Semi-analytic solutions for enhanced water recovery modeling

Karl W. Bandilla, Michael A. Celia

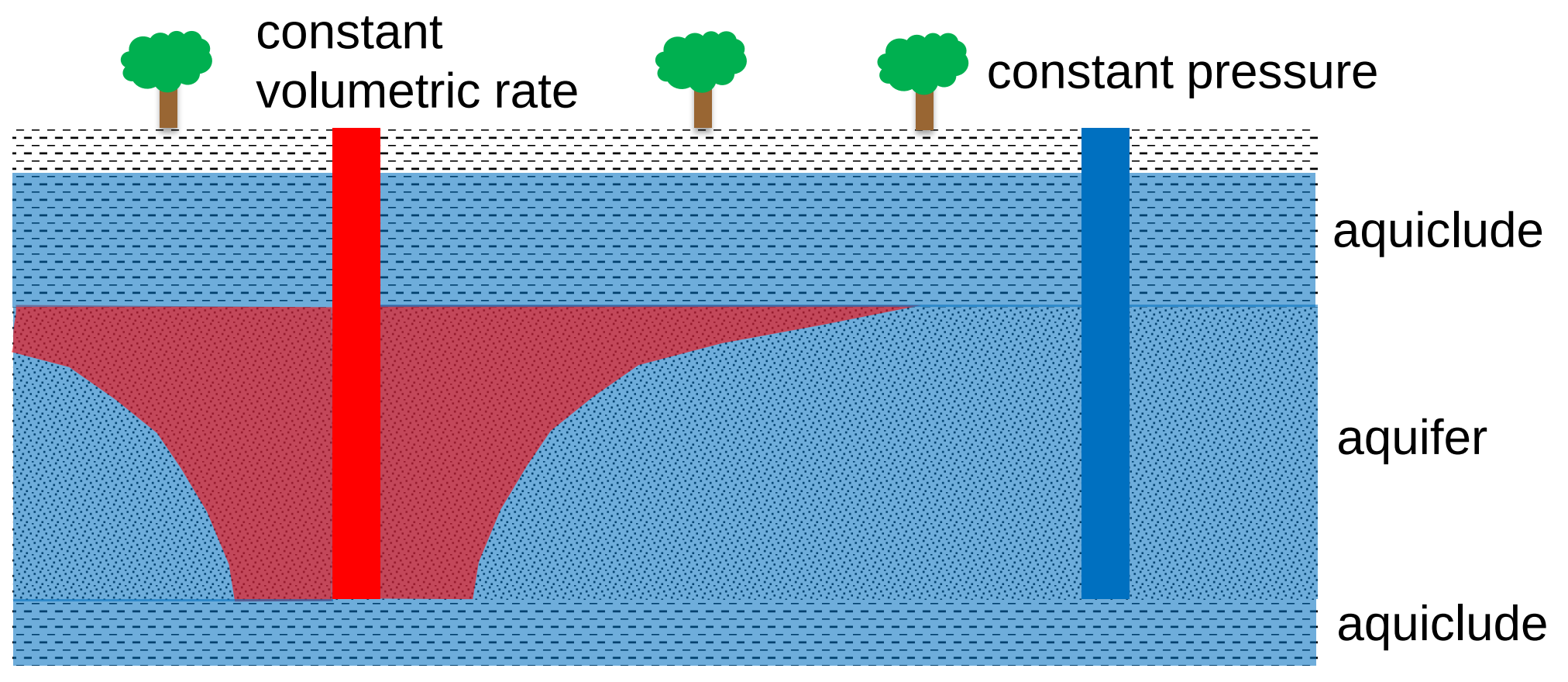
email: bandilla@princeton.edu

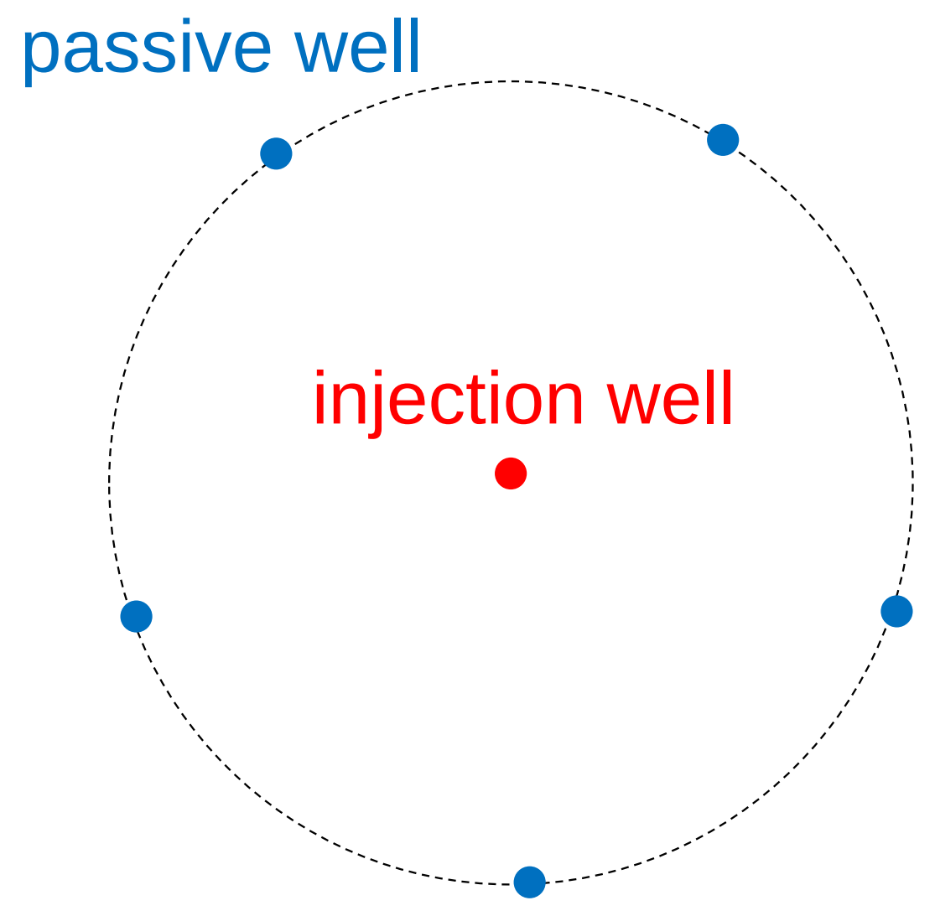
Department of Civil and Environmental Engineering, Princeton University, Princeton, New Jersey, USA

1. Abstract

During geologic carbon storage (GCS) operations the resident brine is pressurized due to the injection of carbon dioxide (CO_2). The pressure increase leads to brine migration both laterally in the injection formation and vertically through the caprock, and may even lead to seismic events. Brine migration may have detrimental impacts on water resources and seismicity may reduce storage safety, so that GCS sites are often operated to limit the pressure increase. However, the pressure increase may be harnessed to bring brine to the surface for desalination and use in the carbon capture process or in other industrial processes. This concept has been termed CO_2-enhanced water recovery, with the CO_2 injection induced pressure increase acting to enhance water production. In this poster semi-analytic solutions are used to model the impact of injection-induced pressure increase on producing water from the injection formation through passive wells. A parameter study is conducted to explore the impact of formation properties and operational conditions on enhanced water recovery. The trade-off between enhanced water recovery and pressure management is also discussed.

2. Model setup





parameter	unit	low	base	high
permeability	mD	10	250	2000
thickness	m	10	50	250
porosity	-	0.05	0.15	0.3
well length	m	500	1000	3000
well radius	m	0.05	0.1	0.5
injection rate	Mt/yr	0.5	1	10
relative distance to CO_2 plume	-	0.5	1	2

	CO_2 density [kg/m³]	CO_2 viscosity [Pa s]	brine density [kg/m³]	brine viscosity [Pa s]
shallow-cold	714	5.77×10^{-5}	1121	11.88×10^{-4}
shallow-warm	266	2.3×10^{-5}	1104	6.87×10^{-4}
deep-cold	733	6.11×10^{-5}	1099	5.11×10^{-4}
deep-warm	479	3.95×10^{-5}	1045	2.54×10^{-4}

3. Modeling approach

- Single-phase flow in homogeneous laterally infinite domain
- Volume-equivalent brine injection
- Wells modeled by superposition of Theis solutions
- Constant flow rate in injection well
- Transient flow rate in passive well(s) based on pressure difference between formation and surface at previous time step
- Numerical approximation of convolution integral of passive wells
- CO_2 plume radius based simplified version of similarity solution for two-phase flow

Volumetric flow rate in passive well:

$$Q_p = \frac{K_p \pi r_p^2}{L}\left[\left(h_{inj} - \sum_{i=1}^{N_p} h_{p,i}\right) - h_{top}\right]$$

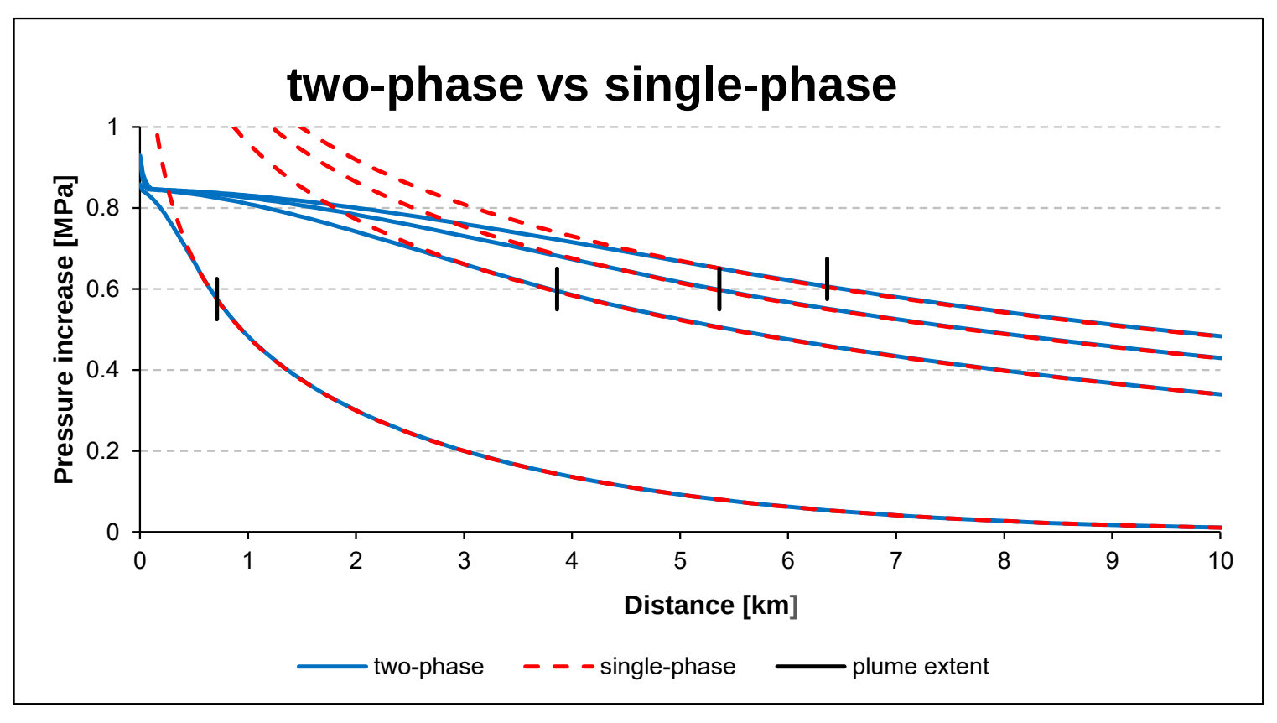
Head impact of passive wells:

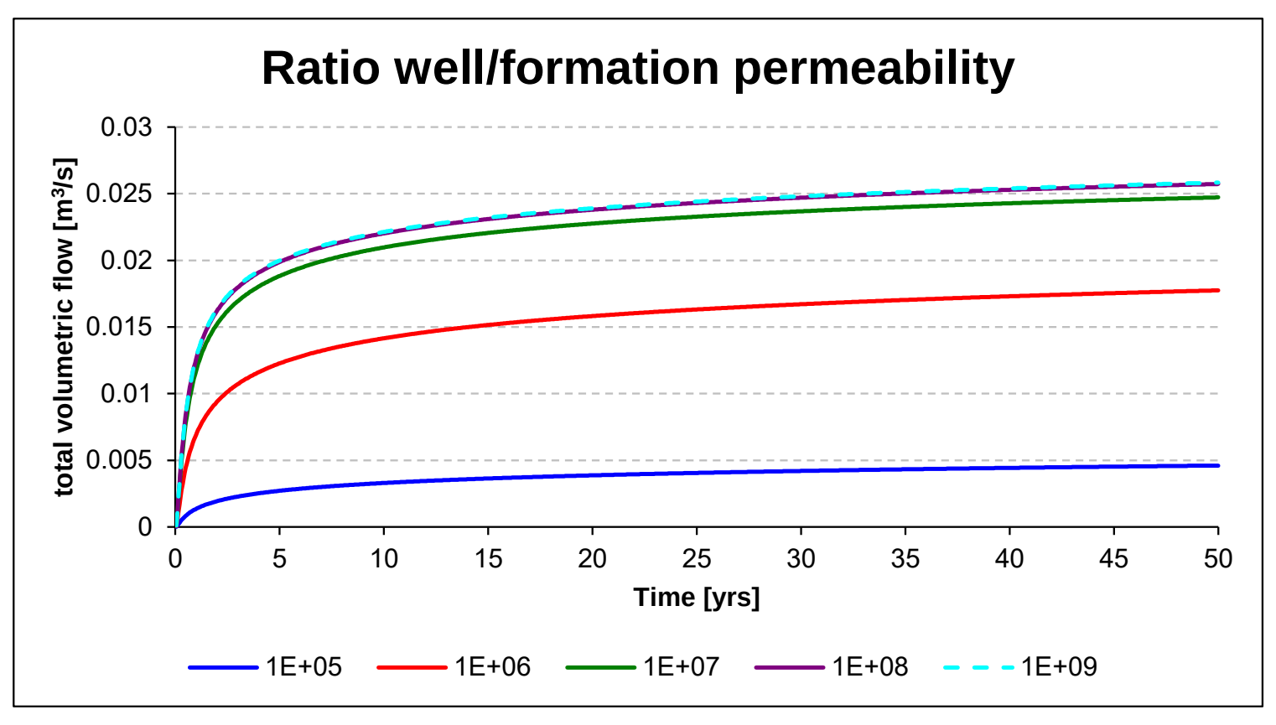
$$h_p \approx \frac{1}{4\pi T}\sum_{j=1}^{N_t} \Delta Q_{p,j} W\left(\frac{d^2 S}{4T\left(t - t_j\right)}\right)$$

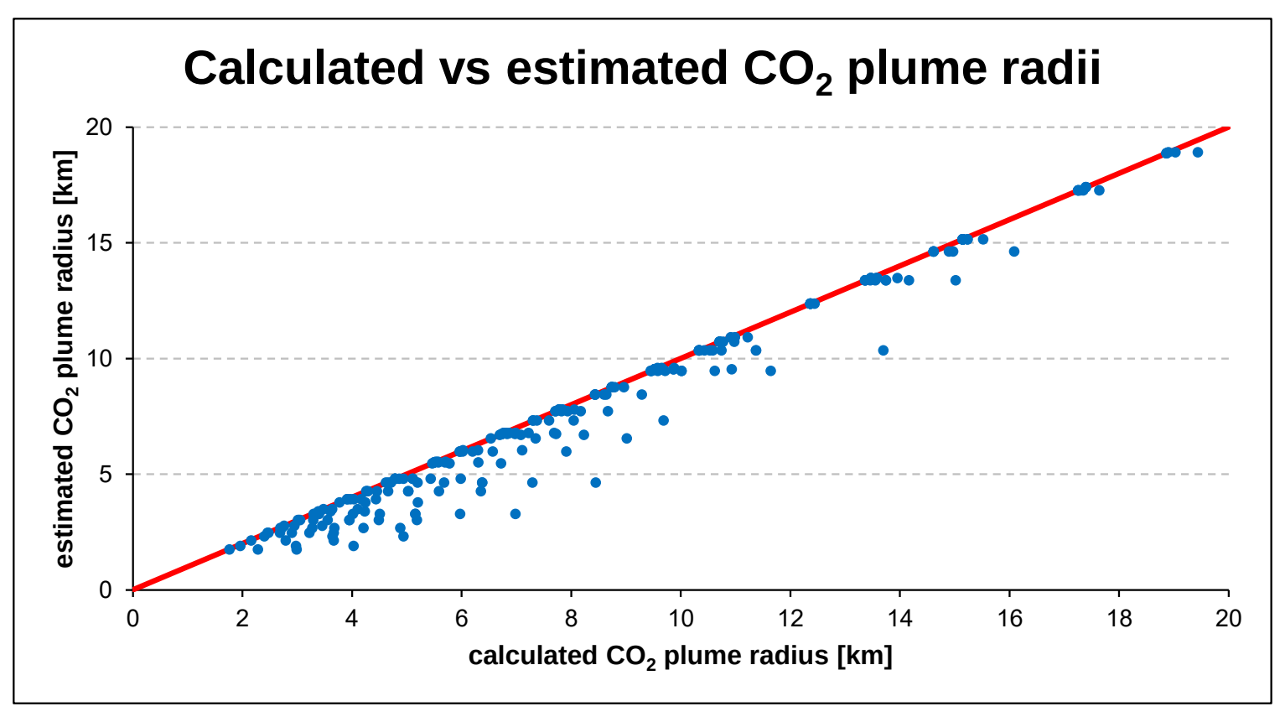
CO_2 plume radius:

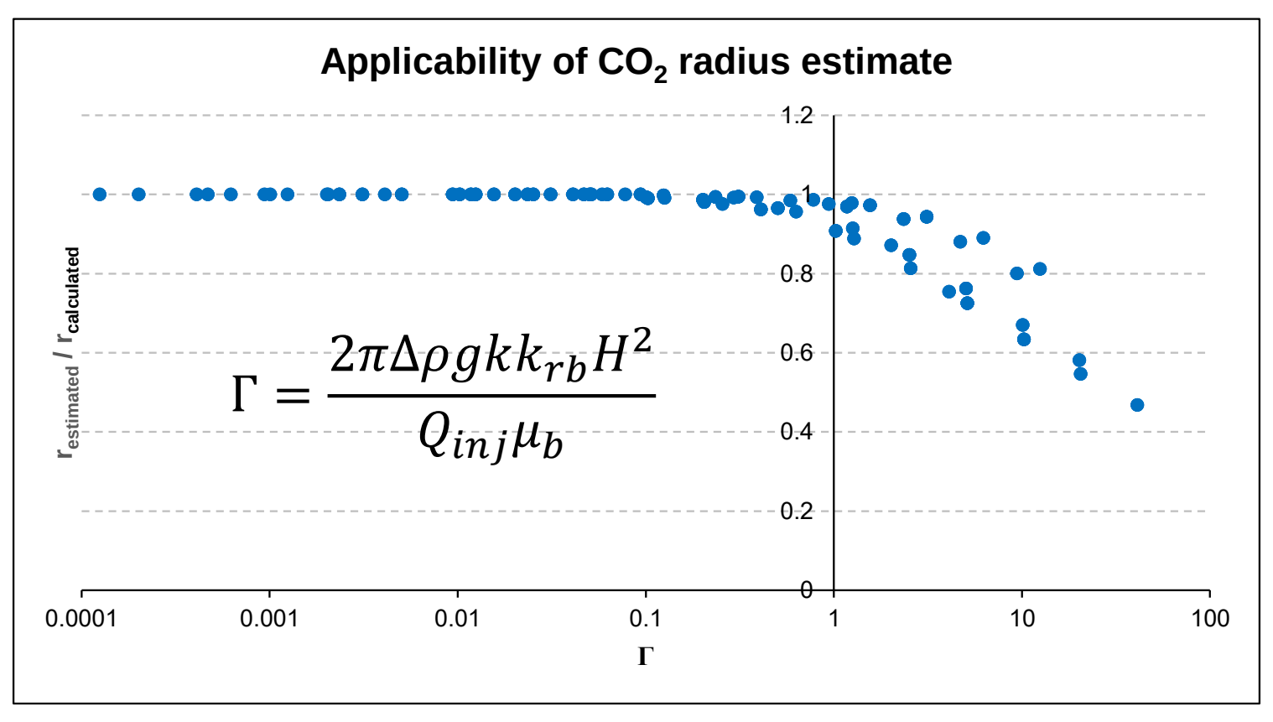
$$r = \sqrt{\frac{\mu_b}{\mu_c}\frac{Q_{inj} t}{\pi H \phi}}$$

4. Applicability of semi-analytic model





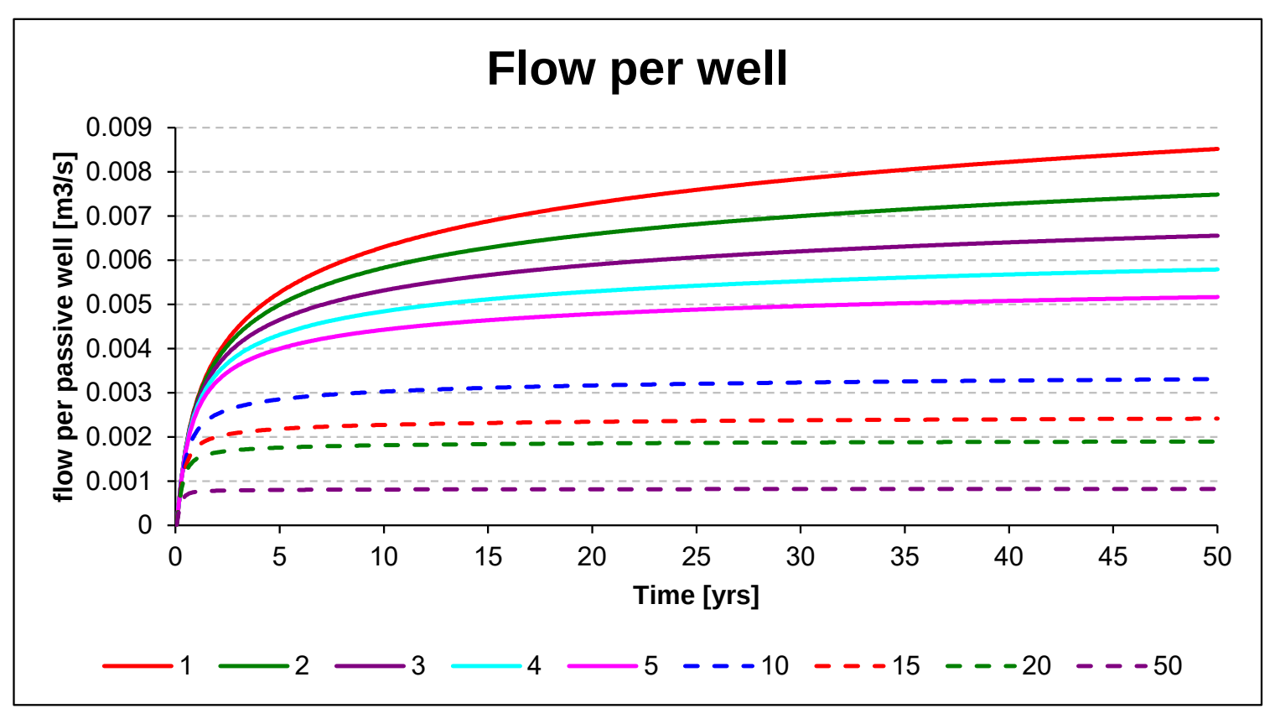


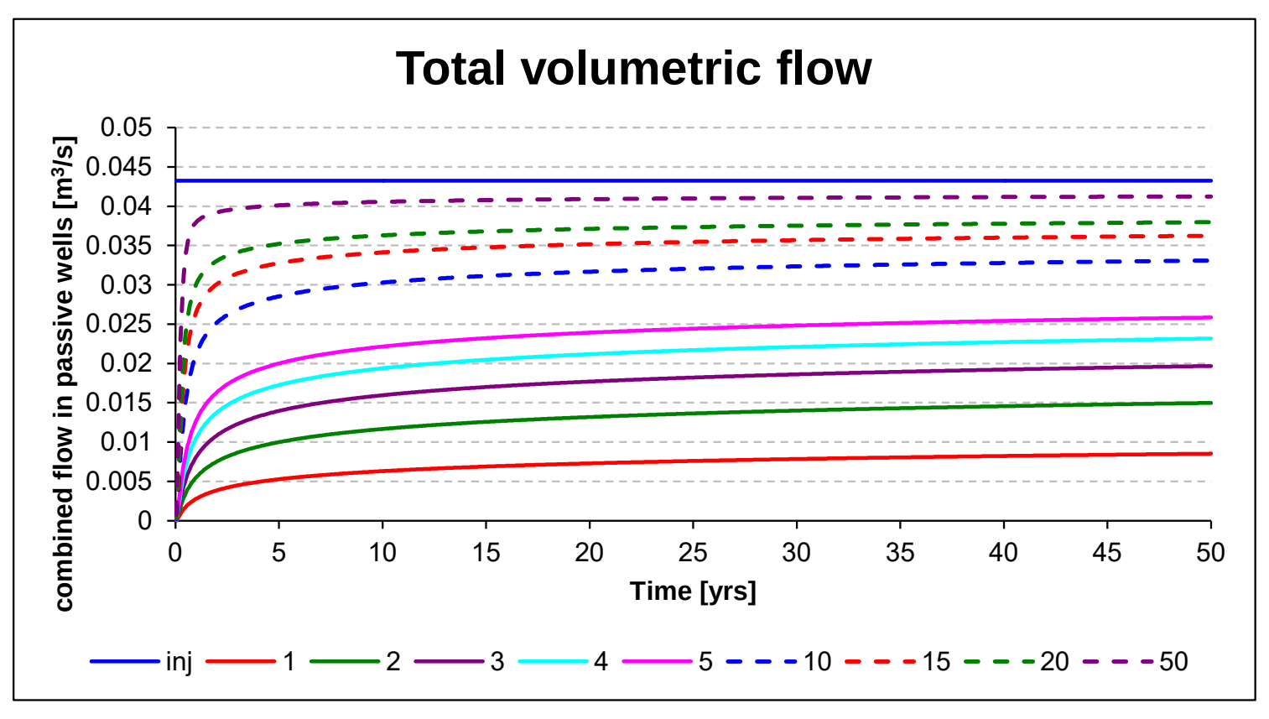


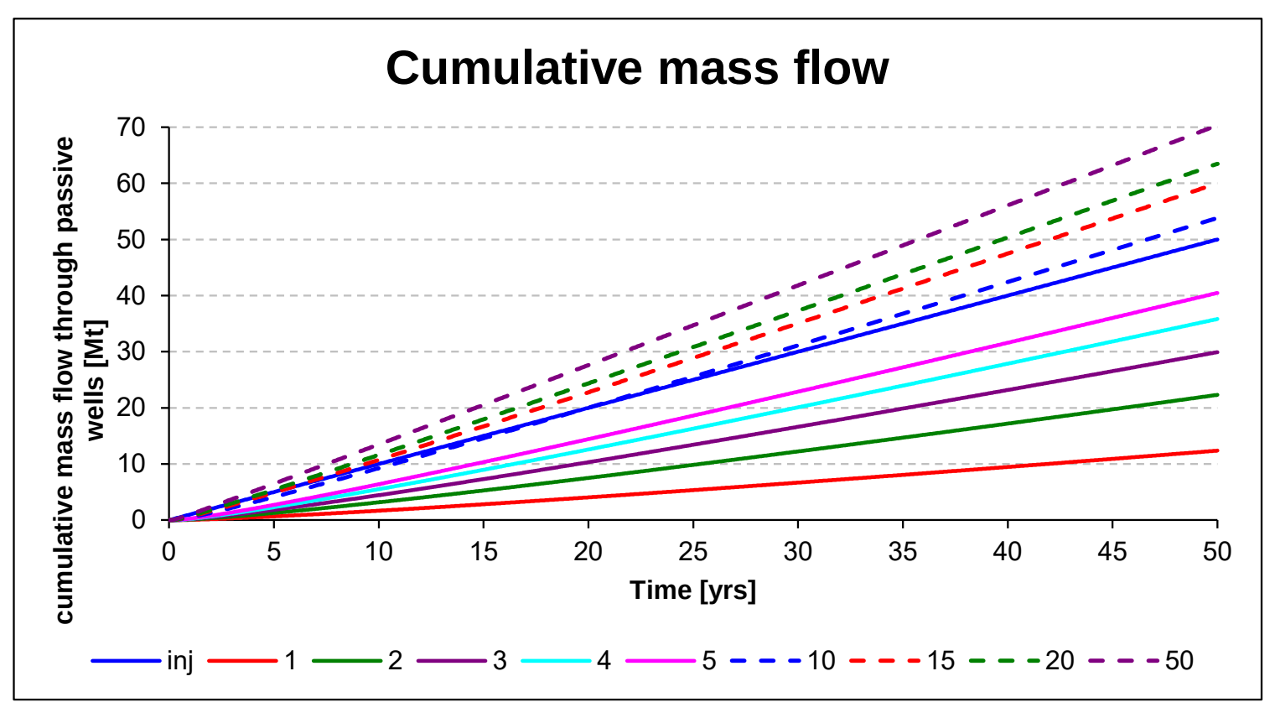
$$\Gamma = \frac{2\pi \Delta\rho g k k_{rb} H^2}{Q_{inj}\mu_b}$$

5. Impact of number of passive wells

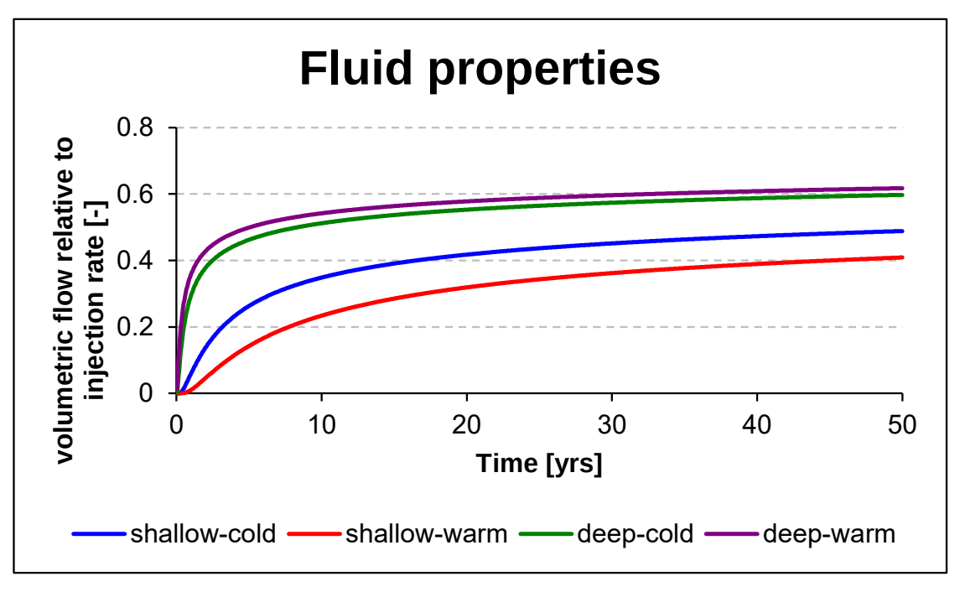
- Interaction between passive wells reduces flow rate as number of wells increases
- Total flow increases with increasing number of wells as the flow rate reduction is compensated by number of wells

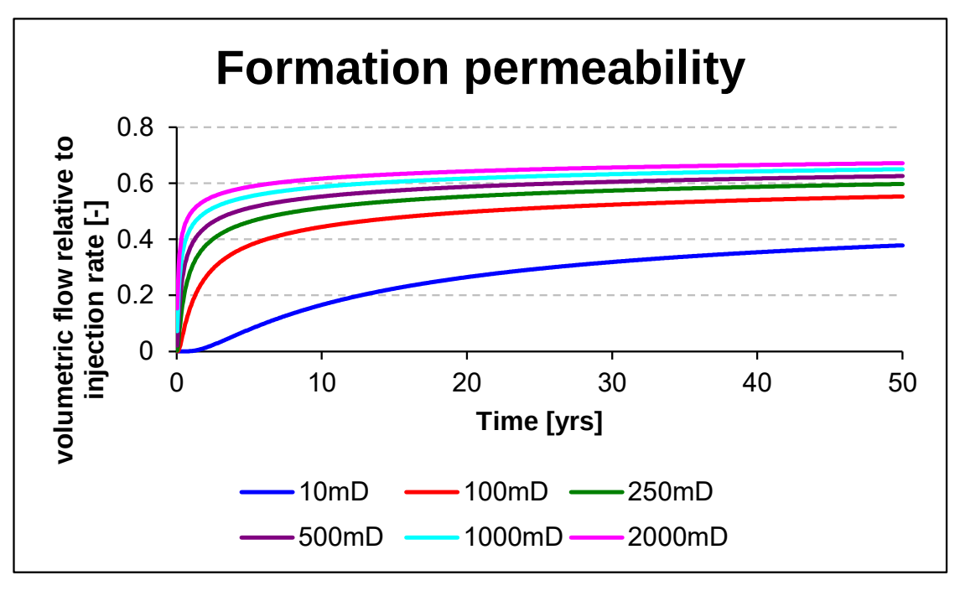


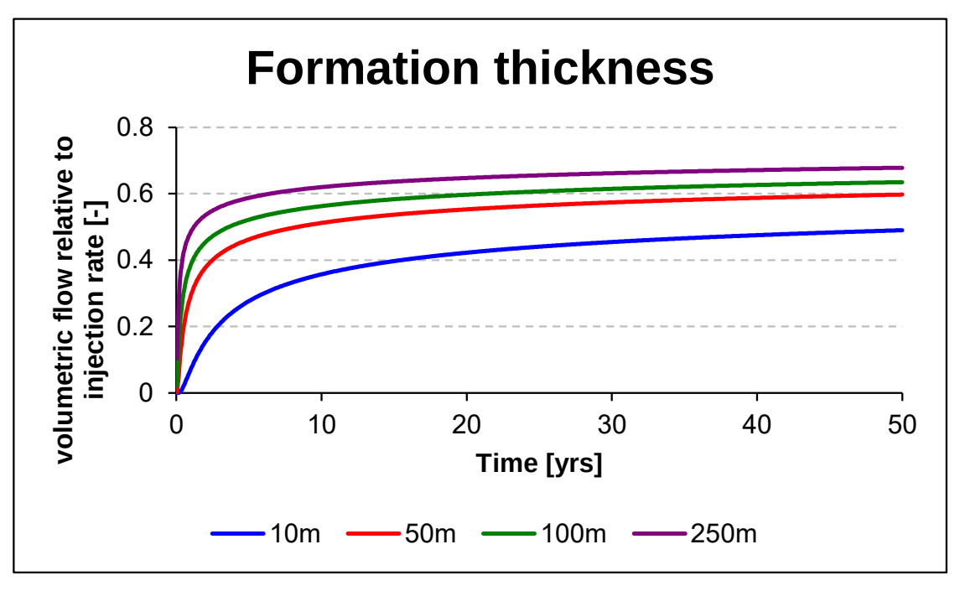


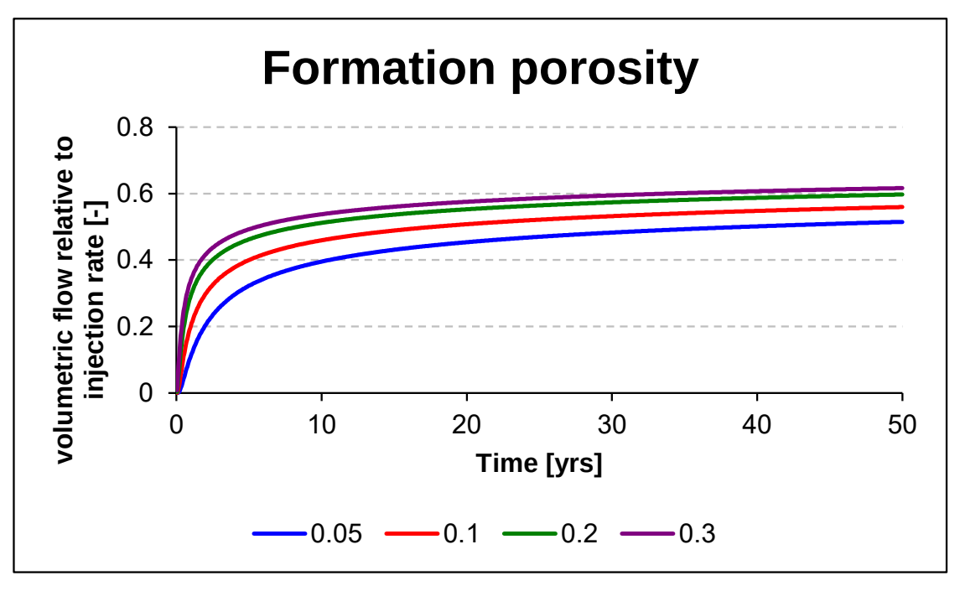


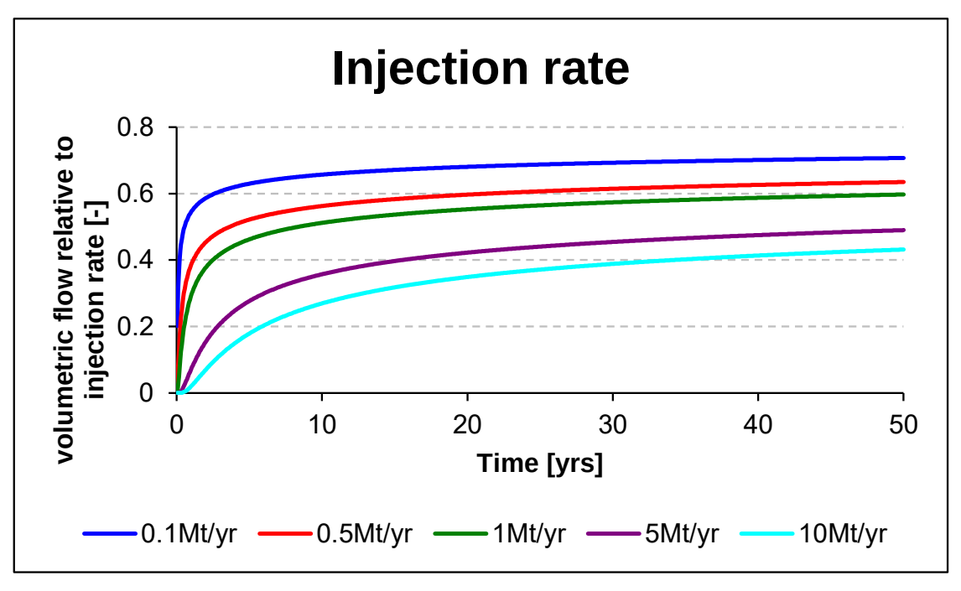
6. Impact of other parameters

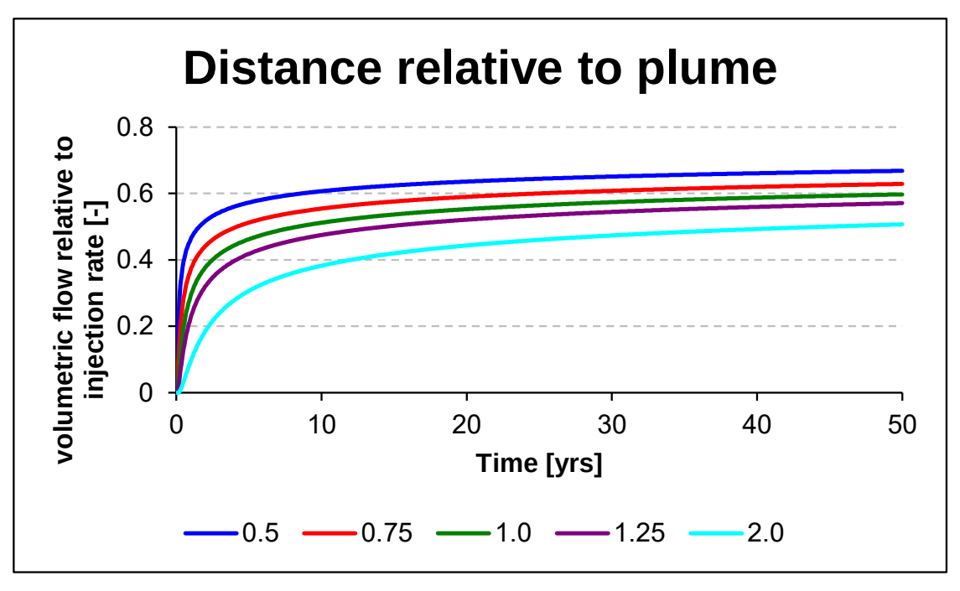


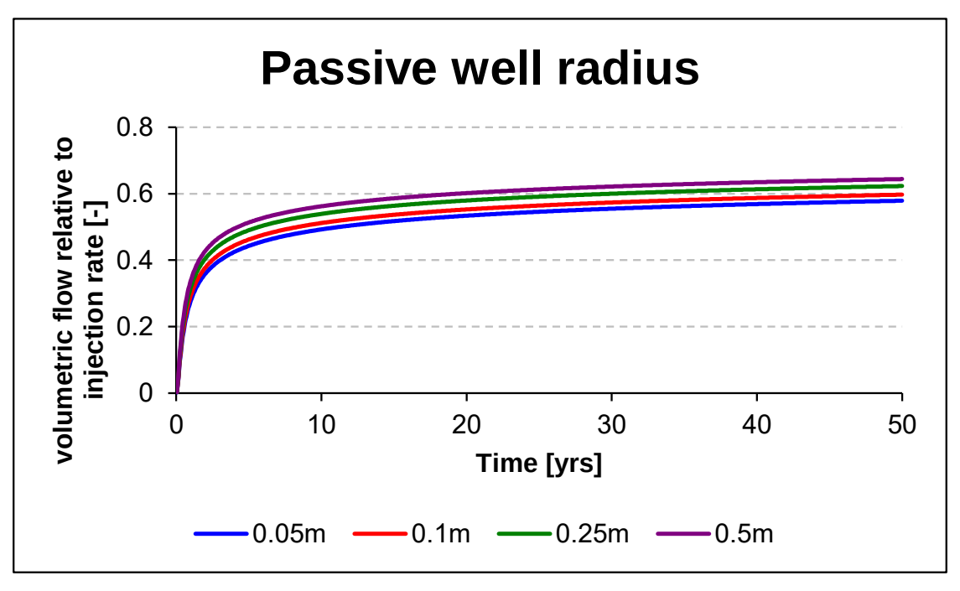


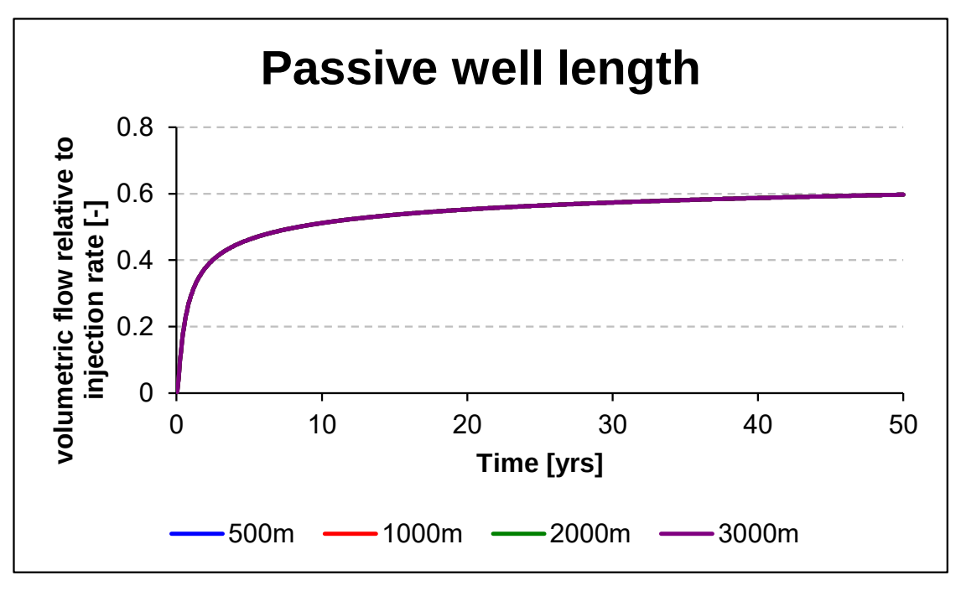




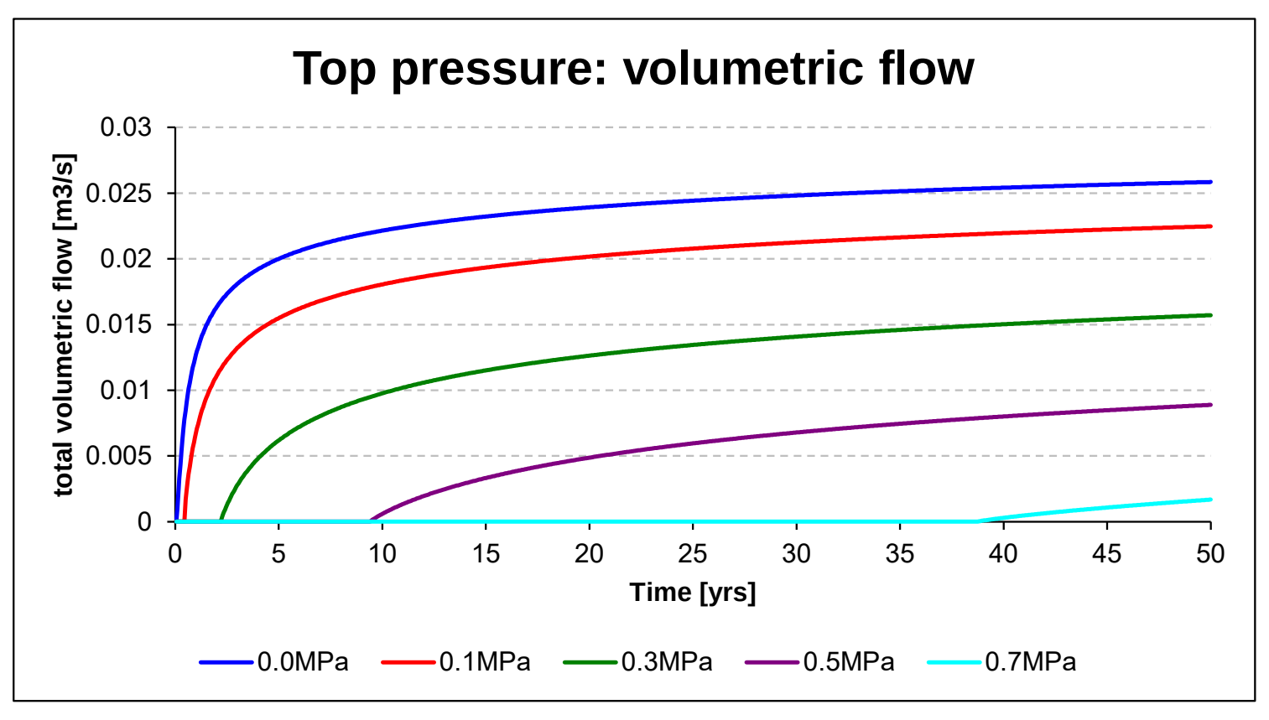


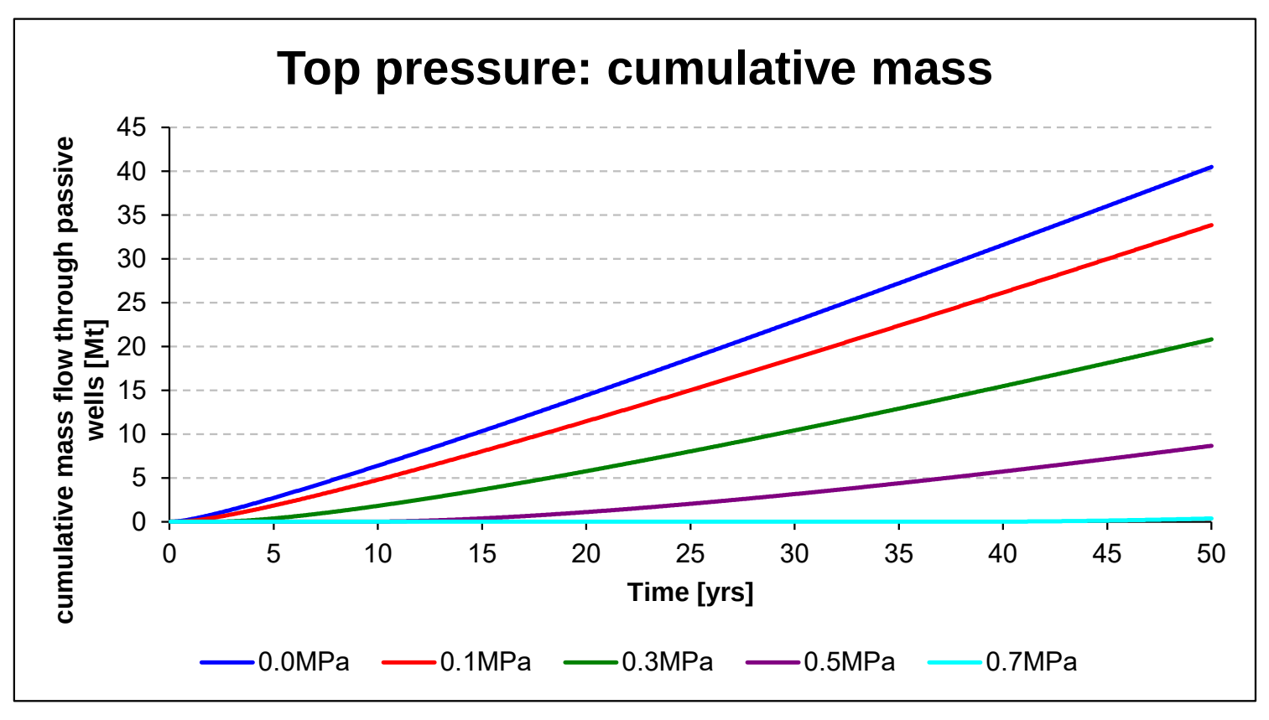




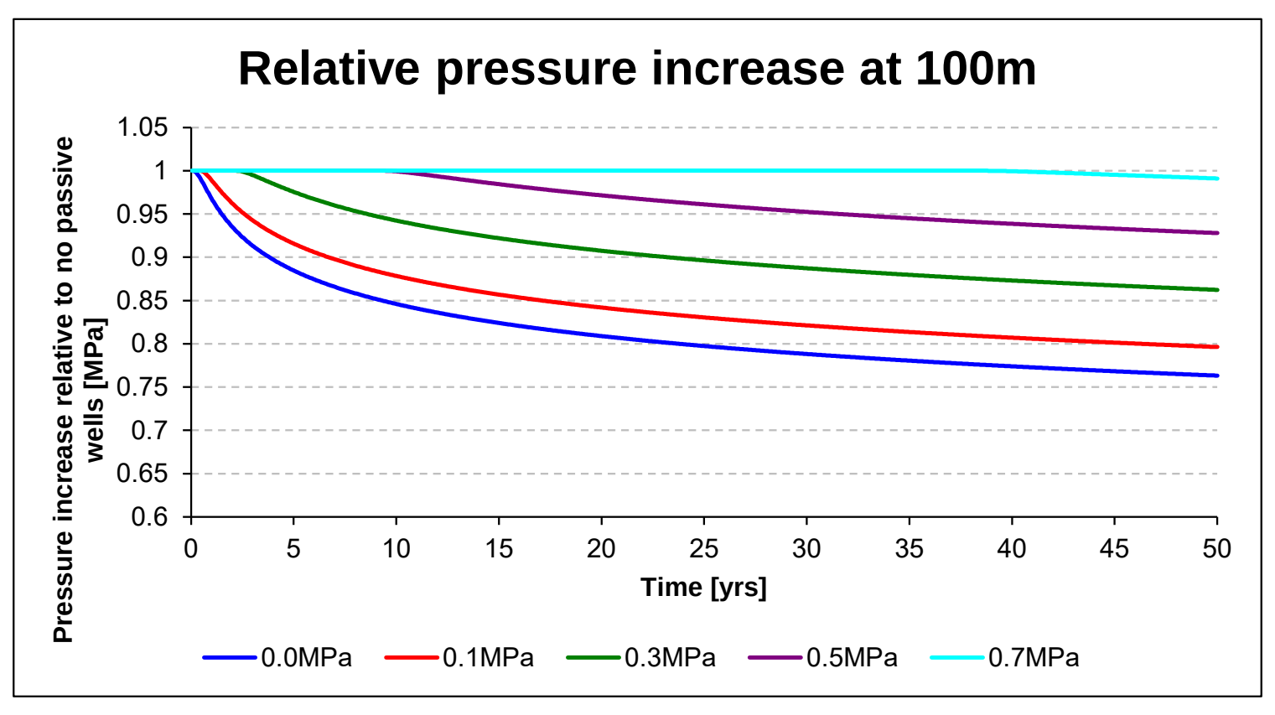


7. Pressurized brine at the surface





- Save energy costs for treatment through pressurized brine
- Significant reductions in flow rates and total mass
- Very little impact in terms of pressure management at injection well from passive well (max ~20% pressure reduction).



8. Conclusions

- Semi-analytical single-phase solutions based on superposition of Theis solution can be used to investigate enhanced water recovery during geologic carbon storage operations.
- Combined volumetric flow rates in the passive production wells reaches between 25 and 60% depending on number of wells and other parameters.
- Parameters affecting the CO_2 plume size (e.g., CO_2 density, formation thickness) have a stronger impact, because the distance between injector and passive wells is determined by CO_2 plume extent.
- Requiring pressurized brine at the surface (e.g., to reduce treatment cost) significantly reduces flow rates, due to delayed startup and lower pressure gradients.
- Passive wells do not seem to be effective for reducing injection pressure.

Acknowledgments

This work was supported by the Princeton Environmental Institute, the Carbon Mitigation Initiative at Princeton University and by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) under Grant Number FE009563.