Injection Capacity Challenges and Opportunities: Delaware Basin

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What are the deterministic geologic conditions that promote fault rupture and seismicity?

What are the reservoir dynamics of large-scale injection?

(… *and what is the injection capacity?*)

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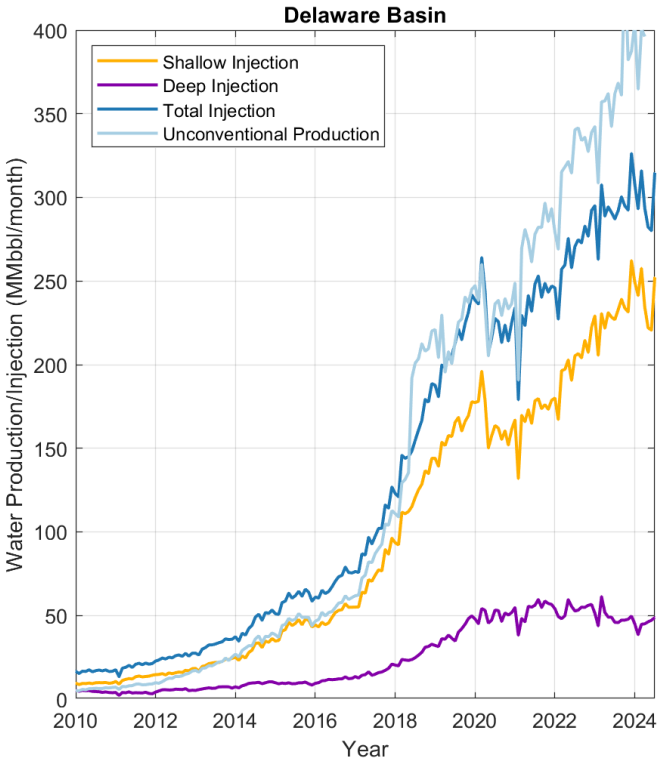
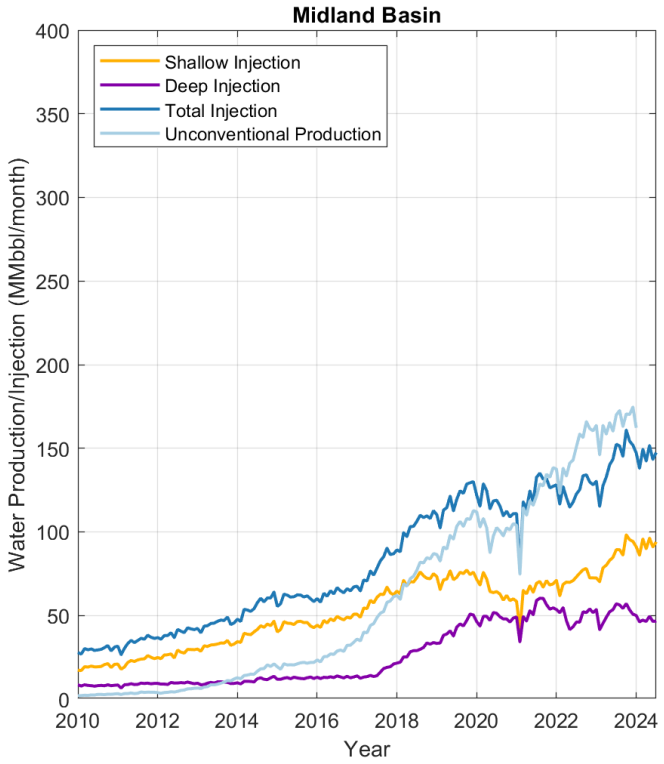
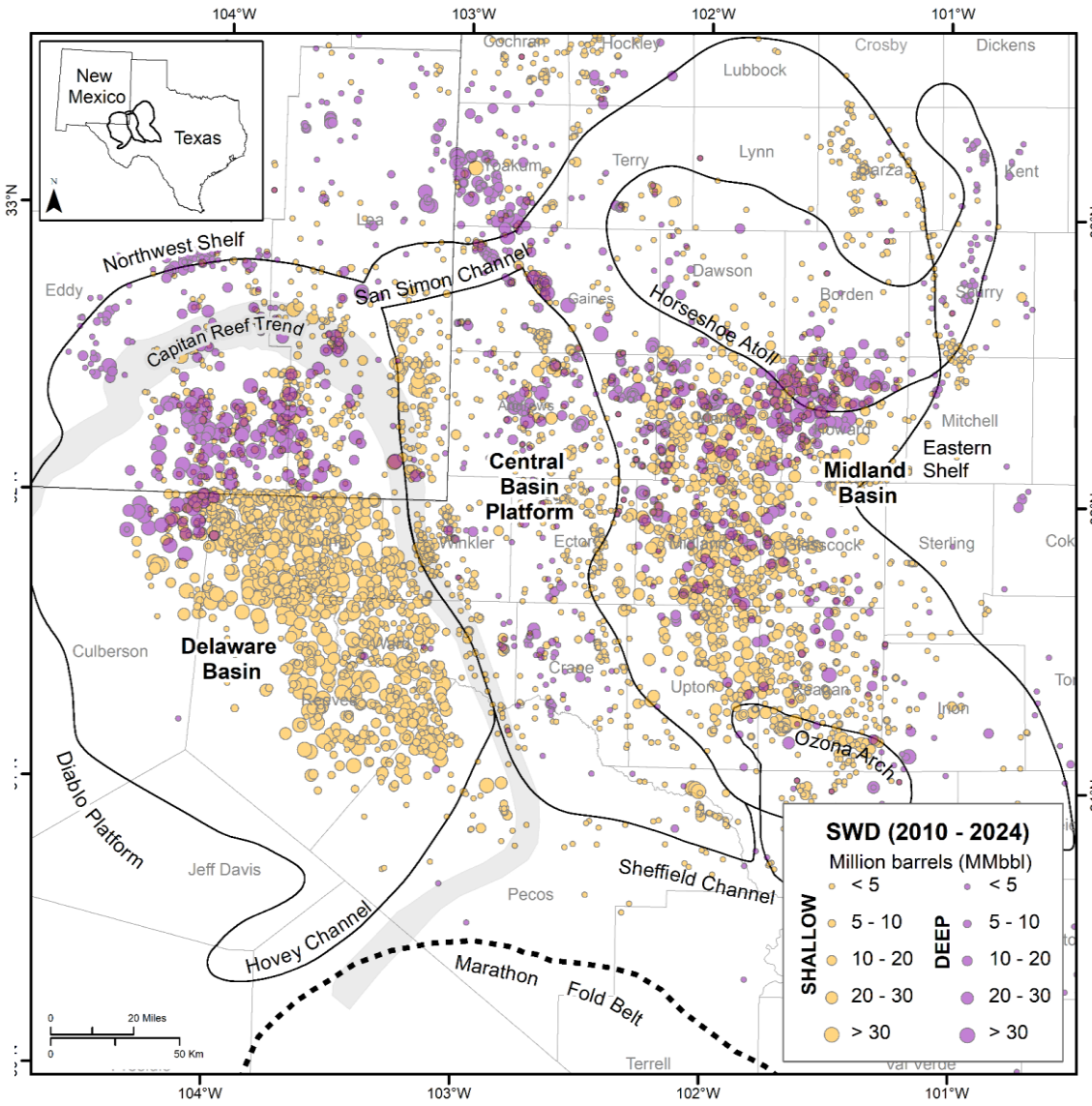
Permian Basin Injection Trends

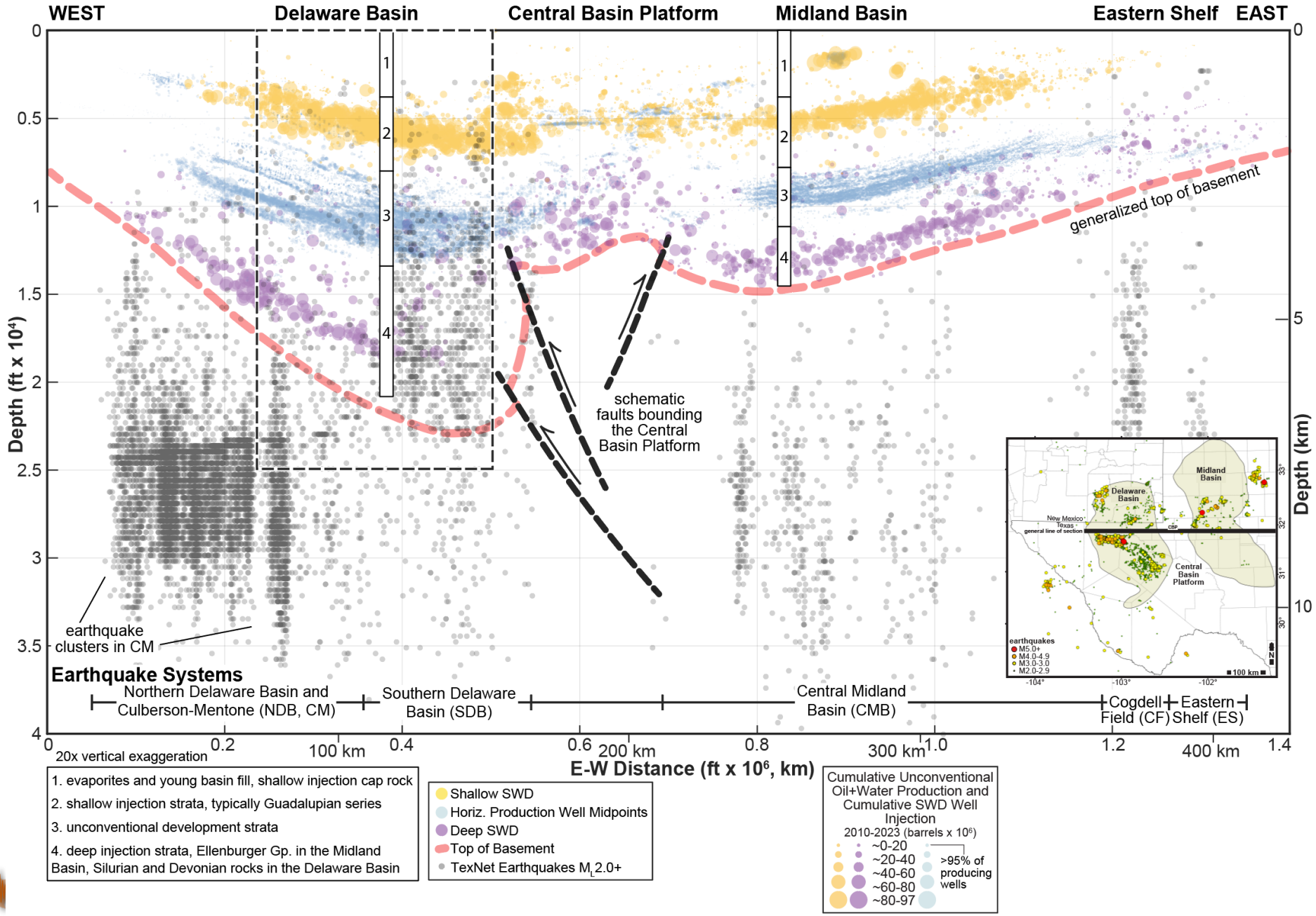
- Nearly all unconventional produced water not recycled for HF is injected for permanent disposal into strata shallower (~70% of injection) or deeper (~25%) than shale reservoirs
- Shallow injection occurring at rate of ~350 MMbbl/month, and deep at ~100 MMbbl/month, with **total daily injection of over 16 MMbbl**







Permian Basin Operations and Earthquakes



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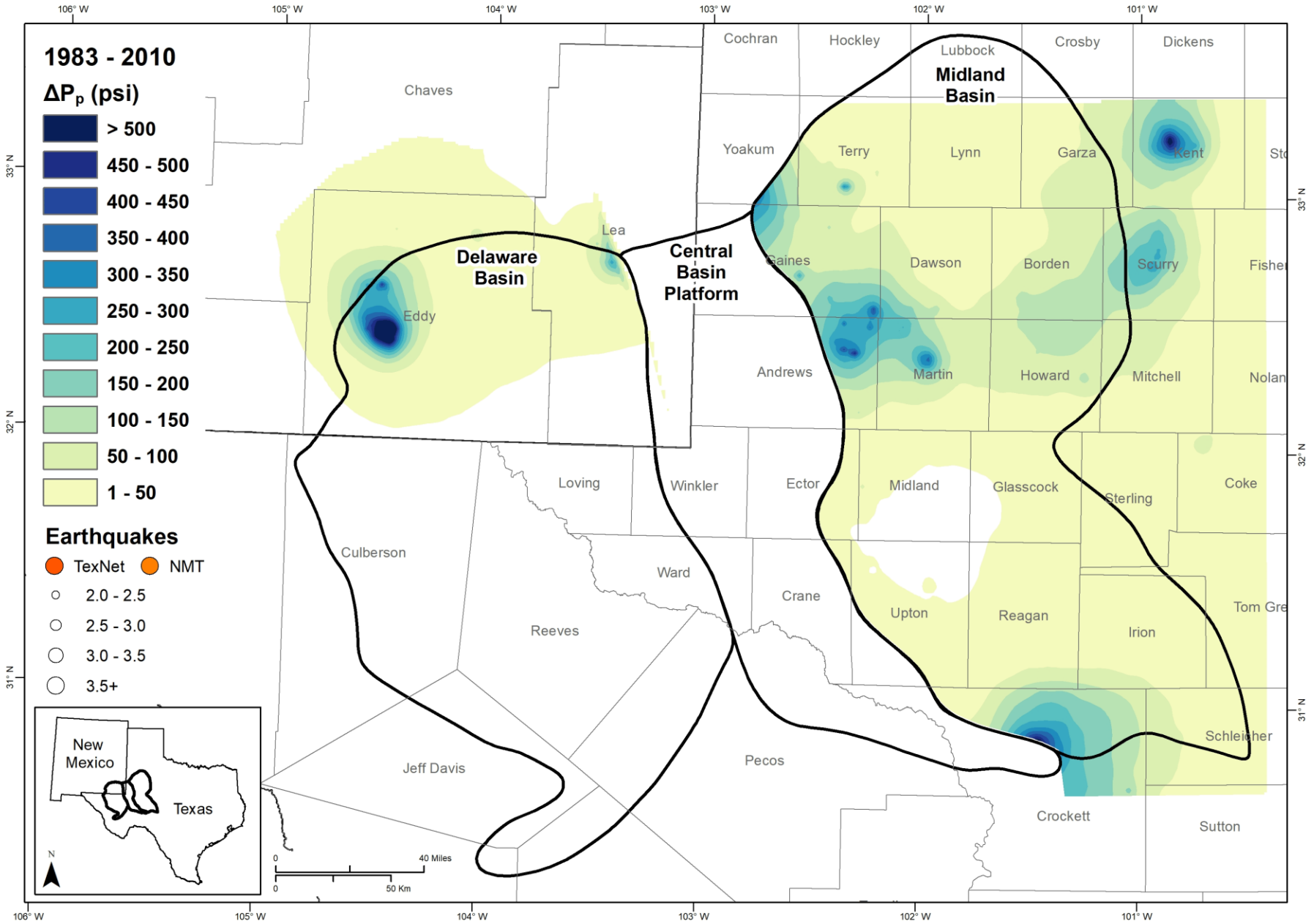
Deep Pore Pressure Change and Earthquakes (2015-2023)



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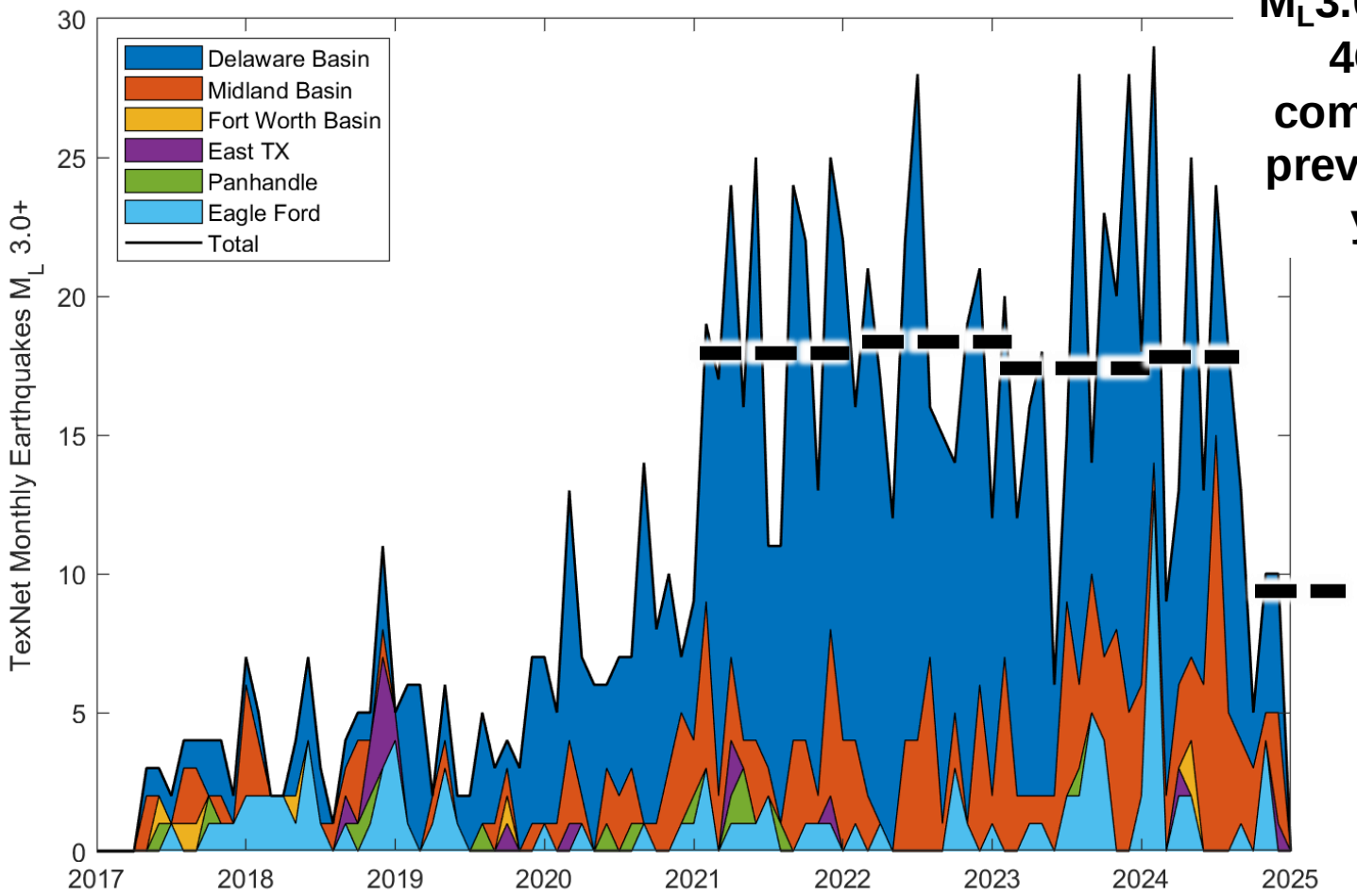
M3.0+ Earthquake History in TX

- Rates of Permian Basin earthquakes of M3.0+ have reduced from a peak ~20 per month in 2022 and 2023 to ~8 per month in 4Q 2024, largely driven by a reduction in earthquakes in the Delaware Basin
- Success largely due to changes in regulations and operations (voluntary and mandatory reduction in deep injection volumes in areas)
- However, events of M5.0+ still occur!



50% reduction in rate of M_L3.0+ EQs in 4Q2024 compared to previous 3.75 years

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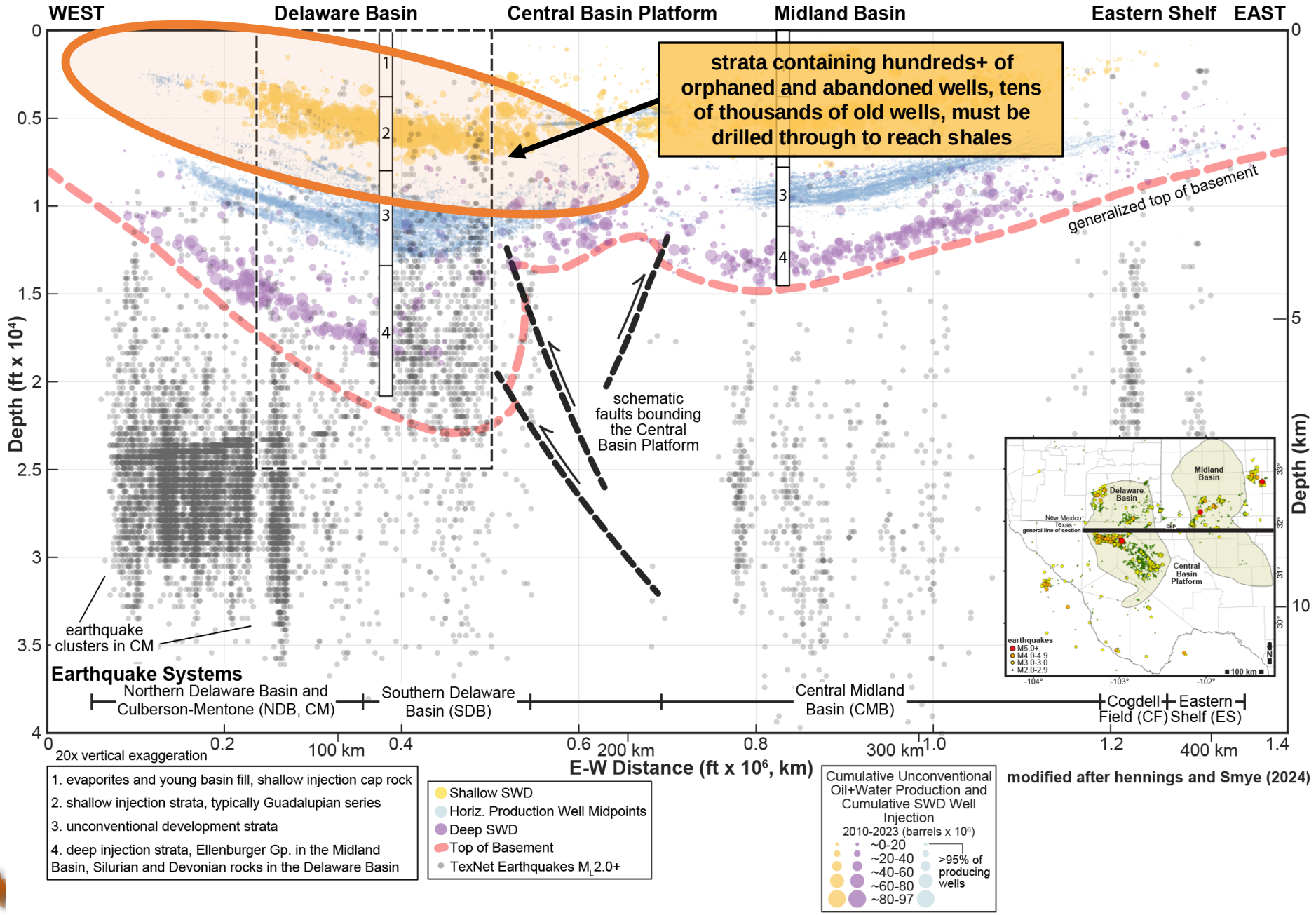
Permian Basin Operations and Earthquakes



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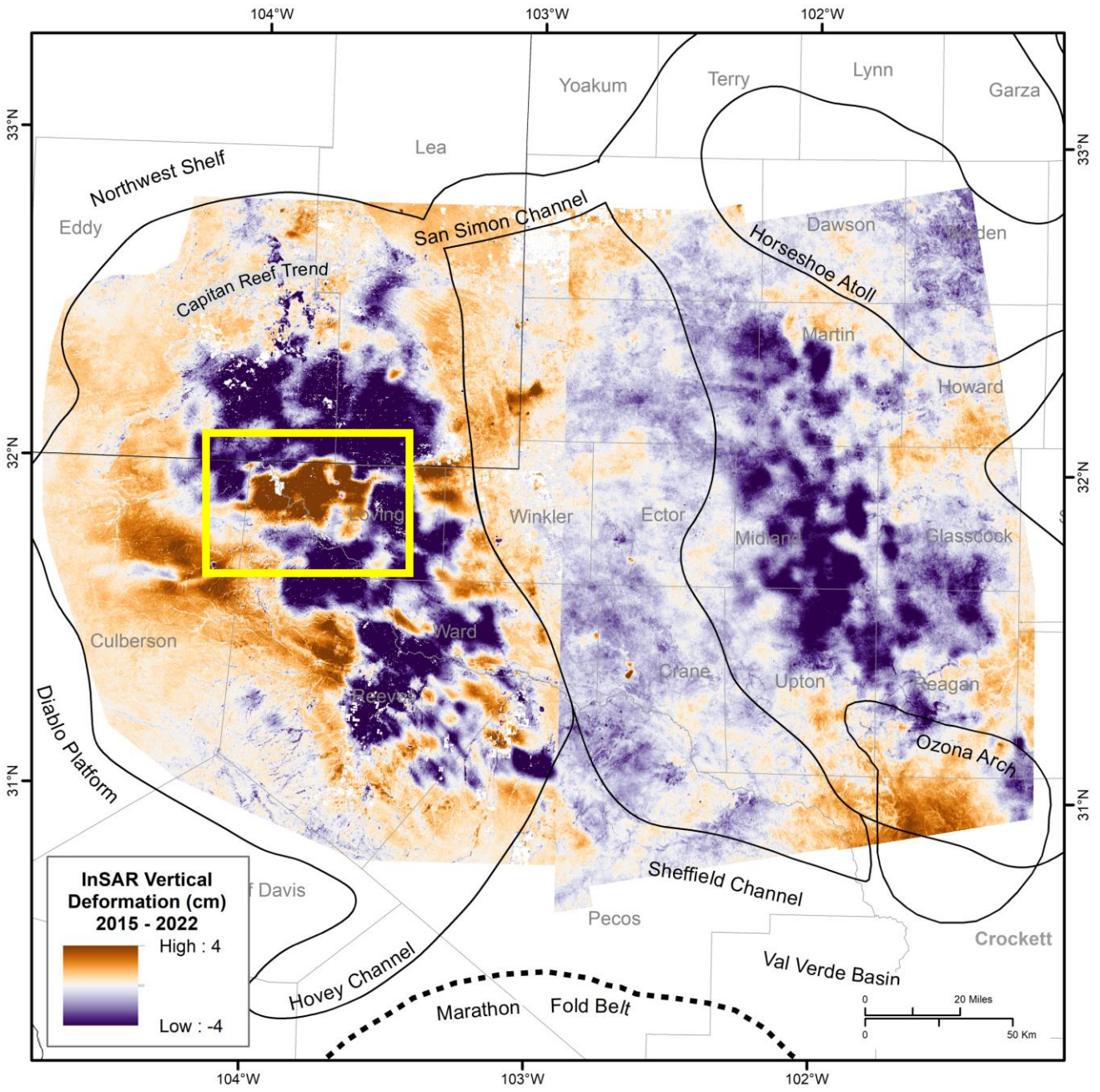
Surface Deformation Reflects Production and Vast Injection

- Well-documented link between surface deformation and oil and gas operations in the Delaware Basin
  - Subsidence broadly reflects production of fluids from shales
  - In some areas, uplift from shallow injection overcomes subsidence from production and causes an increase in the ground surface elevation
- Evidence of exceeded injection capacity: surface uplift associated with surface flows, blowouts, drilling challenges, well control issues
- **What is the remaining injection capacity in the DMG and where is it located?**



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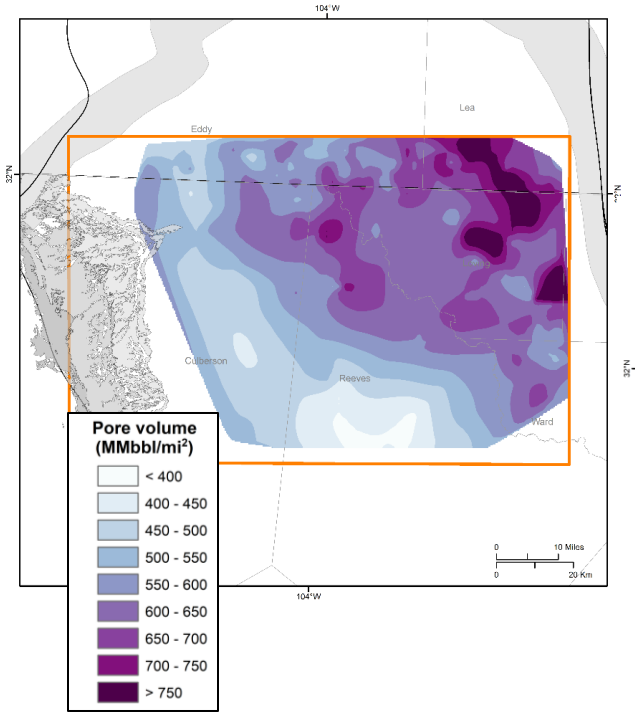
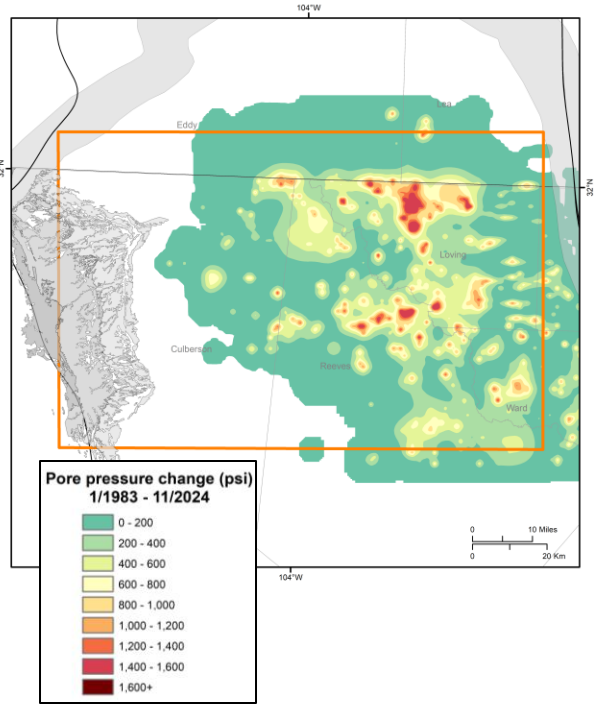
Where and What is the Injection Capacity of the System?

Pore Volume Assessment:
Static Capacity of
up to 800 MMbbl/mi^2



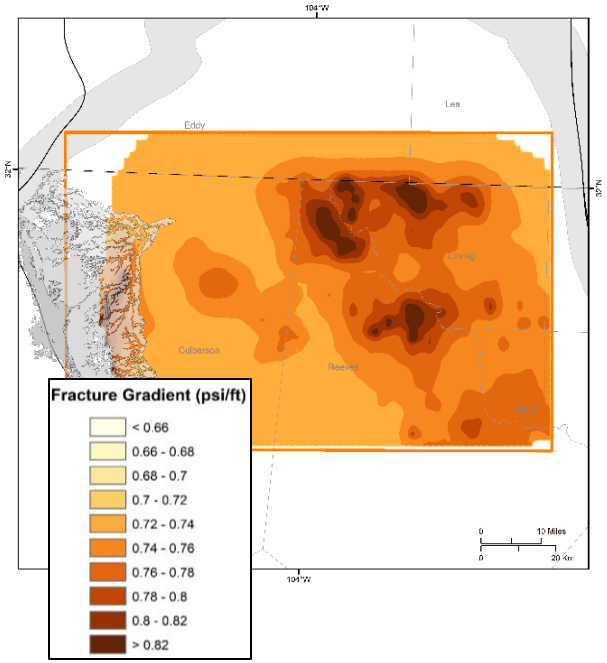
Calle, Smye, Hoffman

Modeling of Pore Pressure:
Increase of up to
1600 psi locally
(40% of initial pressure)



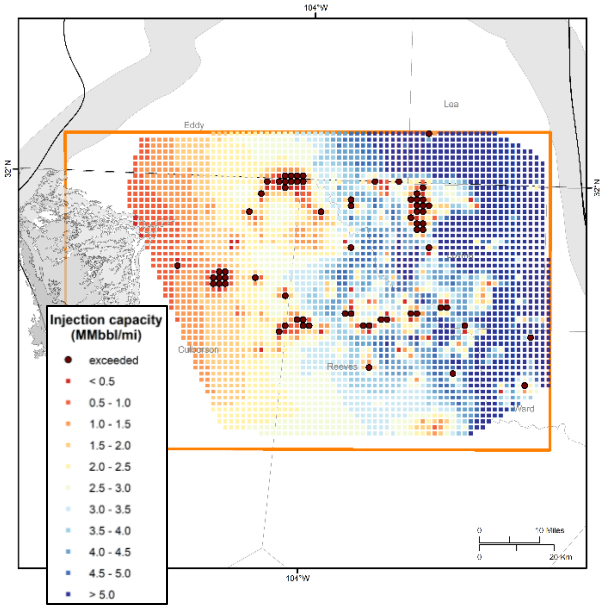
Leng, Ge, Nicot

Mapping of Fracture Gradient:
Injection Pressure Limit of
0.66 – 0.8 psi/ft



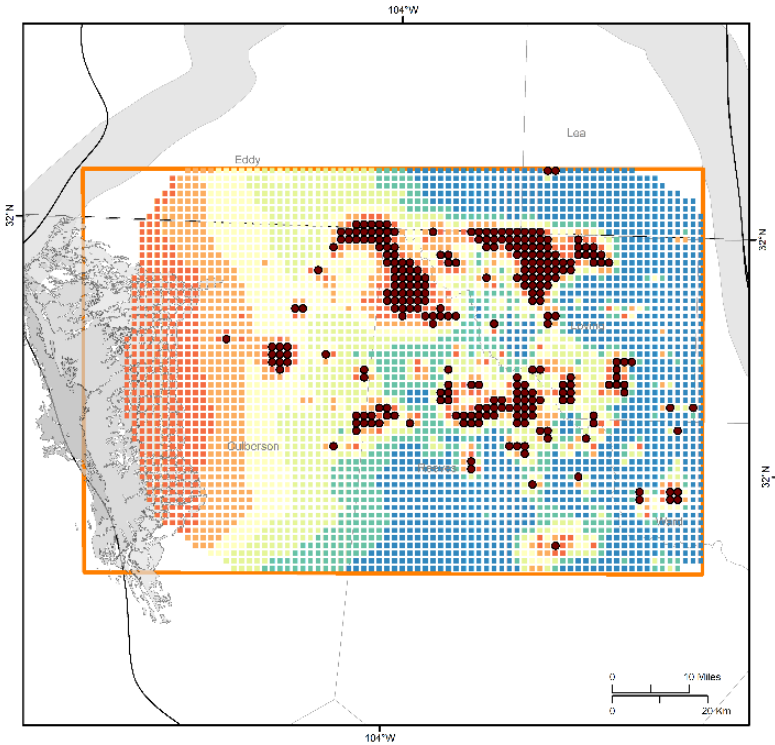
Ulfah, Hennings, Smye

Calculation of Capacity:
27 scenarios with varying
pore and water compressibility,
pressure limits, pressure models

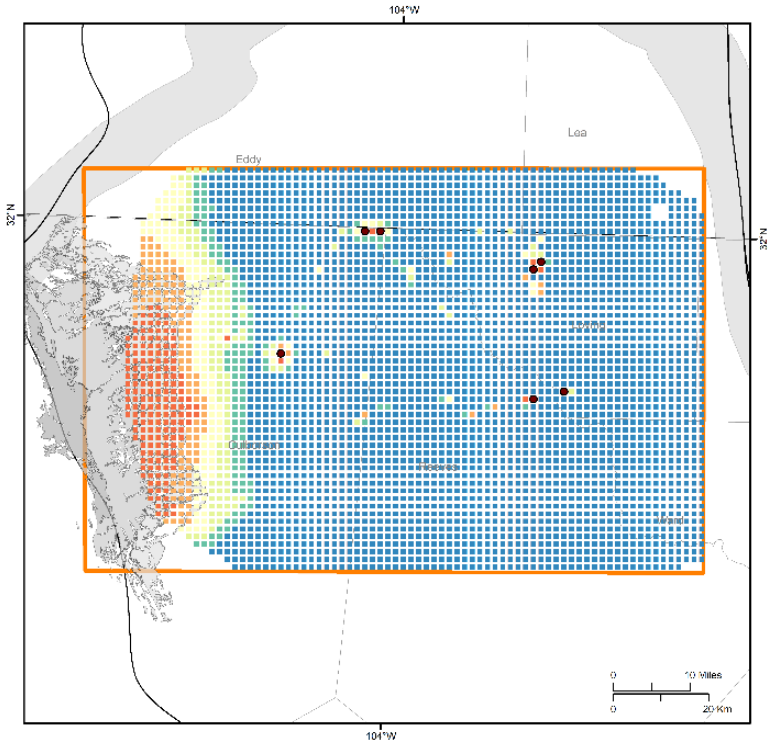


Injection Capacity Example: Bell Canyon Formation

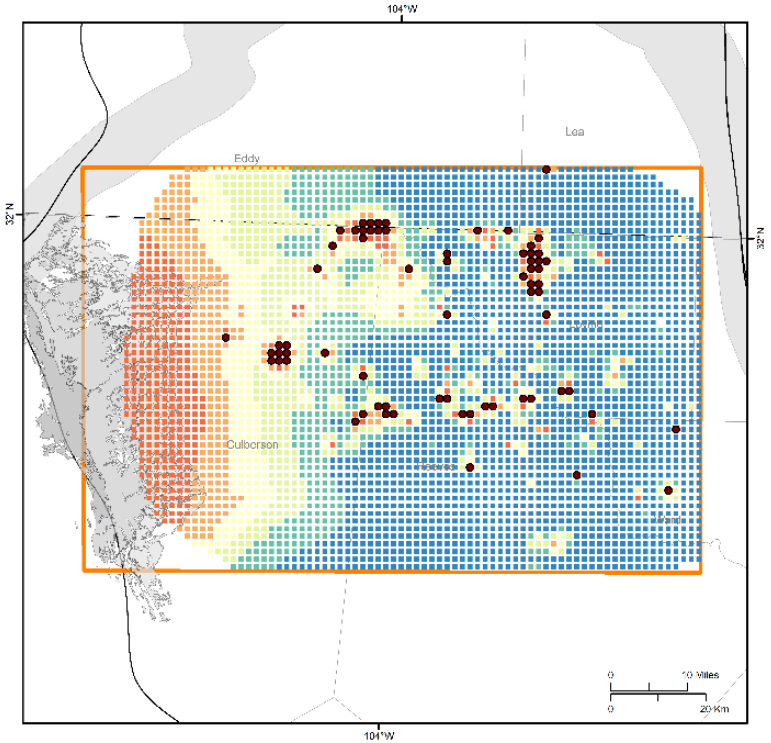
0.25 psi/ft surface



0.50 psi/ft surface



Fracture gradient



Pressure capacity (psi)

- exceeded
- 0 - 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 500
- > 500

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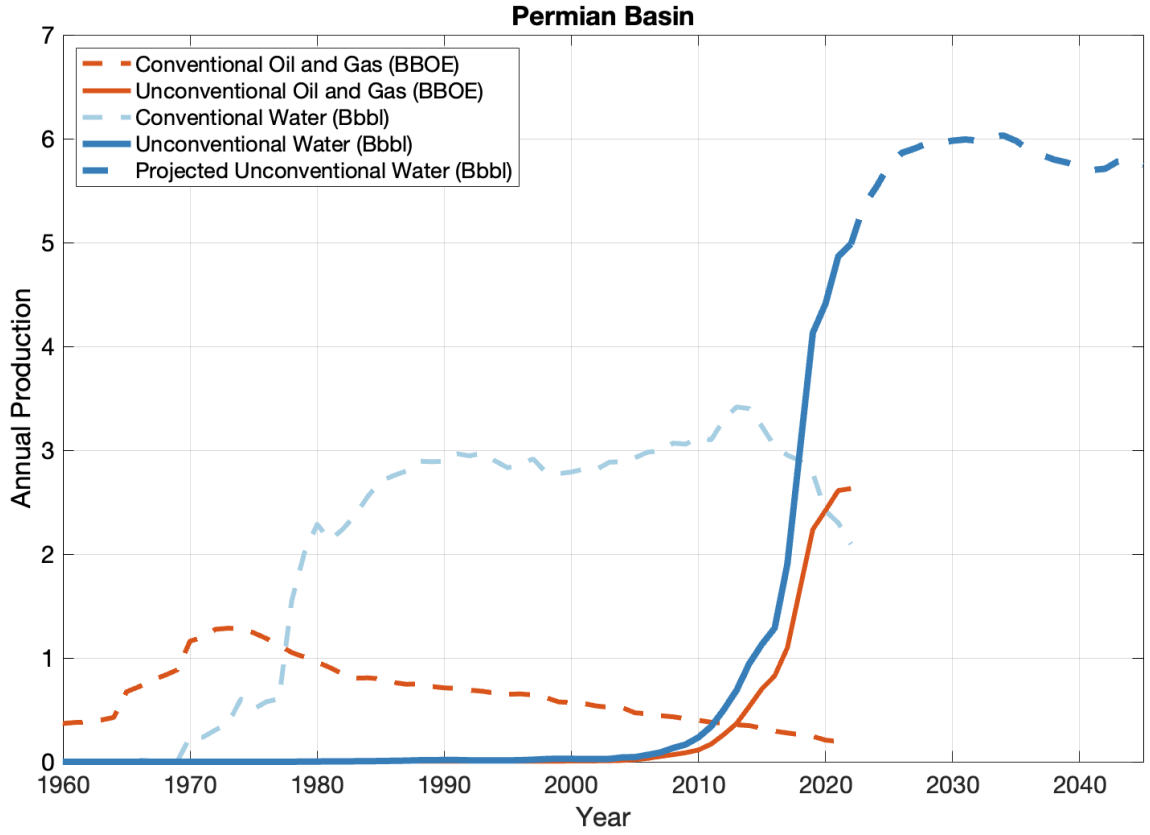
Future Opportunities and Challenges

- Subsurface pressure increases related to wastewater injection result in challenges in both deep and shallow systems in the Permian Basin region
- An operator-regulator-academic **success**: seismicity has been mitigated in the most problematic areas of the Delaware Basin
- A **challenge**: increases in shallow injection have resulted in unsustainable pressure increases in some areas of the Delaware Basin in particular; this challenge is urgent when combined with the complex operational history of the basin and the presence thousands of older vertical wellbores



- Although tens of billions of barrels of prior injection for permanent disposal in the Permian Basin have been managed, several hundred billion barrels likely as production is maintained in the basin
- An **opportunity**: a coherent and collaborative water management strategy in the basin informed by geology and cognizant of the hazard of exceeded injection capacity