



## NRAP Risk Assessment Tool Webinar Series

### Webinar 1

# NRAP-Integrated Assessment Model for Carbon Storage: A Tool for Better Decision Making Amidst Uncertainty

Tuesday October 13, 2015

Presenter: Rajesh Pawar  
NRAP Systems Working Group Lead  
NRAP Lab Lead - Los Alamos National Laboratory

**Contributors:** Rajesh Pawar, (LANL), Robert Dilmore (NETL), Shaoping Chu (LANL), Curt Oldenburg (LBNL), Philip Stauffer (LANL), Yingqi Zhang (LBNL), Grant Bromhal (NETL), George Guthrie (LANL)

### NRAP-IAM-CS

(NRAP's Integrated Assessment Model for CO<sub>2</sub> Storage)

#### OPERATORS

Current Tool and Inputs

View-Only Settings

Results

Run Model

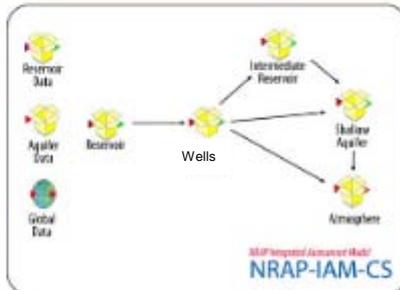
#### INFORMATION

System Administrator

Contact Information

Newsroom

Job Portal



# Outline

- **Welcome and Overview of NRAP – Technical Approach and Tool Development**
- **Introduction to the NRAP Integrated Assessment Model for Carbon Storage (IAM-CS)**
- **Navigating the IAM-CS tool**
- **Example use cases**
- **Demonstration of IAM-CS Viewer**
- **Quality Assurance**
- **Questions and Open Discussion**

# Outline

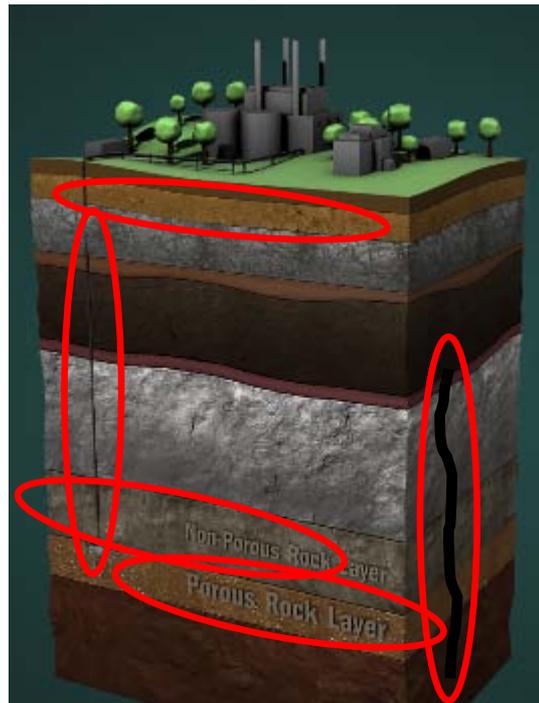
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# National Risk Assessment Partnership (NRAP)

NRAP leverages DOE's capabilities to help quantify uncertainties and risks necessary to remove barriers to full-scale CO<sub>2</sub> storage deployment.

**Objective:** Building toolset and improving the science base to address key questions about potential impacts related to release of CO<sub>2</sub> or brine from the storage reservoir, and potential ground-motion impacts due to injection of CO<sub>2</sub>

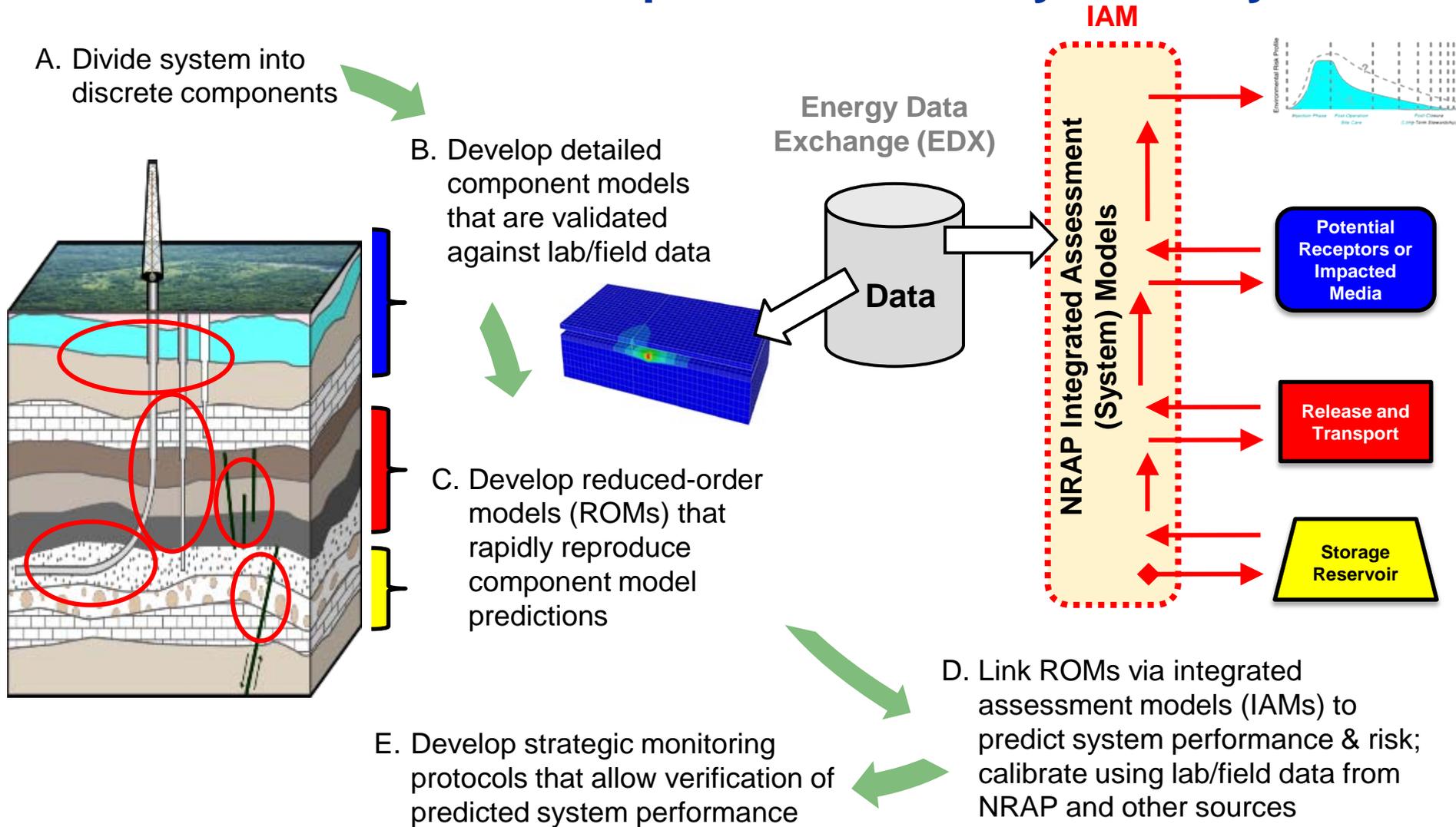
## Technical Team



## Stakeholder Group



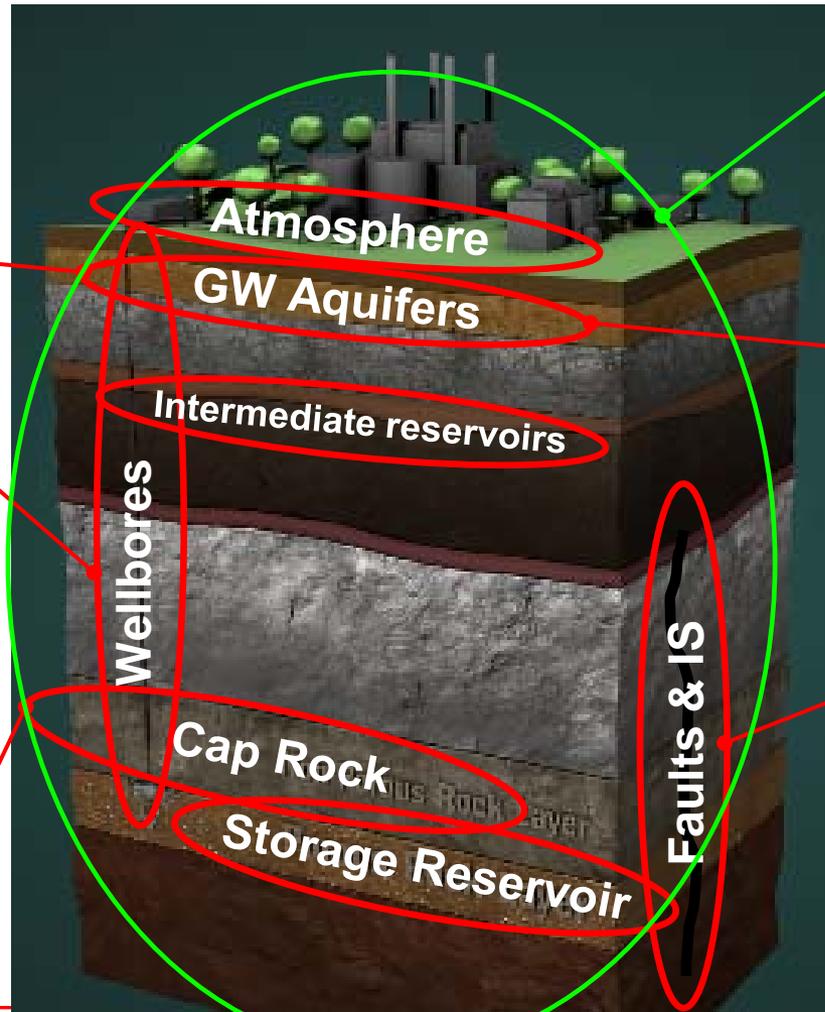
# NRAP's approach to quantifying performance relies on reduced-order models to probe uncertainty in the system.





# NRAP Tools

Now available for beta testing



NRAP-IAM-CS

Design for Risk Evaluation and Monitoring

Aquifer Impact Model

Wellbore Leakage Analysis Tool

Short Term Seismic Forecasting

Natural Seal ROM

Reservoir Evaluation and Visualization

[www.edx.netl.doe.gov/nrap](http://www.edx.netl.doe.gov/nrap) → TOOL BETA TESTING link

# Schedule for NRAP Tool Webinar Series

Date/ Time	Tool	Presenter(s)
<b>October 13</b> <b>Time: 1pm ET</b>	Integrated Assessment Model–Carbon Storage (NRAP-IAM-CS) (2.5 hours)	Rajesh Pawar
<b>October 19</b> <b>Time: 1pm ET</b>	Natural Seal ROM (NSealR) (1 hour)	Nicolas Huerta, Ernest Lindner
<b>October 26</b> <b>Time: 1pm ET</b>	Reservoir Evaluation and Visualization (REV) Tool (1 hour)	Seth King
<b>November 2</b> <b>Time: 1pm ET</b>	Wellbore Leakage Analysis Tool (WLAT) (1.5 hour)	Nicholas Huerta
<b>November 9</b> <b>Time: 1pm ET</b>	Aquifer Impact Model (AIM) (1.5 hour)	Diana Bacon
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<b>December 7</b> <b>Time: 1pm ET</b>	TBD	

Check for updates at [www.edx.net/doi.gov/nrap](http://www.edx.net/doi.gov/nrap)

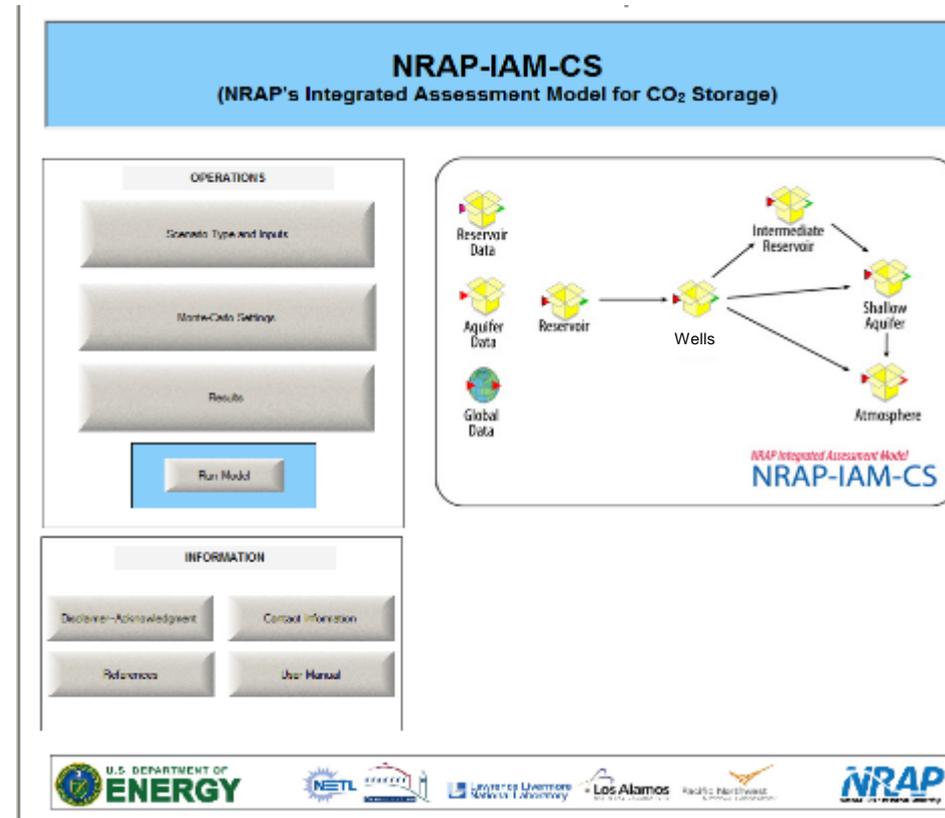
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# What is NRAP-IAM-CS?

- An integrated model that can be used to predict leakage-related behavior of a CO<sub>2</sub> storage site
- Simulate long-term full system behavior (reservoir to aquifer/atmosphere)
- Take into account key site-specific unknown or variable parameters

NRAP-IAM-CS Front Page



# What can be done with NRAP-IAM-CS?

- **Capture important system behavior to:**
  - Evaluate the probability of potential leakage into groundwater aquifers or the atmosphere
  - Evaluate impacts of potential leaks on groundwater aquifers based on user-specified threshold values (e.g. MCL or no-impact)
  - Determine the impact of system parameters and uncertainties (e.g., reservoir, wellbore properties) on the potential for leakage
- **Inform decision making while taking into account uncertain site characteristics**
  - Example 1: Will legacy wells compromise storage containment goals? If so, which wells?
  - Example 2: What systems level trends impact effective and efficient monitoring strategy during and post injection?
- **Can be used by multiple stakeholders: regulators, site operators, policy makers**

# Accessing and Using NRAP-IAM-CS

- **Where do I get it?** <http://edx.netl.doe.gov>
- **Do I need a license?** No, but registration required
- **What platform will I need to run it?** Windows machine; Mac (e.g., running Windows in Boot Camp or VMware Fusion)
- **How do I install it?** Unzip the file from EDX; install GoldSim player (available free from <http://goldsim.com>); double click the example model (provided). Details are in the manual
- **How do I run it?** NRAP-IAM-CS has a simple-to-use GUI (will be shown during the demo) with some visualization capability built in; it also comes with a versatile Java program to visualize results; Details are in the manual
- **How do I get help if there are questions or bugs?** Feedback forms are available when downloaded. Address questions to [NRAP@netl.doe.gov](mailto:NRAP@netl.doe.gov)
- **Can I input site-specific information into NRAP-IAM-CS?** Yes

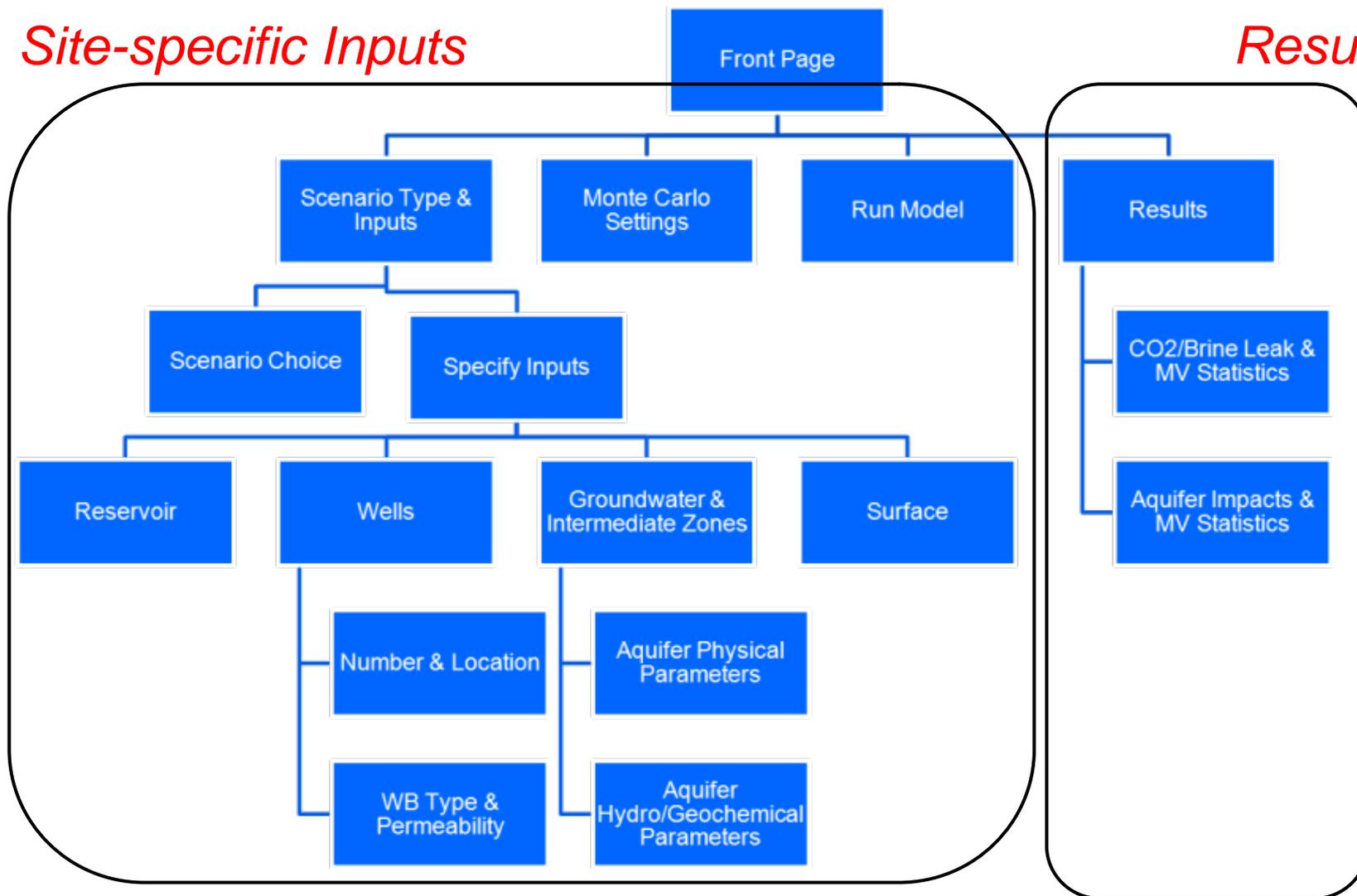
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# NRAP-IAM-CS has interfaces to input data and access results

*Site-specific Inputs*

*Results*



# Example input dashboard for reservoir

## Simple Reservoir Characteristics

**Reservoir Domain**

X min (m)  Y min (m)

X max (m)  Y max (m)

Reservoir elevation (m)

Reservoir Initial Pressure (MPa)

Reservoir Initial Temperature (°C)

### Reservoir Parameters

### Use Single Value

### Sample from Distribution

Thickness (m)

Uniform

Mean

Std. Dev.

Min

Max

Permeability (m<sup>2</sup>)

Uniform

Porosity

Uniform

Residual Water Saturation

Uniform

Residual CO<sub>2</sub> Saturation

Uniform

### Location of CO<sub>2</sub> Injection Well

X (m)  Y (m)

### CO<sub>2</sub> Injection Parameters

CO<sub>2</sub> Injection Rate (tonnes/day)

Maximum Injection Pressure (MPa) to avoid seal fracture

CO<sub>2</sub> Injection Duration (Years)

Back to RESERVOIR

Back to STORAGE

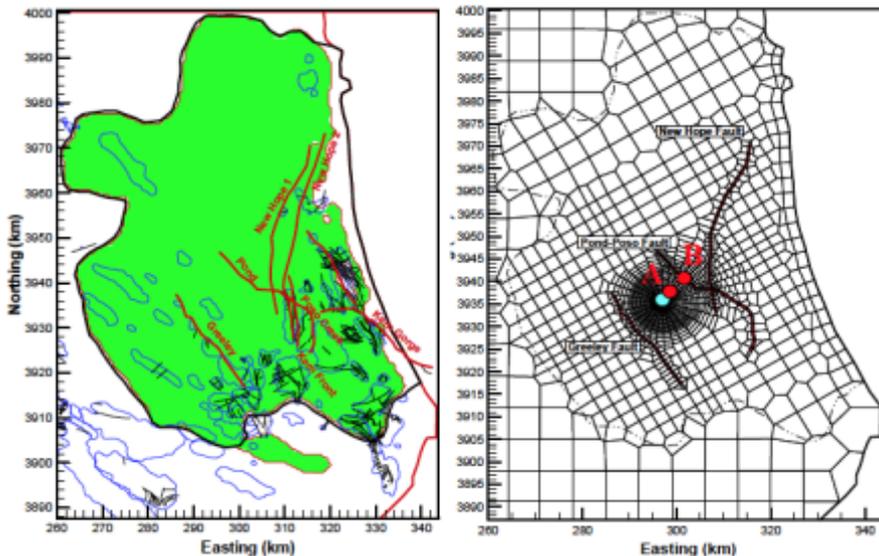
# User can perform site-specific calculations

Component	Data
Reservoir	Can choose: Built-in ROM (semi-analytical model), User supplied site-specific simulation results Specify: Spatial Extent, Permeability, Thickness, Porosity, Injection parameters
Wellbore	Built-in ROM Location, Type (Cemented/Open), Spatial Density, Cement Permeability
Shallow Aquifer	Built-in ROMs for Carbonate and Sandstone aquifers Aquifer Hydrological and Geochemical Parameters
Intermediate Reservoir	Location, Permeability, Thickness
Atmosphere	Built-in ROM Elevation, Wind speed, Ambient T & P, Leak Temperature, Detection Threshold

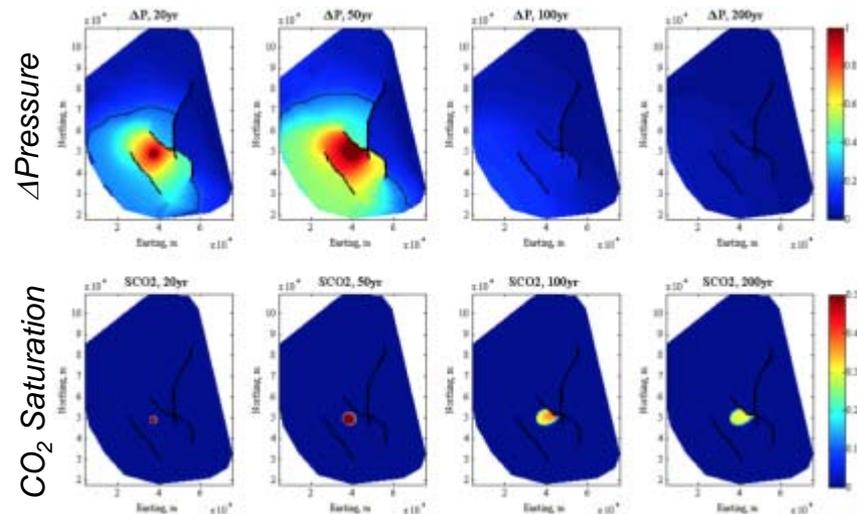
Specify site-specific data and design scenarios of interest

# Site-specific application: reservoir simulations

- Many site-specific studies have reservoir simulation results of CO<sub>2</sub> injection and subsequent migration
  - Reservoir simulation results can be directly brought in and stored as lookup-tables:
    - **Scripts to write lookup tables have been developed for TOUGH2, FEHM, CMG-GEM, STOMP generated results (further details during REV Webinar)**
  - During IAM simulation the look-up tables are used to determine pressure and saturation at the top of reservoir as function of location and time

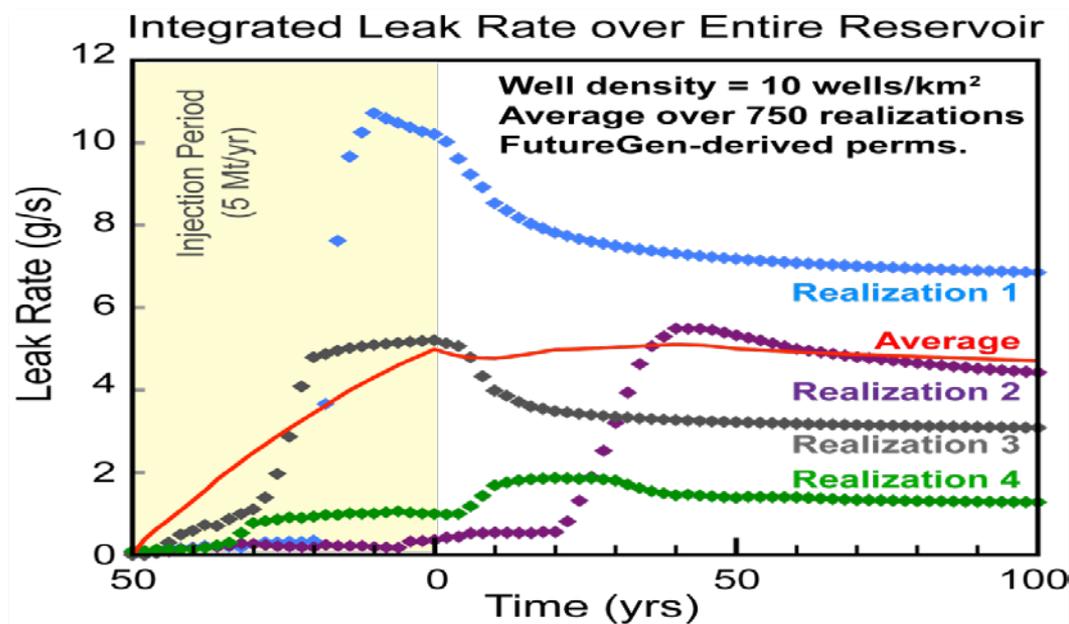


Example simulation of a site (Kimberlina) using TOUGH2



# IAM Outputs

- **Time-dependent CO<sub>2</sub> and brine leakage rate through wellbores**
  - To atmosphere, intermediate aquifer, groundwater
  - Plots and data



- **Time-dependent volumes of groundwater impacts**
  - pH, TDS, metals, organics
  - Plots and data

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# What decisions can be informed using the NRAP-IAM-CS: Example 1

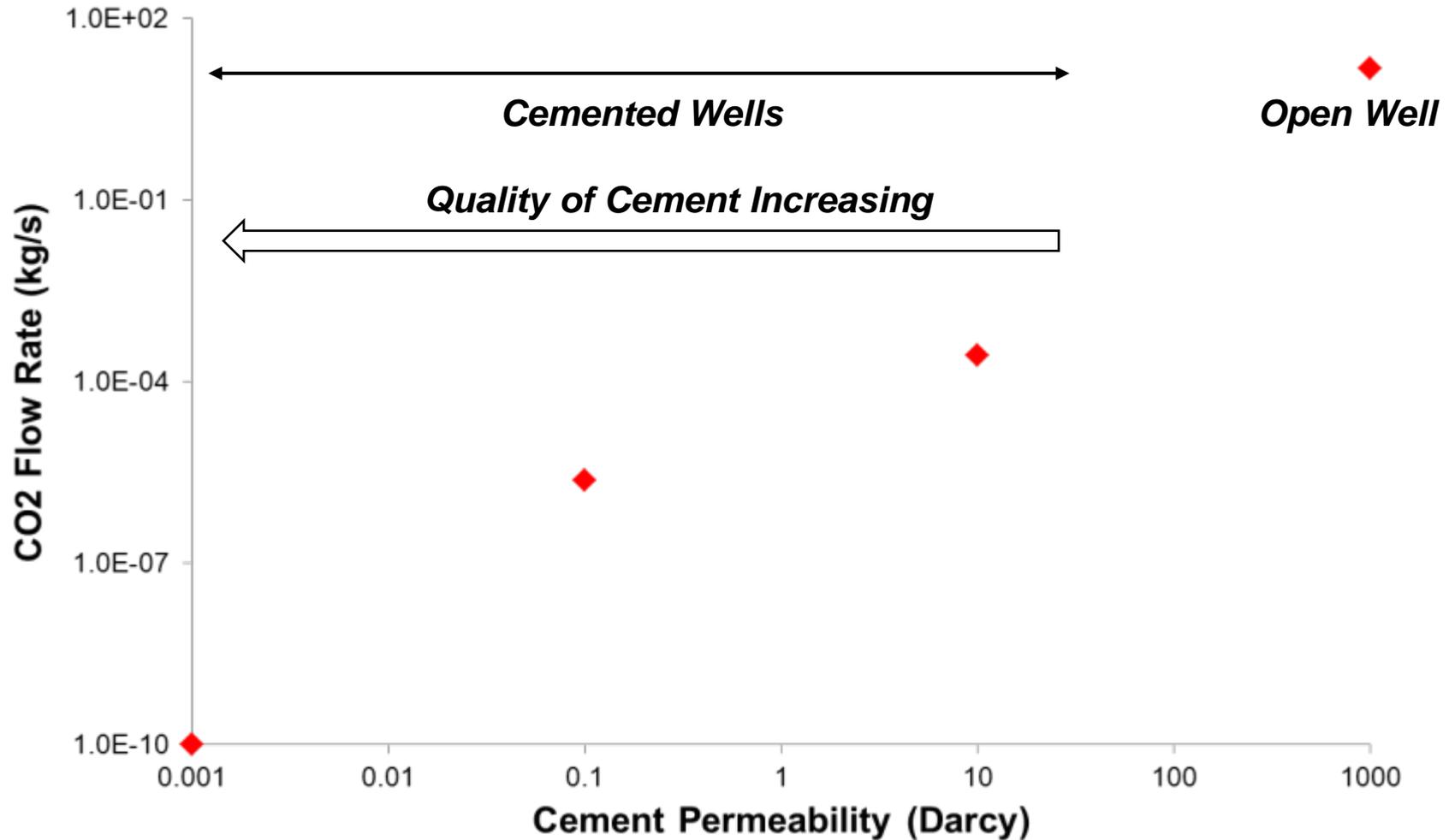
- **Will legacy wells compromise storage containment goals?**
  - Will all the wells in my reservoir be impacted due to CO<sub>2</sub> injection?
  - How will injection operational parameters affect the impacted wellbores?
- **Scenario: Potential CO<sub>2</sub> leakage through wellbores at a saline reservoir site**

# Example 1: Setup

- **Hypothetical scenario for demonstration purpose only**
- Model includes: a saline reservoir and wellbore
  - Site-specific reservoir parameters:
    - ❖ Spatial extent : 10 km x 10 km
    - ❖ Porosity: 0.2
    - ❖ Permeability: 3 Darcy
    - ❖ Thickness: 20 m
  - User-defined injection rates: 50 tpd, 500 tpd
    - Injector at 5 km x 5 km
    - Use built-in reservoir ROM to calculate pressure and saturation
  - Assess impact of wellbore location and type: vary wellbore location and type (open or cemented)
  - IAM is used to compute CO<sub>2</sub> leak rate to atmosphere

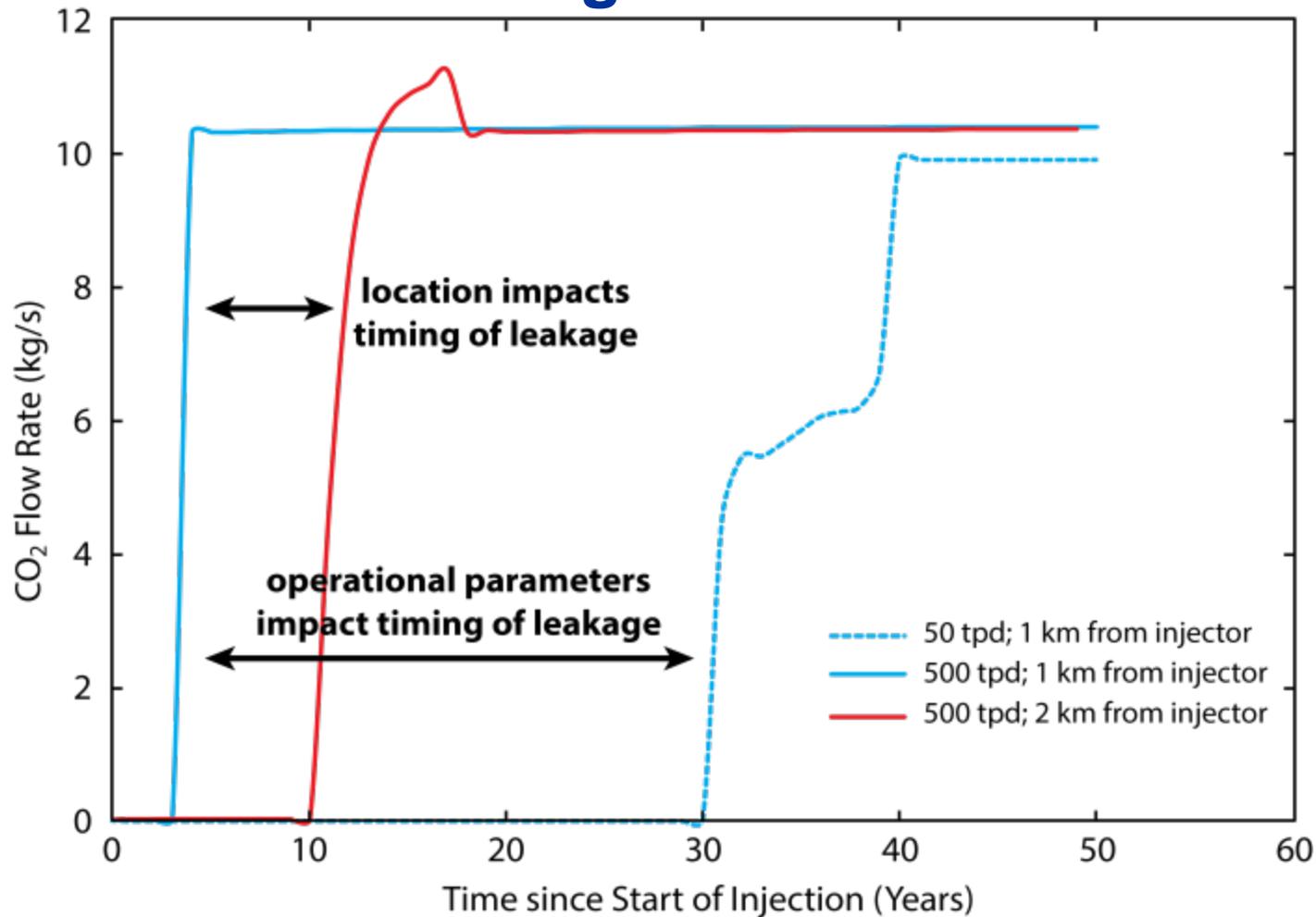
# Example 1: IAM Walkthrough

# How does well type affect leakage?



*Wellbore location: 1 km from injector*

# How do operational parameters affect leakage?



***Effect of injection rate and wellbore location***

# What decisions can be informed using the NRAP-IAM-CS: Example 2

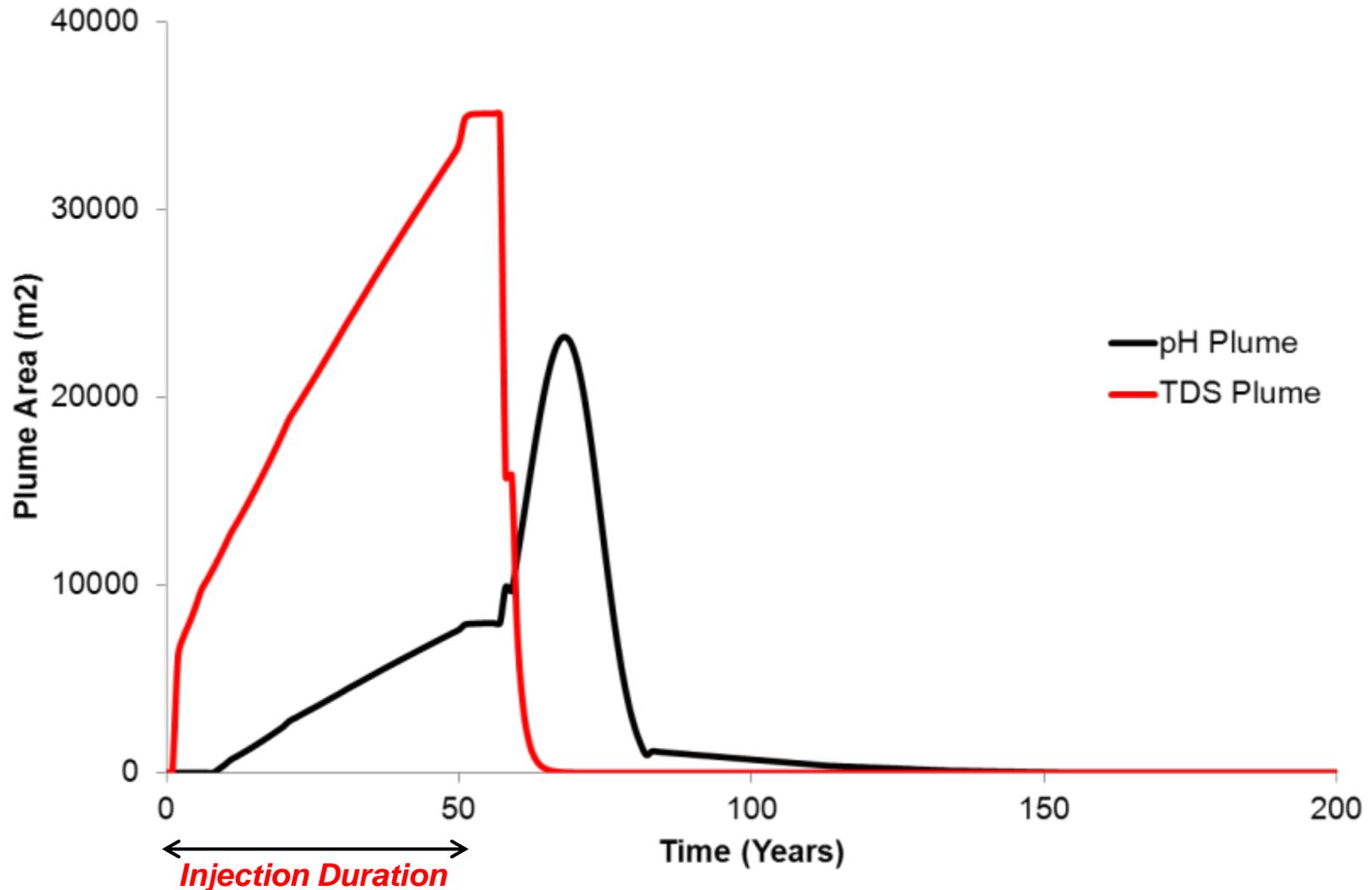
- **What is an effective and efficient groundwater monitoring strategy during and post injection?**
  - What area do I need to monitor?
  - When?
  - How long do I need to monitor?
- **Scenario: Potential brine and CO<sub>2</sub> leakage through wellbores into groundwater aquifer at a saline reservoir site**

# Example 2: Model Setup

- **Hypothetical scenario for demonstration purpose only**
- Reservoir, Intermediate Reservoir, Cemented wellbore
  - User-performed site-specific reservoir simulation (multiple runs)
    - ❖ Example calculations use results of simulations with TOUGH2 for Kimberlina site: 5 MT/yr CO<sub>2</sub> injection rate, 50 yrs injection with 150 yrs post-injection
    - ❖ Lookup tables for reservoir pressure and saturation developed with scripts
  - Assess impact of wellbore location
    - ❖ Wellbore location varied
    - ❖ Assumed wellbore cement permeability: 10 D
  - ❖ IAM is used to calculate CO<sub>2</sub> and brine leak rates into the groundwater and subsequent impacts

# Example 2 IAM-Walkthrough

# What type of chemical signals can be monitored in groundwater during and post-operations?



# Probabilistic Assessment & Uncertainty Analysis

- **The main advantage of NRAP-IAM-CS is ability to perform Monte-Carlo simulations**
  - Multiple realizations (10s-100s of thousands)
  - Specify uncertain/variable parameters as distributions
- **Example: 500 realizations of CO<sub>2</sub> leakage through a unknown cemented wellbore at a saline reservoir site**
  - **Hypothetical scenario for demonstration purpose only**
  - Saline reservoir assumed to be similar to Kimberlina
  - Wellbore location and cement permeability assumed to be unknown

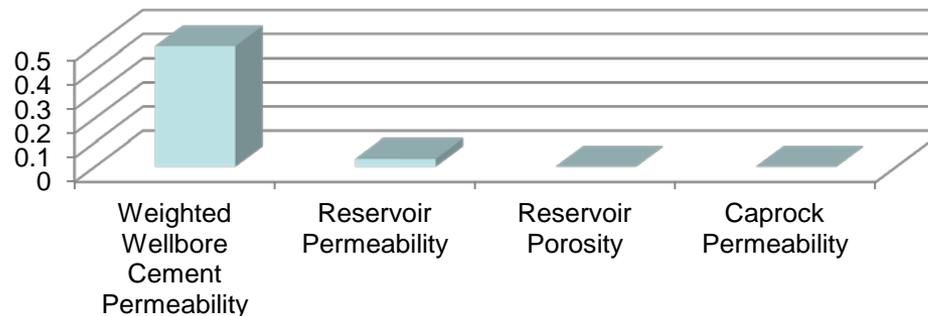
# Example 3 IAM-Walkthrough

# NRAP-IAM-CS provides results of multi-variate analysis

## Multi-variate correlations

	CO <sub>2</sub> Leak Rate	Wellbore Cement Permeability	Reservoir Permeability	Reservoir Porosity	Caprock Permeability
CO <sub>2</sub> Leak Rate	1	0.155	0.094	0.006	0.011
Wellbore Cement Permeability	0.155	1	0.069	-0.055	-0.055
Reservoir Permeability	0.094	0.069	1	-0.043	0.034
Reservoir Porosity	0.006	-0.055	-0.043	1	-0.066
Caprock Permeability	0.011	-0.055	0.034	-0.066	1

## Importance Measure

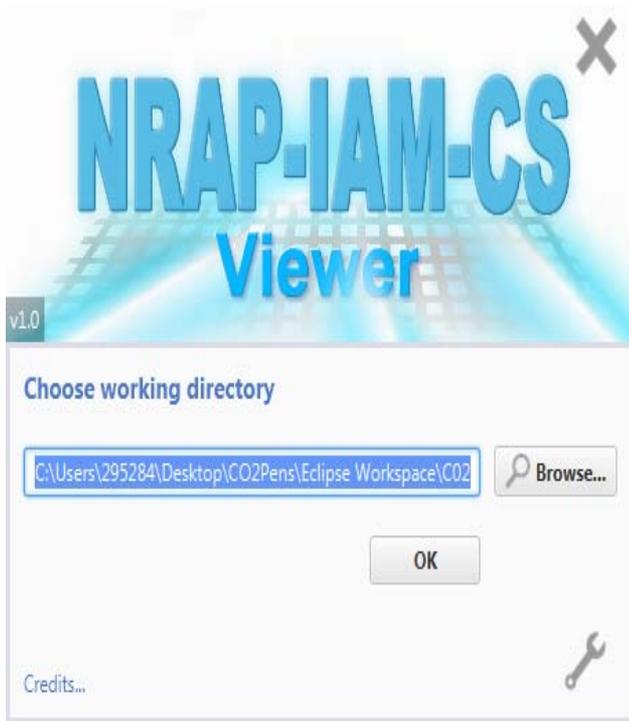


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# NRAP-IAM-CS Viewer

**A JAVA-based tool to visualize and explore results from NRAP-IAM-CS realizations**



The main interface of the NRAP-IAM-CS Viewer is shown with several components labeled with red boxes and lines:

- Color Scale**: A vertical color bar on the left side of the main window, ranging from blue at the bottom to red at the top.
- Animation Panel**: A central panel containing a 2D visualization of a reservoir with a color-coded area.
- Reservoir Property Info**: A panel on the right side showing details for a selected reservoir, including "CO2 Saturation at selected node and time step" and "CO2 Saturation at selected node over time" with a line graph.
- Leakage Info**: A panel on the right side showing details for a selected leakage node, including "Leakage" and "Leakage over time" with a line graph.
- General Node Info**: A panel on the right side showing general information for a selected node.
- Time Navigator**: A panel at the bottom left containing a timeline slider and playback controls (play, stop, previous, next).
- Options**: A panel at the bottom center containing various settings like "Color scale", "Number of contours", and "Axis labels".
- Plotting**: A panel at the bottom right containing a "Memory Usage" section with two progress bars and a "Show as: Reservoir" button.

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# NRAP-IAM-CS is going through a QA/QC process

- **Quality Assurance/Quality Check (QA/QC):**
  - In progress
  - Various sub-system ROM (reduced order model) predictive capabilities have been compared against detailed process-level simulations
    - Reports with details available on EDX
  - The IAM implementation of ROMs is currently being tested
    - Reports with details will be made available on EDX
  - The IAM performance is being tested through applications as part of internal beta-testing

# Verifying Cemented Well/Reservoir Decoupling

**nrap**  
National Risk Assessment Partnership

**Assessment of Decoupling Wellbore Leakage from Reservoir Flow in Reduced-Order Models**

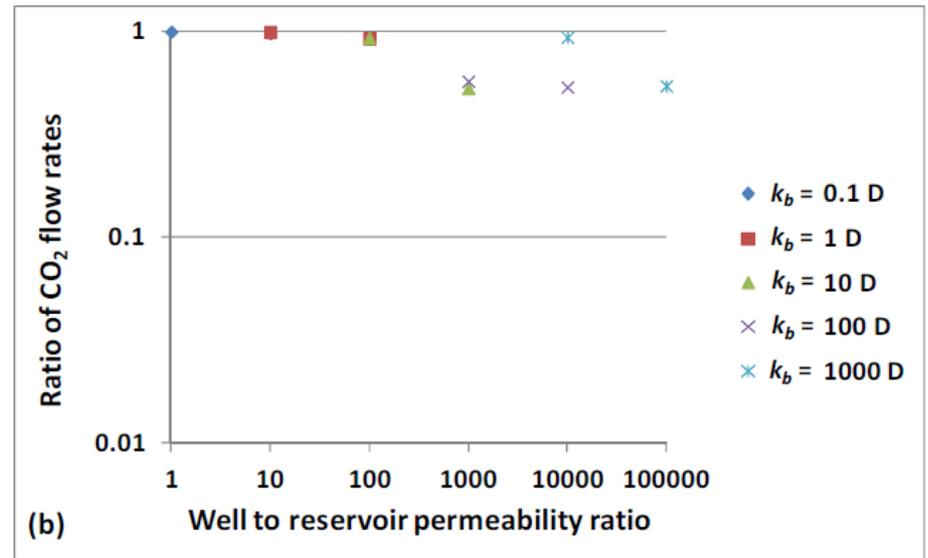
3 January 2013

U.S. DEPARTMENT OF ENERGY  
NETL

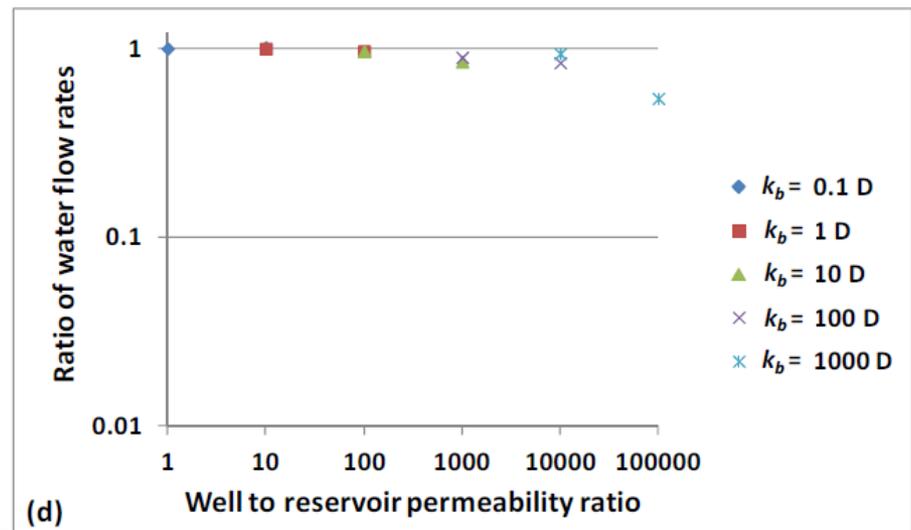
Office of Fossil Energy  
NRAP-TRS-III-001-2013

*“Coupled effects between the reservoir flow restrictions and well leakage have been found to be relatively weak if well-to-reservoir permeability ratios are 100 or less and if CO<sub>2</sub> saturations in the reservoir are not too small.”*

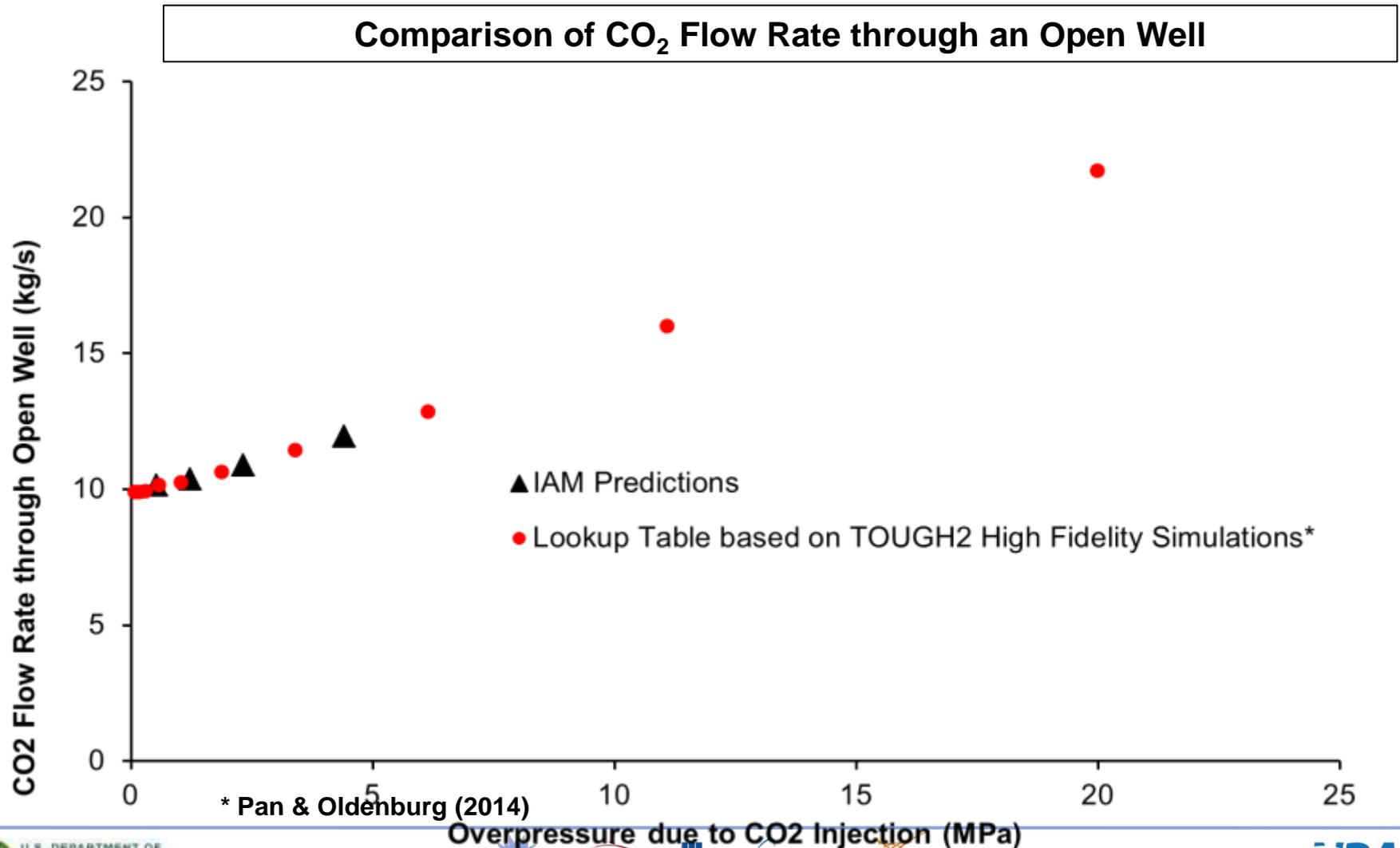
## CO<sub>2</sub> Flux



## Brine Flux



# Comparison between IAM and Fully Coupled High Fidelity Models



## Comments and Questions

- To manage Q&A session, we request that you “raise your hand” in the webex comment window. The speaker will call on meeting participants consecutively from the queue of questions one at a time.
- Please keep your phone line muted until your name is called.
- Questions/comments not addressed during the scheduled meeting time can be addressed to [NRAP@netl.doe.gov](mailto:NRAP@netl.doe.gov)
- Thank you!

# Beta Tool and User Manual Available on EDX

## NRAP Tool Beta-Testing Portal

The screenshot shows the EDX (National Energy Technology Laboratory's Energy Data eXchange) website. At the top, there is a search bar and navigation links like 'Home', 'Search', 'My EDX', etc. The main content area is titled 'NRAP Tools Beta Testing' with a URL <https://edx.netl.doe.gov/nrap/>. Below the title is the NRAP logo and a question: 'Would you like to participate in NRAP tools beta testing?'. A paragraph of text follows, explaining that the National Risk Assessment Partnership (NRAP) has developed simulation tools for beta testing, seeking input from interested testers for a carbon storage subsurface containment system.

## NRAP-IAM-CS User's Manual

The cover of the user's manual features the NRAP logo at the top left. The central graphic is a multi-scale diagram showing four levels: Site Scale (0.1km-10km) with an injection well and abandoned oil/gas wells; Reservoir Scale (10km-100km) showing a reservoir with CO<sub>2</sub> plume; Pore Scale (100nm-100μm) showing CO<sub>2</sub> molecules and water molecules; and Nano Scale (1-100nm) showing molecular field experiments and theoretical connectivity. Below the diagram, the title 'NRAP Integrated Assessment Model-Carbon Storage (NRAP-IAM-CS) Tool User's Manual' is printed, followed by the date '12 August 2015'. A red note states 'DRAFT – Do not cite or quote'. At the bottom right, the U.S. Department of Energy logo and 'Office of Fossil Energy' are displayed, along with the reference number 'NRAP-TRS-III-00X-2015'.

## NRAP-IAM-CS Front Page

The screenshot shows the front page of the NRAP-IAM-CS tool. The title is 'IAM-NRAP-CS (NRAP's Integrated Assessment Model for CO<sub>2</sub> Storage)'. On the left, there is an 'OPERATIONS' section with buttons for 'Scenario Type and Inputs', 'Monte Carlo Settings', 'Results', and a 'Run Model' button. On the right, a flow diagram shows data inputs: Reservoir Data, Aquifer Data, and Global Data feed into a 'Reservoir' box. This box connects to 'Wells', 'Fractures', and 'Caprock'. 'Wells' and 'Fractures' connect to an 'Intermediate Reservoir', which then connects to a 'Shallow Aquifer' and 'Atmosphere'. The diagram is labeled 'NRAP Integrated Assessment Model NRAP-IAM-CS'. Below the diagram is an 'INFORMATION' section with buttons for 'Disclaimer-Acknowledgment', 'Contact Information', 'References', and 'User Manual'. At the bottom, there are logos for the U.S. Department of Energy, NETL, and NRAP.

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