PNNL-SA-137185

National Risk Assessment Partnership – Application of Risk Assessment Tools and Methodologies to Synthetic and Field Data

Diana Bacon[1], Liange Zheng[2], Catherine Yonkofski[1], Inci Demirkanli[1], Kelly Rose[3], Quanlin Zhou[2] , Ya-Mei Yang[3]

[1]Pacific Northwest National Laboratory, [2]Lawrence Berkeley National Laboratory, [3]National Energy Technology Laboratory

U.S. Department of Energy

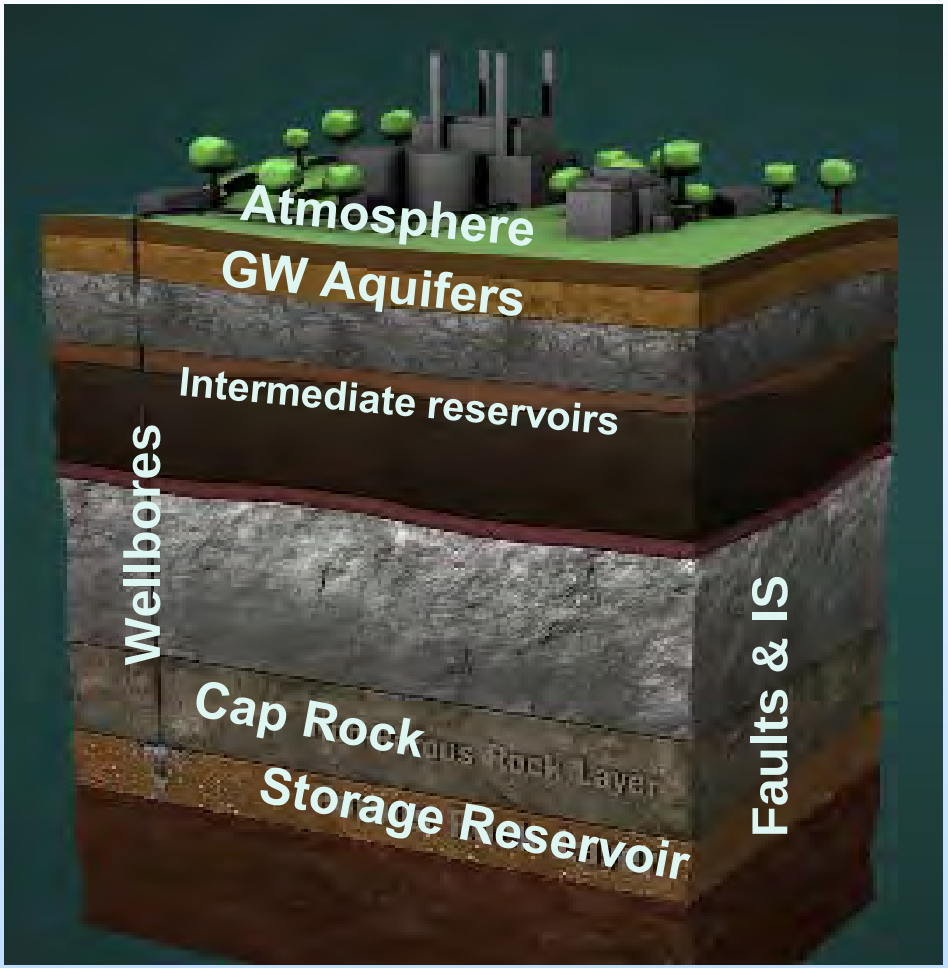
National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 13-16, 2018

Presentation Outline

- National Risk Assessment Partnership (NRAP) risk assessment tools and methodologies are being applied to data from field experiments and potential or active geologic storage projects
- Since there are no comprehensive field data sets where a large scale CO_2 leak has occurred, the partnership is also collecting and developing synthetic datasets for NRAP community use

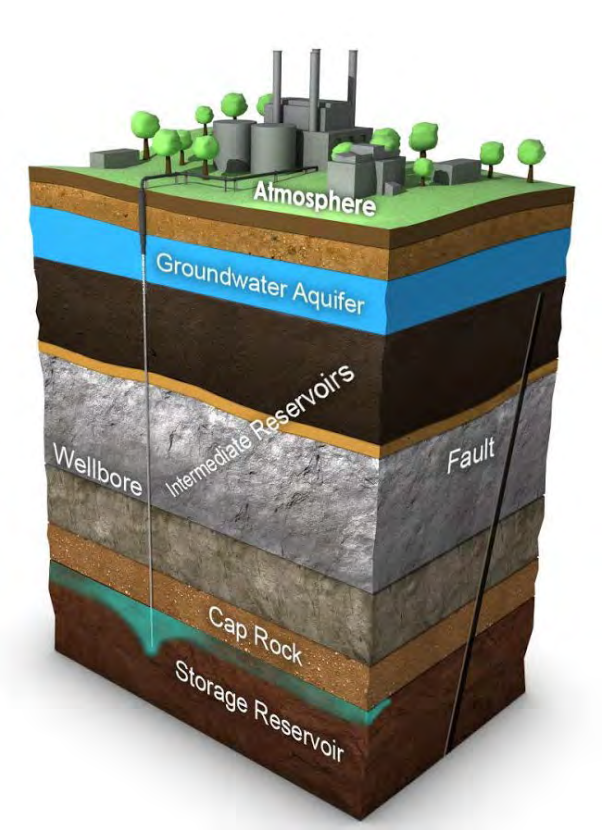


Presentation Outline

- **Field Applications**
  - Containment Tools and Methodologies Field Demonstration (Liange Zheng, LBNL)
  - Strategic Monitoring Tools and Methodologies Demonstration (Catherine Yonkofski, PNNL)
  - Application of OpenIAM for Risk-Based AoR to FutureGen 2.0 Dataset (Inci Demirkanli, PNNL)
  - Application of NRAP-IAM-CS for Preliminary Risk Assessment for GCS Candidate Site Selection (Ya-Mei Yang, NETL)
- **Community Datasets**
  - Kimberlina Site Data set for Testing of Monitoring Tools/Approaches (Quanlin Zhou, LBNL)
  - Development of Community Data Sets (Kelly Rose, NETL)

NRAP Tools

- **Containment**
  - RROM-GEN (Reservoir Reduced-Order Model Generator)
  - NSEALR (NRAP Seal Barrier Reduced-Order Model)
  - WLAT (Wellbore Leakage Analysis Tool)
  - AIM (Aquifer Impact Model)
  - MSLR (Multiple Source Leakage Reduced-Order Model) atmospheric dispersion



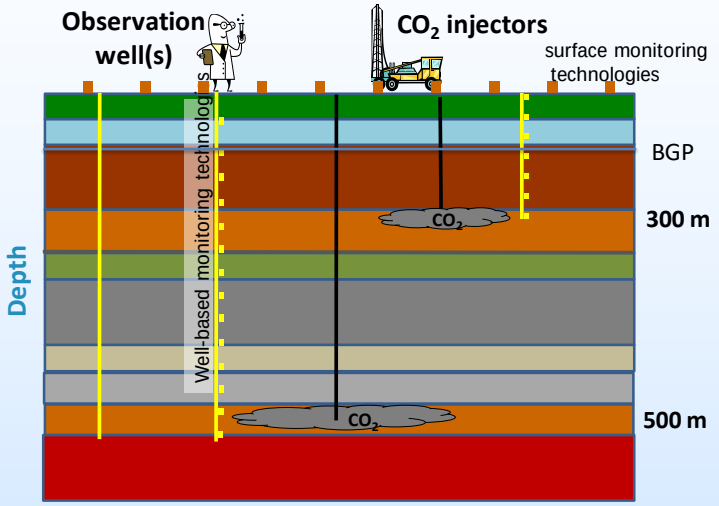
NRAP Tools

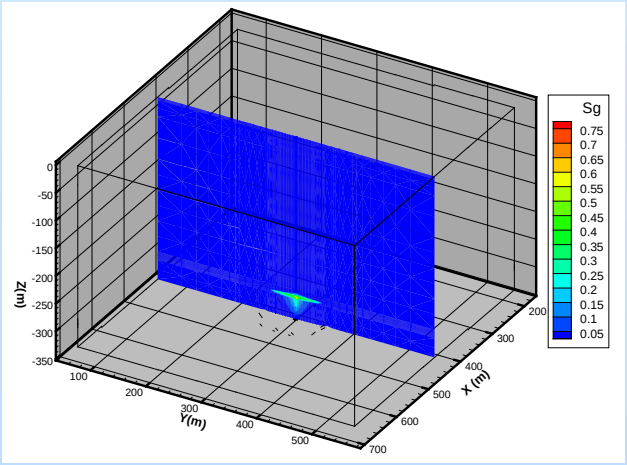
- **Integrated Assessment**
  - NRAP-IAM-CS (Integrated Assessment Model – Carbon Storage)
  - OpenIAM (Open Source Integrated Assessment Model)
- **Induced Seismicity**
  - STSF (Short Term Seismic Forecasting)
  - GMPIS (Ground Motion Prediction applications to potential Induced Seismicity)
  - SOSAT (State of Stress Analysis Tool)
- **Monitoring Design**
  - DREAM (Designs for Risk Evaluation and Management)

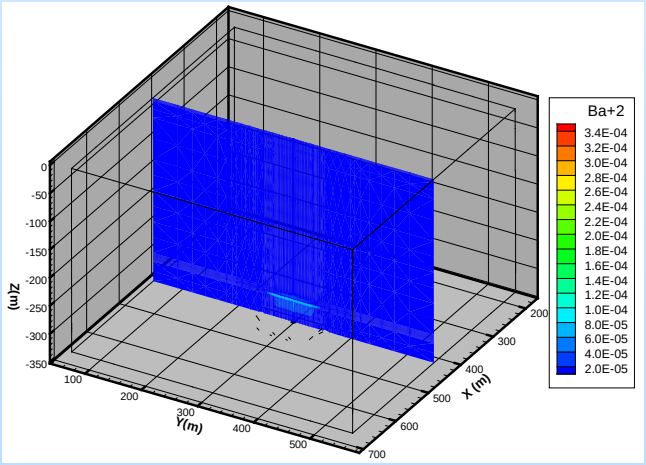
Containment Tools and Methodologies Field Demonstration

Liange Zheng & Tom Daley, LBNL

- Objective
  - Participating CaMI field test in which CO_2 is injected into an aquifer 300 m deep
  - Collecting seismic and geochemical data
  - Testing process model and then develop components for OpenIAM
- Status
  - Injection started in Oct 2007
  - Baseline seismic data were collected
  - Predictive models were developed and hypothetical leakage scenarios were modeled







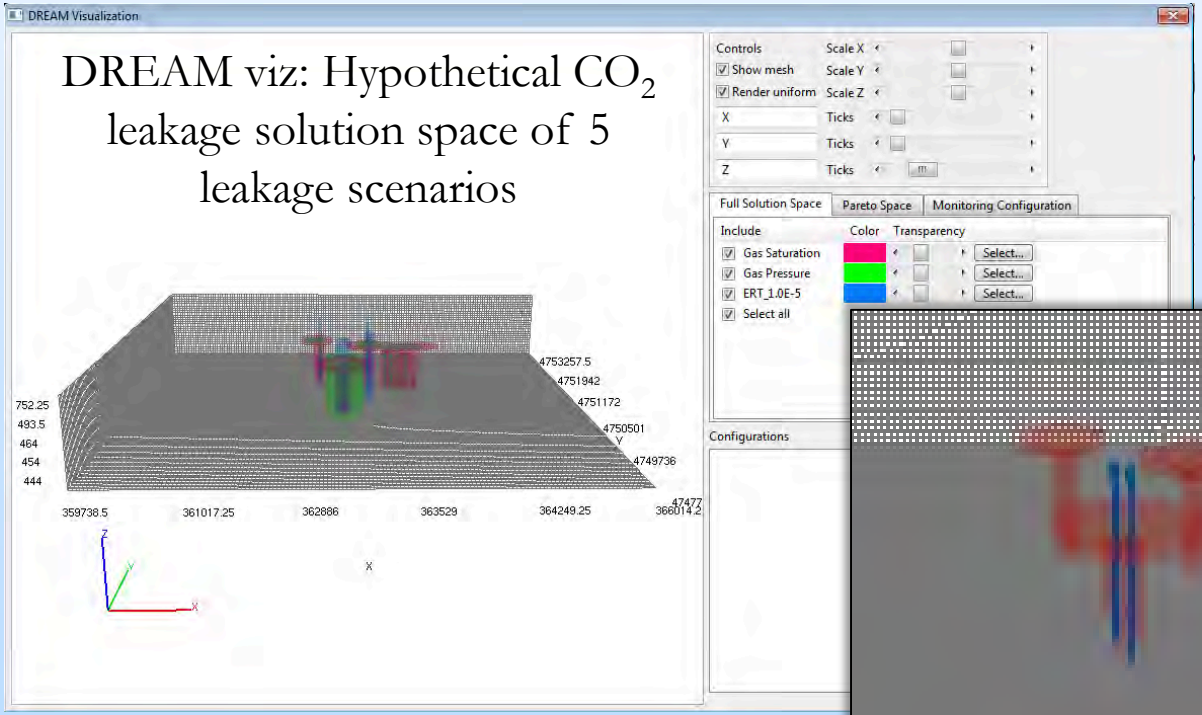
Predicted plume of gaseous CO_2 saturation and Barium concentration in groundwater after 2 years with an injection rate of 1 ton/day

Strategic Monitoring Tools and Methodologies Demonstration

Catherine Yonkofski, Jonathan Whiting, Jeff Burghardt

- Demonstration of DREAM v2 beta release with ERT module to detect hypothetical CO_2 leaks within a deep (600m bgs) AZMI
- Using WLAT output, modeled hypothetical CO_2 and brine leakage into the deepest overlying aquifer.

DREAM viz: Hypothetical CO_2 leakage solution space of 5 leakage scenarios



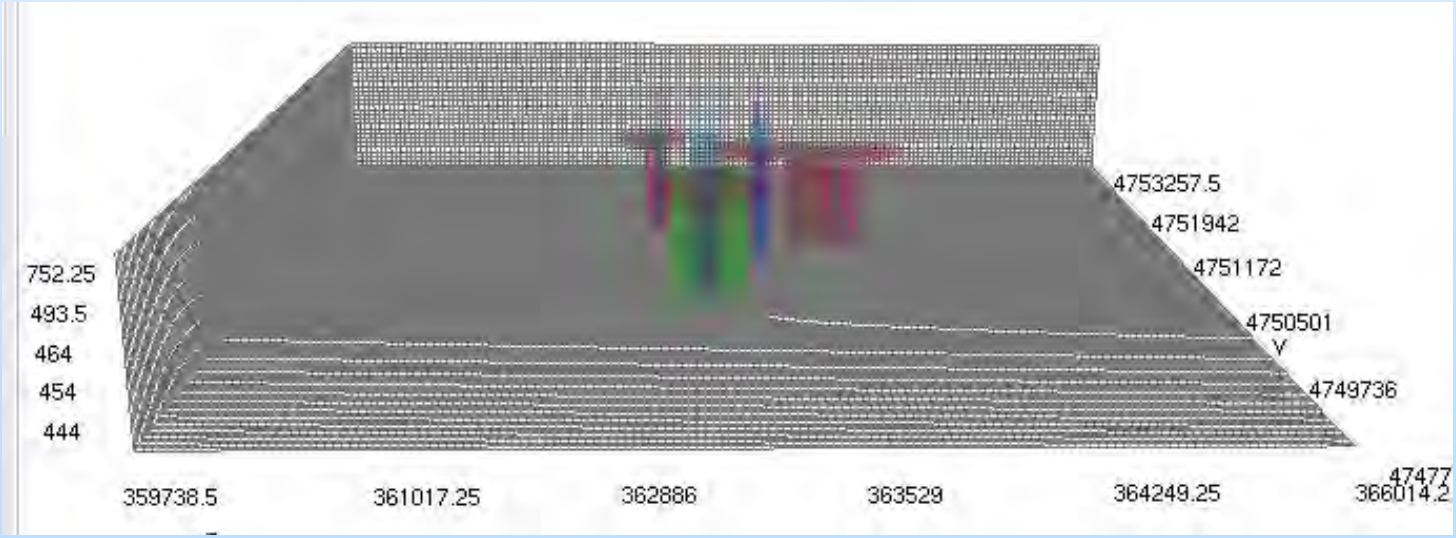
Demonstration results presented in the poster session "DREAM 2.0: ERT Placement and Beyond"

Movie: DREAM well placement for cross borehole ERT sensors within AZMI

Lessons Learned

Strategic Monitoring Tools and Methodologies Demonstration

- Relative changes in electrical conductivity due to leakage from the underling storage formation fell between 0.001% (100% leak detection across scenarios) and 0.01% (0% leak detection).
- Difference in salinity between injection reservoir and AZMI are relatively small.
- ERT may be a better monitoring option for freshwater units where a brine leak would result in greater change in electrical conductivity

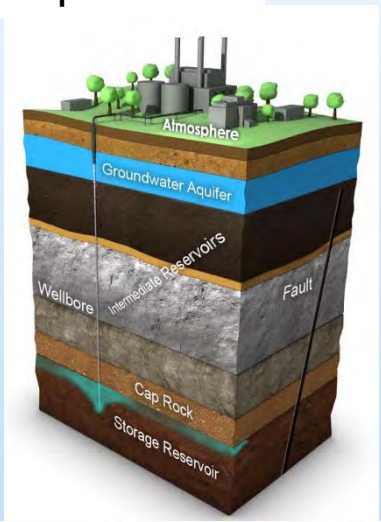


Research gaps/challenges

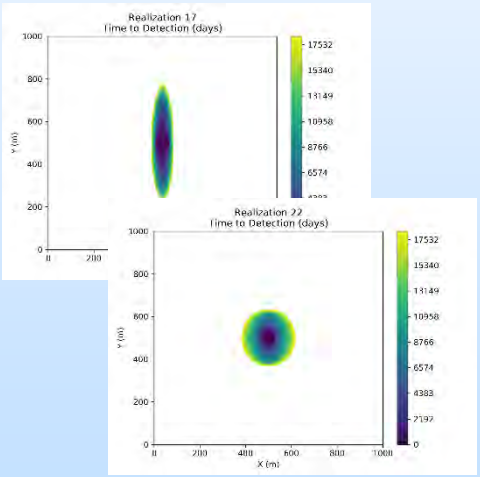
Strategic Monitoring Tools and Methodologies Demonstration

- Problem: Groundwater leakage simulations needed as input to DREAM are not typically available at carbon storage sites
- Solution: Link DREAM to OpenIAM

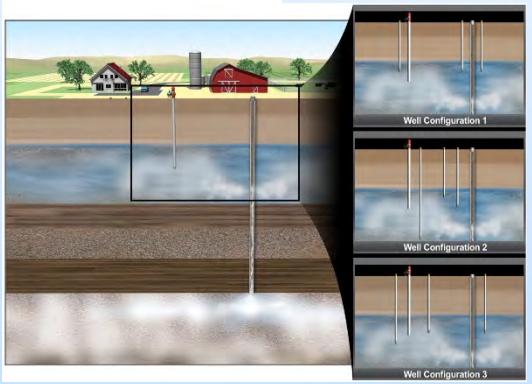
Open IAM

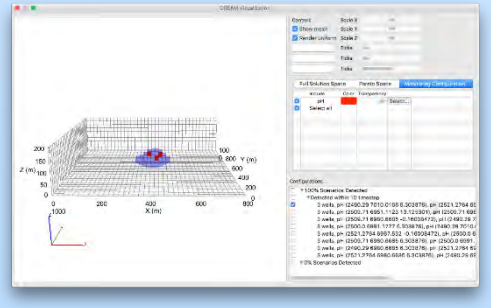


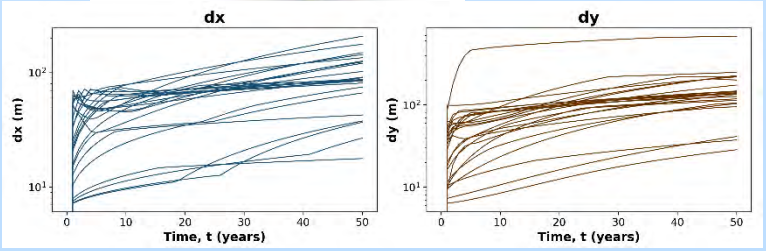
Time-to-Detection



DREAM





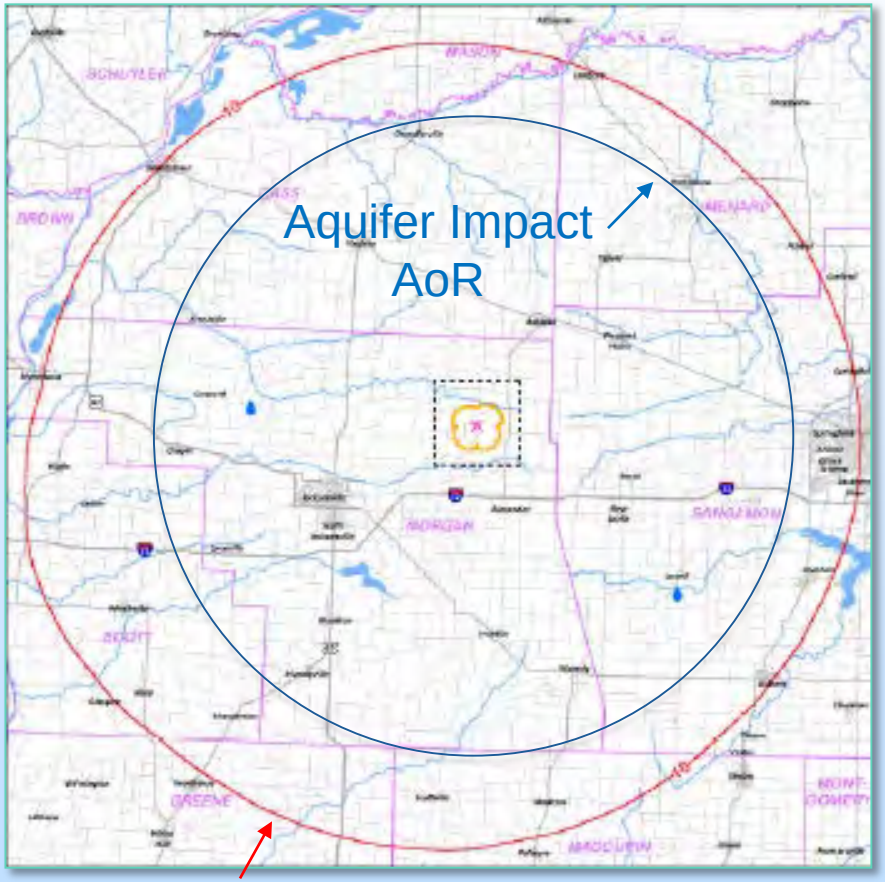


Application of OpenIAM for Risk-Based AoR to FutureGen 2.0 Dataset

Inci Demirkanli, Signe White, Diana Bacon PNNL

- Over-pressurized injection formations are challenging for delineating AoR, where the project may cause endangerment of USDWs
- OpenIAM has been applied to Futuregen 2.0 dataset for risk-based Area of Review

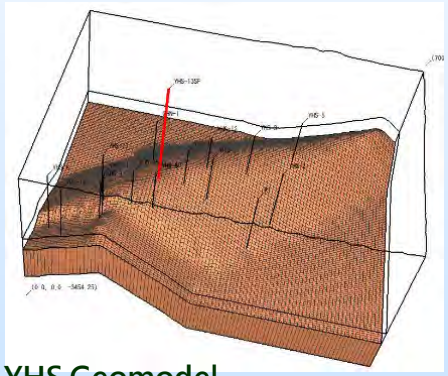
Method	AoR, mi²
10 psi Critical Pressure	50
Aquifer Impact (TDS)	37
Aquifer Impact (pH)	4
Plume Footprint	4



Application of NRAP-IAM-CS for Preliminary Risk Assessment for GCS Candidate Site Selection

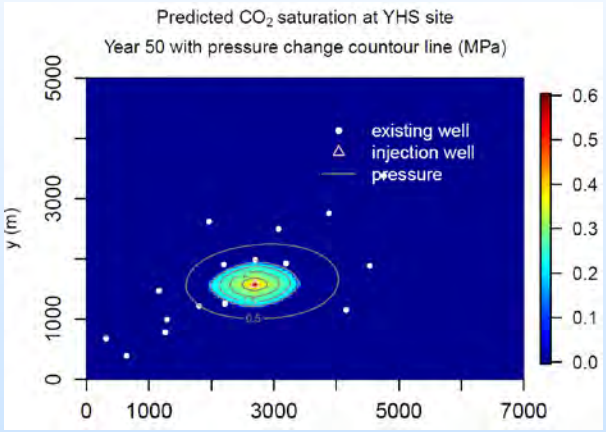
Ya-Mei Yang, Bob Dilmore, NETL

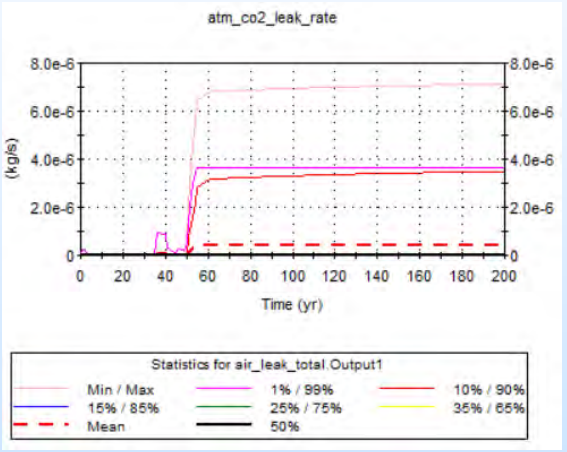
- Reservoir injectivity simulations for YHS sites, with total 10, **50**, 100, 150, 200 Mt injection by TOUGH2 ECO2N
- NRAP-IAM-CS applied to the 50Mt injection scenario for preliminary risk assessment

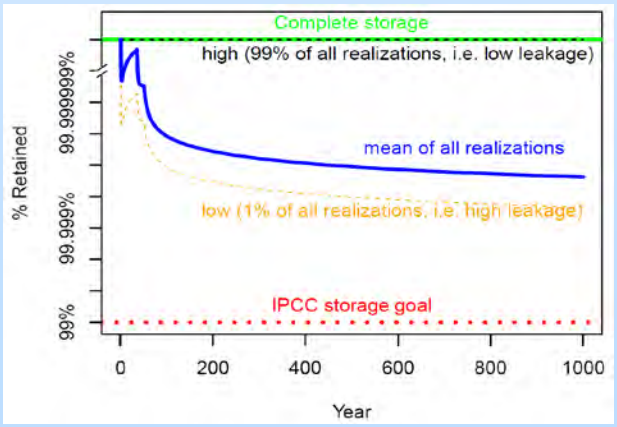


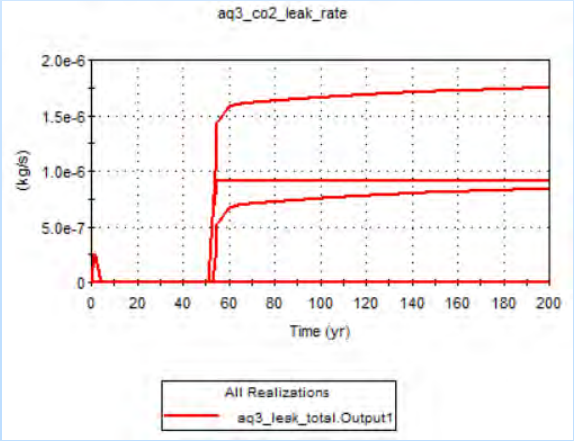
YHS Geomodel

- On shore depleted natural gas field
- Small domain (5km x 7km) with multiple storage layers.
- More background data
- Faults as seal







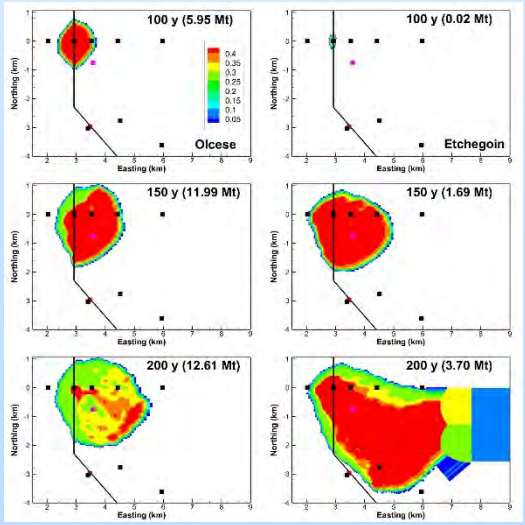


Kimberlina Site Data set for Testing of Monitoring Tools/Approaches

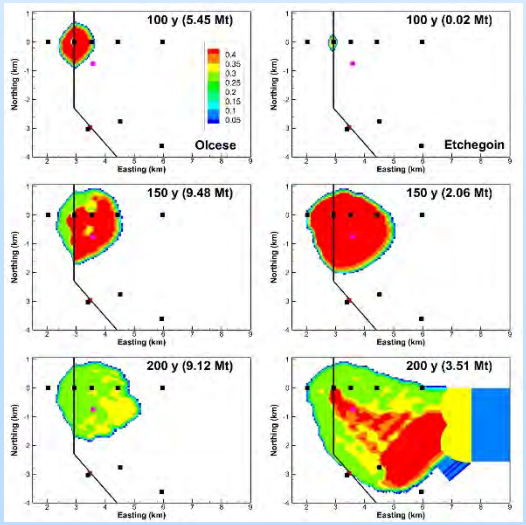
Quanlin Zhou, LBNL

- Accomplishment: Additional 11 scenarios for Kimberlina 2.0 uploaded to EDX for modeling of monitoring strategies
- Leaky Window 1: updip of the injection well; the leaky window is 50 m wide and 250m long, and the scenarios were simulated: two scenarios for the Olcese and Etchegoin in a separate leaky mode, and one in a combined mode.

Window 1: Separate leakage



Combined leakage

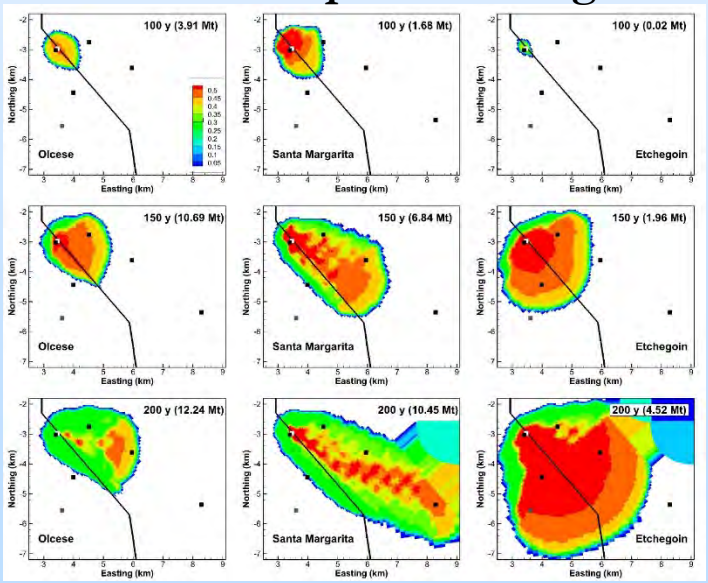


Kimberlina Site Data set for Testing of Monitoring Tools/Approaches

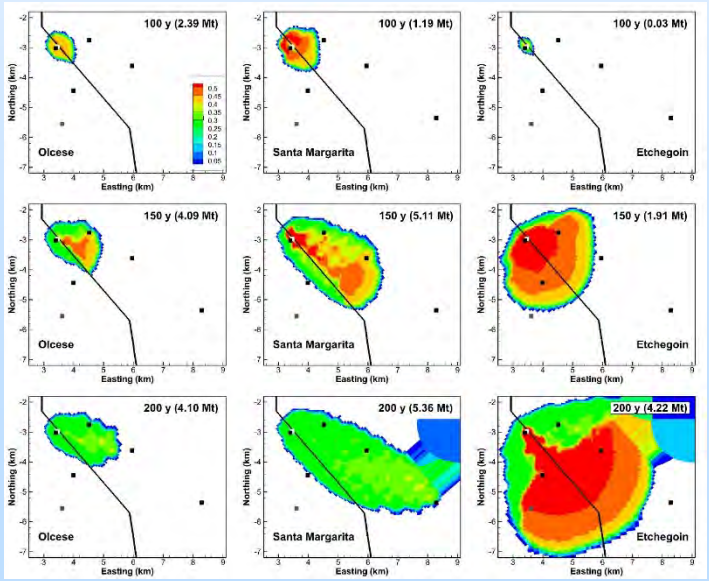
Quanlin Zhou, LBNL

- Accomplishment: Simulated CO_2 plume in Thief Zones
- Leaky Window 2: located south-east, with the same properties of the leaky widow. Three scenarios for separate leakage into Olcese, Santa Margarita, and Etchegoin, and one scenario for combined leakage into the three thief zones

Window 2: Separate leakage

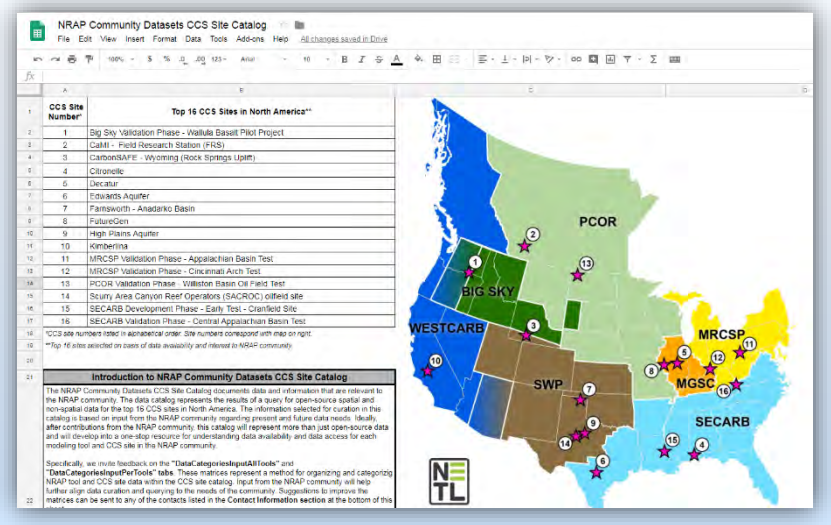


Combined leakage



Developing an NRAP Community Dataset

Kelly Rose, Jennifer DiGiulio, Gabriel Creason, Katherine Jones, Michael Sabbatino, Aaron Barkhurst, NETL



NRAP Community Datasets CCS Site Catalog

CCS Site Number*	Top 16 CCS Sites in North America**
1	Big Sky Validation Phase - Wallula Basalt Pilot Project
2	CaMI - Field Research Station (FRS)
3	CarbonSAFE - Wyoming (Rock Springs Uplift)
4	Citronelle
5	Decatur
6	Edwards Aquifer
7	Farnsworth - Anadarko Basin
8	FutureGen
9	High Plains Aquifer
10	Kimberlina
11	MRCSP Validation Phase - Appalachian Basin Test
12	MRCSP Validation Phase - Cincinnati Arch Test
13	PCOR Validation Phase - Williston Basin Oil Field Test
14	Scurry Area Canyon Reef Operators (SACROC) oilfield site
15	SECARB Development Phase - Early Test - Cranfield Site
16	SECARB Validation Phase - Central Appalachian Basin Test

*CCS site numbers listed in alphabetical order. Site numbers correspond with map on right.
**Top 16 sites selected on basis of data availability and interest to NRAP community.

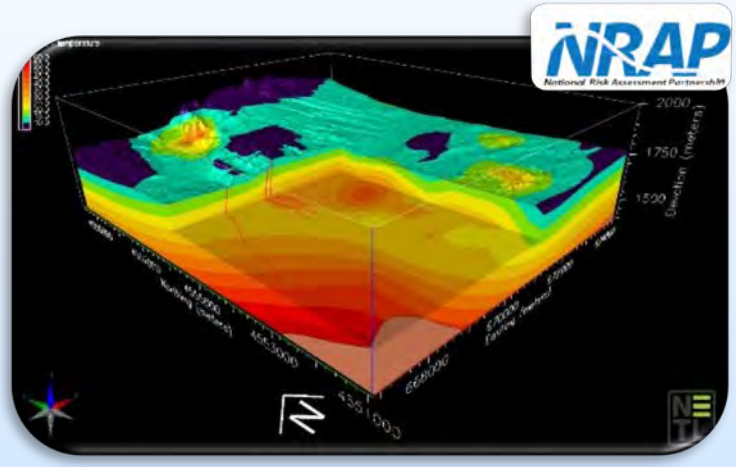
Introduction to NRAP Community Datasets CCS Site Catalog

The NRAP Community Datasets CCS Site Catalog documents data and information that are relevant to the NRAP community. The data catalog represents the results of a query for open-source spatial and non-spatial data for the top 16 CCS sites in North America. The information selected for curation in this catalog is based on input from the NRAP community regarding present and future data needs. Ideally, after contributions from the NRAP community, this catalog will represent more than just open-source data and will develop into a one-stop resource for understanding data availability and data access for each modeling tool and CCS site in the NRAP community.

Specifically, we invite feedback on the **"DataCategoriesInputAllTools"** and **"DataCategoriesInputPerTools" tabs**. These matrices represent a method for organizing and categorizing NRAP tool and CCS site data within the CCS site catalog. Input from the NRAP community will help further align data curation and querying to the needs of the community. Suggestions to improve the matrices can be sent to any of the contacts listed in the **Contact Information section** at the bottom of this

EDX Energy Data eXchange

GEO CUBE



Design and distribute community datasets survey

Synthesize results

Identify priority sites

Compile open-access data

Identify utility of tools at each priority site and mitigate gaps

ID Kimberlina as top site

Share Data Catalog on EDX

Prepare conceptual 3D model for Kimberlina site data

Prepare interactive atlas in EDX/ Geocube

Completed

In Progress & Next Steps

CCS Field Site Data Catalog

Building the Data Foundation

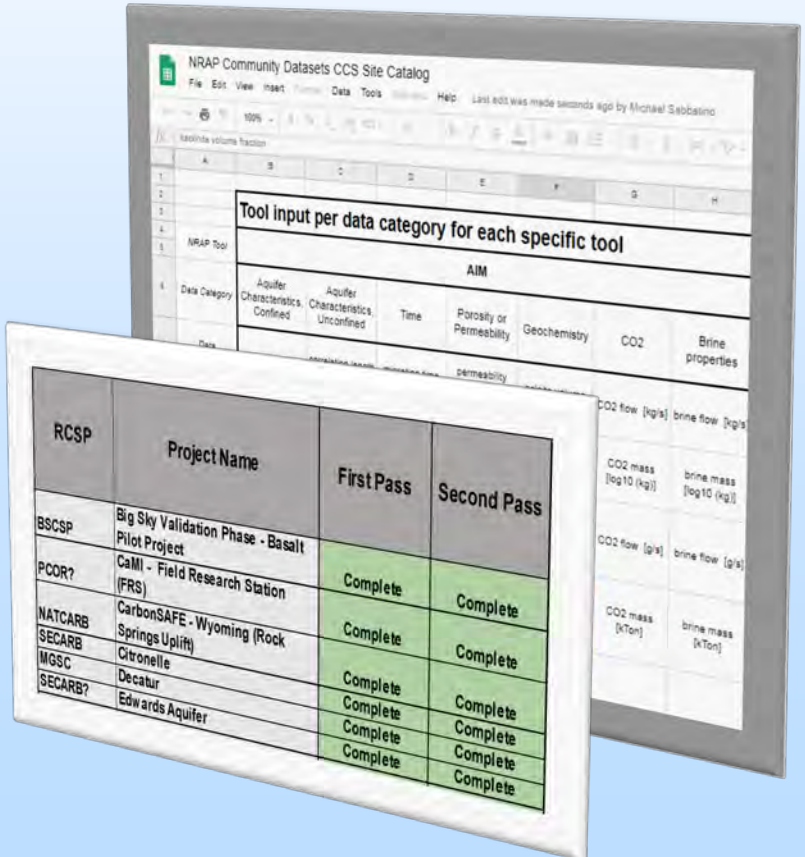
TOOL INPUTS:

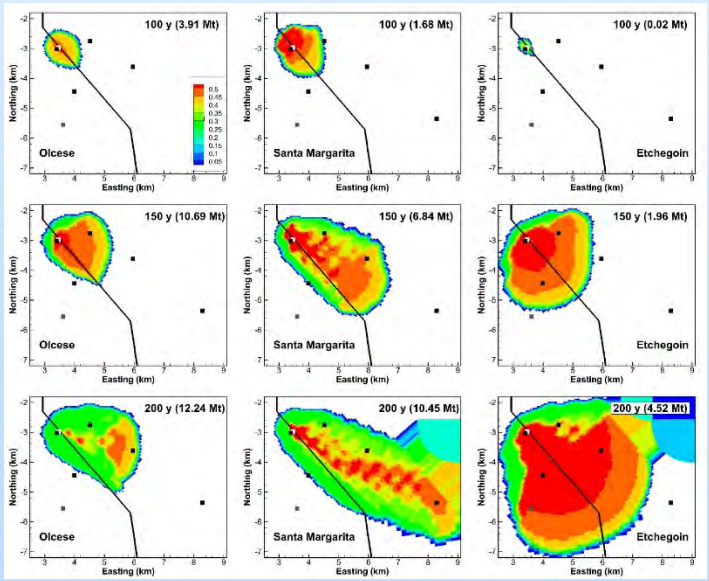
- 281 unique inputs
- 17 categories

Data Explore/ Transform

RESOURCES (as of August 2018):

- 554 records; **219 spatial**
- 12 types of resources
- **14 sites** with datasets **aligned to tool needs**
  - **7 sites** with **>4 tool needs**



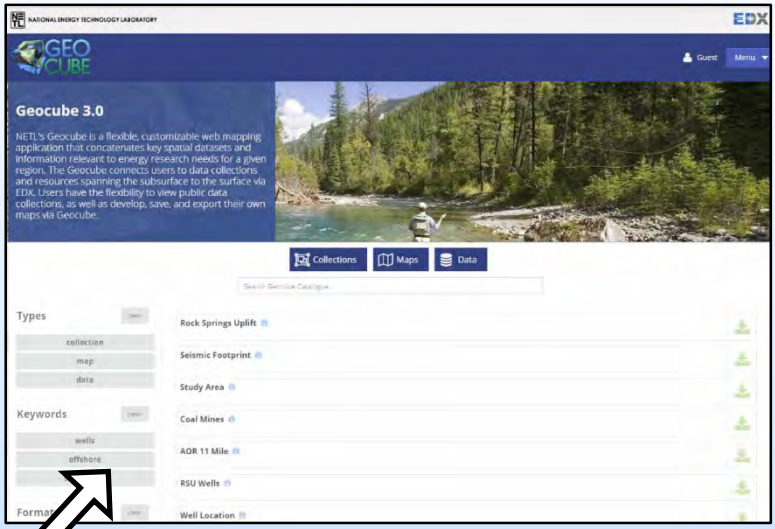


GeoCube 3.0

NETL's Flexible, Customizable Web Mapping Application

What is Geocube?

- **Geocube** is a **virtual web mapping platform** launched through NETL's **Energy Data eXchange**
- Connects users to **spatial data** resources suitable for a range of **energy** needs and **applications**
- Direct link to EDX's data repository and streamlined user interface allows users to **rapidly access and visualize data** on interactive maps

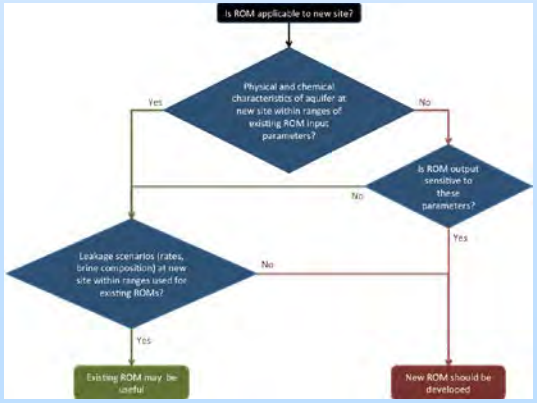


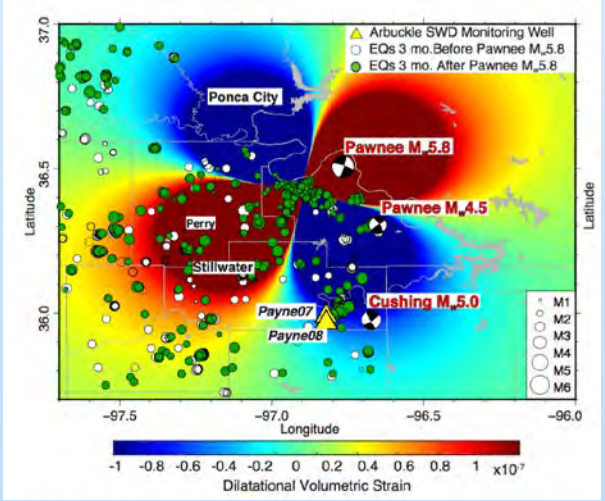
How does Geocube benefit the NRAP Community?

- Geocube's virtual modeling environment can serve as the central data framework to **integrate NRAP tools and data**
- Standardized data framework will allow NRAP community to **optimize simulations,** facilitate **advanced data analytics,** and more rapidly **mitigate risk** at carbon storage sites across U.S.

Accomplishments to Date

- Field Applications
  - Groundwater Assessment Field Application at the Illinois Basin Decatur Project site (Diana Bacon, PNNL) **Complete**
  - Induced Seismicity Tools and Methodologies Demonstration at an Oklahoma field site (Kayla Kroll, LLNL) **Complete**
  - Application of the SOSAT tool at the Farnsworth site (Jeff Burghardt, PNNL) **Complete**





Accomplishments to Date

- Field Applications
  - At CaMI site, unique field site for testing CO_2 leakage monitoring technologies, predictive models were developed and hypothetical leakage scenarios were simulated
  - Risk-based AoR using OpenIAM has been demonstrated at the FutureGen 2.0 site
  - DREAM-OpenIAM coupling has been demonstrated for a hypothetical case and will be applied to the FutureGen 2.0 site
  - NRAP-IAM-CS applied to a 50Mt injection scenario for preliminary risk assessment at YHS site

Accomplishments to Date

- Datasets
  - Additional 11 scenarios for Kimberlina 2.0 were uploaded to EDX and the subtask is completed
  - Kimberlina identified as top site for data catalog
  - Data catalog shared on edx.netl.gov
    - 14 sites with datasets aligned to NRAP tool needs

Lessons Learned

- At the CaMI field site, a site-specific components will need to be developed for NRAP's Integrated Assessment Model to handle the expected injection size and leakage rates
- For DREAM/ERT application, changes in salinity due to leakage were too low to detect due to low contrast between AZMI and reservoir, will investigate applicability of technique to monitoring in freshwater aquifers
- OpenIAM can provide groundwater leakage scenarios needed for DREAM

Lessons Learned

- At the YHS field application of NRAP-IAM-CS
  - Found that wellbore information from private land is difficult to obtain
  - Memory efficiency of NRAP-IAM-CS on a PC could be improved; in order to perform a 1000-realization simulation had to divide into two 500-realization simulations.
- For application of OpenIAM to the Futuregen 2.0 for risk-based AoR
  - AoR based on likely impact to groundwater is smaller than from critical pressure analysis
  - Shallow carbonate aquifer component is not appropriate for the deep USDW (St. Peter sandstone) so a site-specific groundwater component is being developed

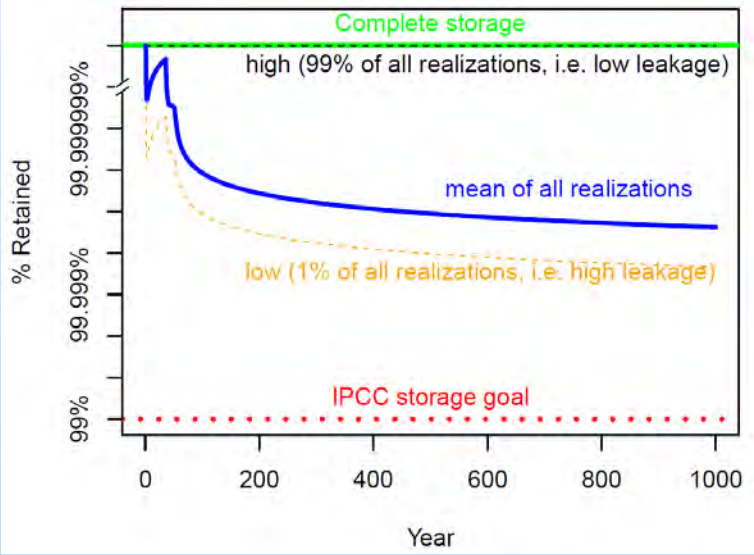
Synergy Opportunities

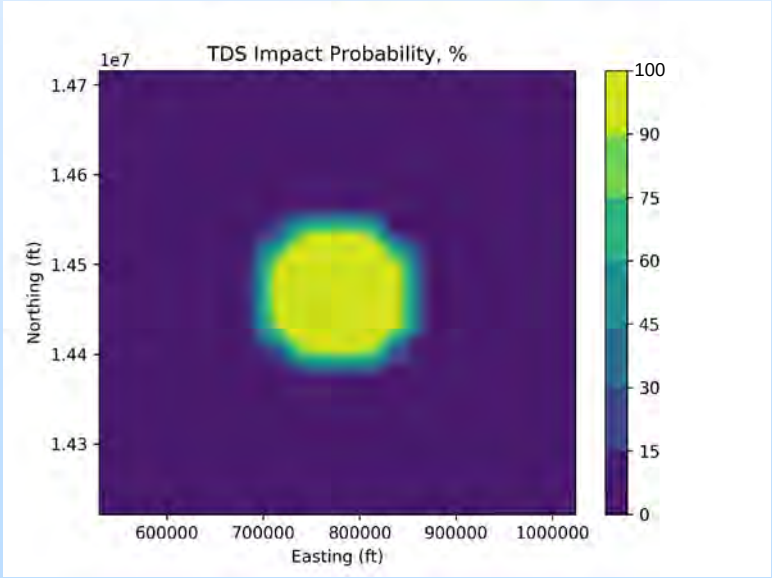
- Application of NRAP tools by CarbonSAFE projects is helping to
  - demonstrate how the tools can be applied at carbon storage sites
  - identify ways in which the tools can be made more flexible and useful
- Synthetic datasets will be made available to the broader community
- Further application of NRAP Tools to Post-injection Site Care in process under NRAP Task 6

Project Summary

NRAP Field Applications

- Field applications are driving enhancements to NRAP's Integrated Assessment Model and DREAM tools
  - New groundwater ROMs for Kimberlina, CaMI, and Futuregen 2.0 sites
  - Coupling of OpenIAM and DREAM for monitoring design
  - Application of OpenIAM for Risk-based AoR at FutureGen 2.0 site
  - Application of NRAP-IAM-CS for Preliminary Risk Assessment for GCS Candidate Site Selection

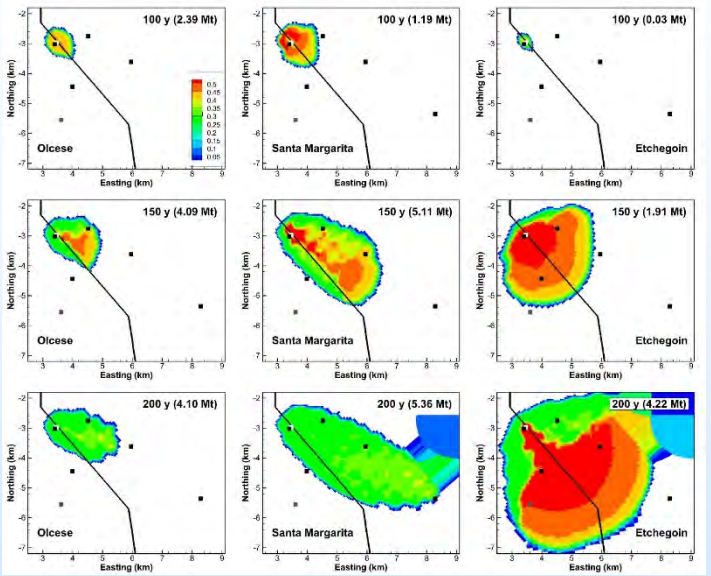




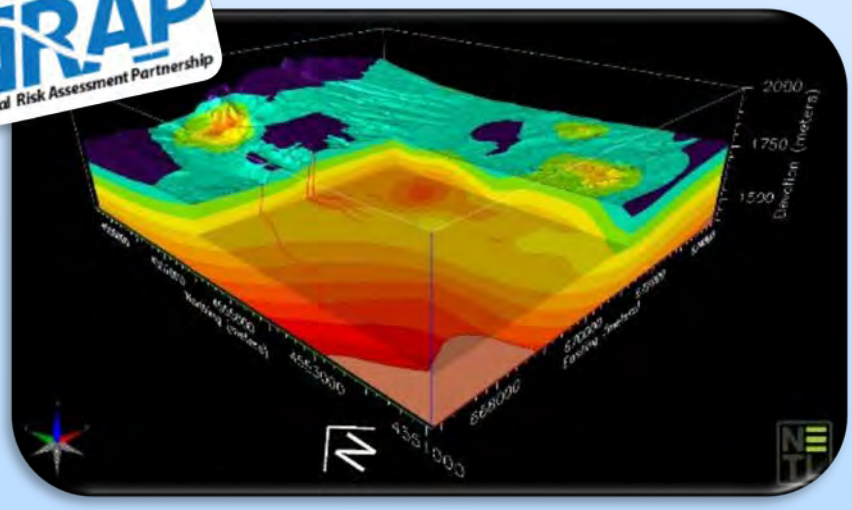
Project Summary

NRAP Community Datasets

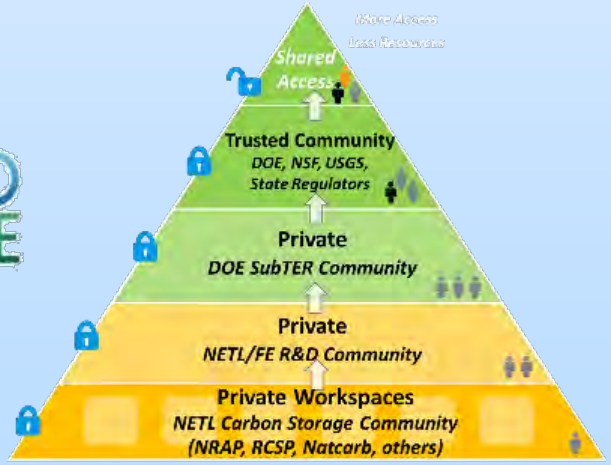
- Kimberlina dataset
  - is growing with addition of new leakage scenarios
  - has been selected as primary community dataset



NRAP National Risk Assessment Partnership



GEO CUBE



Appendix

– These slides will not be discussed during the presentation, but are mandatory.

Benefit to the Program

- The motivating goal of NRAP is to develop science-based methodologies and tools for calculating risks at any CO_2 storage site while providing necessary scientific and technological advances to support that methodology. Phase II is focusing on management of risk associated with large-scale CO_2 storage, and with reducing associated uncertainties.
- Objectives of efforts under Phase II will focus on applying and extending that predictive capability to actively manage risks related to CO_2 storage to quantitatively assess improvements in environmental risk performance afforded by select mitigation strategies, and to reduce uncertainties in system performance through iterative conformance assessment and prediction improvement.

Project Overview

Goals and Objectives

- This task focuses on the validation of various components of the NRAP toolset, and the NRAP-IAM-CS. A primary goal of this task is to compare the predictive capability of the tools with data from real field observations.
- However, since field data are limited, and since there are no comprehensive field data sets where a large scale CO_2 leak has occurred, a synthetic data set based on simulated CO_2 storage with hypothetical leakage and stress effects at the Kimberlina site is being developed and used as a community dataset.

Organization Chart

- Field Applications
  - Containment Tools and Methodologies Field Demonstration (Liange Zheng, LBNL)
  - Strategic Monitoring Tools and Methodologies Demonstration (Catherine Yonkofski, PNNL)
  - Application of OpenIAM to FutureGen 2.0 Dataset for Risk-Based AoR (Inci Demirkanli, PNNL)
  - Application of NRAP-IAM-CS for Preliminary Risk Assessment for GCS Candidate Site Selection (Ya-Mei Yang, NETL)
- Synthetic Datasets
  - Development of Community Data Sets (Kelly Rose, NETL)
  - Kimberlina Site Data set for Testing of Monitoring Tools/Approaches (Quanlin Zhou, LBNL)

Task Milestones

Field Applications

- 9/30/19: Select set of NRAP tool field application studies to detail in report of NRAP field application
- 12/31/19: Develop catalog of studies testing and demonstrating NRAP Phase I tools
- 3/31/20: Manuscript(s) or report summarizing NRAP tools field application experience
- 9/30/21: Final report on NRAP tools field validation

Community Datasets

- 6/30/18: Select site for detailed geo-data model development (Kimberlina)
- 12/31/18: Develop prototype geo-data model for a U.S. carbon storage site
- 9/30/20: Decide if the NRAP community dataset and geodatabase are ready for external release
- 12/31/20: Complete NRAP community dataset and geodatabase development
- 3/31/20: NRAP community dataset and geo-database, with supporting documentation uploaded to NRAP Energy Data Exchange workspace

Bibliography

- Yonkofski C., G.D. Tartakovsky, N.J. Huerta, A.M. Wentworth, and J.R. Sminchak. 2018. "Risk Based Monitoring Designs for CO2 Leakage through Abandoned Wellbores: An application of NRAP's WLAT and DREAM tools." International Journal of Greenhouse Gas Control (pending)
- Demirkanli, D.I., S.K. White, D.H. Bacon, Application of NRAP's Integrated Assessment Model to Determine Risk-Based Area of Review, International Journal of Greenhouse Gas Control (pending)
- Liao, C., Wang, P., Yang, Y., Dilmore, 2018, Preliminary leakage risk assessment for geologic carbon storage site selection: a case study. GHGT-14 conference, in preparation.
- Bacon D H, Locke R, Keating E, Carroll S A, Iranmanesh A, Mansoor K, Wimmer B, Zheng L, Shao H, Greenberg S, submitted. "Applicability of the Aquifer Impact Model to Support Decisions at a CO_2 Sequestration Site" Greenhouse Gases: Science and Technology.
- Burghardt J A, submitted. "Geomechanical risk assessment for subsurface fluid disposal operations" Rock Mechanics and Rock Engineering.
- Kroll, K. A. Cochran, E. S., and Murray, K. E., 2017. "Poroelastic properties of the Arbuckle Group in Oklahoma derived from well fluid level response to the Mw5.8 Pawnee and Mw5.0 Cushing Earthquakes", Seis. Res. Letters.