Estimates of Permeability and Storage Capacity for the CO_2 Storage Hub Complex at Patterson Field, Western Kansas

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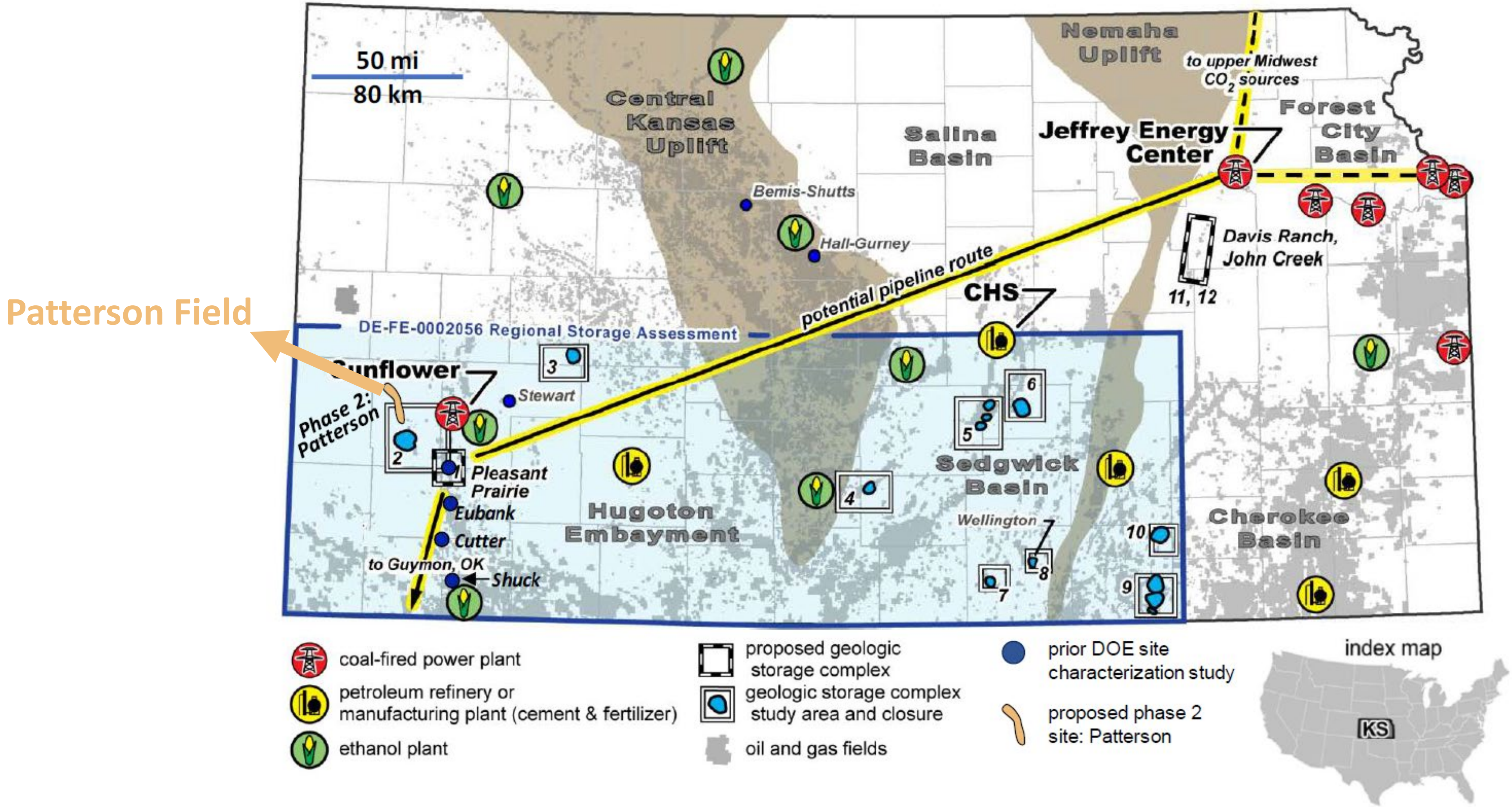
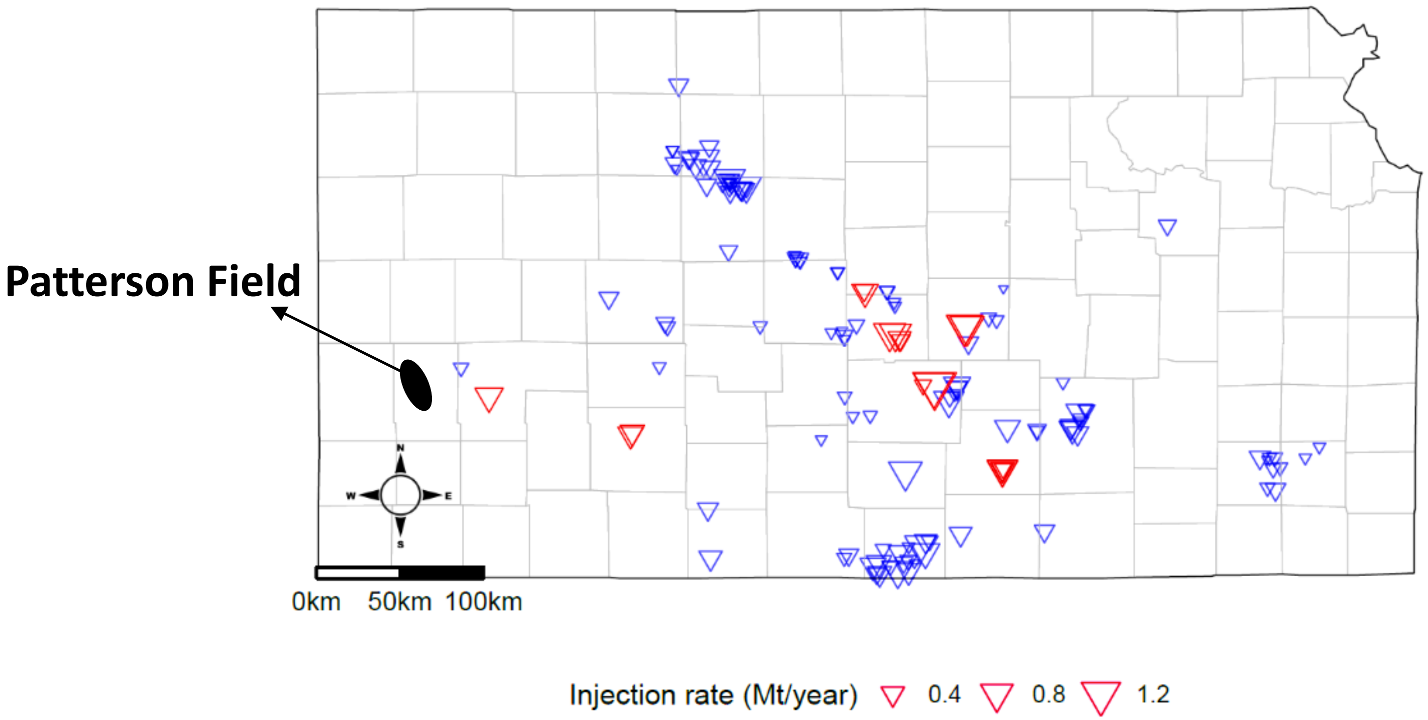
Introduction: Jeffrey to SW Kansas

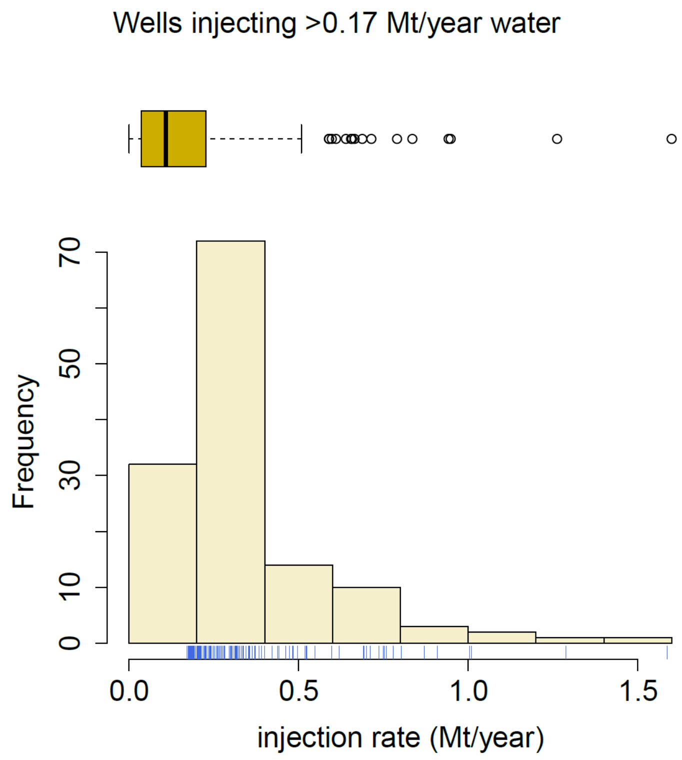
- **Objective**: Inject 50 Mt CO_2 during 25 years into the Patterson field, located in western Kansas, using maximum 6 wells (three formations: the Osage, Viola and Arbuckle)



Which wells inject similar mass?

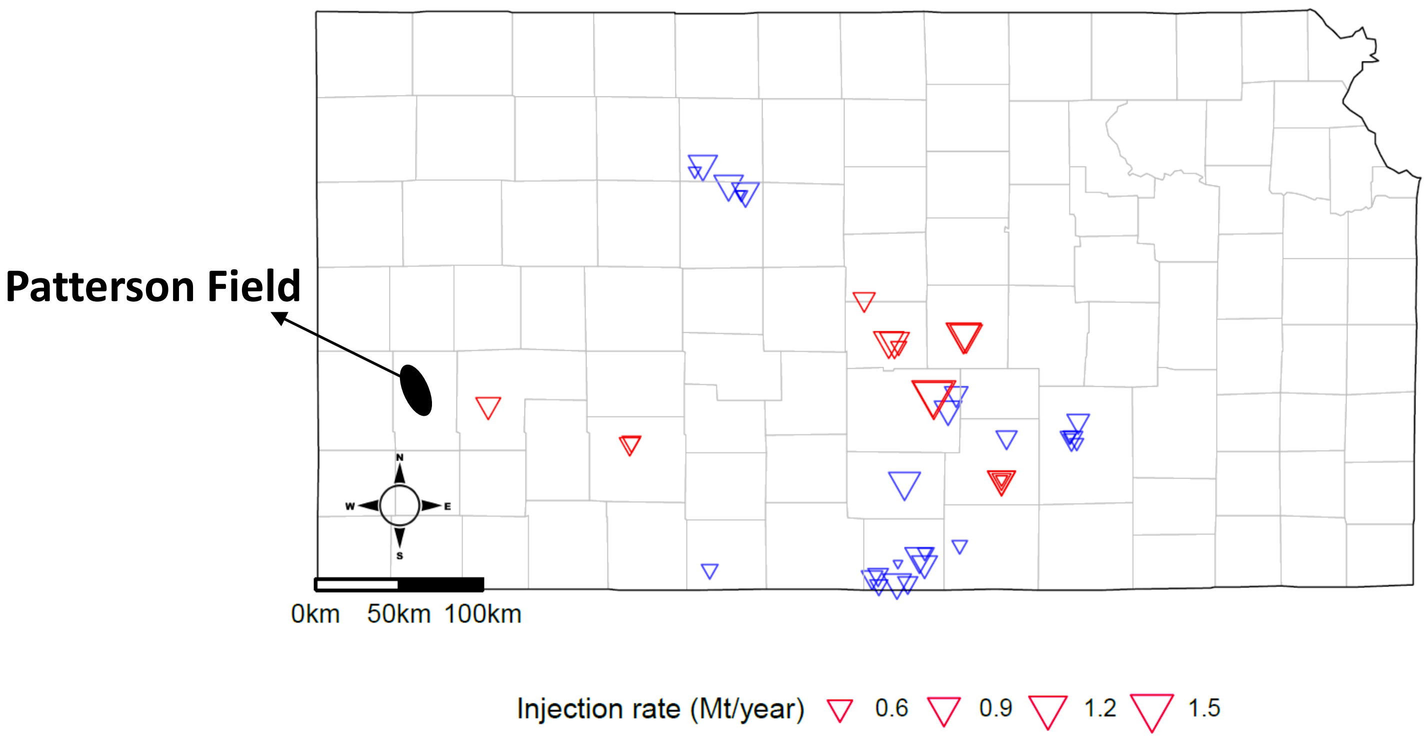
- ❑ **0.17 Mt/year** injection volume into Arbuckle (using 6 wells)
- ❑ 135 wells (21 Class I wells and 114 Class II wells) are injecting more than 0.17 Mt/year across Kansas (2016 data)

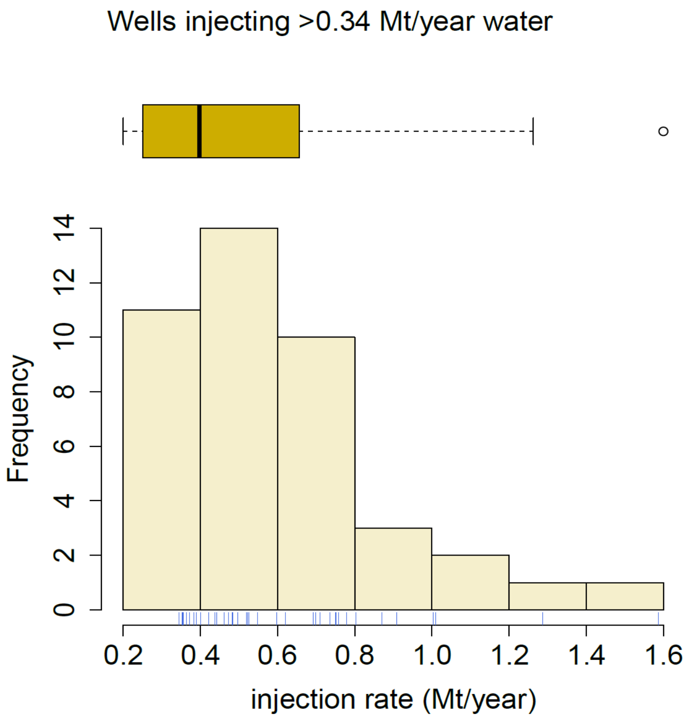




Which wells inject similar volume?

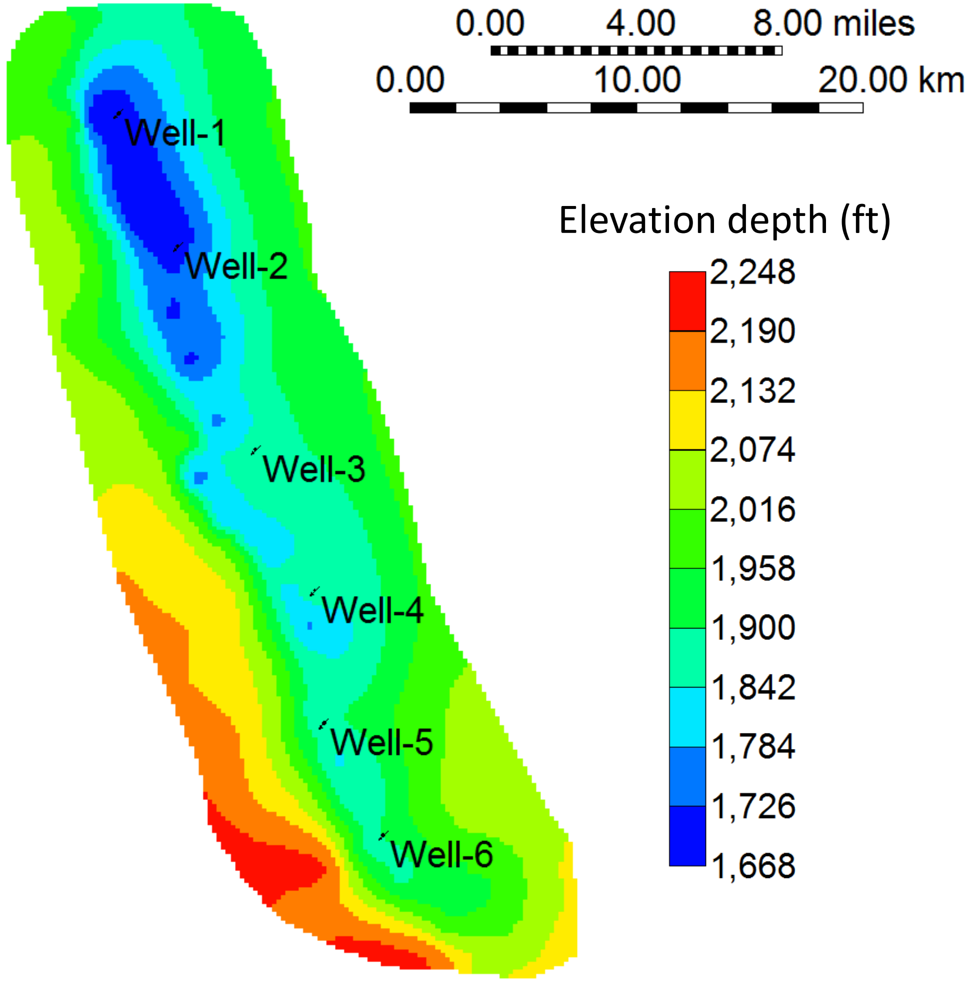
- The Arbuckle formation in the Patterson site has a temperature of 50 $°C$ and pressure of 11.8 MPa, a condition in which the CO_2 density is 500 kg/m^3, half of water density (density of water is assumed 1000 kg/m^3). 42 wells (16 Class I wells and 26 Class II wells) inject at this rate including one in west Kansas (year 2016).





Reservoir area and well locations

- The model was created based on 20 well logs in Petrel and exported to CMG
- 6 wells at the top of structural closures inject CO_2 for 25 years under constant pressure followed by 25 years of shutdown.



Reservoir properties

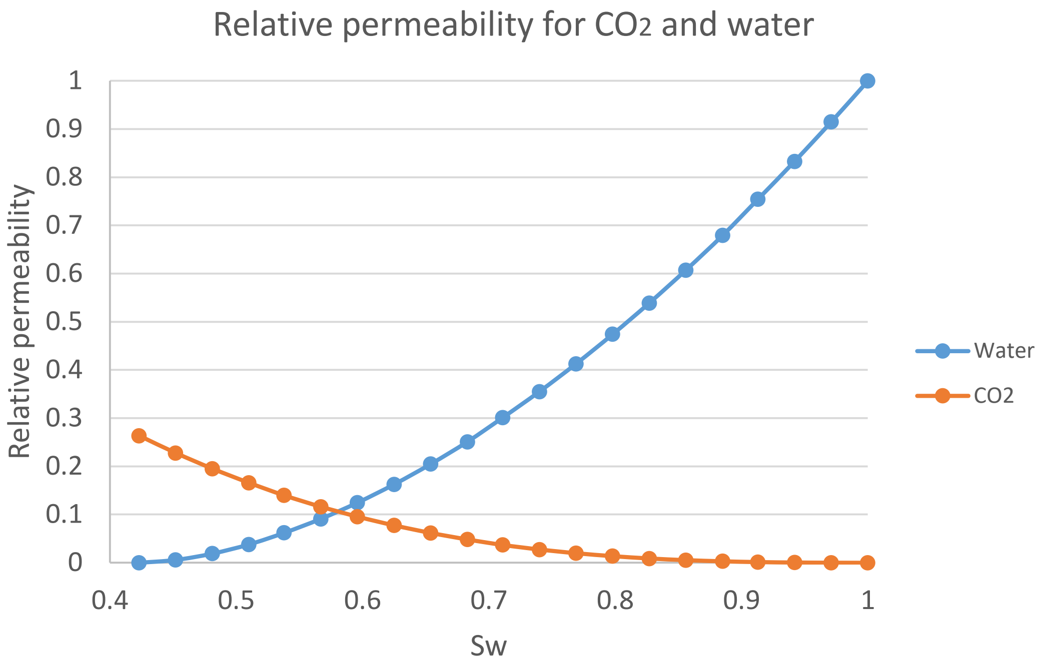
- Patterson area consists of three formations: Osage-Warsaw, Viola and Arbuckle Group. Formation properties are:

Zone	Thickness (m)	Porosity	Permeability (md)
Osage-Warsaw	150	0-0.31	0-184
Viola	180	0.008-0.204	0-26
Arbuckle Group	570	0.01-0.38	0-518

- Formation temperature (Arbuckle): 50 $°C$
- Formation average pressure (Arbuckle): 11.8 MPa
- CO_2 density : 497 kg/m3
- CO_2 viscosity : 38×10^{-6} Pa.s
- Water viscosity: 0.6×10^{-3} Pa.s
- The reservoirs are considered horizontally isotropic with vertical to horizontal permeability ratio of 0.1.

Rock-Fluid and other model properties

- The relative permeability curves used for the simulation runs:



- Supercritical CO_2 properties are calculated at reservoir temperature and pressure and the dissolved CO_2 in water is modeled using Henry's model.

- Outer boundary

  Open Carter-Tracy aquifer model with leakage
- Bottom boundary

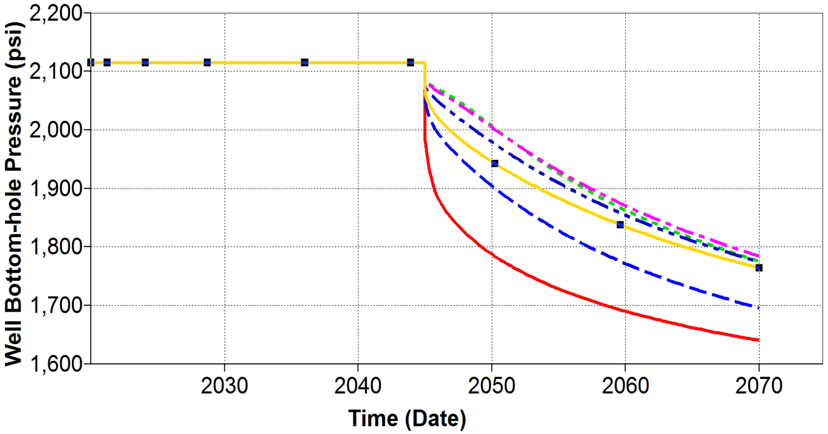
  Closed Carter-Tracy aquifer model with no leakage

Well bottomhole pressure

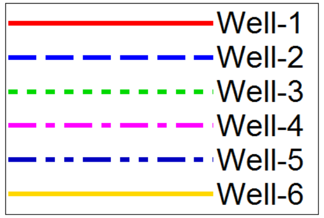
- Well BHP is kept constant at 500 psi above the reservoir pressure during the first 25 years of injection and allowed to drop after injection ceases.

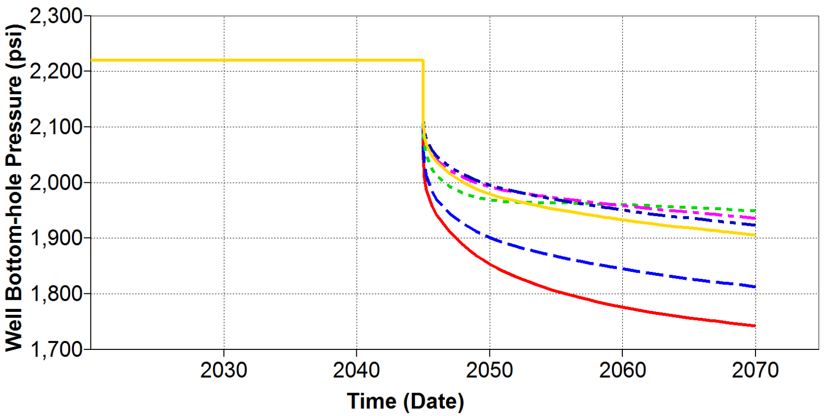
- The wells experience 300 to 450 psi pressure drop after 25 years or shut-in.

- The middle of the reservoir (well#3 and#4) experience the least pressure drop.

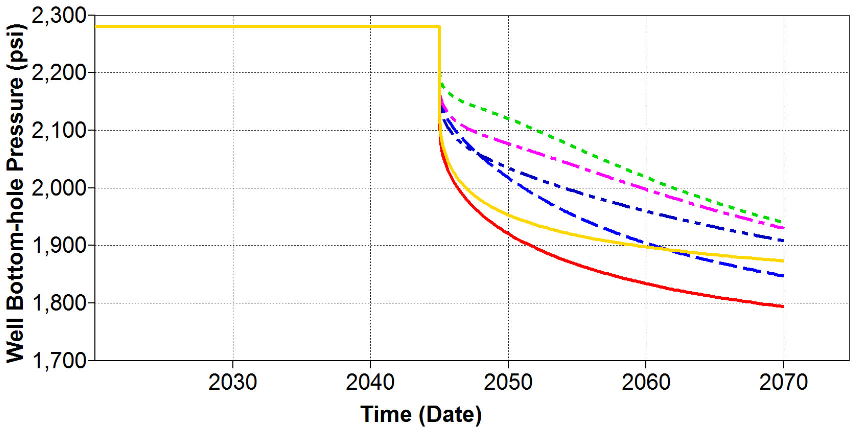


Osage-Warsaw





Viola



Arbuckle group

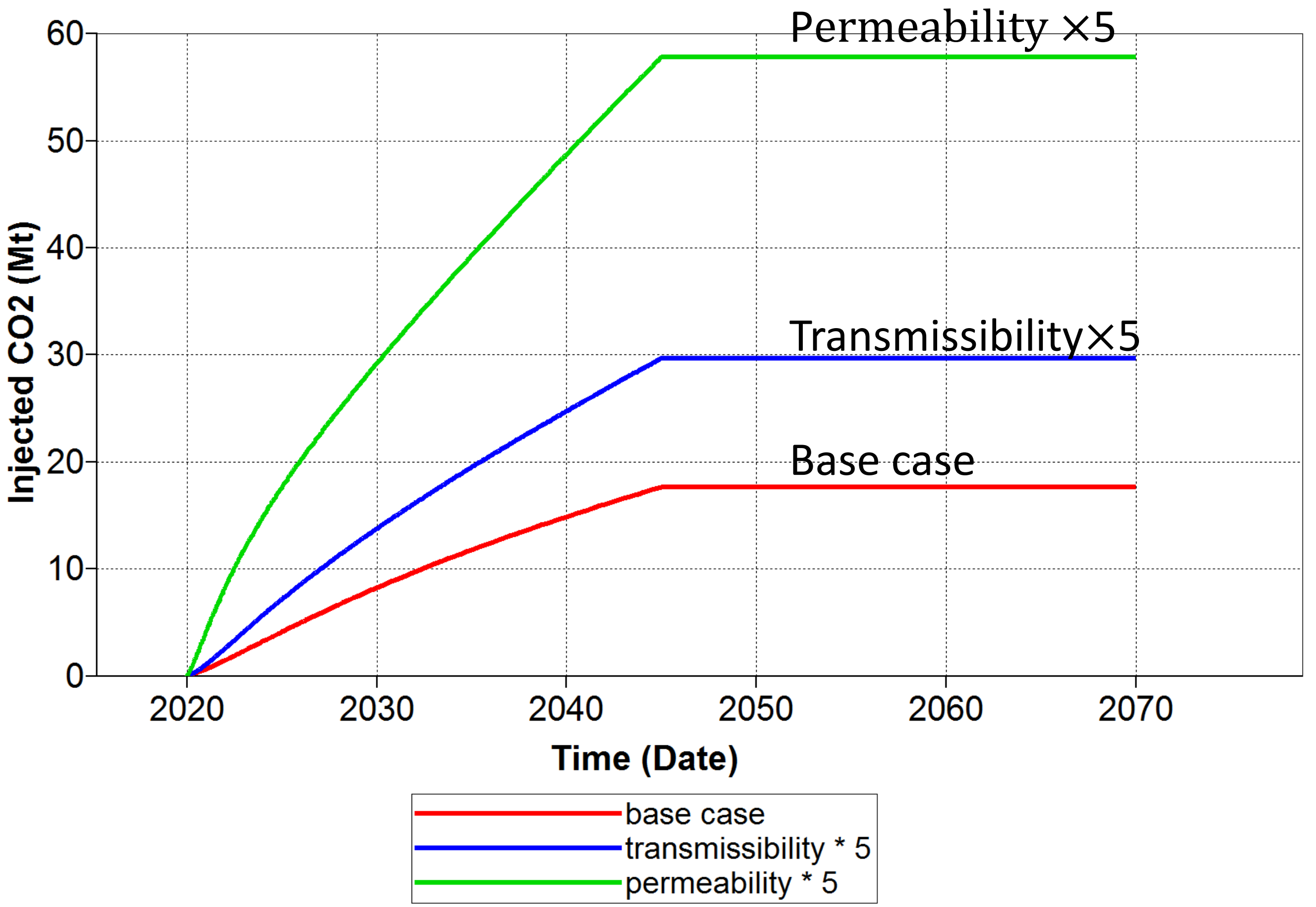
CO_2 storage

Total field CO_2 storage capacity are simulated for three cases:

1- base case with underestimated permeability and no fractures.

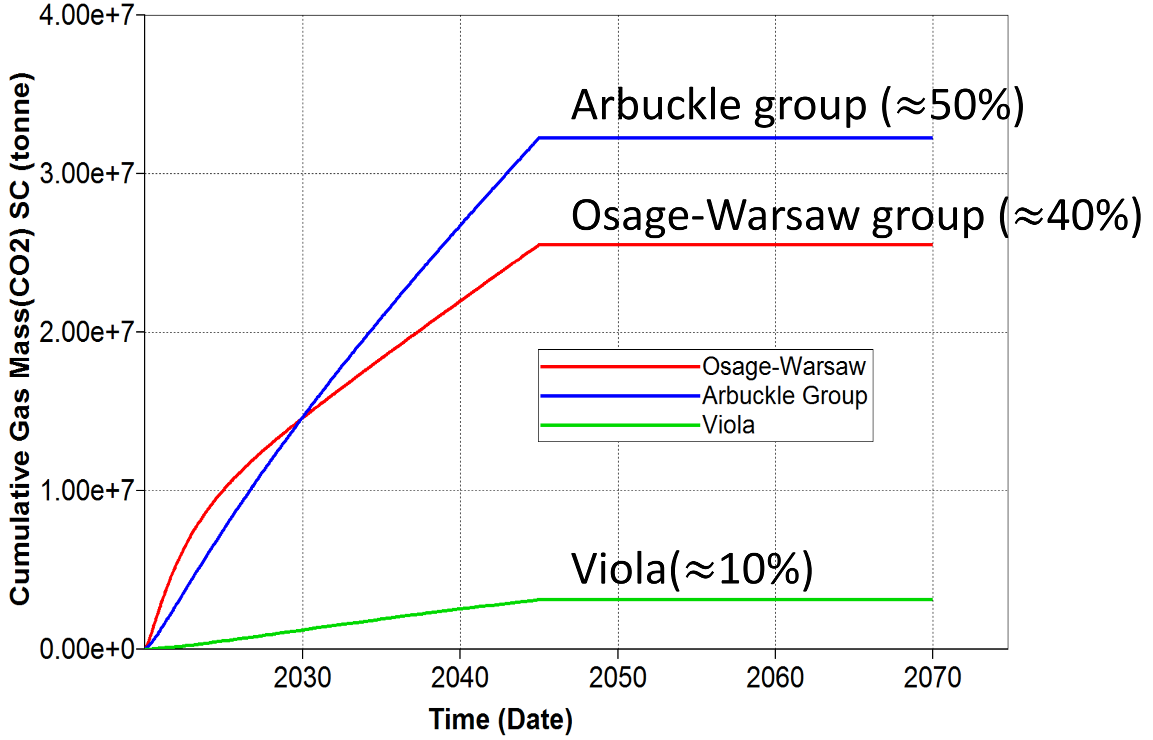
2- base case with transmissibility (kh/μ) multiplier of 5.

3- base case with permeability multiplier of 5 to account for fracture permeability. Presented results are for this case.

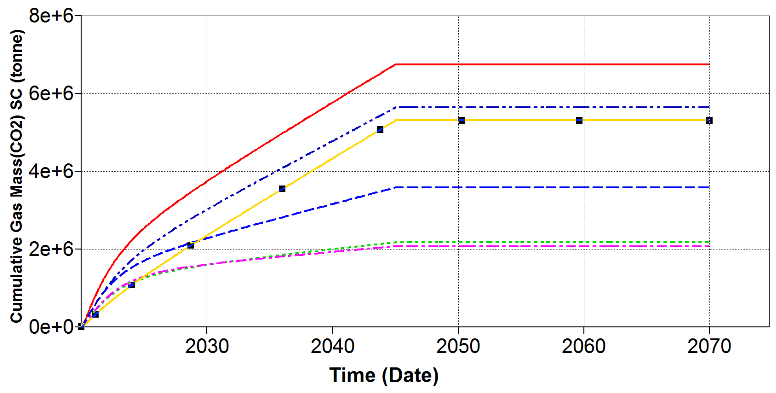


Injection into each formation

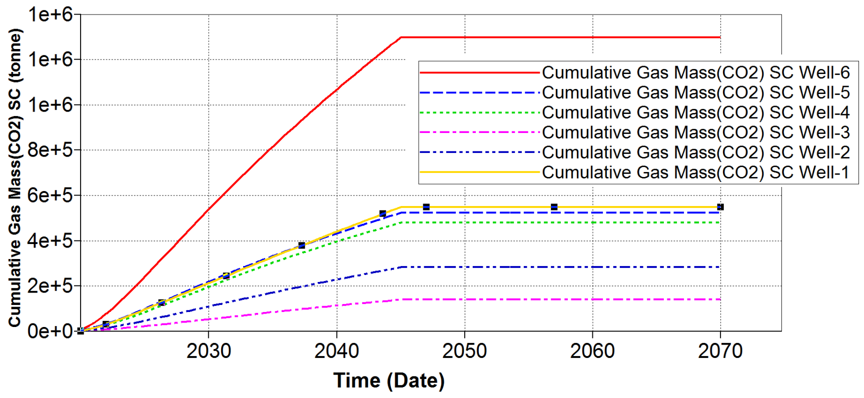
- The injection detail into each formation. Arbuckle (50%) has the maximum CO_2 storage followed by the Osage-Warsaw (40%) and the Viola formations (10%).



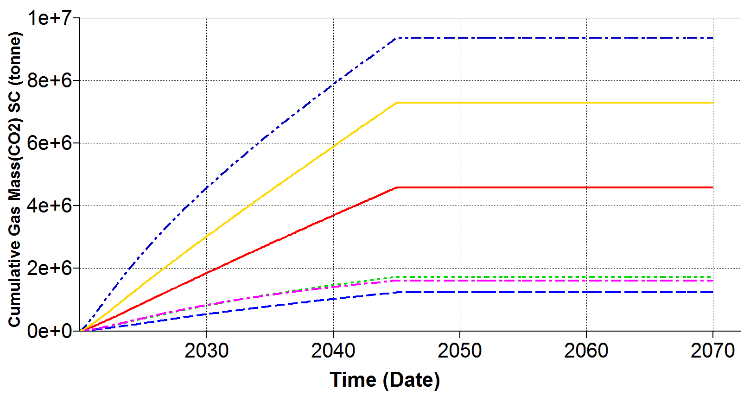
- Injection from each well into each formation.



Osage-Warsaw



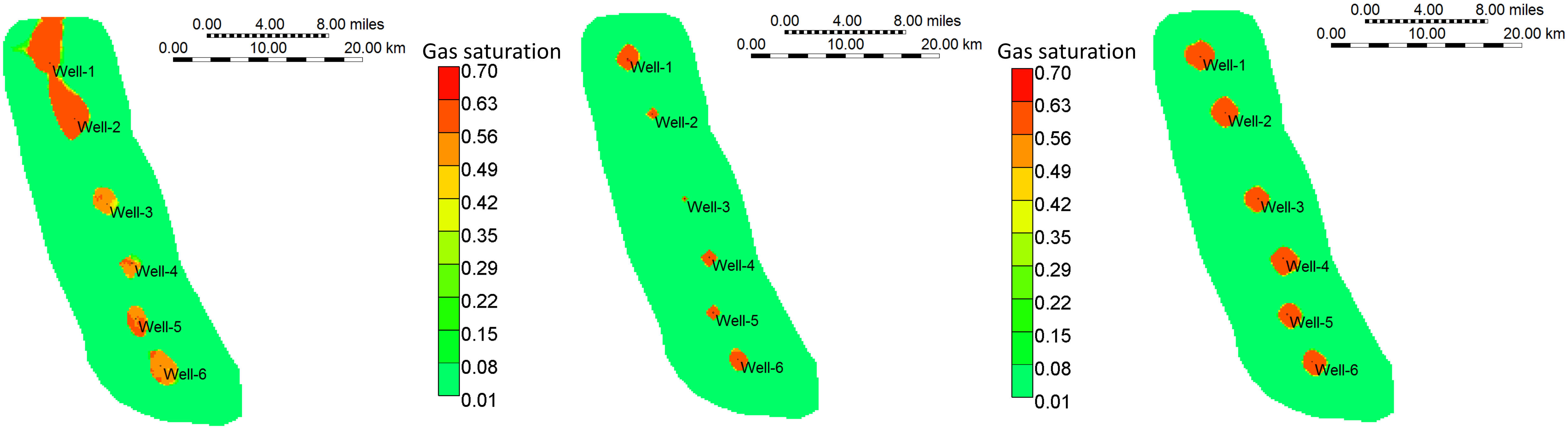
Viola



Arbuckle

2D CO_2 plumes (Gas saturation) after 50 years

- CO_2 plume has the maximum extent in Osage formation and minimum in viola.
- The maximum plume extent is less than 15 km.
- The CO_2 saturation increases up to 70 percent.



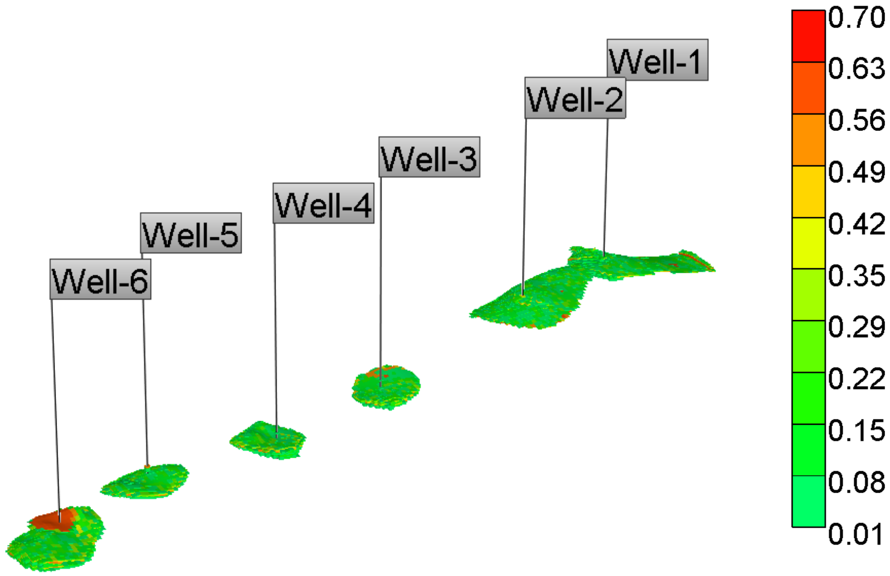
Top of Osage formation

Top of Viola formation

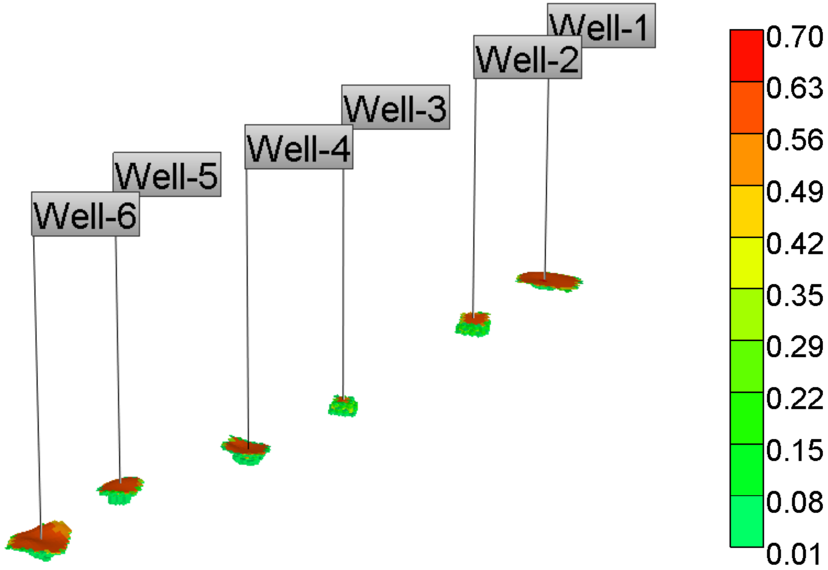
Top of Arbuckle formation

3D CO_2 plumes (Gas saturation) after 50 years

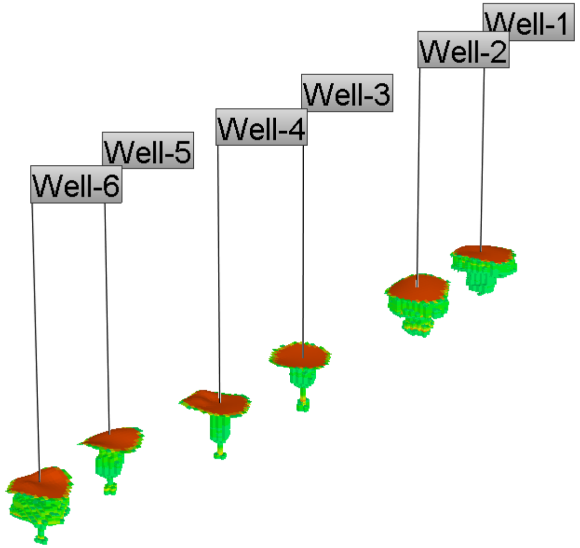
- Wells 1, 2 and 6 create the maximum CO_2 plume extent.
- CO_2 plume migrates upwards due to lower density and viscosity.
- Osage-Warsaw has the most lateral CO_2 plume extent while Arbuckle has the maximum vertical extent.



Osage-Warsaw formation



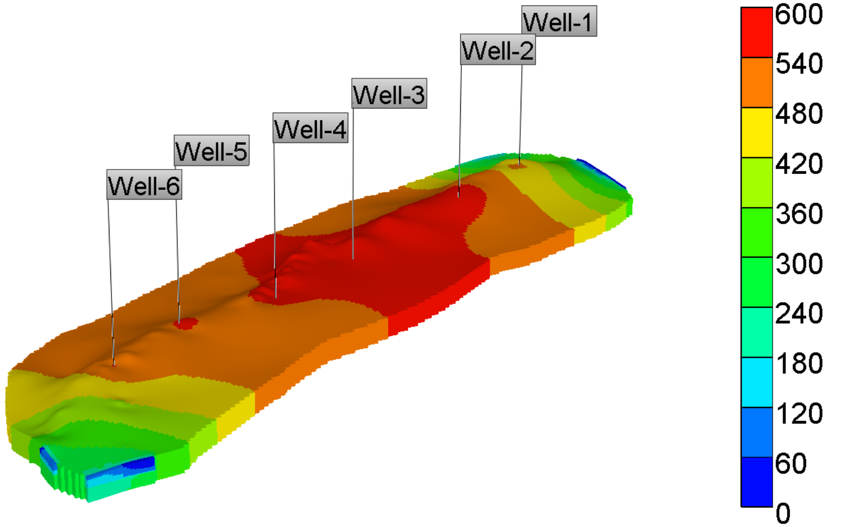
Viola formation



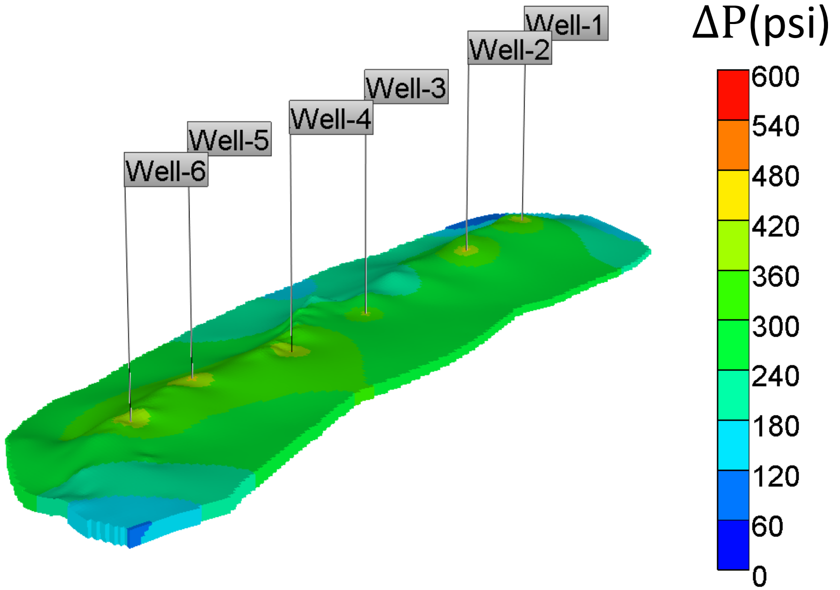
Arbuckle formation

Pressure plumes before shut-in

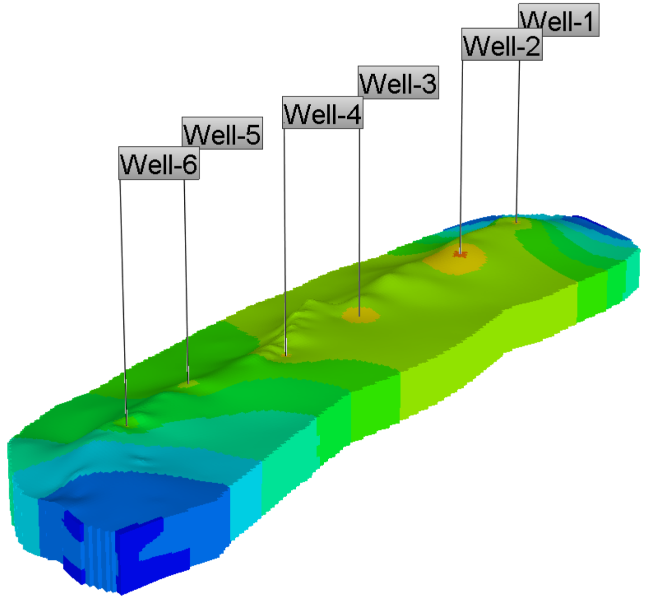
- High permeability and storage capacity creates the most pressure increase in Osage-Warsaw.
- Because BHP is assigned to the entire perforation interval (reservoir thickness here), equilibrium increases ΔP to more than 500 psi in parts of the reservoir.
- Pressure change in the Arbuckle Group is important because of its connection to the basement faults.



Osage-Warsaw formation



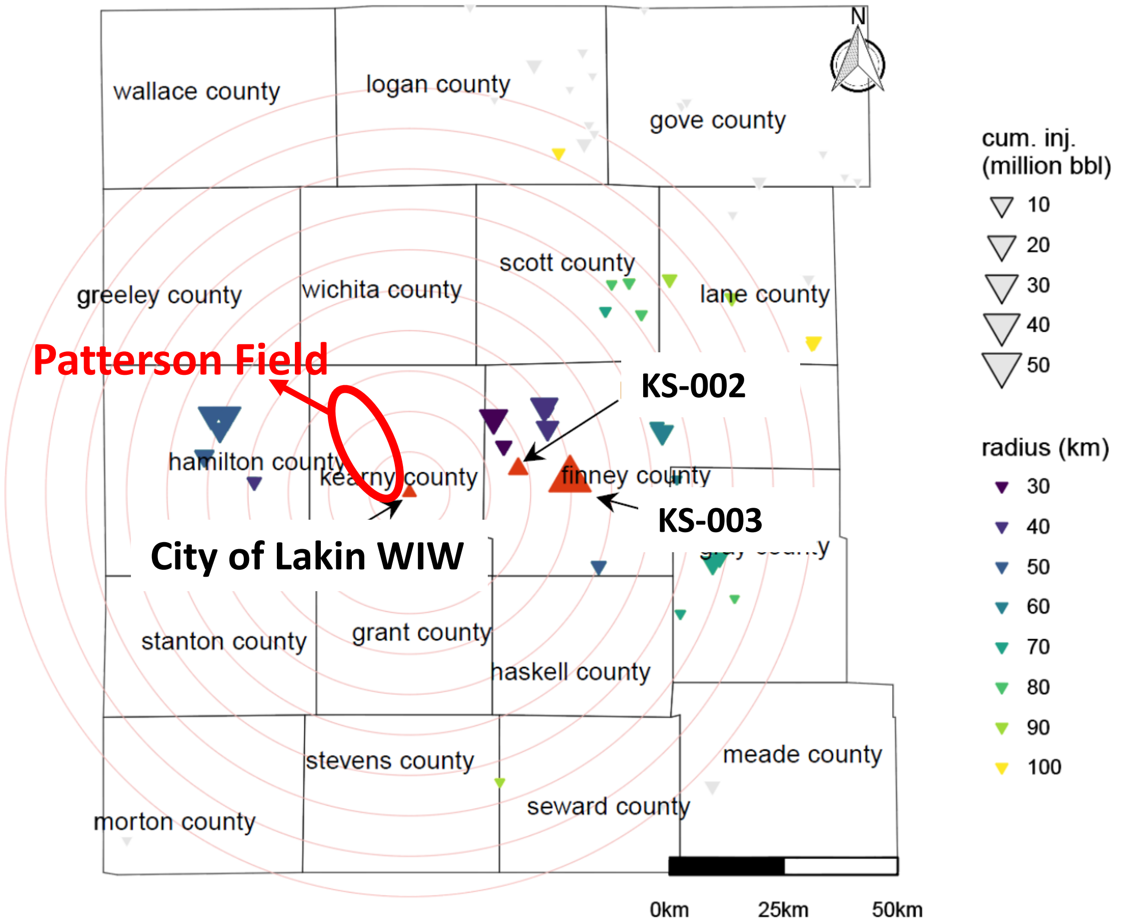
Viola formation

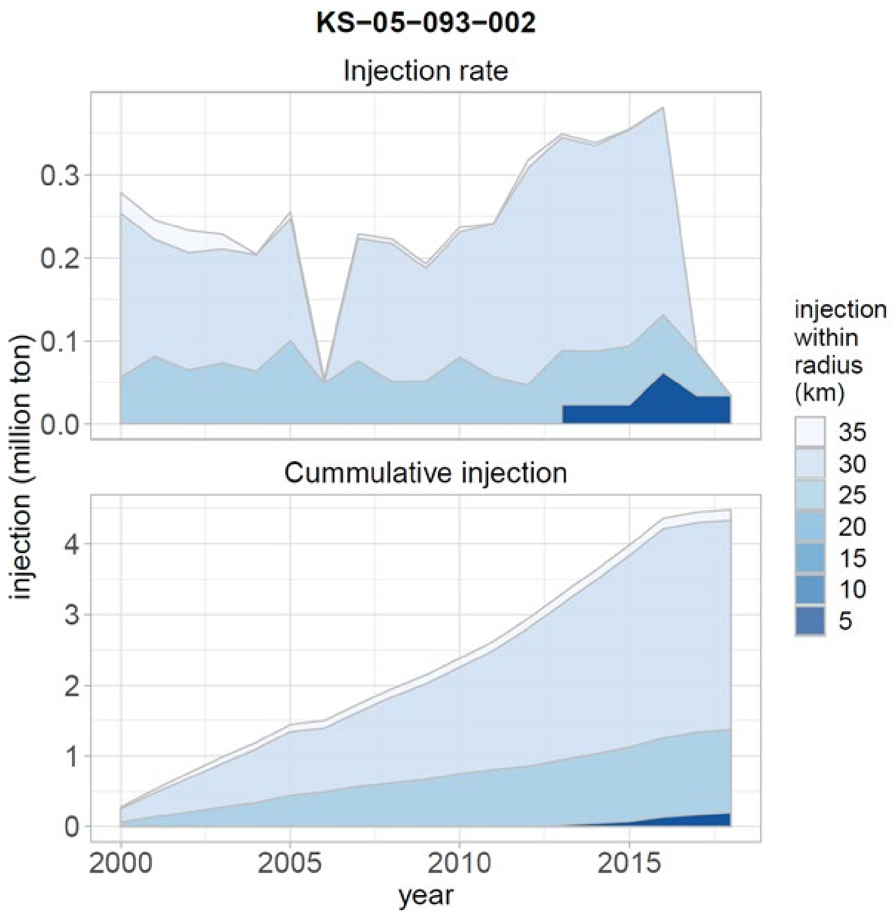


Arbuckle formation

Injection experience in west Kansas?

- 25 years of 0.34 Mt/year equals 8.5 Mt injection. We have an experience of injecting half this amount in the Arbuckle in west Kansas (not from a single well). Injection rate is always more important for leakage and induced seismicity evaluations because they control pressure gradient in time ($\Delta p/\Delta t$).

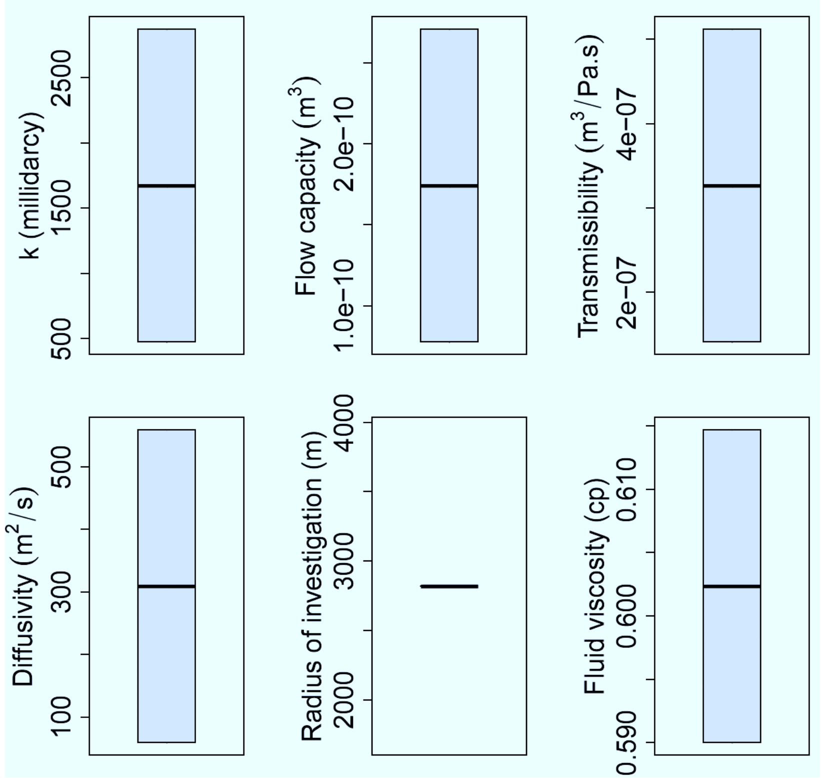




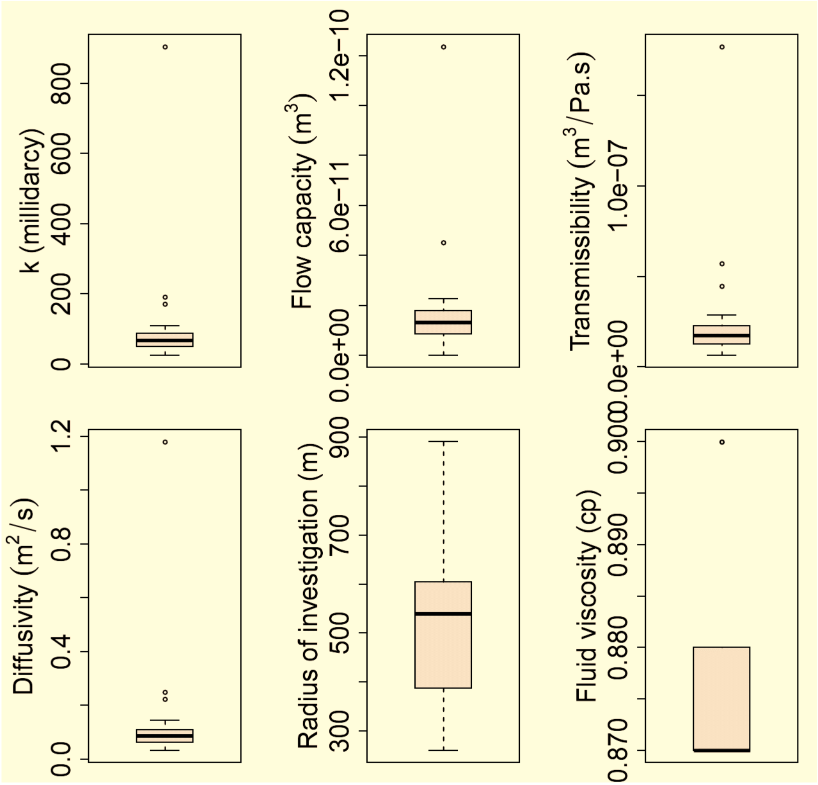
Fall-off test data from nearby wells

- Annual fall-off test measurements from three nearby wells give average reservoir scale permeability.
- Average reservoir scale permeability of the Arbuckle is in the scale of 100 md scale. For the Patterson Field it may reach 500 md.

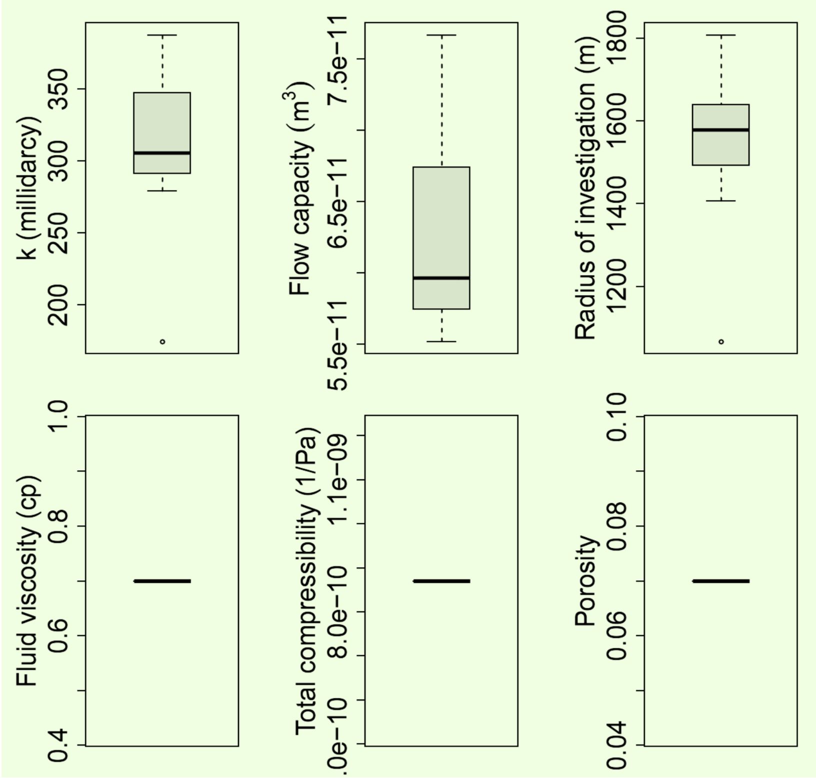
City of Lakin well



KS-002

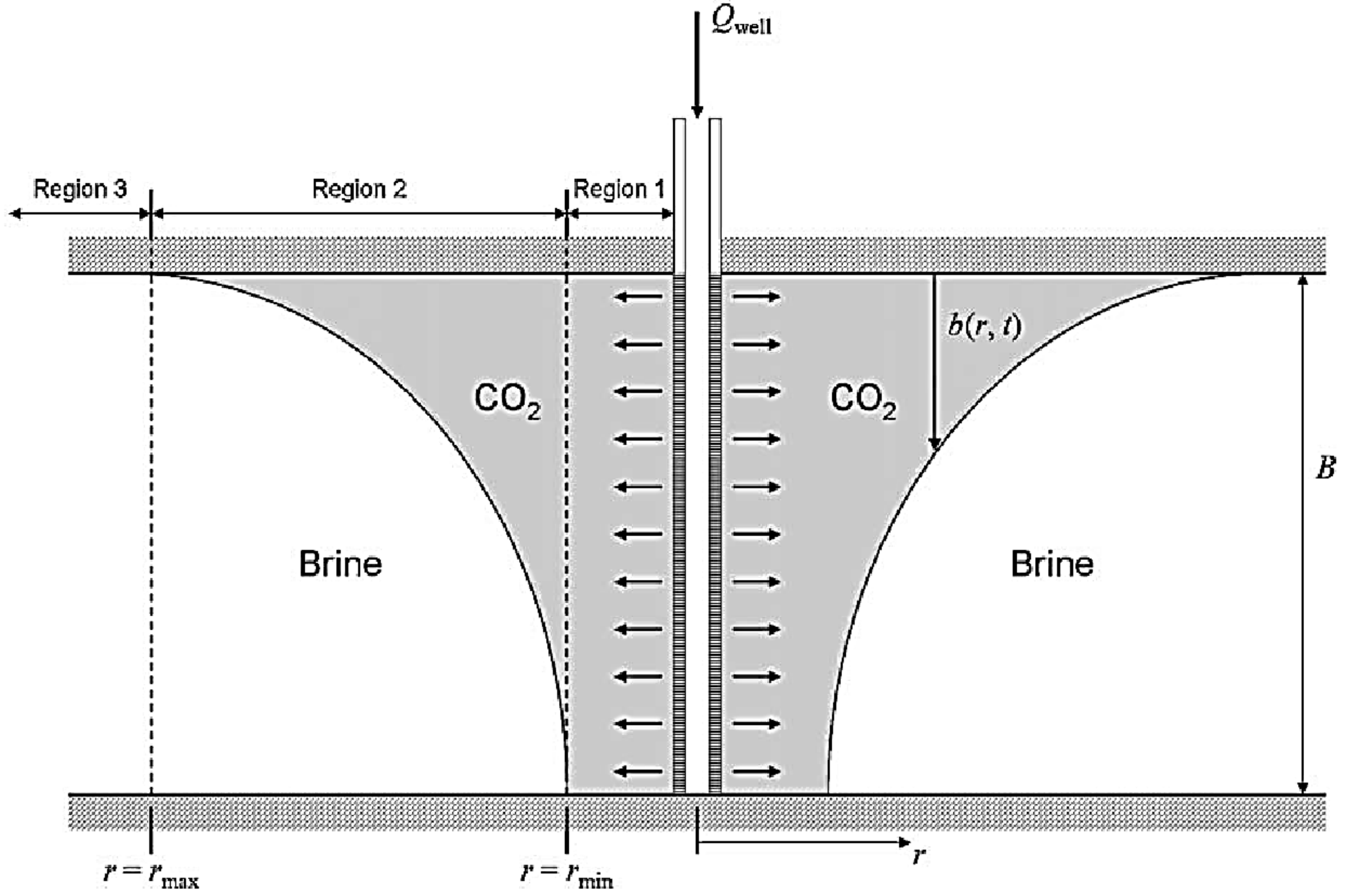


KS-003



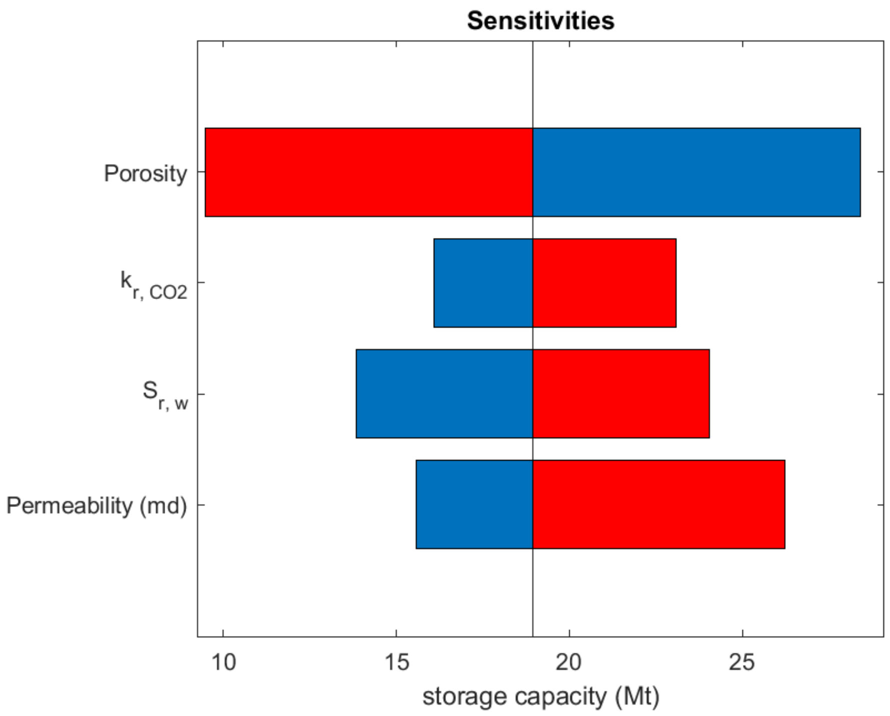
Analytical solution

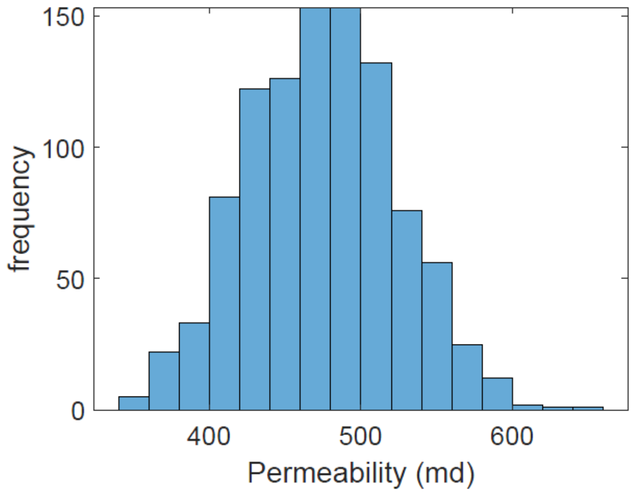
- Because CO2 is less dense than formation water, the plume cone rises and develops at the top of the aquifer, limiting storage capacity.
- We want the plume to travel slower and sweep a larger volume.
- Available analytical solutions are useful when we have limited data.

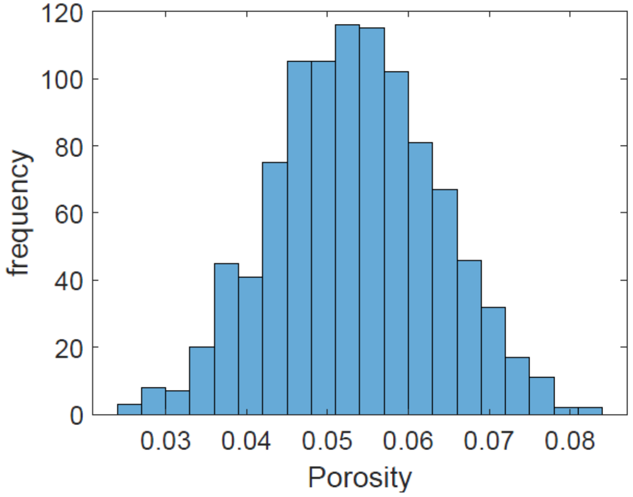


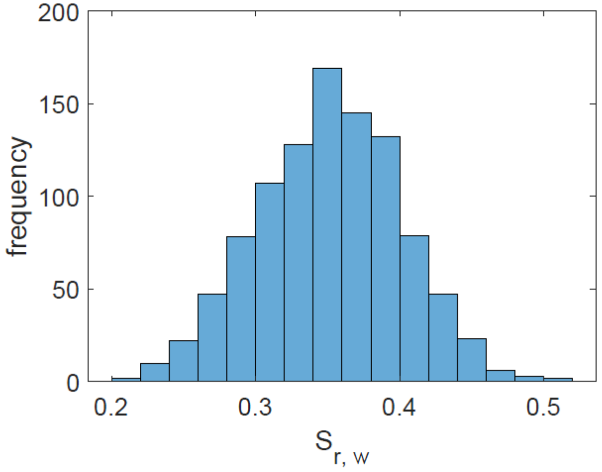
Sensitivity and Monte-Carlo approach

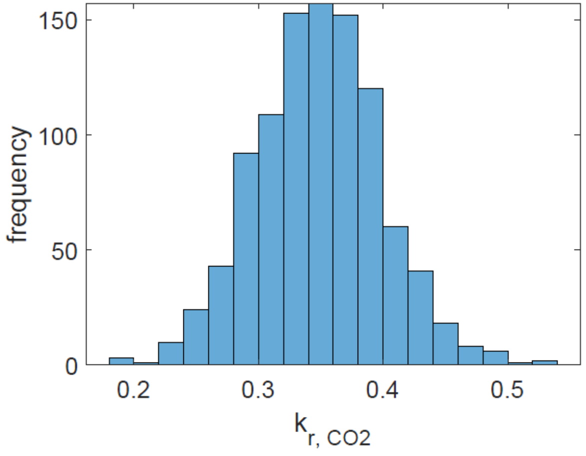
- Sensitivity analysis (Tornado chart) shows four parameters control the CO_2 storage capacity: Permeability, porosity, residual water saturation and relative permeability of CO_2.
- Porosity increases the storage capacity while the permeability decreases the capacity.
- Because of uncertainty in the parameters, a distribution is assigned to each and a Monte-Carlo approach is used.





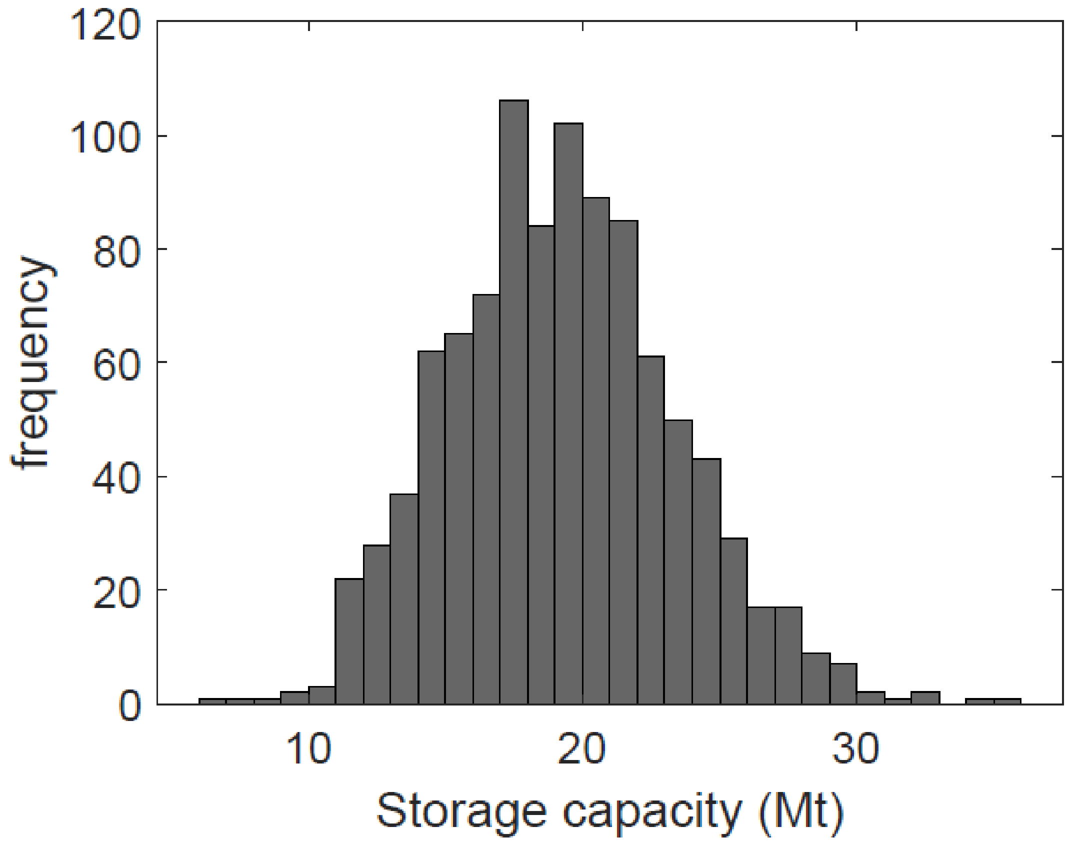


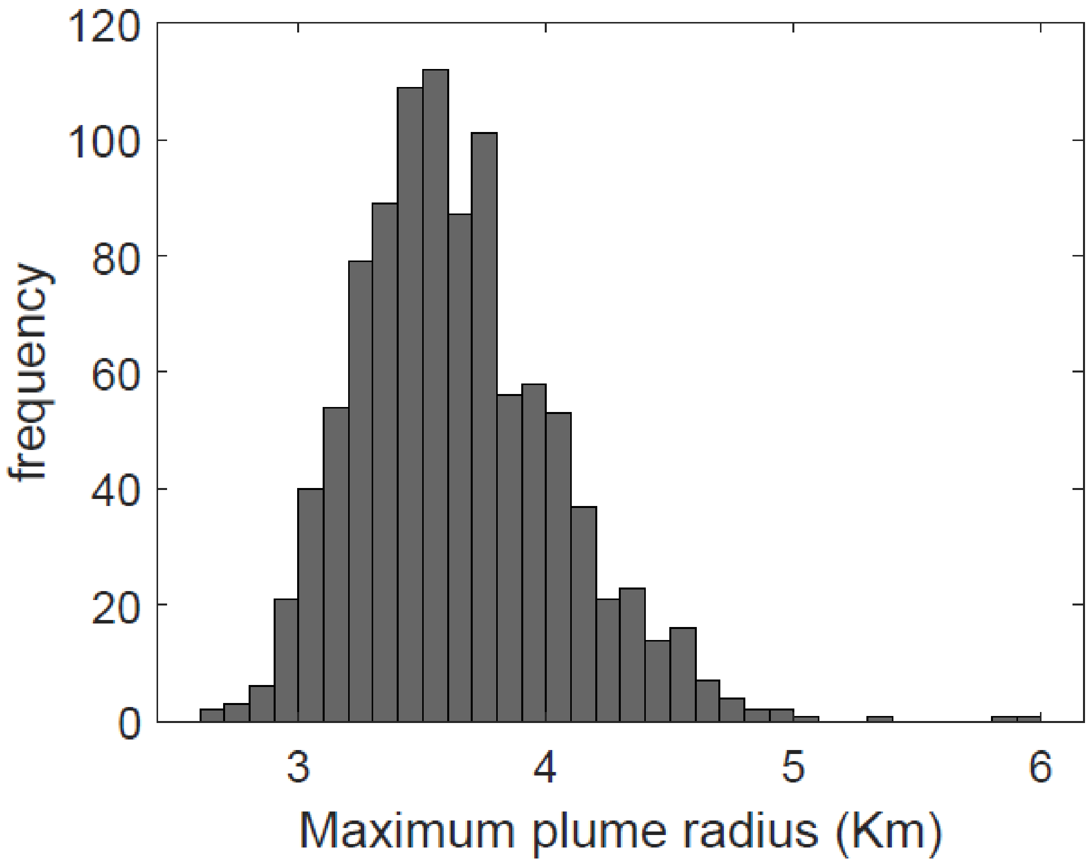




Storage capacity and plume radius

- A storage capacity of less than 30 Mt CO_2 for the Arbuckle aquifer
- The plume radius is be less than 5 km from the Arbuckle aquifer





Conclusions

- The key feature of the Kansas deep aquifers, particularly the Arbuckle Group, is that they are underpressured and act as giant sinks. These aquifers have been used as safe means for disposing wastewater for more than seven decades.

- Kansas carbonate aquifers are highly fractured and have high permeability. The permeability values used in the simulation runs are relatively modest.

- Because injection across western Kansas has been low due to lower oil developments, the underlying deep aquifers are suitable for CO_2 storage.

- Currently 42 wells across Kansas (16 Class I wells and 26 Class II wells) are injecting more wastewater mass than the planned CO_2 into the Arbuckle Group aquifer.

- Using 6 wells assures sufficient injectivity for meeting 50 Mt DOE target within 25 years.

Thank you!

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Analytical solution used

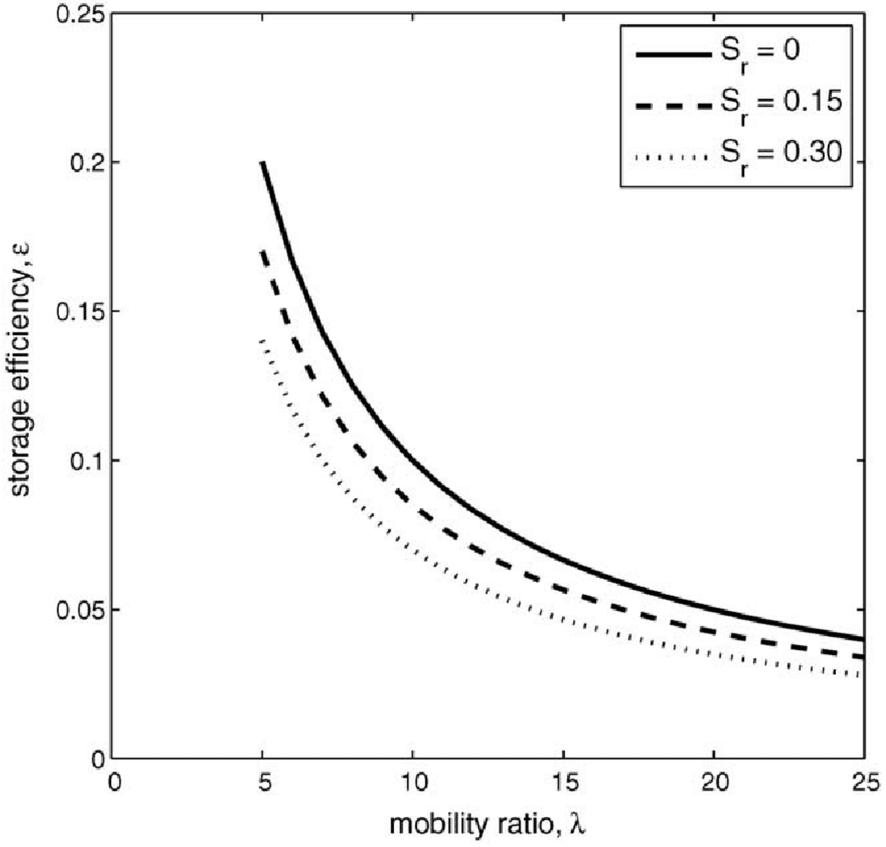

Fig. 2. Storage efficiency (ϵ) vs. mobility ratio (λ) when the effect of gravity is negligible (small Γ).

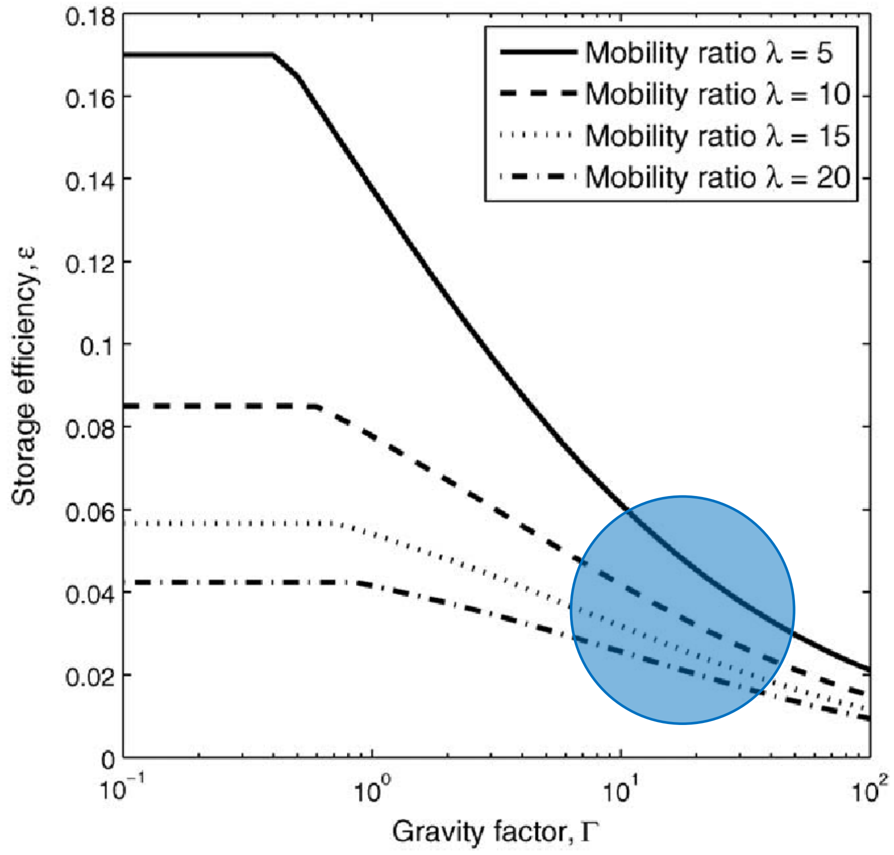

Fig. 3. Storage efficiency (ϵ) vs. gravity factor (Γ). The curves shown were generated assuming a value of residual brine saturation $S_r = 0.15$.

$$\Gamma = \frac{2\pi\Delta\rho g k \lambda_b B^2}{Q_{well}} \qquad \epsilon = \frac{2(1 - S_r)}{\chi_{max}} \qquad r_{max} = \sqrt{\frac{Q_{max} t}{\phi B \pi \epsilon}}$$

$$\chi_{\max} \approx (0.0324\lambda - 0.0952)\,\Gamma + (0.1778\lambda + 5.9682)\,\Gamma^{\frac{1}{2}} + 1.6962\lambda - 3.0472$$

Calculated mobility ratio and storage efficiency