Management of Site-Scale Leakage Risk

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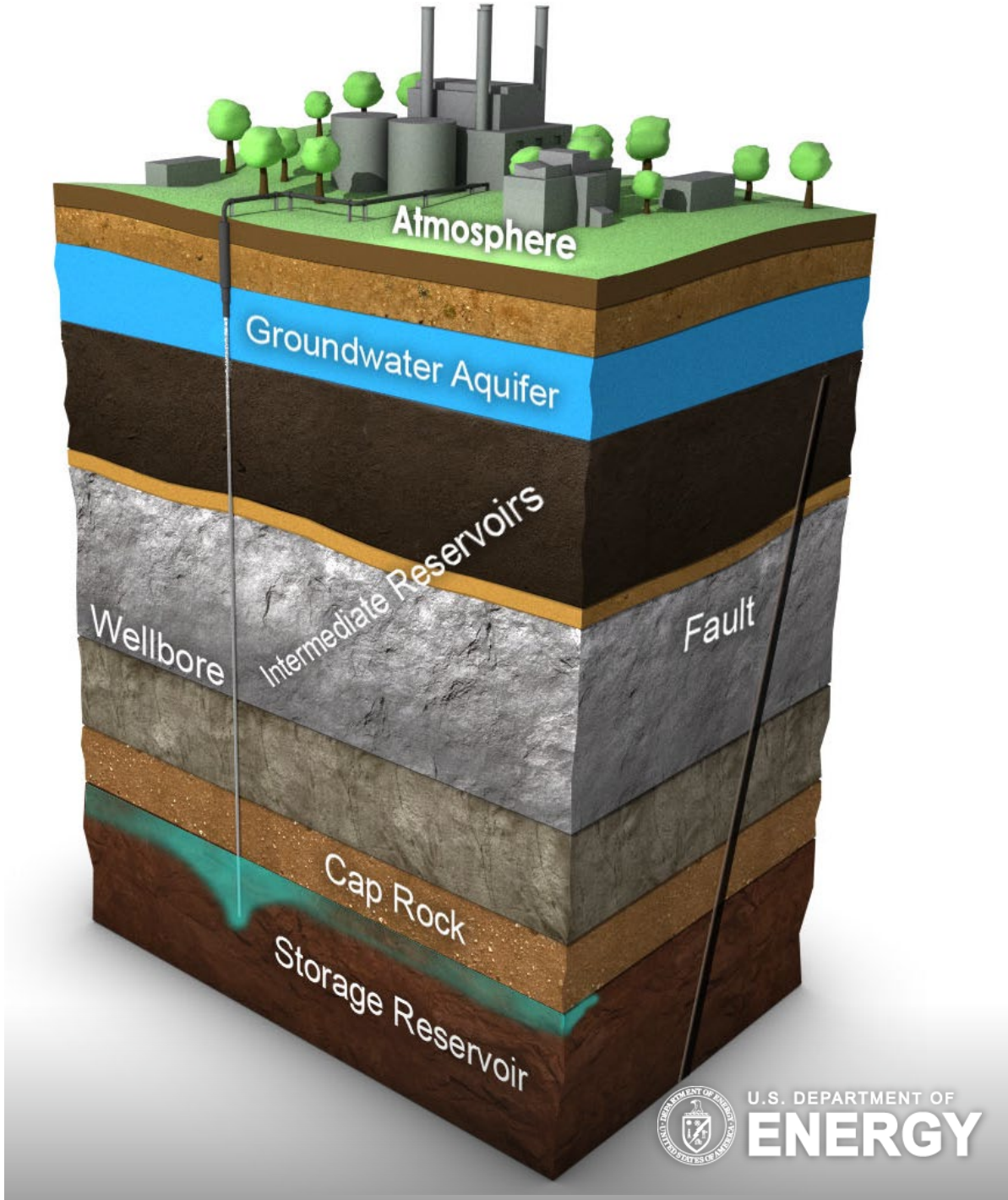
2023 FECM / NETL Carbon Management Research Project Review Meeting

August 28 - September 1, 2023

NRAP
National Risk Assessment Partnership



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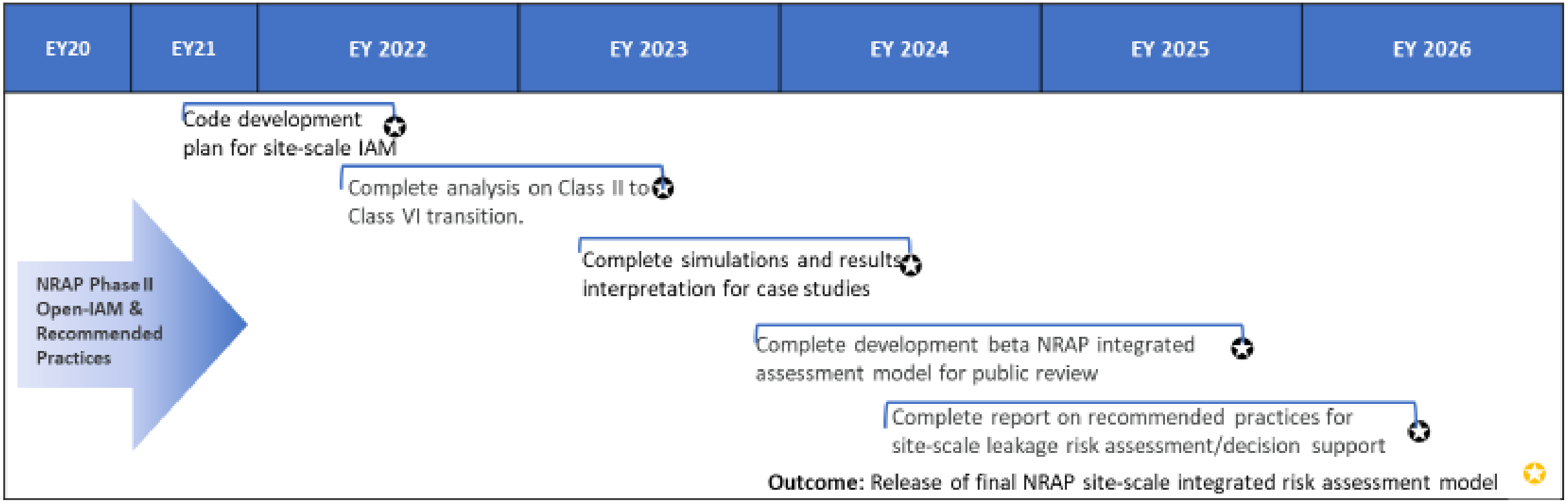
Tools to Manage Subsurface Risks

Objective: to demonstrate and improve the utility of NRAP integrated assessment model and workflows for GCS leakage and containment decision-making



NRAP-Open-IAM Updates

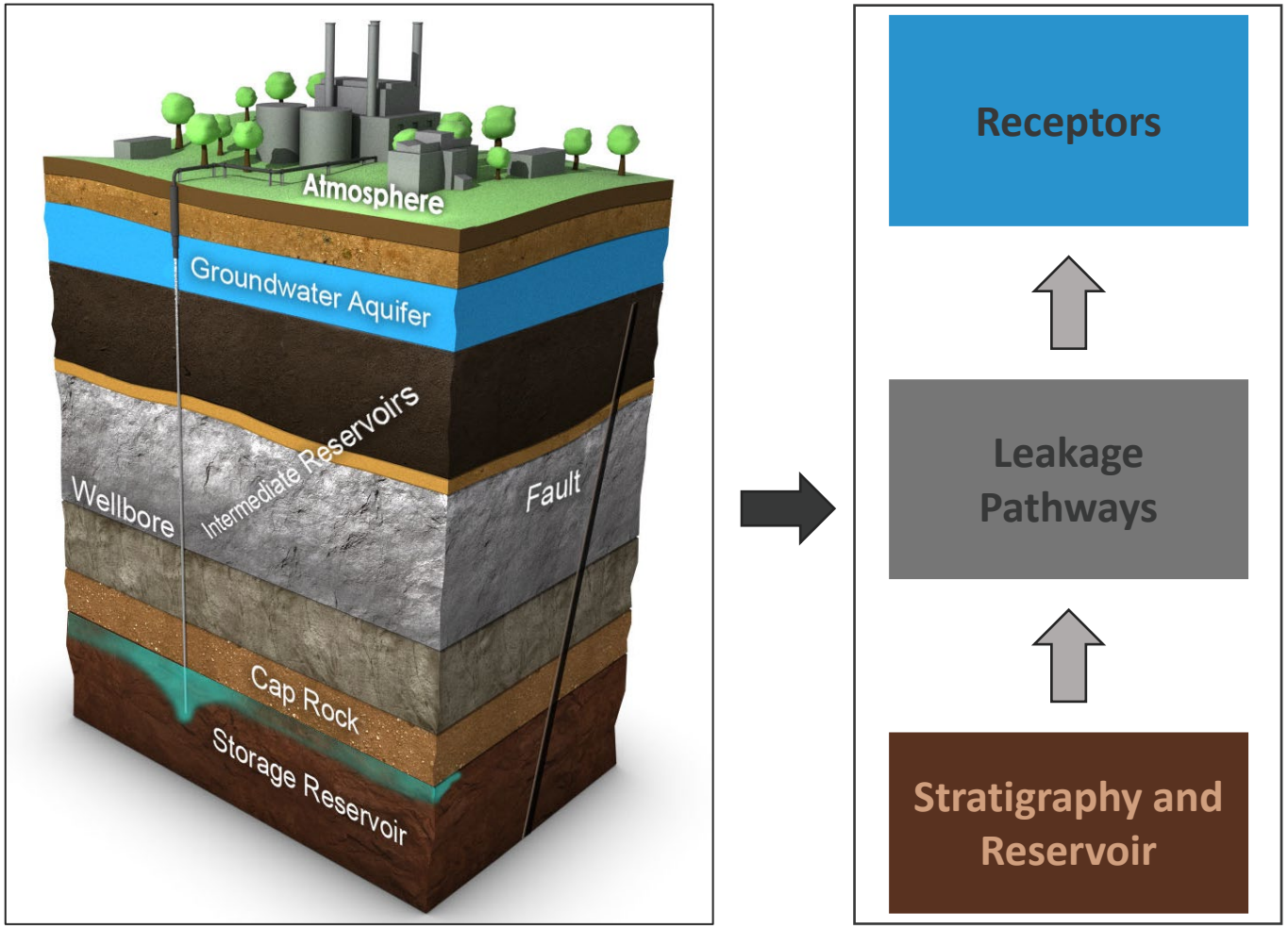
Latest release: August 2023 (https://gitlab.com/NRAP/OpenIAM)

New Components Released

- Generic Reservoir
- Fault Leakage
- Hydrocarbon Leakage

Components Updated

- Lookup Table Reservoir (3d interpolation; h5 data format)
- Plume Stability (3d interpolation; h5 data format)



New Developments: User Interface

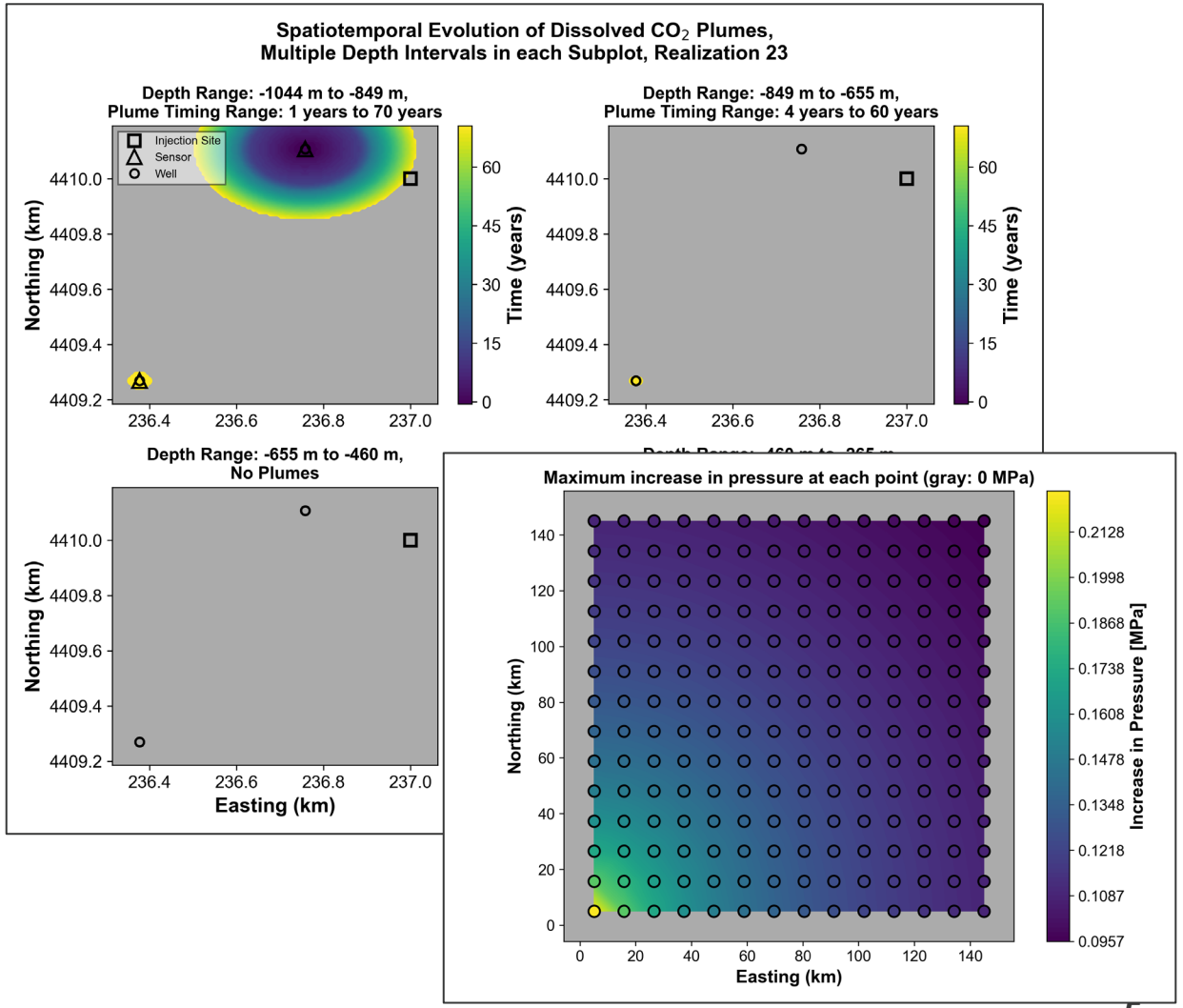
Control File Interface

(New) Workflow section

- Risk-based Area of Review (AoR)
- Total time to the first detection (TTFD)

Visualization capabilities

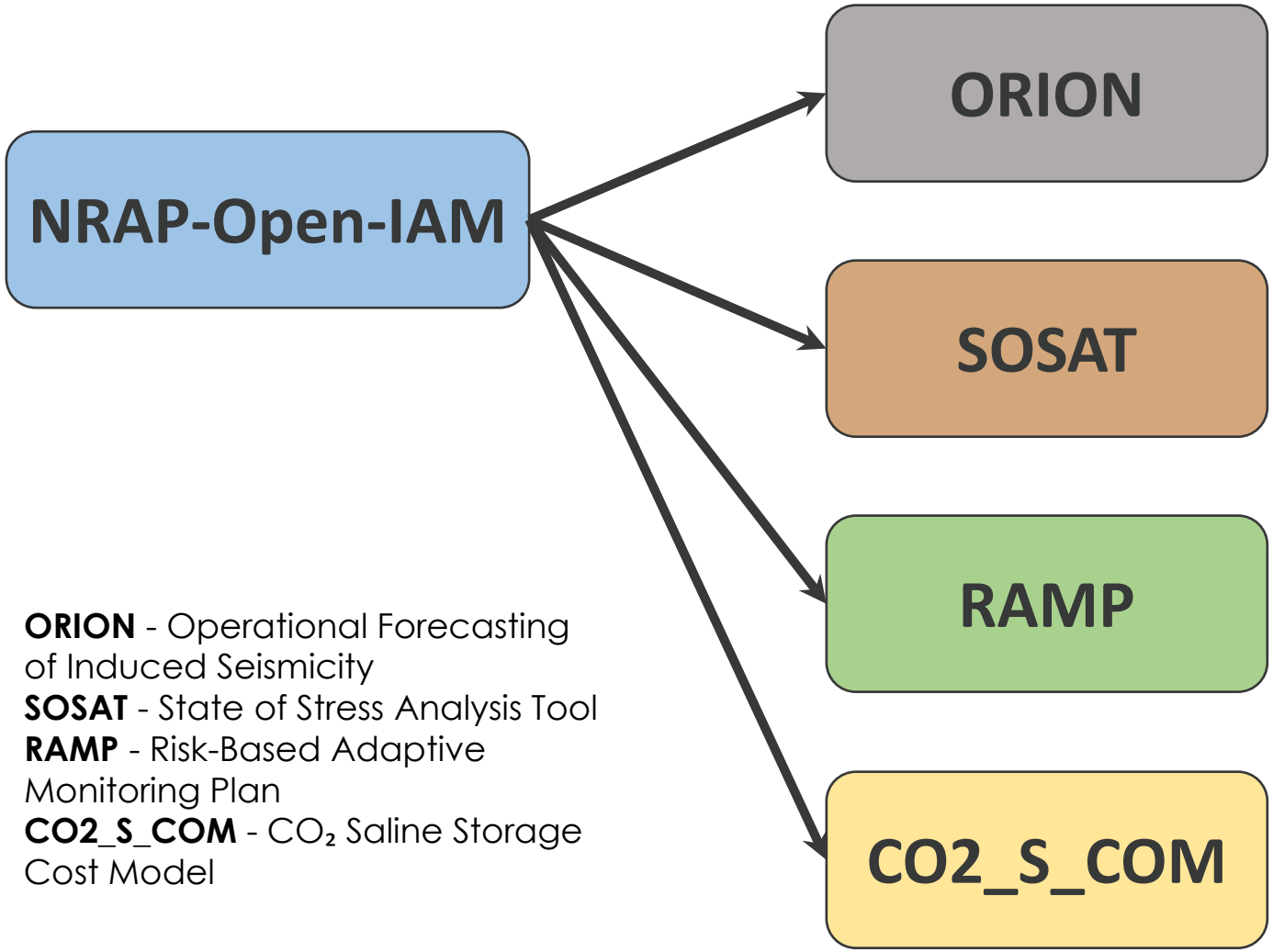
- AoR
- TTFD
- Stratigraphy plots
- *Time series plots **
- *Sensitivity analysis **
- *2d plots **



* *Updates of the existing capabilities*

Connections Between NRAP Tools

Development of Functionality and Workflows

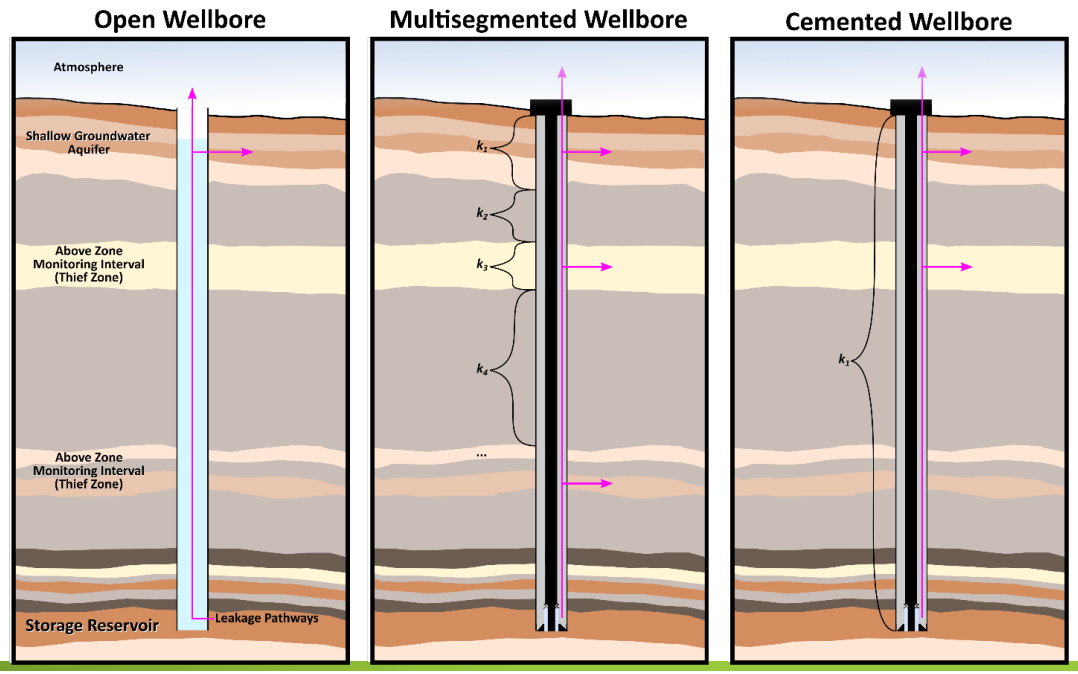


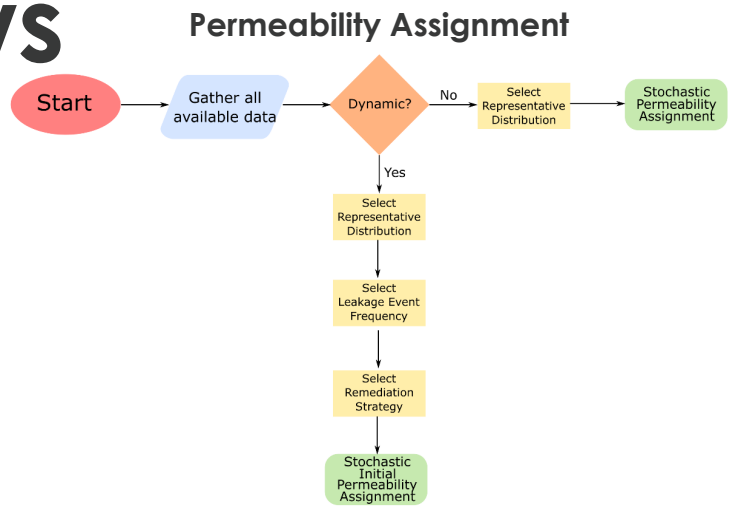
ORION - Operational Forecasting of Induced Seismicity
SOSAT - State of Stress Analysis Tool
RAMP - Risk-Based Adaptive Monitoring Plan
CO2_S_COM - CO_2 Saline Storage Cost Model

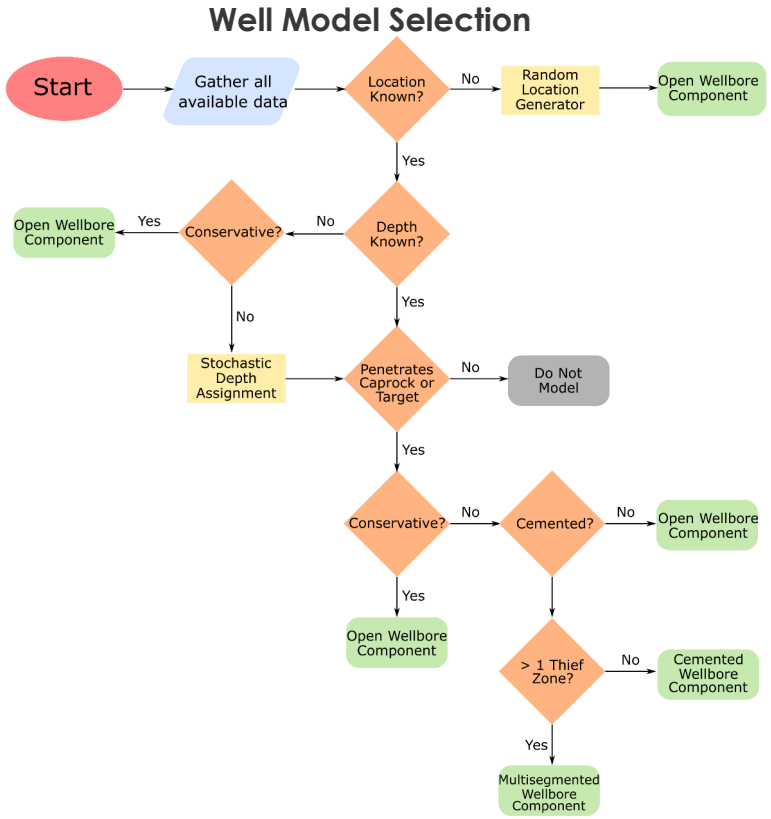
- Pressure outputs to spatial and temporal ensemble forecast of seismicity
- Reservoir pressure changes (at site and basin scale) to state of stress forecasts
- Temporally and spatially-resolved leakage risk forecasts to adaptive, risk-based monitoring design
- CO_2 plume and pressure front evolution forecasts to financial performance of a CO_2 storage project

Well Leakage Modeling Workflows

- One-page fact sheet describing well leakage modeling in NRAP Open-IAM
- Aids model selection and well permeability assignment
- Will be available online and in user manual







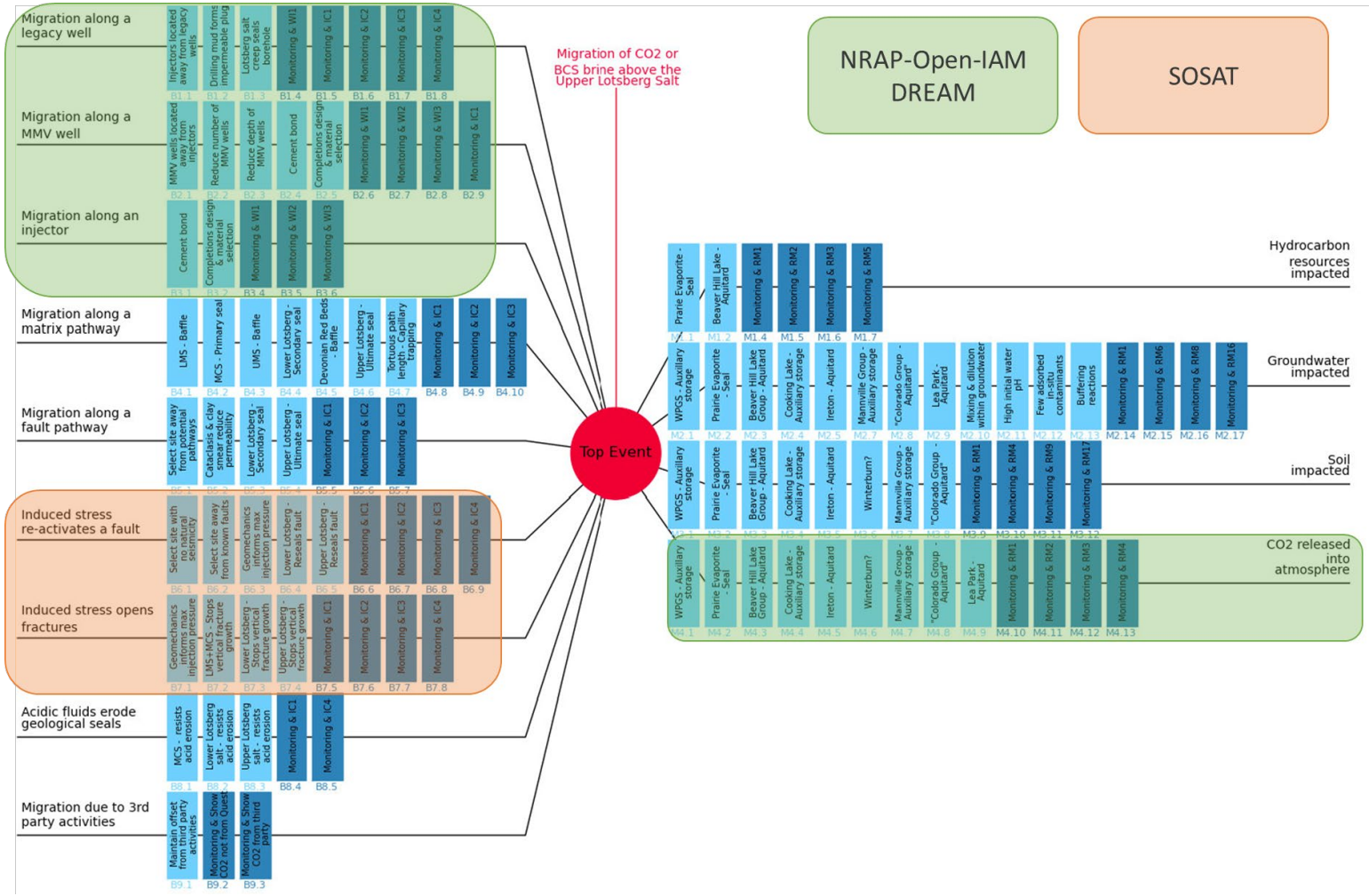
NRAP tools and bowtie risk analysis

Objective:

Increase utilization of NRAP tools by the carbon geologic storage (CGS) community

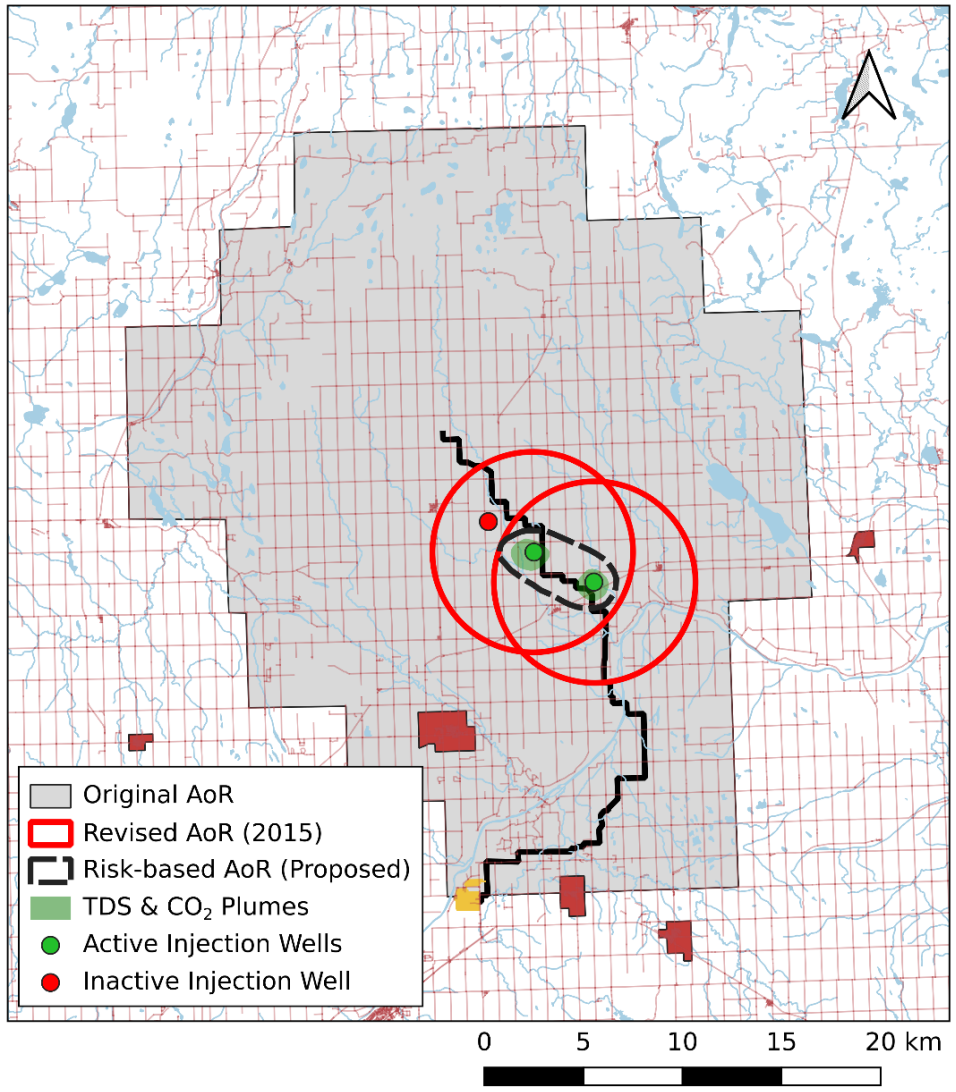
Approach:

Demonstrate how NRAP tools can complement these risk assessment methods



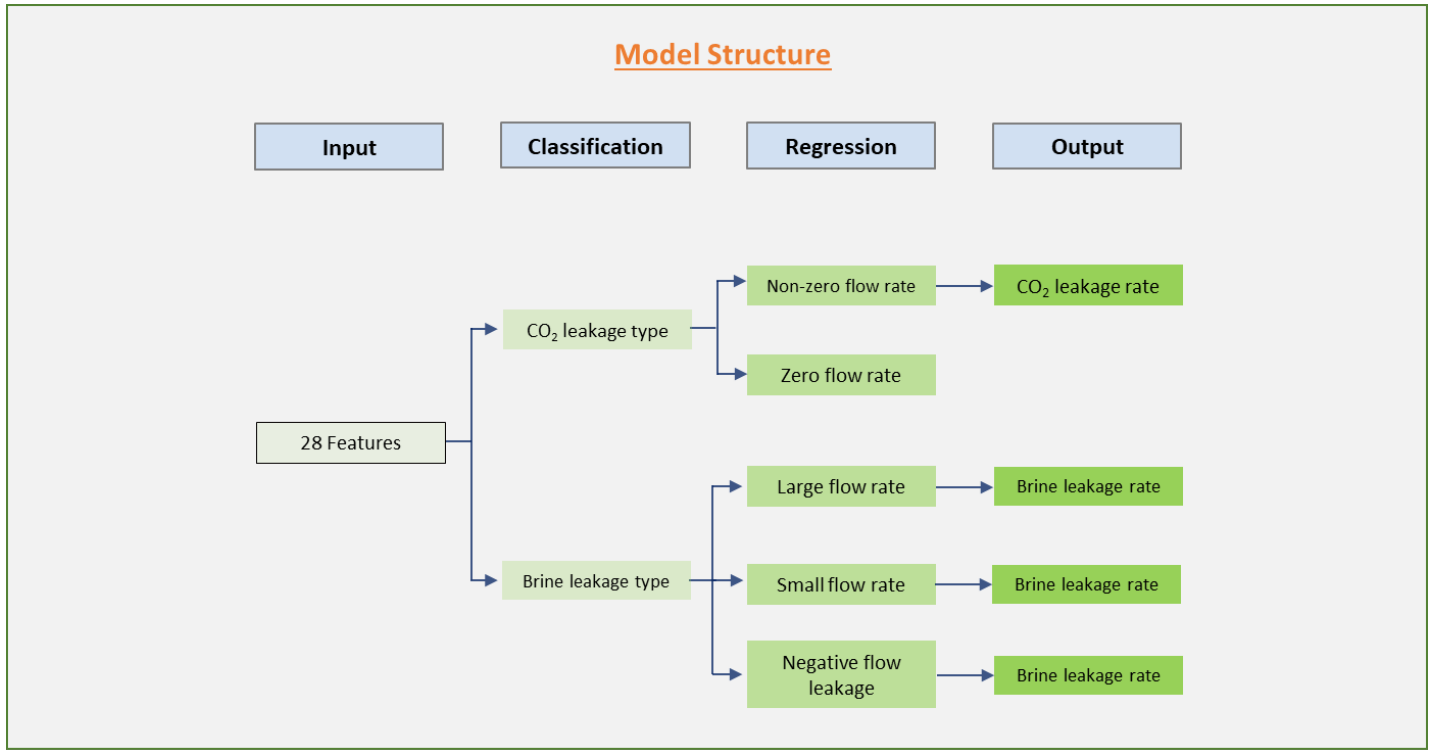
Area of Review Comparison

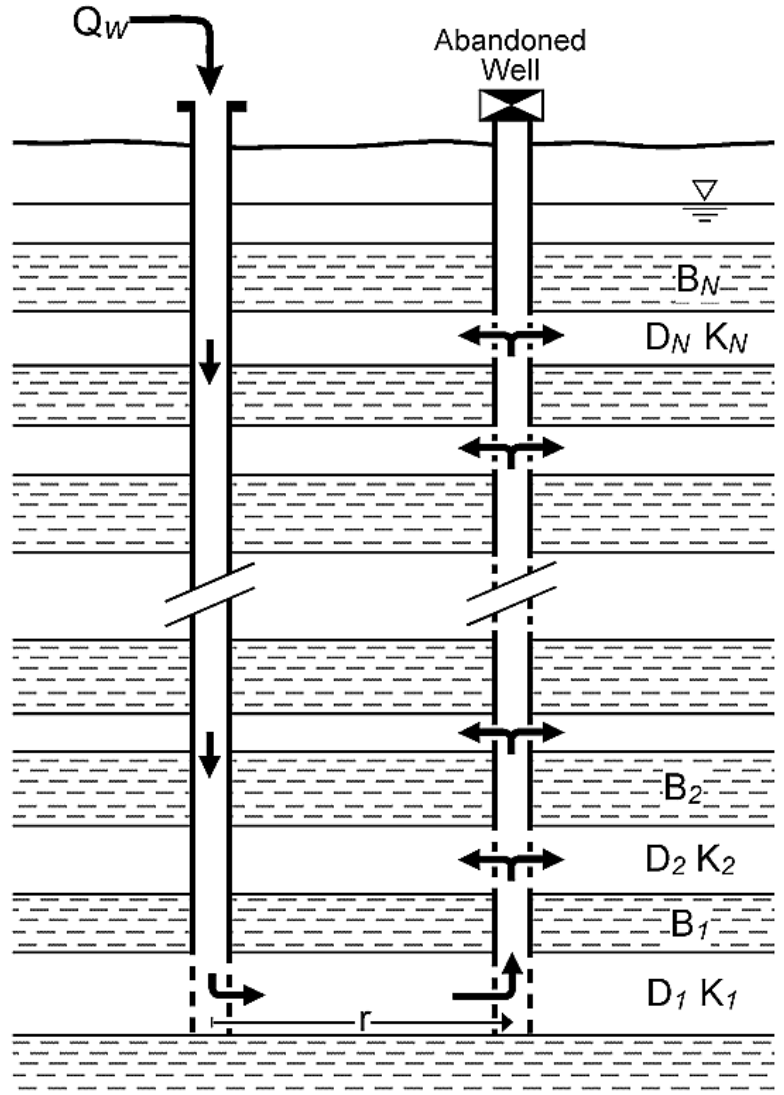
- Original AoR had an area of 3,780 km^2
- Revised (2015) AoR has an area of 461 km^2 or ~12% of the original AoR
- NRAP-Open-IAM AoR has an an area of 102 km^2 or ~3% of the original AoR
- An AoR based solely on the TDS & CO_2 plumes has an area of 28.5 km^2 or ~0.8% of the original AoR



Multisegmented Wellbore ROM

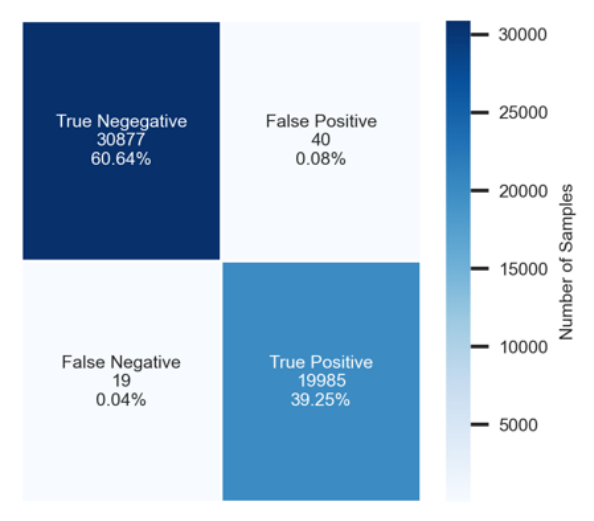
- Leakage of CO2 and brine through cemented wellbores
- Leakage into multiple impermeable caprock layers and permeable aquifers
- Overcomes deficiencies of the analytical multisegmented wellbore ROM using ML/DL-based approach





Caprock Segment Wellbore Model

Classification

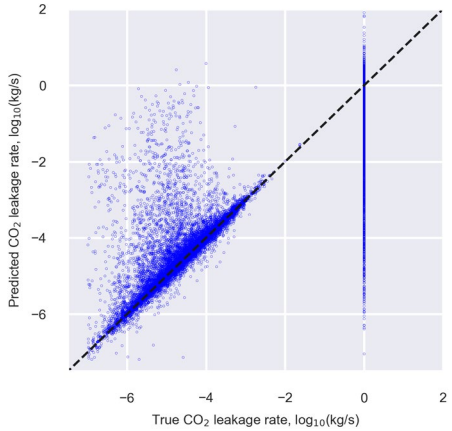


Regression

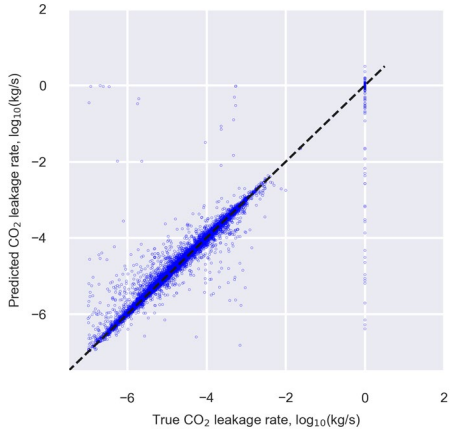
Data set	Classification[1] Accuracy	Regression[2] Mean Squared Error[3]
Training	0.9990	9.2302e-05
Validation	0.9988	2.8170e-04
Testing	0.9991	2.0172e-04

[1]The numbers of data set for training, validation and testing are 737,713, 229,779 and 50,921, respectively.
[2]The numbers of data set for training, validation and testing are 290,754, 89,316 and 20,004, respectively.
[3]Unit: $\log_{10}$(kg/s)
*Accuracy and mean squared errors for training and validation are at 200th epoch.

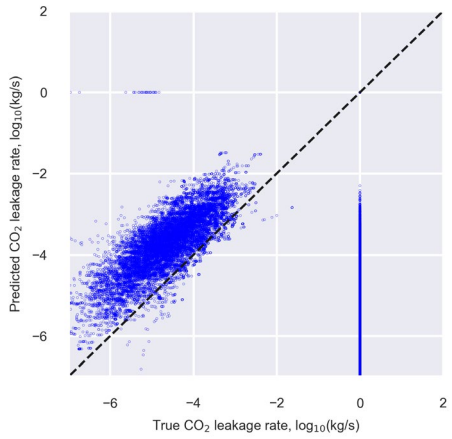
Using only simulation input

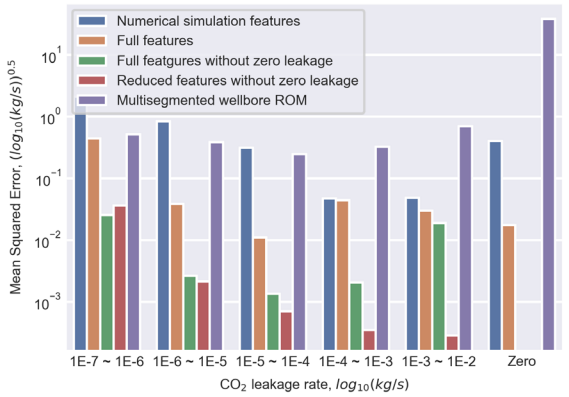


Without separation



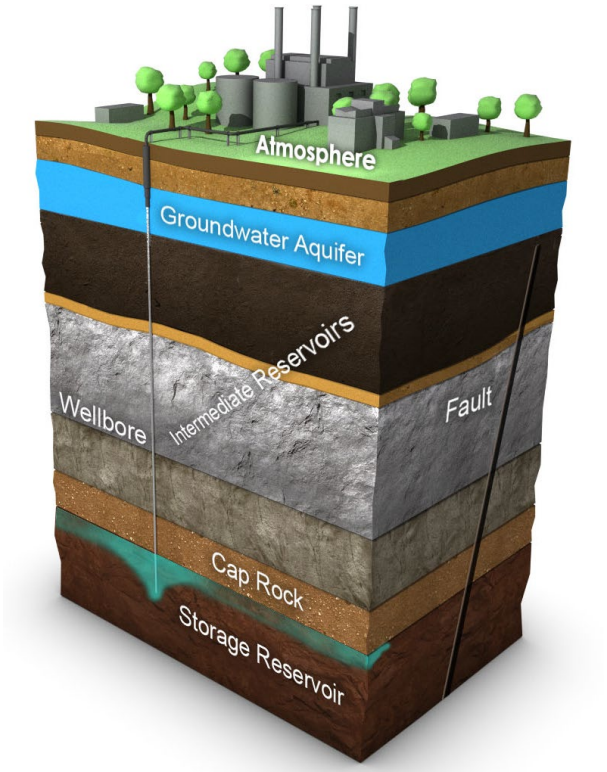
Analytical MSW



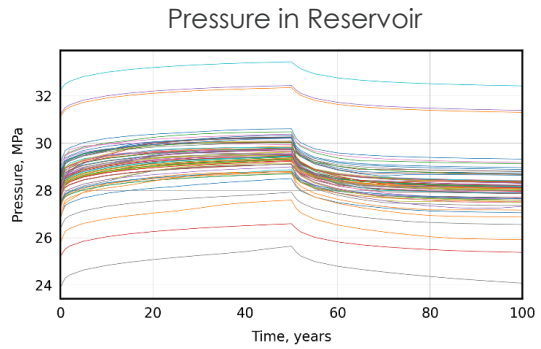


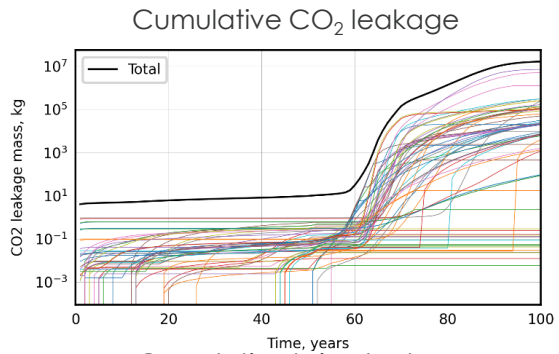
Caprock Segment Wellbore Model

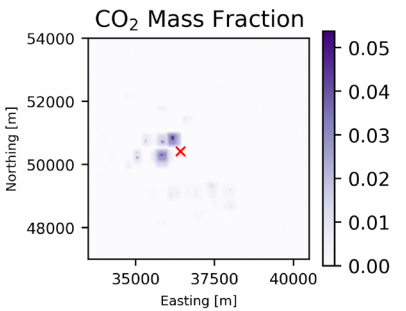
Model Application

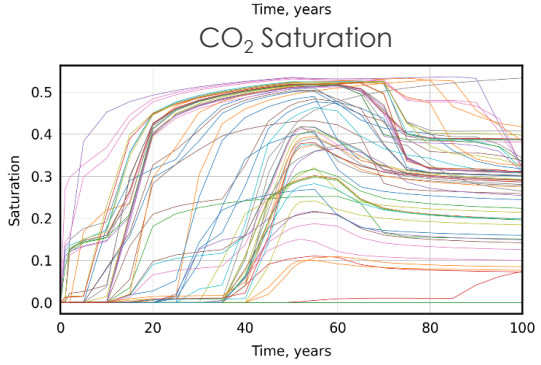


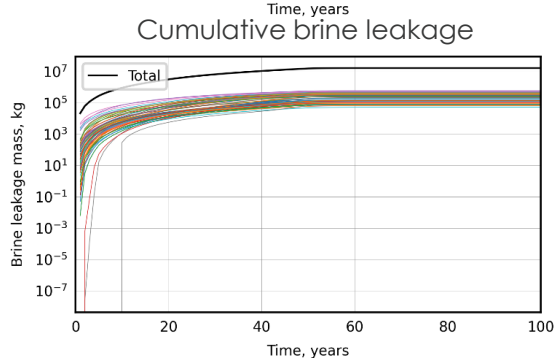
Reservoir LUT (Kimberlina Site) → **Multisegmented Wellbore ROM** → **Aquifer Impact ROM**

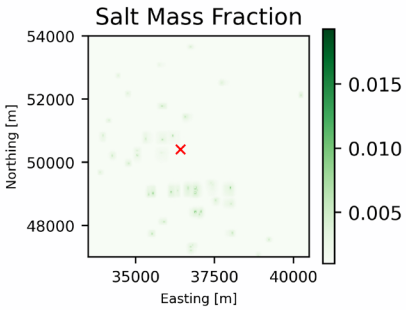






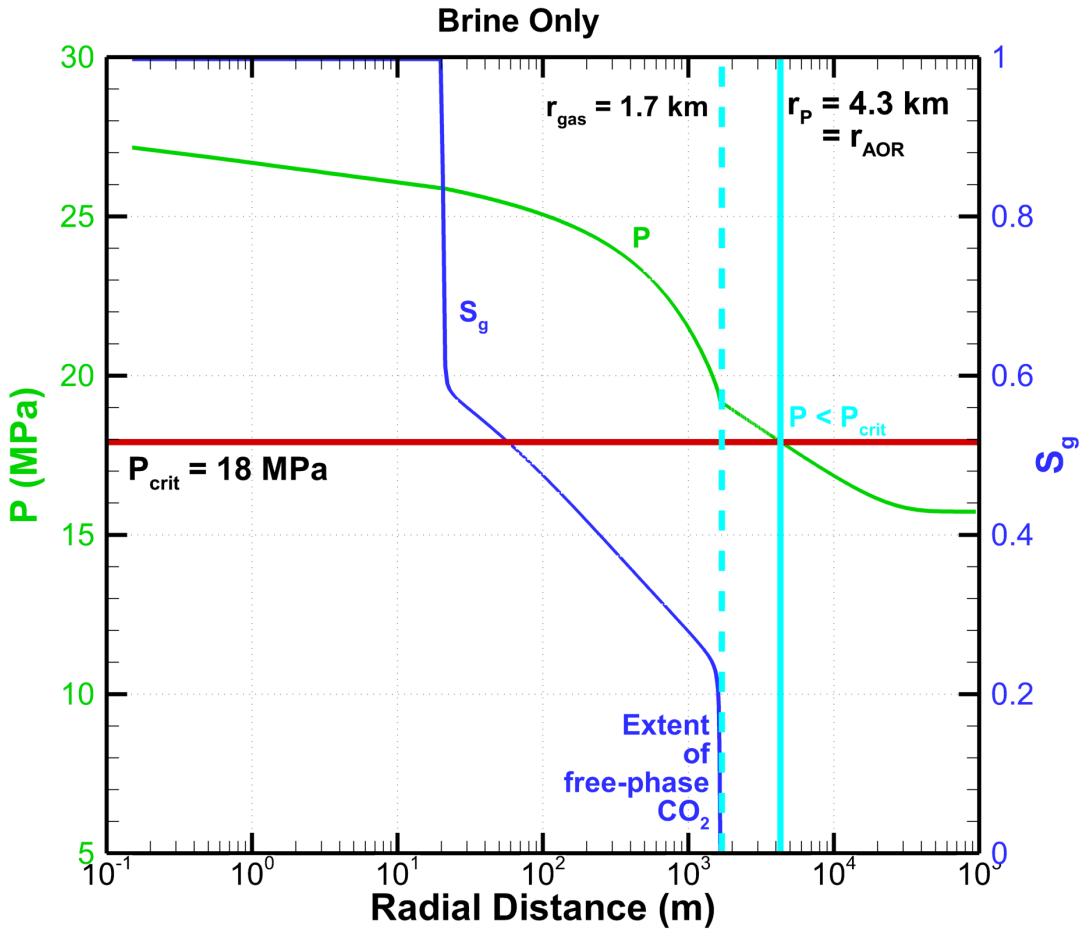




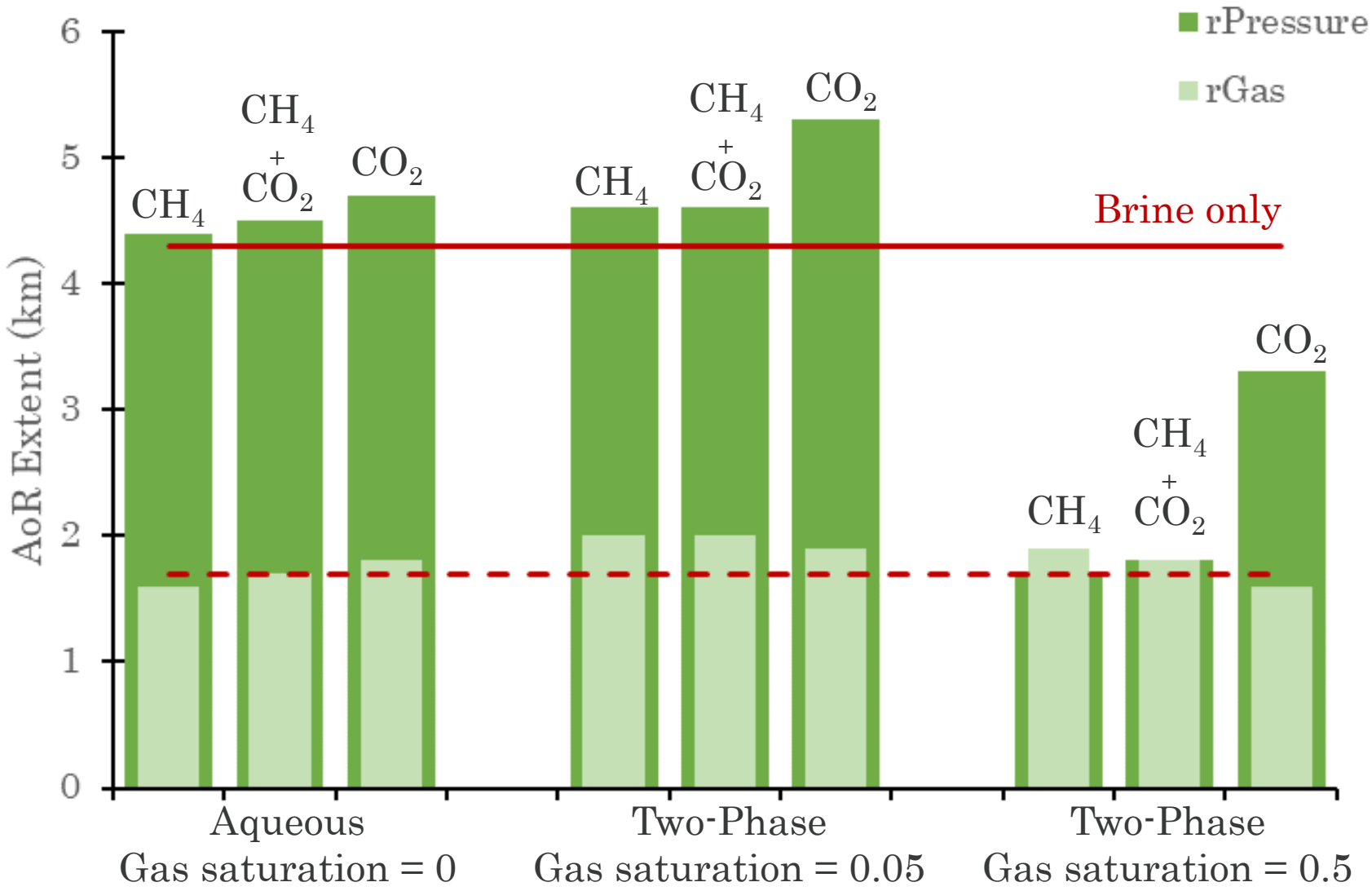


The Effect of Hydrocarbons on the AoR

- Study the effect of initial conditions with hydrocarbons on the extent of the AoR
- Use simple, generic models
  - Depth 1900 m
  - Thickness 300 m
  - Porosity 0.08
  - Permeability 10 mD horizontal, 1 mD vertical
  - Reservoir pressure 15.7 MPa
  - CO_2 injection rate 41 kg/s = 3500 T/day
  - Injection duration 40 years
- Compare P(r) to P_{crit}: r_p is where $P(r)<P_{crit}$
- Maximum extent of gas phase determines r_{gas}
- Extent of the AOR is the greater of r_p and r_{gas}

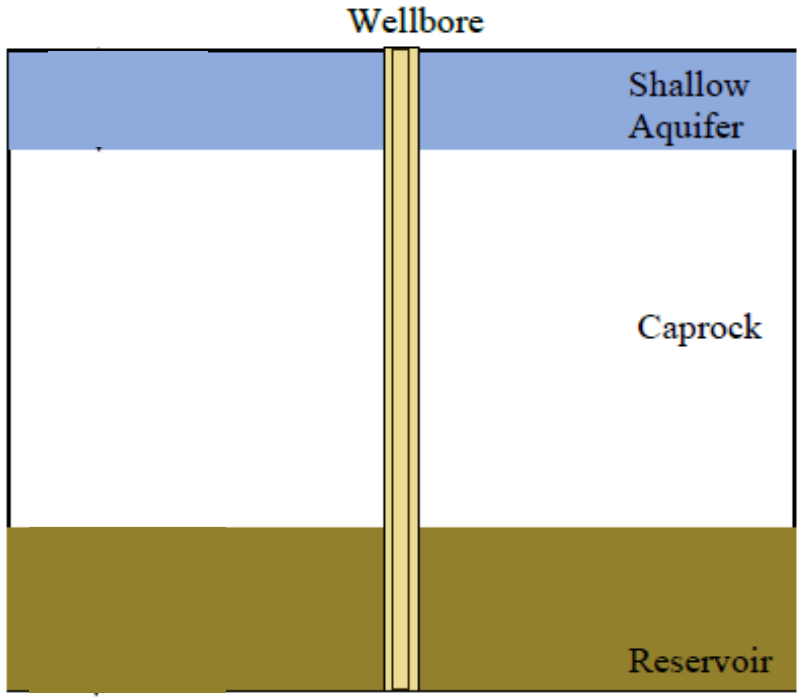


AOR dependence on Initial Conditions

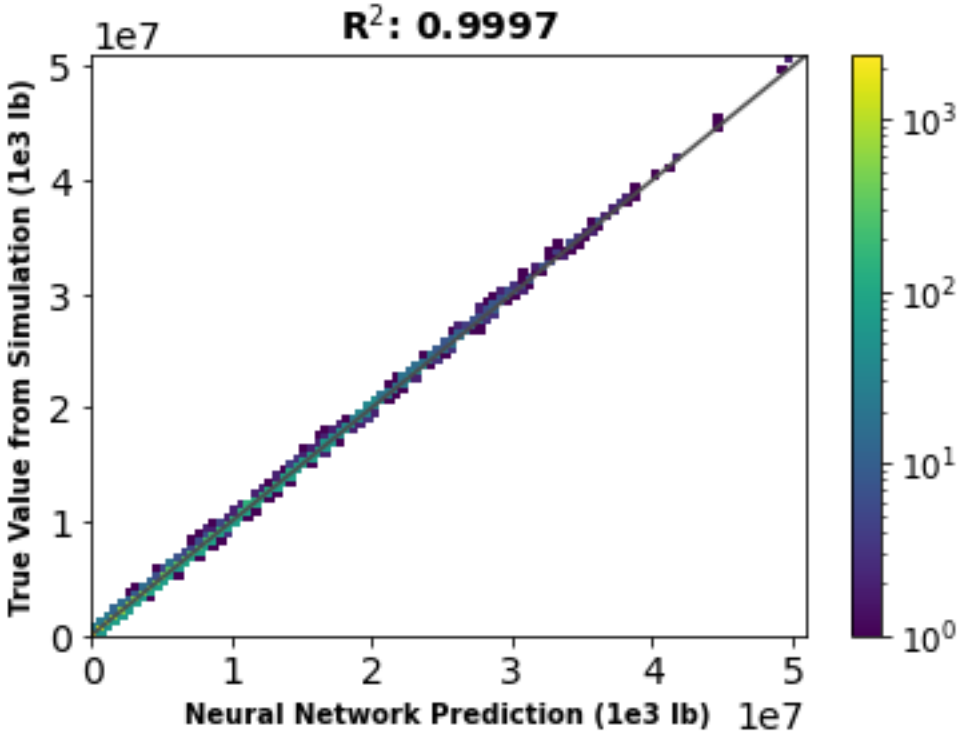


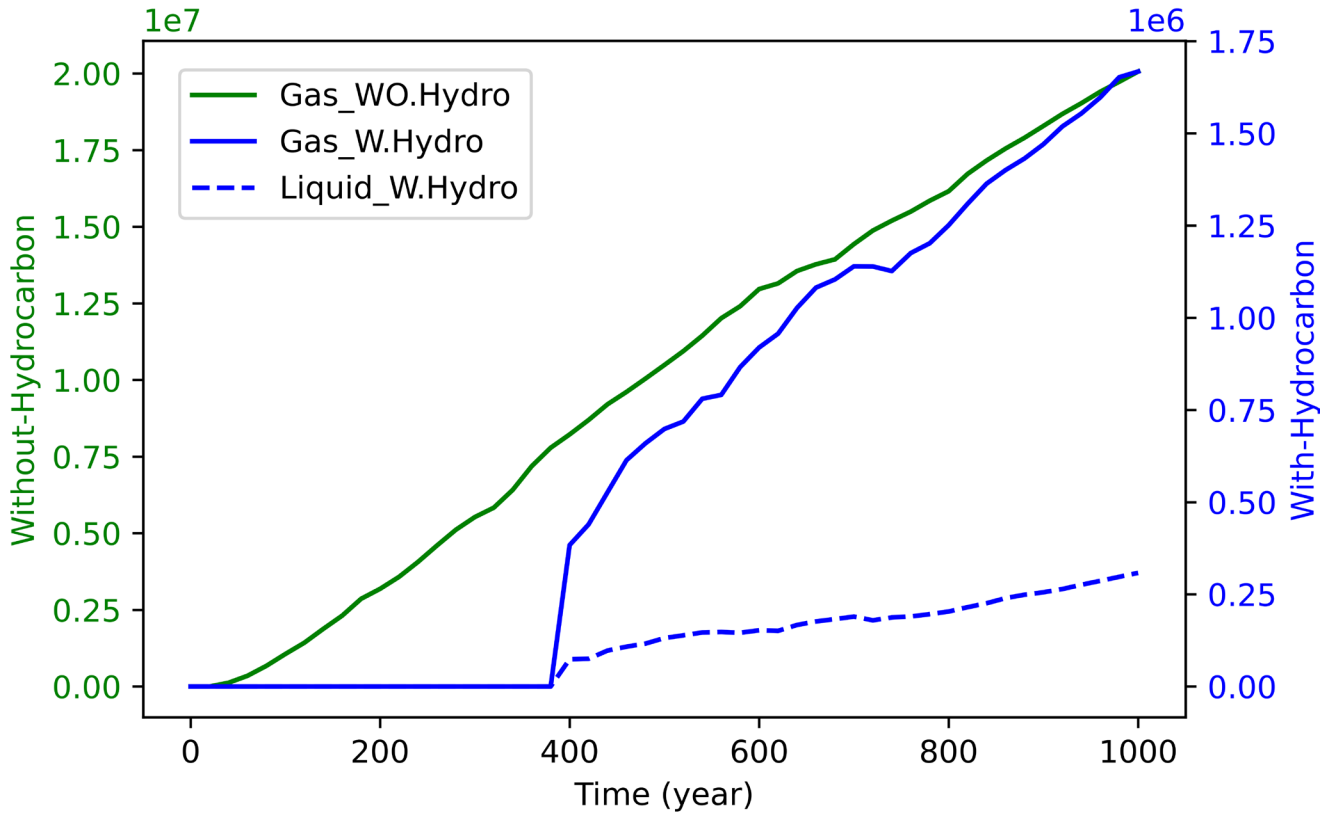
Reduced order model for hydrocarbon fields

Input parameters	Ranges		Units
	Minimum	Maximum	
Reservoir depth	3000	9000	ft
Aquifer depth	200	2000	ft
Reservoir pressure multiplier	1.0	1.2	-
Wellbore permeability	0.01	1000	mD
Average water saturation	0.2	0.8	-
FC_{light}	0.05	0.3	-
$Fc_{intermediate}$	0.05	0.3	-
Fc_{heavy}	0.05	0.3	-
Time	0	1000	year



Leakage profile for hydrocarbon fields



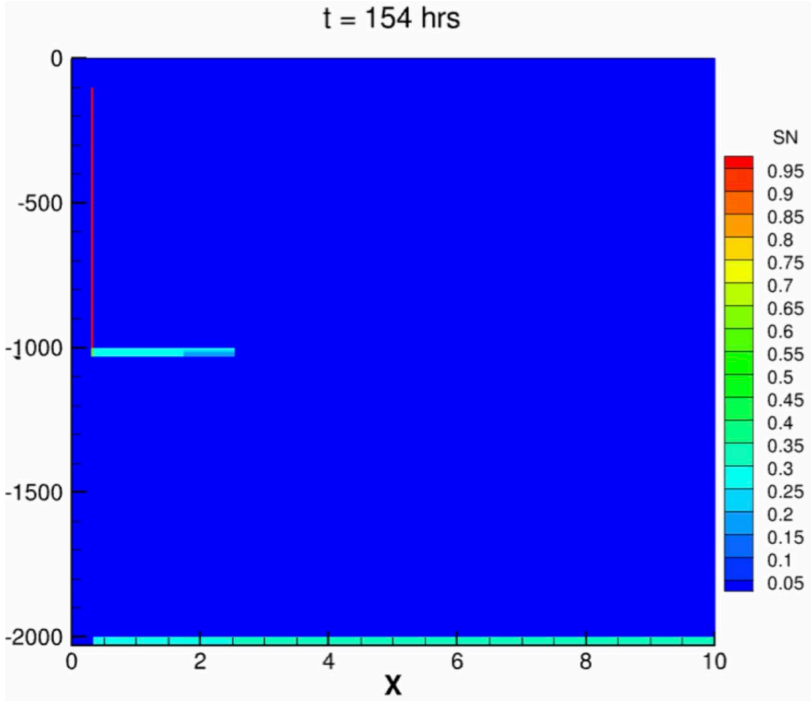


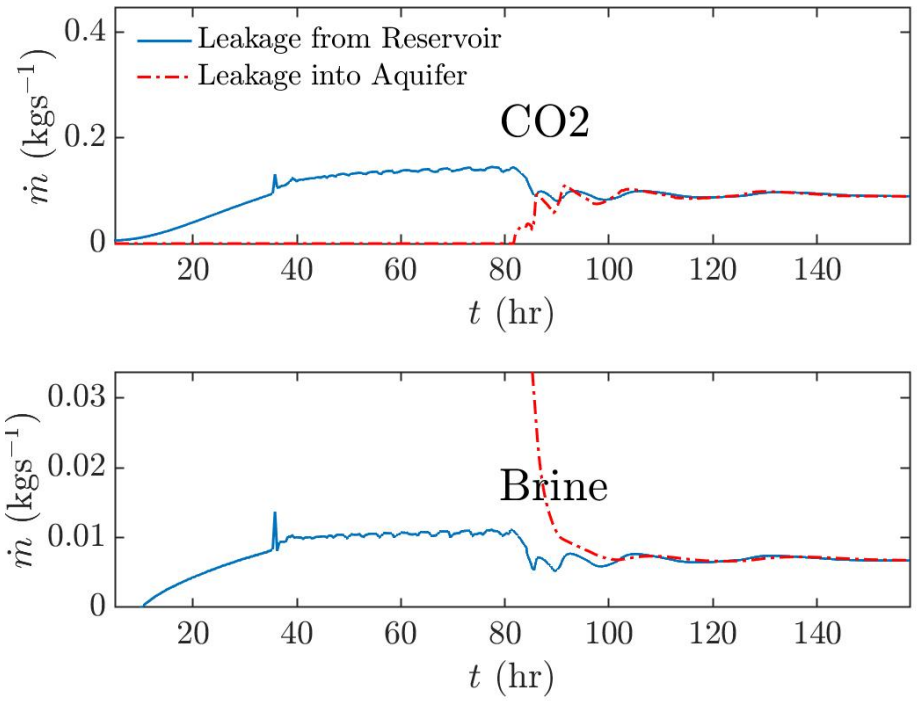
Leakage through Uncemented Annuli

The multi-segmented well leakage ROM in NRAP Open-IAM doesn't account for leakage through uncemented, open annuli.

Methodology:

- Reservoir & Aquifer flow model: Using Multiphase Darcy flow capabilities of TPFLOW
- Uncemented annulus: Using a simplified Drift-flux model or a liquid column model.



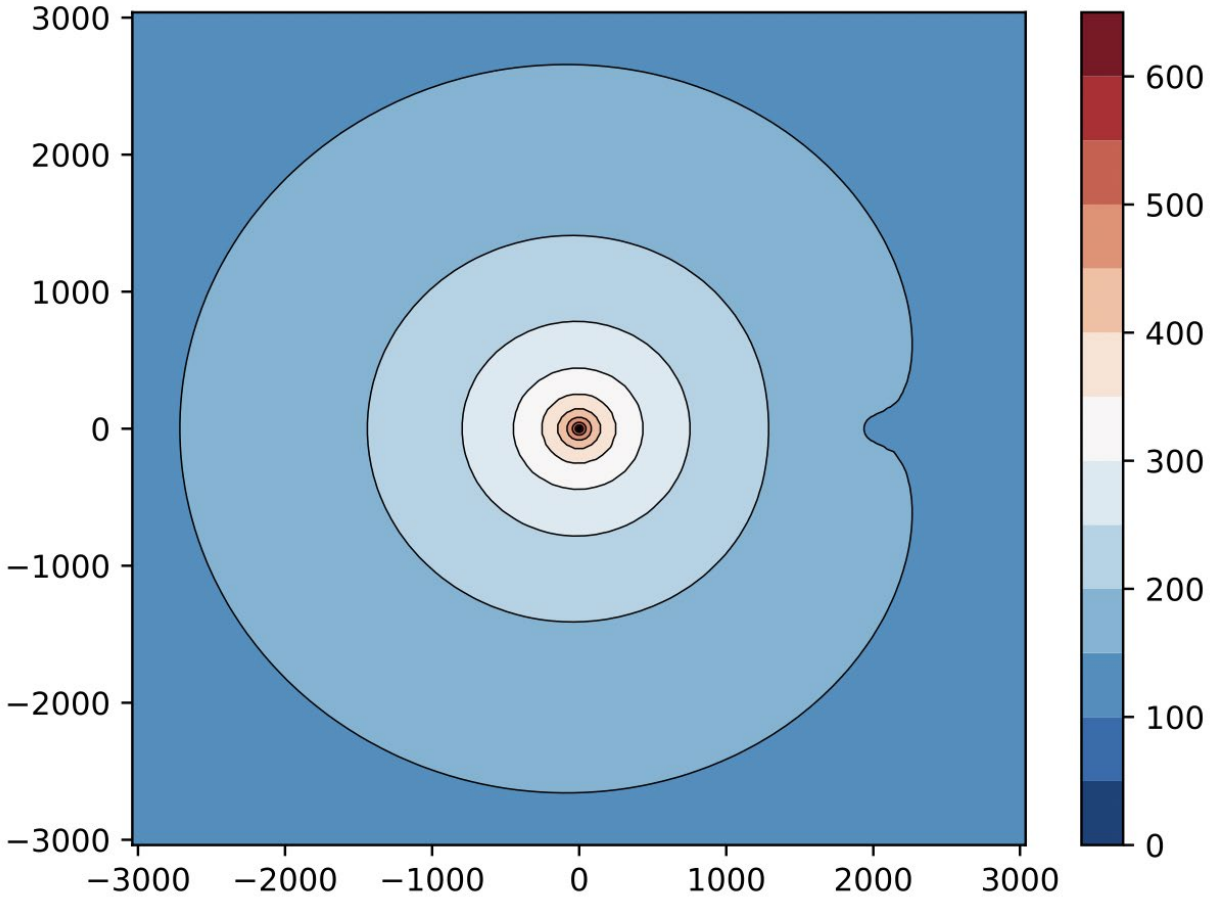


Integration of SALSA into NRAP Open-IAM

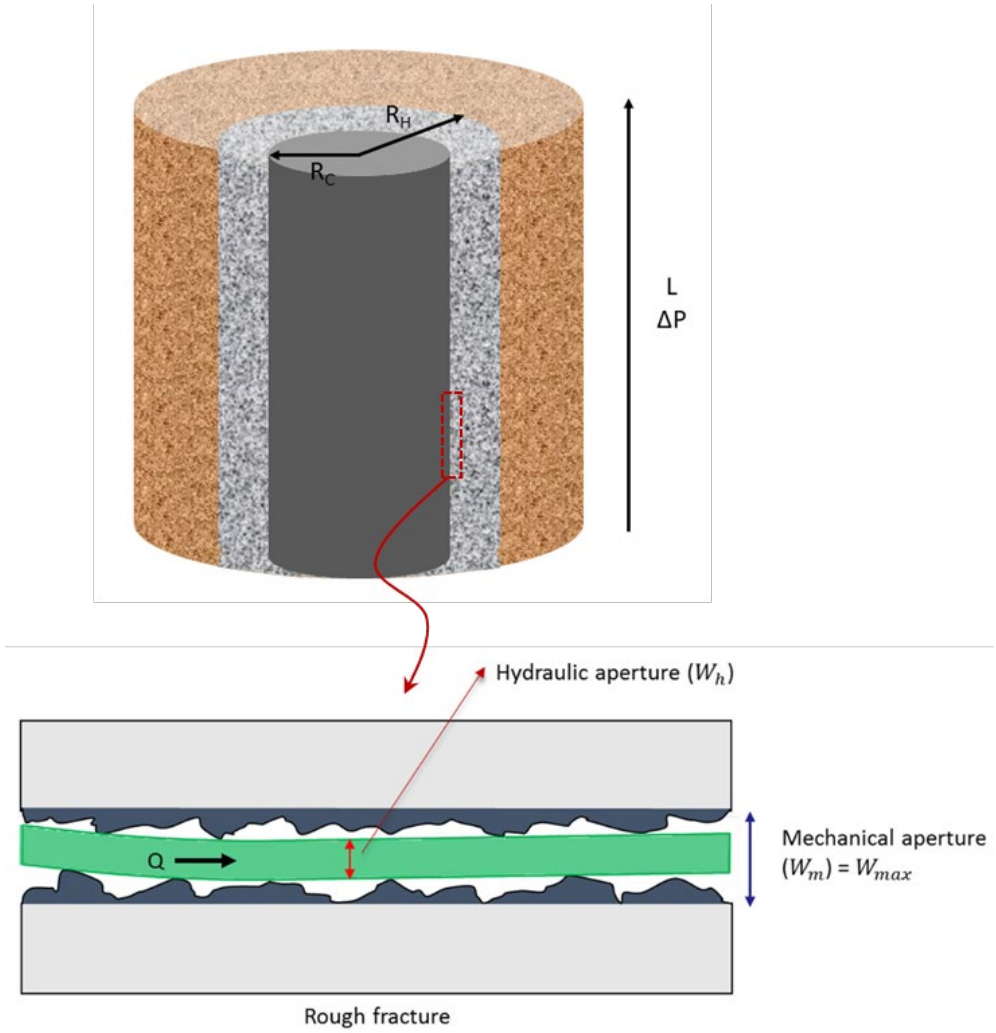
Semi-**A**nalytical **L**eakage **S**olutions for **A**quifers (SALSA) is a FORTRAN77 code that calculates pressures in a multiple aquifers-aquitard system, along with cumulative leakage rates in individual leaky wells.

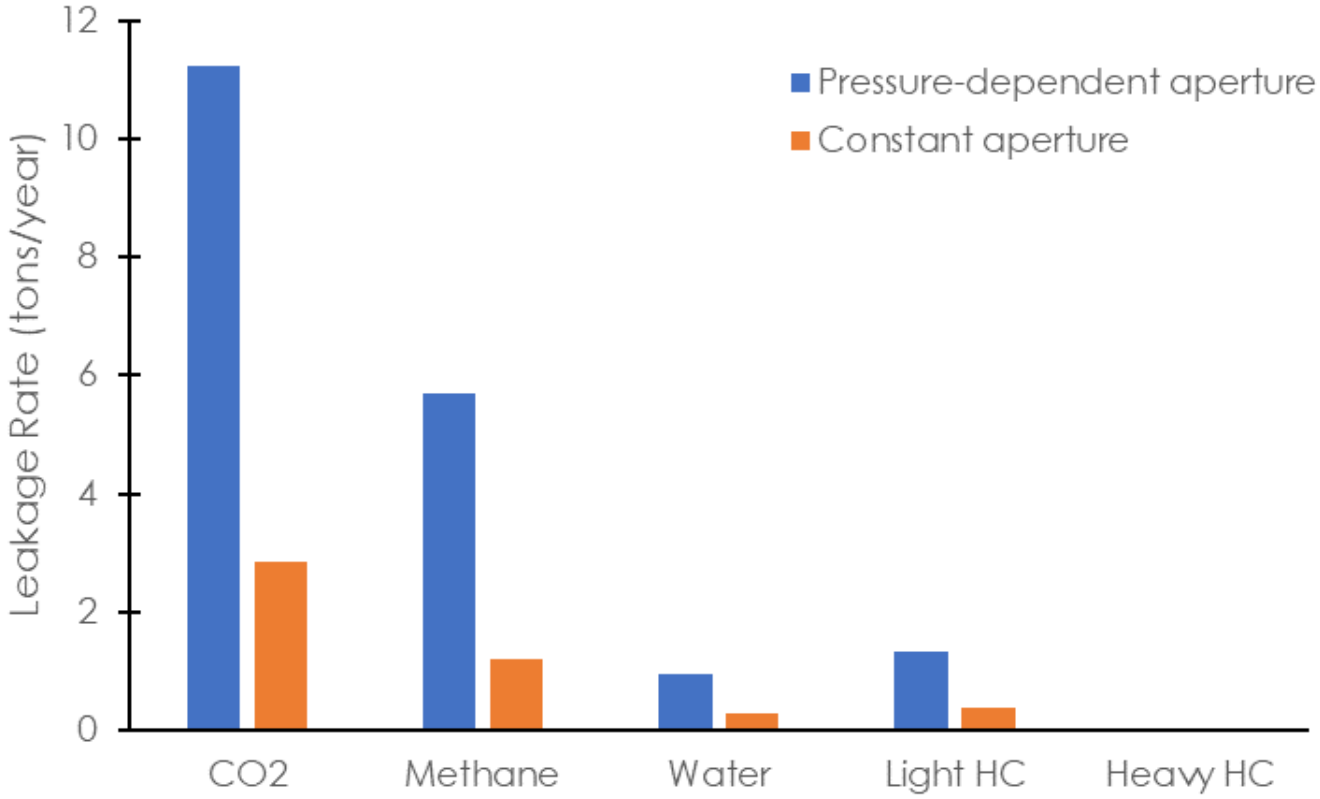
We are creating python wrappers of SALSA to enable integrating it into NRAP Open-IAM as a new feature

SALSA Python, t = 7300 days



Leakage Through Wellbore Microannuli





Constant aperture assumption underestimates the leakage up to 4 times.

Thank you!

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