National Risk Assessment Partnership Task 2: Containment Assurance

Dylan Harp

National Risk Assessment Partnership

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

- Task 2 (Containment Assurance) subtasks:
  - Task 2.1: NRAP-Open-IAM
  - Task 2.2: Well Integrity
  - Task 2.3: Dynamic Risk
- Accomplishments to date
- Synergy opportunities
- Project summary

Containment Assurance Subtasks

Task 2.1 NRAP-Open-IAM

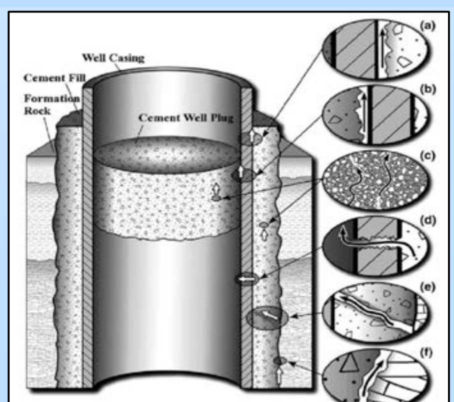
Veronika Vasylkivska (Lead)
Diana Bacon
Greg Lackey
Bailian Chen
Yingqi Zhang
Kayyum Mansoor

Task 2.2 Well Leakage

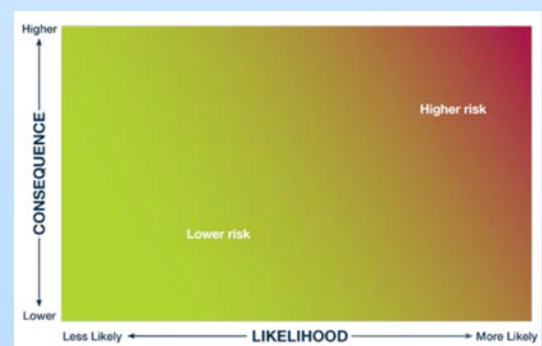
Jaisree Iyer (Lead)
Nik Huerta
Kenton Rod
Ernest Lindner
Veronika Vasylkivska
Susan Carrol
Bill Carey
Xiao Chen
Curt Oldenburg
Mohammad Islam
Lehua Pan
Diana Bacon
Bob Dilmore
Greg Lackey
Kevins Rhino
Megan Smith

Task 2.3 Dynamic Risk

Yingqi Zhang (Lead)
Abdullah Cihan
Bailian Chen
Veronika Vasylkivska
Erika Gasperikova
Yang Xianjin
Kayyum Mansoor
Catherine Yonkofski
Robert Dilmore



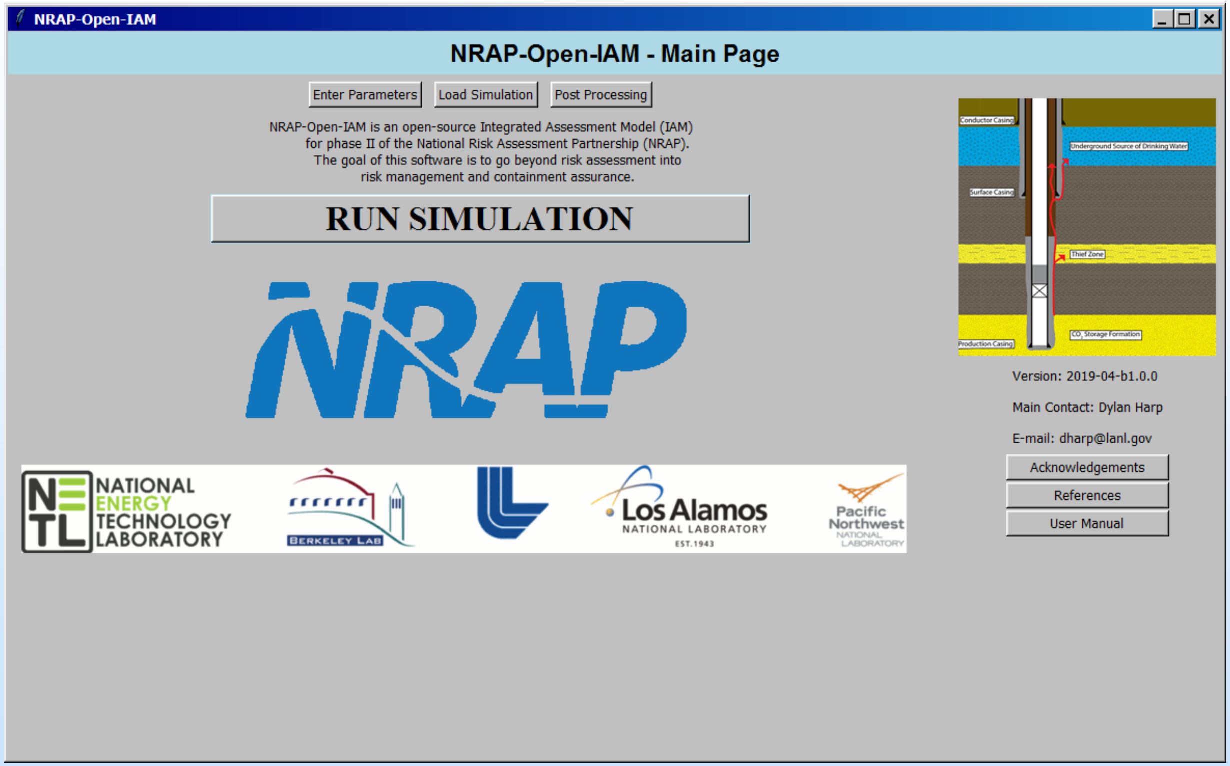
Gasda S et al. (2004) Environmental Geology

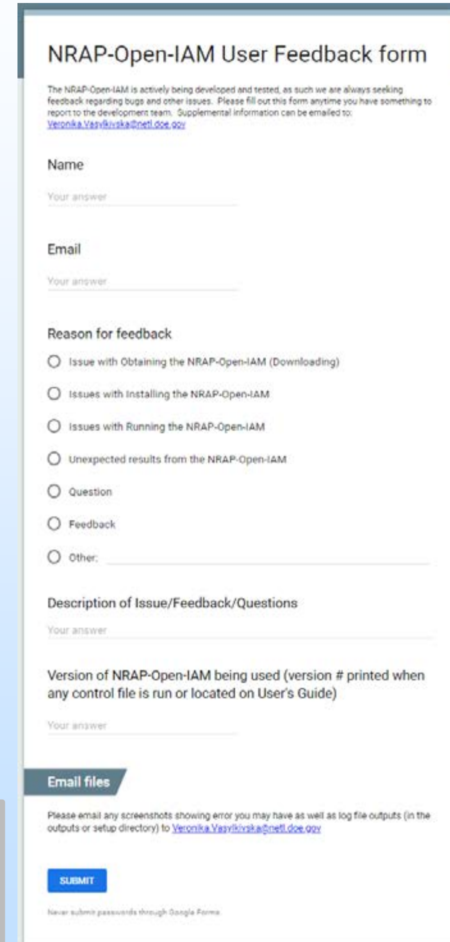


https://www.ato.gov.au/Business/Privately-owned-and-wealthy-groups/What-you-should-know/Transparency/How-we-assess-risk/

Task 2.1 NRAP-Open-IAM

Graphical User Interface: Current state





NRAP-Open-IAM User Feedback form

The NRAP-Open-IAM is actively being developed and tested, as such we are always seeking feedback regarding bugs and other issues. Please fill out this form anytime you have something to report to the development team. Supplemental information can be emailed to: Veronika.Vasylkivska@netl.doe.gov

Name

Your answer

Email

Your answer

Reason for feedback

- Issue with Obtaining the NRAP-Open-IAM (Downloading)
- Issues with Installing the NRAP-Open-IAM
- Issues with Running the NRAP-Open-IAM
- Unexpected results from the NRAP-Open-IAM
- Question
- Feedback
- Other:

Description of Issue/Feedback/Questions

Your answer

Version of NRAP-Open-IAM being used (version # printed when any control file is run or located on User's Guide)

Your answer

Email files

Please email any screenshots showing error you may have as well as log file outputs (in the outputs or setup directory) to Veronika.Vasylkivska@netl.doe.gov

SUBMIT

Never submit passwords through Google Forms.

https://docs.google.com/forms/d/e/1FAIpQLSed5mcX0OBx1dLNmYGbmS4Vfc0mdOLapIzFqw-6vHoho9B19A/viewform

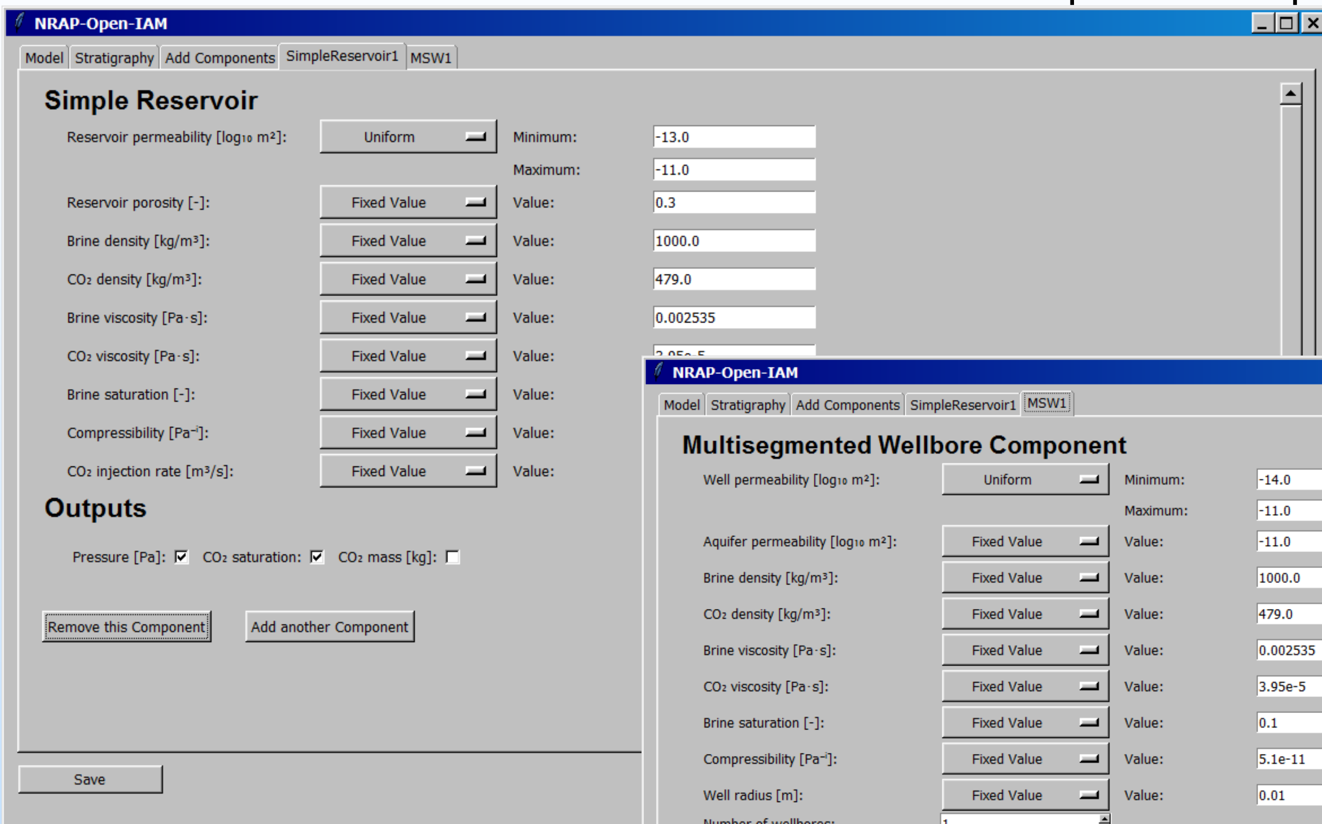
- Beta release (July, 2019):
  - EDX: https://edx.netl.doe.gov/dataset/openiam-beta-release-June-2019
  - Docker image: `docker pull dharp/openiam-gui`
- Feedback is always welcome
  - Contact us: Veronika.Vasylkivska@netl.doe.gov

EDX Energy Data eXchange

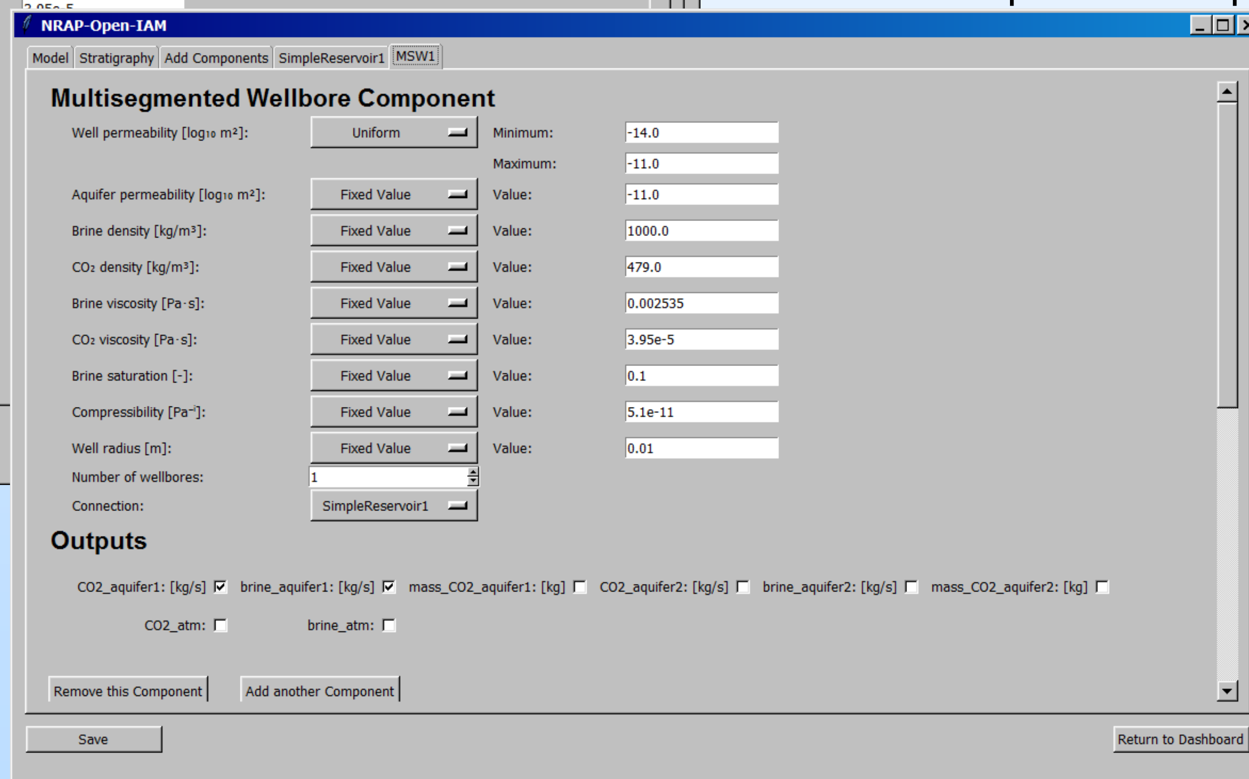
Task 2.1 NRAP-Open-IAM

GUI: Example use case

Reservoir component setup



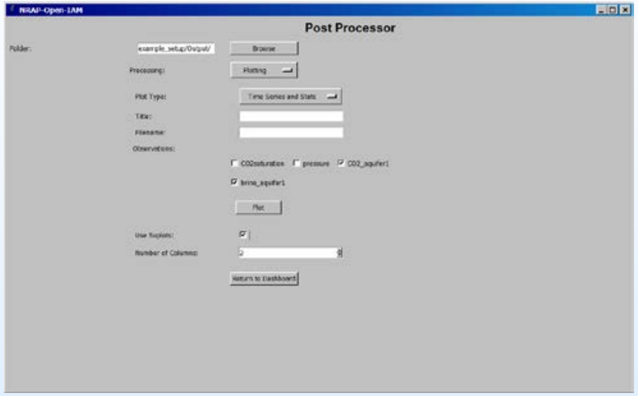
Wellbore component setup



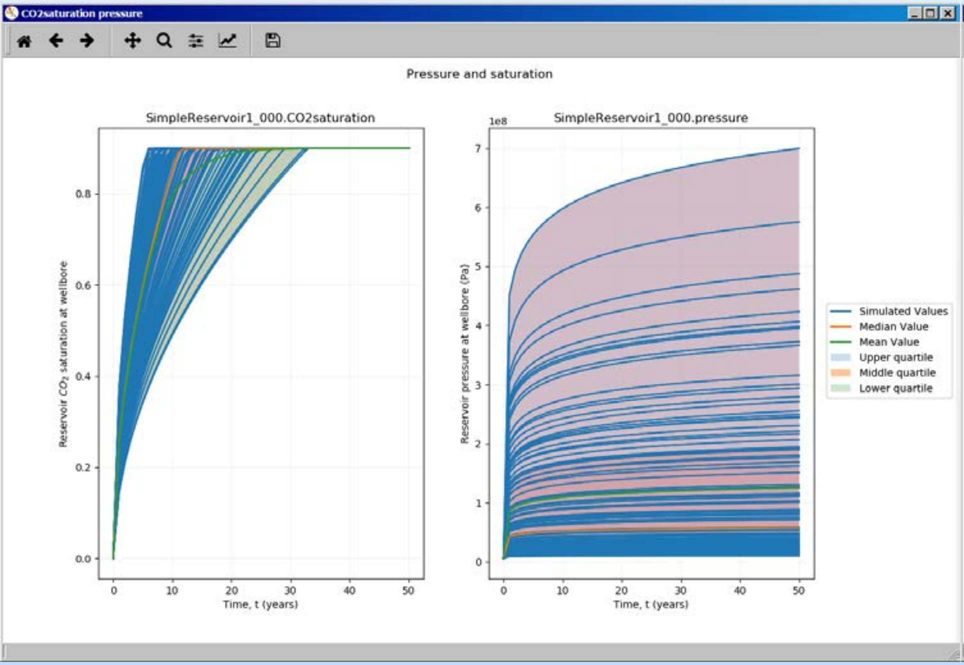
Task 2.1 NRAP-Open-IAM

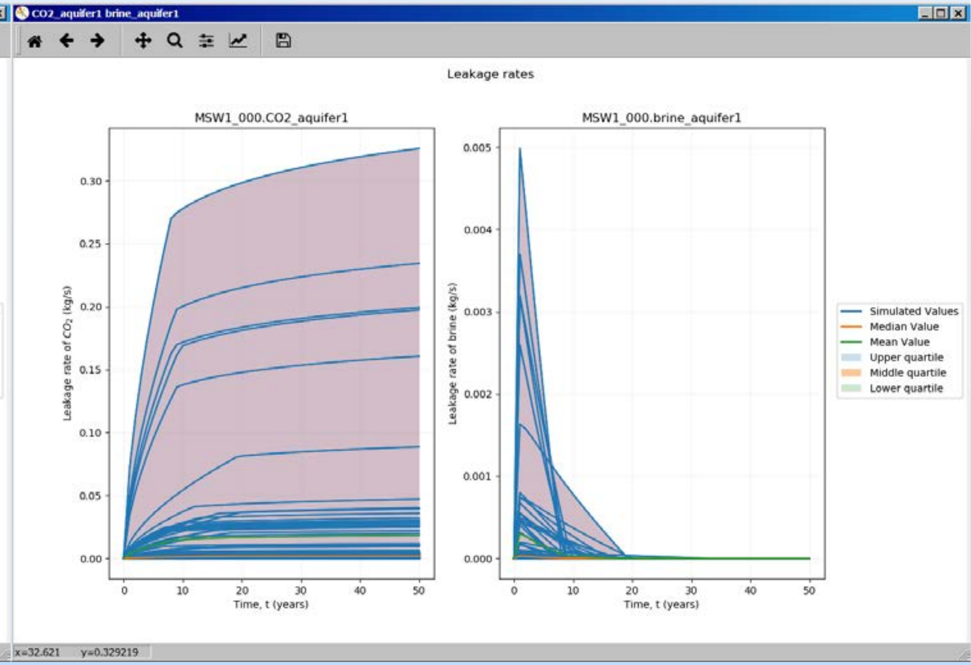
GUI: Example use case

Postprocessing options



Statistical plots of outputs





Task 2.2 Well Leakage

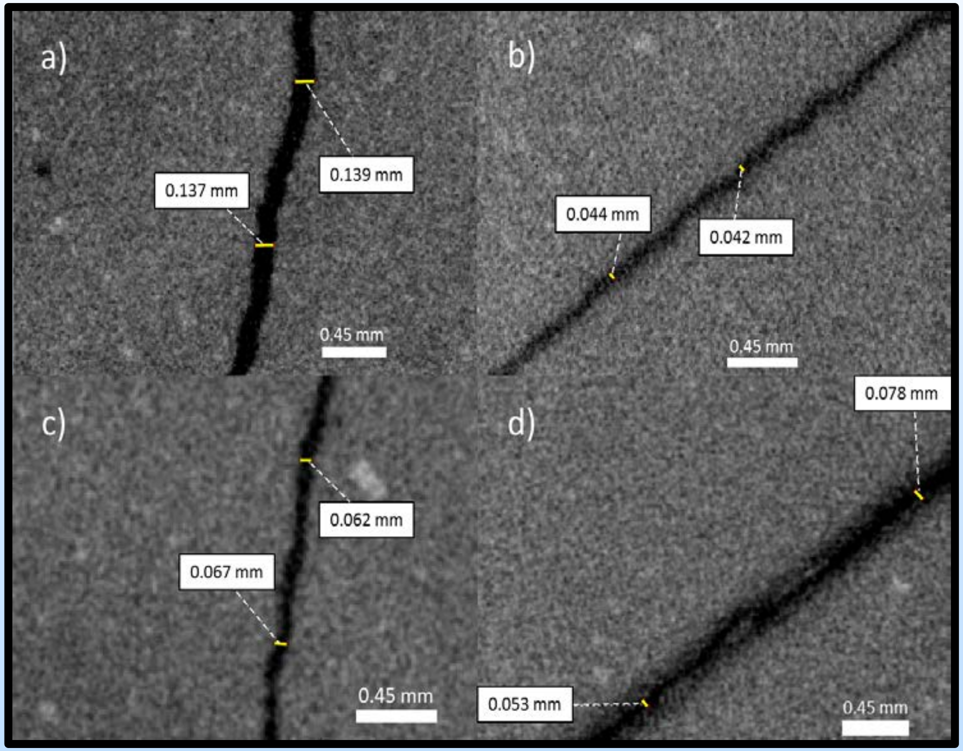
Laboratory experiments characterizing the impact of reservoir fluids and state of stress on well leakage

- Role of supercritical CO_2 (Rod)
  - Aperture reduction of existing cement fractures
  - Crack formation possibly due to dehydration
  - Manuscript submitted to IJGGC

Initial Final

Outlet

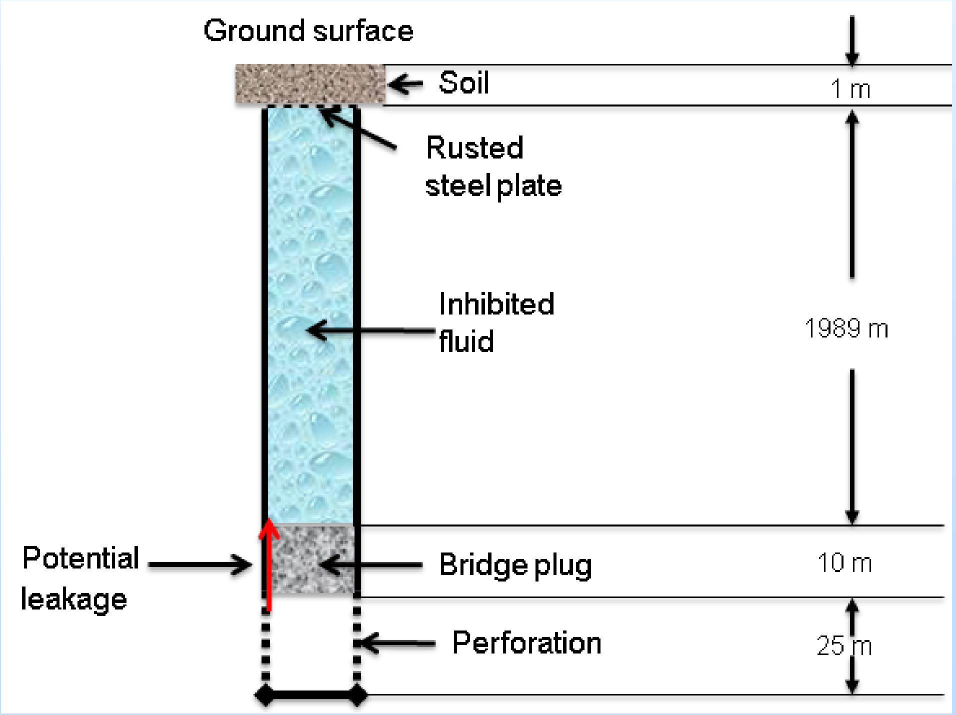
Inlet



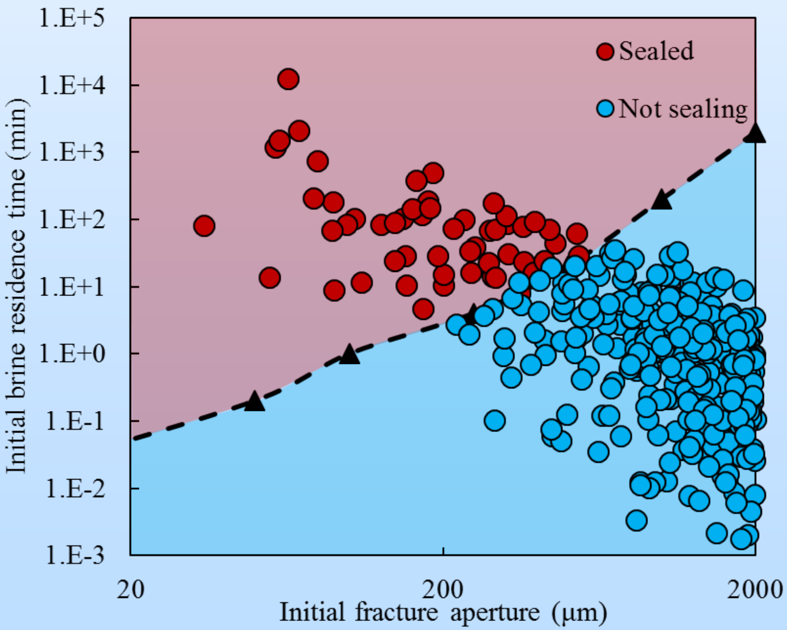
Task 2.2 Well Leakage

Model and field-based studies on improving the science behind well leakage

- Leakage of CO_2 through gaps in plugs (Pan and Oldenburg)
  - Large leakage rates can result in decompression cooling and phase change
  - Temperature signal can be large enough to detect the leak
  - Manuscript submitted to IJGGC



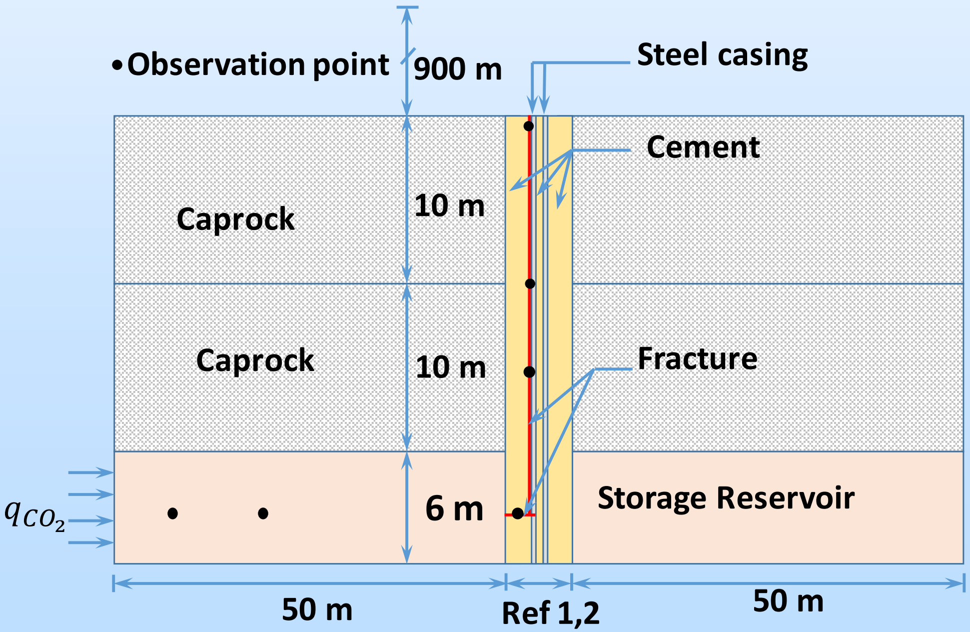
- Defining conditions under which chemical-mechanical processes can self seal fractures (Iyer, Chen, Carrol)
  - Fractures with aperture <200 μm will seal
  - Sealing time varies between 3 and 750 days
  - Manuscript in preparation



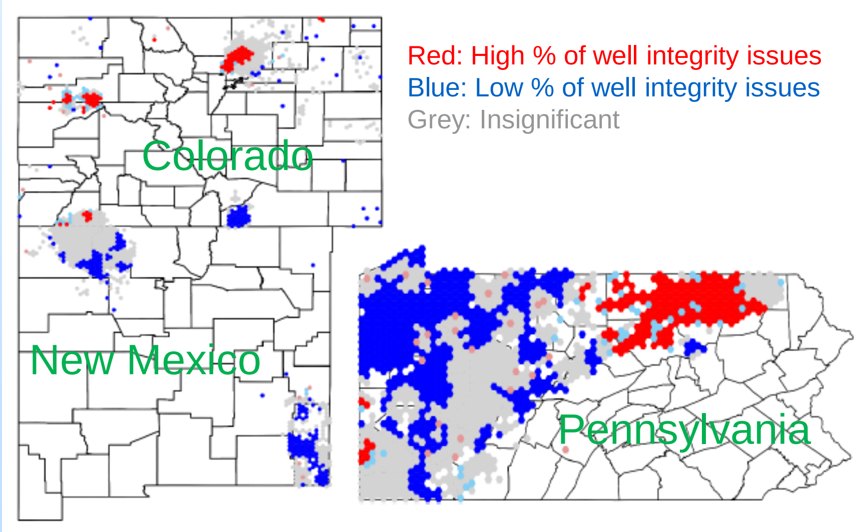
Task 2.2 Well Leakage

Model and field-based studies on improving the science behind well leakage

- Coupling two-phase and deformational flow (Islam, Dilmore, Huerta)
  - Evaluate numerical algorithms and solvers for coupling two-phase flow with geomechanics
  - Identify conditions under which CO_2 injection can result in fracture propagation
  - Manuscript in preparation

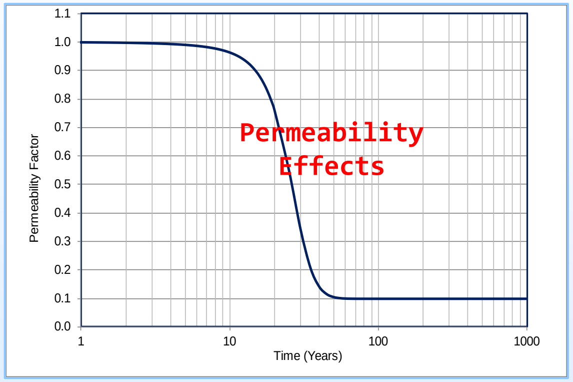


- Field study to analyze well integrity in Pennsylvania, Colorado, and New Mexico (Lackey)
  - Improve understanding of the factors that influence well integrity
  - Compile the most comprehensive well integrity database for onshore wells in the US

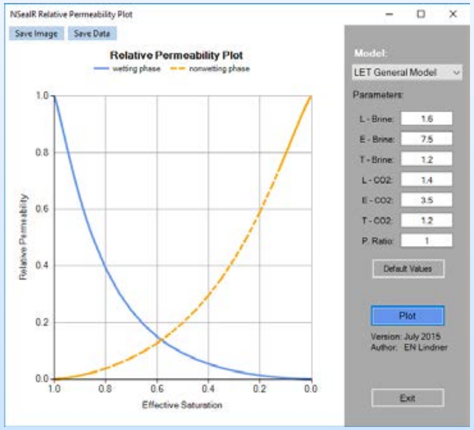


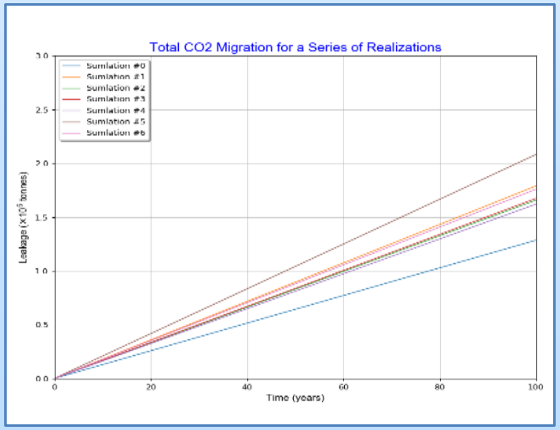
Task 2.2 Well Leakage

Improving the well and seal leakage-related reduced order models



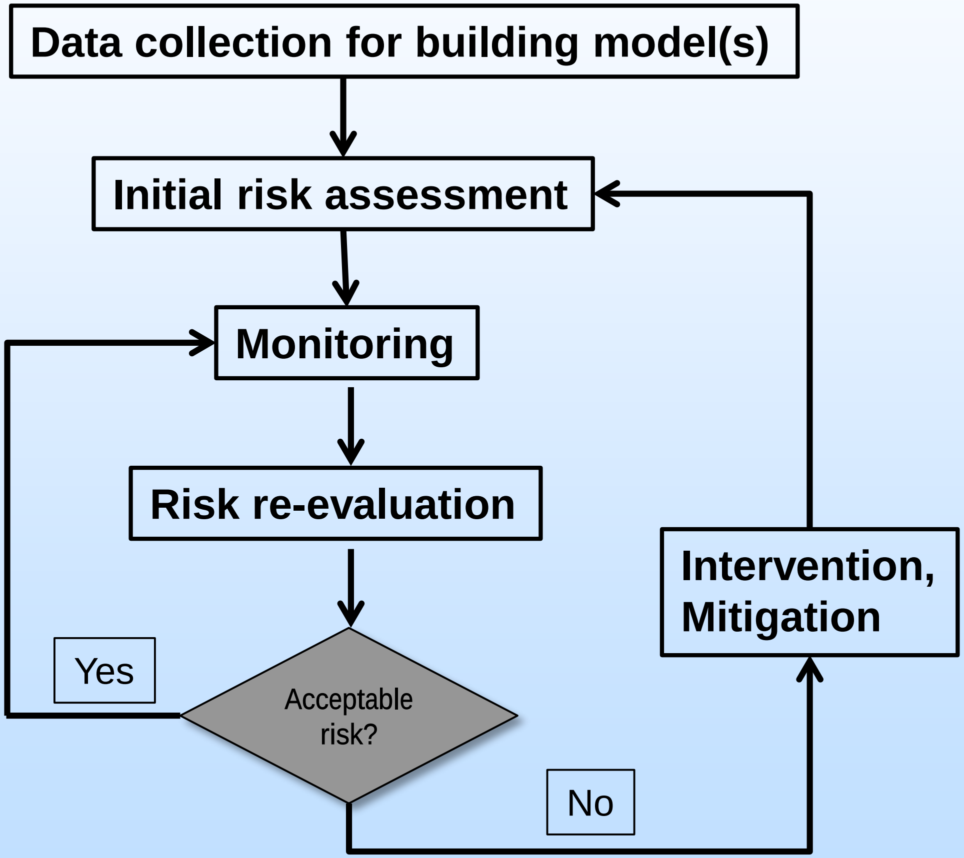
- Seal Flux ROM (Lindner)
  - Improved version of the NSealR ROM for CO_2 leakage through a barrier layer in Python
  - Includes two-phase flow, reactions with CO_2, and heterogeneous permeability





Task 2.3 Dynamic Risk

- Definition: Dynamic risk = changes in risk over time as the system evolves, mitigations are applied, and management is carried out.
- Goal: Demonstrate iterative risk assessment/management/mitigation Process

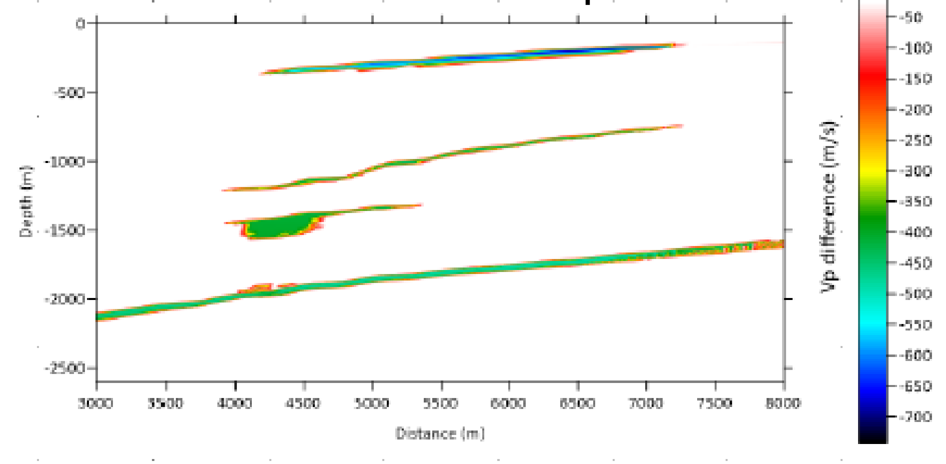


Task 2.3 Dynamic Risk

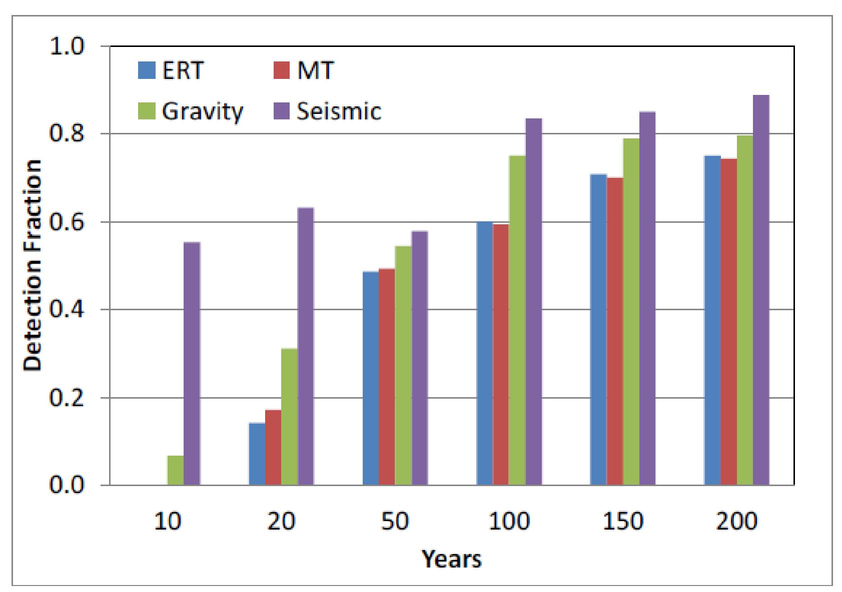
Selection of monitoring approaches

- Geophysical monitoring
  - Active seismic and EM monitoring for Kimberlina 2 (Erika)
    - Fault leakage
    - Feedback to flow model: leaky location
  - MT, ERT, gravity and seismic for Kimberlina 1 (Xianjin)
    - Well leakage
    - Feedback: total leakage mass
- Wellbore monitoring
  - Pressure
  - Plume (saturation)
  - DTS

Seismic detection of plumes



Geophysical approaches to leak detection

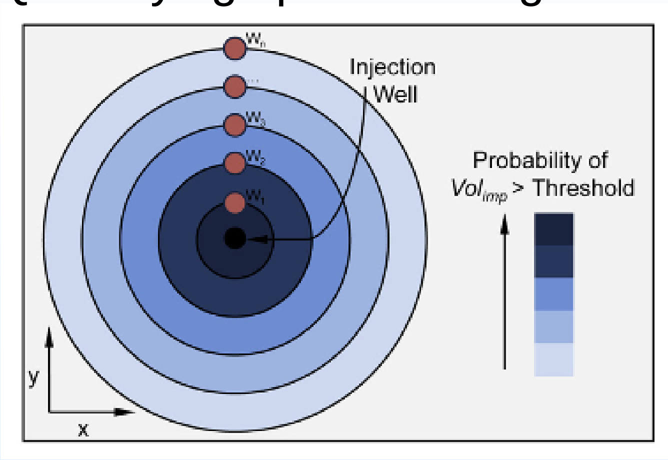


Task 2.3 Dynamic Risk

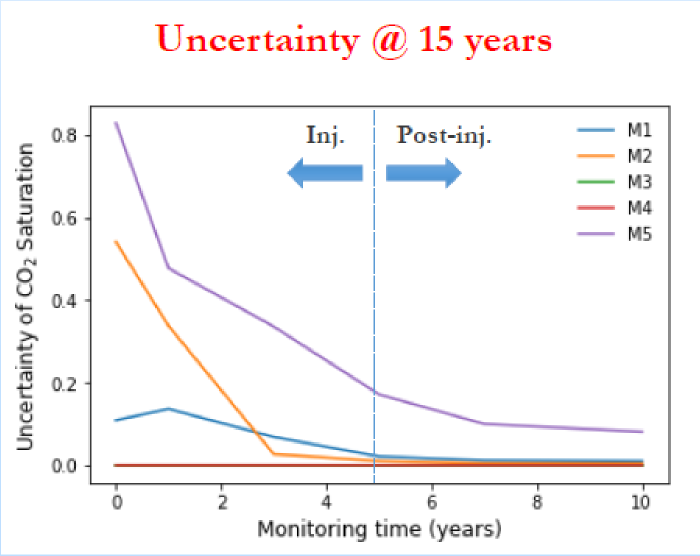
Potential Risk Assessment Tools

- Risk map
  - Probability of impacting a volume within USDW due to potential CO_2 leakage from wells (leaky well permeability is uncertain)
  - Provide initial risk assessment
- Model update
  - Reduce uncertainty in risk assessment by incorporating monitoring data (pressure and CO_2 saturation at monitoring wells)
  - Update models using ensemble-based methods or MCMC

Quantifying spatial leakage risk



Mapping uncertainty reduction over time



Accomplishments to Date

- Beta release of NRAP-Open-IAM
- Multi-phase (SC CO2 and brine) lab experiments completed (IJGGC manuscript submitted; Rod)
- Modeling of leakage around plugs completed (IJGGC manuscript submitted; Pan)
- Modeling defining conditions for self sealing completed (manuscript in preparation; Iyer)
- Coupled modeling of two-phase and deformational flows completed (manuscript in preparation; Islam)
- Open wellbore leakage ROM updated
- Seal flux ROM converted to Python and modified (manuscript in preparation; Lindner)
- Conformance analysis completed (Harp et al., IJGGC, 2019)
- Plume stability analysis developed and added to NRAP-Open-IAM (Harp et al., GG:S&T, 2019)
- NRAP-Open-IAM manuscript in preparation (Zhang)
- Task 2.3 lead selected and initiated

Synergy Opportunities

- Application of NRAP-Open-IAM for risk-based Area of Review determination (Task 5) (Bacon, Demirkanli, White)
- Coupling of NRAP-Open-IAM and DREAM (developed under Task 4) for Post-Injection Site Care period determination (Task 6) (Bacon, Yonkofski, Brown, Demirkanli, Whiting)
- Application of NRAP-Open-IAM for managing well leakage risks at a geologic carbon storage site with many wells (Task 6) (Lackey, Vasylkivska, Huerta, King, Dilmore)

Project Summary

1. The containment assurance task is developing robust, science-based workflows and software tools to:
    1. predict containment effectiveness and leakage risk
    2. evaluate the effectiveness of leakage risk monitoring, management, and mitigation.

Appendix

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

Benefit to the Program

- Program goals being addressed:
  - To address concerns of containment effectiveness, leakage potential, and related impacts at CO2 storage sites, it is necessary to develop defensible, science-based tools and methodologies to understand how large-scale injection leads to fluid migration and impacts in various system components as a function of complex and inter-related physical and chemical phenomena. The objective of Task 2.0 is to develop robust, science-based workflows and software tools to predict long-term containment effectiveness and leakage risk at storage sites, in the context of system uncertainty, and develop approaches to evaluate effectiveness of leakage risk management/mitigation approaches.
- Project benefits statement:
  - This research directly addresses the programmatic goal of building confidence that CO2 storage can be implemented safely and effectively at scale, and that risks related to potential leakage can be effectively mitigated/managed. This will help to build stakeholder confidence in this technology, and methods/tools developed here can serve as a bridge in the evolution to future real-time risk management at CO2 storage sites. Methods, tools, and technical insights developed through the NRAP research effort directly address technical questions that currently represent hurdles to wide-spread adoption of geologic carbon storage technology. The NRAP technical approach also has broad applicability to other engineered geologic systems.

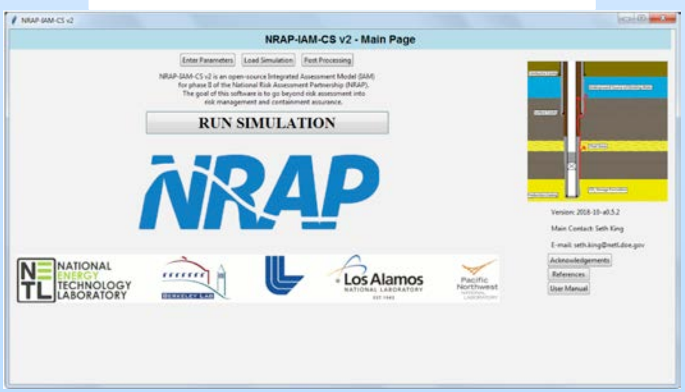
Project Overview

Goals and Objectives

- Project goals:
  - Release of NRAP Open Integrated Assessment Model on the NETL Energy Data Exchange for beta testing (Complete).
  - Manuscript on risk-based conformance assessment (Complete)
  - Manuscript on leakage risk mitigation scenario evaluation (In progress; Subtask 2.3)
  - Release of final NRAP open-source integrated assessment model on the NETL Energy Data Exchange (Complete)
  - Technical report summarizing protocols/recommended practice for leakage risk assessment and management and conformance assessment (Not started)

Organization Chart

<u>Task 2.1 NRAP-Open-IAM</u>
Veronika Vasylkivska (Lead)
Diana Bacon
Greg Lackey
Bailian Chen
Yingqi Zhang
Kayyum Mansoor



<u>Task 2.2 Well Leakage</u>
Jaisree Iyer (Lead)
Nik Huerta
Kenton Rod
Ernest Lindner
Veronika Vasylkivska
Susan Carrol
Bill Carey
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Curt Oldenburg
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Lehua Pan
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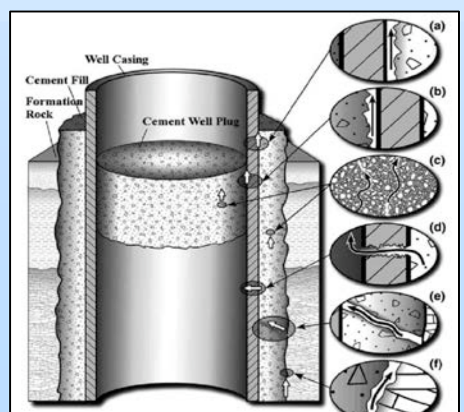
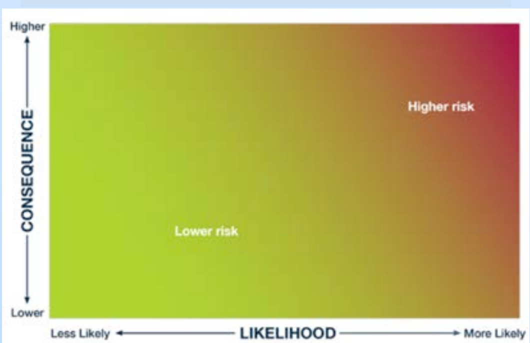


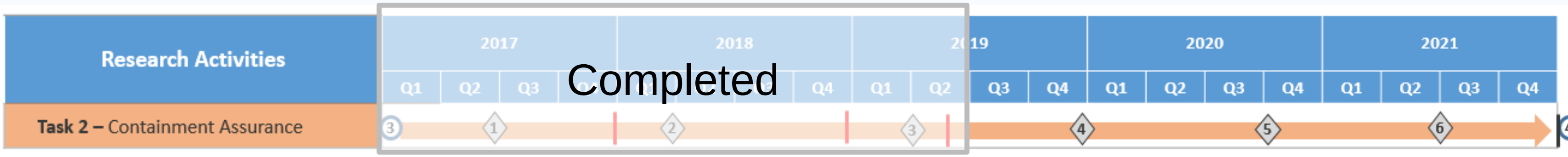
Gasda S et al. (2004) Environmental Geology

<u>Task 2.3 Risk AMM Process</u>
Yingqi Zhang (Lead)
Abdullah Cihan
Bailian Chen
Erika Gasperikova



https://www.ato.gov.au/Business/Privately-owned-and-wealthy-groups/What-you-should-know/Transparency/How-we-assess-risk/

Gantt Chart



Milestones

1. Complete NRAP Phase II software development plan (June 2017)
2. Prototype NRAP Phase II integrated assessment model developed for internal testing (March 2018)
3. Release of NRAP open-source integrated assessment model for external release and beta testing (March 2019)
4. Complete analysis on risk-based conformance assessment (December 2019)
5. Complete draft manuscript on leakage risk mitigation scenario evaluation (September 2020)
6. Develop protocols/recommended practice for leakage risk management (June 2021)

Chart Key

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

Decision Points

- Selection of storage scenarios/simulation datasets for use in conformance assessment study (March 2019)
- Selection of leakage mitigation scenarios for analysis (Jan. 2020)
- Decide if NRAP open-IAM ready for final release (March 2021)

Impact

Key Accomplishments/Deliverables	Value Delivered
2019: Beta NRAP Phase II open-source integrated assessment model for leakage risk **2020**: Risk-based conformance assessment methodology and report **2021**: Final NRAP Phase II open-source IAM; leakage risk management/mitigation risk assessment protocol document	• Risk-based concordance evaluation/conformance assessment • Robust leakage risk quantification methods and tools • Recommended protocols for leakage risk management • Scientific insights and improved predictive tools on leakage pathway behavior

Bibliography

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- Oldenburg, C.M., Are we all in concordance with the meaning of the word conformance, and is our definition in conformity with standard definitions?, Greenhouse Gases: Science and Technology, 8(2), pp. 210-214, April 2018.
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- Demirkanli, D.I., Bacon, D.H., White, S.K., in revision. Risk-based Area of Review (AoR) Determination for a Deep-Saline Carbon Storage Site Using National Risk Assessment Partnership's Open-Source Integrated Assessment Model (NRAP-Open-IAM). International Journal of Greenhouse Gas Control.
- Bacon, D.H., Yonkofski, C.M.R., Brown, C.F., Demirkanli, D.I., Whiting, J.M., 2019. Risk-based post injection site care and monitoring for commercial-scale carbon storage: Reevaluation of the FutureGen 2.0 site using NRAP-Open-IAM and DREAM. International Journal of Greenhouse Gas Control 90, in press.
- Lackey, G., Vasylkivska, V.S., Huerta, N.J., King, S., Dilmore, R.M., 2019. Managing well leakage risks at a geologic carbon storage site with many wells. International Journal of Greenhouse Gas Control 88, 182-194.

Extra Slides

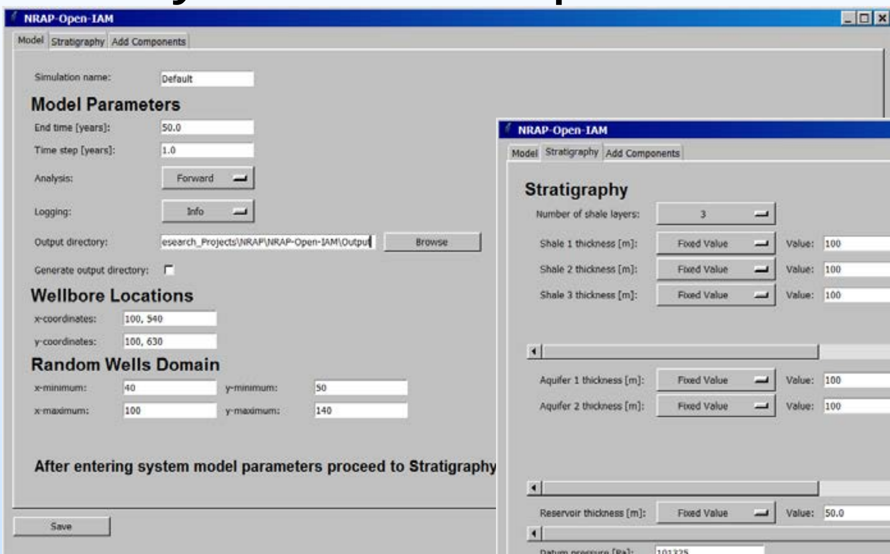
Lessons Learned

– Even relatively mature simulation tools may be found unable to simulate key scenarios, and one needs to go back to the code and expand its range of capability before completing what had initially been thought of as a routine exercise of the simulator.
– Research gaps/challenges.
– Unanticipated research difficulties.
– Technical disappointments.
– Changes that should be made next time.
– Multiple slides can be used if needed.

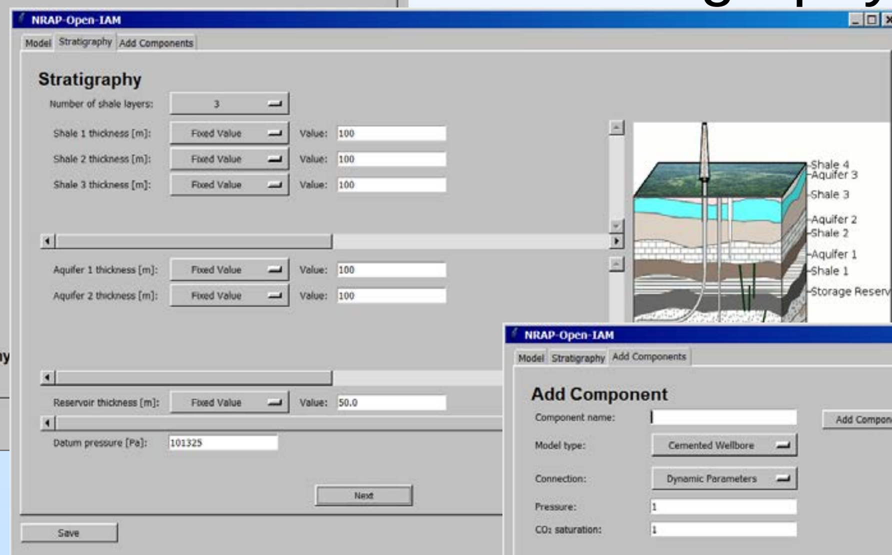
Task 2.1 NRAP-Open-IAM

Graphical user interface

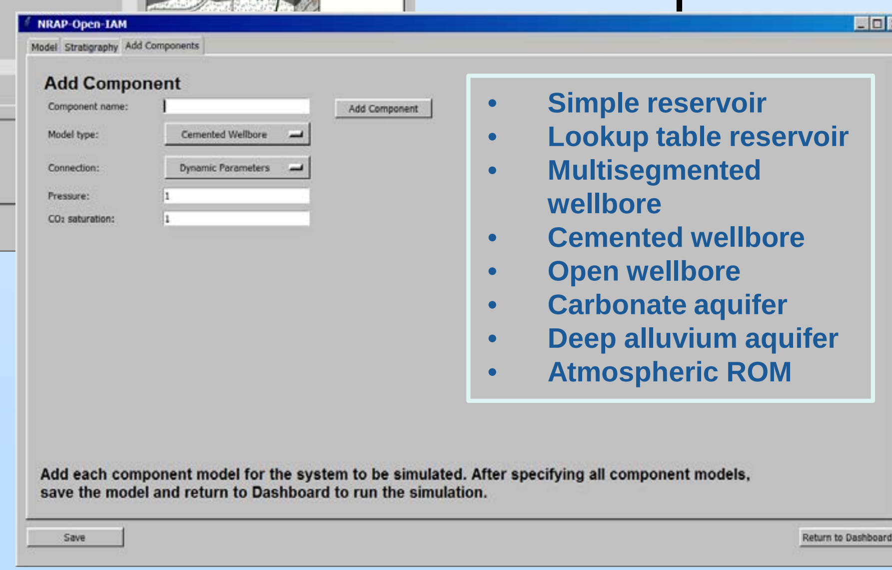
System model parameters



Stratigraphy



Beta release components



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Laboratory experiments characterizing the impact of reservoir fluids and state of stress on well leakage

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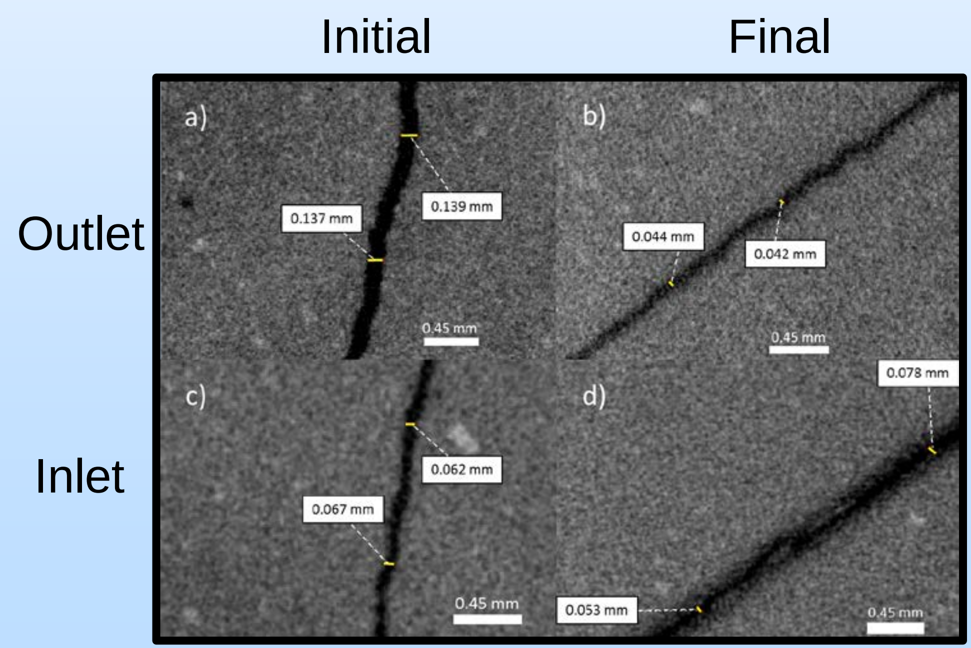
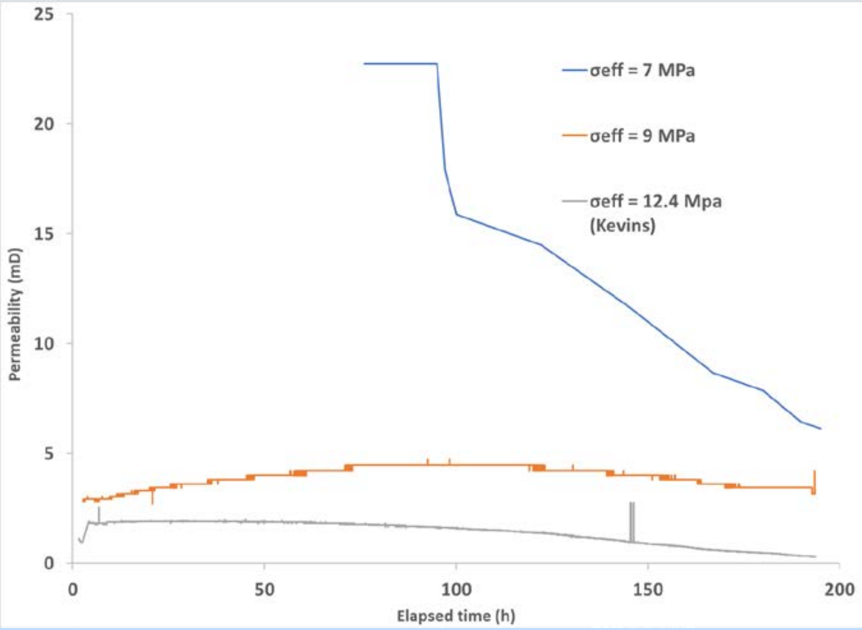


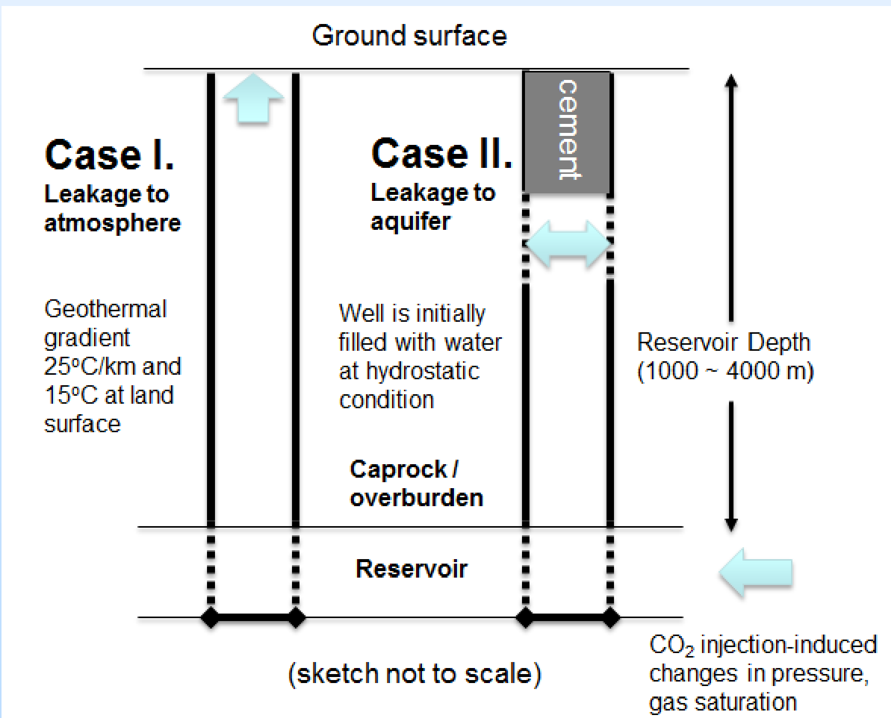
- Impact of effective stress on permeability reduction of fractures at cement-caprock interface (Rhino, Smith, Iyer, and Carrol)
  - In progress



Task 2.2 Well Leakage

Improving the well and seal leakage-related reduced order models

- Well leakage related ROMs
  - Added a new aquifer depth in the open wellbore ROM (Pan and Oldenburg)
  - Extended the coupled chemical-mechanical ROM to longer time windows (Chen)



- Seal Flux ROM (Lindner)
  - Improved version of the NSealR ROM for CO_2 leakage through a barrier layer in Python
  - Includes two-phase flow, reactions with CO_2, and heterogeneous permeability