Application of Risk Assessment Tools and Methodologies to Synthetic and Field Data

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U.S. Department of Energy

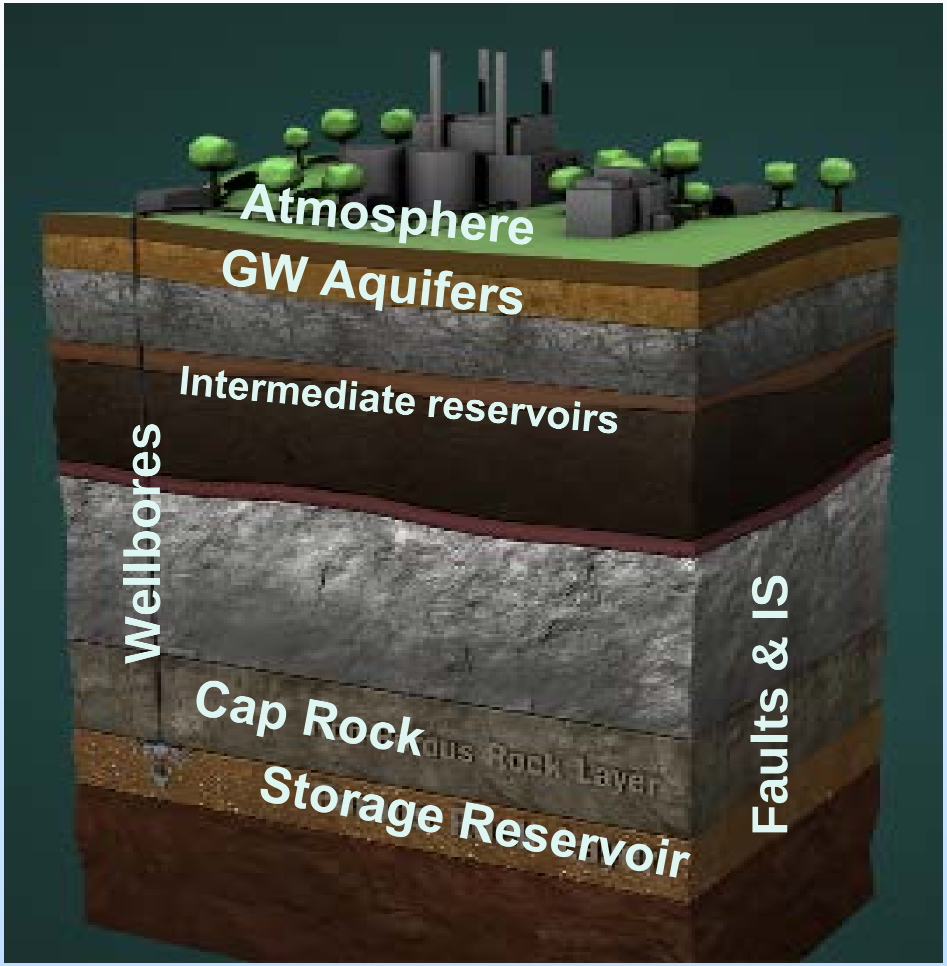
National Energy Technology Laboratory

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

August 1-3, 2017

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

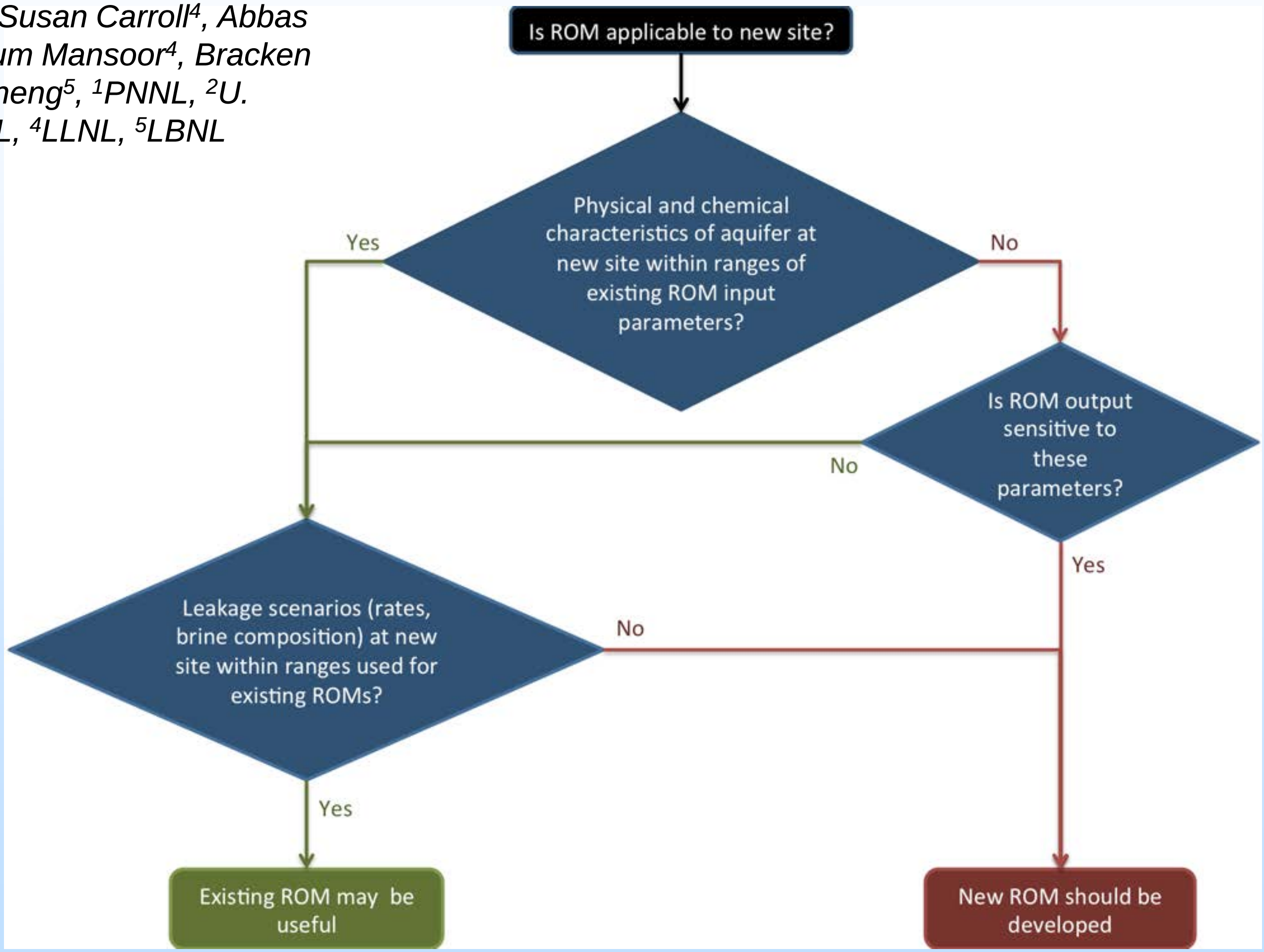


Presentation Outline

- Field Applications
  - Groundwater Assessment Field Application (Diana Bacon, PNNL)
  - Containment Tools and Methodologies Field Demonstration (Liange Zheng, LBNL)
  - Induced Seismicity Tools and Methodologies Demonstration (Josh White, LLNL)
  - Strategic Monitoring Tools and Methodologies Demonstration (Catherine Yonkofski, PNNL)
  - Identify Field Site for Large Scale Leveraged Activities (Inci Demirkanli, PNNL)
- Synthetic Datasets
  - Development of Community Data Sets (Kelly Rose, NETL)
  - Kimberlina Site Data set for Testing of Monitoring Tools/Approaches (Quanlin Zhou, LBNL)

Groundwater Assessment Field Application

Diana Bacon[1], Randall A. Locke II[2], Elizabeth Keating[3], Susan Carroll[4], Abbas Iranmanesh[2], Kayyum Mansoor[4], Bracken Wimmer[2], Liange Zheng[5], [1]PNNL, [2]U. Illinois, ISGS, [3]LANL, [4]LLNL, [5]LBNL

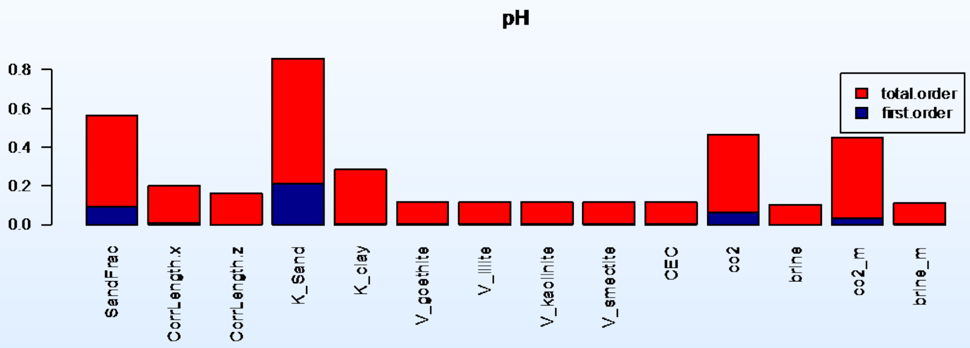


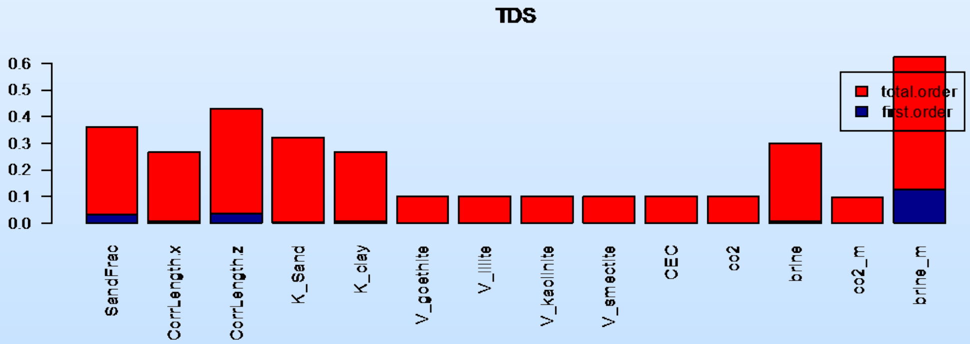
Groundwater Assessment Field Application

	Parameter	Confined Alluvium ROM Parameters[1]	IBDP Pre-Injection Observations[2]	Parameter vs. Observations
Non-adjustable	Initial pH	7.6	7.31 (average)	Higher
	pH No-Impact Threshold	6.625	6.81 (5th percentile)	Lower
	Initial TDS	570 mg/L	1152 (average)	Lower
	TDS No-Impact Threshold	1300 mg/L	1358 (95th percentile)	Similar
Adjustable	Sand fraction	0.35 – 0.65	--	Uncertain
	Correlation length X	200 – 2,500 m	--	Uncertain
	Correlation length Z	0.5 – 25 m	--	Uncertain
	Permeability sand	$10^{-14} – 10^{-10}$ m^2	$10^{-11.8} – 10^{-10.4}$ m^2	Within range
	Permeability clay	$10^{-18} – 10^{-15}$ m^2	--	Uncertain
	Goethite volume fraction	0 – 0.15	--	Uncertain
	Illite volume fraction	0 – 0.2	--	Uncertain
	Kaolinite volume fraction	0 – 0.15	--	Uncertain
	Smectite volume fraction	0 – 0.3	--	Uncertain
	Cation Exchange Capacity	0.1 – 40 meq/100 g	--	Uncertain

Groundwater Assessment Field Application

- Some non adjustable parameters are significantly different than observations
- Hydraulic parameters and source term magnitude are more sensitive than clay fraction or CEC
- Constraining sand permeability reduced aquifer volume impacted by an order of magnitude
- Constraining sand fraction and correlation lengths could reduce uncertainty

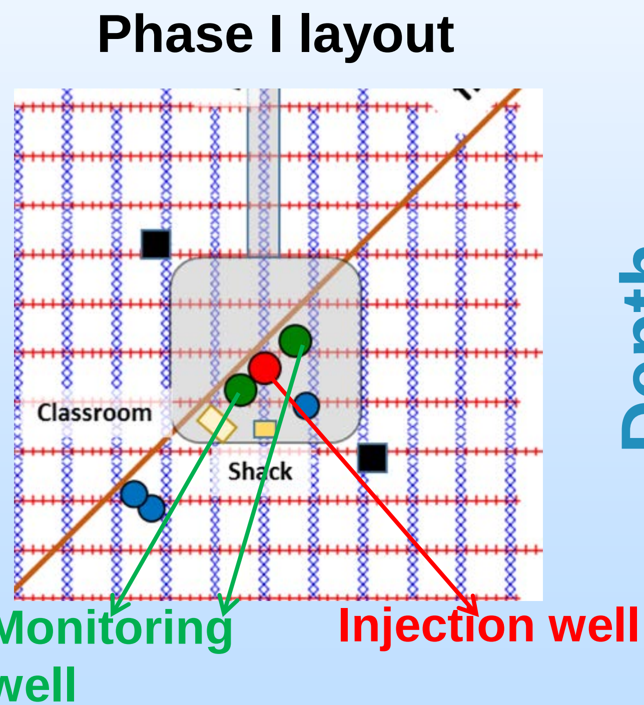


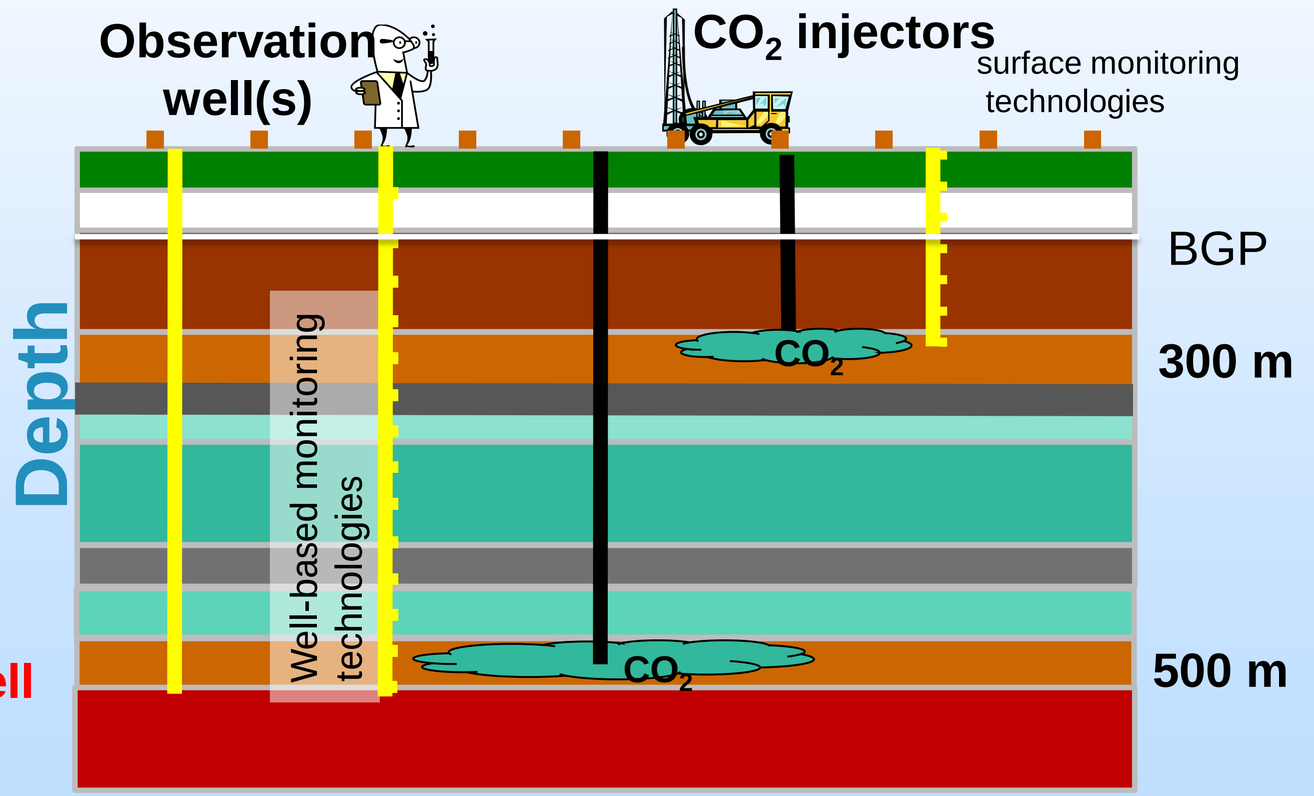


Containment Tools and Methodologies Field Demonstration: Leakage Analog Site

Liange Zheng, Tom Daley, LBNL

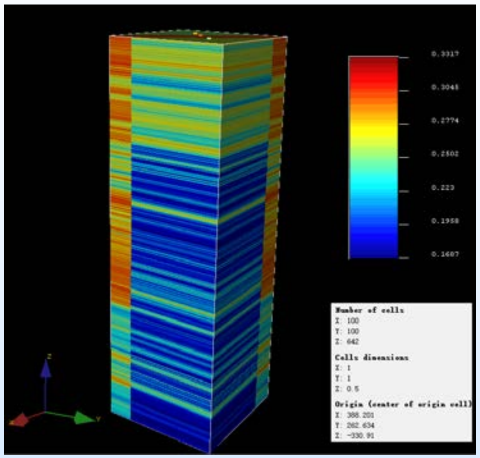
Containment and Monitoring Institute (CaMI) Field Research Station



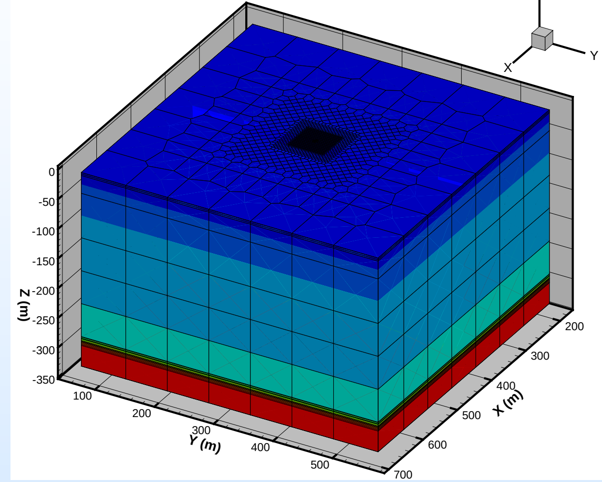


Containment Tools and Methodologies Field Demonstration: Test modeling and monitoring methodologies

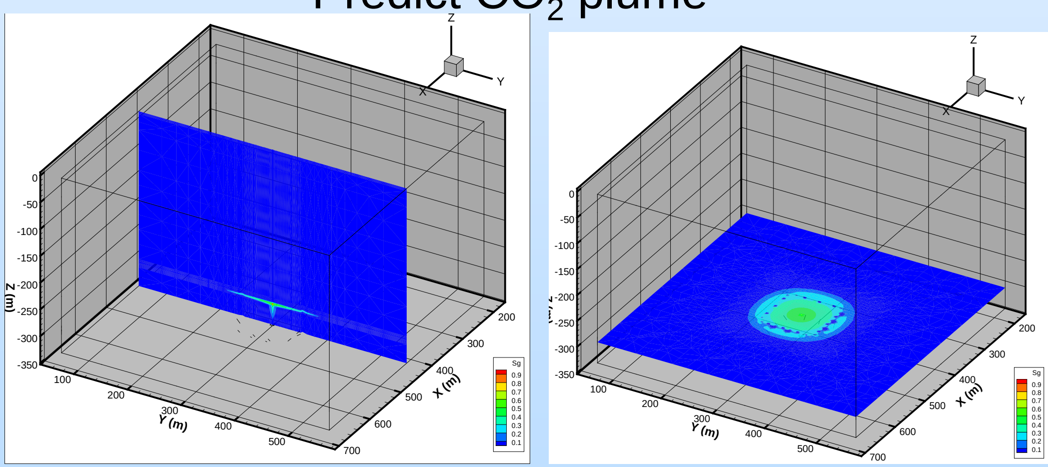
Geological model



Numerical mesh



Predict CO_2 plume



Containment Tools and Methodologies Field Demonstration: Monitoring at CaMI

Continuous monitoring

•Downhole pressure and temperature (injection well)
•Downhole pressure and temperature (observation wells)
•Electrical resistivity tomography, using 128 node CaMI equipment
•Well-based microseismic recording during injection phase, using permanent down-hole geophone array and optical fibre
•Surface-based microseismic recording during injection phase, using buried surface geophones
•Surface-based, broadband regional seismicity (year1); Bristol University

Discrete monitoring - geochemistry

•Atmospheric monitoring leakage program
•Groundwater sampling from domestic well
•Groundwater sampling from multi-level wells
•Soil gas (CO_2 and CH_4) monitoring with up to 24 soil gas probes
•Soil gas (CO_2 and CH_4) monitoring using 12 moveable soil gas flux measurements
•Surface casing vent flow monitoring
•Observation well fluid sampling and analysis
•Tracer studies including 'doped' CO_2 with a trace of thermogenic methane
•Tracer studies including noble gases (collaboration with Edinburgh University, UK)

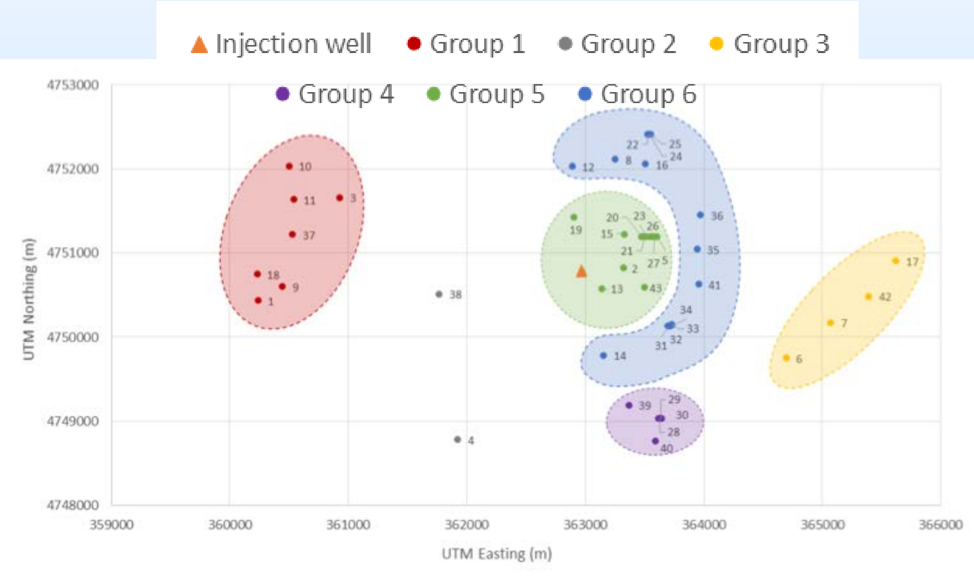
Discrete monitoring – geophysics and well logging

•3C-3D surface seismic surveys using 500 CaMI nodes and fibre-based sensors
•Vertical seismic profiles – both permanent sensors and removable (Dave Eaton)
•Cross-well seismic surveys (LBNL)
•Cross-well electromagnetic surveys (LBNL)
•Surface-borehole electromagnetic surveys (LBNL)
•Surface-borehole electrical resistivity surveys (LBNL)
•Magnetometric resistivity surveys (INRS)
•Time-domain electromagnetic surveys (INRS)
•Pulsed neutron logs
•Borehole sonic logs
•Borehole induction logs

Strategic Monitoring Tools and Methodologies Demonstration

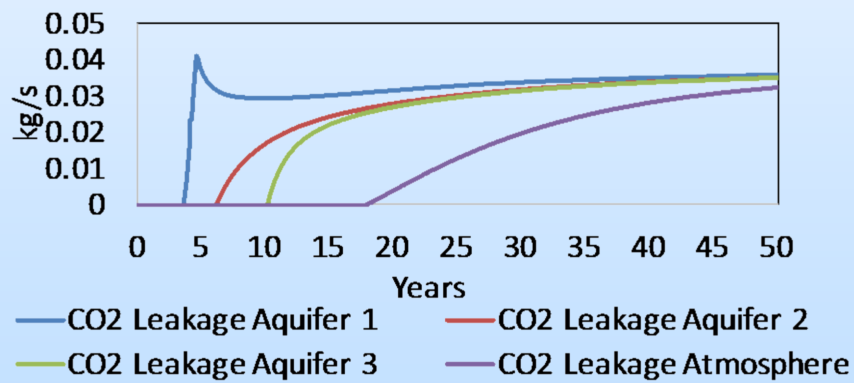
Catherine Yonkofski[1], Guzel Tartakovsky[1], Diana Bacon[1], Nik Huerta[2], Andy Wentworth[2], Joel Sminchak[3], Glenn Larson[3], Neeraj Gupta[3]
1. PNNL 2.NETL 3.BCO

BCO's well integrity database (WID) is being used by the WLAT and DREAM tools to demonstrate design of practical monitoring strategies based on hypothetical leakage risk derived from the wellbore integrity indicator index (WBI).

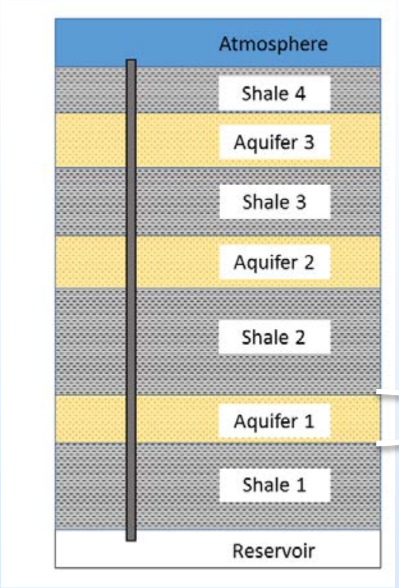


WLAT Tool

CO2 Leakage (kg/s): Well 15 into all layers

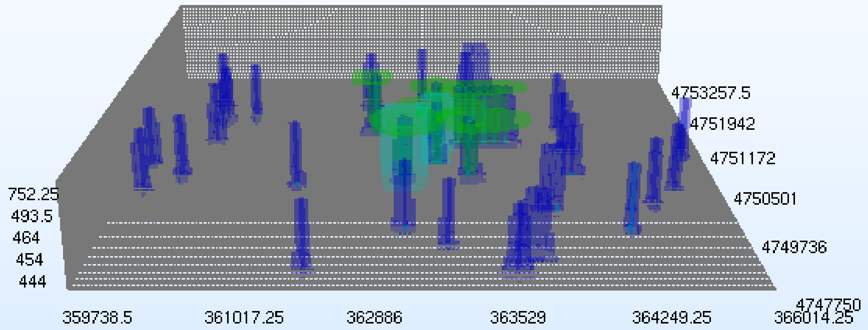


Strategic Monitoring Tools and Methodologies Demonstration



DREAM Tool

Leakage Solution Space

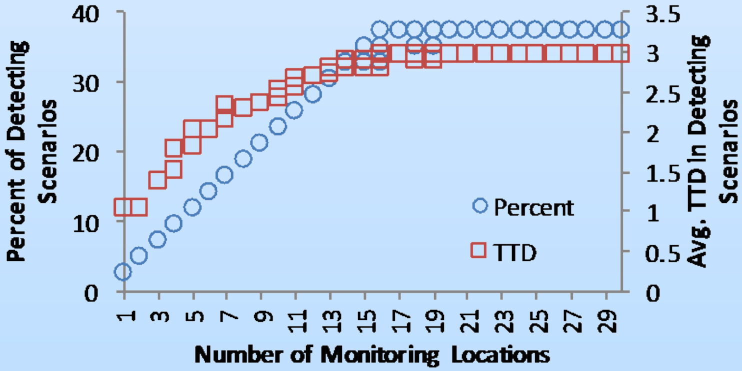


$C_{aq,NaCl}$ S_g dP

Using WLAT output, we modeled hypothetical CO_2 and brine leakage into the deepest overlying aquifer.

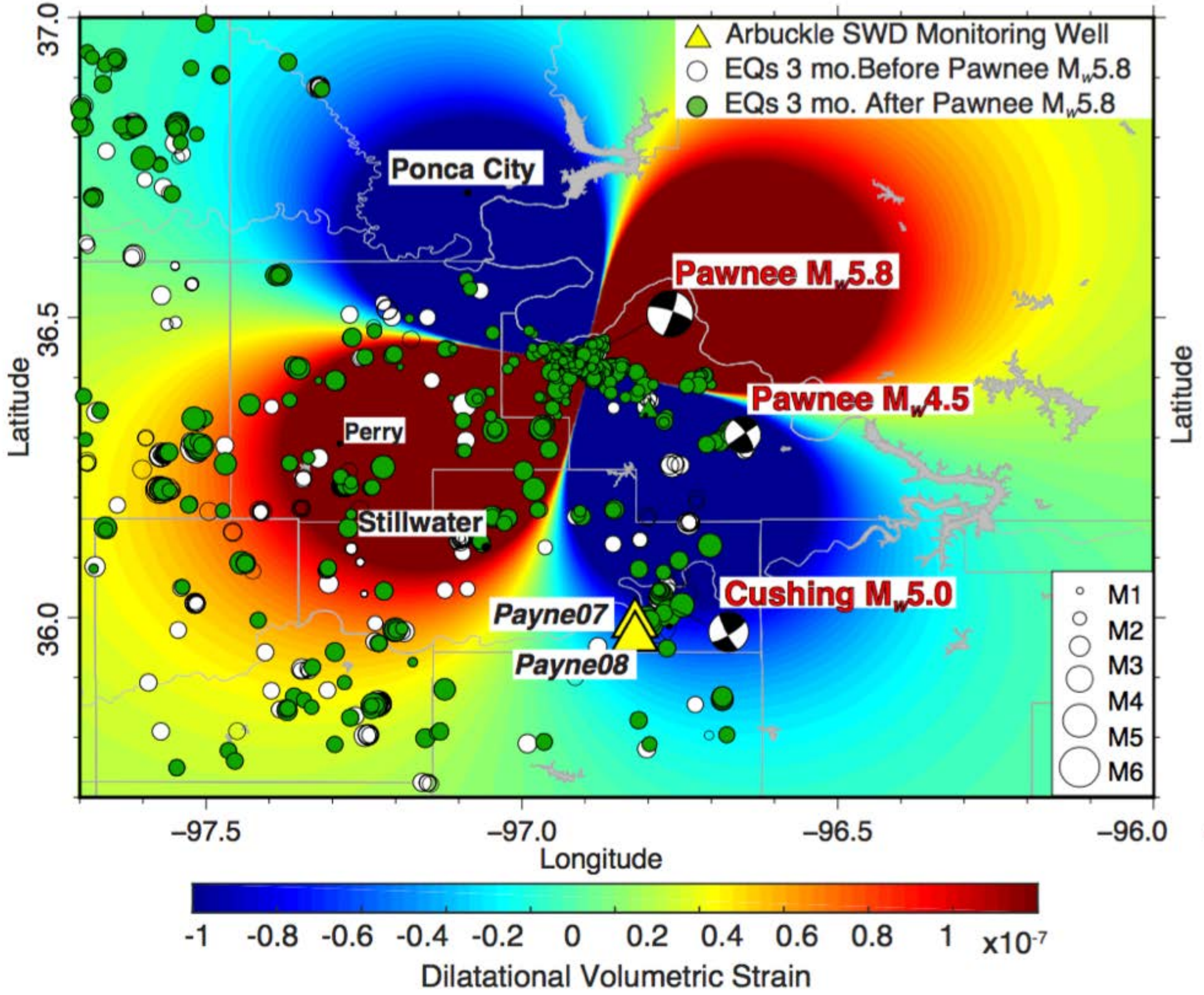
DREAM results show the optimal pressure-based monitoring schemes based on

- Time to leak detection
- Marginal advantage of additional pressure sensors (right)
- Cost of system



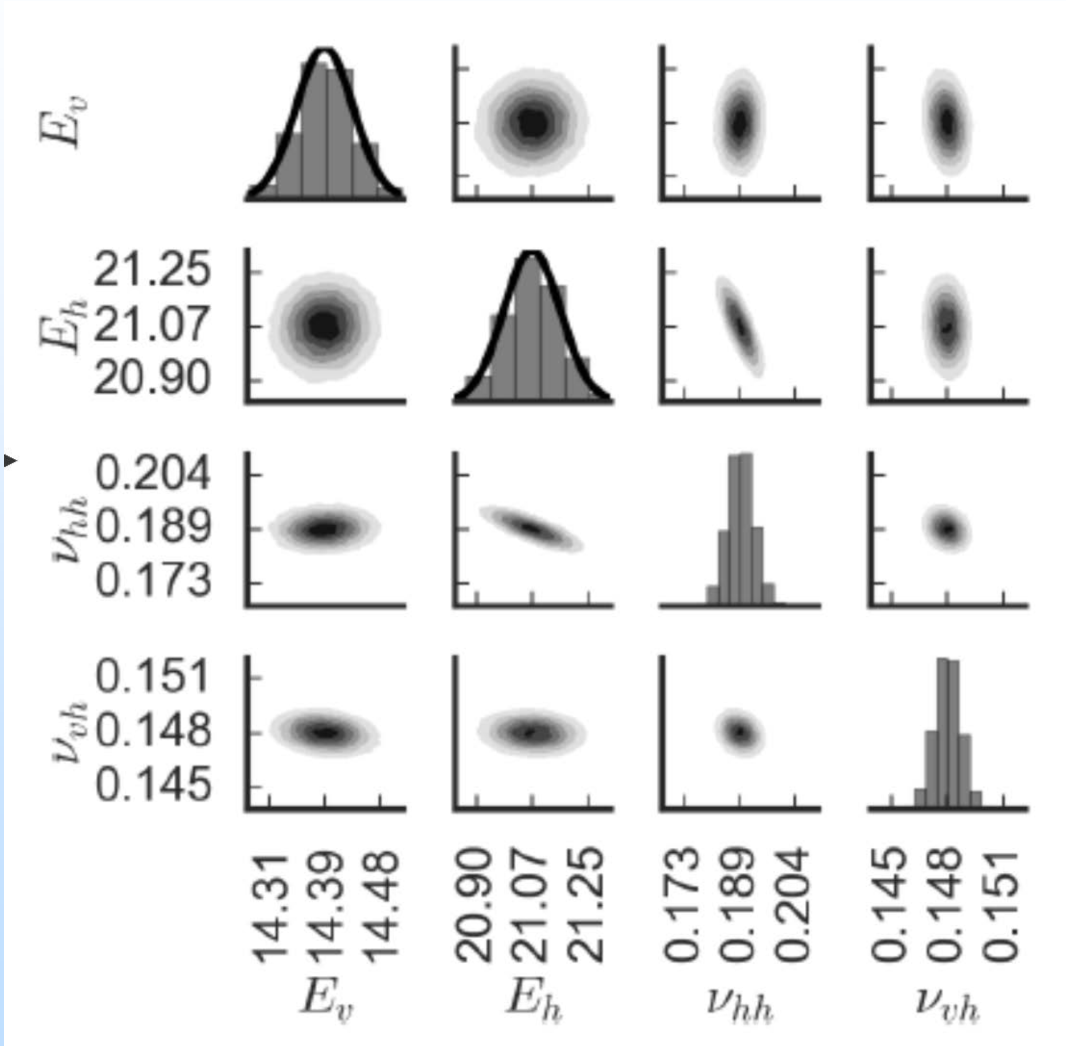
Induced Seismicity Tools and Methodologies Demonstration

Kayla Kroll, Josh White
LLNL



Oklahoma Application. Monitoring data and RSQSim simulation results analyzing the poroelastic deformation of the Arbuckle group [Kroll et al. 2017]

Induced Seismicity Tools and Methodologies Demonstration



Jeff Burghardt, Mark White
PNNL

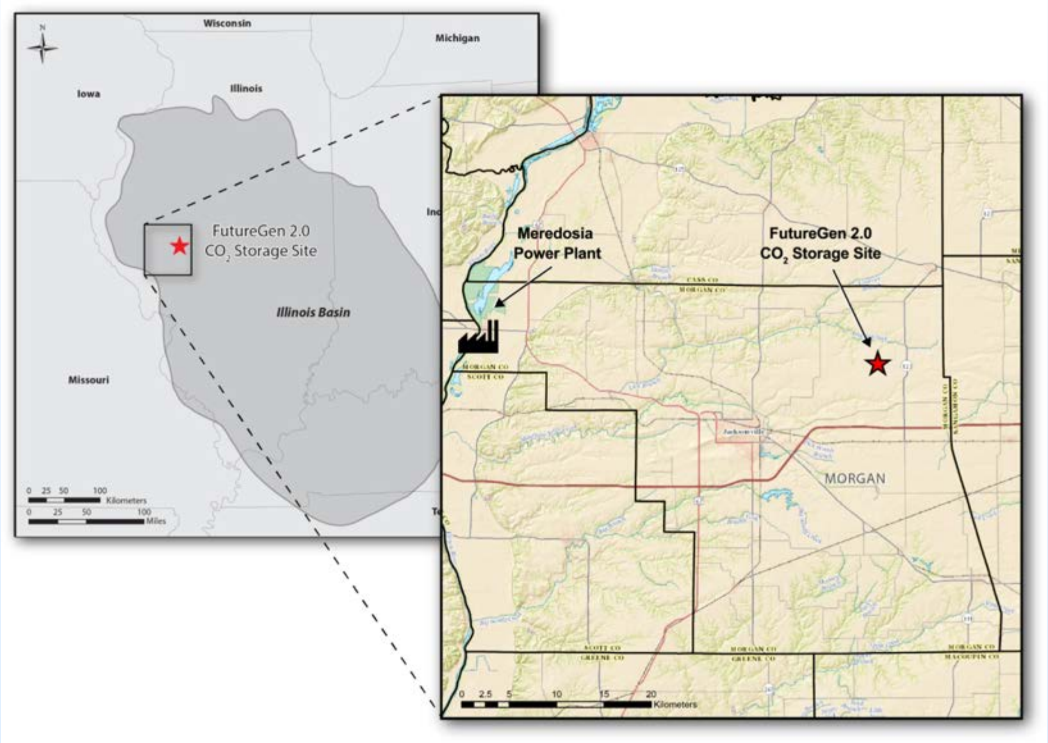
Farnsworth Application.

Posterior probability distributions of elastic properties inferred from triaxial testing data [Burghardt et al. 2017].

Identify Field Site for Large Scale Leveraged Activities

Inci Demirkanli, Delphine Appriou, Signe White, PNNL

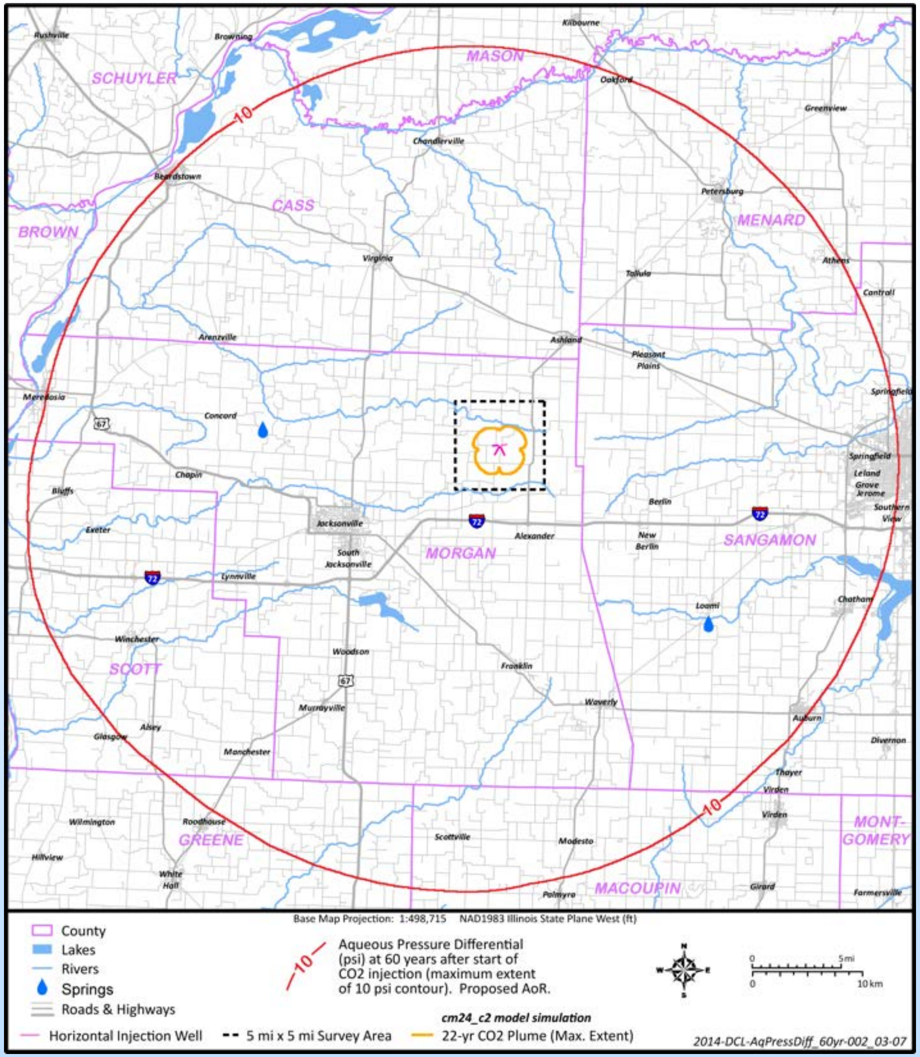
- A subset of FutureGen 2.0 project data was identified for supporting
  - Validation and testing activities; and
  - Compilation of a community dataset



- Data uploaded to EDX for larger NRAP community use included:
  - 2D seismic
  - Geophysical logs
  - Core analyses
  - Gravity and geodetic surveys
  - Borehole VSP
  - In-situ stress characterization
  - Hydrologic field test
  - Reservoir model
  - Leakage model

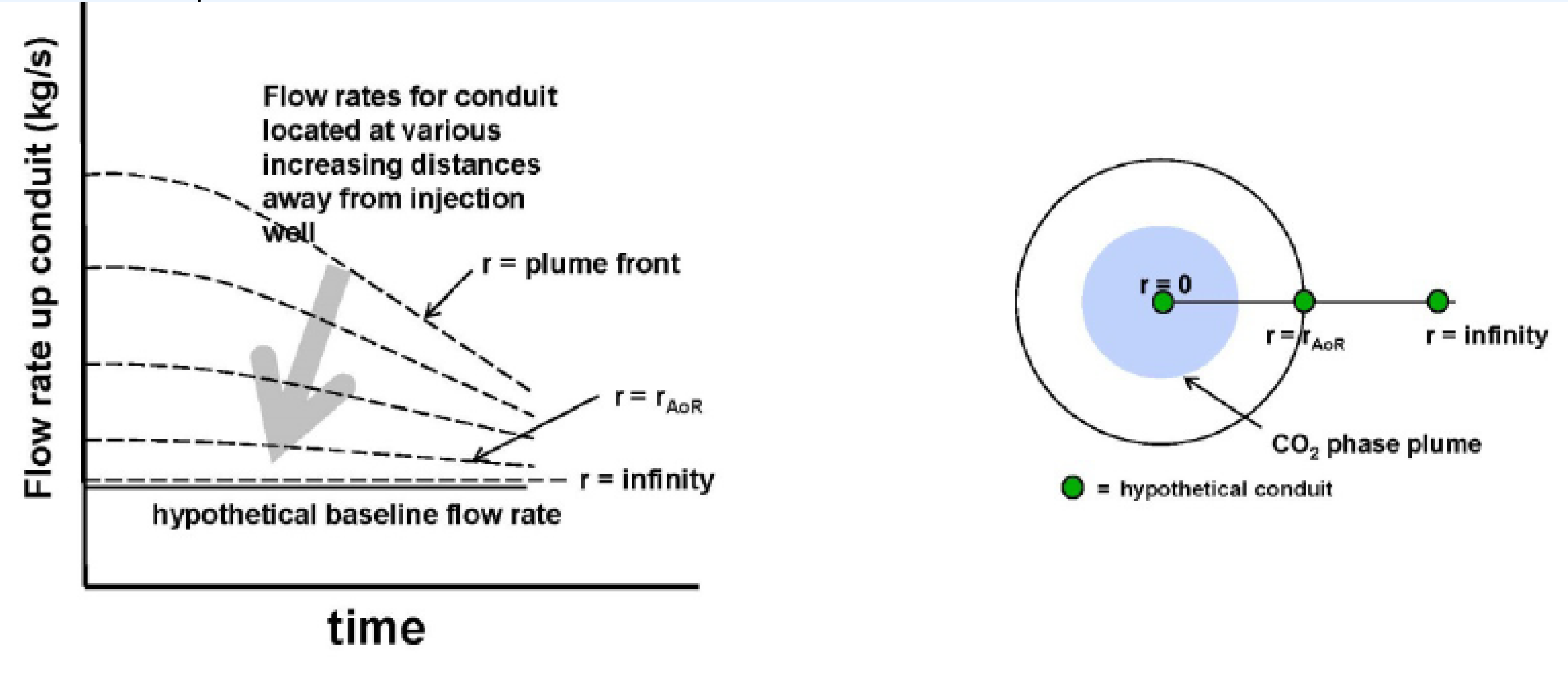
Use of NRAP-IAM-CS for Risk-Based AoR: FutureGen 2.0 Application

- Use of FutureGen 2.0 data for demonstrating a risk-based project Area of Review (AoR) delineation
  - Over-pressurized injection formations are challenging for delineating AoR, where the project may cause endangerment of USDWs
  - Current methods to calculate a critical pressure increase rely on the assumption that the injection zone is in hydrostatic equilibrium with respect to the USDW (Nicot et al., 2009; Birkholzer et al., 2011)



Use of NRAP-IAM-CS for Risk-Based AoR: Delineation Methodology

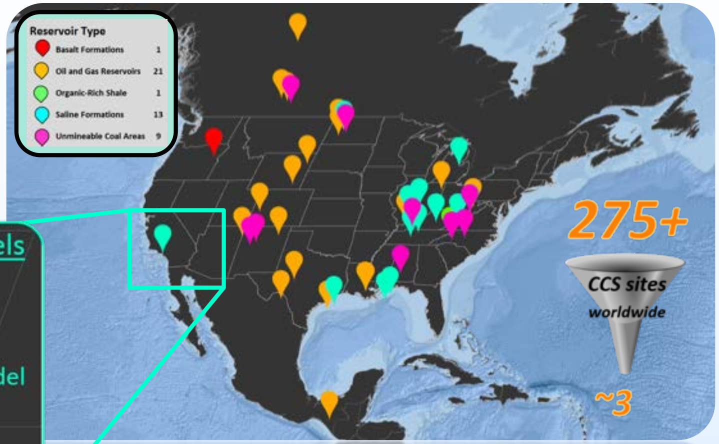
- Oldenburg et al. (2016):
  - Evaluation of the incremental increase in flow rate
  - Assume a **hypothetical open borehole** at varying distances from the injection well.

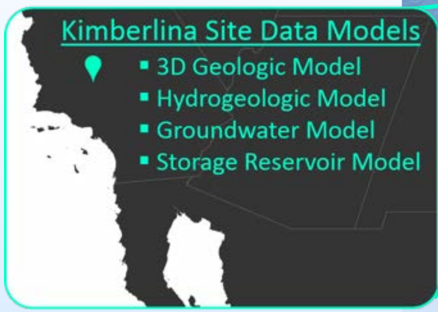


Development of Community Datasets

Jennifer DiGiulio[1], Kelly Rose[1], Bradley Gooch[1], Andrew Bean[1], Emily Cameron[1], Michael Sabbatino[1], Diana Bacon[2]
1. NETL 2. PNNL

NRAP Tool Developer Community Datasets Needs/Requests Survey	Number of Responses
What is your name?	19
What is your affiliation?	19
What is your contact email?	19
Researcher Background?	19
Do you have an account on EDX?	19
Which specific NRAP Tasks are you affiliated with?	19
Which NRAP tool(s), if any, were you involved with development of in NPAP's first phase?	11
Which kind(s) of data and/or simulation results are you looking for to aide in your tool development?	19
Are there specific input/export data formats that are key to your validation and testing needs?	17
Are there field or synthetic datasets that you are currently using to develop NRAP tools?	10
Any other comments or suggestions?	5





Completed

Design and distribute community datasets survey → Synthesize results

In Progress

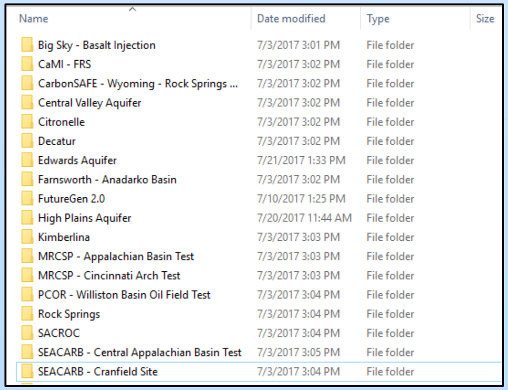
Develop preliminary data catalog → Compile accessible data / Identify priority sites

Upcoming Tasks

Identify utility of tools at each priority site → Consider tools; identify and mitigate gaps → Prepare interactive atlas in EDX/GeoCube

Accomplishments to Date

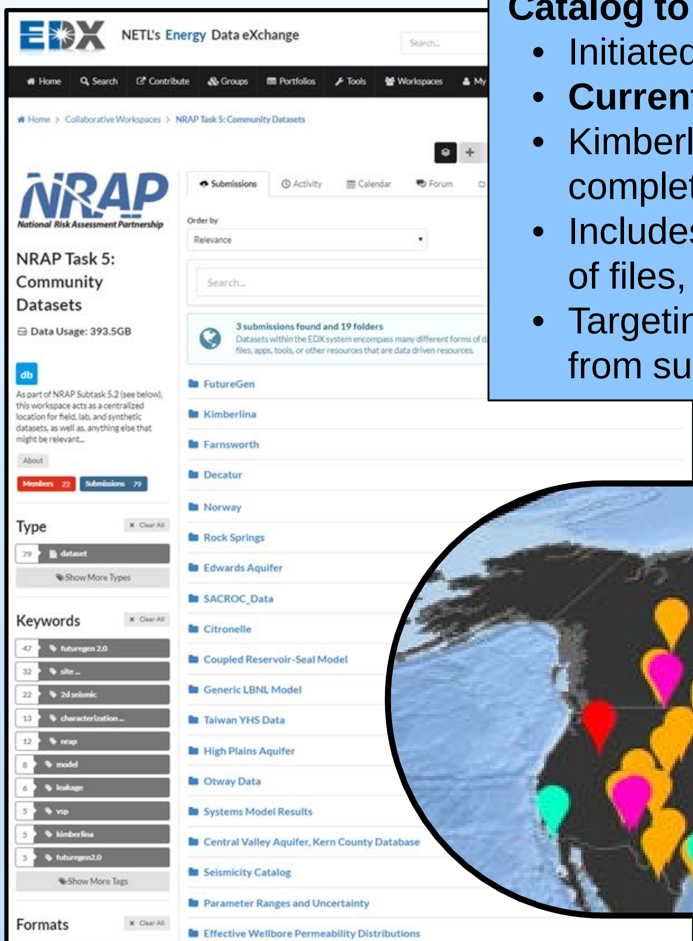
- Executed an 11-question survey to **identify data needs** of NRAP tools
  - Responses from 19 NRAP tool researchers spanning 6 of 7 tools
- Initiated **development of US CCS data catalog for 18 sites on EDX**
- **Needs being cross-referenced against CCS sites** to prioritize sites that meet NRAP tool needs



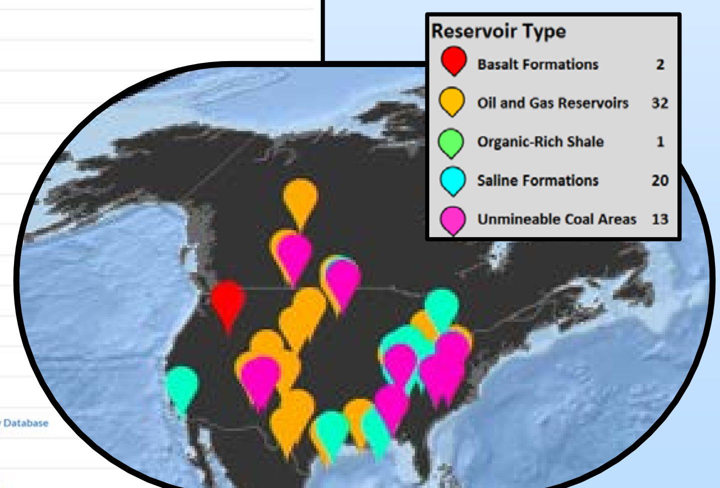
Name	Date modified	Type	Size
Big Sky - Basalt Injection	7/3/2017 3:01 PM	File folder	
CaMI - FRS	7/3/2017 3:02 PM	File folder	
CarbonSAFE - Wyoming - Rock Springs ...	7/3/2017 3:02 PM	File folder	
Central Valley Aquifer	7/3/2017 3:02 PM	File folder	
Citronelle	7/3/2017 3:02 PM	File folder	
Decatur	7/3/2017 3:02 PM	File folder	
Edwards Aquifer	7/21/2017 1:33 PM	File folder	
Farnsworth - Anadarko Basin	7/3/2017 3:02 PM	File folder	
FutureGen 2.0	7/10/2017 1:25 PM	File folder	
High Plains Aquifer	7/20/2017 11:44 AM	File folder	
Kimberlina	7/3/2017 3:03 PM	File folder	
MRCSP - Appalachian Basin Test	7/3/2017 3:03 PM	File folder	
MRCSP - Cincinnati Arch Test	7/3/2017 3:03 PM	File folder	
PCOR - Williston Basin Oil Field Test	7/3/2017 3:04 PM	File folder	
Rock Springs	7/3/2017 3:04 PM	File folder	
SACROC	7/3/2017 3:04 PM	File folder	
SEACARB - Central Appalachian Basin Test	7/3/2017 3:05 PM	File folder	
SEACARB - Cranfield Site	7/3/2017 3:04 PM	File folder	

Data for NRAP Tools –
Building an NRAP Community Data Catalog

- **Developing a catalog of CCS data for US sites**
- Will help provide **efficient access** to authoritative, priority data for NRAP users **& highlight data gaps**



Catalog to Date:
- Initiated development in EDX
- **Currently includes 18 US sites**
- Kimberlina & Futuregen most complete
- Includes ~400 GB of data, 100's of files, largely open-source
- Targeting desired datasets ID's from survey



Desired Datasets

Subsurface Structure	Geologic framework
	Fault surfaces and orientations
	Petrophysical parameters
	In-situ geophysical data
	Pressure-temperature data
Seismic	Seismic and microseismic data
	Seismic velocity and Q structure
	Waveform data
Field Production Data	Injection volume and pressure histories
	Operating GCS/EOR site data
Hydromechanical Characterization	Well logs
	Porosity and permeability
	In-situ stress data
	Historical well log data
	Elastic properties
Electrical Properties	Conductivity, MT, SP, Permittivity data
Geochemistry	Geochemical reaction data
Simulation Data	Leakage simulation resullts
Laboratory Experiments	Experimental injection data

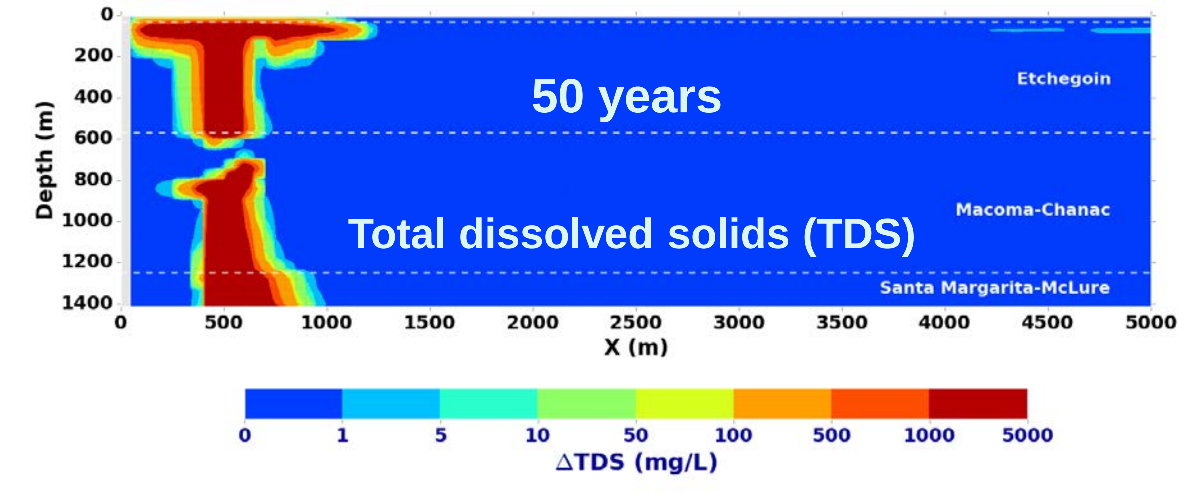
Tool	Tool Description	Number of Users*
AIM	Aquifer Impact Model	1
DREAM	Design for Risk Evaluation and Monitoring	1
NRAP-IAM-CS	Integrated Assessment Model	4
NSealR	Natural Seam ROM	1
REV	Reservoir Evaluation and Visualization Tool	-
STSF	Short Term Seismic Forecasting	4
WLAT	Wellbore Leakage Analysis Tool	4

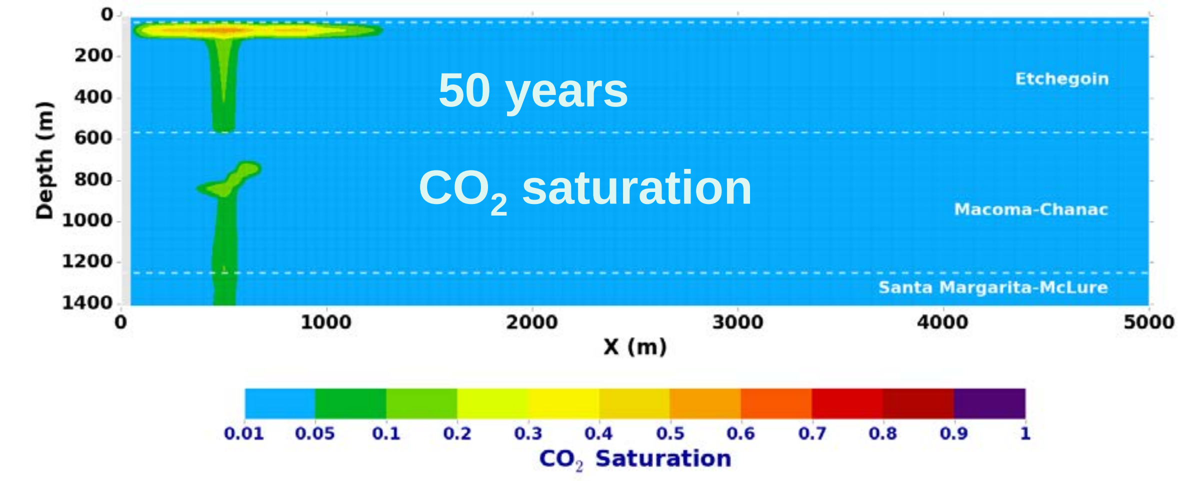
*11 of 19 survey participants were involved in tool development

Synthetic Data Set: Kimberlina V1.1

Susan Carroll, Kayyum Mansoor, LLNL

- Leakage from a wellbore into overlying aquifers
- Change in groundwater chemistry near wellbore





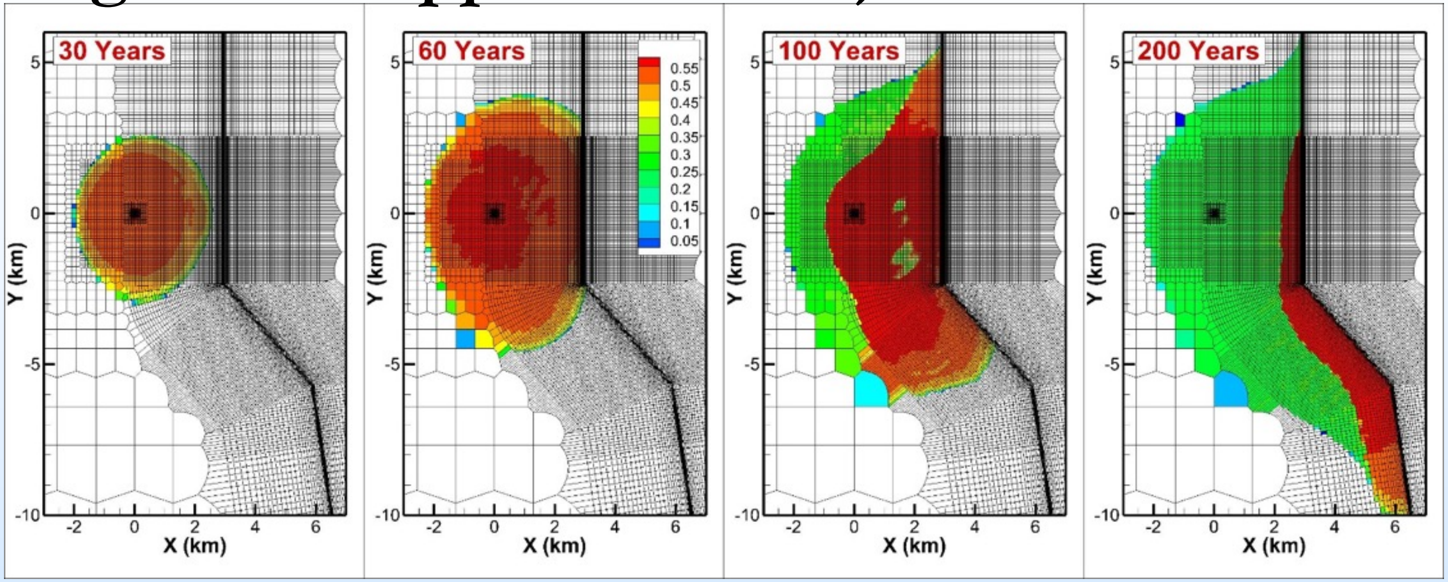
Leakage monitoring using multiple geophysical methods

Geophysical Method	Signals	Lab
MT and ERT	Gas phase and dissolved CO_2	LLNL
Pressure	Pressure plume	LLNL
Gravity	Gas phase CO_2	PNNL
Seismic	Gas phase CO_2	LANL

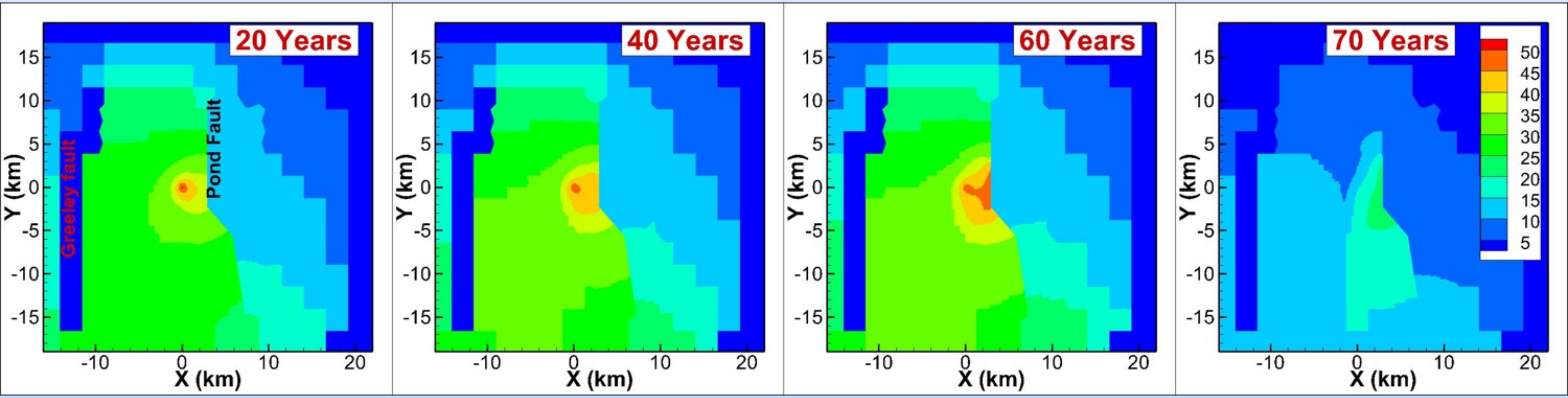
Kimberlina Site Data set v2.0 for Testing of Monitoring Tools/Approaches: Injection Scenarios

Quanlin Zhou, LBNL

CO_2 Plumes in Vedder Injection Reservoir

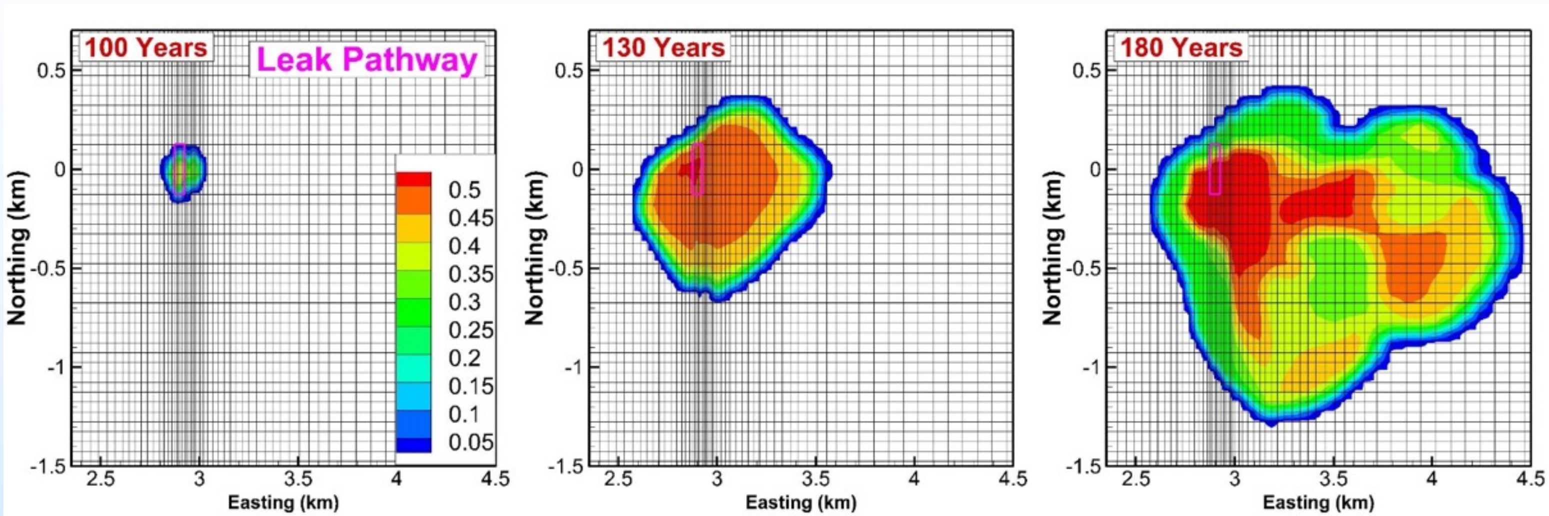


Pressure-Buildup Plumes in Vedder Injection Reservoir

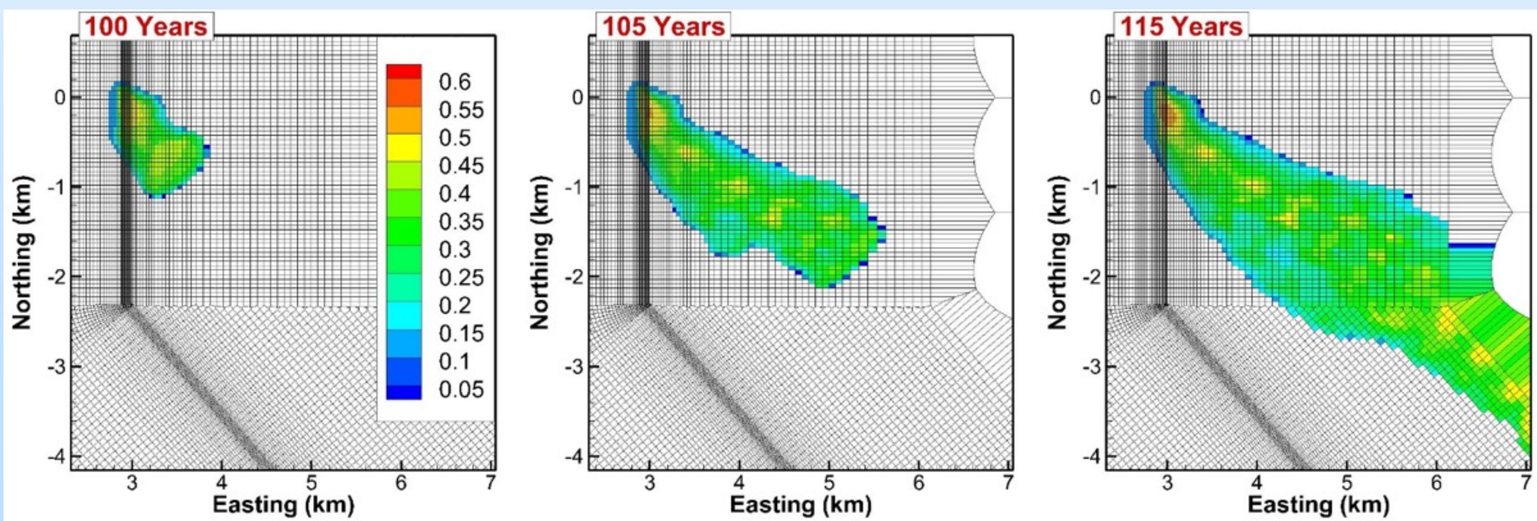


Kimberlina Site Data set v2.0 for Testing of Monitoring Tools/Approaches: Fault Leakage Scenarios

Olcese Secondary Plume



Echegoin Secondary Plume



Accomplishments to Date: Field Applications

– Demonstrated protocol for applying the Aquifer Impact Model to the Illinois Basin – Decatur Site
– Developed model to help plan the Containment and Monitoring Institute (CaMI) controlled leakage experiment
– Used field and laboratory data to better understand the relationship between rock elastic properties and induced seismicity
– Battelle's well integrity database is being used with the Wellbore Leakage Analysis Tool (WLAT) and DREAM tools to demonstrate design of practical monitoring strategies
– Developed risk-based AOR method using the NRAP-IAM-CS integrated assessment model

Accomplishments to Date: Synthetic Datasets

– FutureGen 2.0 project data uploaded to EDX for use by NRAP community
– Surveyed NRAP tool developers to determine what data they need for testing the tools and what data they have to share
– Results being cross-referenced against CCS sites to prioritize sites that meet NRAP tool needs and identify data gaps
– Developed synthetic datasets for wellbore leakage at Kimberlina to be used for testing monitoring methodologies
– Distributed first synthetic datasets for fault leakage at Kimberlina for scientists to develop data readers for testing monitoring methods

Lessons Learned

– Field Applications
  - Current aquifer ROMs may not be flexible enough to apply to all sites, but a site-specific groundwater model may not have been developed for a potential storage site
  - Biggest obstacle in DREAM tool demonstration task was data generation. It took a significantly longer time to generate the example leakage simulations than to demonstrate the tool capabilities
  - The complex pore pressure history at the Farnsworth site make estimating the state of stress and risk of induced seismicity a bigger challenge than it would be in a greenfield

– Synthetic Datasets
  - User training for EDX is needed and was offered during this afternoon

Synergy Opportunities

- Application of NRAP tools by CarbonSAFE projects will help
  - 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

Project Summary

– Key Findings
  - Aquifer Impact Model can be used to guide characterization by identifying sensitive parameters
  - Using a typical pressure-based monitoring technology, DREAM results showed optimal configurations detecting hypothetical leaks in ~40% of scenarios. The rest did not exceed the user-defined detectable thresholds.
  - At the Oklahoma site there are indications of permeability modification due to earthquakes.
  - At the Farnsworth site even a few stress and pore pressure measurements could have a significant value by allowing an expanded operating pressure range
  - Datasets for the other 43 CCS sites in North America have been cataloged on EDX for community access

Project Summary

– Next Steps
  - At the CaMI site, update CO_2 plume prediction, simulate the geochemical change at the injection formation, simulate hypothetical leakage of CO_2 to shallow aquifer
  - Will submit journal article on results of DREAM field application
  - Data analysis methods for identify permeability changes due to earthquakes will be enhanced using data from the Oklahoma site
  - Identify 2-3 priority CCS sites and prepare detailed data catalogs for each
  - Complete development and sharing of Kimberlina 2.0 synthetic dataset

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

- Field Applications
  - Groundwater Assessment Field Application (Diana Bacon, PNNL)
  - Containment Tools and Methodologies Field Demonstration (Liange Zheng, LBNL)
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Task Milestones

Milestone	Date	Status
Submit journal article on application of AIM to a large field demonstration project	3/17	Manuscript submitted to peer-review journal, and uploaded to NRAP EDX
Archive Kimberlina version 1 site reservoir, groundwater models, including metadata on domain size; parameters; and data set(s)	3/17	Archived data uploaded to EDX

Bibliography

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