Task 2: Tools, and Methods to Manage Subsurface Risks

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2024 FECM / NETL Carbon Management Research Project Review Meeting

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NRAP
National Risk Assessment Partnership

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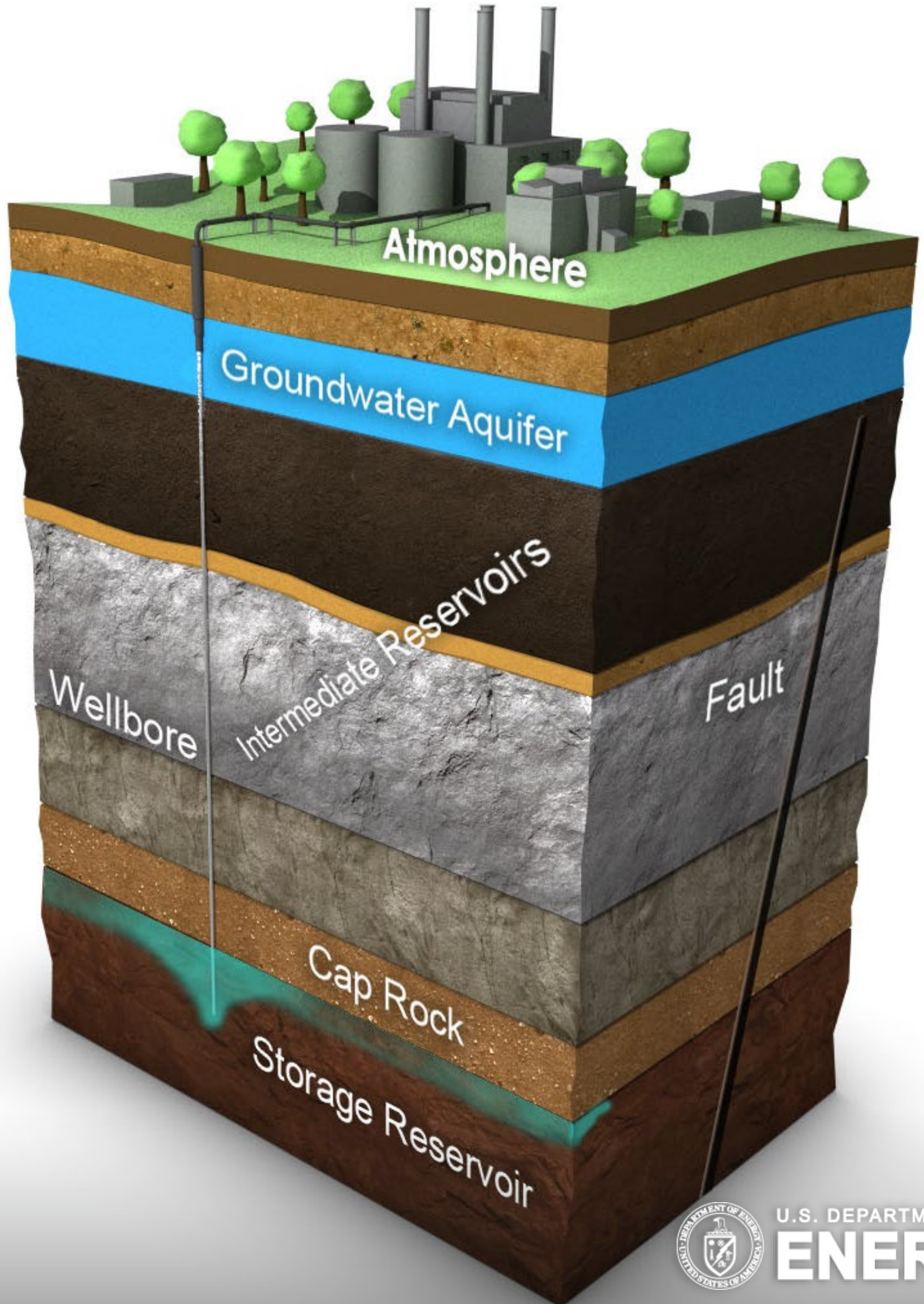

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Task 2: Addressing Stakeholder Needs to Accelerate Geologic Storage Projects: Tools and Methods to Manage Subsurface Risks

Objective To demonstrate and improve the utility of NRAP integrated assessment model and workflows for GCS leakage and containment decision making.

EY20	EY21	EY 2022	EY 2023	EY 2024	EY 2025	EY 2026

NRAP Phase II Open-IAM & Recommended Practices

- Code development plan for site-scale IAM
- Improved well leakage models, prototype AOR and bowtie workflows
- Improved user experience, integration with other NRAP tools, etc
- Complete simulations and results interpretation for initial case studies
- Complete simulations and results interpretation for refined case studies
- NRAP integrated assessment model initial public beta release
- NRAP integrated assessment model second public beta release
- NRAP integrated assessment model v1.0 release
- Complete report on recommended practices for site-scale leakage risk assessment/decision support

Outcome: Release final NRAP site-scale leakage risk assessment tools, tool application catalog/use cases, and recommended practices

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NRAP
National Risk Assessment Partnership

NRAP releases a new version of NRAP-Open-IAM, an integrated assessment model for geologic carbon storage sites

June 11, 2024

Read More

Task 2: Addressing Stakeholder Needs to Accelerate Geologic Storage Projects: Tools and Methods to Manage Subsurface Risks

2 Stakeholder needs

Objective To demonstr… utility of NRAP integrated assessment model and workflows for GCS leakage and containment decision making.

EY20	EY21	EY 2022	EY 2023	EY 2024	EY 2025	EY 2026

4 New Functionalities

4 Updates to NRAP-OPEN-IAM

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2 Case Studies

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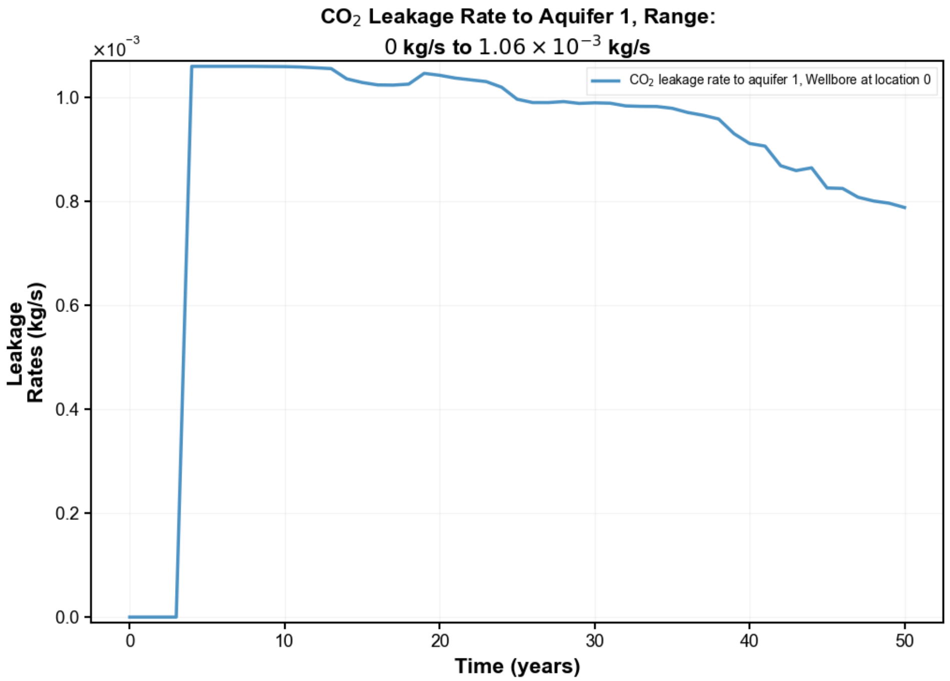
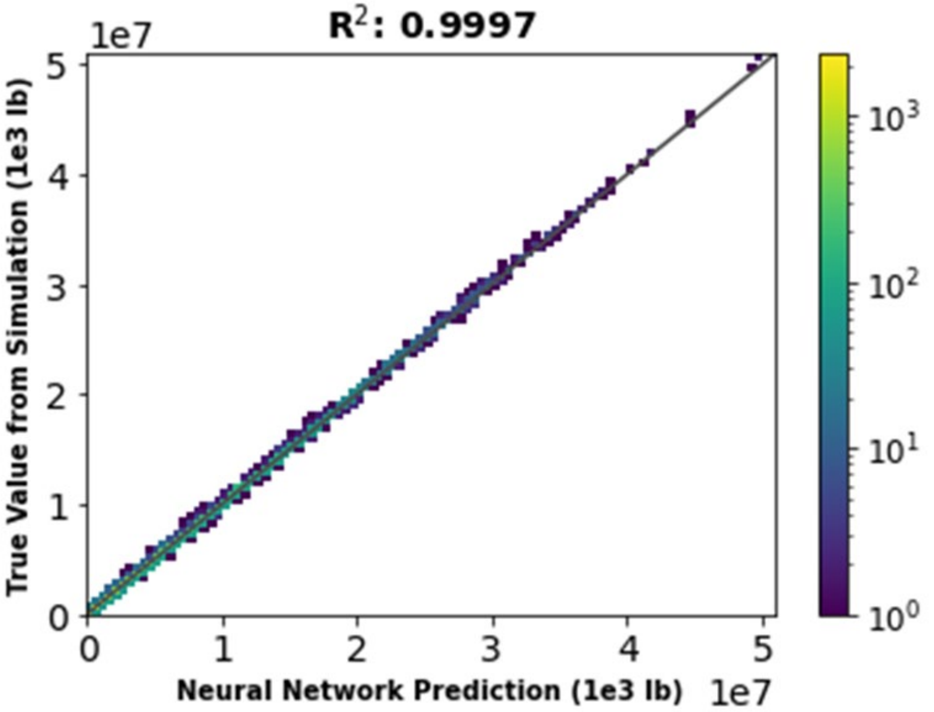
Updates to NRAP-Open-IAM (1) – Wellbore Leakage

- **Multisegmented Wellbore AI**: machine-learning wellbore leakage model with an improved performance.
- Wellbore Leakage Model for Hydrocarbon Fields.

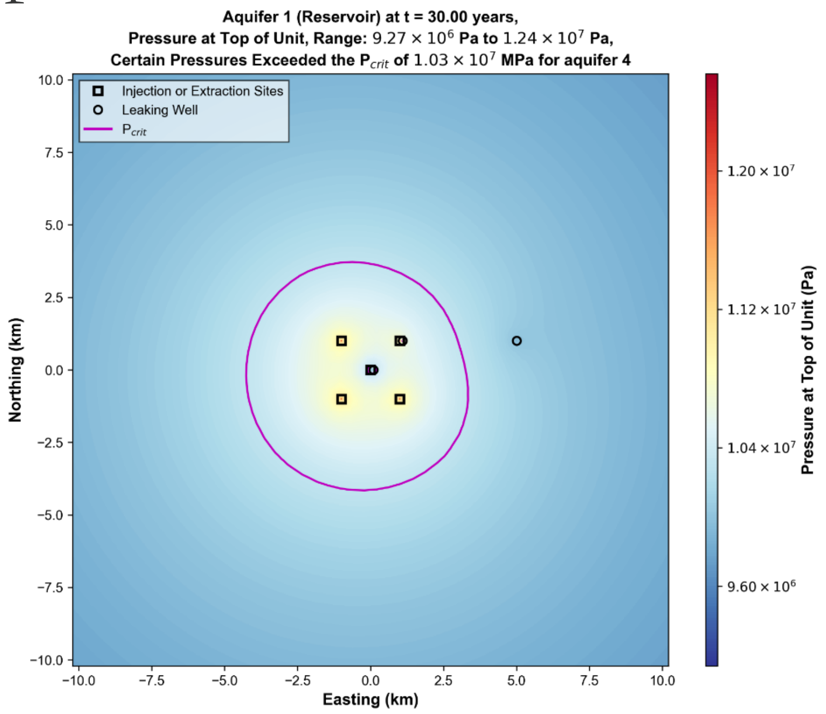


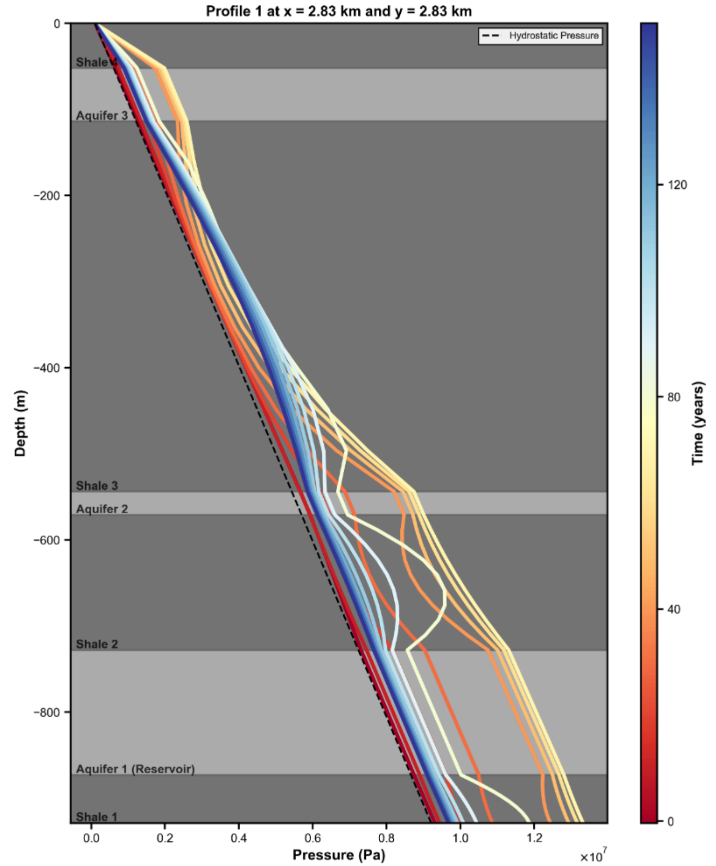


Updates to NRAP-Open-IAM (2) - SALSA

SALSA: flexible model capable of modeling the responses of reservoirs, other aquifers, aquitards, and wellbores to injection and/or extraction.

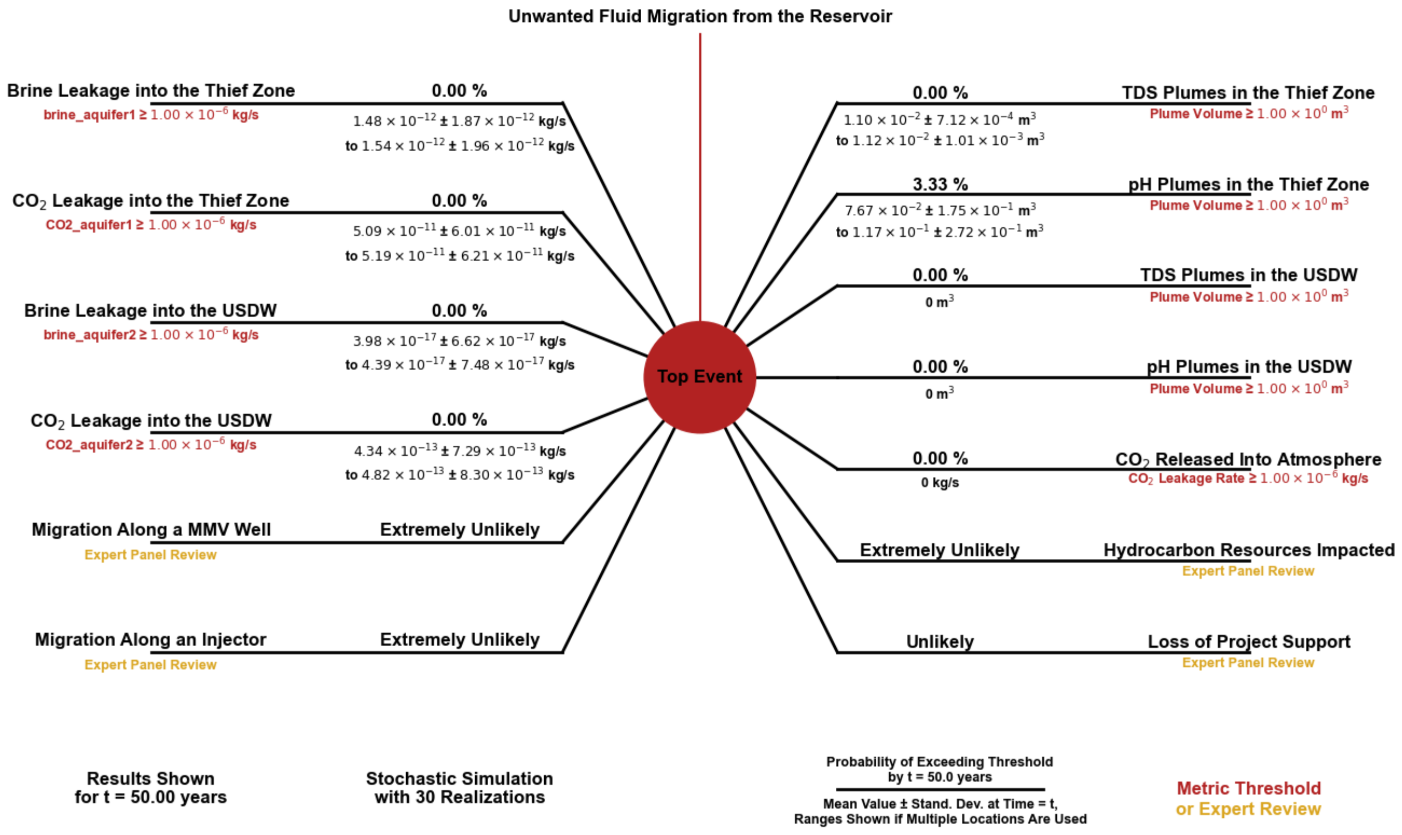
- SALSA produces:
  - Well leakage
  - Leakage across aquifer-aquitard interfaces
  - Hydraulic head and pressure in aquifers and aquitards





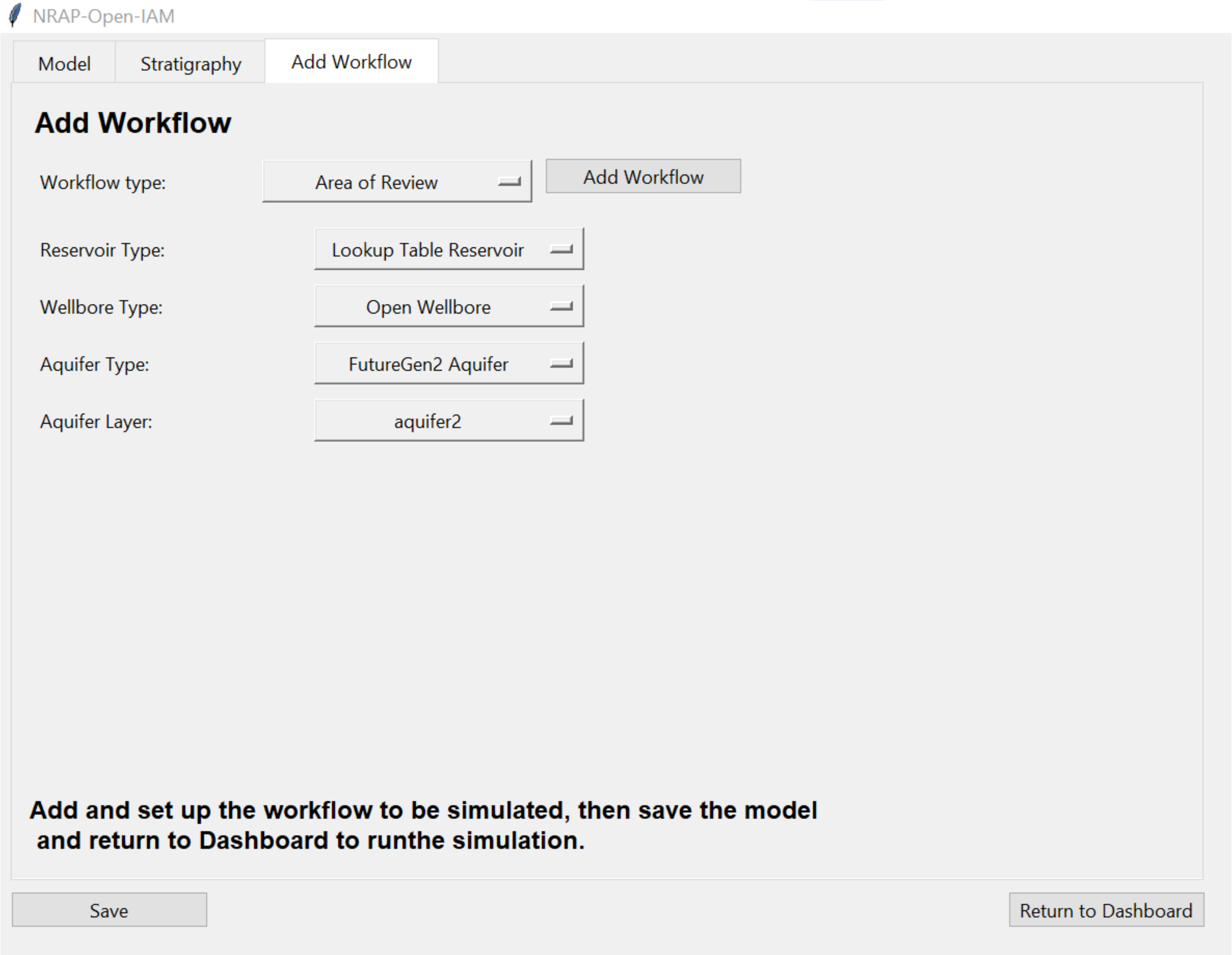
Updates to NRAP-Open-IAM (3) - Bowtie

Bowtie plot: risk assessment visualization tool that combines quantitative and qualitative metrics for a wholistic evaluation.



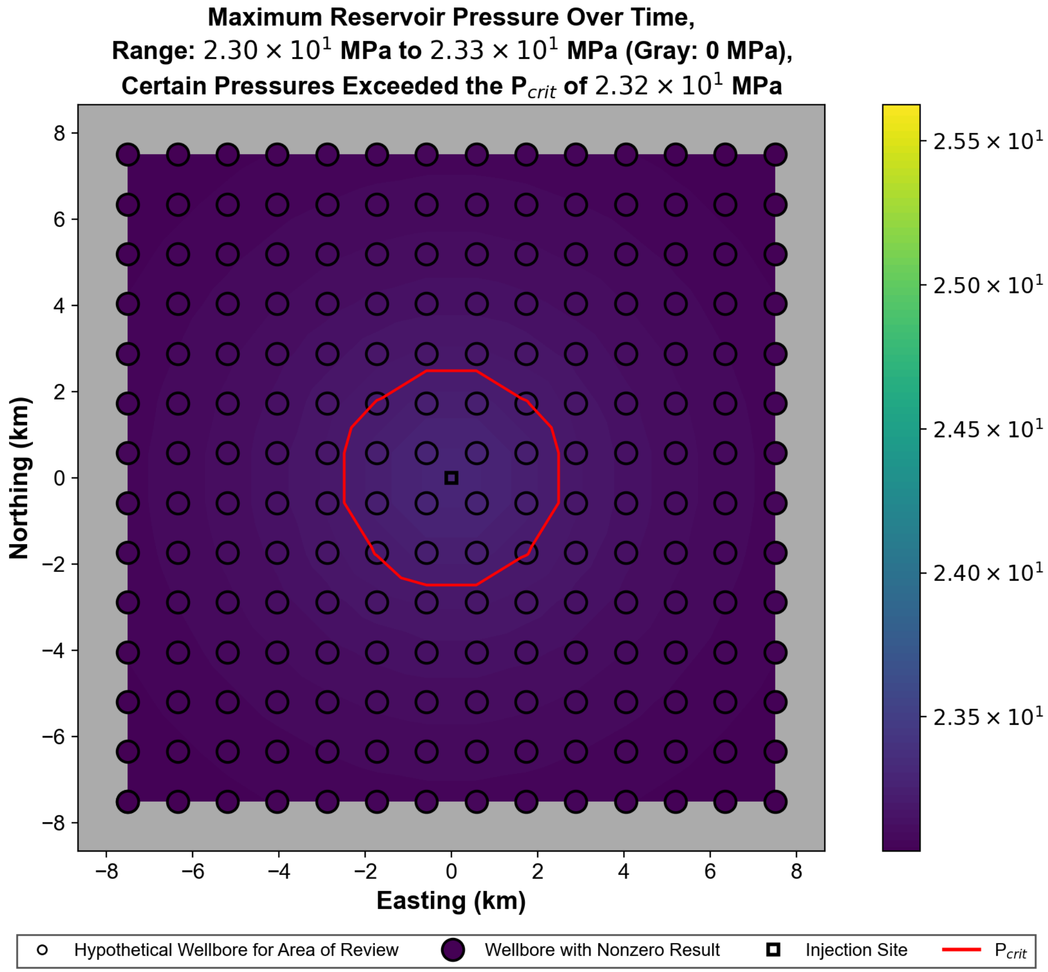
Updates to NRAP-Open-IAM (4) – Workflows

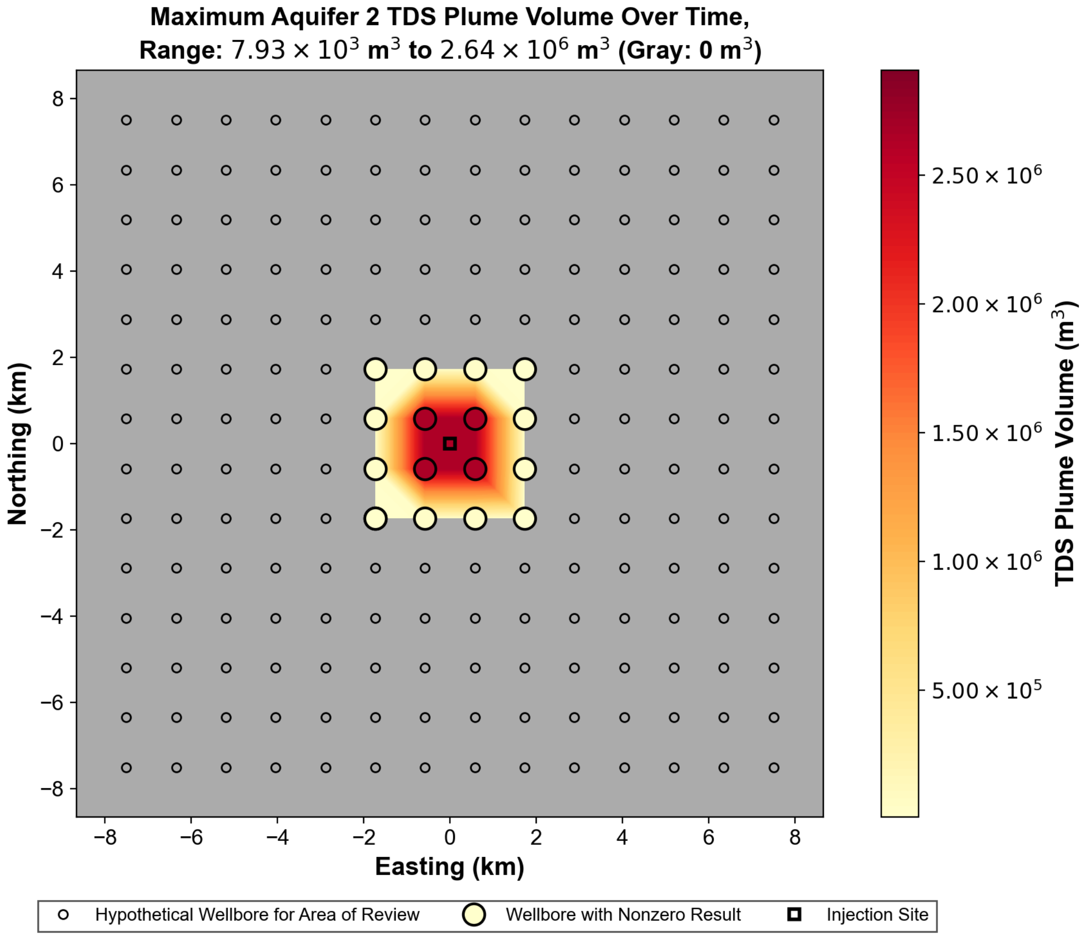
- **Workflows Integrated into Graphical User Interface:** Workflows are made to <u>streamline analyses that are frequently performed</u> for activities such as permit applications.
  - Area of review analysis
  - Time to first detection analysis



Area of Review Workflow

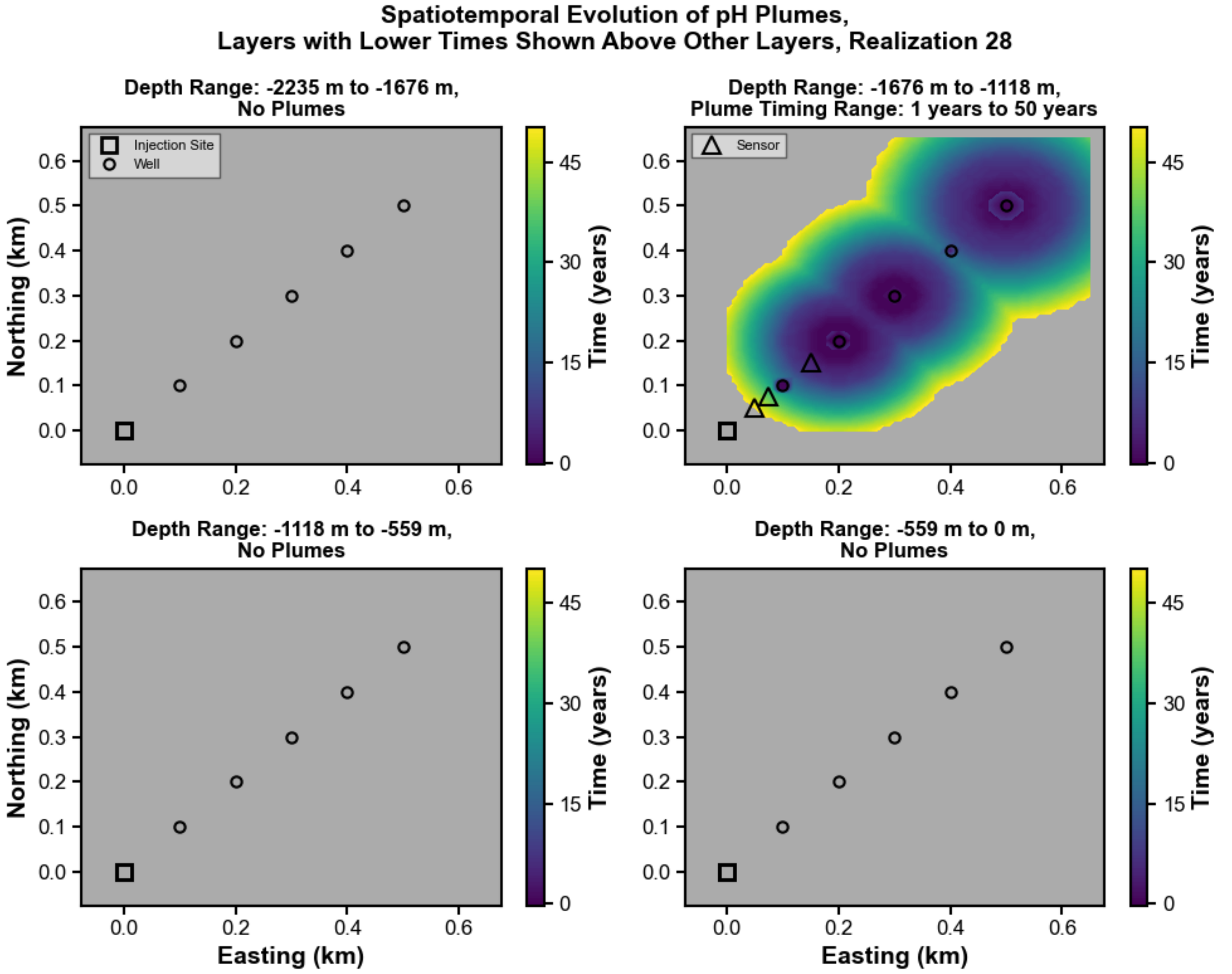
How far do potential impacts extend from the injection site(s)?

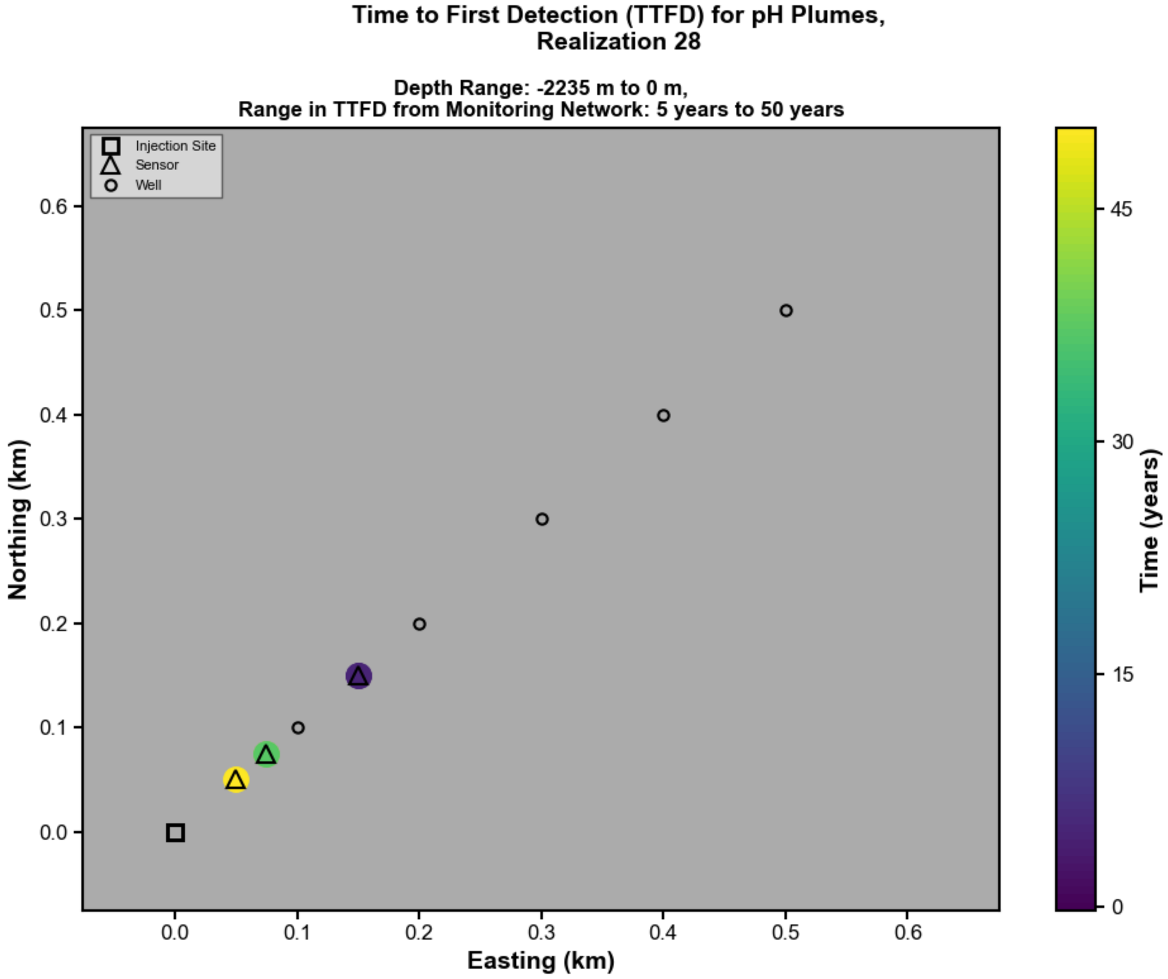




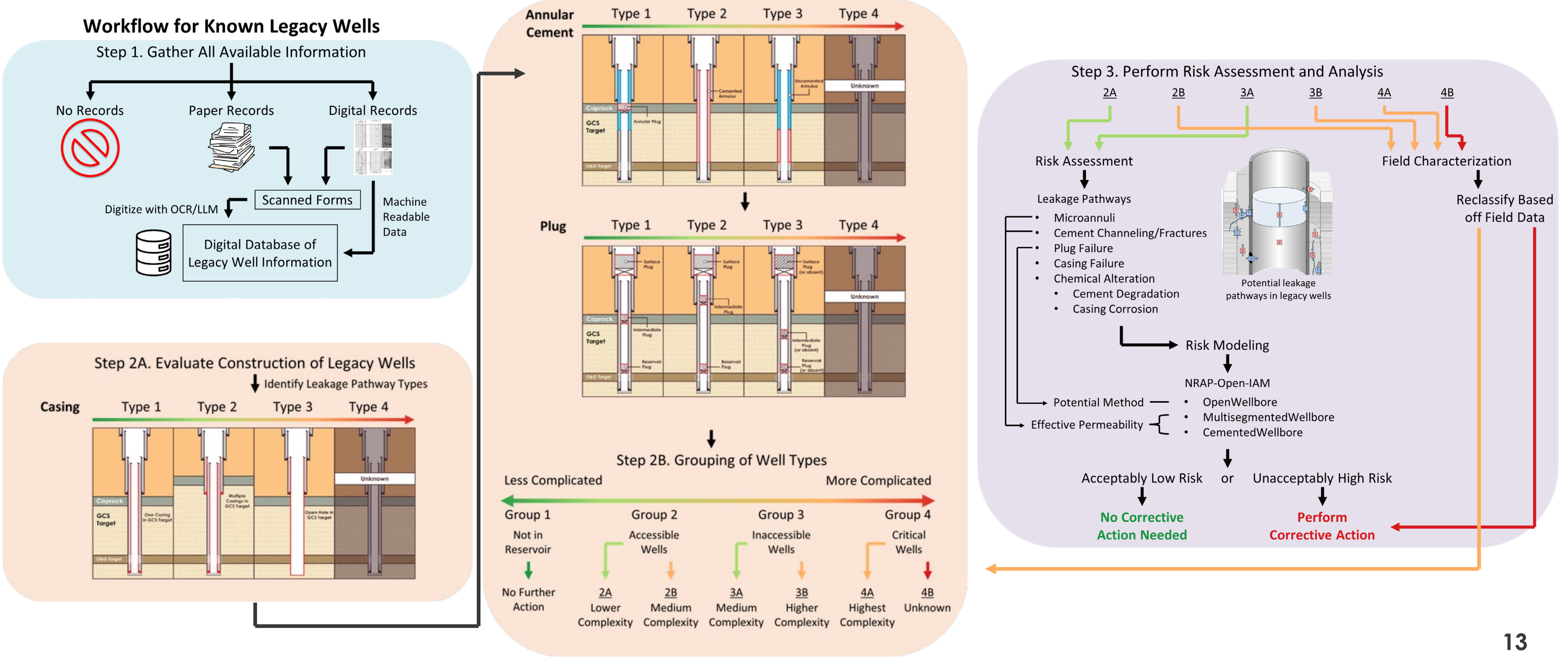
Time to First Detection Workflow

How do contaminant plumes spread through aquifers? When would they reach monitoring wells?



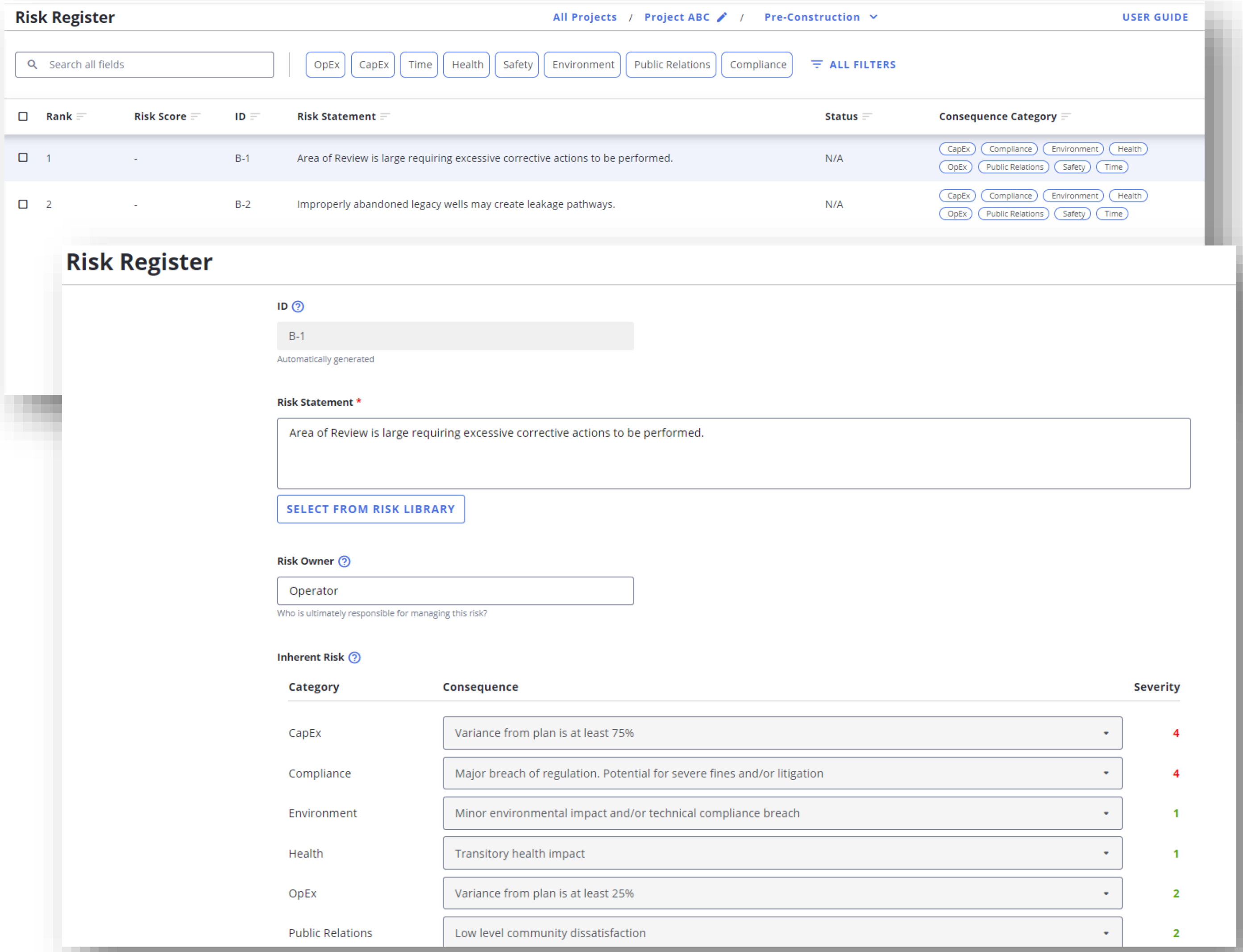


Stakeholder needs (1): Legacy Wells Characterization Workflow



Stakeholder needs (2): NRAP Risk Register Tool

- A new tool will allow users to develop a Risk Register for their carbon storage site(s). The tool contains a library of risks commonly found at carbon storage sites but also allows users to efficiently input additional risks pertinent to their site(s).
- The risk library was externally peer-reviewed by carbon storage experts and suggested edits were considered and implemented where appropriate.
- A prototype available for demonstration purposes.

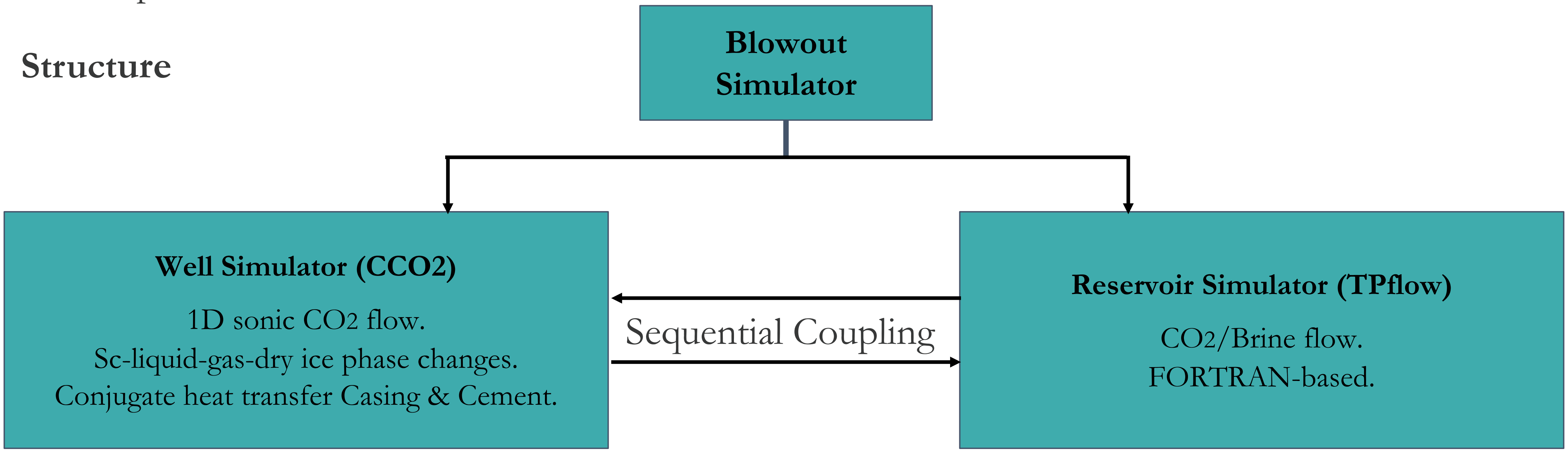


New Functionality (1): Physics-Based CO_2 Well Blowout Model

Motivations

- A physics-based model to estimate **CO_2 leaked** in the event of **catastrophic well failure** from an **insurance claims** point of view.
- To understand the **thermal impacts** of **CO_2 cooling** on casing and cement during dense-phase CO_2 decompression.

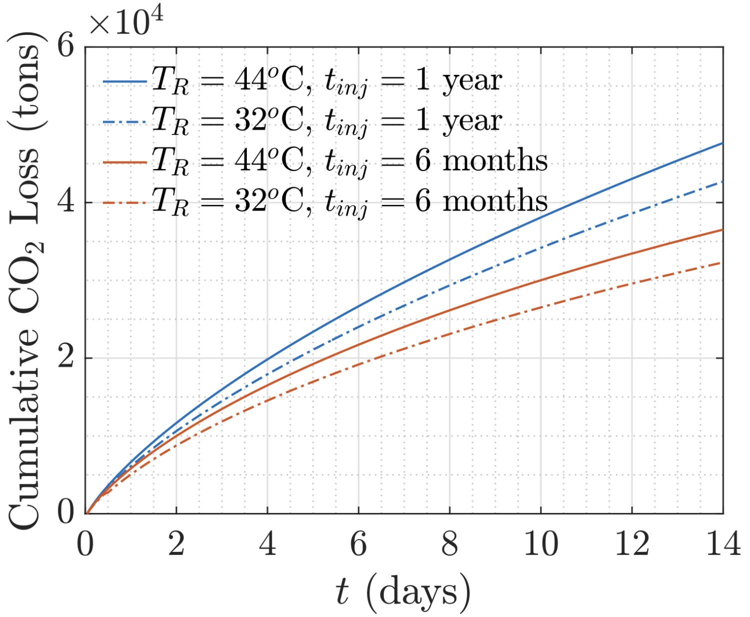
Structure



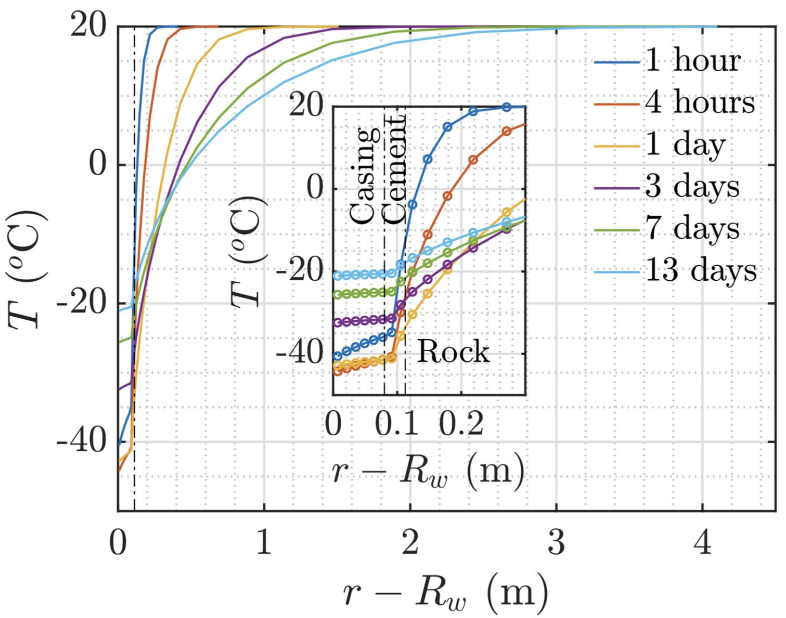
Demo Scenario: Injection Well Blowout

- **14 day blowout** of a **1500m** deep well after **1 year** and **6 months** of injection into a **30 m** thick reservoir of permeability **100 mD**.

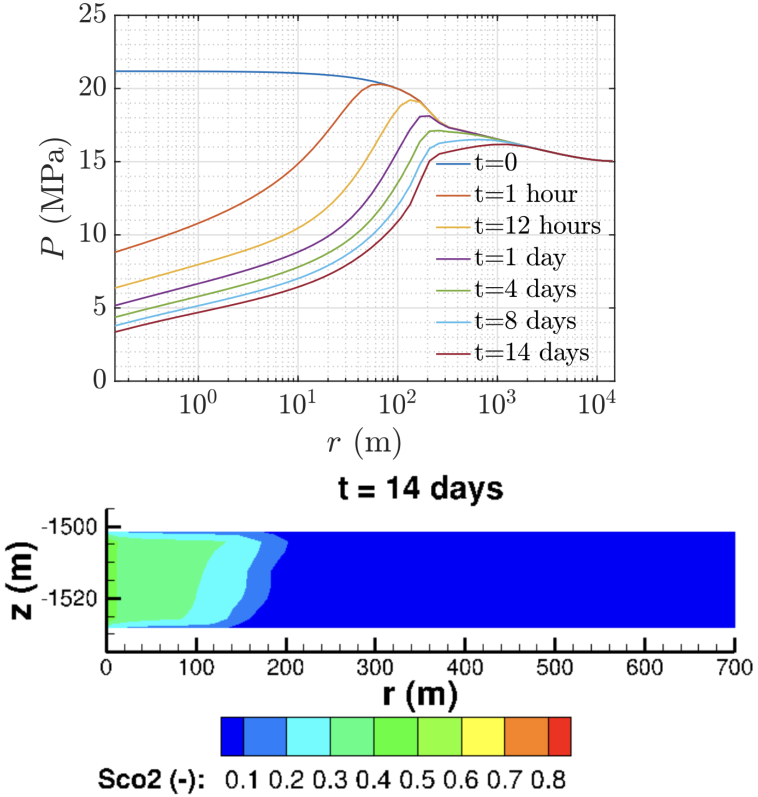
Cumulative Leakage



Casing & Cement Temperature



Reservoir Pressure & Saturation



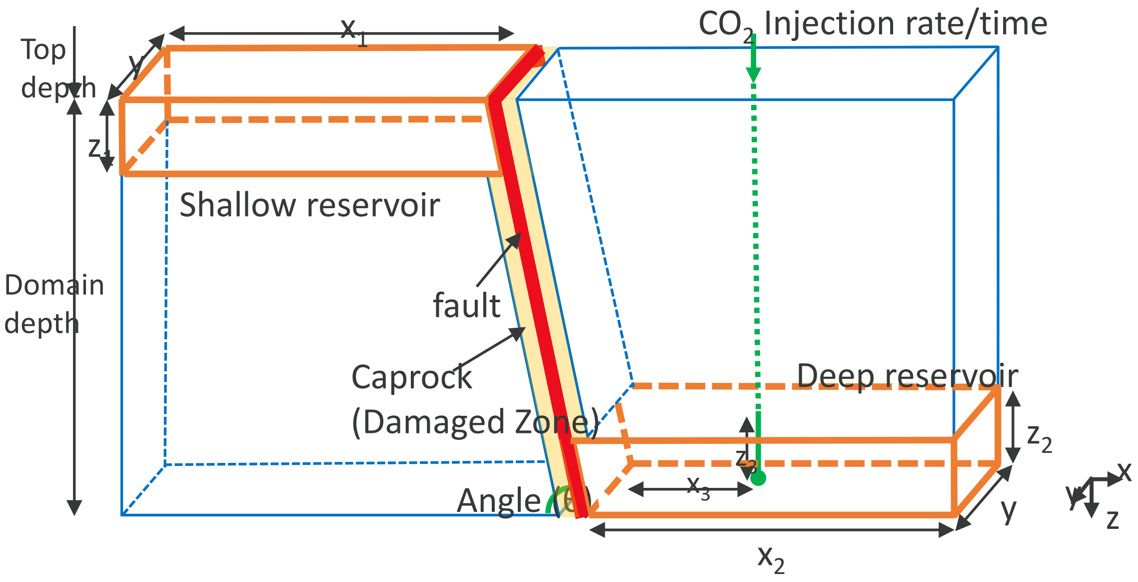
New Functionality (2): CO_2 Fault Leakage ROM Model

- Challenge:

  Current Fault leakage models are limited.

- Solutions:

  New ML model with a wide range of parameters (+20).



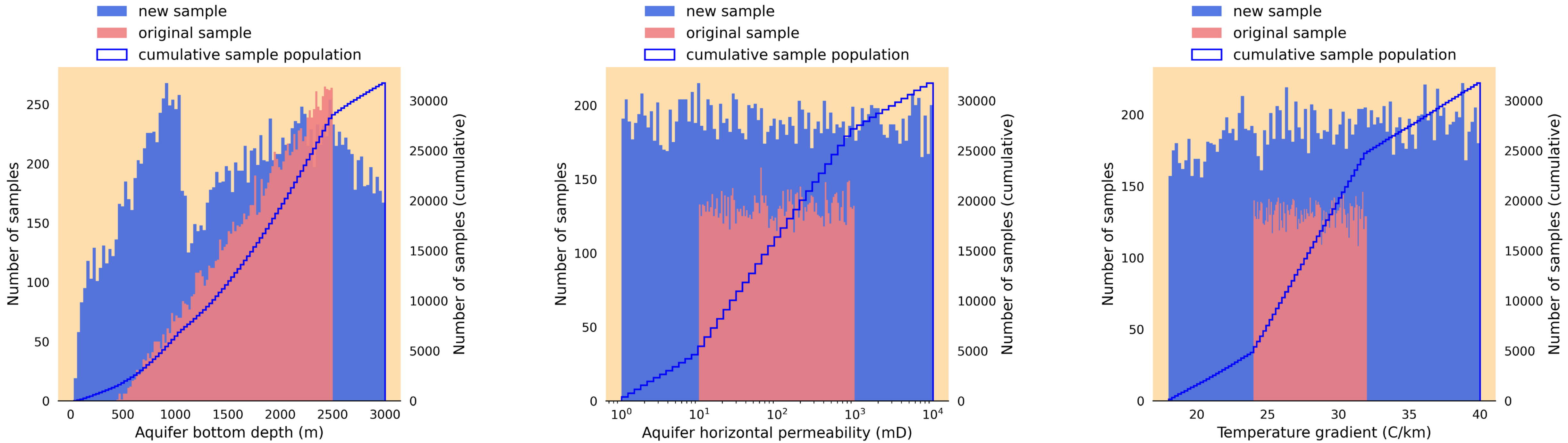
	Min	Max	
Angle_degrees	20 / 95	85 / 160	degree
top_depth	1000	3000	ft
domain_depth	1000	3000	ft
reservoir_deep_X_2	1000	4000	dt
reservoir_deep_Z_2	5	40	% of Domain depth
reservoir_shallow_X_1	1000	4000	ft
reservoir_shallow_Z_1	5	40	% of Domain depth
reservoir_y	1000	2000	ft
perm_fault	20	100	mDarcy
poro_fault	5	20	%
thick_fault	2	10	% of Domain depth
perm_caprock	1	5	mDarcy
poro_caprock	0.5	1	%
thick_caprock	3	20	% of Domain depth
perm_deep_reservoir	20	100	mDarcy
poro_deep_reservoir	5	20	%
perm_shallow_reservoir	20	100	mDarcy
poro_shallow_reservoir	5	20	%
injection_rate	1000	5000	Mscf/day
well_index_X_3	50	5000	(distance (x-axis) from fault)
injection_time	10	100	year

New Functionality (3): Multisegmented Wellbore Model

Expansion of Simulation Dataset

: To improve the applicability and robustness of the MSW-AI model for wellbore leakage analysis, we have expanded our simulation dataset:

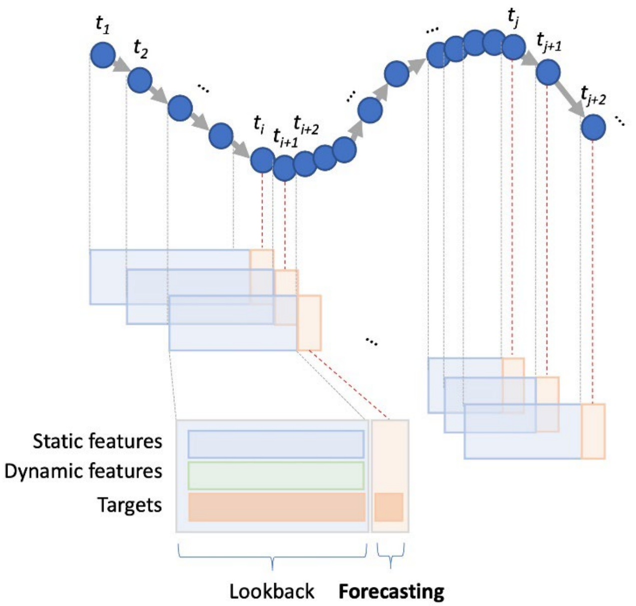
- Original dataset: ~13,000 realizations
- Enhanced dataset: ~(13,000 + **15,000**) realizations

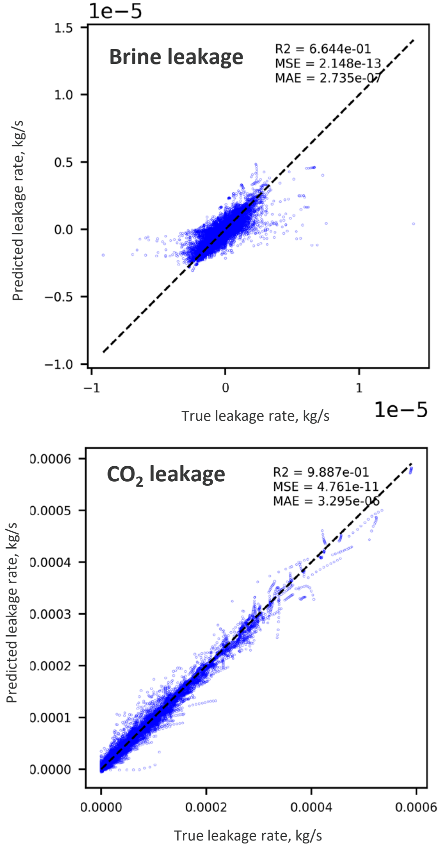


Multisegmented Wellbore Model – AI Model Development

Data Processing for AI Model

: The previous MSW model relied solely on data from the immediately preceding step for predictions. In our new version, we are evaluating whether incorporating information from multiple previous steps enhances prediction accuracy.

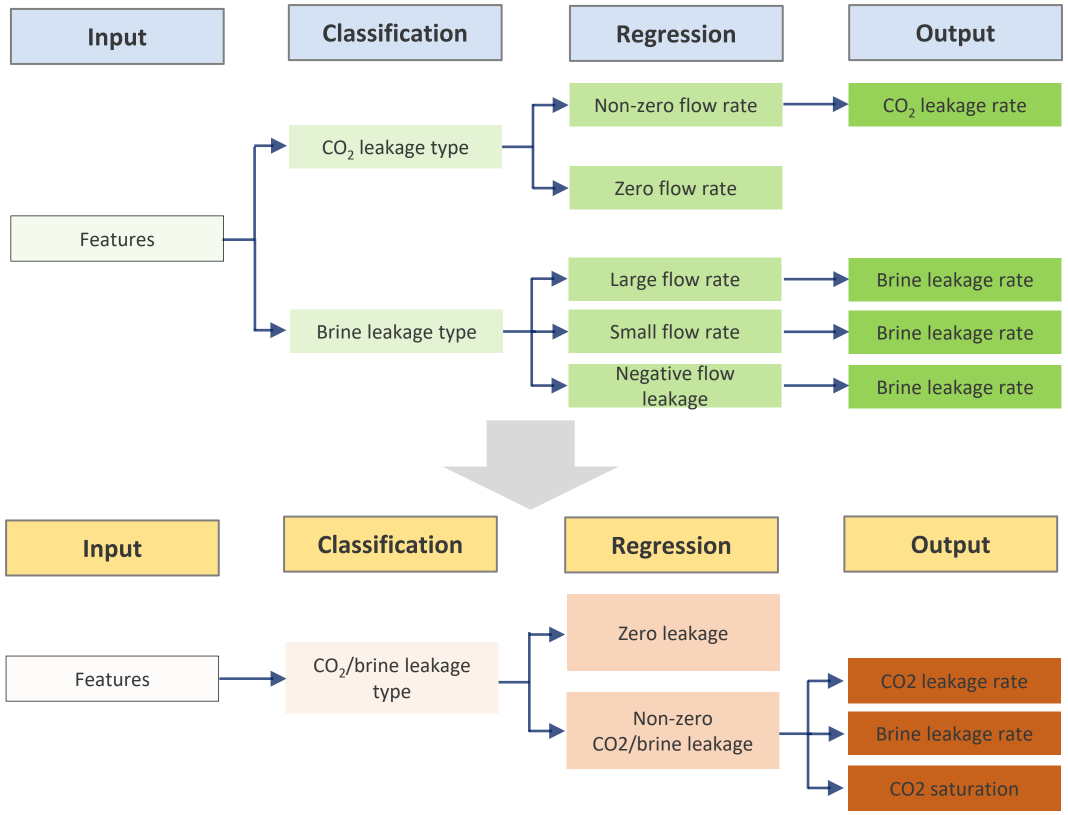




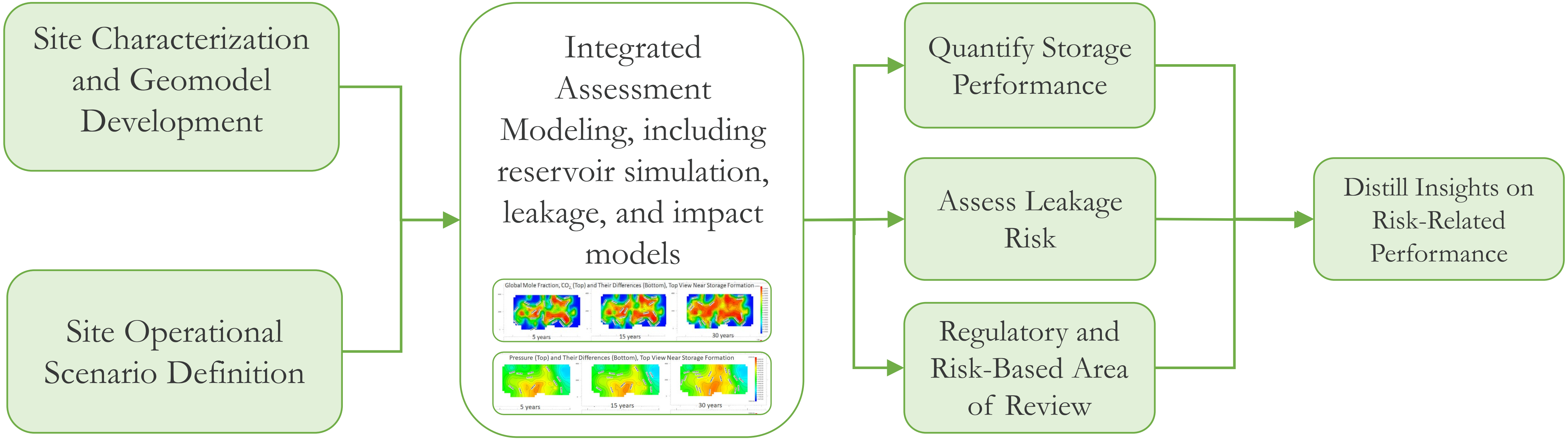
(preliminary results with the existing data set)

MSW Model Structure

: Previously, the MSW model was developed with 7 component models to improve the prediction accuracy, and it was streamlined into 2 models for a new version.



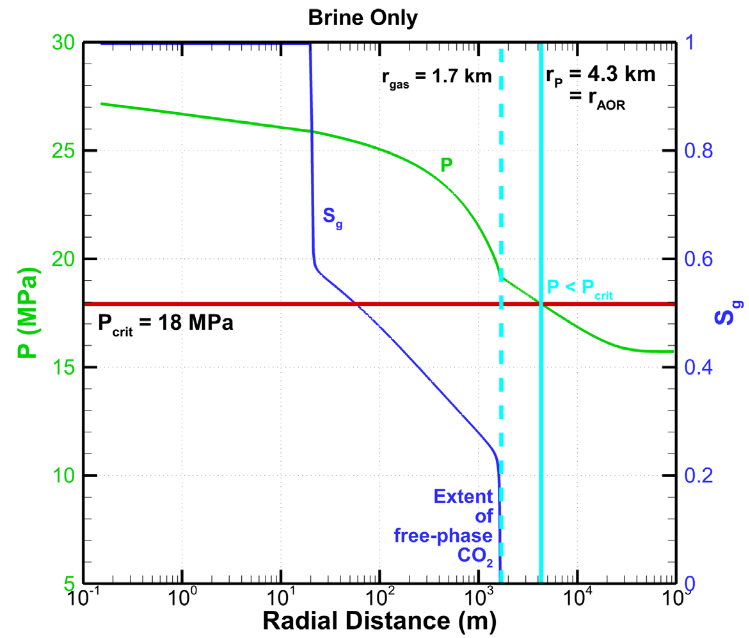
Case Study 1: CO_2 Storage in Hydrocarbon Formations Transitioning from EOR



The Effect of Hydrocarbons on the AoR

Influence of reservoir settings (geology, fluid composition, environmental variables, operational parameters, etc.) on the AOR of GCS in saline aquifer (CO_2 + brine) is well understood. Repurposing CO_2-EOR fields to dedicated GCS poses a new challenge—How is AOR impacted by previous CO_2 operations in oil and gas fields?

- 1D Radial, Three-phase, Five-component Reservoir Model
  - ✓ Constant CO_2 injection rate: 30-year injection, 50-year post injection
  - ✓ Initial conditions of components after CO_2-EOR:
    - ○ < 5 km of injection well (2000 scenarios)
      - ✓ S_w ranges between 0.2 – 0.8
      - ✓ X_{CO2} ranges between 0.05 – 0.3
      - ✓ X_{CH4} ranges between 0.05 – 0.3
      - ✓ X_{C4H10} ranges between 0.1 – 0.3
      - ✓ X_{C10H22} ranges between 0.15 – 0.75
    - ○ > 5 km: no dissolved components



Determination of the Area of Review (AOR) Extent

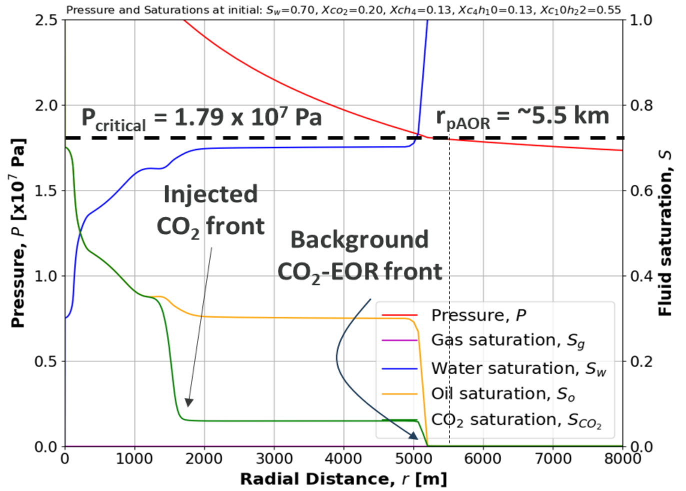
EPA Guidance on AOR Modeling: Larger value of:

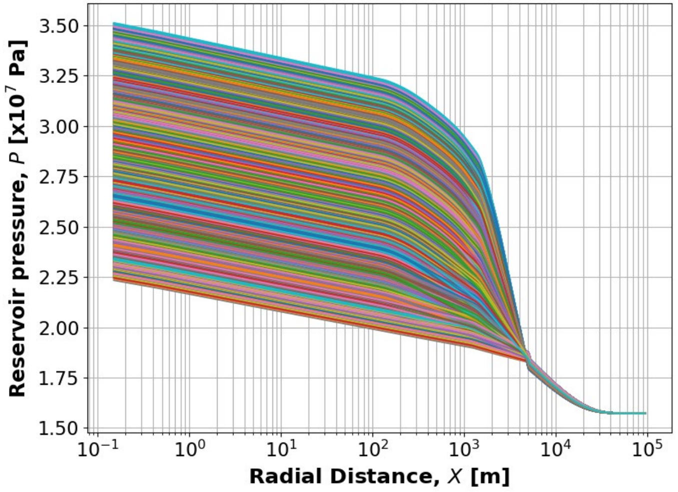
- AOR where $P_{\text{reservoir}} > P_{\text{critical}}$

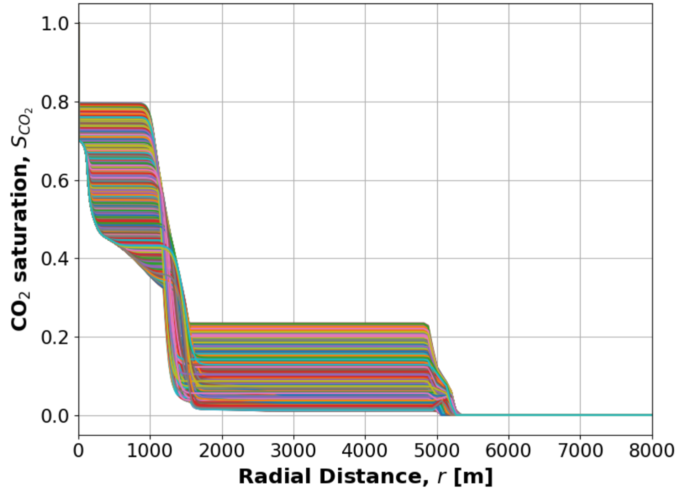
Where P_{critical} = pressure required to lift fluid to the deepest overlying USDW

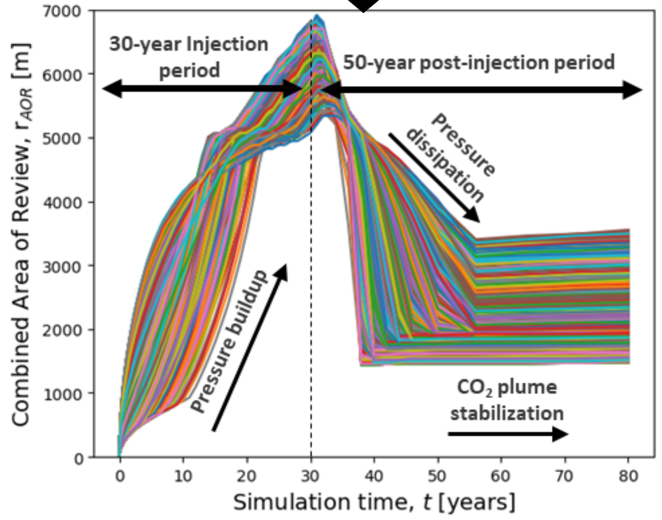
$$P_{\text{critical}} = P_u + \rho_b * g * (Z_u - Z_{res})$$

- AOR where $S_{CO2} > S_{CO2,\text{critical}}$



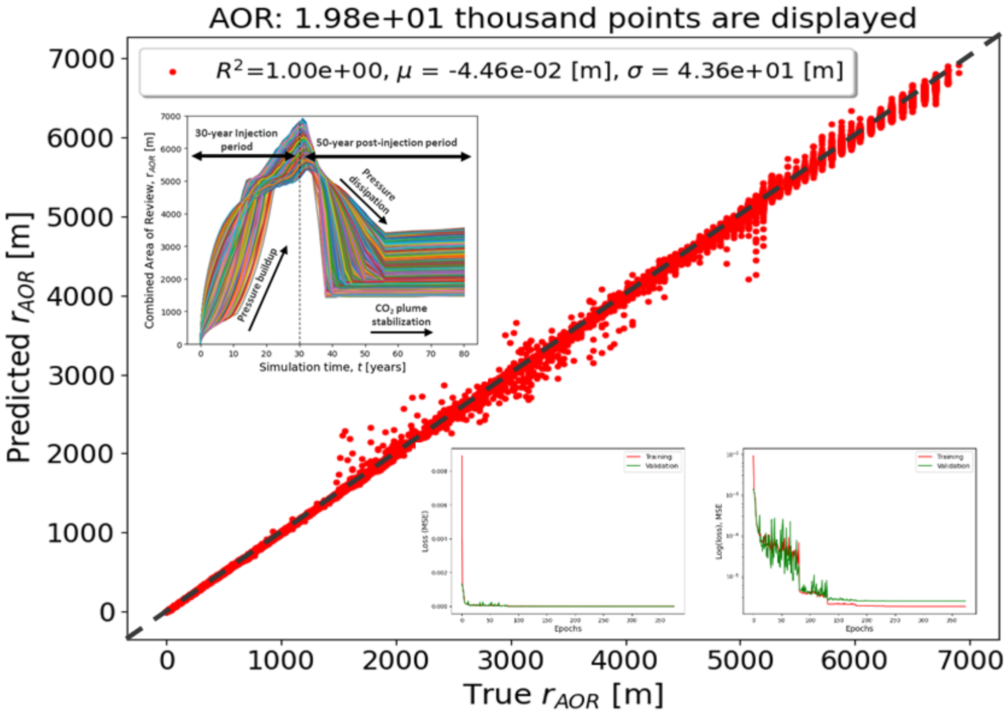


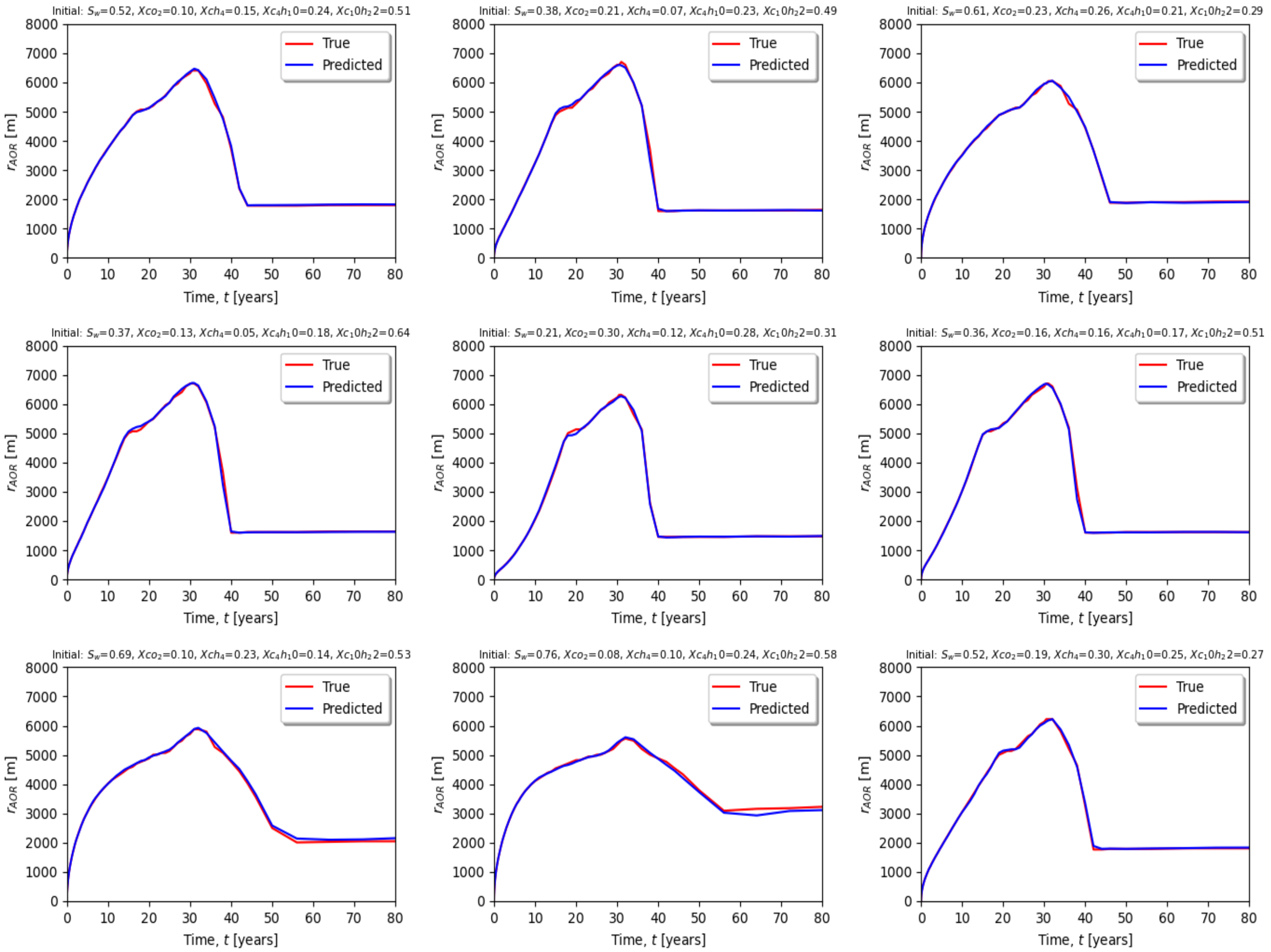




Machine-Learning-base Reduced-Order Model (ROM) for AOR Extent

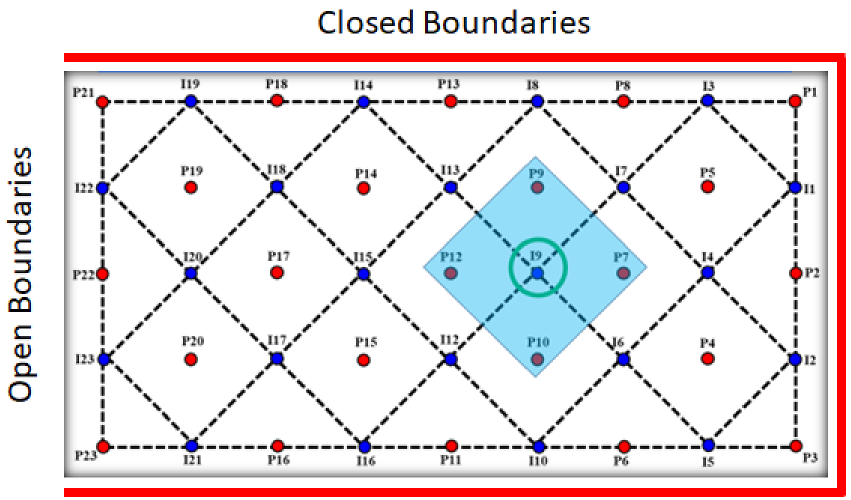
ROM developed for the combined AOR extent successfully represents combined AOR behavior during the pressure buildup, plume development (which has been masked by pressure), pressure dissipation, and plume stabilization periods.

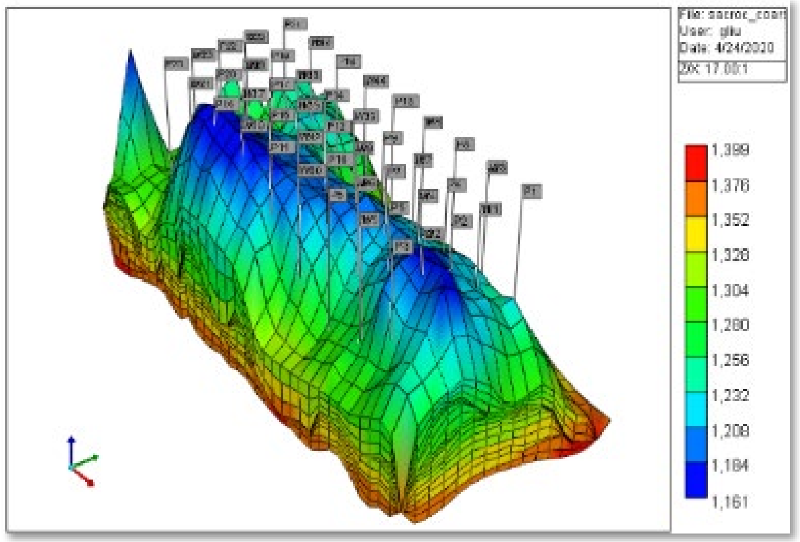




Main Insights from Reservoir Simulation

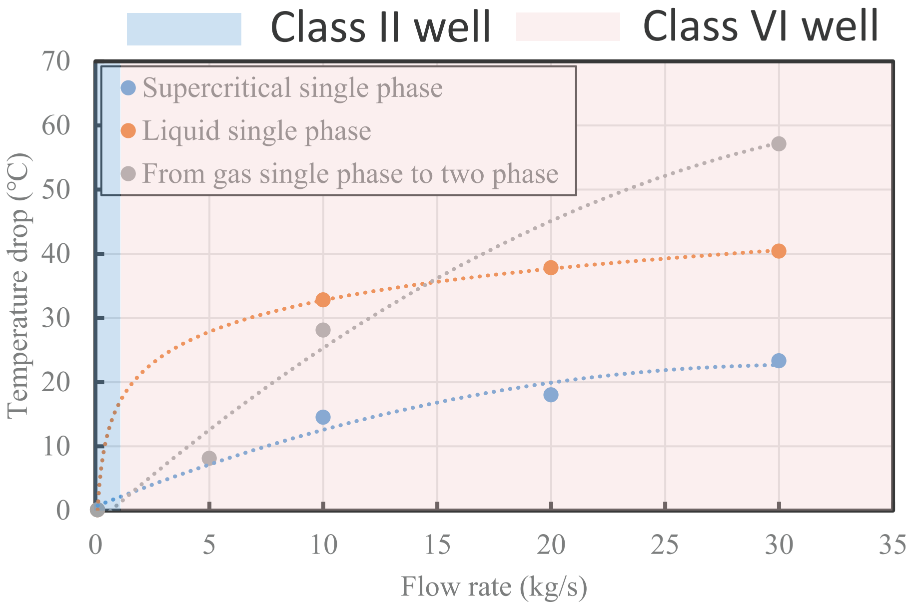
- ❑ Explored reservoir response for various scenarios that can support stakeholder decision-making for Class II to Class VI transition.
- ❑ Designed scenarios for hydrocarbon and saline reservoirs comparisons and boundary condition impacts
- ❑ Preliminary Results and considerations for risk assessment
  - ✓ The union of the CO_2 plume and AOR is the primary consideration based on the critical pressure calculation and mapping
  - ✓ Reservoir depletion status.
  - ✓ Model domain coverage may impact the AOR, especially for the saline case.
  - ✓ Boundary conditions impact of the AOR for such structure as a secondary consideration

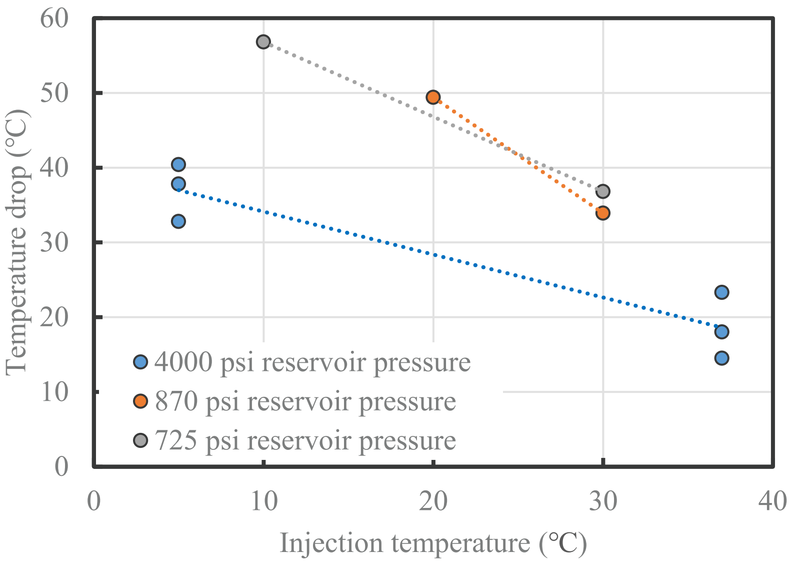


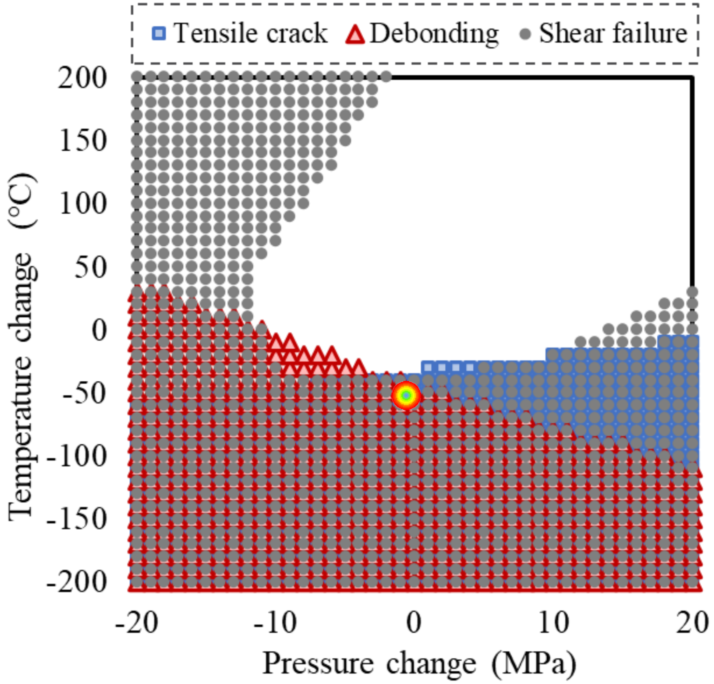


New Functionality (4): Wellbore integrity for Class II to Class VI

- Injection rates for Class II wells range from 0.01 to 1 kg/s, while Class VI wells reach up to 30 kg/s. High injection rates lead to significant wellbore cooling, inducing wellbore failures.
- The worst scenario is injecting CO_2 rapidly into depleted reservoirs during winter seasons.

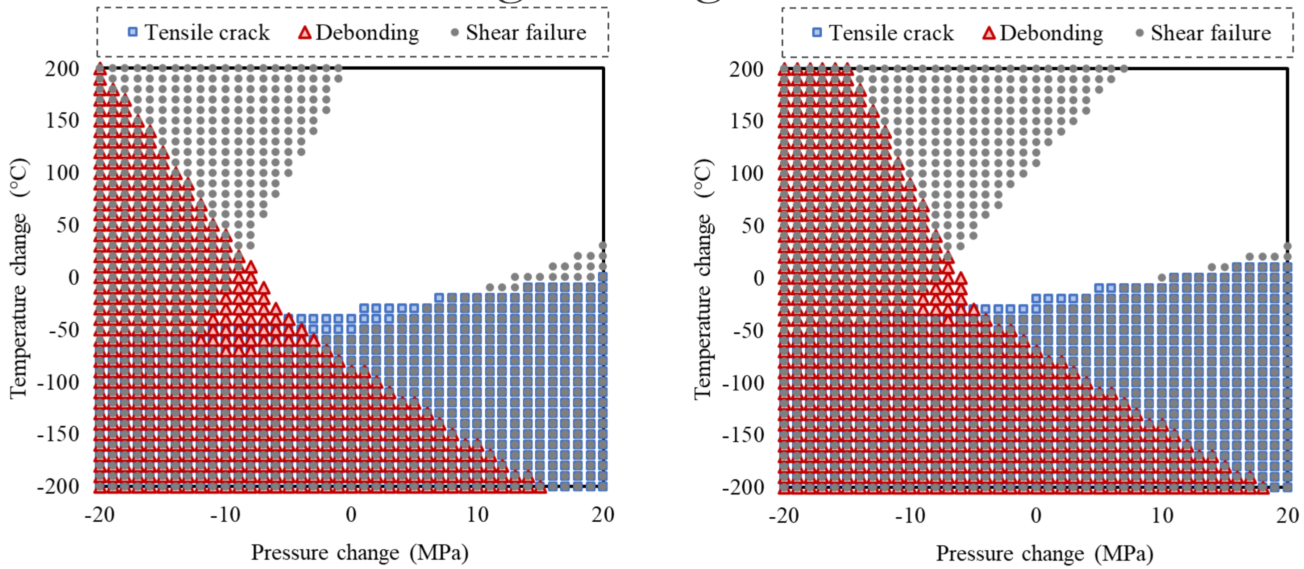






Wellbore Integrity for Transitioning Class II to Class VI

- How the material degradation affects cement integrity, how do leakage pathways get initiated and grow, what is the corresponding leakage rate, and do such leakage rates present a risk?
- CO_2 flow across microannulus might expand its fracture size, and the dynamic CO_2 injection and problematic cementing job will accelerate this process. The riskiest scenario is a combination of engineering, mechanical and chemical alterations to the cement integrity.



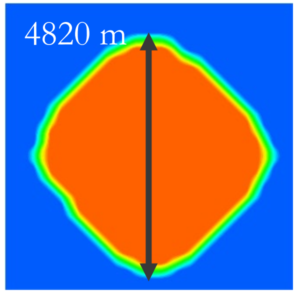
Before degradation After degradation

Cement becomes more brittle and easier to be damaged after degradation

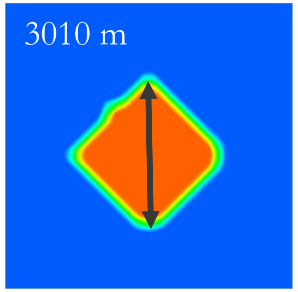
Case Study 2: Acid Gas Disposal - Reservoir Type

Gas Plume

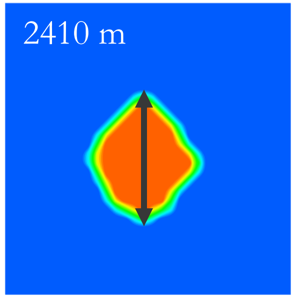
Depleted Gas Field

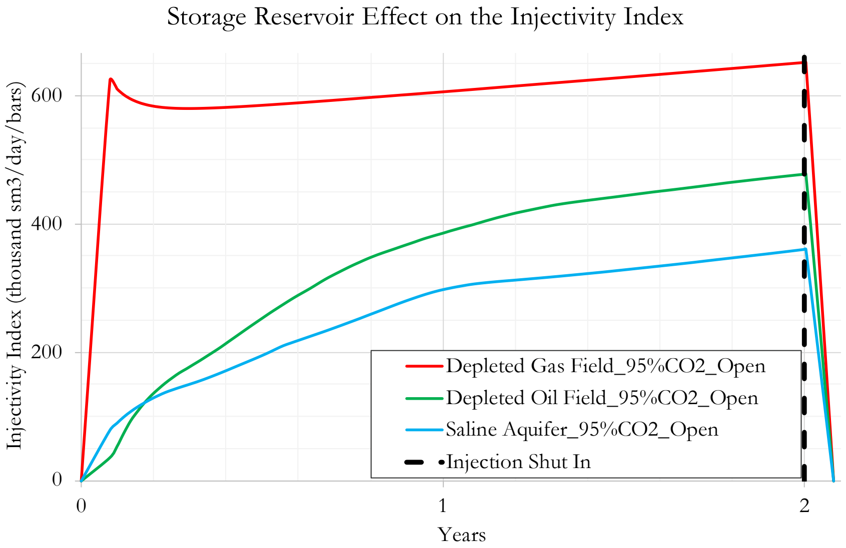


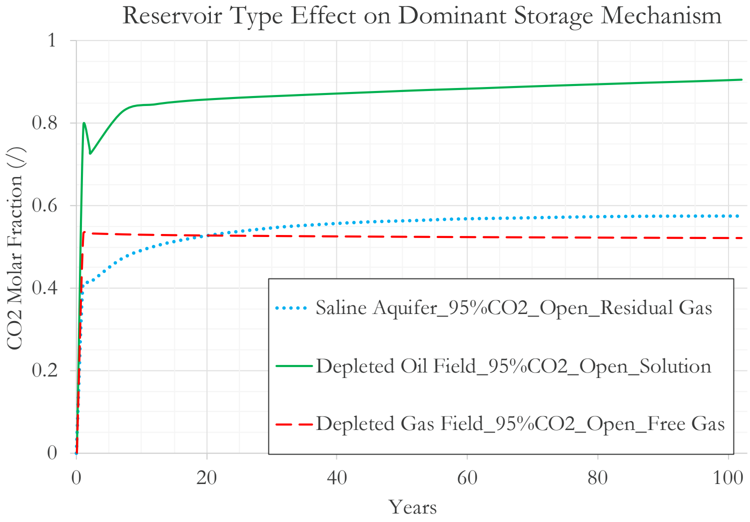
Depleted Oil Field



Saline Aquifer



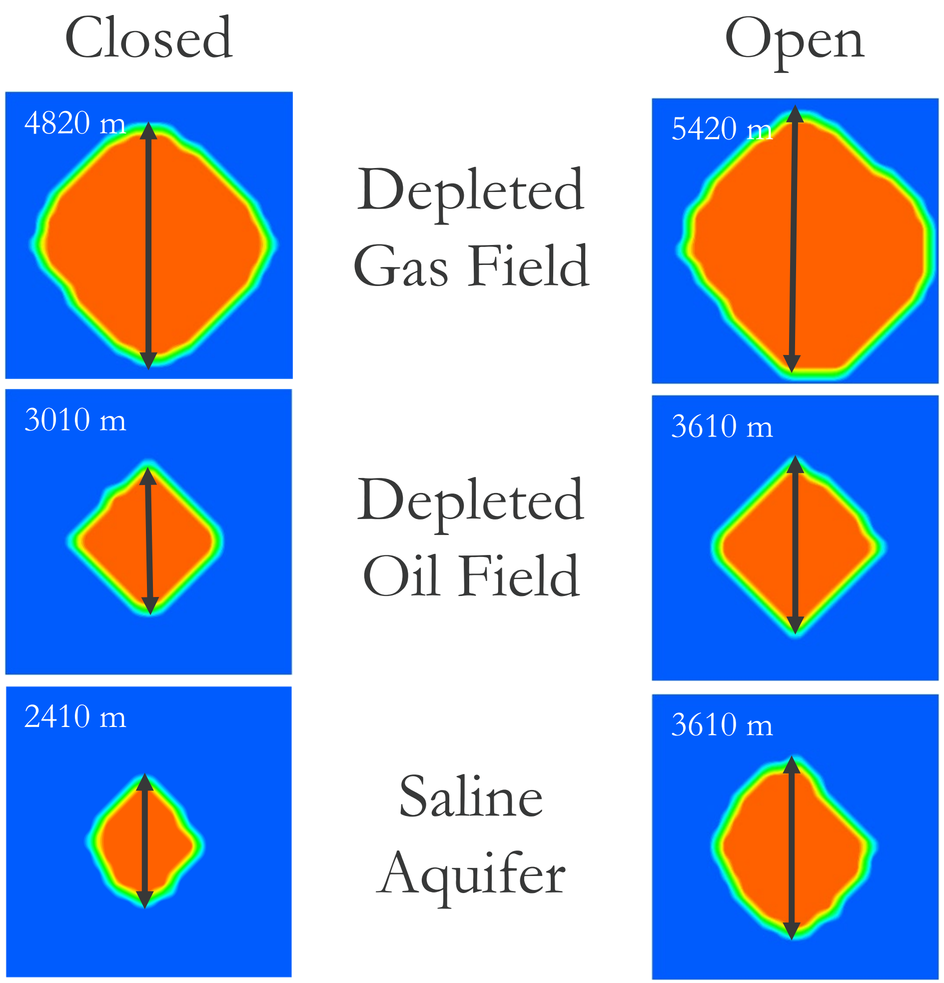


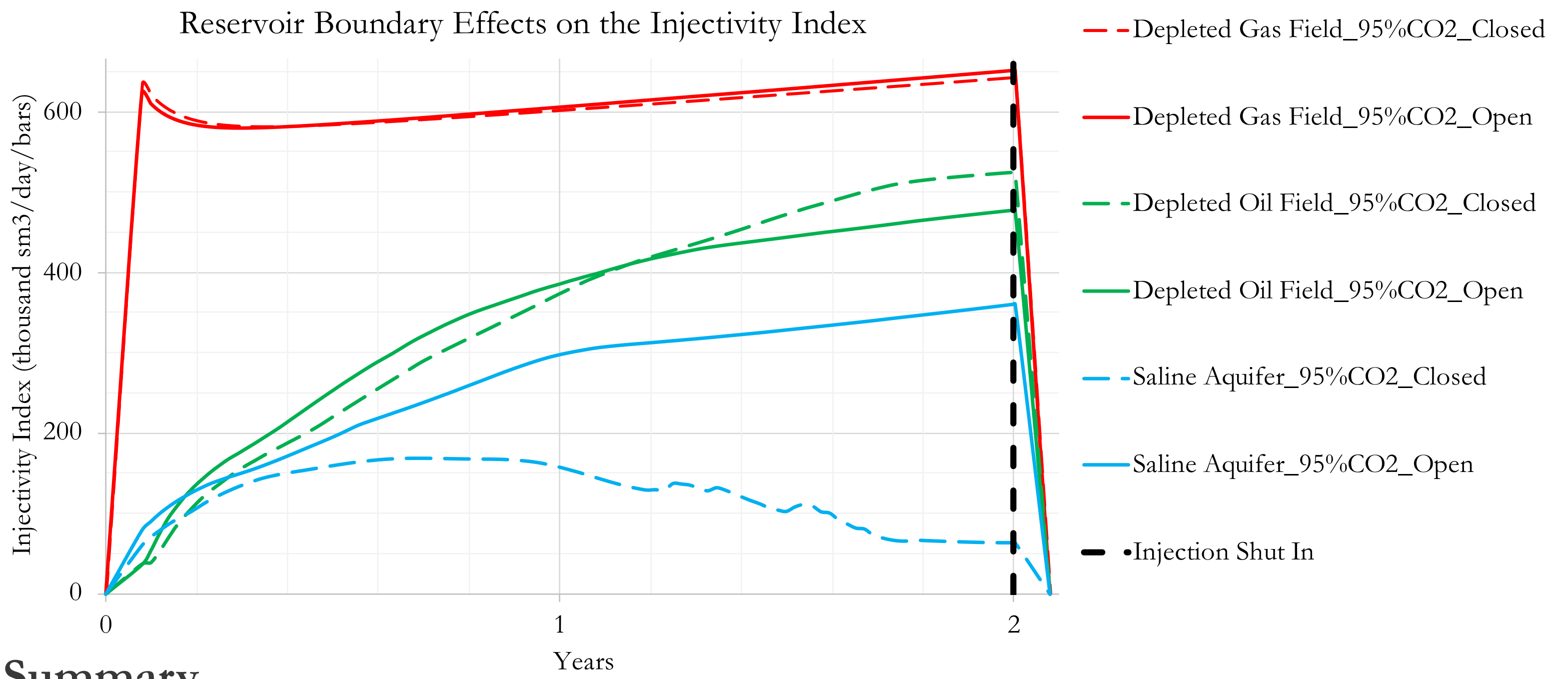


Summary

- The different types of storage reservoirs affect the size of the plume, the injectivity index, and the storage mechanisms substantially
- The dominant storage mechanism was affected the most by the type of storage reservoir where 80 to 90% of the injected gas was trapped in solution in the depleted oil fields, and 50 to 60% was trapped as residual gas in the saline aquifer while around 55% stayed as free mobile gas in the depleted gas reservoir

Reservoir Boundary Effects



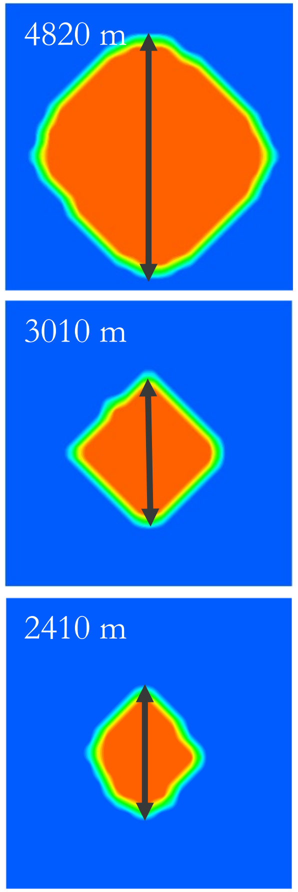


Summary

- Open Boundary conditions increased the size of the gas plume regardless of the reservoir type or injection composition
- Boundary Type effect on injectivity index is most important in saline aquifers and negligible in depleted gas fields
- With longer injection times, an open boundary favors higher storage capacity in depleted oil fields

Area of Review (AoR)

Gas Plume



Depleted Gas Field

Depleted Oil Field

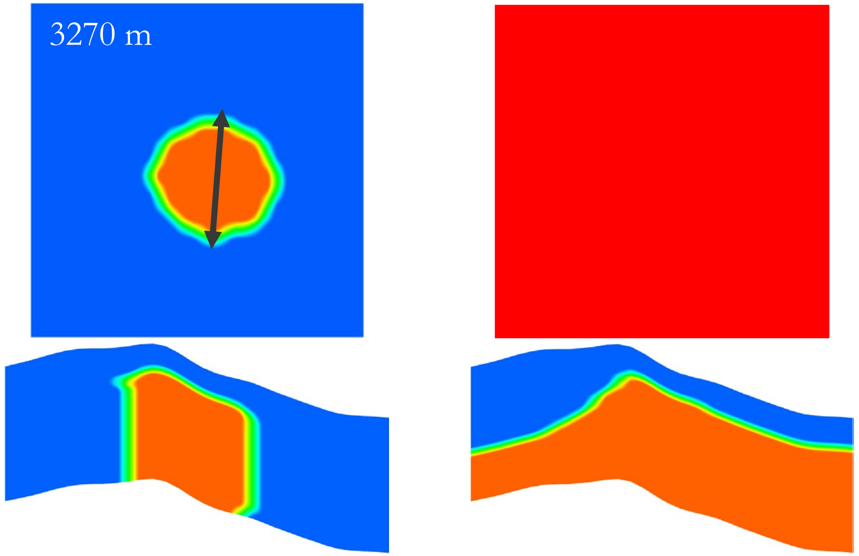
Saline Aquifer

Critical Pressure

It is recommended to incorporate hydrostatic pressure corrections across the thickness of the reservoir when calculating the AoR critical pressure front

With

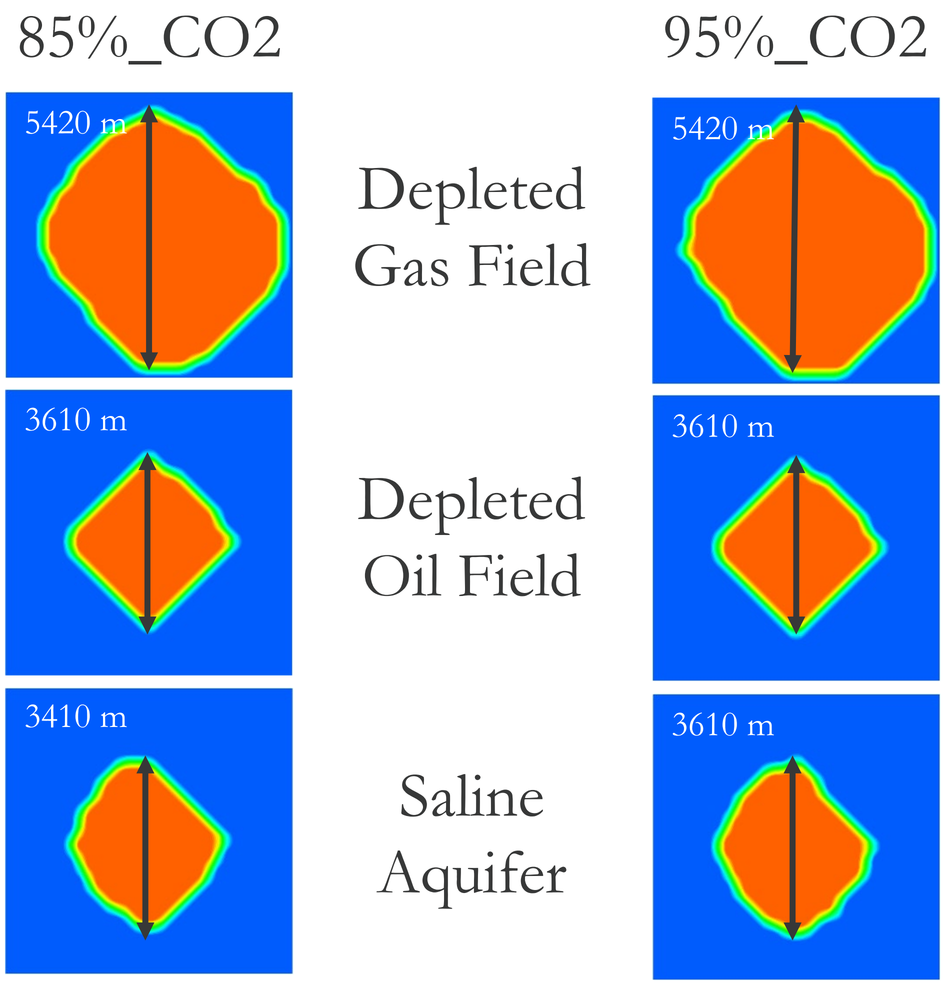
Without

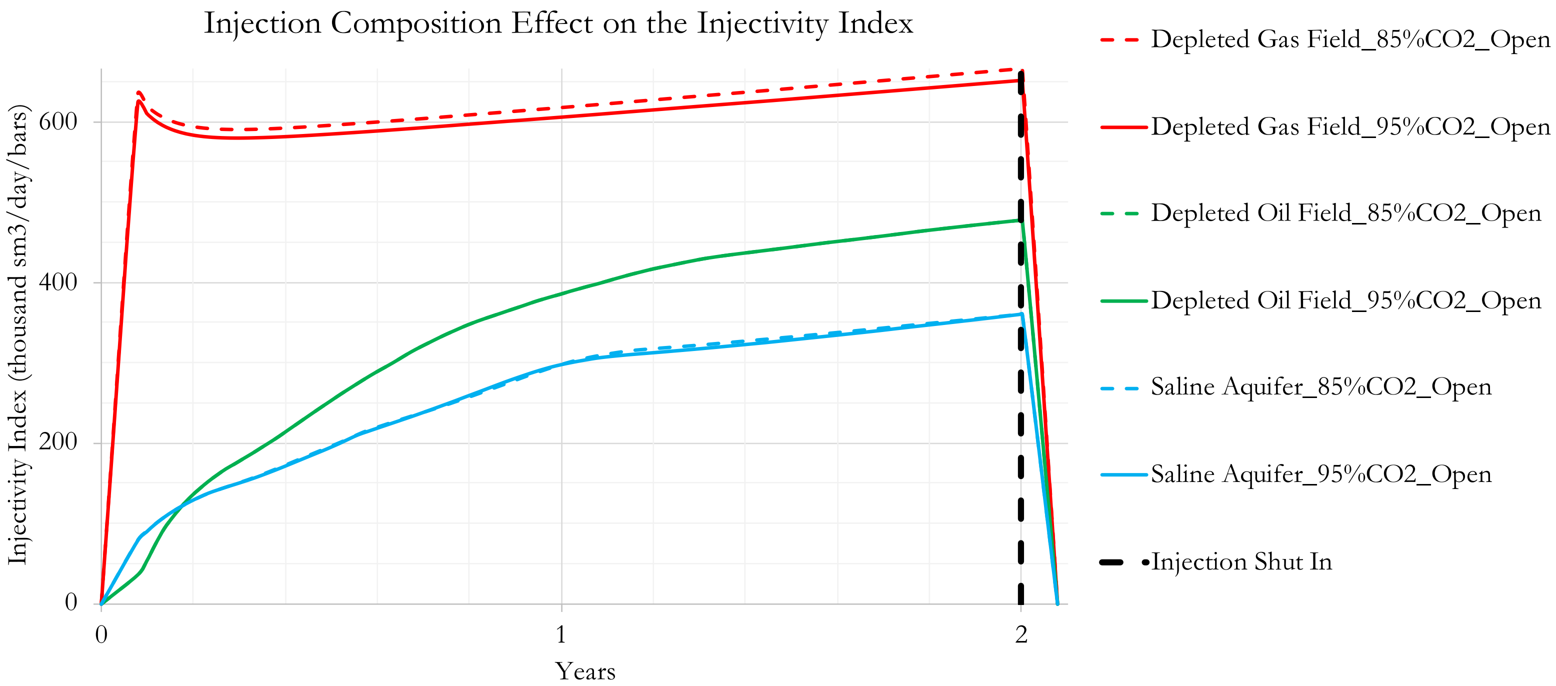


Summary

- The extent of the AoR in depleted oil and gas fields is usually decided by the gas plume extent
- In saline aquifer, the boundary of the reservoir plays a crucial role in deciding whether the extent of AoR is dictated by the pressure front or the gas saturation front

Injection Composition Effects





Summary

- Injected gas composition effects are minimal on the size of the plume, the injectivity index as well as the storage mechanisms regardless of the type of the storage reservoir or the boundary condition

Task 2: Addressing Stakeholder Needs to Accelerate Geologic Storage Projects: Tools and Methods to Manage Subsurface Risks

2 Stakeholder needs

Objective To demonstr[...]utility of NRAP integrated assessment model and workflows for GCS leakage and containment decision making.

EY20	EY21	EY 2022	EY 2023	EY 2024	EY 2025	EY 2026

4 New Functionalities

4 Updates to NRAP-OPEN-IAM

2 Case Studies

NRAP Phase II Open-IAM & Recommended Practices

Code development plan for site-scale IAM

Improved well leakage models, prototype AOR and bowtie workflows

Improved user ex[...]ols, etc

Complete simulations and results interpretation for initial case studies

[...]e simulations and results inte[...]

NRAP integrated assessment model initial public beta release

NRAP integrated assessment model second public beta releas[...]

Comple[...] site-scal[...] [...] for [...]upport [...]sment tools, [...]ended practices

Outcome: Release fi[...] tool applic[...]

NRAP
National Risk Assessment Partnership

NRAP releases a new version of NRAP-Open-IAM, an integrated assessment model for geologic carbon storage sites

June 11, 2024

Read More

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NATIO[...] ENERG[...] TECHN[...] LABOR[...]

[...]lamos LABORATORY EST. 1943

Pacific Northwest NATIONAL LABORATORY

Thank you!

Comments and Questions:

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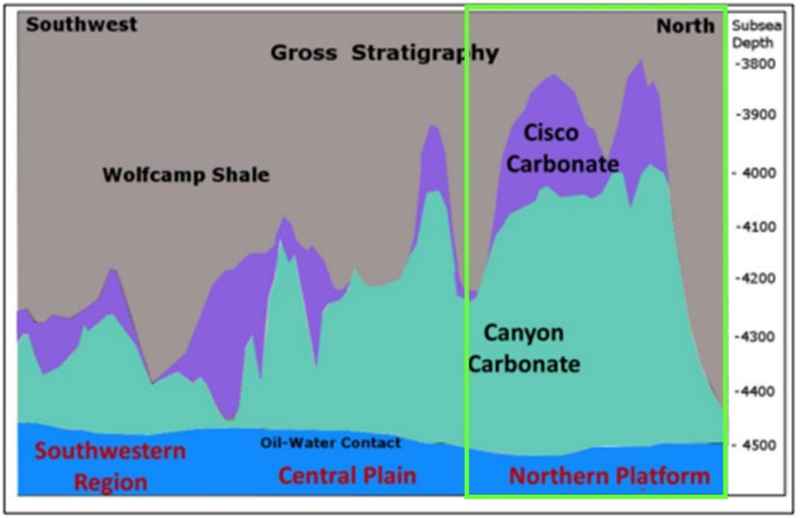
Nrap@netl.doe.gov

NRAP Website: https://edx.netl.doe.gov/nrap/

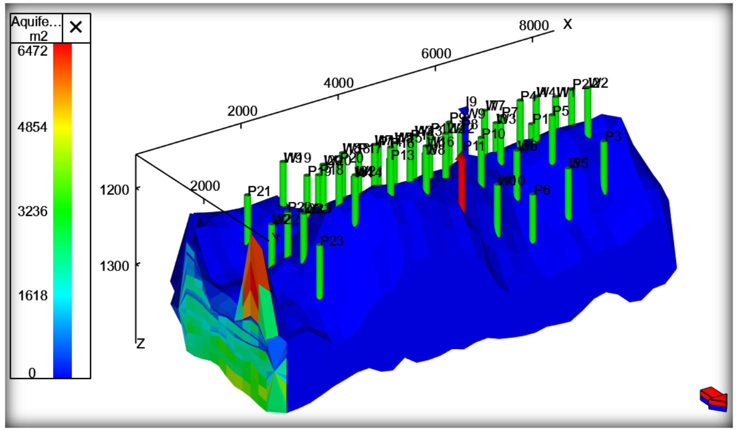
National Risk Assessment Partnership

Case Study Selection and Model Setups

Base reference of the formation for model generalization



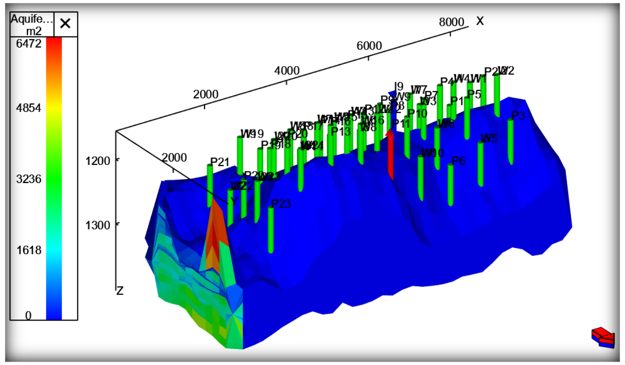
Base Geological Model



Isdiken, B., Thesis, The University of Texas at Austin, December 2013

Scenario Design

- 1 Mt/year of injection target rate
- Single well, 30 years injection, and 50 years post-injection
- CO2 interaction with hydrocarbon reservoir
- CO2 interaction with saline reservoir conditions for comparisons
- Boundary condition impacts



Jia W. and McPherson B., DOI: 10.18141/1465116

	Injection Cases	Reservoir Conditions	Boundary Conditions
Scenario 2	Dedicated CO_2 injection (1 MT/year)	Hydrocarbon reservoir	One side open
Scenario 3	Dedicated CO_2 injection (1 MT/year)	Hydrocarbon reservoir	All sides open
Scenario 4	Dedicated CO_2 injection (1 MT/year)	Saline reservoir	One side open
Scenario 5	Dedicated CO_2 injection (1 MT/year)	Saline reservoir	All sides open

Liu G., Dilmore R., Strazisar B., Lackey G., Class II to Class VI Well Operations - Insights from Simulation-Based Investigation of CO2-EOR to Dedicated Storage Scenario. United States: N. p., 2023. Web.

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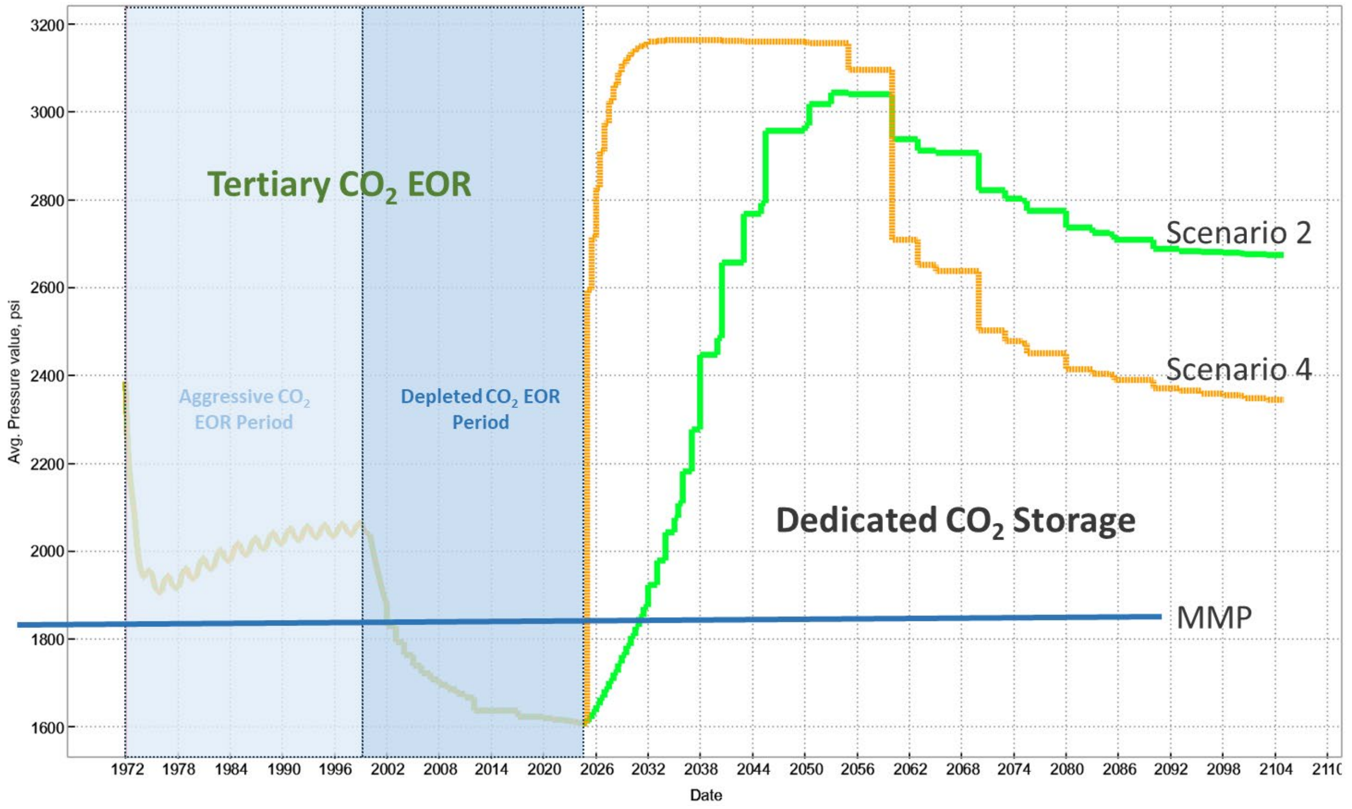
Average Reservoir Pressure Profile in Tertiary CO_2 EOR Period

- Reservoir pressure in CO2 EOR period became lower from secondary EOR
- Over the depleted condition, reservoir pressure lower than the MMP, 1850 psi
- During injection period, reservoir pressure buildup in saline reservoir is much quicker than hydrocarbon reservoir
- Overall, hydrocarbon reservoir pressure buildup is slower and lower, but the reservoir pressure is higher due to more CO2 storage in it.



Boundary Flux Profile

- Pressure and flux response in saline reservoir is much quicker than hydrocarbon reservoir
- Major reasons result in the differences are the miscible flow with CO_2 and compressibility of the fluids