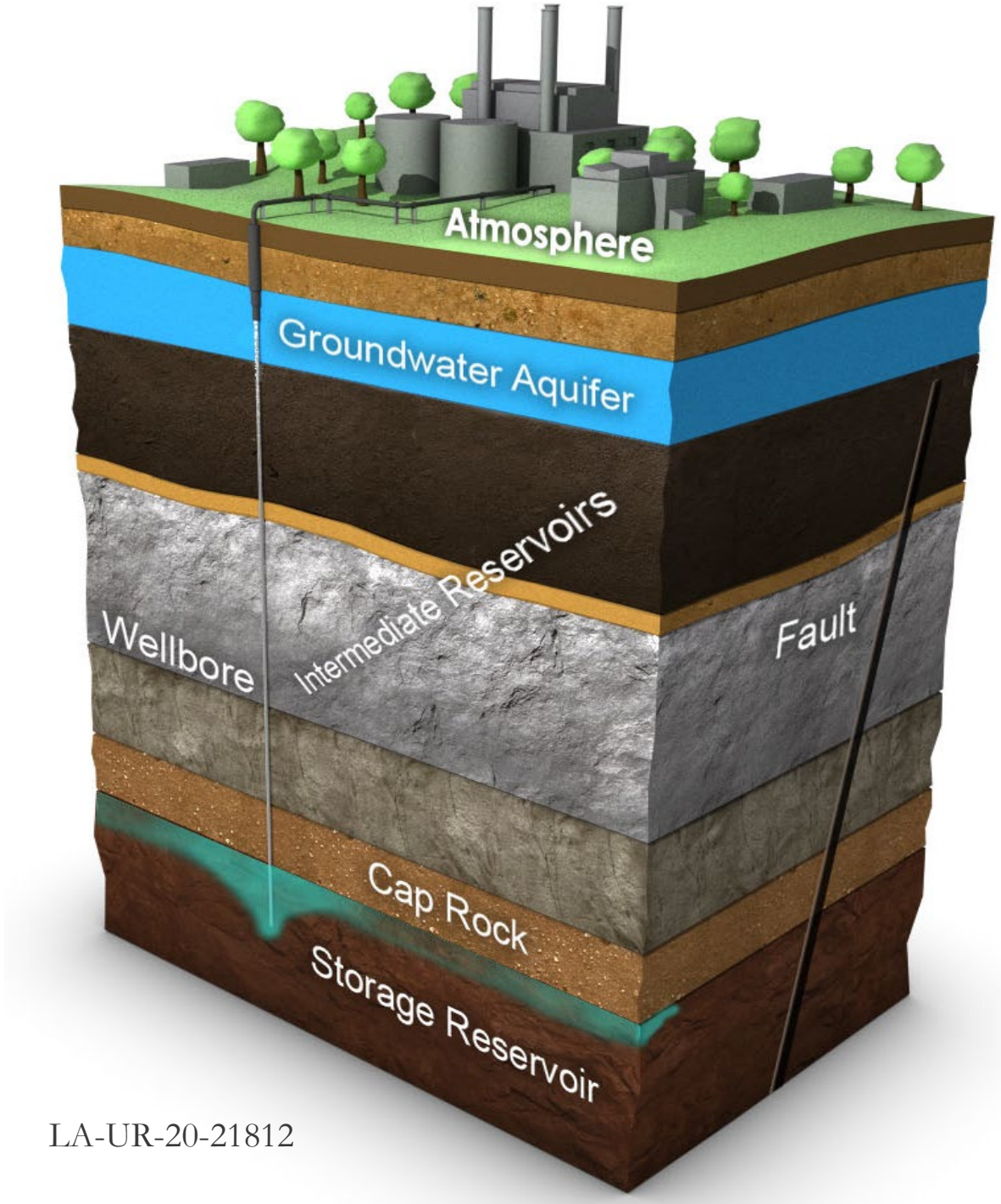
- Introduction
- Fluid Migration Characterization
- State-of-stress Characterization
- Risk-based Area of Review
- U.S. DOE's SMART Initiative
- Plume Dynamics and Conformance
- Induced Seismicity Management
- Monitoring for Leak Detection
- Site Closure
- Discussion

Evaluating potential leakage risks during pre-injection characterization stage amidst uncertainty

Integrating the NRAP approach with the Class VI permitting process



NRAP
National Risk Assessment Partnership

NATIONAL ENERGY TECHNOLOGY LABORATORY

BERKELEY LAB

Los Alamos NATIONAL LABORATORY EST. 1943

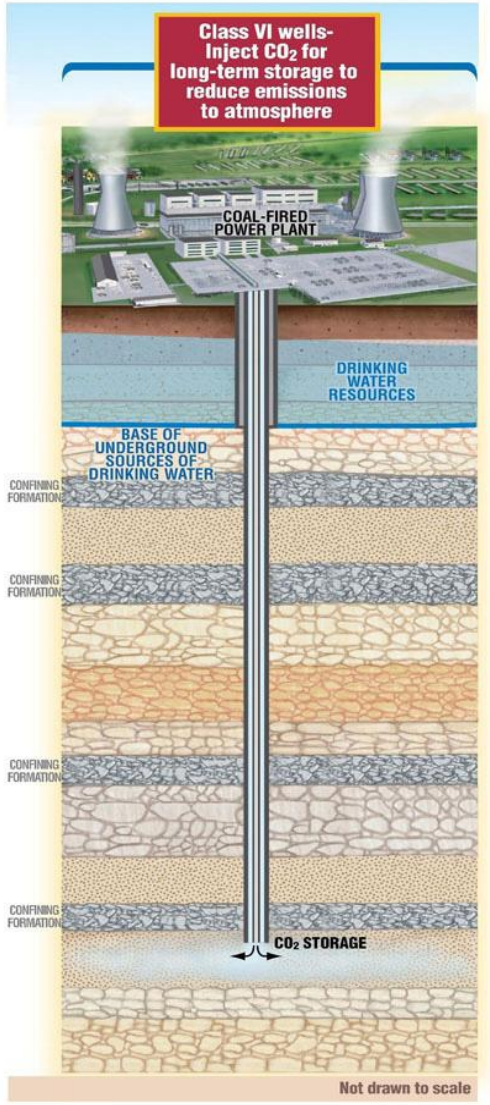
Pacific Northwest NATIONAL LABORATORY

LA-UR-20-21812

Class VI - Site Characterization

Overview

- **Site characterization: gather the data necessary to justify selection of a CO_2 storage site**
- **Class VI wells must be located in a geologic system that:**
  - Has the properties necessary to receive the total anticipated injected volume of CO_2 - capacity & injectivity
  - Has a caprock sufficient to contain the injected CO_2 - containment



https://www.epa.gov/uic/class-vi-wells-used-geologic-sequestration-co2

Class VI - Site Characterization

Class VI permit applicants must provide extensive information about the local and regional geology and hydrogeology of the proposed site [40 CFR 146.82(a)(2),(3),(5),(6)].

- Regional geology, hydrogeology
- Thickness, mineralogy, porosity, permeability of injection zone & overlying formations
- Suspected faults and fractures
- Geomechanical properties
- Seismic history
- Locations and geochemistry of USDWs

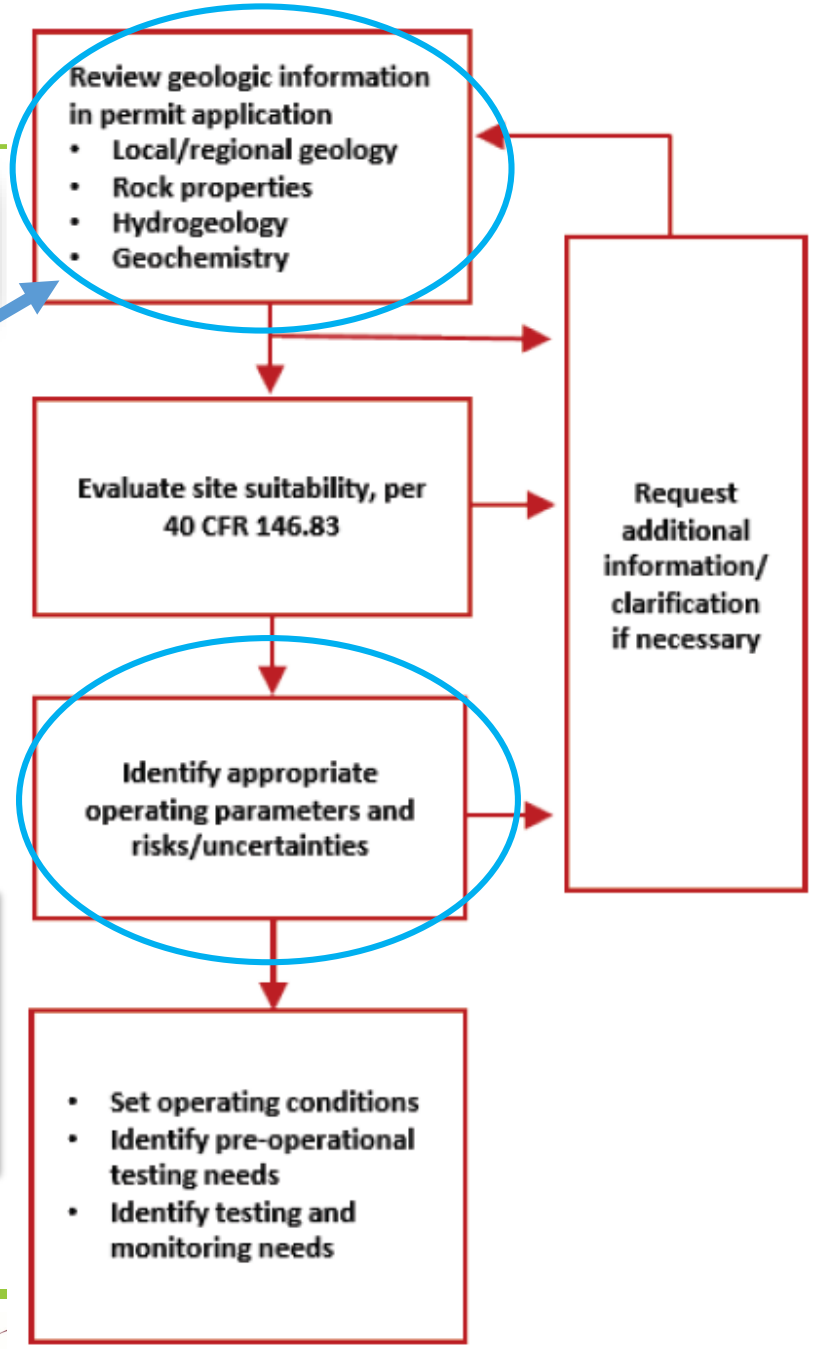


Figure 4-1: Site Characterization Review

described where appropriate. Additionally, the UIC Program reviewers should confirm that secondary data are from reliable sources (e.g., federal or state agencies) and are recent and representative of the proposed site. The geologic data should represent all formations of interest, from the land surface to the injection zone (or to the lower confining zone, if the applicant is seeking an injection depth waiver). Data should be representative of the entire AoR and optimally provide some information on the general area surrounding the AoR. There should also

Source: UIC Program Class VI Implementation Manual for UIC Program Directors

Class VI – AoR & Corrective Action

4.1.2 AoR and Corrective Action

The Class VI Rule requires owners or operators to develop and submit an AoR and Corrective Action Plan as part of their permit application [40 CFR 146.82(a)(4),(13); 146.84(b)]. The plan must document the owner or operator's compliance with the AoR delineation requirements (including the AoR delineation modeling approach), present a comprehensive strategy for AoR reevaluations over the duration of the project, and describe how any necessary corrective action will be conducted.

determination of site-suitability and strategies for compliance with the testing and monitoring, financial responsibility, and emergency and remedial response requirements).

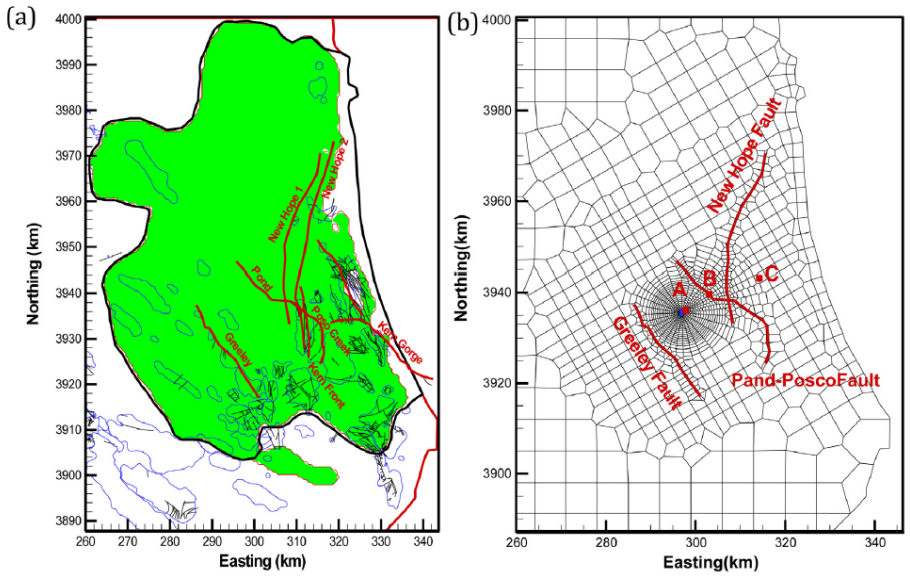
The UIC Program should also review all corrective action information to ensure that all artificial penetrations that may allow fluid movement into USDWs in the AoR are identified and appropriately addressed by corrective action to ensure that they do not serve as conduits for fluid movement.

Source: UIC Program Class VI Implementation Manual for UIC Program Directors

Reservoir characterization can be used for modeling

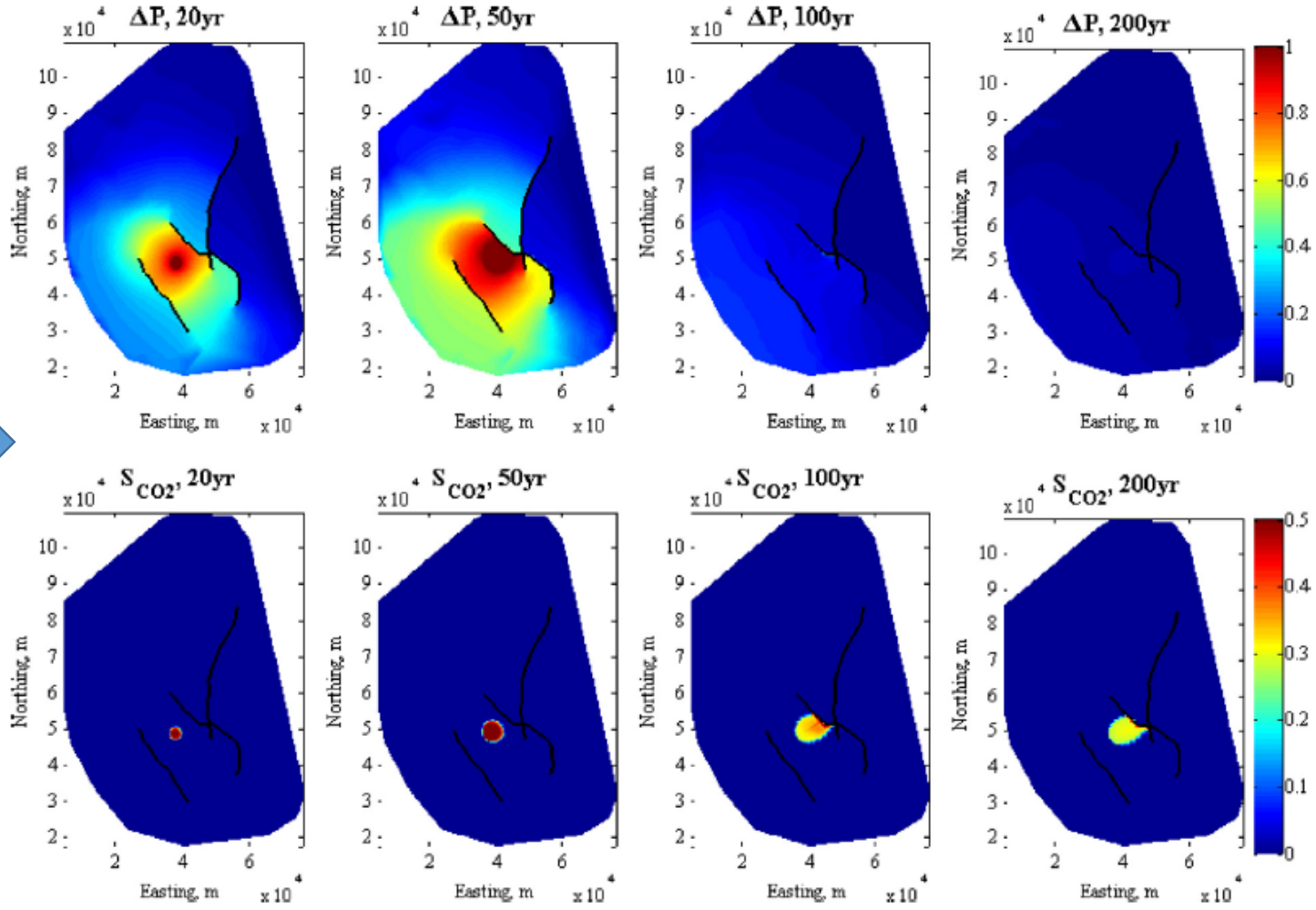
Site Characterization Data

Numerical Reservoir Model

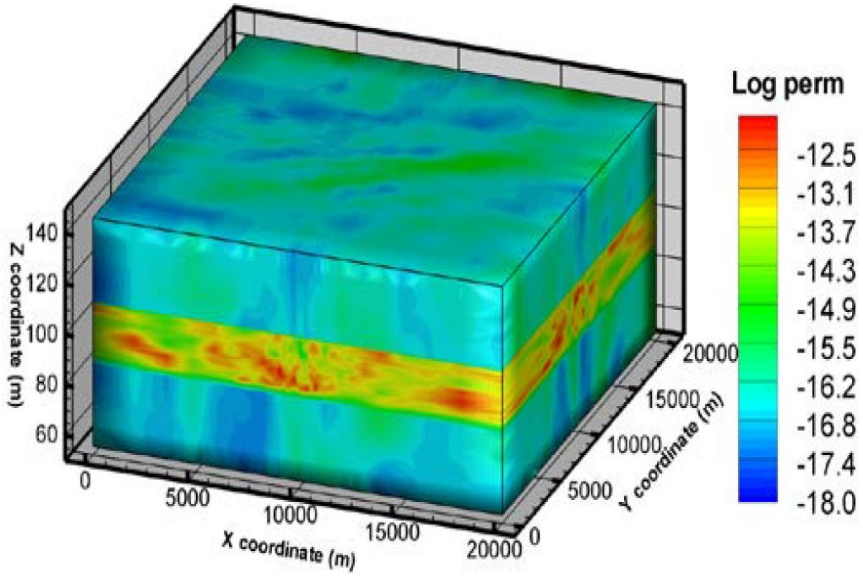


Wainwright et al, IJGGC 2013

Reservoir Simulation Results



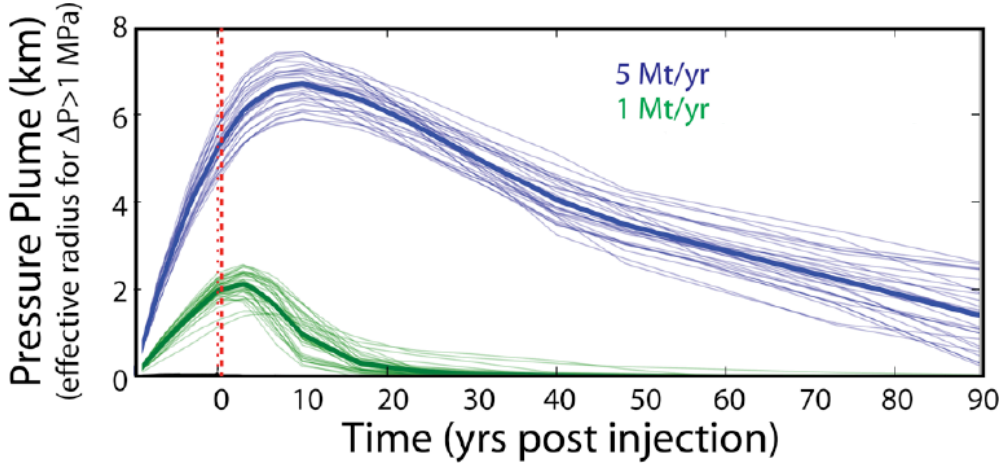
Uncertainties in permeability (& porosity, …) impact predictions of AoR



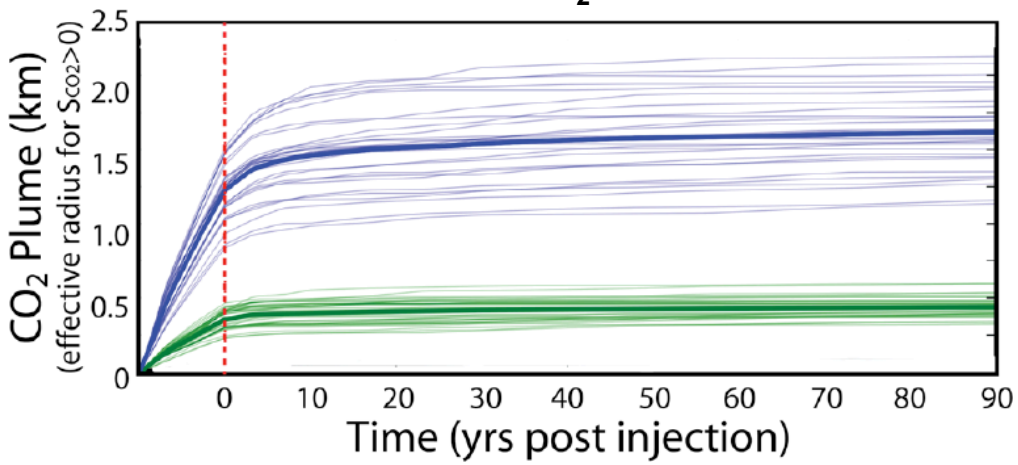
Multiple realizations of permeability distributions developed using site data from multiple wells.

(Pawar et al, Energy Procedia, 2016)

Size of Pressure Plume



Size of CO_2 Plume

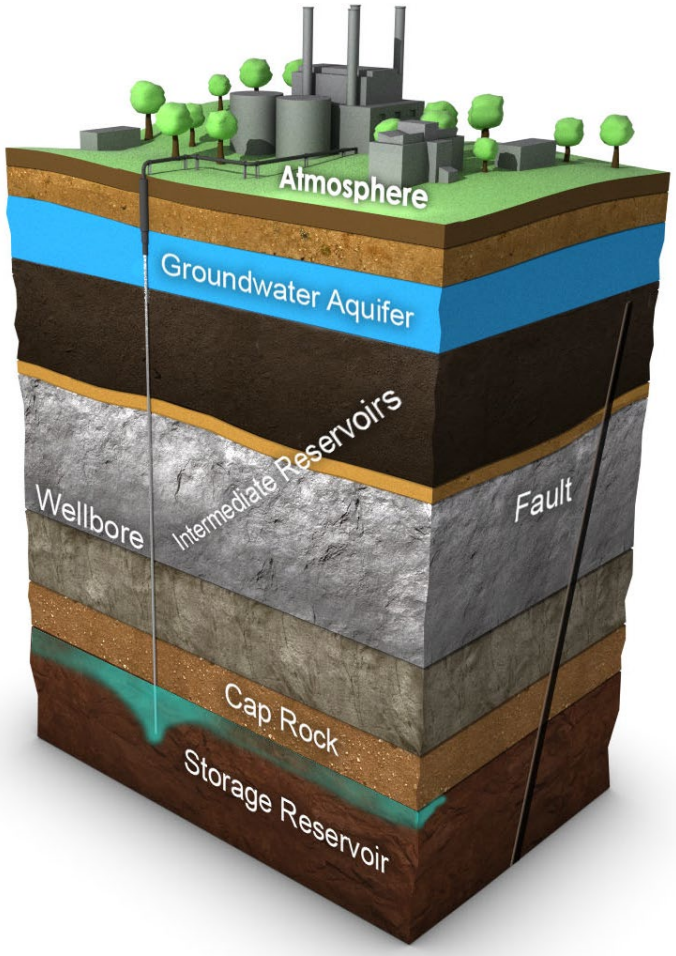


From reservoir simulations to identifying risks of fluid movement through wells

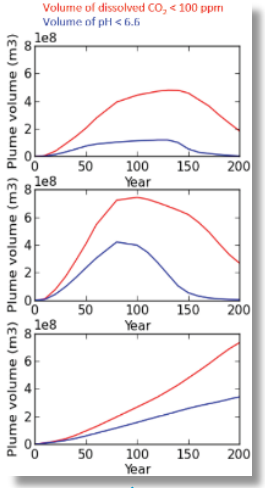
determination of site-suitability and strategies for compliance with the testing and monitoring, financial responsibility, and emergency and remedial response requirements).

The UIC Program should also review all corrective action information to ensure that all artificial penetrations that may allow fluid movement into USDWs in the AoR are identified and appropriately addressed by corrective action to ensure that they do not serve as conduits for fluid movement.

NRAP's Integrated assessment modeling approach: NRAP-Open-IAM

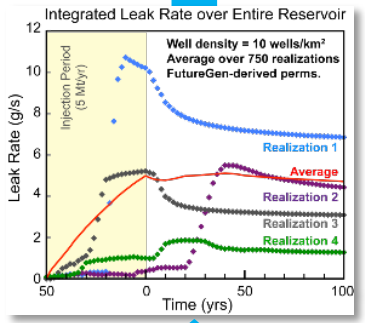


Potential Groundwater Impacts



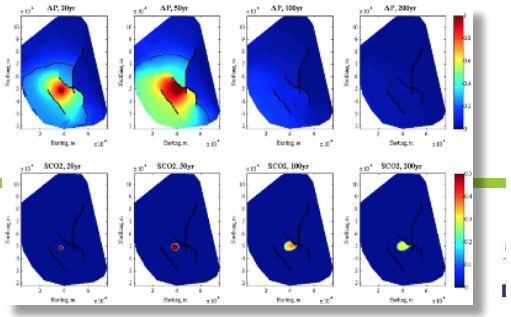
Groundwater pH /TDS change

Potential Fluid Movement



Brine/CO_2 Rate

Reservoir Changes



Pressure & Saturation

NRAP-Open-IAM:

- Demonstrates how a system, from surface to target formation, can be simulated
- Integrates multiple, fast, predictive models (reduced order models, ROMs) for predicting fluid movement and groundwater impacts

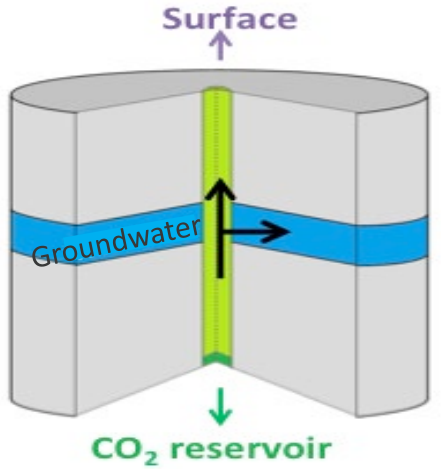
NRAP-Open-IAM:

- "Not" intended to replace existing reservoir simulators
- "Not" aimed at being a catch-all for all GCS sites
- Workflow and design can be adapted for different sites

Wellbore ROM

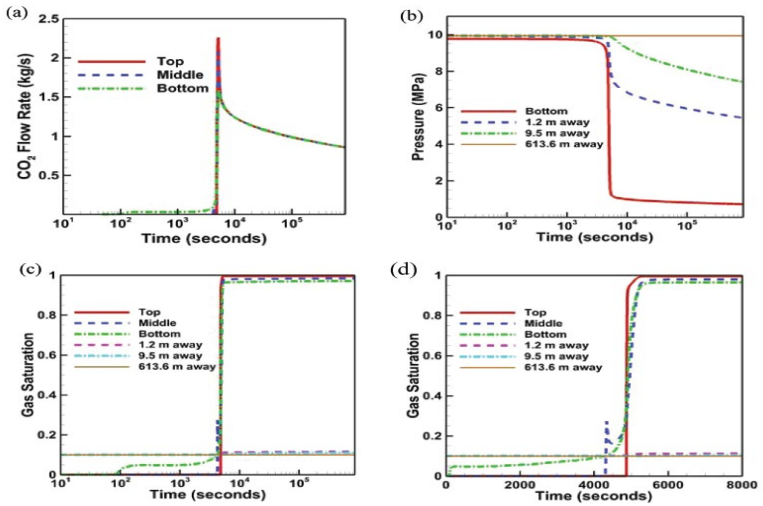
- **Calculate rates of CO_2 and brine flow through a wellbore**
  - Flow into groundwater and atmosphere
  - Account for fluid migration into intermediate permeable zones
- **Two types of built-in ROMs**
  - Cemented wellbore
  - Open wellbore
- **ROMs developed using high-fidelity simulations coupling reservoir and wellbore**
  - Complex physics of multi-phase flow with phase change

Cemented wellbore simulations to develop ROM



(Jordan et al., 2015; Harp, et al., 2016)

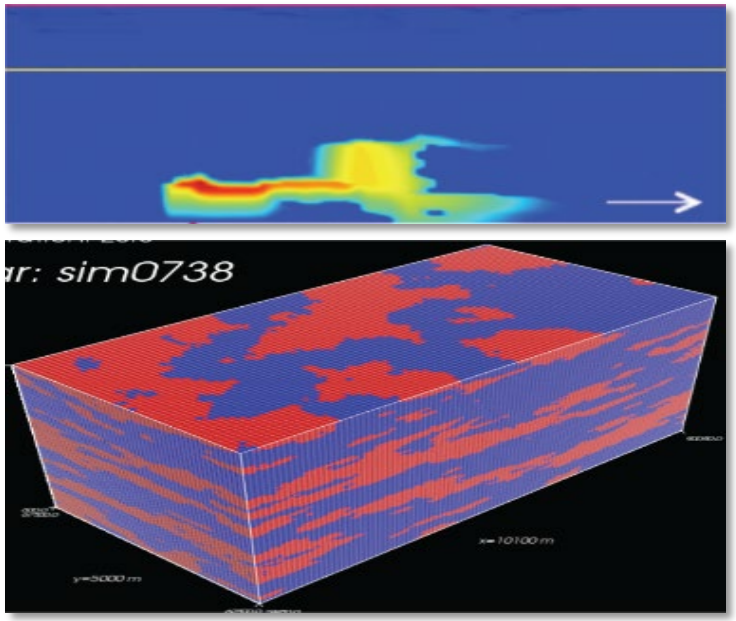
Open wellbore simulations to develop ROM



Aquifer ROM

- **Calculate impacted volume of aquifer above threshold concentrations in case of unintended fluid migration:**
  - pH
  - TDS
  - Trace metals: arsenic, barium, cadmium, lead
  - Organics: benzene, naphthalene, phenol
- **Two threshold values:**
  - MCL
  - No-impact (background 95th percentile) - Last, 2013
- **Two aquifer models:**
  - Unconfined, oxidizing carbonate aquifer (based on Edwards Aquifer)
  - Confined alluvium aquifer (based on High Plains Aquifer)

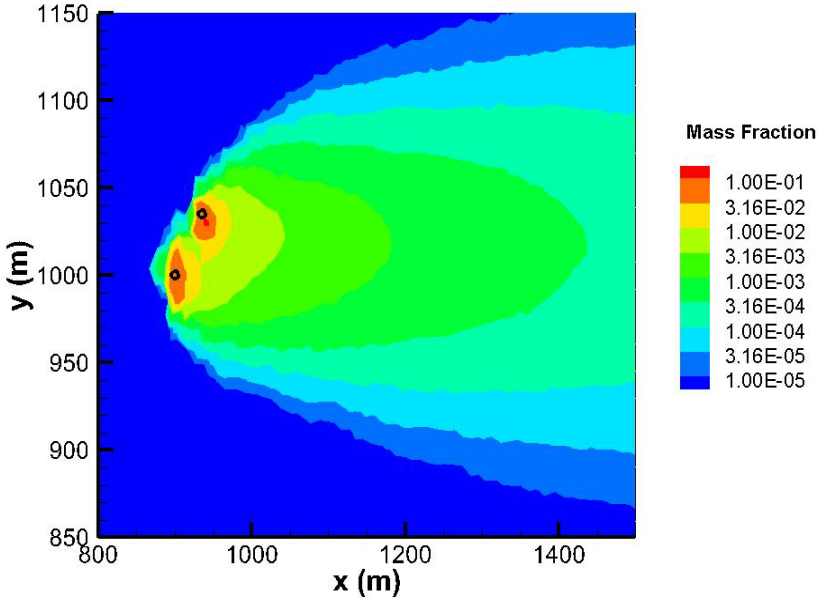
Geochemical simulations of CO_2 and brine flow and subsequent changes in groundwater aquifer to develop ROM

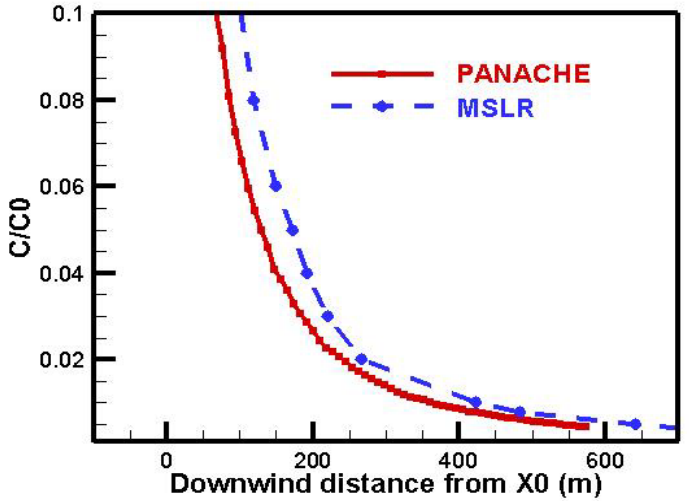


Atmospheric ROM

- **Calculate CO_2 concentration at receptors and critical zone of concentration change**
  - Given locations of leak and potential receptors
- **Account for surface atmospheric conditions**
  - Ambient pressure
  - Ambient temperature
  - Wind velocity at 10 m height
  - Critical concentration
  - Source temperature

Prediction of CO_2 concentration in case of migration to the surface

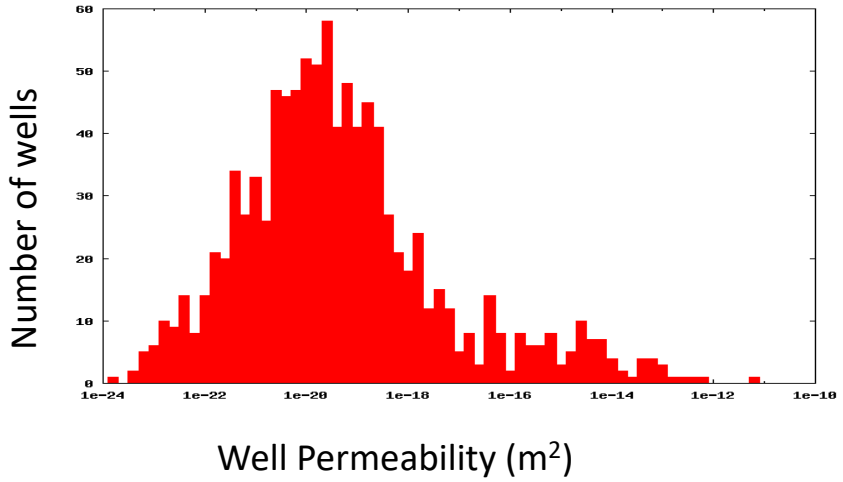




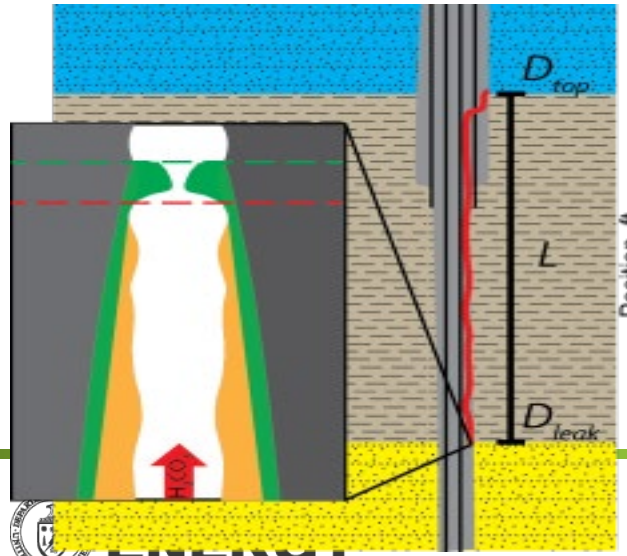
Model verified against CFD simulations

NRAP's Wellbore Characterization Research

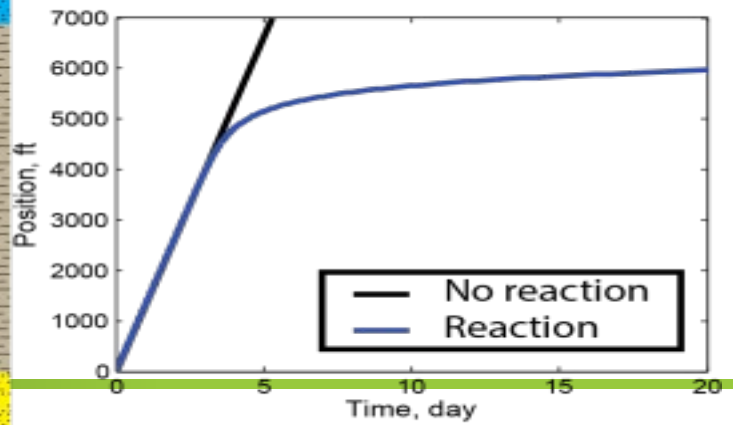
Developed distributions of wellbore cement permeability based on SCP-VF field observations



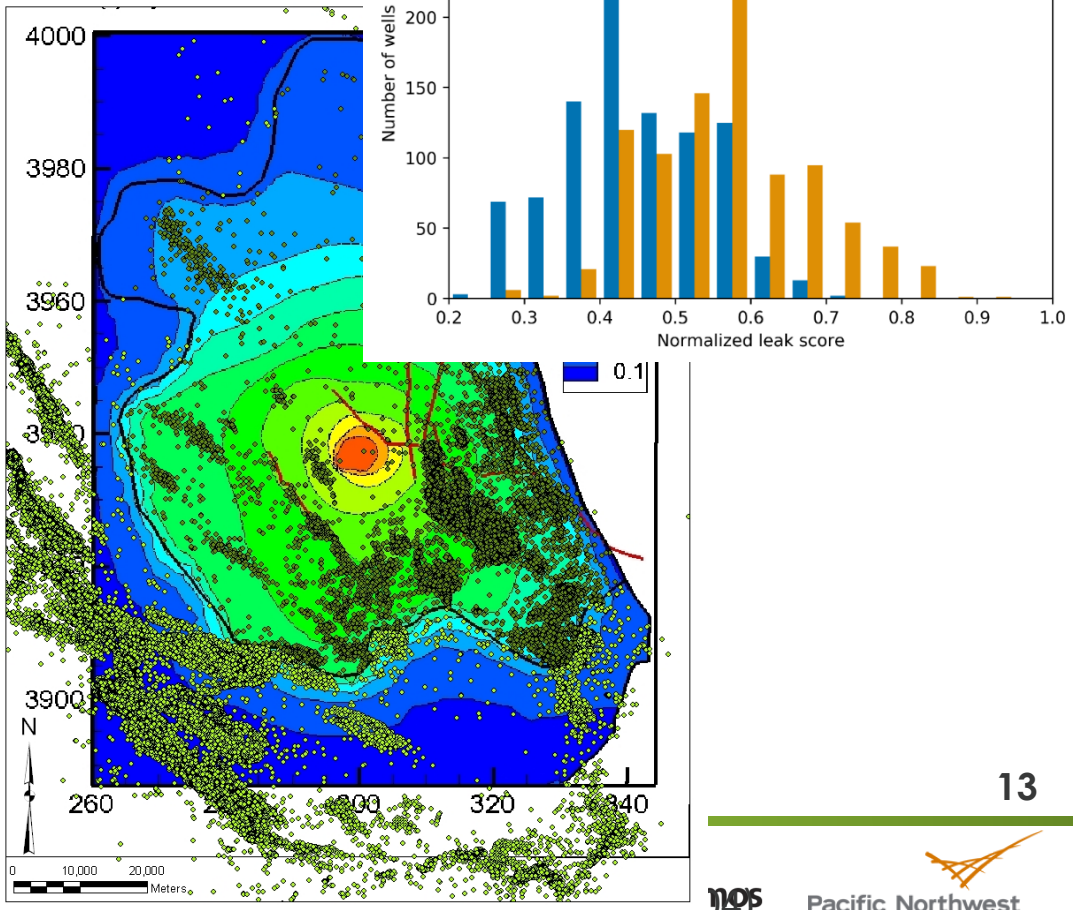
Laboratory experiments to characterize CO_2/Brine flow through fractured cement



(Huerta, et al., 2016)



Methodology for characterization of leakage potential of existing wells



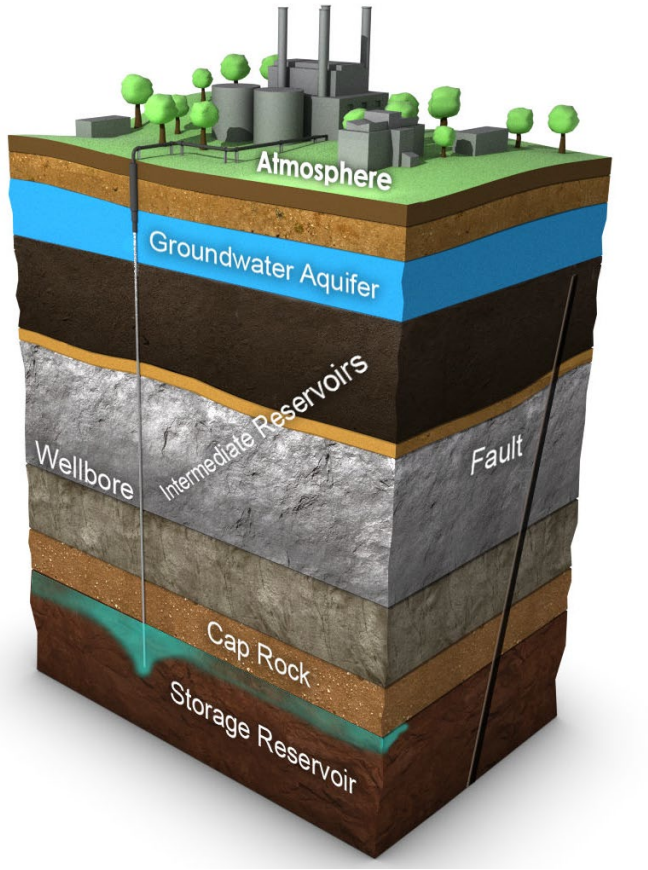
What can be done with NRAP-Open-IAM during pre-injection phase

- **Identify artificial penetrations within AoR that may lead to fluid movement**
  - Compute the probability of unintended fluid migration into groundwater aquifers or the atmosphere
  - Compute impacts of unintended fluid migration on groundwater aquifers based on threshold values

- **Inform decision making while taking into account uncertainties**
  - Determine the importance of parameters and uncertainties on the probability of unintended fluid migration
    - Site characteristics, operational choices, etc.

Review geologic information submitted per 40 CFR 146.82(a). Review this information to confirm that the geologic site characterization is based on appropriately collected site-specific information or relevant existing data or literature about the proposed site; identify any potential site attributes that may affect its suitability for GS; and identify uncertainties to be addressed via pre-operational testing, operational changes, targeted testing and monitoring, or other permit conditions.

NRAP-Open-IAM can be used for site-specific applications

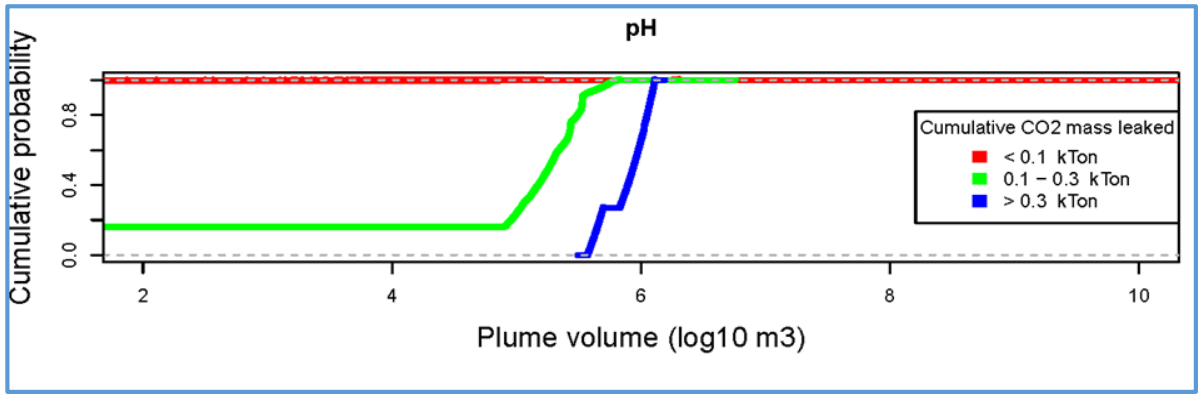


Component	Data
Reservoir	User supplied site-specific simulation results
Wellbore	Location, Type (Cemented/Open), Spatial Density, Cement Permeability
Groundwater Aquifer	Hydrological and Geochemical Parameters
Intermediate Reservoir	Location, Permeability, Thickness
Atmosphere	Elevation, Wind speed, Ambient T & P, Leak Temperature, Detection Threshold

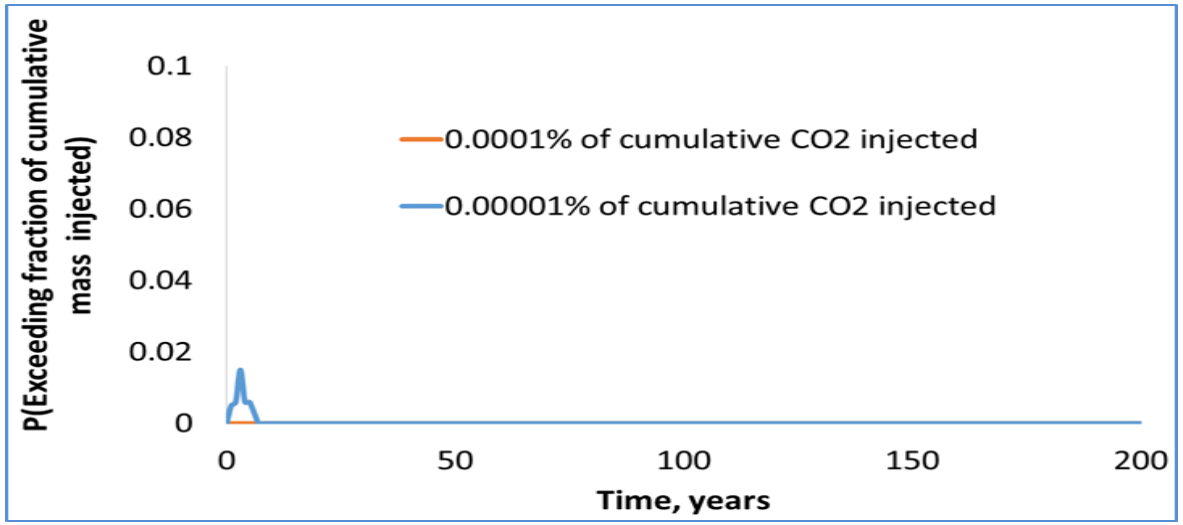
- Parameters can be specified as distributions
- Probabilistic calculations using multiple realizations

Probabilistic assessment of unintended fluid migration and impacts

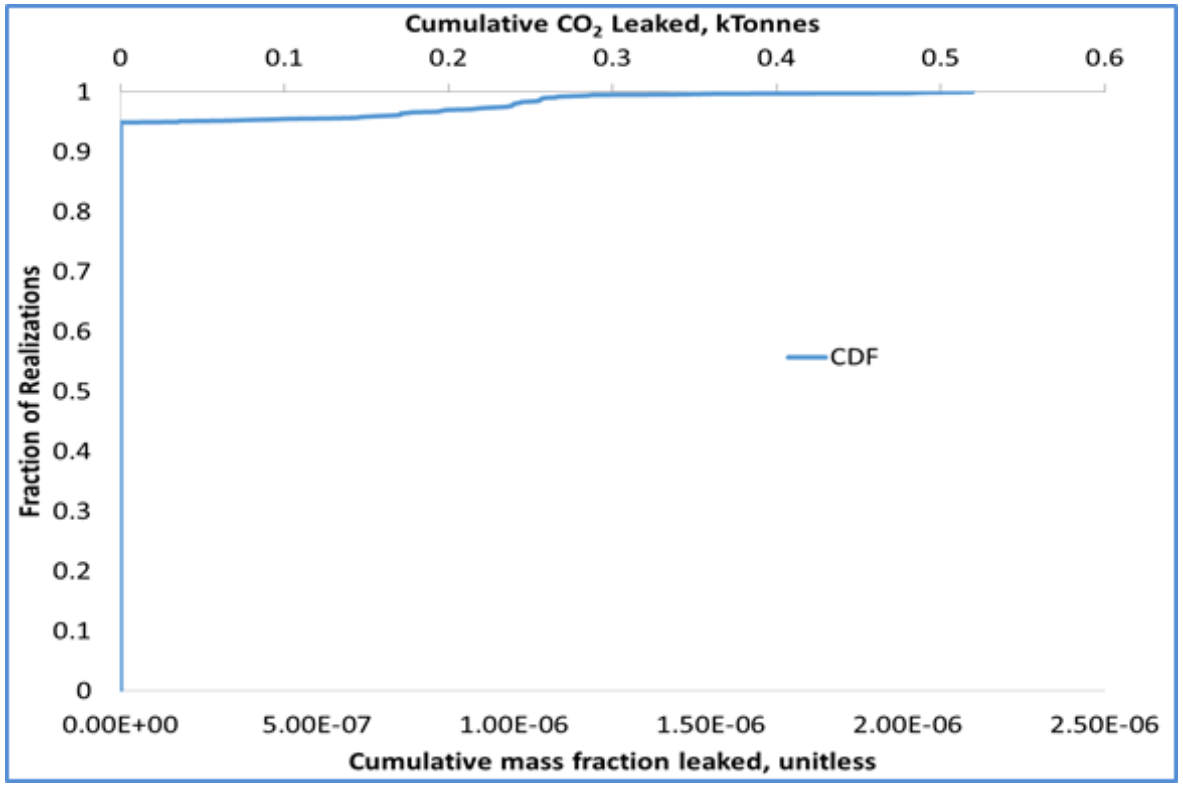
Probability of potential groundwater impact: volume of groundwater with pH change



Probability of CO_2 migration into the atmosphere



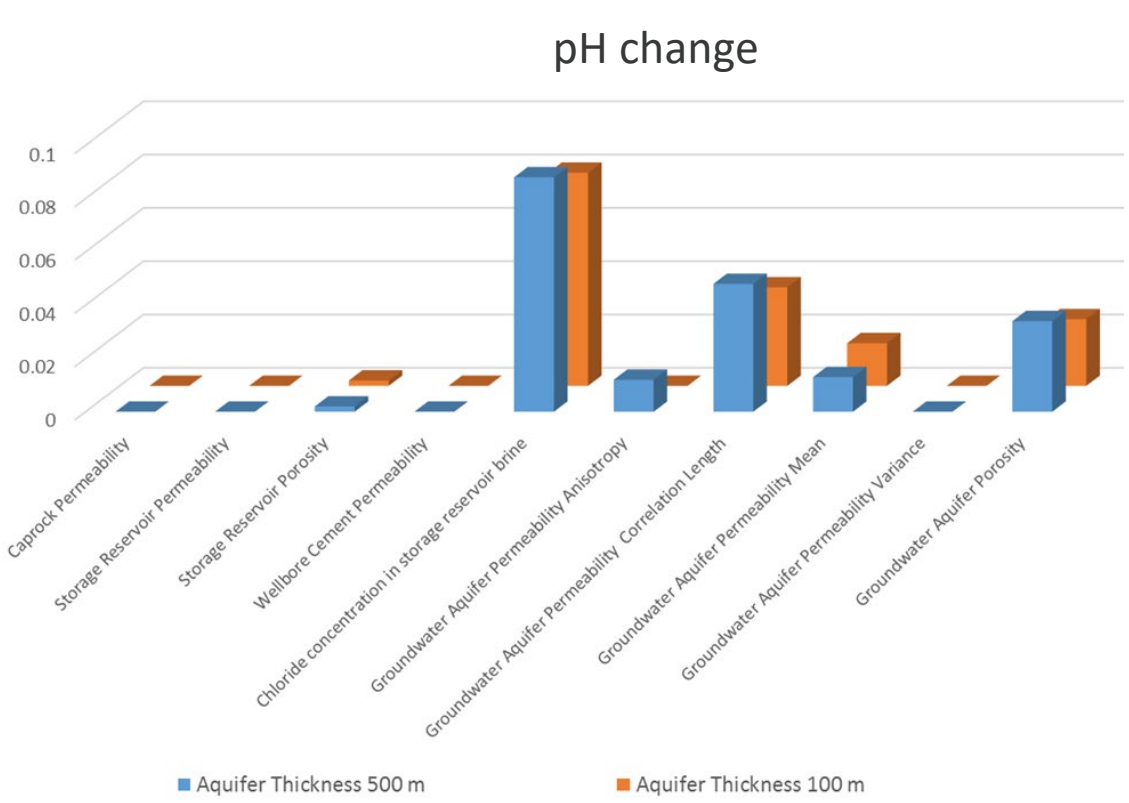
Probability of CO_2 migration out of primary containment

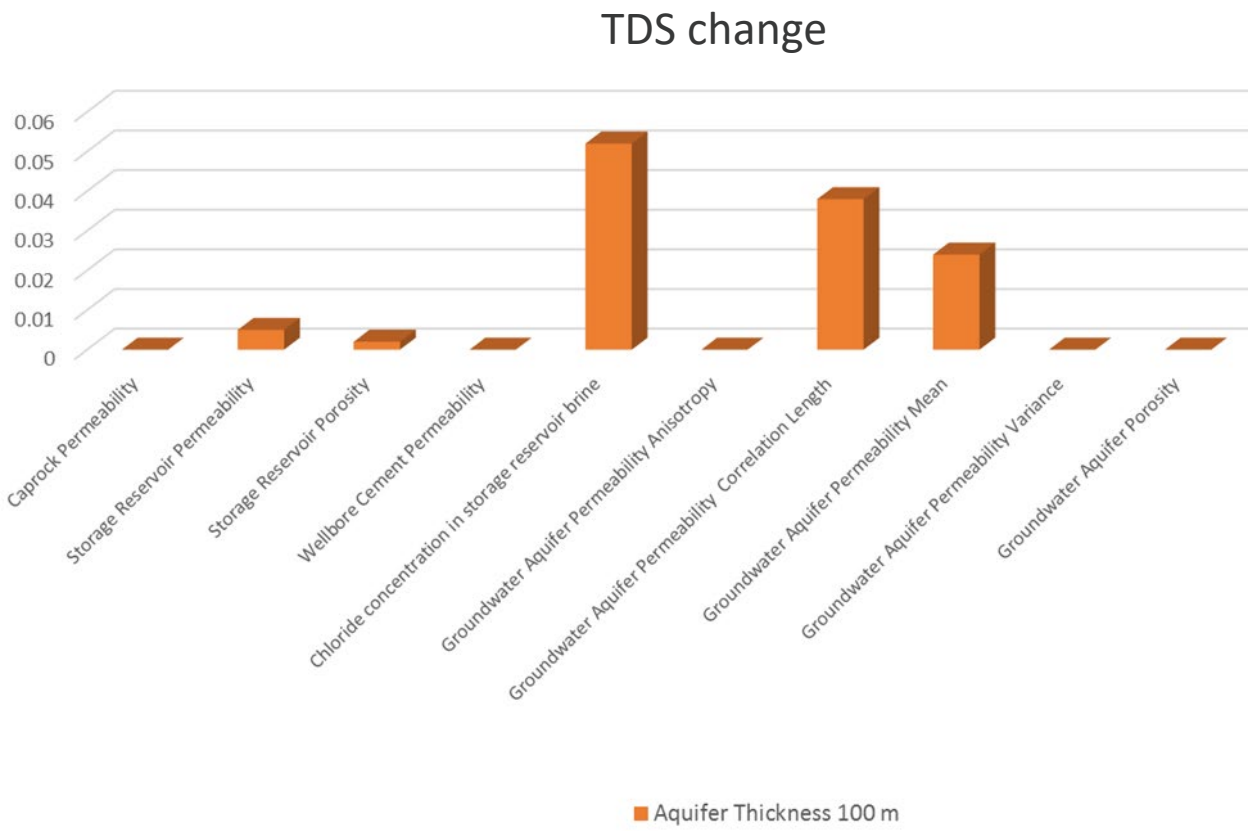


Hypothetical cases, for demonstration only

Assessing impact of uncertain parameters

Importance of different uncertain parameters on impacts of fluid movement into groundwater





Hypothetical case, for demonstration only

Summary

- The Class VI regulations require extensive geologic and hydrogeologic information to demonstrate suitability of a CO_2 storage site.
- Many of the key elements of a GCS site have uncertainties.
- Site characterization data can be used to not only simulate injection response in the reservoir but also potential fluid migration beyond.
- The quantitative framework embodied in the NRAP approach and NRAP-Open-IAM can be used to assess risks of unintended fluid migration at a GCS site.
- NRAP-Open-IAM can also be used to characterize and constrain uncertainty which can aid the decision making process.