NRAP Task 6: Addressing Critical Questions Related to Risk Management at Geologic Carbon Storage Sites

(Risk-Based Approach to Post-Injection Site Closure)

Project Number 1022407

Diana Bacon; Grant Bromhal; Christopher Brown; Susan Carroll; Robert Dilmore; Christine Doughty; Dylan Harp; Nicolas Huerta; Greg Lackey; Curtis Oldenburg; Rajesh Pawar; Xianjin Yang; Bailian Chen; Shaoping Chu; Nataliia Makedonska; Eugene Morgan; Brandon Schwartz; R. Burt Thomas; Veronika Vasylkivska

U.S. Department of Energy

National Energy Technology Laboratory

Addressing the Nation's Energy Needs Through Technology Innovation – 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting

August 26-30, 2019

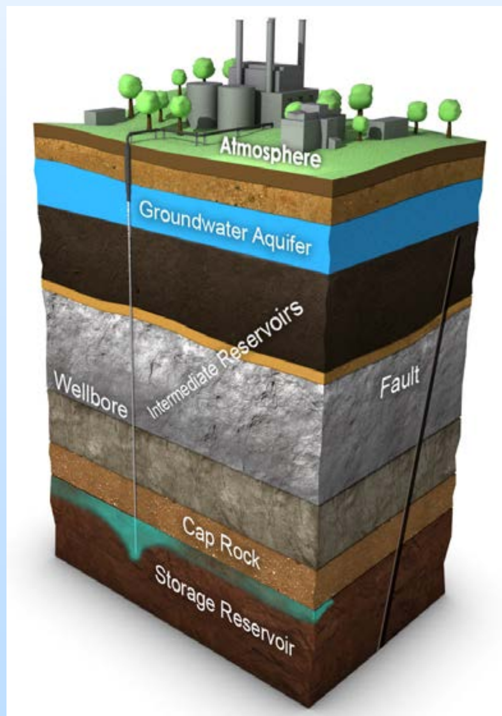
Presentation Outline

- NRAP overview and Task 6 focus
- Post-injection closure studies
- Pursuing workflows to address critical stakeholder questions

National Risk Assessment Partnership

Objective: Building tools improving the science base to address key questions related to environmental impacts from potential release of CO_2 or brine from the storage reservoir, and potential ground-motion impacts due to injection of CO_2

Technical Team



Stakeholder Group

How can a risk-based approach be used to justify early closure at a GCS site?

Purpose: to provide a technical basis to support the cost-effective and safe closure of GCS projects, using a risk-based justification as opposed to a generic, default monitoring plan.

Focus: Ensuring non-endangerment of groundwater resources post closure

- Is plume immobility required to ensure future containment?
- What defines conformance in the context of long-term containment?
- What is the anticipated evolution of risk at a storage site, post injection?
- How does a risk-based monitoring strategy differ from a default monitoring strategy?

Approach: A multi-site study to probe questions related to GCS site closure

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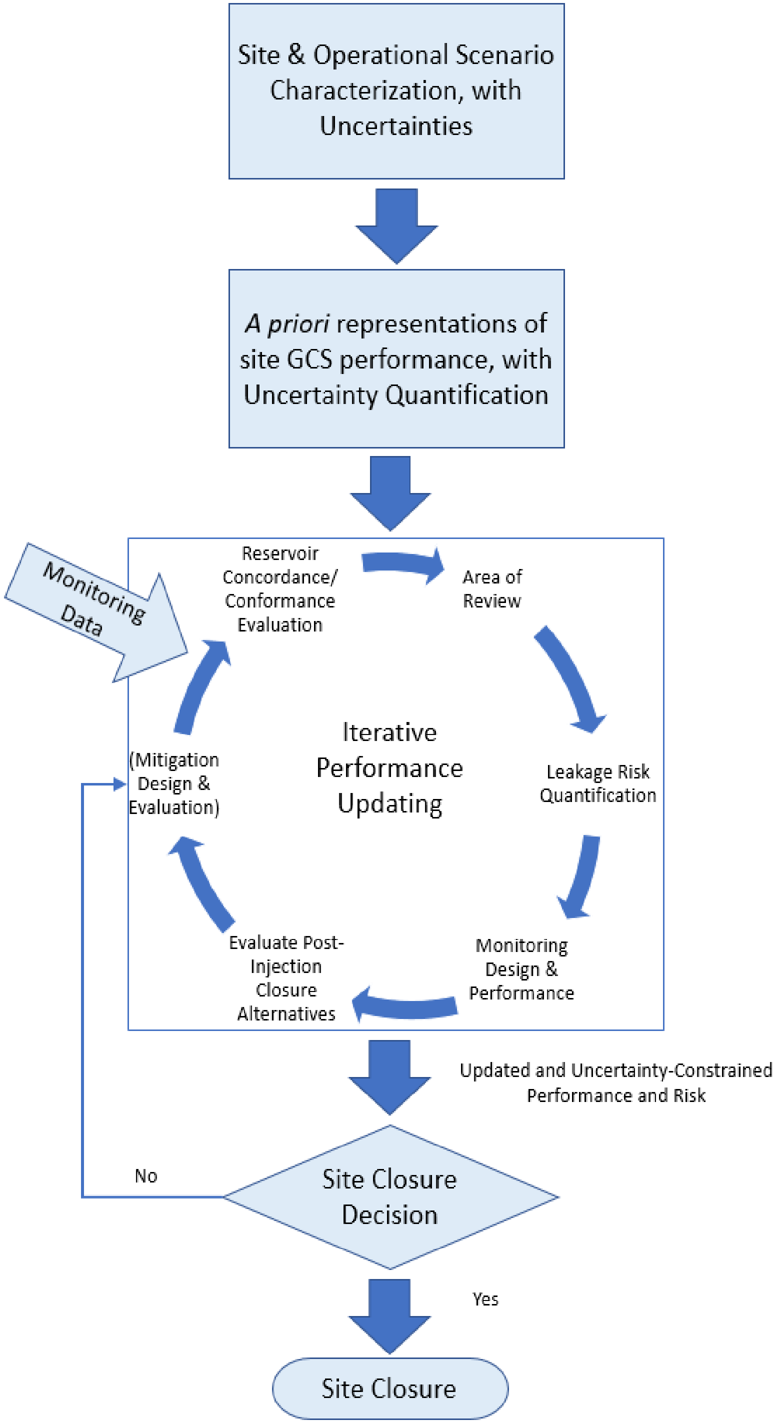
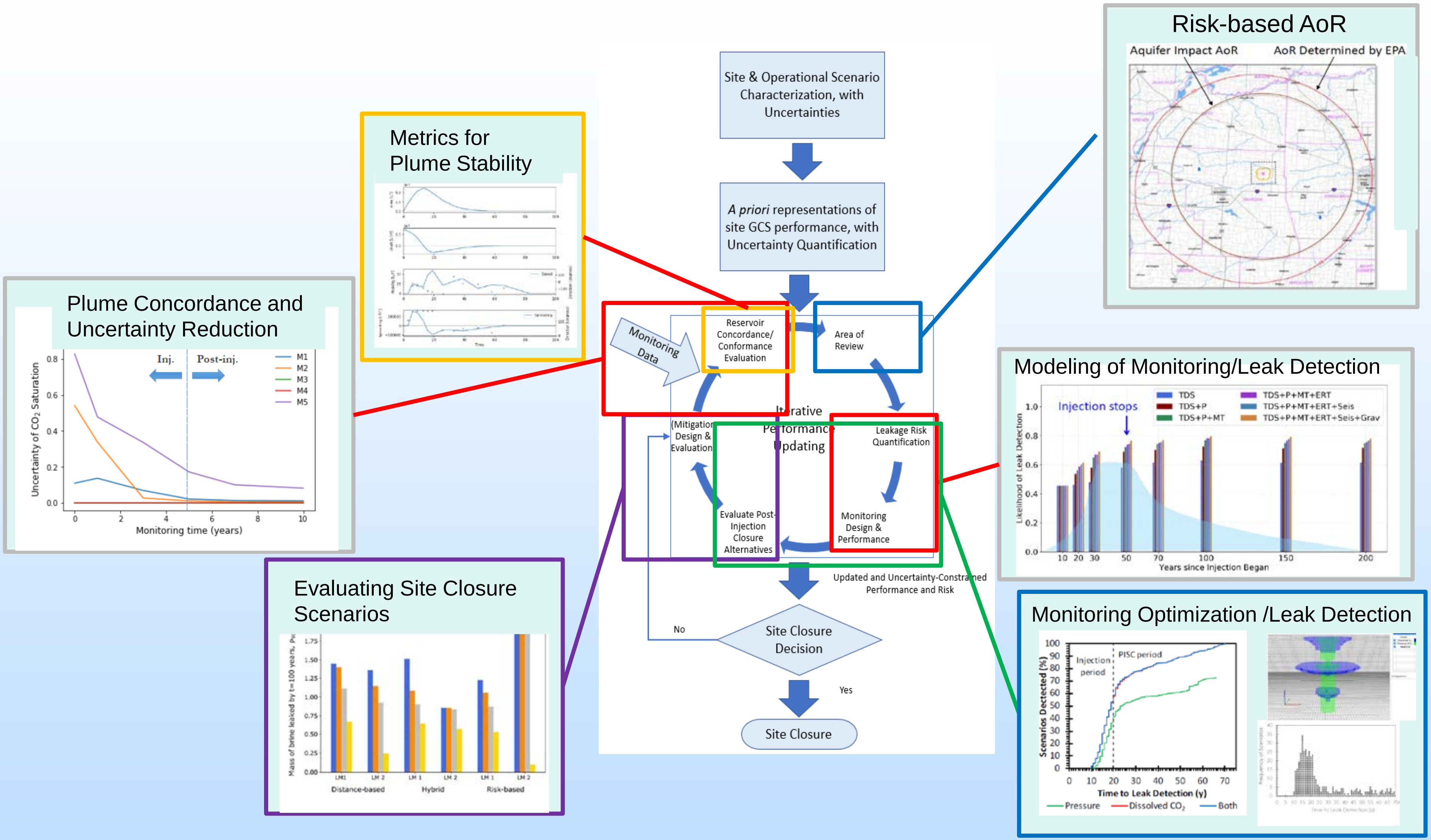
Approach: A multi-site study to probe questions related to GCS site closure





Metrics for Plume Stability
Plume Concordance and Uncertainty Reduction
Uncertainty of CO₂ Saturation
Inj.
Post-inj.
M1
M2
M3
M4
M5
Monitoring time (years)
Evaluating Site Closure Scenarios
Mass of brine leaked by t=100 years
Distance-based
Hybrid
Risk-based
Site & Operational Scenario Characterization, with Uncertainties
A priori representations of site GCS performance, with Uncertainty Quantification
Monitoring Data
Reservoir Concordance/ Conformance Evaluation
Area of Review
Iterative Performance Updating
(Mitigation Design & Evaluation
Leakage Risk Quantification
Evaluate Post-Injection Closure Alternatives
Monitoring Design & Performance
Updated and Uncertainty-Constrained Performance and Risk
No
Site Closure Decision
Yes
Site Closure
Risk-based AoR
Aquifer Impact AoR
AoR Determined by EPA
Modeling of Monitoring/Leak Detection
Injection stops
TDS
TDS+P
TDS+P+MT
TDS+P+MT+ERT
TDS+P+MT+ERT+Seis
TDS+P+MT+ERT+Seis+Grav
Likelihood of Leak Detection
Years since Injection Began
Monitoring Optimization /Leak Detection
Injection period
PISC period
Scenarios Dectected (%)
Time to Leak Detection (y)
Pressure
Dissolved CO₂
Both

Quantification of plume stability

Harp, D., Ohishi, T., Chu, S., Chen, S., Pawar, R. *GHG S&T*, 2019

Spatial moment:

Moment order

Scalar field (e.g., CO2 sat)

$$M_{pqr}(t) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} x^p y^q z^r f(x,y,z,t)\, dx\, dy\, dz$$

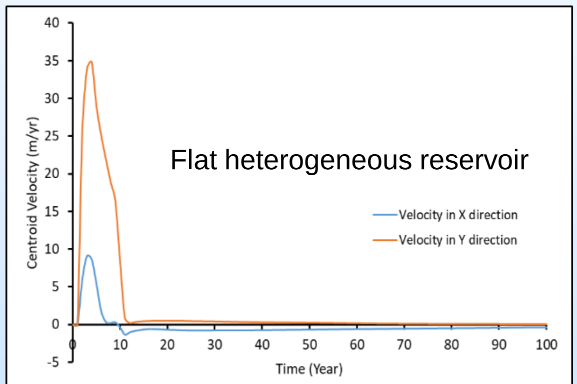
Coordinates

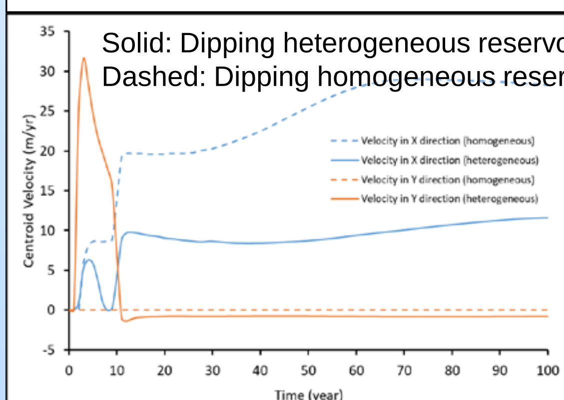
Time

Objective:
Development and application of plume stability metrics relevant to closure considerations (e.g., EPA Class VI PISC, EU CCS Directive)

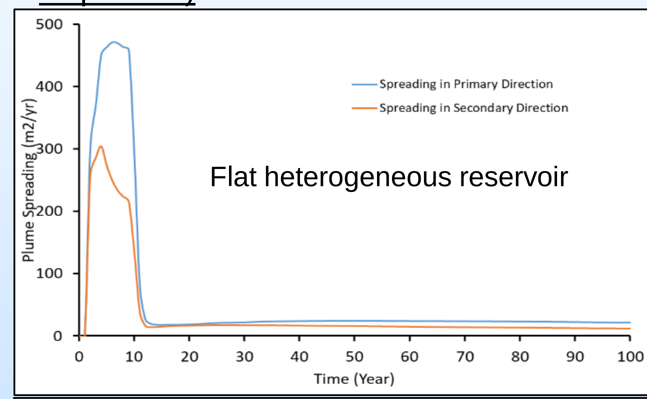
Approach:
Spatial moment analysis tailored to GCS applications.

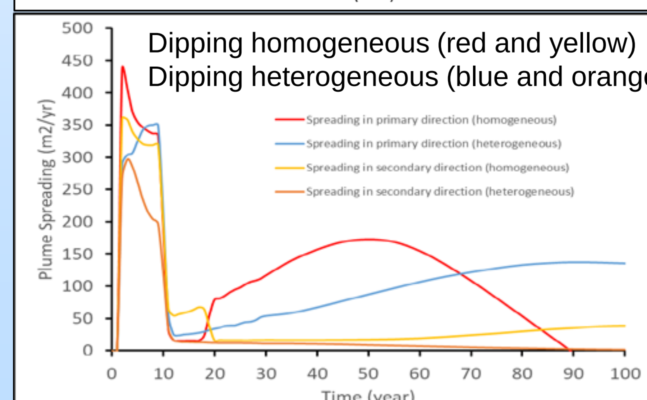
Mobility metric (effective centroid velocity)





Spreading metric (effective longitudinal dispersion)





Relationship between plume stability and risks

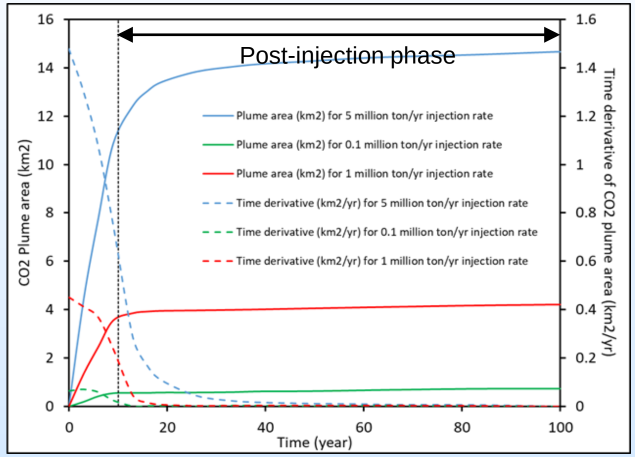
Pawar, R., Chu, S., Makedonska, N., Onishi, T., Harp, D. (forthcoming)

Objective: Assess whether lack of CO_2 plume stability implies there is risk to groundwater

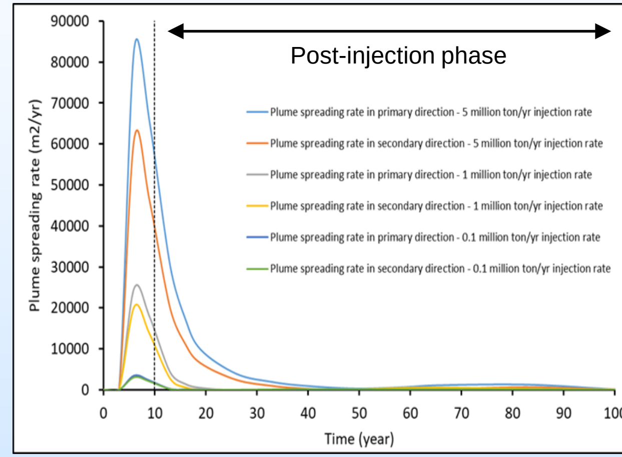
Approach:
Compute risks using NRAP-IAM-CS. Assess links between risks and plume stability.

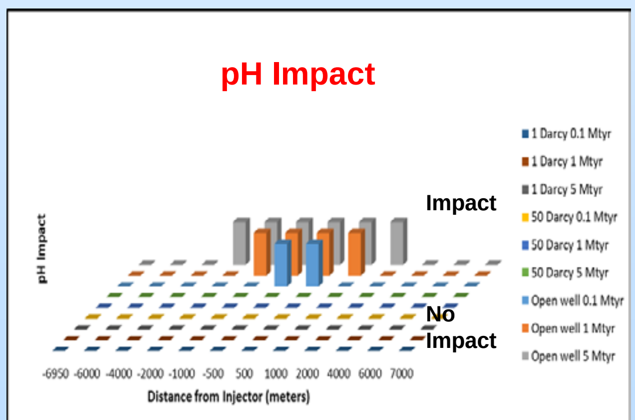
Results:
Lack of plume stability does not directly imply risks:

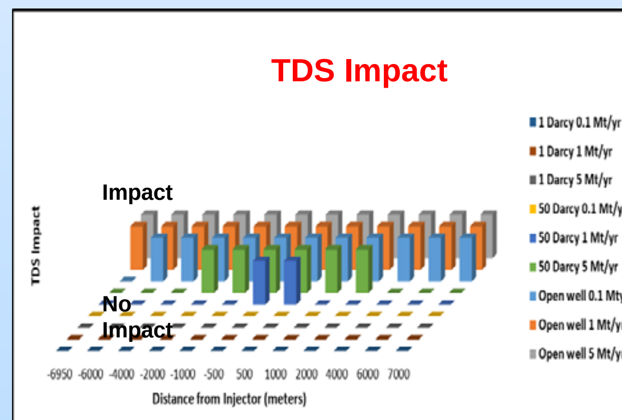
CO_2 plume area and derivative for different injection rates



CO_2 plume spreading for different injection rates







Application using model for Rock Springs Uplift

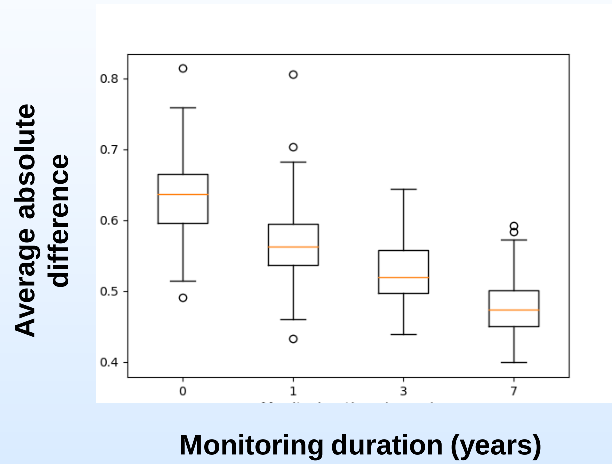
Reducing Uncertainty by Assimilating Monitoring Data

Chen, B., Harp, D., Lu, Z., Pawar, R (forthcoming)

Objectives:

- **Conformance/concordance assessment**
  - ✓ Monitoring data/simulation agreement improves over time
  - ✓ Improve/refine reservoir models
- **Reduce uncertainty** in predictions of risk metrics, such as plume area, P/S predictions at legacy wells, wellbore leakage rates, groundwater aquifer impact (pH/TDS plume size)

- **Model improvement over monitoring durations**

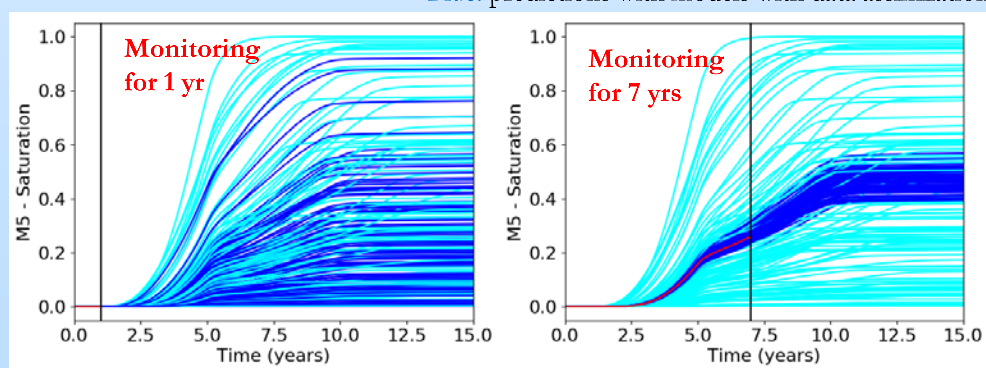


✓ "Average absolute difference" is an indicator of the difference between the predictions with and without monitoring data assimilation

✓ The reservoir models are significantly improved/refined with repeated assimilation of monitoring data.

- **Uncertainty reduction in predictions (e.g., CO_2 saturation) over monitoring durations**

Cyan: predictions with models without data assimilation
Blue: predictions with models with data assimilation



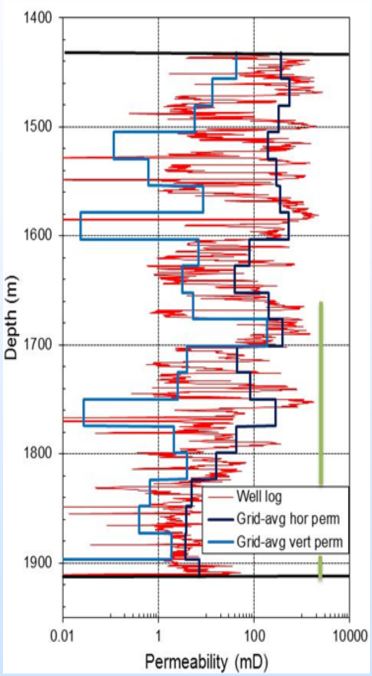
Simulation Study of Conformance Uncertainty Reduction Over Time

Christine Doughty and Curtis M. Oldenburg (LBNL)

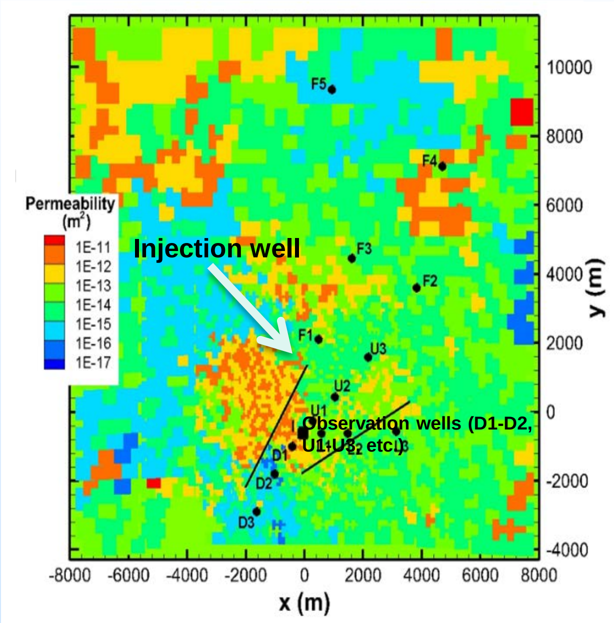
<u>Definition</u>: Conformance is the combination of (i) models matching observations and (ii) performance.

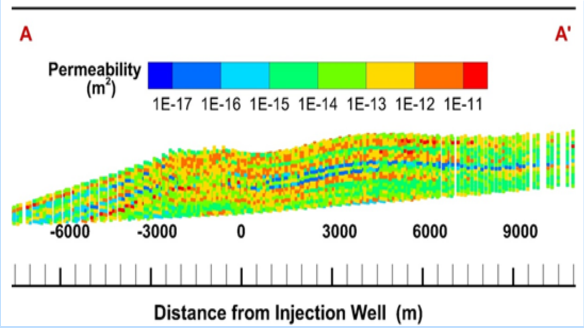
<u>Hypothesis</u>: The uncertainty in conformance decreases over time as models are improved based on observations of the system.

<u>Approach</u>: Build a virtual GCS site at a depleted natural gas reservoir to generate a set of "actual" data. Play out a scenario where an operator builds and runs successively better models each year based on monitoring observations of the "actual" system.

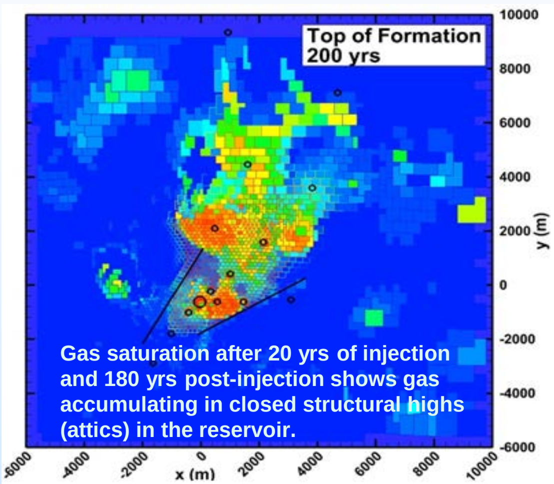


We chose a typical California depleted natural gas reservoir as the site. Heterogeneous permeability, undulating lower-most caprock, residual CH_4, etc. add complexity to the system.



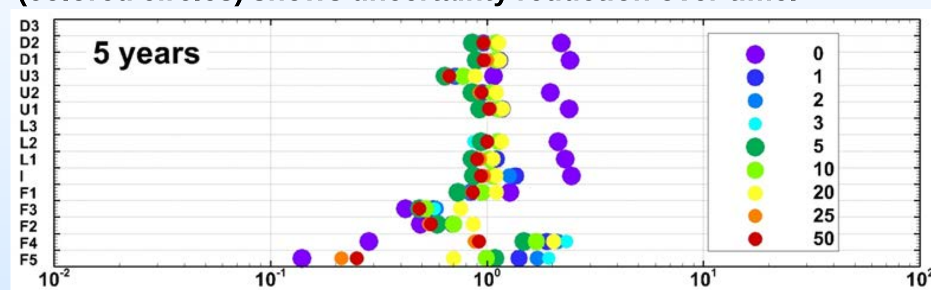


Simulations show that pressure and saturation forecasts become better over time although saturation is affected by local heterogeneity



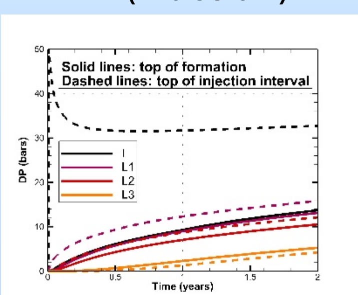
We sequentially simulated forecasts year by year using the latest monitoring data to update the operational model over time. Comparing these forecasts to the "actual" system showed uncertainty reduction over time.

P_{model}/P_{actual} at 15 observation points (y axis) after 5 yrs of injection using models developed at nine different times (colored circles) shows uncertainty reduction over time.

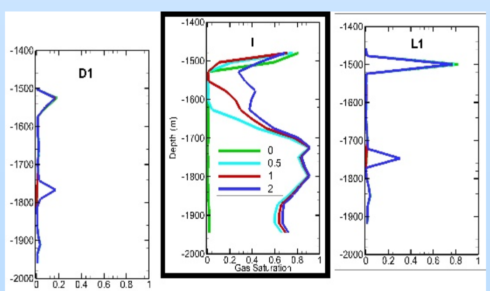


Example: Monitoring Data Available at Two Years

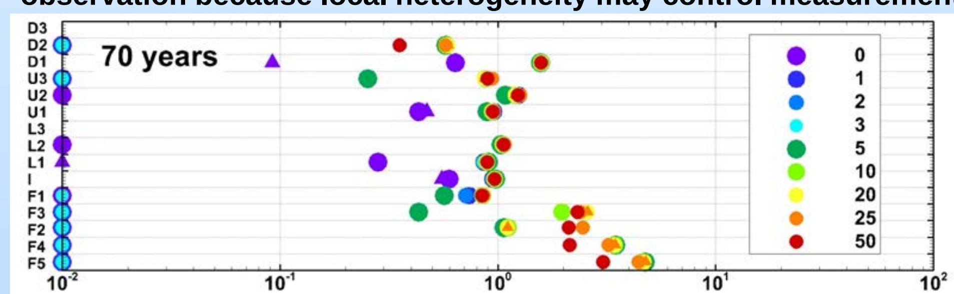
Pressure transients at 15 wells (4 wells shown)



Gas saturation profiles at 3 wells



$S_{g,model}/S_{g,actual}$ 50 yrs after end of injection is a less generalizable observation because local heterogeneity may control measurement.



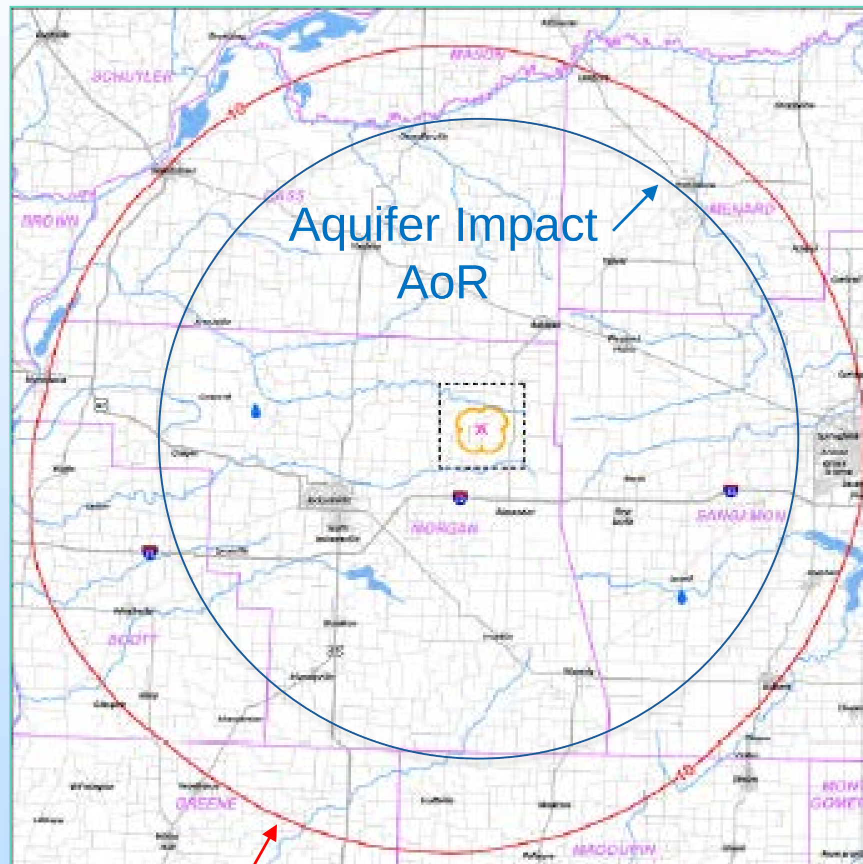
Ref. Doughty, C., and C.M. Oldenburg, CO_2 Plume Evolution in a Depleted Natural Gas Reservoir: Modeling of Conformance Uncertainty Reduction Over Time, IJGGC NRAP Special Issue, submitted.

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

Demirkanli, I. White, S. Bacon, D. PNNL (forthcoming)

- 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

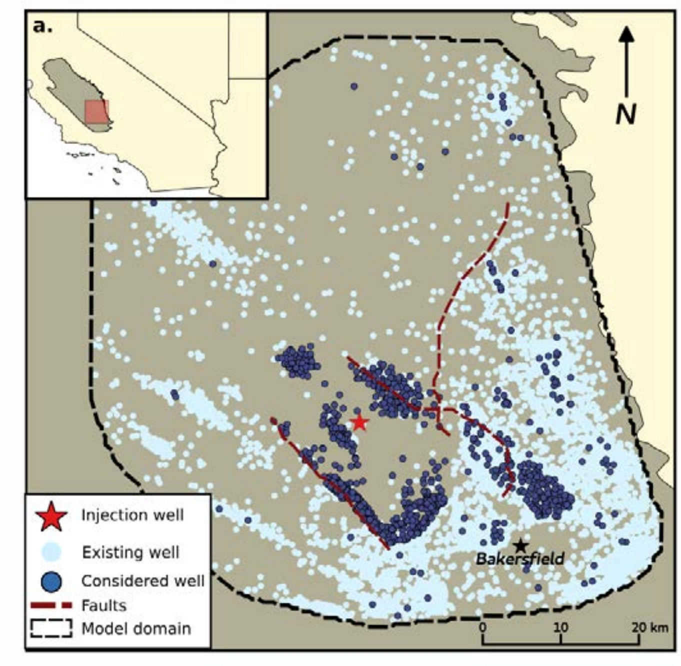
Method	AoR, mi^2
10 psi Critical Pressure	50
Aquifer Impact (TDS)	37
Aquifer Impact (pH)	4
Plume Footprint	4

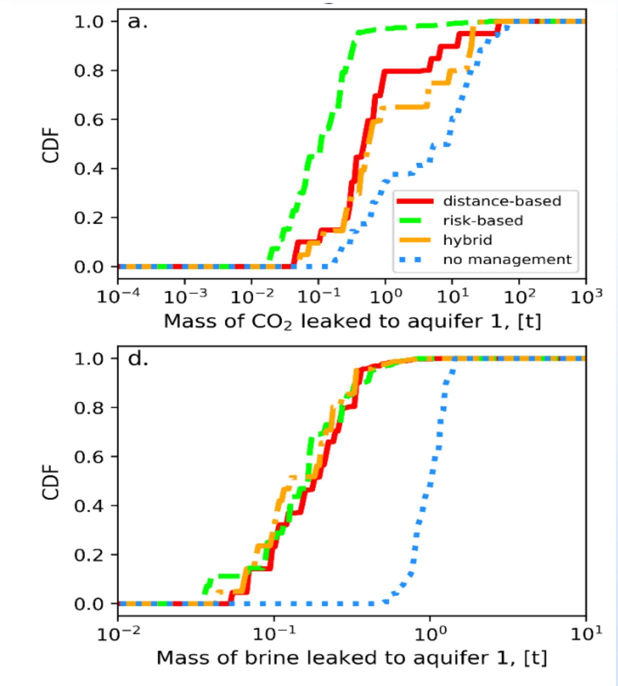


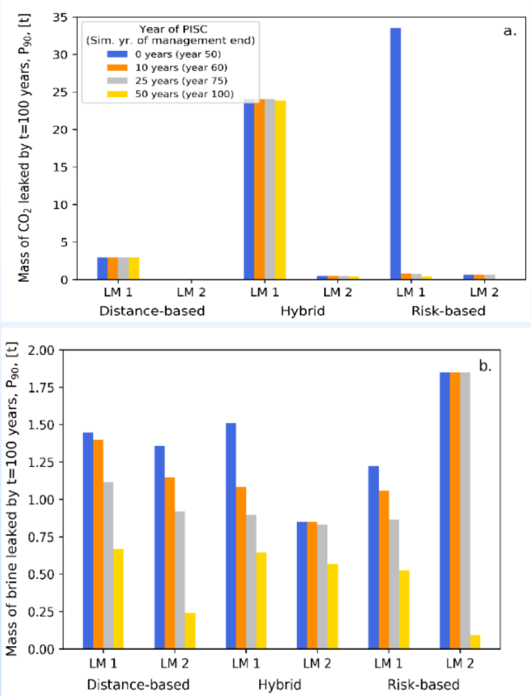
AoR Determined by EPA using 10 psi critical pressure

Managing Well Leakage at a GCS Site with Many Wells

Lackey, G.; Vasylkivska, V.; Huerta, N.; King, S.; Dilmore, R. (2019)







Methods

- Demonstrate a workflow for characterizing well leakage risks at a brownfield GCS site and explore the efficacy of different risk management strategies.
- Considered three leakage risk management strategies: (1) risk-based, (2) distance-based (3) hybrid risk and distance
- Determine the impact of the PISC period length on the efficacy of long-term leakage risk management.

Accomplishments to Date

- Establish list of critical GCS risk-related questions
- Conducted set of studies on risk-based post-injection closure
  - 9 peer reviewed manuscripts published or in review
  - Develop new approaches and NRAP tool functionality to enable workflows related to closure
- Initiated development of risk-assessment workflows

Synergy Opportunities

- NRAP is interested to engage with stakeholders from the CCUS community to test, validate, and improve risk management tools, workflows, and protocols

- Please contact us at: nrap@netl.doe.gov

Other NRAP Presentations

- NRAP Tool Users Meeting; *Tuesday 6:00 – 7:00 PM; Room 303, 304, 305*
- NRAP Oral Presentations; Room 303, 304, 305

Presenter	Time	Title
Erika Gasperikova, LBNL	Wed. 2:10 PM	Task 4: Strategic Monitoring for Uncertainty Reduction
Dylan Harp, LANL	Wed. 3:30 PM	Task 2: Containment Assurance
Diana Bacon, PNNL	Wed. 4:10 PM	Task 5: Application of Risk Assessment Tools and Methodologies
Joshua White, LLNL	Thurs. 1:00 PM	Task 3: Induced Seismicity Risk

- Poster Session Wed. 5:00 – 6:30 PM; Ballroom Foyer

Project Summary

- Key Findings.
  - Closure can be safe even when plumes in the reservoir are mobile.
  - A risk-based approach to site care and closure can save both time and resources.
  - Adaptive, risk-based monitoring across space and over time can reduce costs without increasing risks.
  - Brownfields (sites with many wells) can be safe storage sites.
  - Recursive improvement of models with monitoring data can enhance system knowledge and assure safe site closure.
- Next Steps.
  - Continue to define, test, and refine risk assessment workflows
  - Risk Management/Mitigation

Thanks!

www.edx.netl.doe.gov/nrap
NRAP@netl.doe.gov

Appendix

– Benefits to the Program
– Project Overview
– NRAP Organizational Chart
– Project Timeline Overview (Gannt Chart)
– Bibliography
– NRAP Posters at this meeting

Benefit to the Program

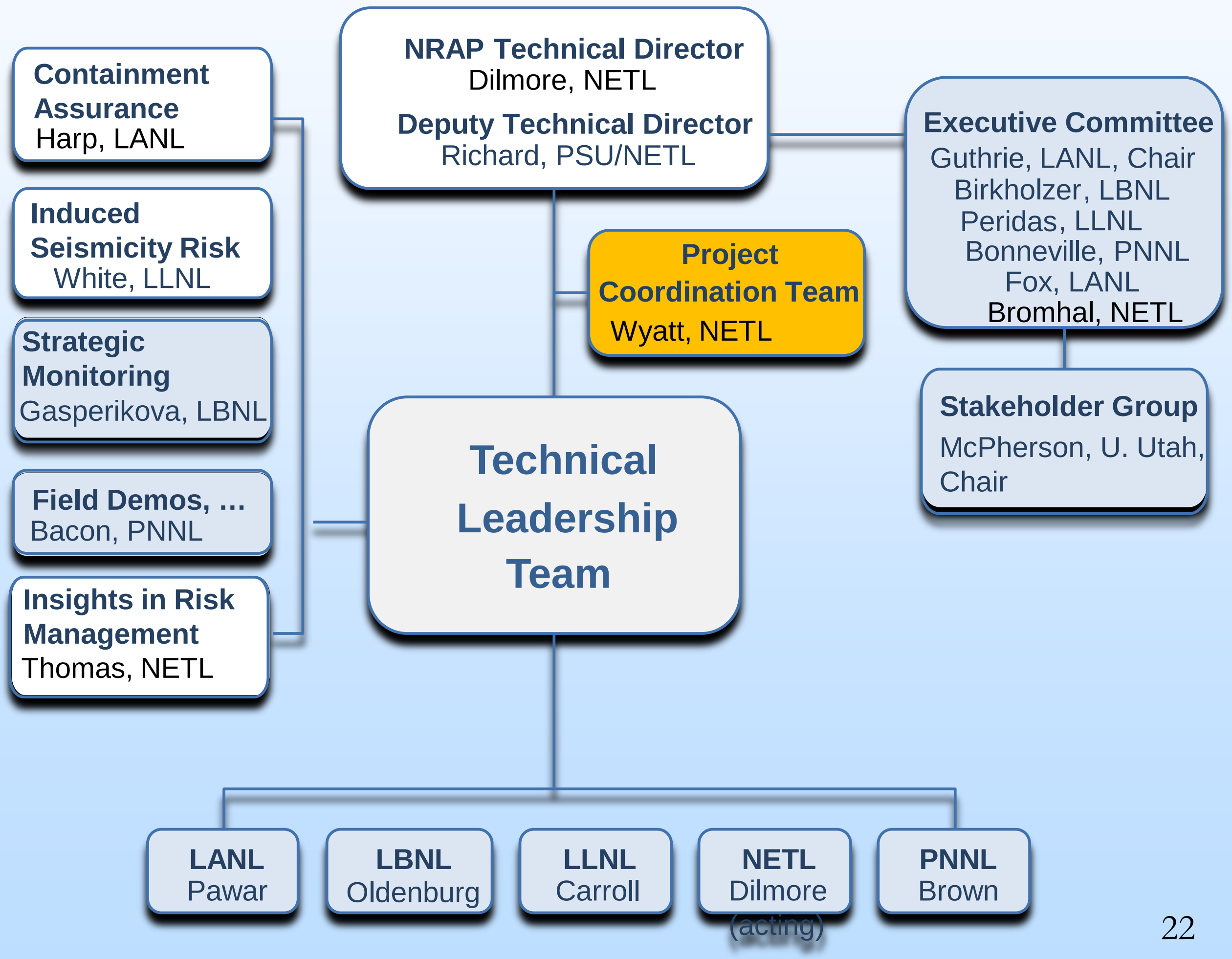
- NRAP products will improve the ability to evaluate and manage environmental risks, and reduce uncertainty in those assessed risks, at specific carbon storage sites. The tools, methodologies, and improved science base generated by NRAP can be used by both operators and regulators to advance the state of understanding and improve communication of risks and risk management strategies associated with a storage site, thereby reducing barriers to large-scale deployment of this technology. These products will aid operators in the design and application of monitoring and mitigation strategies. These tools can also be used by regulators, or their agents, to help identify and quantify risks associated with geologic carbon storage and perform appropriate cost-benefit analyses for specific carbon storage projects. Taken together, NRAP products will help build confidence in critical areas of site performance that will support investors, regulators, and other stakeholders to advance CCS projects.

Project Overview

Goals and Objectives

- The objective of NRAP Task 6.0 is to identify and distill critical insights from NRAP risk assessment methodologies and tool development and demonstration efforts to inform stakeholders and their decision making on critical issues of GCS risk assessment, risk management, and uncertainty reduction.
- To accomplish Task 6.0 objectives, researchers will employ tools and methodologies developed previously under NRAP Phase I, as well as new methodologies, tools, and scientific findings developed through the course of NRAP Phase II (e.g., the new NRAP open-source IAM) to perform analyses targeted to addressing critical risk-related questions. A key aspect of this work will use the NRAP approach of considering probabilistic, whole-system performance to develop those insights in the context of system uncertainty.
- The results from environmental risk studies at GCS sites will directly address prioritized questions, which helps to address programmatic goals related to GCS, to build confidence in the viability of large-scale CO2 storage and to guide future R&D efforts.

NRAP Organization Chart



Task 6: Project Timeline Overview (Gantt Chart)

Addressing Critical Questions Related to Assessment and Management of Environmental Risk at CO_2 Storage Sites

Milestones

1. Establish Task 6 prioritized risk-related questions and presentation to NRAP Executive Committee and Stakeholder Group, (August 2017)
2. Complete analysis and draft report on evaluating residual risk in post-injection site care period to inform decisions about monitoring requirements (March 2019)
3. Develop draft NRAP tools workflow manuscript (August 2019); Complete final NRAP tools workflow report (December 2019)
4. Complete analysis and draft report on risk management / mitigation alternative evaluation (August 2020); final report (December 2020)
5. Complete draft synthesis report on key NRAP Phase II findings (August 2021); final report (December 2021)

Chart Key

\# TRL Score | Go / No-Go Timeframe | Project Completion | Milestone

Decision Points

NRAP Executive Committee feedback following annual NRAP EC/SG briefing (August)

Impact

Key Accomplishments/Deliverables	Value Delivered
2019: Technical report detailing insights on risk-based assessment of post-injection site closure requirements **2019**: Technical report describing NRAP tools workflow for risk assessment **2020**: Technical report on risk management / mitigation alternative evaluation **2021**: Technical report summarizing insights on risk management and uncertainty reduction from NRAP Phase II research	• Inform stakeholder decisions (operators, regulators, insurers, etc.) about risk-based post-injection site closure justification • Workflows detailing application of NRAP tools to address critical risk performance questions at GCS sites • Insights on risk management and uncertainty reduction at CO_2 storage sites

Bibliography

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- Yang, X., Buscheck, T. A., Mansoor, K., Carroll, S. A. Assessment of Geophysical Monitoring Methods for Detection of Brine and CO_2 Leakage in Drinking Aquifers. IJGGC Volume 90, November 2019
- Harp, D., Oldenburg, C., Pawar, R. A metric for evaluating conformance robustness during geologic CO_2 sequestration operations. IJGGC, Volume 85, June 2019, Pages 100-108
- Pawar, R., Chu, S., Makedonska, N., Onishi, T., Harp, D. Assessment of relationship between post-injection plume migration and leakage risks at geologic CO_2 storage sites. submitted to IJGGC
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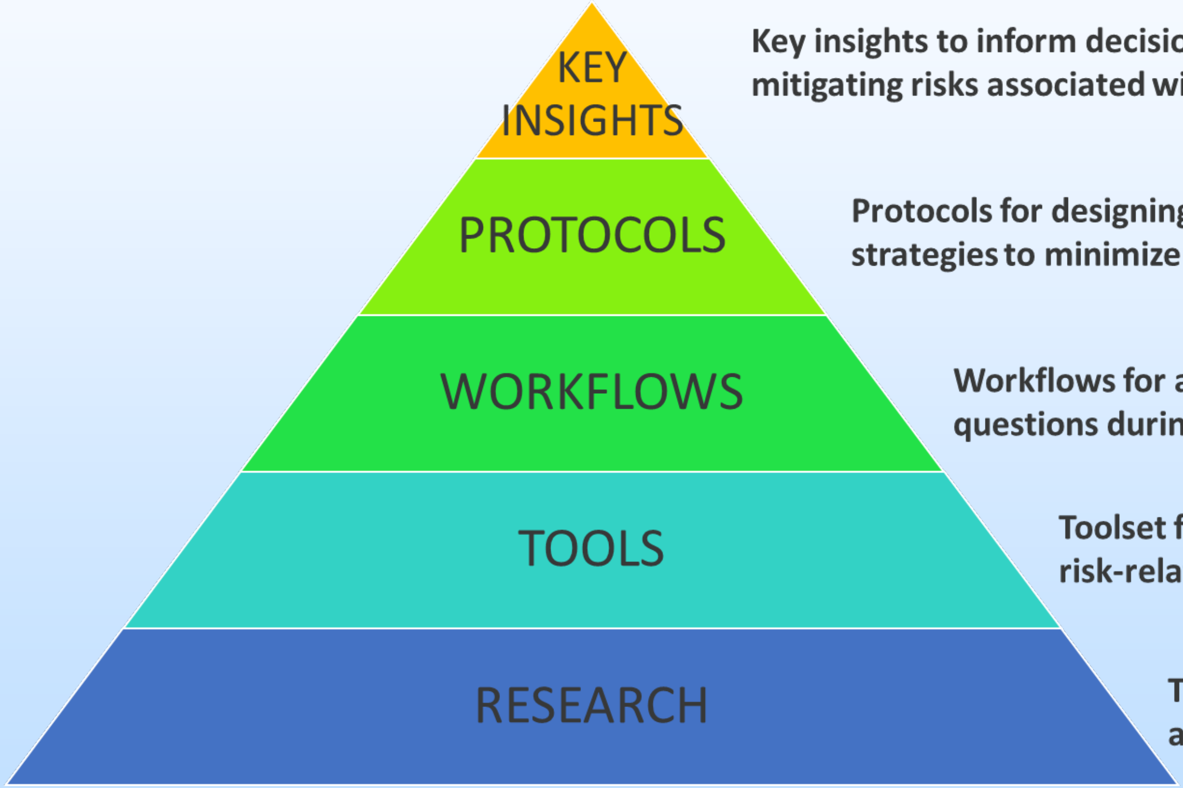
- Chen, B., Harp, D., Lu, Z., Pawar, R. On Reducing Uncertainty in Geologic CO_2 Sequestration Risk Assessment by Assimilating Monitoring Data. submitted to IJGGC
- Lackey, G.; Vasylkivska. V.; Huerta, N.; King, S.; Dilmore, R. Managing Well Leakage Risks at a Geologic Carbon Storage Site with Many Wells. IJGGC Volume 88, September 2019, Pages 182-194.
- Doughty, C. and Oldenburg, C.M. CO_2 Plume Evolution in a Depleted Natural Gas Reservoir: Modeling of Conformance Uncertainty Reduction Over Time. submitted to IJGGC

Poster Session
Wed., 5:00 – 6:30 PM; Ballroom Foyer

Presenter	Title
Burt Thomas, NETL	Tools and Workflows for risk assessment and management at geologic carbon storage sites
Chris Brown, PNNL	Considerations for risk-based determination of post-injection closure period at geologic carbon storage sites
Bailian Chen, LANL	Risk-based conformance evaluation at geologic carbon storage sites
Erika Gasperikova, LBNL	Using modeling of monitoring for leak detection threshold evaluation at geologic carbon storage sites
Dennise Templeton, LLNL	Toward a recommended practice for induced seismicity risk quantification and management at geologic carbon storage sites

What will be the outcomes of NRAP by the end of Phase II?



Key insights to inform decisions related to minimizing and mitigating risks associated with long-term storage of CO_2

Protocols for designing monitoring and operational strategies to minimize & mitigate risk

Workflows for answering specific risk-mitigation questions during the project-planning phase

Toolset for rapid, science-based quantification of key risk-related processes; released beta-versions

Targeted research to validate/quantify NRAP approach