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)
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
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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\textsubscript{2} storage deployment.

**Objective:** Building toolset and improving the science base to address key questions about potential impacts related to release of CO\textsubscript{2} or brine from the storage reservoir, and potential ground-motion impacts due to injection of CO\textsubscript{2}
NRAP’s approach to quantifying performance relies on reduced-order models to probe uncertainty in the system.

A. Divide system into discrete components

B. Develop detailed component models that are validated against lab/field data

C. Develop reduced-order models (ROMs) that rapidly reproduce component model predictions

D. Link ROMs via integrated assessment models (IAMs) to predict system performance & risk; calibrate using lab/field data from NRAP and other sources

E. Develop strategic monitoring protocols that allow verification of predicted system performance
NRAP Tools
Now available for beta testing

Design for Risk Evaluation and Monitoring

Wellbore Leakage Analysis Tool

Natural Seal ROM

Reservoir Evaluation and Visualization

NRAP-IAM-CS

Aquifer Impact Model

Short Term Seismic Forecasting

www.edx.netl.doe.gov/nrap → TOOL BETA TESTING link
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• Welcome and Overview of NRAP – Technical Approach and Tool Development

• **Introduction to the NRAP Integrated Assessment Model for Carbon Storage (NRAP-IAM-CS)**
  • Navigating the IAM-CS tool
  • Example use cases
  • Demonstration of IAM-CS Viewer
  • Quality Assurance
  • Questions and Open Discussion
What is NRAP-IAM-CS?

- An integrated model that can be used to predict leakage-related behavior of a CO₂ storage site
- Simulate long-term full system behavior (reservoir to aquifer/atmosphere)
- Take into account key site-specific unknown or variable parameters
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

• 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

- Scenario Type & Inputs
  - Scenario Choice
  - Specify Inputs
    - Reservoir
    - Wells
      - Number & Location
      - WB Type & Permeability
    - Groundwater & Intermediate Zones
      - Aquifer Physical Parameters
    - Surface

Results

- Monte Carlo Settings
- Run Model
- Results
  - CO2/Brine Leak & MV Statistics
  - Aquifer Impacts & MV Statistics
Example input dashboard for reservoir

Simple Reservoir Characteristics

Reservoir Domain
X min (m) 0  Y min (m) 0
X max (m) 50000  Y max (m) 50000

Reservoir elevation (m) -2000
Reservoir Initial Pressure (MPa) 10
Reservoir Initial Temperature (°C) 100

Reservoir Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Use Single Value</th>
<th>Sample from Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness (m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permeability (m²)</td>
<td></td>
<td>Uniform 25 1 0.0 25</td>
</tr>
<tr>
<td>Porosity</td>
<td></td>
<td>Uniform 1e-14 1e-15 1e-16 1e-10</td>
</tr>
<tr>
<td>Residual Water Saturation</td>
<td></td>
<td>Uniform 0.2 0.01 0 1</td>
</tr>
<tr>
<td>Residual CO₂ Saturation</td>
<td></td>
<td>Uniform 0.2 1 0 1</td>
</tr>
</tbody>
</table>

Location of CO₂ Injection Well
X (m) 25000  Y (m) 25000

CO₂ Injection Parameters
CO₂ Injection Rate (tonnes/day) 50
CO₂ Injection Duration (Years) 50
Maximum Injection Pressure (MPa) to avoid seal fracture 16.5
User can perform site-specific calculations

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

Specify site-specific data and design scenarios of interest
Site-specific application: reservoir simulations

• Many site-specific studies have reservoir simulation results of CO₂ 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 CO₂ 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$_2$ injection?
  ➢ How will injection operational parameters affect the impacted wellbores?

• Scenario: Potential CO$_2$ 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 CO₂ leak rate to atmosphere
Example 1: IAM Walkthrough
How does well type affect leakage?

Cemented Wells

Quality of Cement Increasing

Open Well

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 CO₂ 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$_2$ 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$_2$ 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?

Injection Duration
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\textsubscript{2} 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

<table>
<thead>
<tr>
<th>CO₂ Leak Rate</th>
<th>Wellbore Cement Permeability</th>
<th>Reservoir Permeability</th>
<th>Reservoir Porosity</th>
<th>Caprock Permeability</th>
</tr>
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<tr>
<td>CO₂ Leak Rate</td>
<td>1</td>
<td>0.155</td>
<td>0.094</td>
<td>0.006</td>
</tr>
<tr>
<td>Wellbore Cement Permeability</td>
<td>0.155</td>
<td>1</td>
<td>0.069</td>
<td>-0.055</td>
</tr>
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<td>Reservoir Permeability</td>
<td>0.094</td>
<td>0.069</td>
<td>1</td>
<td>-0.043</td>
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<td>Reservoir Porosity</td>
<td>0.006</td>
<td>-0.055</td>
<td>-0.043</td>
<td>1</td>
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<td>Caprock Permeability</td>
<td>0.011</td>
<td>-0.055</td>
<td>0.034</td>
<td>-0.066</td>
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Importance Measure
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A JAVA-based tool to visualize and explore results from NRAP-IAM-CS realizations
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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
“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 CO₂ saturations in the reservoir are not too small.”
Comparison between IAM and Fully Coupled High Fidelity Models

Comparison of CO₂ Flow Rate through an Open Well

- IAM Predictions
- Lookup Table based on TOUGH2 High Fidelity Simulations*

* Pan & Oldenburg (2014)
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

• Thank you!
Beta Tool and User Manual Available on EDX

NRAP Tool Beta-Testing Portal

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


12 August 2015

Office of Fossil Energy
NRAP-TR-III-00X-2015

NRAP-IAM-CS Front Page

www.edx.netl.doe.gov/nrap ➔ TOOL BETA TESTING link
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