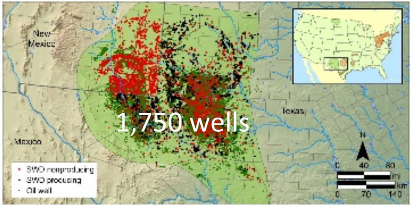
Bakken



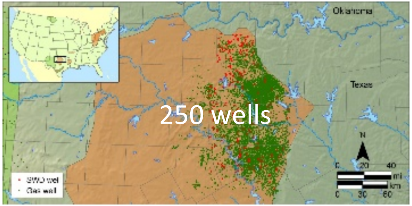
Marcellus/Utica



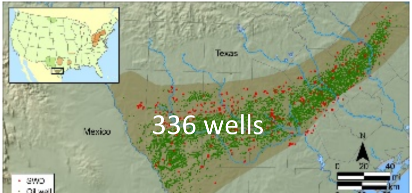
Permian



Haynesville

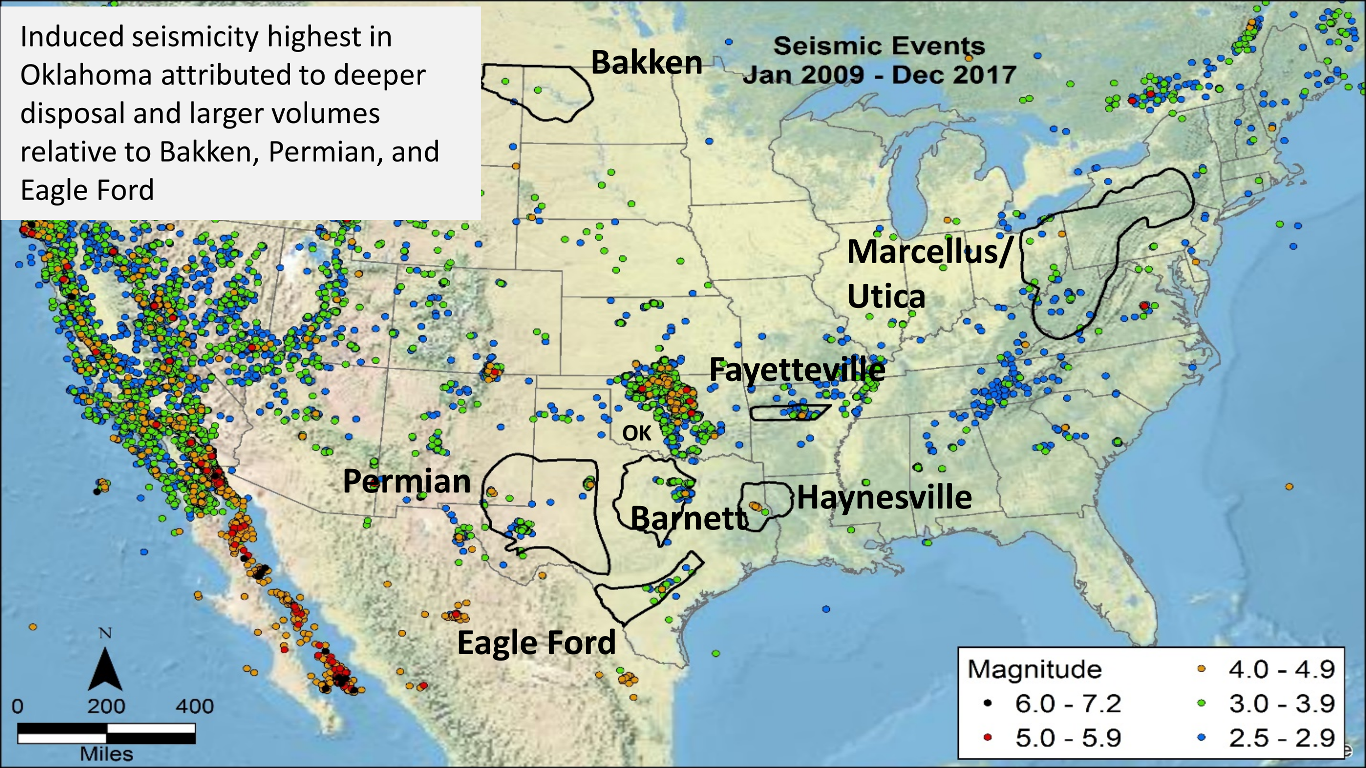


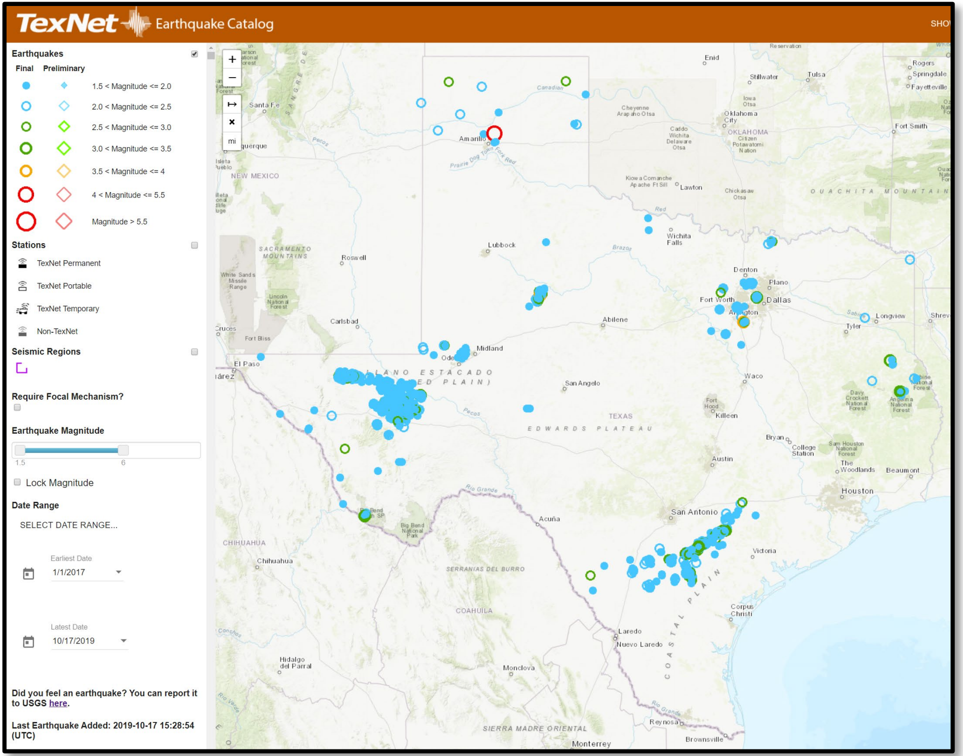
Eagle Ford



Scanlon et al., ES&T, 2020

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





UT-BEG

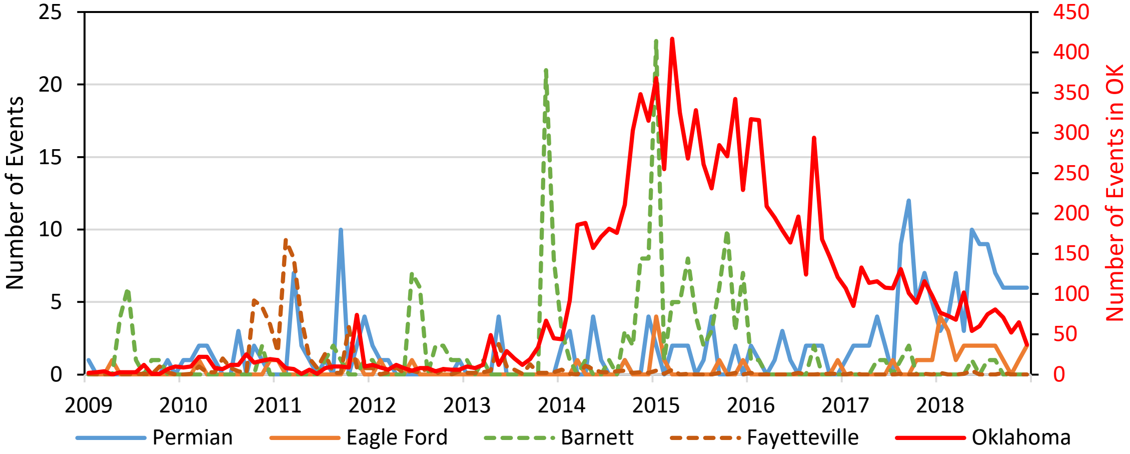
TexNet/CISR

Center for Integrated Seismic Research

Recent study:
EQs related to HF in Delaware Basin

Lomax & Savvaidis, 2019

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



Seismicity increasing in the Permian and Eagle Ford plays

Depth of Water Disposal Affects Seismicity

Managing Basin-Scale Fluid Budgets to Reduce Injection-Induced Seismicity from the Recent U.S. Shale Oil Revolution

by Bridget R. Scanlon, Matthew B. Weingarten, Kyle E. Murray, and Robert C. Reedy

ABSTRACT

With the U.S. unconventional oil revolution, adverse impacts from subsurface disposal of coproduced water, such as induced seismicity, have markedly increased, particularly in Oklahoma. Here, we adopt a new, more holistic analysis by linking produced water (PW) volumes, disposal, and seismicity in all major U.S. unconventional oil plays (Bakken, Eagle Ford, and Permian plays, and Oklahoma) and provide guidance for long-term management. Results show that monthly PW injection volumes doubled across the plays since 2009. We show that the shift in PW disposal to nonproducing geologic zones related to low-permeability unconventional reservoirs is a fundamental driver of induced seismicity. We statistically associate seismicity in Oklahoma to (1) PW injection rates, (2) cumulative PW volumes, and (3) proximity to basement with updated data through 2017. The major difference between intensive seismicity in Oklahoma versus low seismicity levels in the Bakken, Eagle Ford, and Permian Basin plays is attributed to proximity to basement with deep injection near basement in Oklahoma relative to shallower injection distant from basement in other plays. Directives to mitigate Oklahoma seismicity are consistent with our findings: reducing (1) PW injection rates and (2) regional injection volumes by 40% relative to the 2014 total in wells near the basement, which resulted in a 70% reduction in the number of $M \geq 3.0$ earthquakes in 2017 relative to the 2015 peak seismicity. Understanding linkages between PW management and seismicity allows us to develop a portfolio of strategies to reduce future adverse impacts of PW management, including reuse of PW for hydraulic fracturing in the oil and gas sector.

INTRODUCTION

The United States has been the global leader in oil production since 2013, exceeding production in Saudi Arabia (U.S. Energy Information Administration [EIA], 2018a). The marked increase in U.S. oil production is attributed to technology advances, primarily hydraulic fracturing (HF) and horizontal drilling of wells up to 2–3 miles long (~3–5 km). These advances allow oil to be extracted from low-permeability source rocks (e.g., shales, tight sands, or carbonates) or through dewatering of oil reservoirs, as in Oklahoma (Murray, 2013; Scanlon *et al.*, 2016, 2017). Oil production from shales and tight rocks accounted for about half of the U.S. production in 2017, greatly enhancing U.S. energy security (U.S. EIA, 2018a). Shales and tight rocks are generally referred to as unconventional or continuous (areally extensive) reservoirs that require HF and horizontal wells to extract oil (Schenk and Pollastro, 2002). These unconventional reservoirs contrast with traditional higher permeability conventional reservoirs that can be developed with vertical wells and without large-water-volume HF.

Oil wells also produce large volumes of water, averaging ~10 barrels (bbl) of water per barrel of oil in the United States in 2012 (Veil, 2015). Water coproduced with oil has been re-

Main Findings:

High levels of seismicity in Oklahoma related to deep disposal of wastewater near the crystalline basement

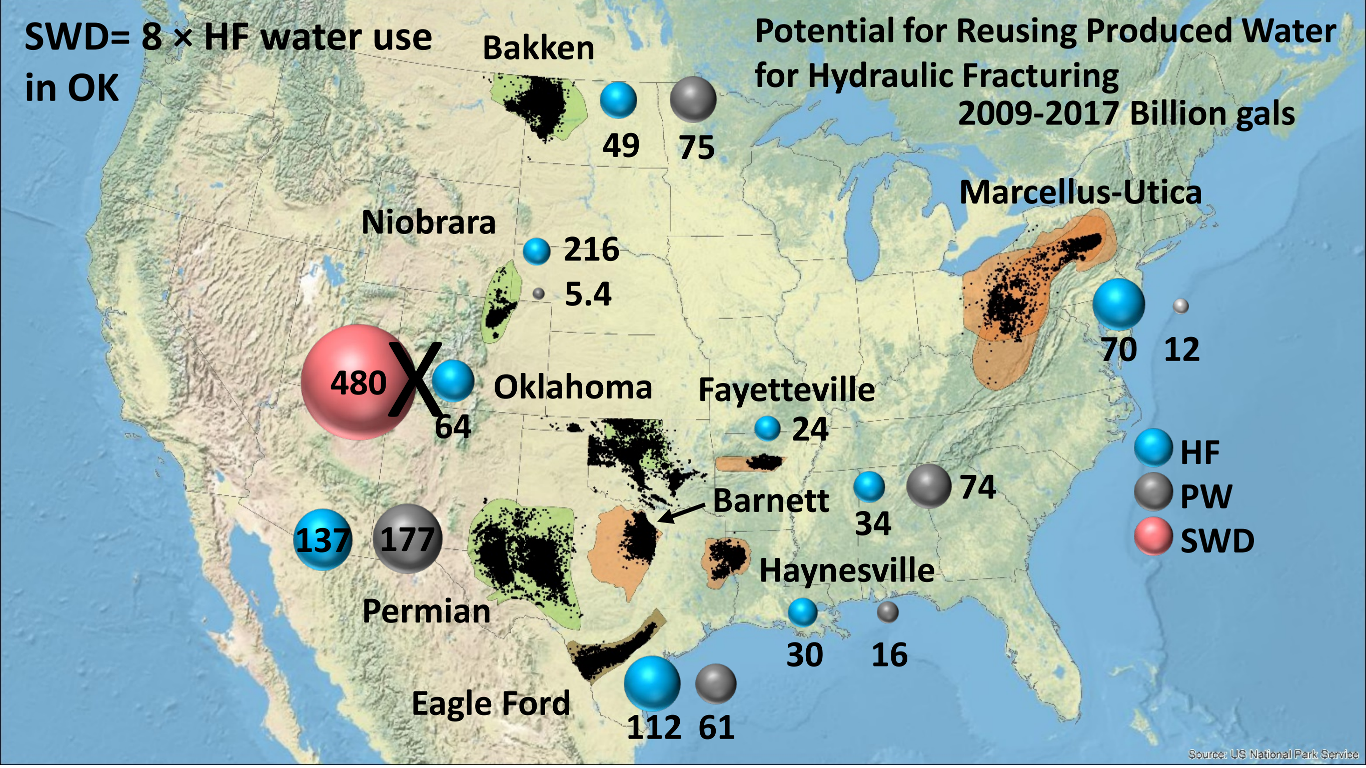
Much lower levels of seismicity in the Bakken, Eagle Ford and Permian Basin plays related to shallow disposal of wastewater.

Scanlon et al., Seism. Res. Lett., 2019

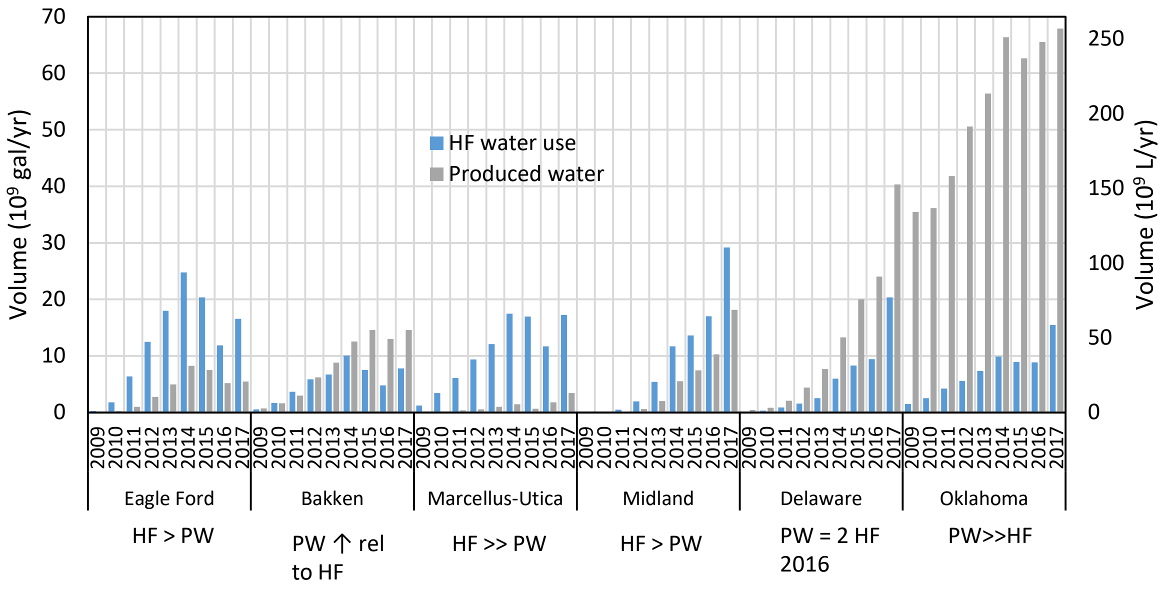
Reducing Tradeoffs Between Shallow and Deep Disposal

Shallow disposal	Deep disposal
Could impact overlying aquifer	Little or no impact on aquifers
Impact oil well drilling (over-pressuring, extra casing)	Little or no direct impact on oil well drilling
Can impact oil production	Little direct impact on oil production
Less seismicity	More seismicity
	Under-pressured, high injectivity
Inexpensive, drill many	Expensive, few wells, high rates

Scanlon et al., Seism. Res. Lett., 2019

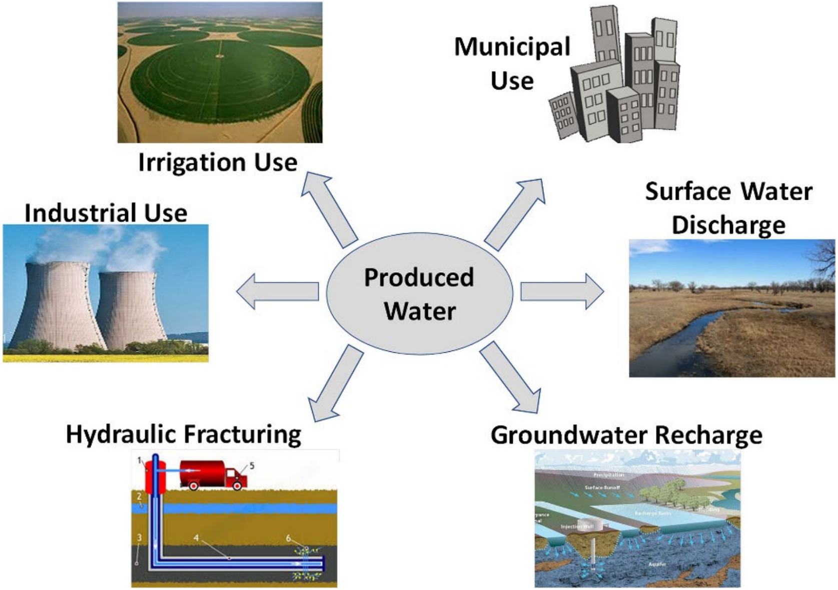

SWD= 8 × HF water use
in OK
Potential for Reusing Produced Water
for Hydraulic Fracturing
2009-2017 Billion gals
Bakken
49
75
Niobrara
216
5.4
Marcellus-Utica
70
12
480
X
64
Oklahoma
Fayetteville
24
HF
PW
SWD
Barnett
34
74
137
177
Permian
Haynesville
30
16
Eagle Ford
112
61
Source: US National Park Service

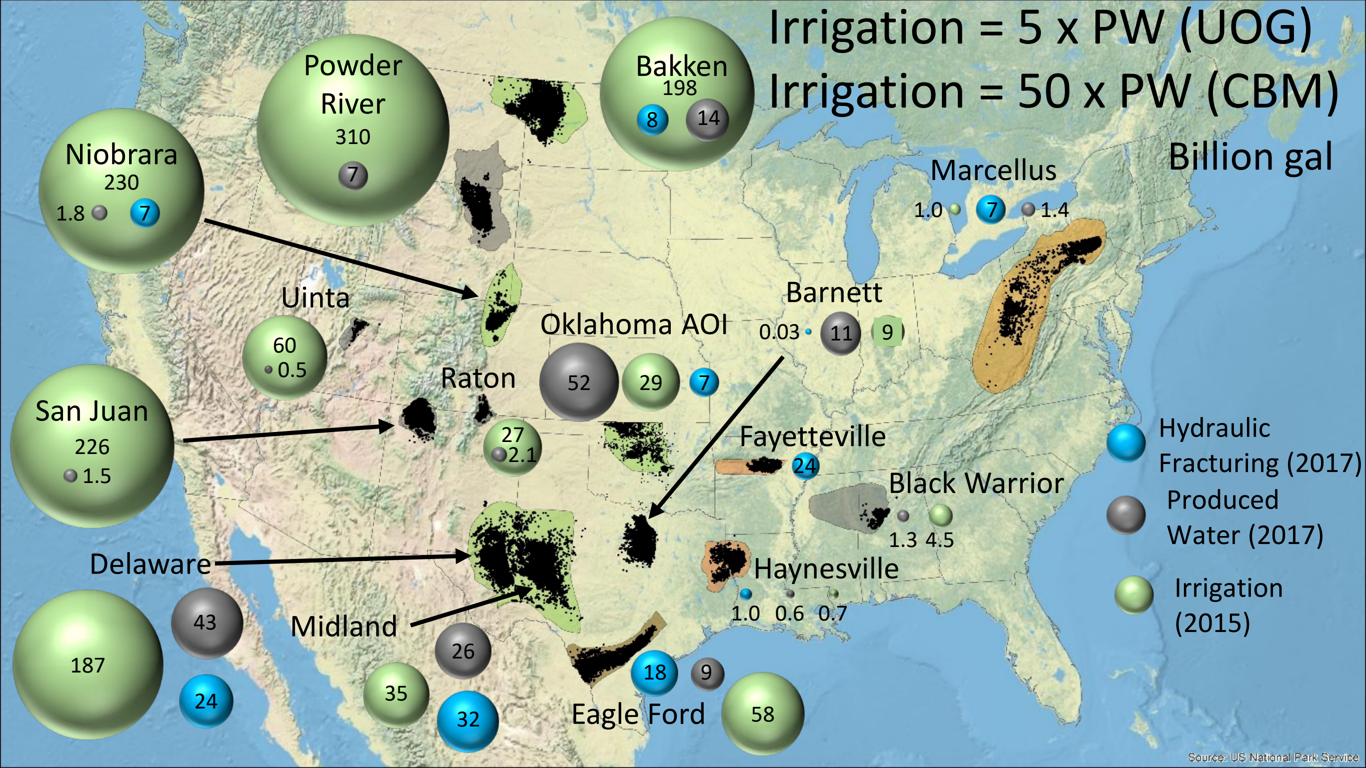
Temporal Variations in PW to HF Ratios by Play



Scanlon et al., ES&T, 2020

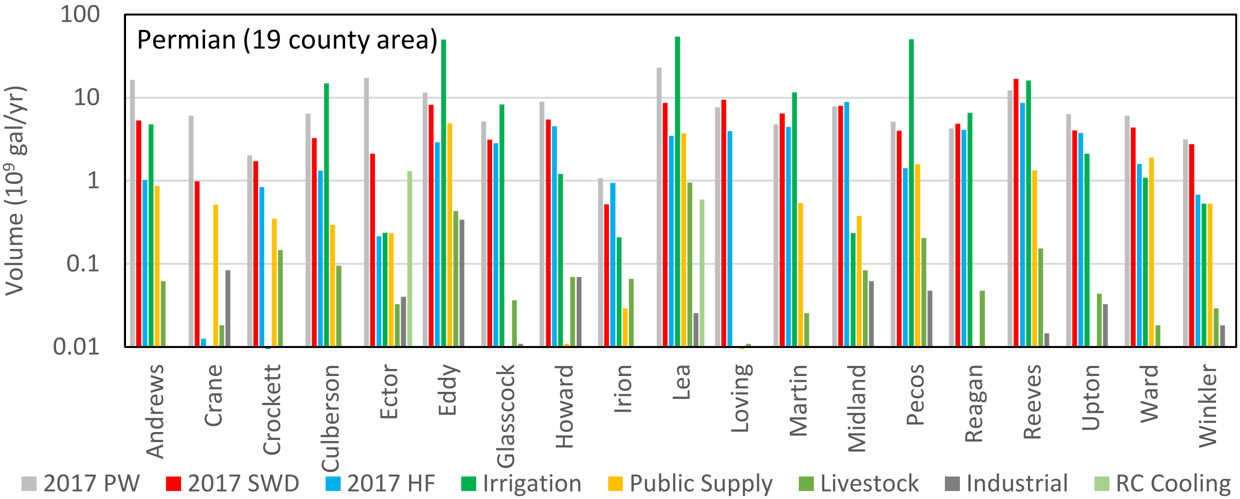
Options for Managing Produced Water



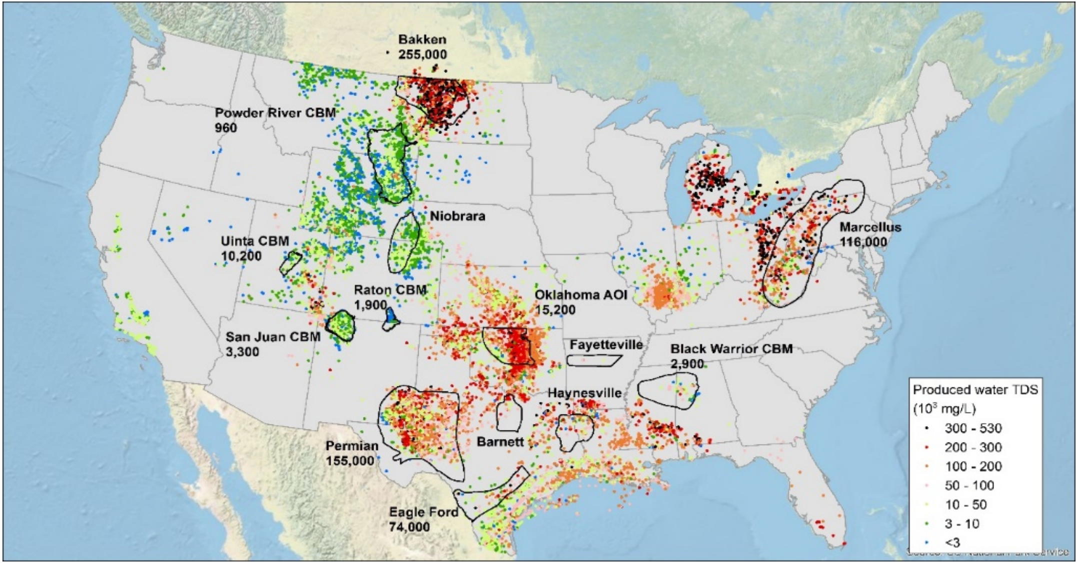


Irrigation = 5 x PW (UOG)
Irrigation = 50 x PW (CBM)
Billion gal
Powder River
310
7
Bakken
198
8
14
Niobrara
230
1.8
7
Marcellus
1.0
7
1.4
Uinta
60
0.5
Oklahoma AOI
52
29
7
Barnett
0.03
11
9
Raton
27
2.1
San Juan
226
1.5
Fayetteville
24
Black Warrior
1.3
4.5
Haynesville
1.0
0.6
0.7
Delaware
187
43
24
Midland
26
35
32
Eagle Ford
18
9
58
Hydraulic Fracturing (2017)
Produced Water (2017)
Irrigation (2015)
Source: US National Park Service

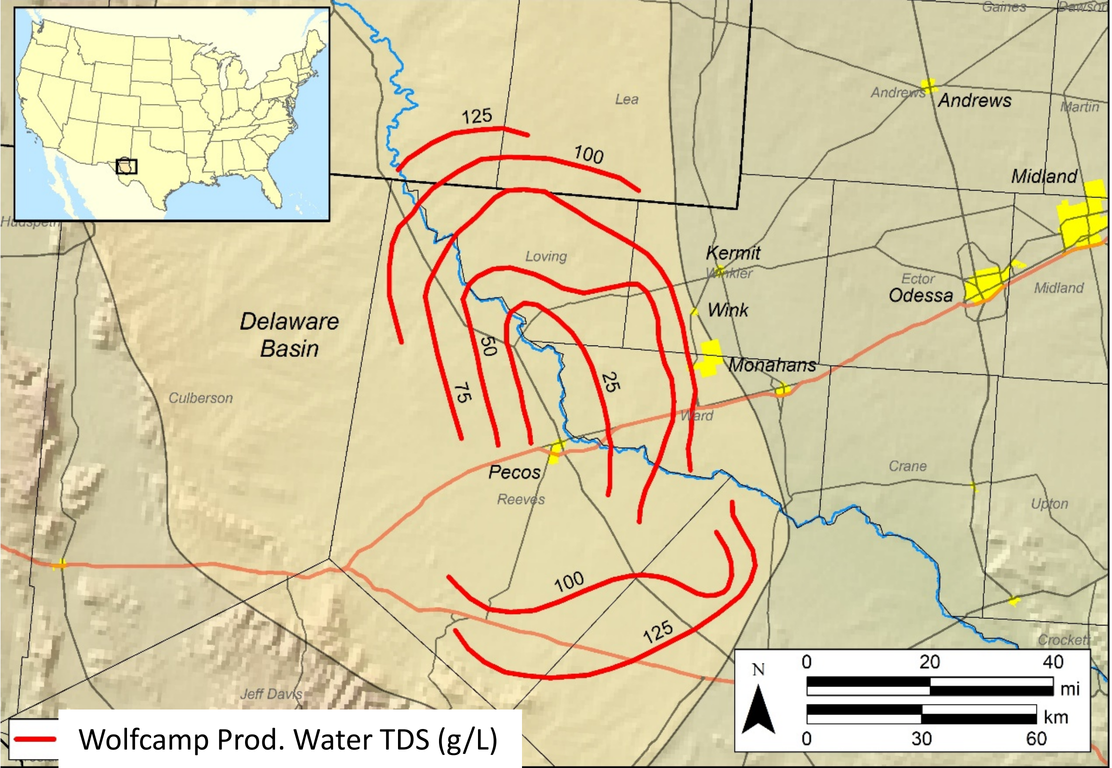
Permian Basin: Water Use relative to Other Sectors



Produced Water Quality: Total Dissolved Solids



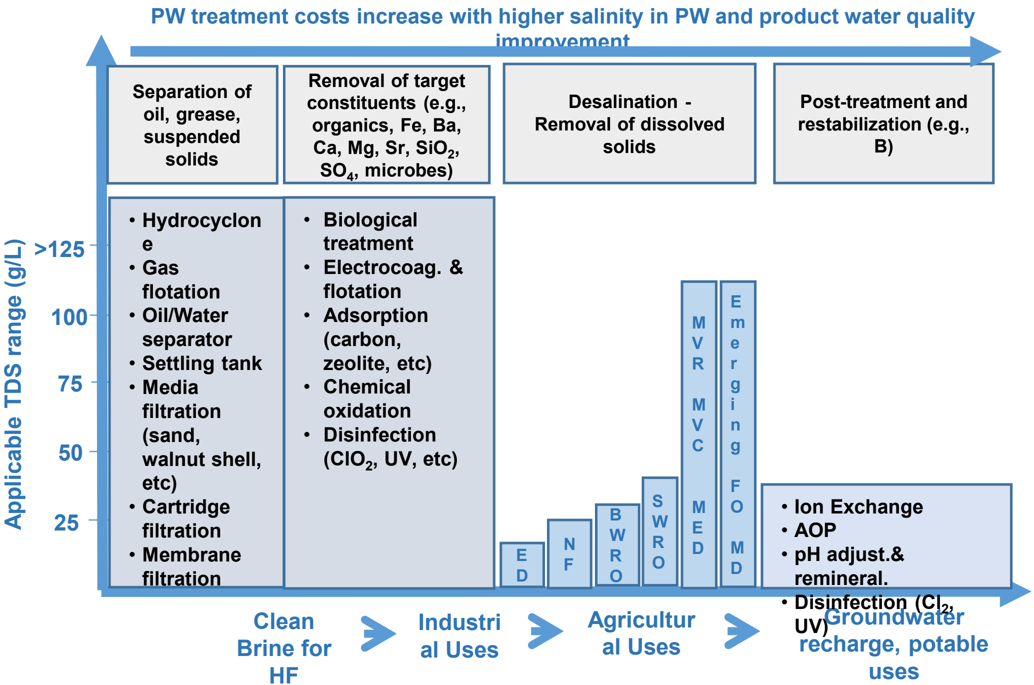
USGS Produced Waters Database
Literature



Produced Water Quality

Wolfcamp Resevoir

~200 points

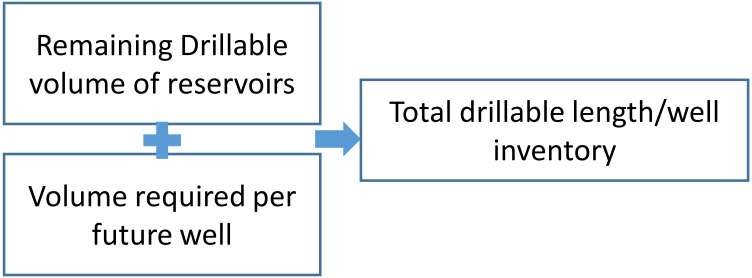

PW treatment costs increase with higher salinity in PW and product water quality improvement
Applicable TDS range (g/L)
>125
100
75
50
25
Separation of oil, grease, suspended solids
Removal of target constituents (e.g., organics, Fe, Ba, Ca, Mg, Sr, SiO2, SO4, microbes)
Desalination - Removal of dissolved solids
Post-treatment and restabilization (e.g., B)
• Hydrocyclone
• Gas flotation
• Oil/Water separator
• Settling tank
• Media filtration (sand, walnut shell, etc)
• Cartridge filtration
• Membrane filtration
• Biological treatment
• Electrocoag. & flotation
• Adsorption (carbon, zeolite, etc)
• Chemical oxidation
• Disinfection (ClO2, UV, etc)
ED
NF
BWRO
SWRO
MVR MVC MED
Emerging FO MD
• Ion Exchange
• AOP
• pH adjust.& remineral.
• Disinfection (Cl2, UV)
Clean Brine for HF
Industrial Uses
Agricultural Uses
Groundwater recharge, potable uses

Basic Questions

1. What is the potential for reusing produced water for hydraulic fracturing based on **historical data**?
2. What is the potential for reusing produced water for hydraulic fracturing based on **projections**?

Projections of water demand for HF and produced water

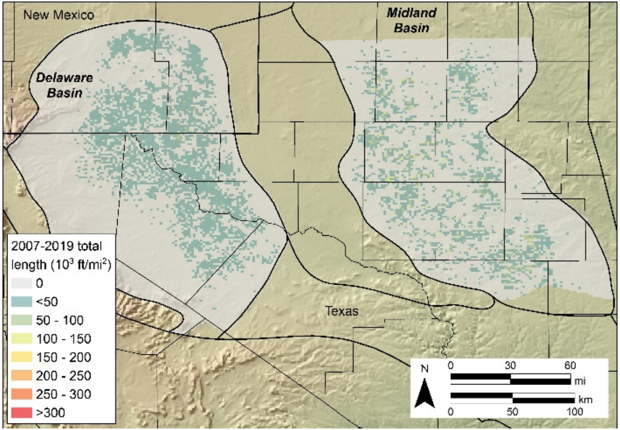
Projections based on **Technically Recoverable Resource Development**: all potential future wells could be drilled using current technology over the life of the plays.

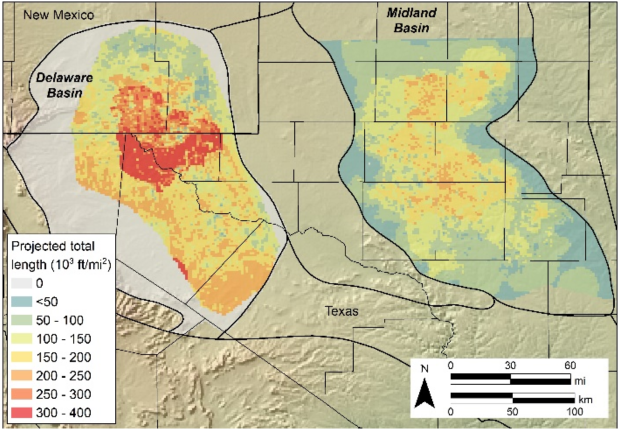


Plays: Permian Delaware (**Wolfcamp [WC] A & B**), Permian Midland (**WC A & B**), Eagle Ford, Bakken, and Marcellus.

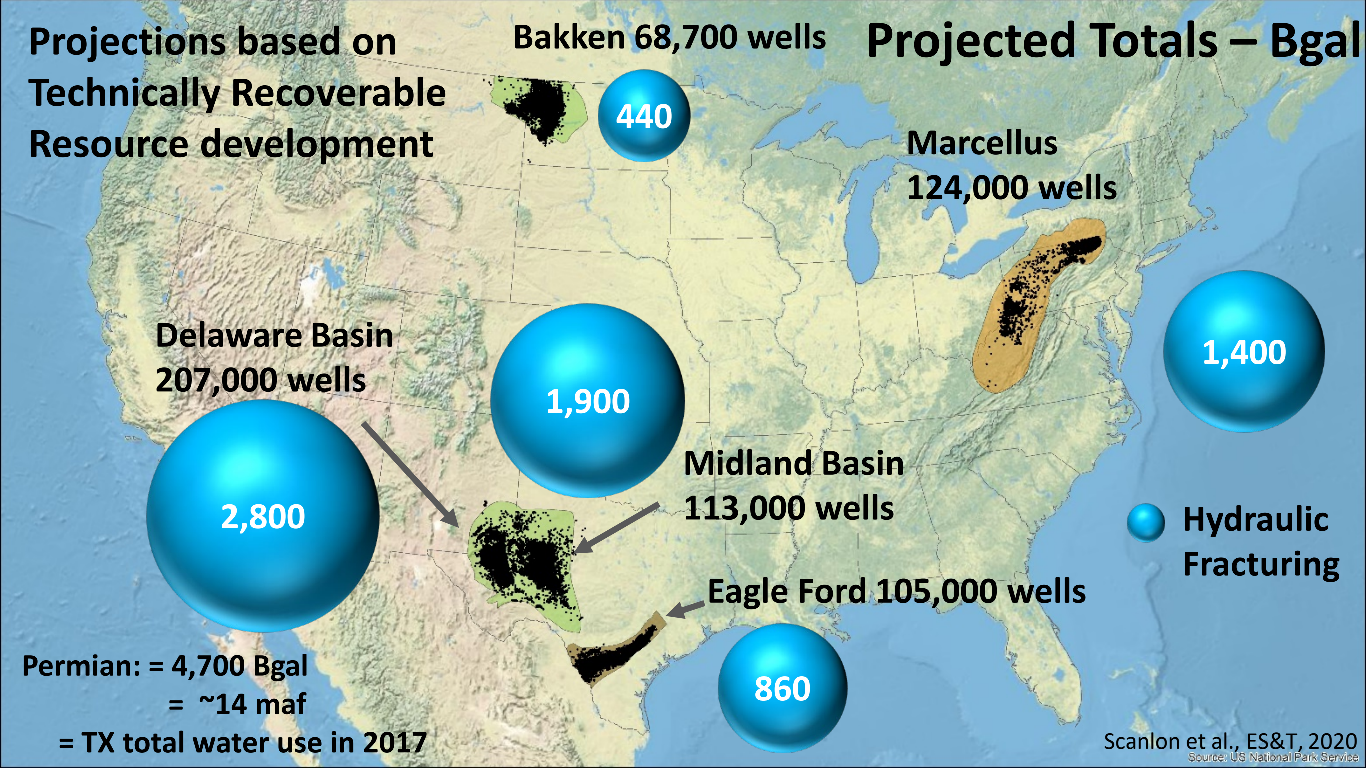
Scale: 1 square mile.

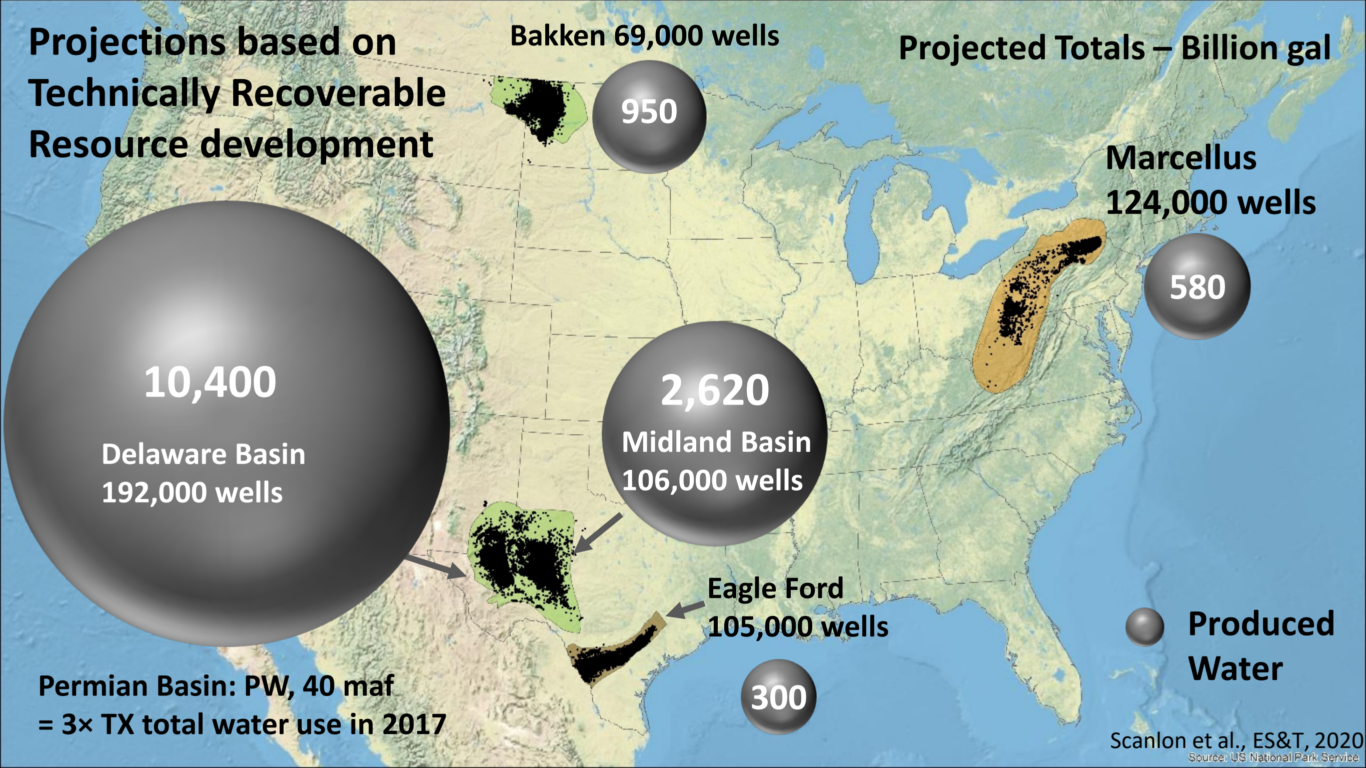
Historical and Projected Drilling Density at grid scale



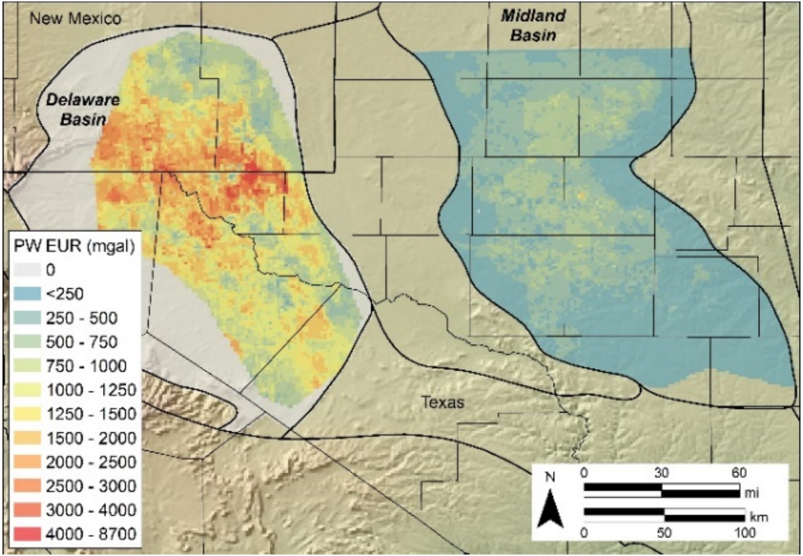


Scanlon et al., ES&T, 2020


Projections based on
Technically Recoverable
Resource development
Bakken 68,700 wells
440
Projected Totals – Bgal
Marcellus
124,000 wells
1,400
Delaware Basin
207,000 wells
1,900
2,800
Midland Basin
113,000 wells
Hydraulic
Fracturing
Eagle Ford 105,000 wells
860
Permian: = 4,700 Bgal
= ~14 maf
= TX total water use in 2017
Scanlon et al., ES&T, 2020
Source: US National Park Service

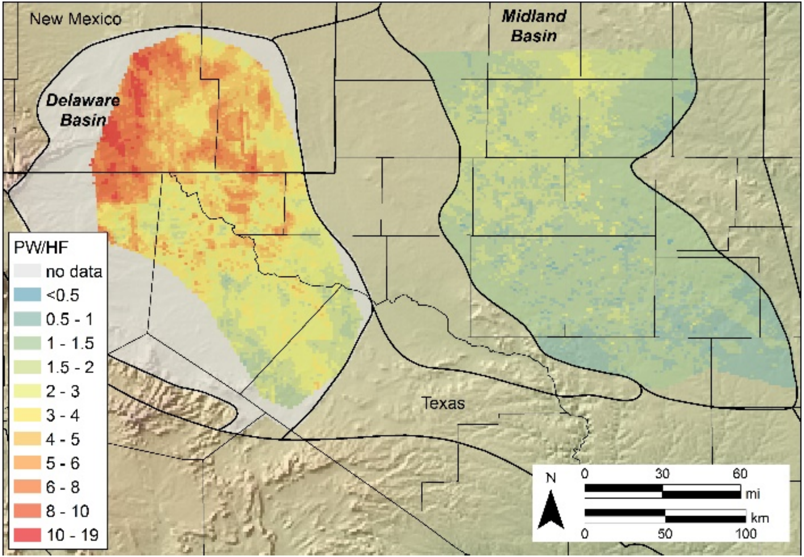

Projections based on Technically Recoverable Resource development
Bakken 69,000 wells
950
Projected Totals – Billion gal
Marcellus
124,000 wells
580
10,400
Delaware Basin
192,000 wells
2,620
Midland Basin
106,000 wells
Eagle Ford
105,000 wells
300
Produced Water
Permian Basin: PW, 40 maf
= 3× TX total water use in 2017
Scanlon et al., ES&T, 2020
Source: US National Park Service

Projected Produced Water at Grid Scale

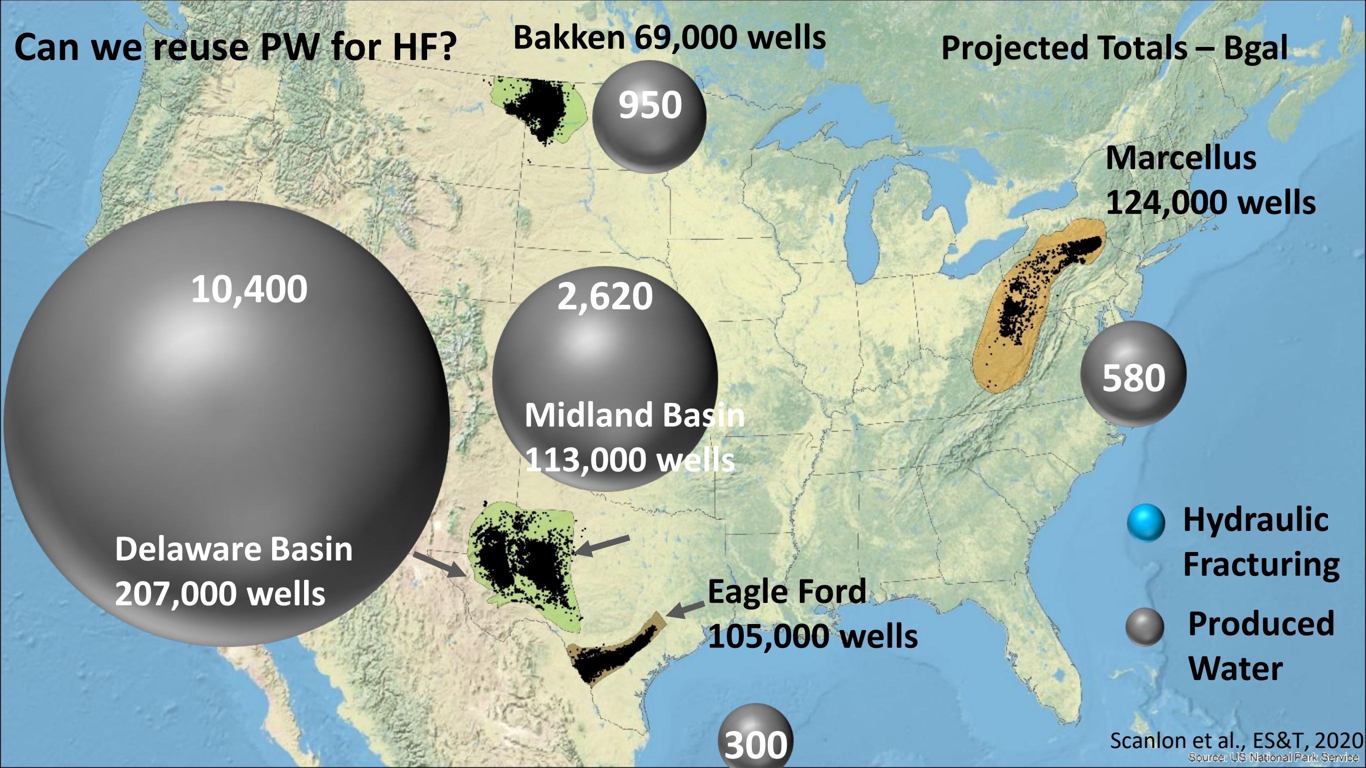


Scanlon et al., ES&T, 2020

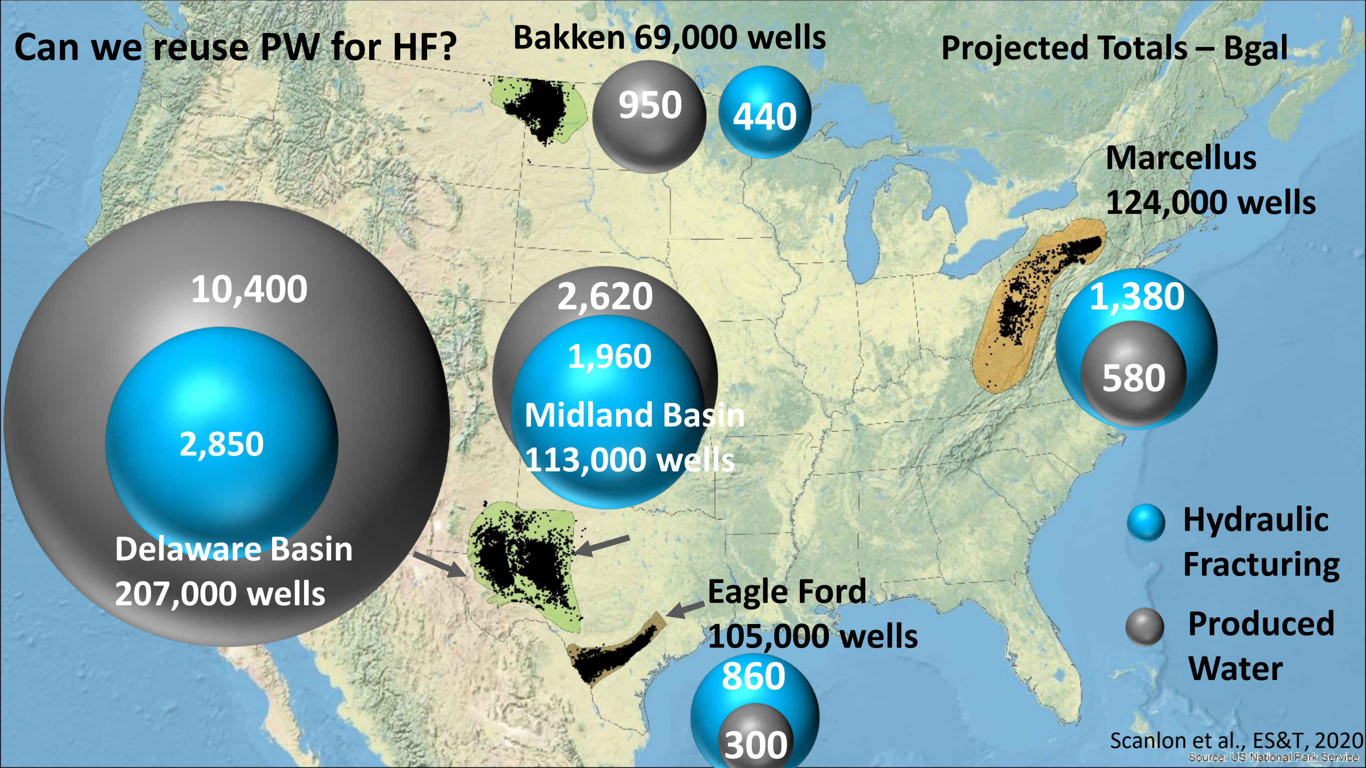
Ratio of Produced Water to Hydraulic Fracturing Water Demand



Scanlon et al., ES&T, 2020



Can we reuse PW for HF?
Bakken 69,000 wells
950
Projected Totals – Bgal
Marcellus
124,000 wells
10,400
2,620
580
Midland Basin
113,000 wells
Delaware Basin
207,000 wells
Eagle Ford
105,000 wells
Hydraulic
Fracturing
Produced
Water
300
Scanlon et al., ES&T, 2020
Source: US National Park Service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Eagle Ford
105,000 wells
860
300
Hydraulic Fracturing
Produced Water
Scanlon et al., ES&T, 2020
Source: US National Park Service

Bureau of Economic Geology

Subsurface Water and Energy Laboratory (SWEL)

Mission

Establish an understanding of the water cycle in all major U.S. unconventional plays developed using hydraulic fracturing (HF) through multiscale data and modeling, promote sustainable water management while minimizing adverse environmental impacts, and integrate water management with energy development scenarios through this proposed Subsurface Water and Energy Laboratory (SWEL) research consortium.

Proposed
Water Consortium
at the Univ. TX
Bureau of
Economic Geology

Meeting Houston
Feb. 27 2020

Main Findings

Produced Water Management

- Oil plays produce much more water than gas plays (Permian PW = 50 × Marcellus PW in 2017)
- Potential issues with PW management (e.g. induced seismicity, disposal capacity)

Management strategies

- Reusing PW for HF of new wells should mitigate water issues in most plays, except Oklahoma or Delaware Basin where PW volume>>HF water demand
- Beneficial reuse in other water sectors, problems with water quality, economics, and regulations

Project Sponsors:

EXXON Mobil

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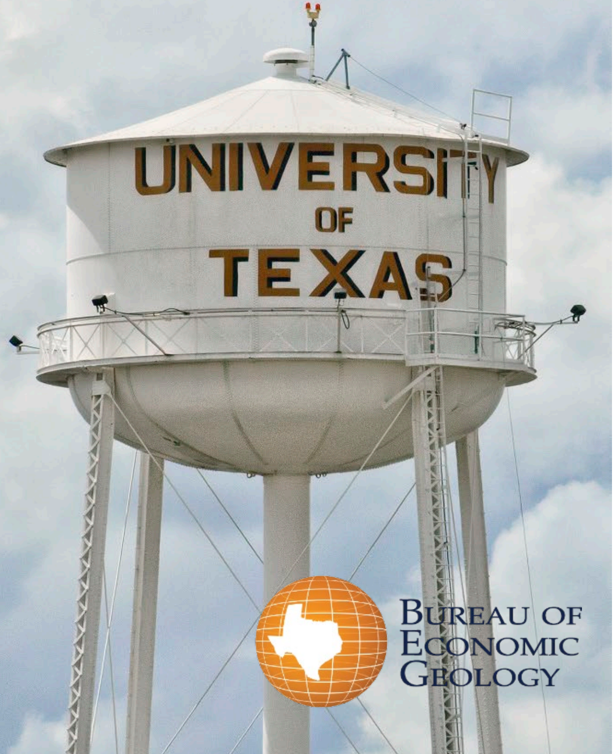
Alfred P. Sloan FOUNDATION

THE UNIVERSITY OF TEXAS AT AUSTIN JACKSON SCHOOL OF GEOSCIENCES



BUREAU OF ECONOMIC GEOLOGY

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