A Pressure-Limited Model to Estimate CO_2 Injection and Storage Capacity of Saline Formations: Investigating the Effects of Formation Properties, Model Variables and Presence of Hydrocarbon Reservoirs

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Estimated CO_2 storage capacity - Mount Simon Formation

- Zhou et al. (2010) model: 5 Gt
- Szulczewski et al. (2012) model: 111 Gt
- Eccles et al. (2012) model: 254 Gt
- NETL (2012) model: 42.2 Gt (medium)
- USGS (2013a) model: 91 Gt (P_{50})

- Modeling Goals
  - Estimating practical CO_2 injection and storage capacity of a given saline formation
  - Designing a CO_2 injection plan (number of wells, well spacing, duration of injection, well injection rate, brine extraction rate) for a given saline formation

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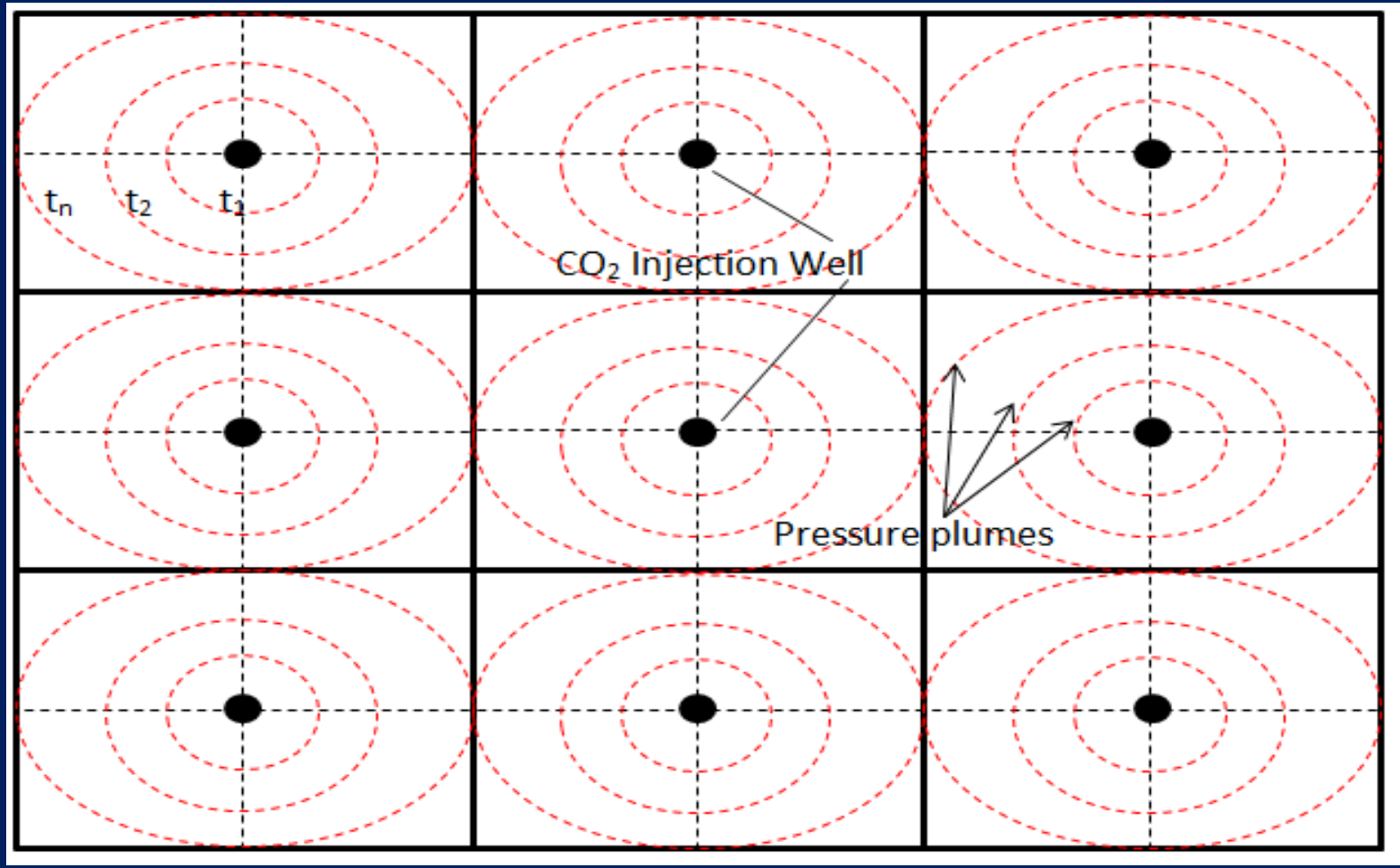
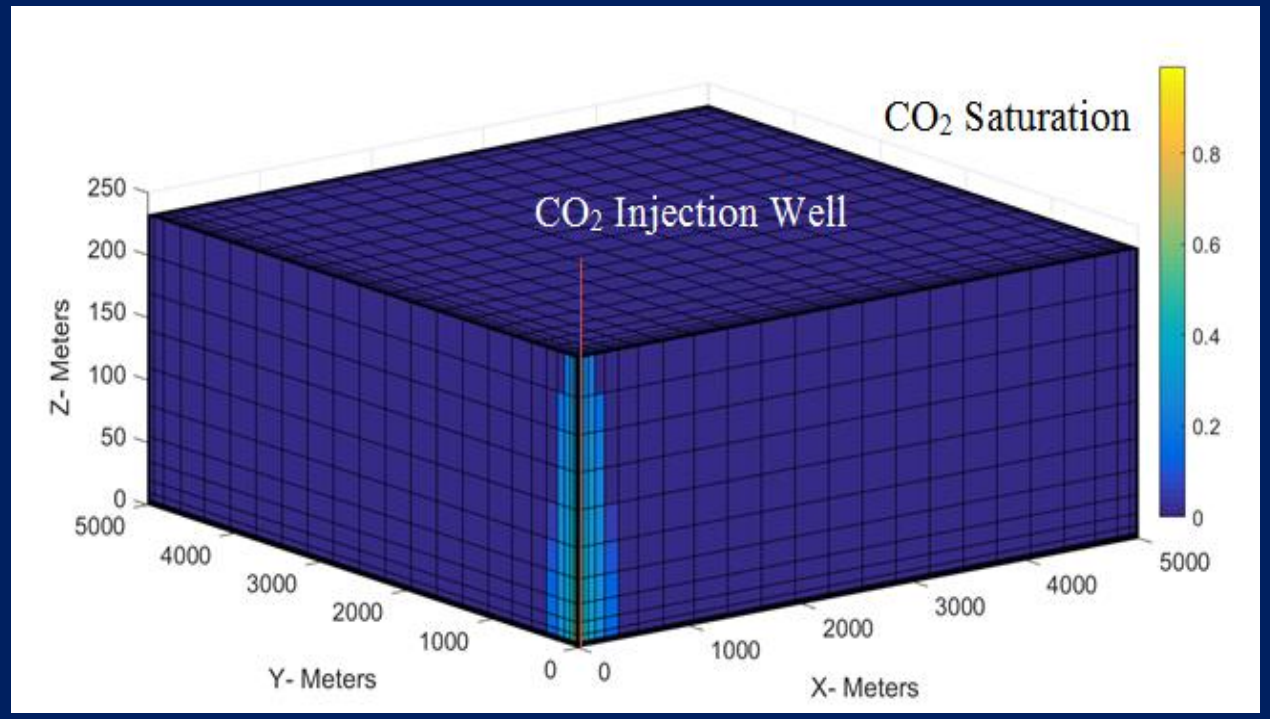
Model development - Numerical models

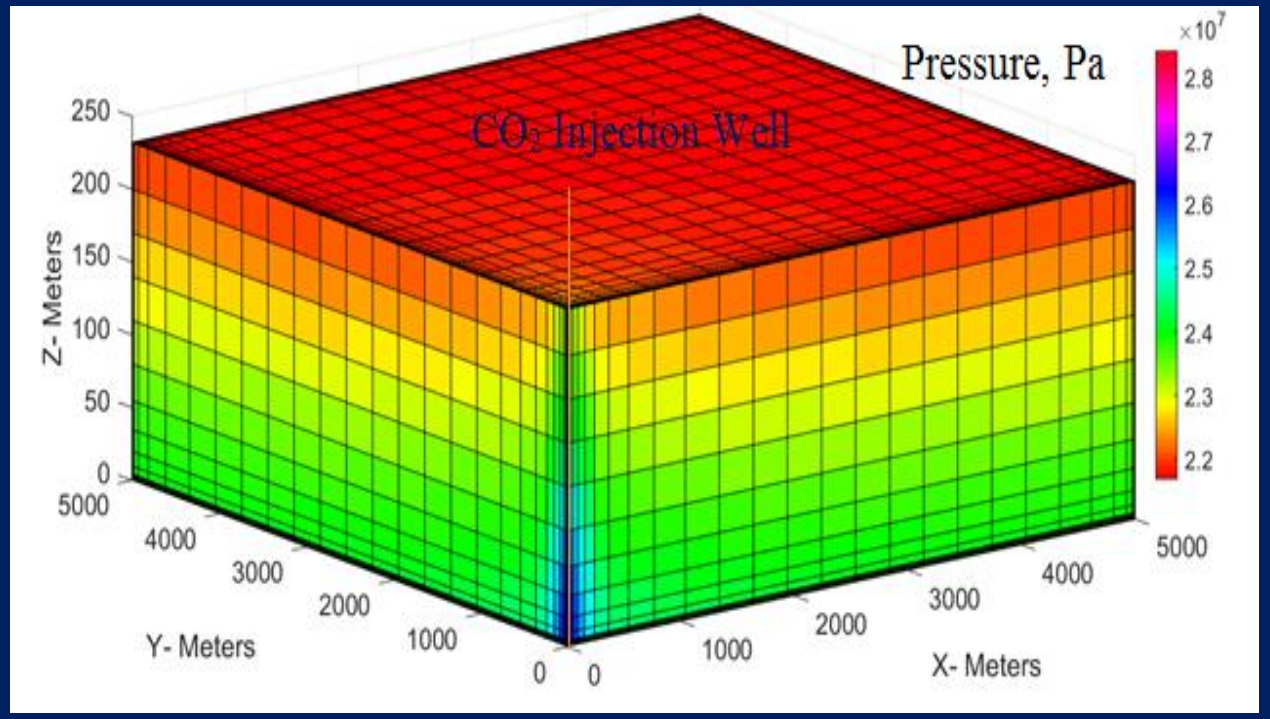
- We used Tough2-ECO2N to model CO_2 injection and storage in saline formations



Model development - Numerical simulation

- We modeled and history matched the Illinois Basin Decatur Project for CO_2 injection based on data from Senel and Chugunov (2013) as a starting point
  - This model covers an effective area of 10 km by 10 km
  - A CO_2 injection rate of 1 Mt over 3 years





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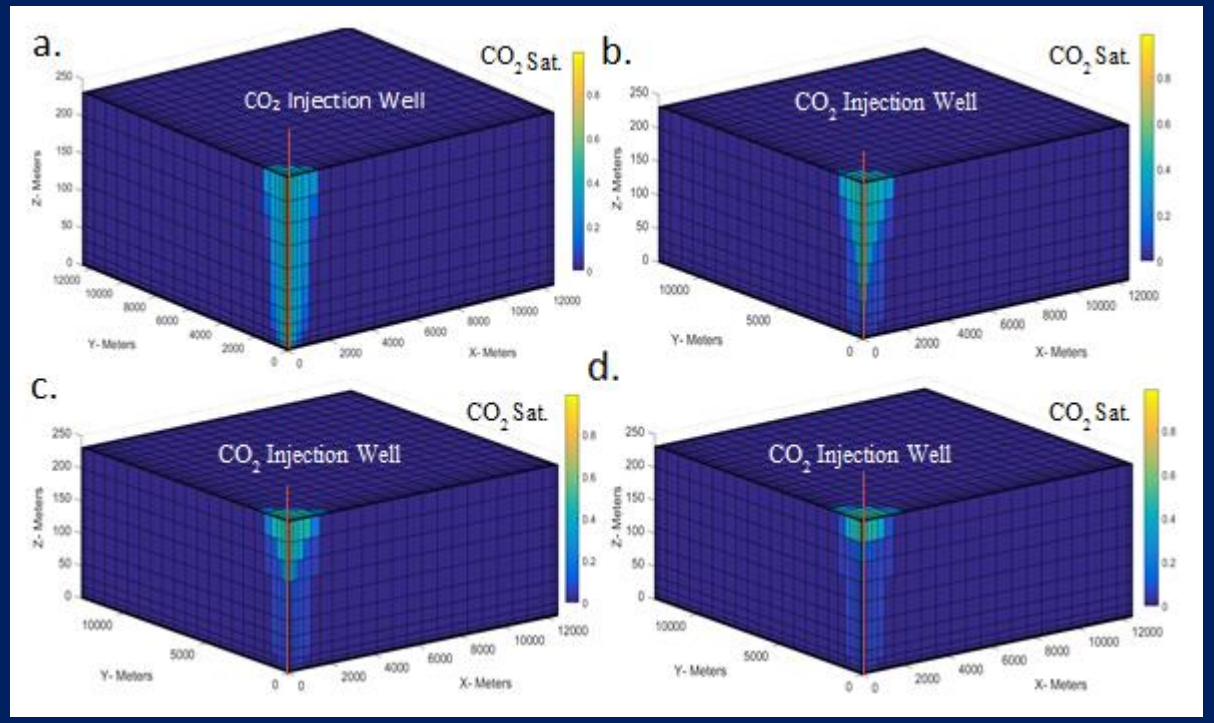
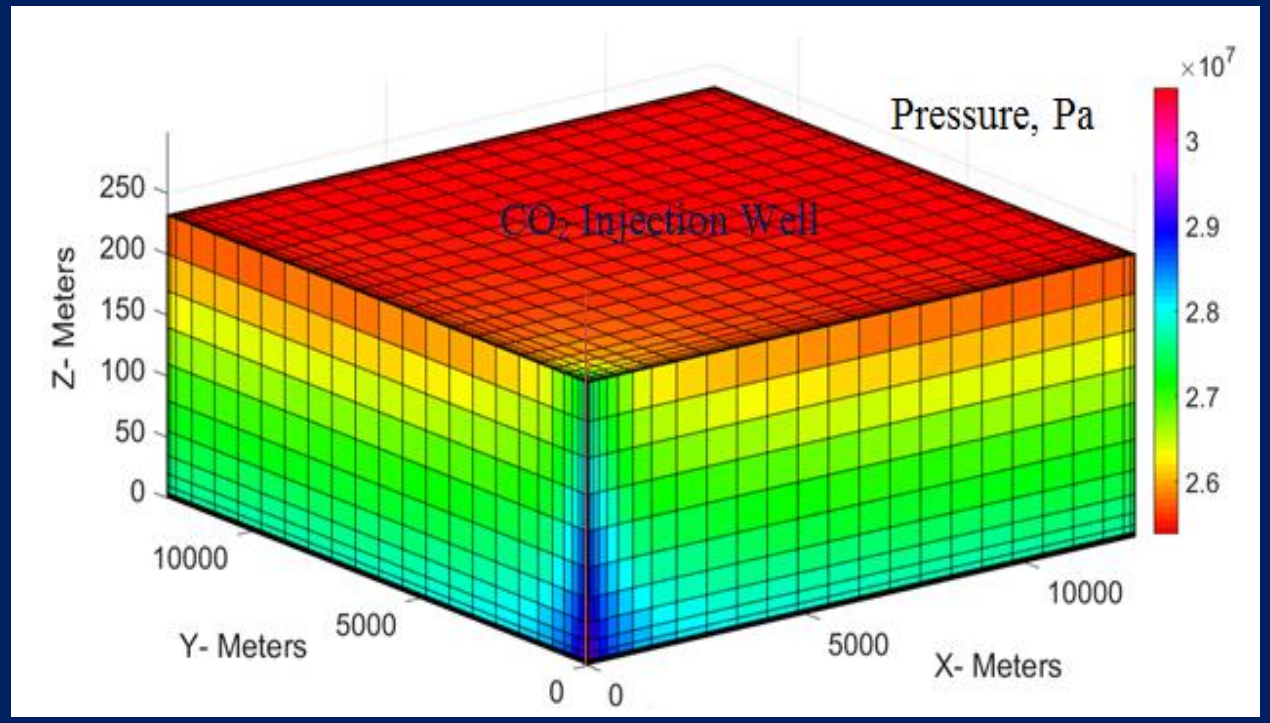
Model development - Numerical simulation (Cont.)

- What if the Illinois Basin Decatur Project continued for longer time (50, 100 years)?
  - The effective CO_2 injection area would be larger (25 by 25 km for this case example)
- Eventually, we are modeling a series of CO_2 injection effective areas (A_{eff})





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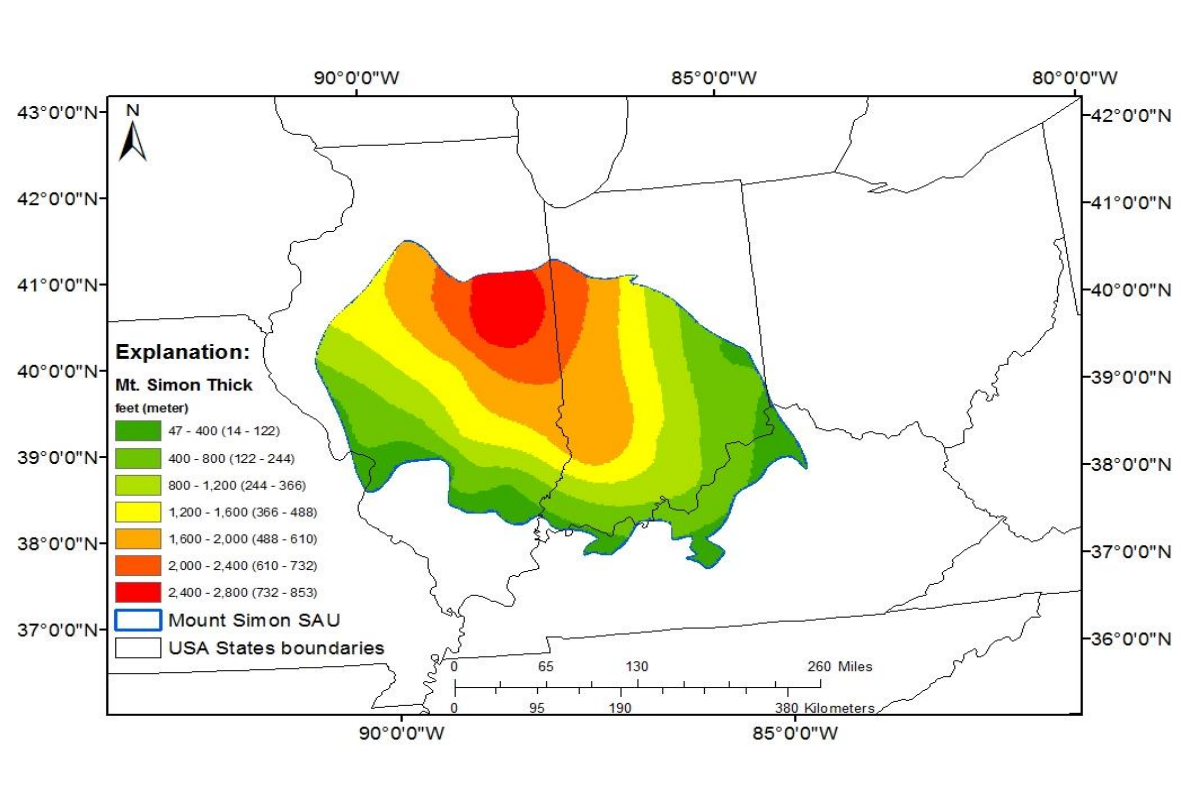
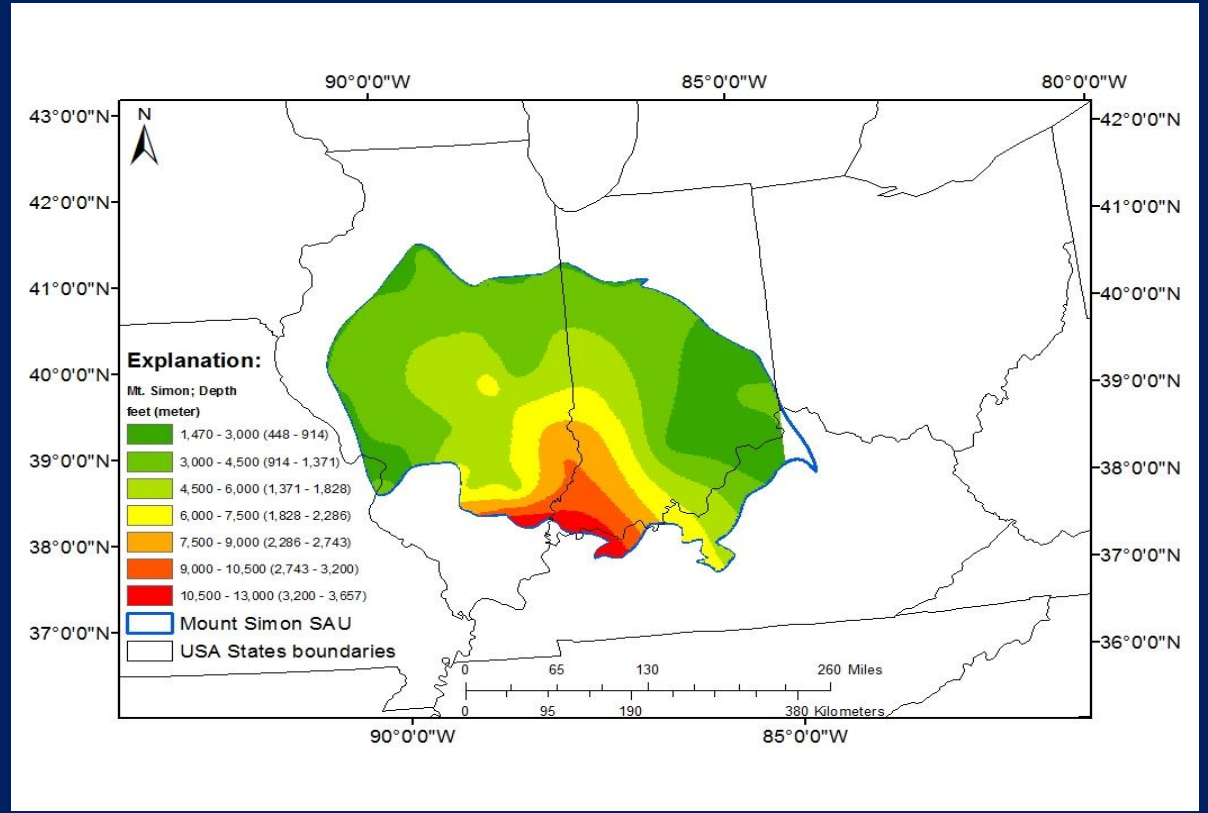
Model development - Formation heterogeneity

- The Mount Simon Formation saline Storage Assessment Unit (SAU) contains a large number of heterogeneities
- Formation porosity, permeability, depth, net thickness…



Thickness



Depth

Model Development - Statistical formulation

- $V_{inj,t} = a\emptyset^b H^c A^d k^e D^f t^g$
- $V_{inj} = V_{inj,t} t$

$V_{inj,t}$: Annual cell injection rate, Mt/year

V_{inj}: Total cell injection, Mt

A: Effective injection (cell) area, km^2

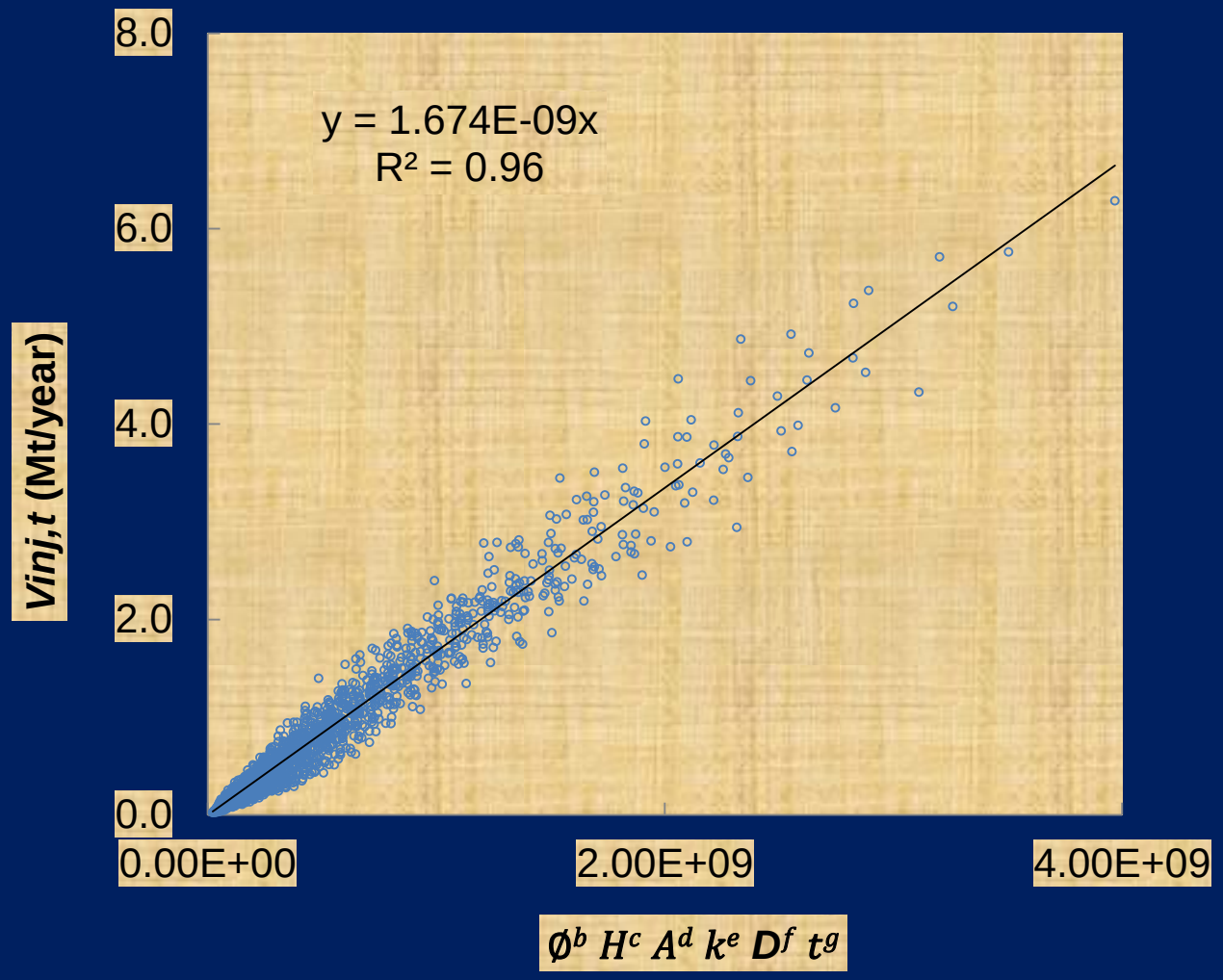
D: Effective injection average depth, m

H: Effective injection thickness (m)

k: Effective injection permeability (mD)

t: Duration of injection (years)

Ø: Effective injection porosity (%)



Parameter	a	b	c	d	e	f	g
Value	1.674E-09	0.66	0.85	0.64	0.18	1.25	-0.31

Model development - Advantages

- The 3D numerical simulation is conducted only for a representative A_{eff}
- Each A_{eff} acts as a closed domain and hence can be operated independently
- Possible to model any fault and natural barrier by considering them as boundary conditions to a given A_{eff}
- The developed statistical method makes it possible to apply this approach to determine the annual CO_2 injection rate for similar saline formations

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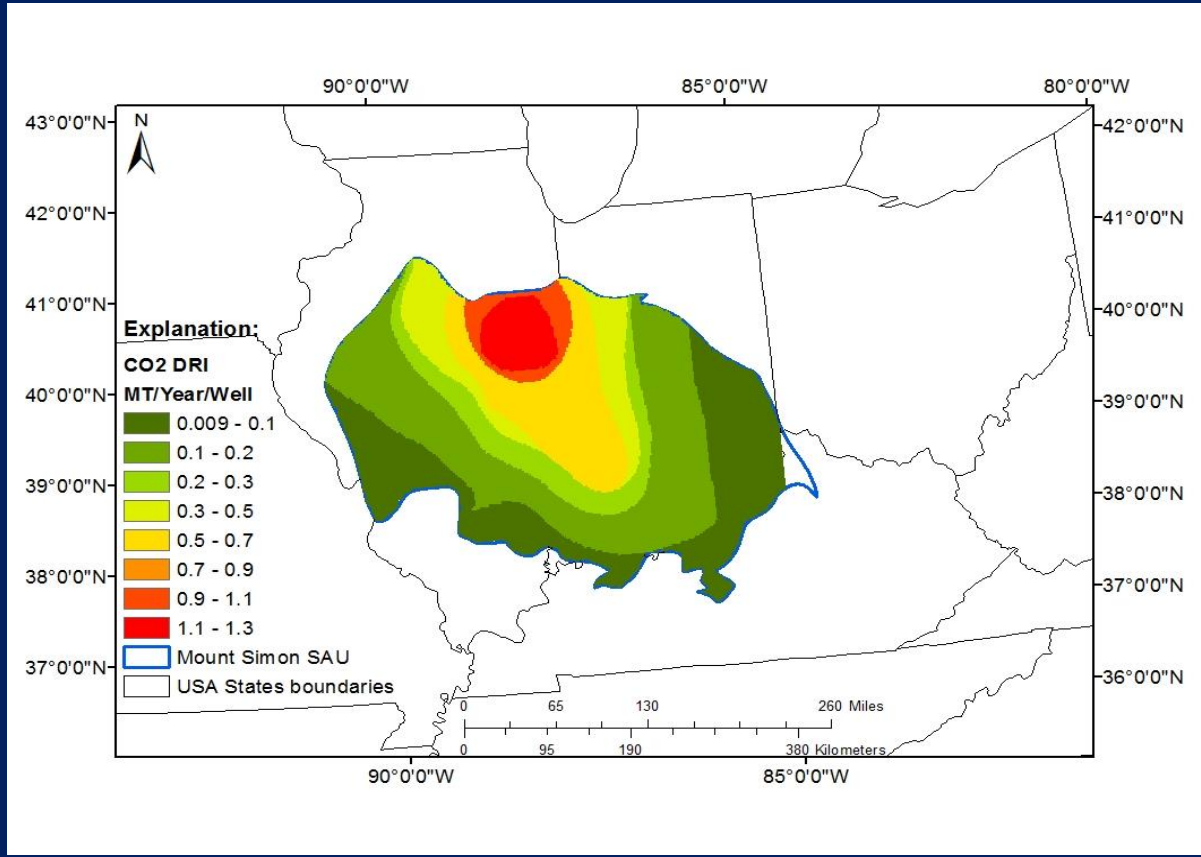
Model results

- This model is applied to estimate the CO_2 injection and storage capacity of 192 Storage Assessment Units (SAUs) in 33 U.S. basins defined and reported by the U.S. Geological Survey Geologic Carbon Dioxide Storage Resources Assessment Team (2013a,b)

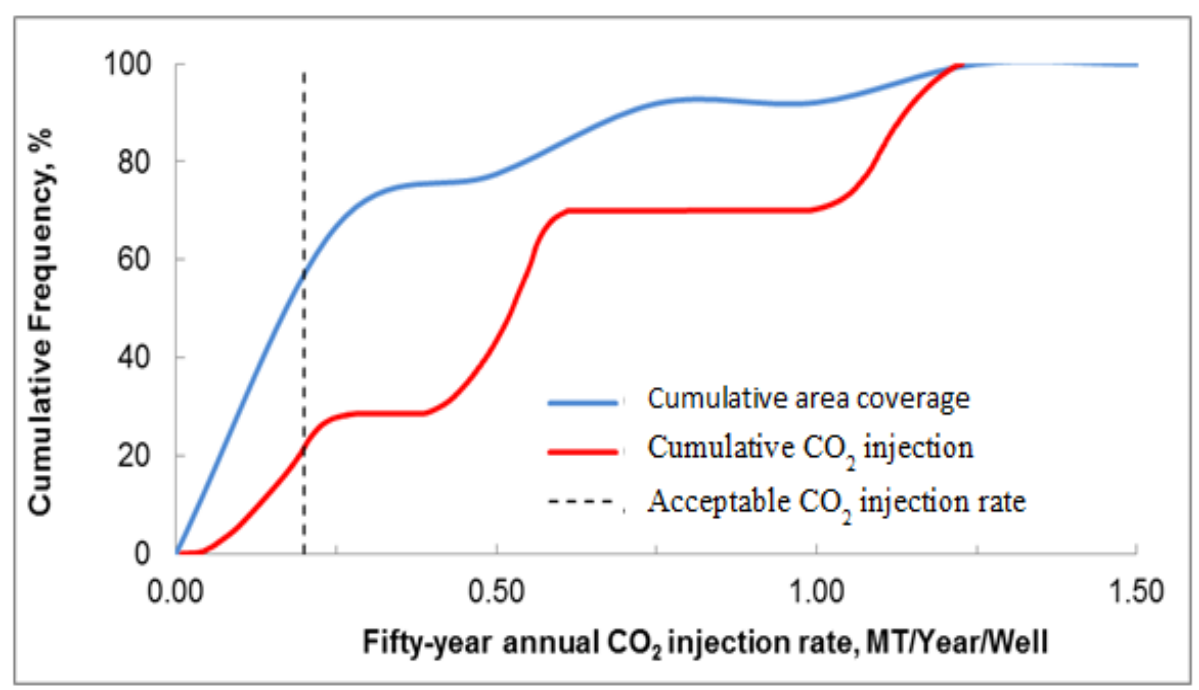
- By applying the model to the Mount Simon Formation, injection rate density maps are produced



CO_2 injection rate density map

Model results - Mount Simon Formation

- Two cases are assumed:
  - Formation heterogeneity is not known: most likely values are used
  - Formation heterogeneity is known and used in capacity estimation



		Entire formation CO_2 net injection volume, MT/y		
Porosity	Permeability, m^2 (mD)	Minimum area	Most likely area	Maximum area
Minimum: 6%	Minimum: 1.0E-14 (10)	33.30	37.00	40.69
	Most likely: 2.0E-14 (20)	46.97	52.19	57.40
	Maximum: 2.0E-13 (200)	59.88	66.54	73.19
Most likely: 11%	Minimum: 1.0E-14 (10)	37.83	42.03	46.23
	Most likely: 2.0E-14 (20)	61.44	68.26	75.09
	Maximum: 2.0E-13 (200)	65.02	72.24	79.46
Maximum: 16%	Minimum: 1.0E-14 (10)	42.50	47.23	51.95
	Most likely: 2.0E-14 (20)	64.26	71.40	78.53
	Maximum: 2.0E-13 (200)	97.23	108.03	118.84

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Model applications: Effect of hydrocarbon reservoirs

- Many of the important SAUs contain a large number of oil and gas reservoirs
- In addition, there could be several undiscovered hydrocarbon reservoirs in the SAUs
- Hydrocarbon production from these reservoirs depends largely on each reservoir's prevailing conditions and operating pressure
- Any CO_2 injection into or near these reservoirs will disturb their governing and driving mechanisms
- Over 5,000 discovered oil and gas reservoirs are in U.S. Gulf Coast SAUs alone with an average decline time to their economic limit of over 40 years

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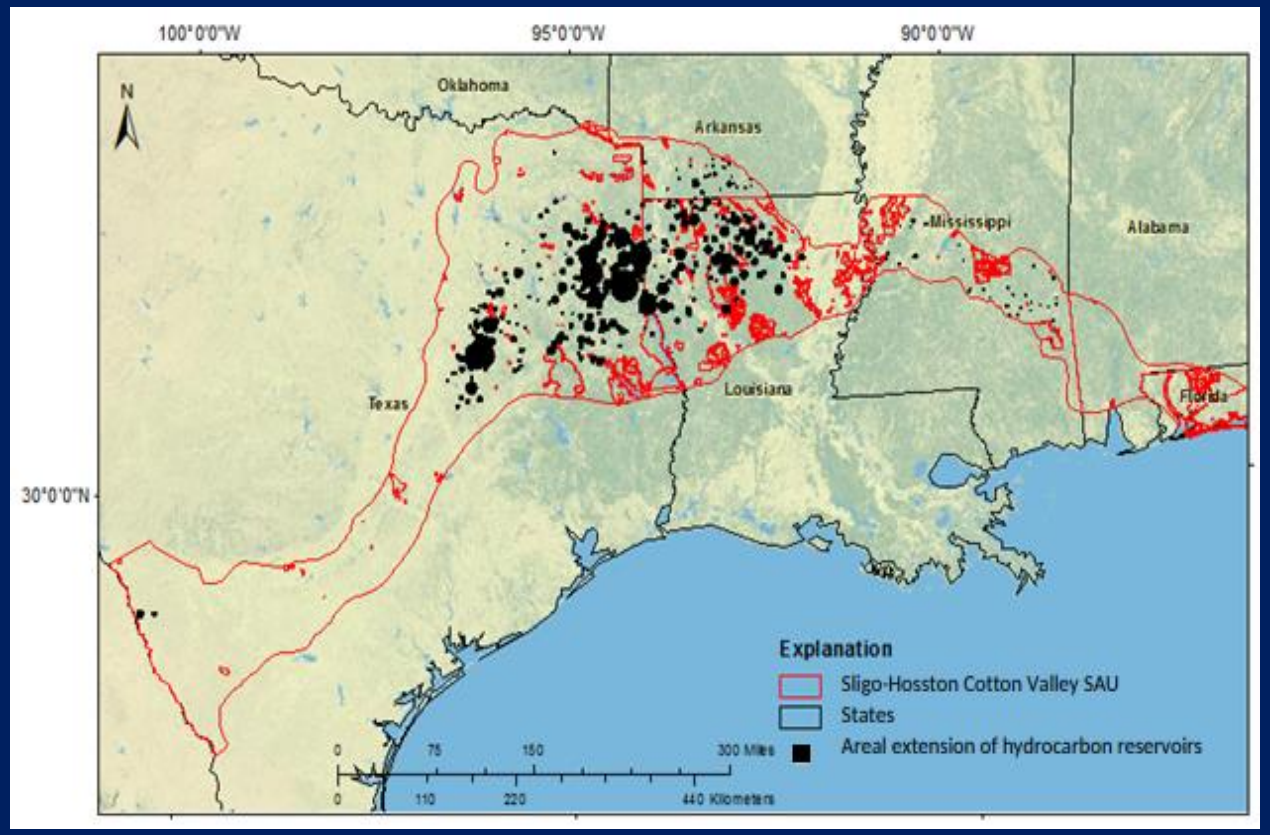
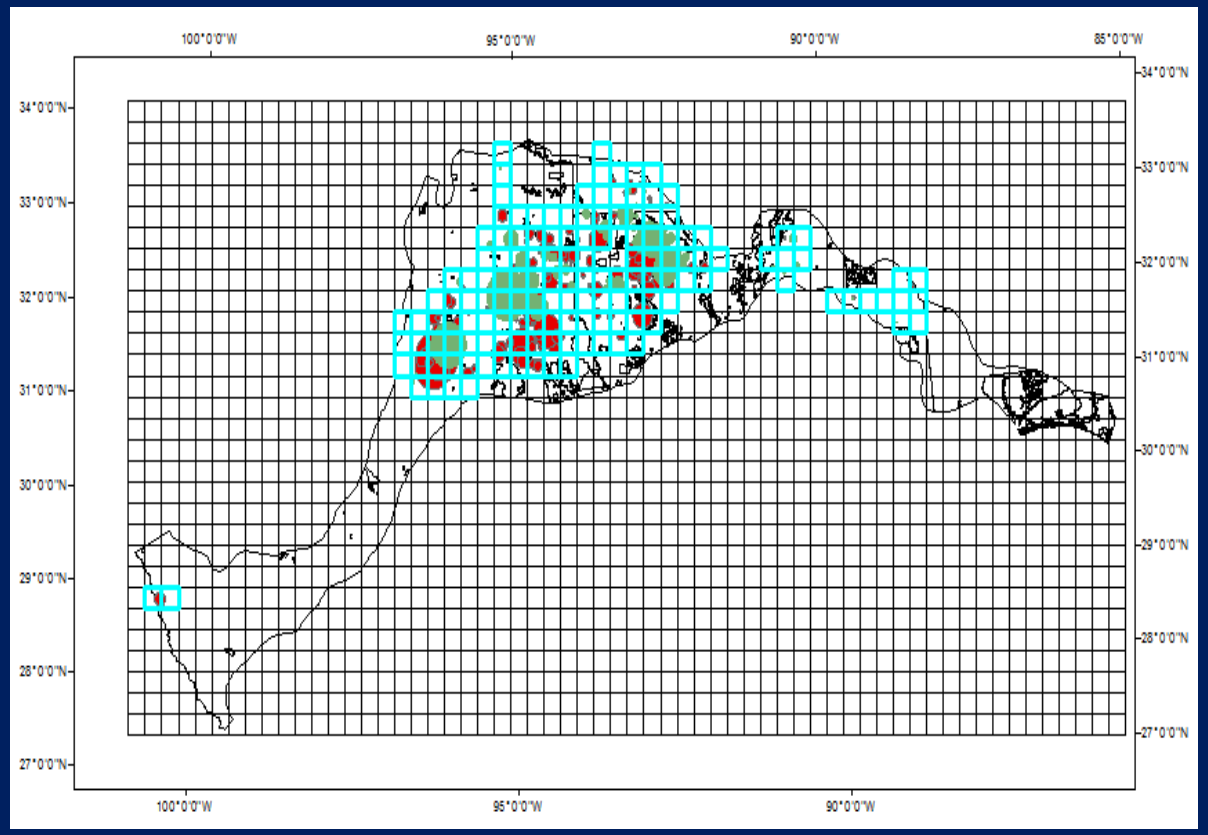
Model applications: Effect of hydrocarbon reservoirs

- Sligo-Hosston- Cotton Valley SAU is the largest defined SAU in Gulf of Mexico
- Determined CO_2 injection capacity is 840 Mt/year ignoring the hydrocarbon reservoirs
- Determined CO_2 injection capacity is 355 Mt/year taking into account the presence of hydrocarbon reservoirs





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Comparison of estimated CO_2 storage capacity – Mount Simon Formation

- Pressure limited models:
  - Zhou et al. (2010) model: 5 Gt
  - Jahediesfanjani et al. (2017) model: 3.5 Gt
- Other Models:
  - Szulczewski et al. (2012) model: 111 Gt
  - Eccles et al. (2012) model: 254 Gt
  - NETL (2012) model: 42.2 Gt (medium)
  - USGS (2013a) model: 91 Gt (P_{50})
- Pressure management techniques, such as brine extraction before or during CO_2 injection, will greatly increase a saline formation's CO_2 storage capacity applying any pressure limited model.

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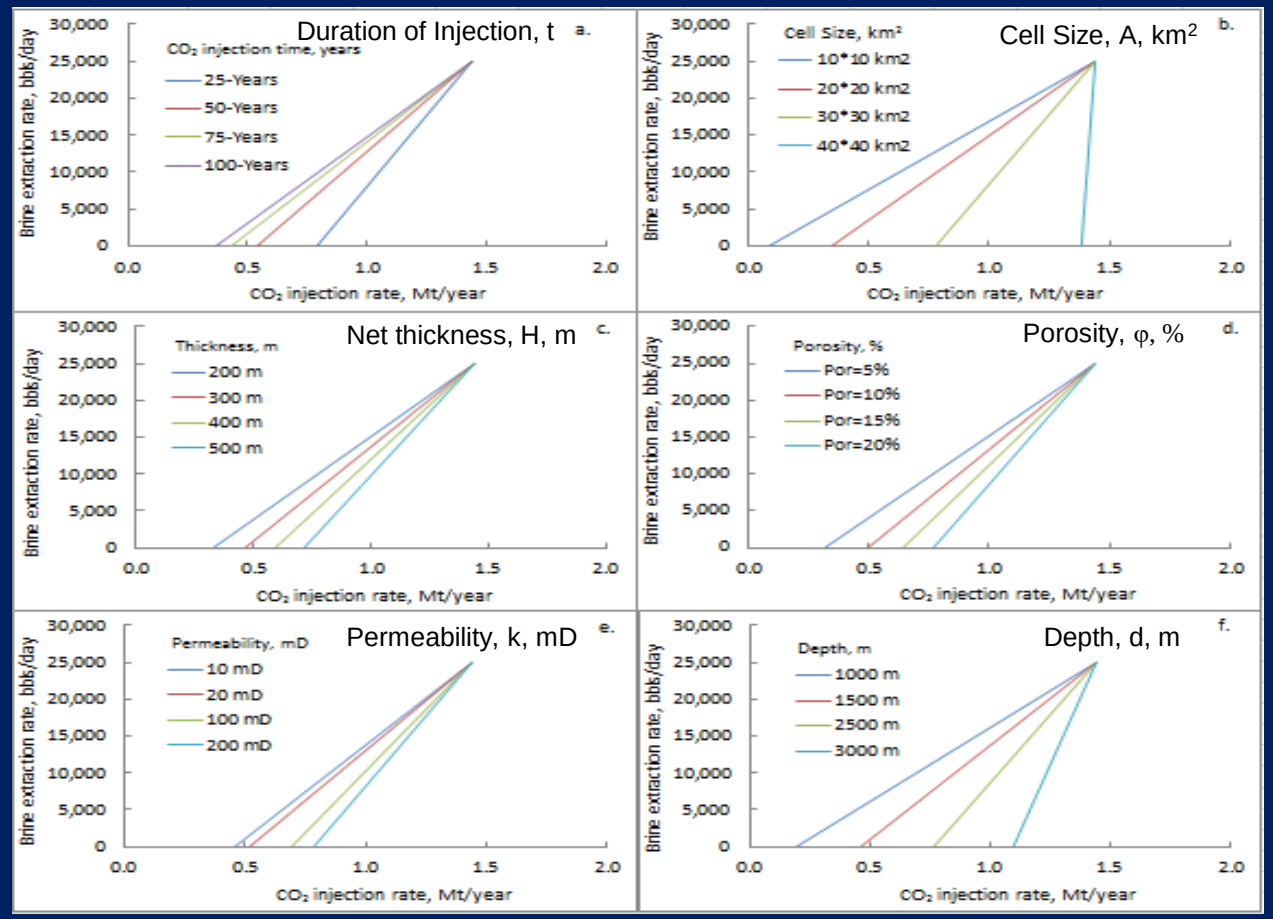
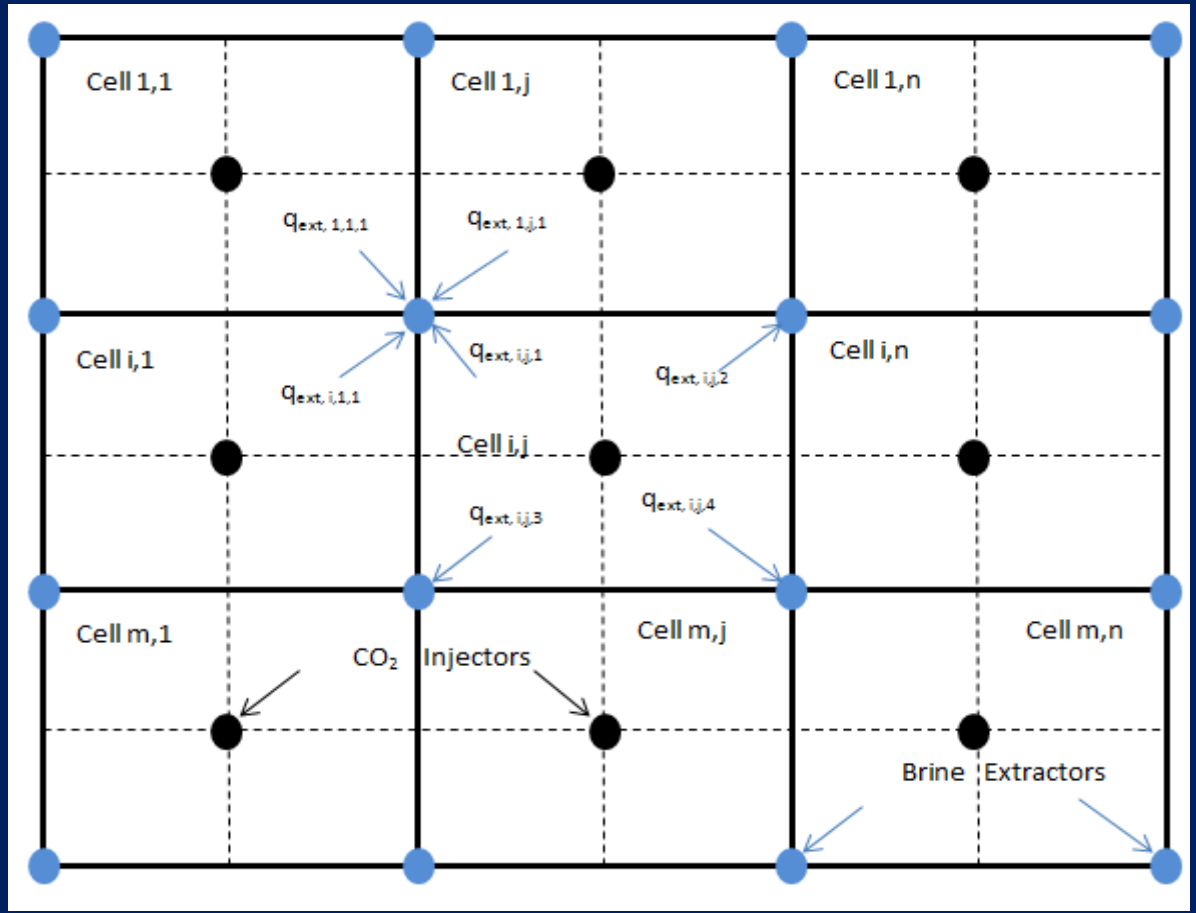
Pressure management - Brine extraction

- We modeled brine extraction scenarios utilizing a 5-spot pattern similar to waterflooding and/or CO_2 EOR operations in oil reservoirs





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Summary

- Based on this model, the entire saline formation is divided into equal cells that:
  - Contain a single CO_2 injection well
  - Each cell functions independently as closed boundary cell
  - Each cell injection rate is a function of formation properties, cell size and duration of injection
  - A buffer zone is created around hydrocarbon reservoirs with no CO_2 injection
- Brine extraction is being modeled to estimate additional CO_2 injection capacity due to proper pressure management technique
- This model provides a practical roadmap to estimate each SAU's CO_2 storage capacity, optimum number of wells, well spacing and injection/extraction rates

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