NRAP workshop

Considerations for non-endangerment and GCS site closure

Application of integrated system modeling to support site closure timeframe decisions

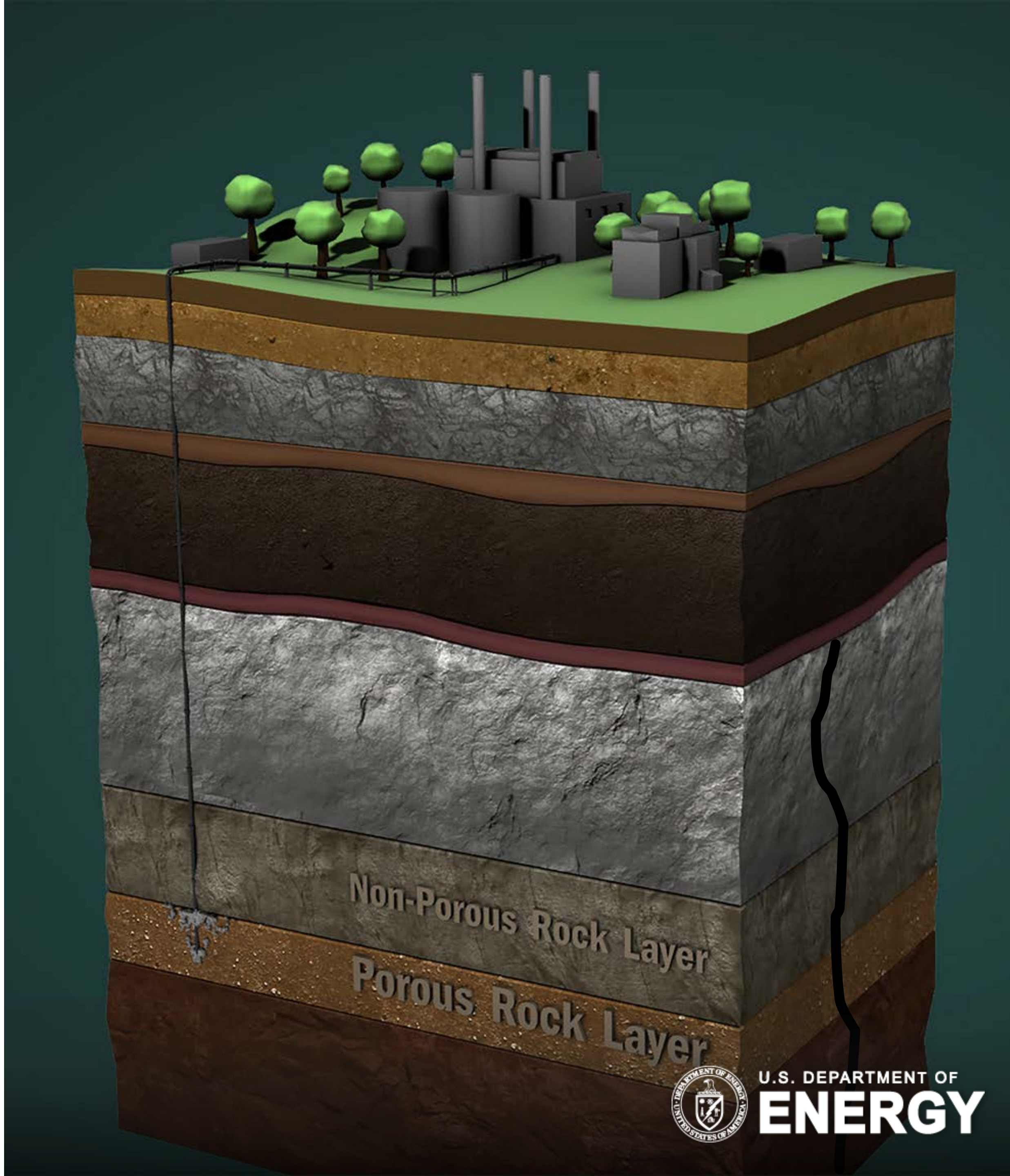
Presenter: Greg Lackey[1,2]

Contributors: Diana H. Bacon[3], Catherine M.R. Yonkofski[3], Christopher F. Brown[3], Deniz I. Demerkanli[3], Jonathan M. Whiting[3], Veronika S. Vasylkivska[1,2], Nicolas J. Huerta[3], and Robert M. Dilmore[1]

[1]National Energy Technology Laboratory, 626 Cochrans Mill Road, P.O. Box 10940, Pittsburgh, PA 15236-0940, USA
[2]Leidos Research Support Team, 626 Cochrans Mill Road, P.O. Box 10940, Pittsburgh, PA 15236-0940, USA
[3]Pacific Northwest National Laboratory, PO Box 999, Richland, WA, 99352, USA

NRAP
National Risk Assessment Partnership

NATIONAL ENERGY TECHNOLOGY LABORATORY
BERKELEY LAB
Los Alamos NATIONAL LABORATORY EST.1943
Pacific Northwest NATIONAL LABORATORY



Acknowledgement & Disclaimer

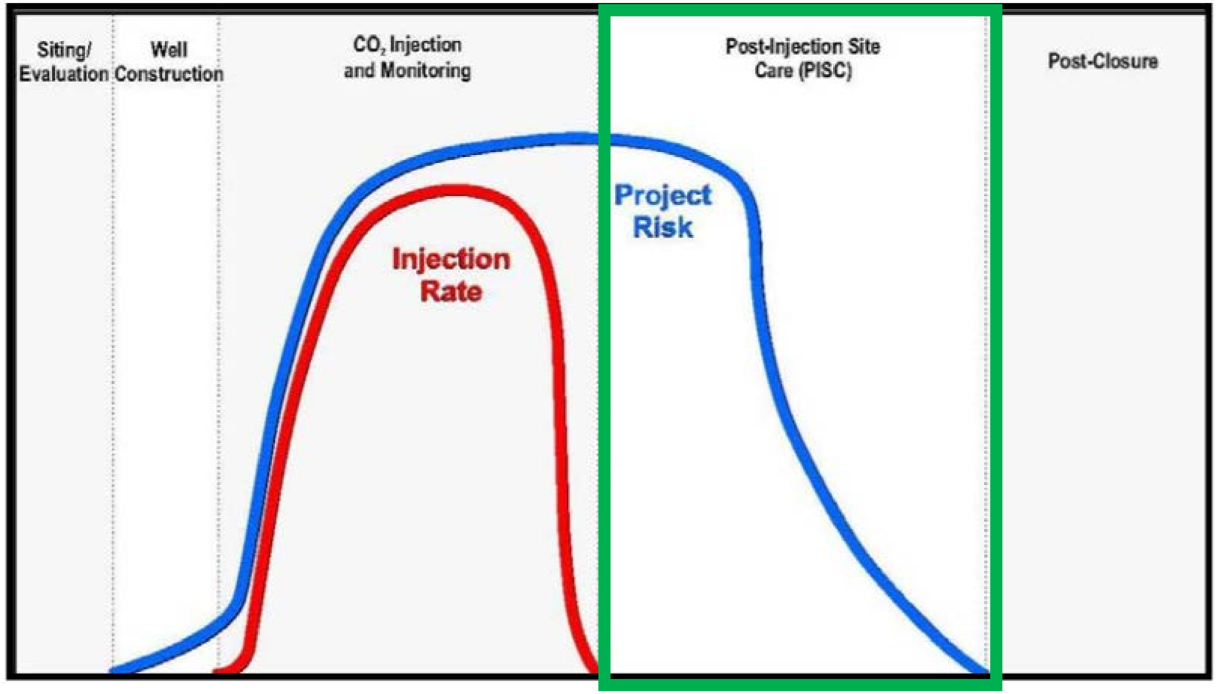
This work was funded by the Department of Energy, National Energy Technology Laboratory, an agency of the United States Government, through a support contract with Leidos Research Support Team (LRST). Neither the United States Government nor any agency thereof, nor any of their employees, nor LRST, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This work was performed in support of the US Department of Energy's Fossil Energy Crosscutting Technology Research Program. The Research was executed through the NETL Research and Innovation Center's Carbon Storage program. Research performed by Leidos Research Support Team staff was conducted under the RSS contract 89243318CFE000003.

Post-injection site care and site closure

40 CFR § 146.93

- **Follows injection phase**
- **Continues until non-endangerment of USDWs can be demonstrated**
  - Default period of 50 years
  - Alternative PISC periods can be justified
- **Site-specific testing and monitoring activities required according to approved plan**



(US EPA)

Non-endangerment

Definition

§ 144.12 Prohibition of movement of fluid into underground sources of drinking water.

(a) No owner or operator shall construct, operate, maintain, convert, plug, abandon, or conduct any other injection activity in a manner that allows the movement of fluid containing any contaminant into underground sources of drinking water, if the presence of that contaminant may cause a violation of any primary drinking water regulation under 40 CFR part 142 or may otherwise adversely affect the health of persons. The applicant for a permit shall have the burden of showing that the requirements of this paragraph are met.

Non-endangerment

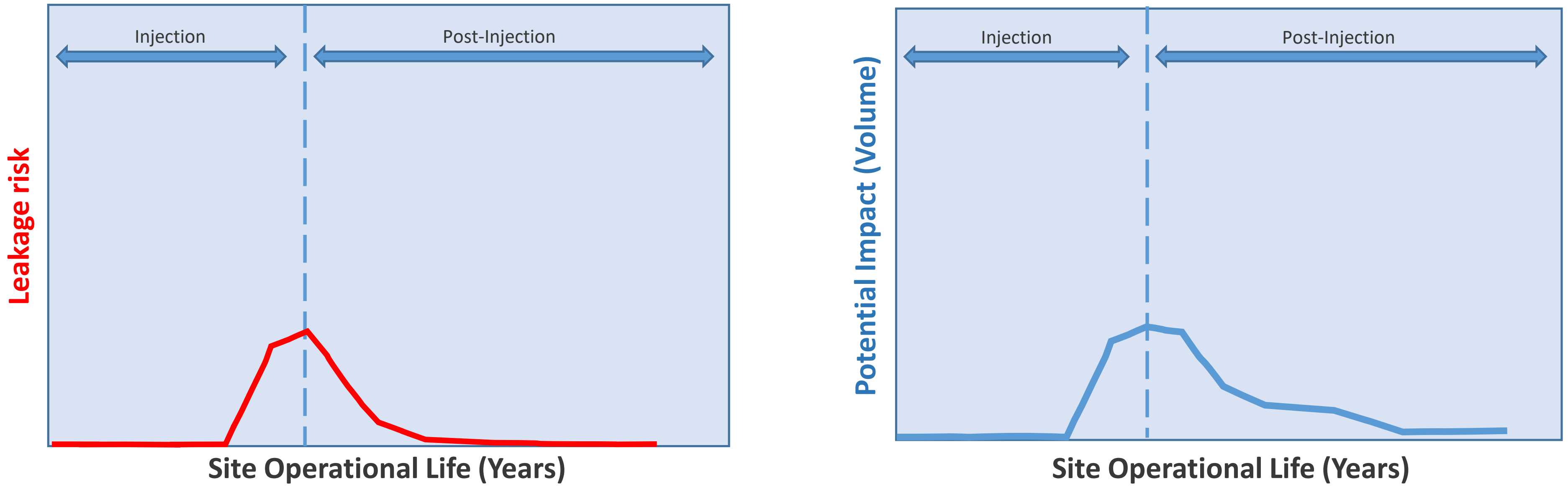
Definition

§ 144.12 Prohibition of movement of fluid into underground sources of drinking water.

(a) No owner or operator shall construct, operate, maintain, convert, plug, abandon, or conduct any other injection activity in a manner that allows the movement of fluid containing any contaminant into underground sources of drinking water, if the presence of that contaminant may cause a violation of any primary drinking water regulation under 40 CFR part 142 or may otherwise adversely affect the health of persons. The applicant for a permit shall have the burden of showing that the requirements of this paragraph are met.

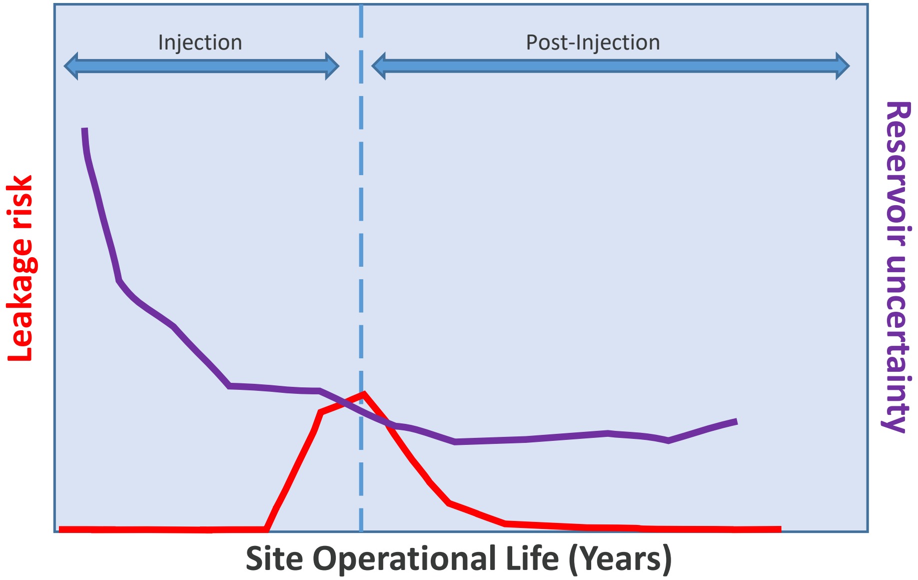
- **40 CFR § 146.93 – PISC and closure**
- **Non-endangerment demonstrations are:**
  - project-specific
  - based on monitoring and other data
  - show that no additional monitoring is needed to guarantee the protection of USDWs.
- **Information and conditions required for non-endangerment justified in PISC plan**

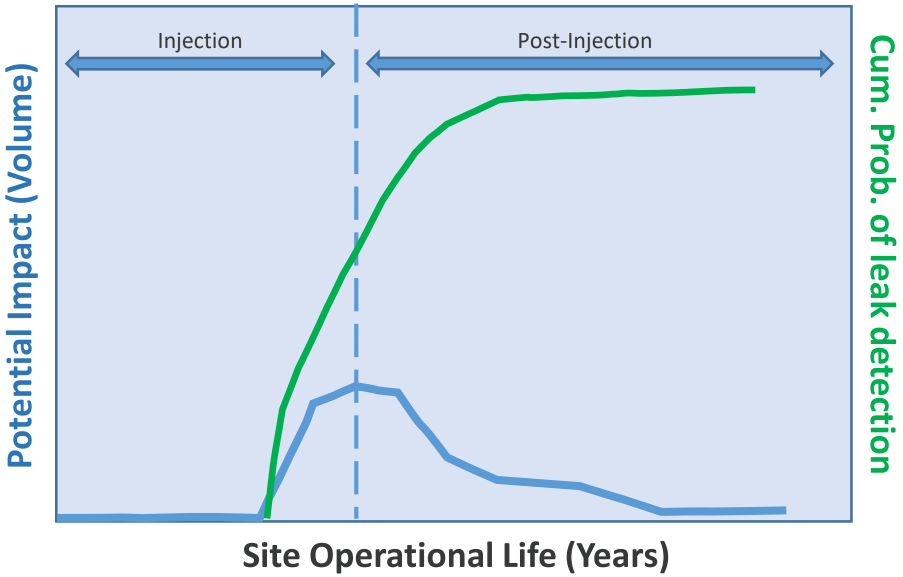
Risk-based containment demonstration



- Leakage risk and potential impact volume increase during injection

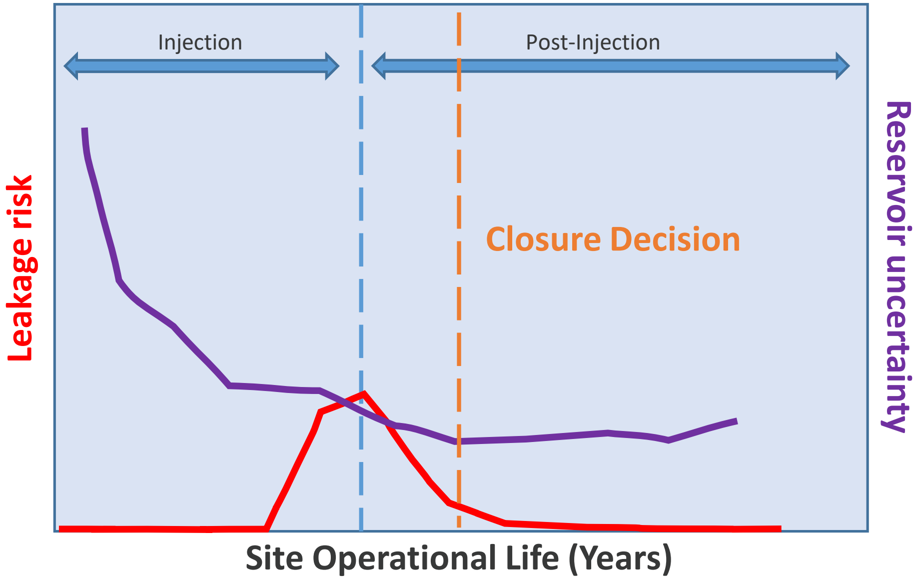
Risk-based containment demonstration

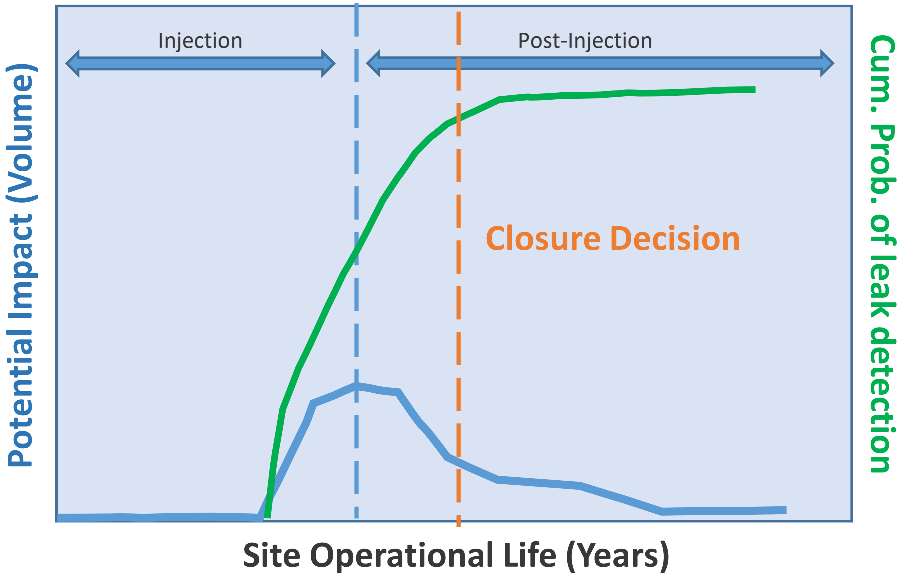




- Leakage risk and potential impact volume increase during injection
- Reservoir uncertainty decreases and cumulative probability of leak detection increases

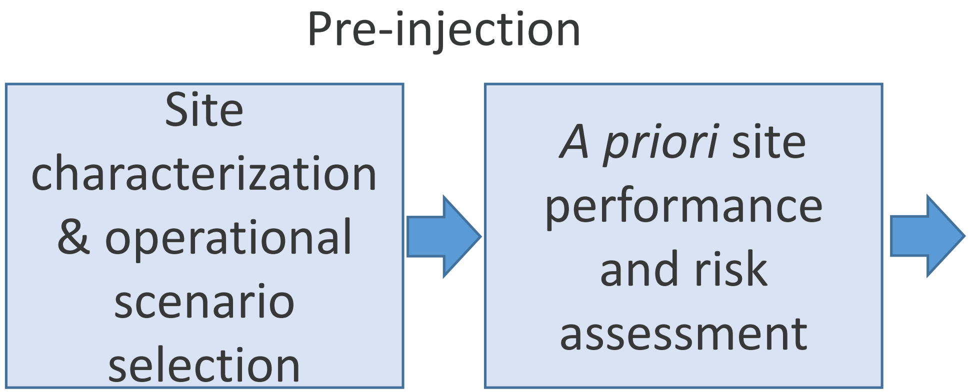
Risk-based containment demonstration



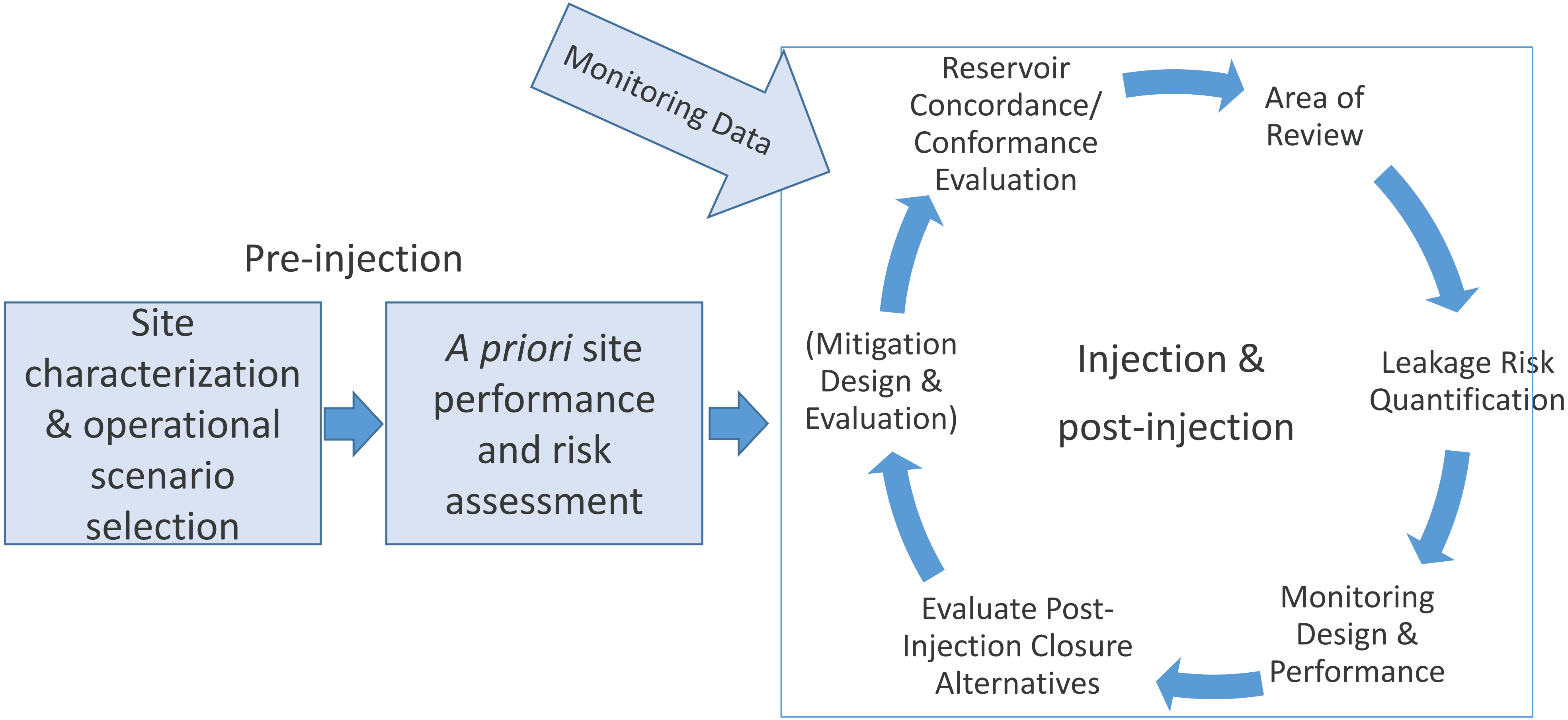


- Leakage risk and potential impact volume increase during injection
- Reservoir uncertainty decreases and cumulative probability of leak detection increases
- Closure decision is made when leakage risks and the cumulative probability of leak detection are deemed to be acceptable

Non-endangerment demonstration

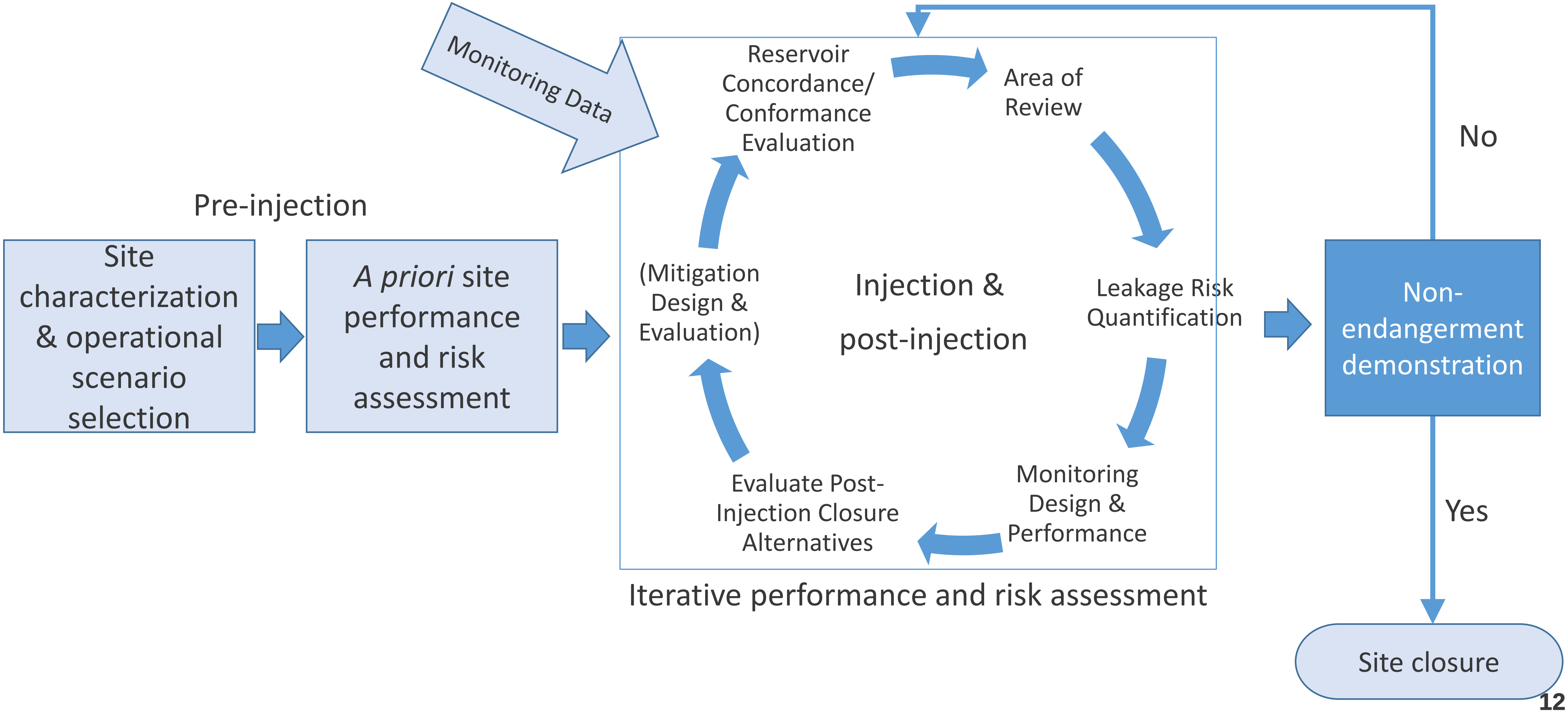


Non-endangerment demonstration



Iterative performance and risk assessment

Non-endangerment demonstration



Keys to demonstrating non-endangerment

For Class VI wells

1. Site selection / characterization
2. History matching / conformance
3. Pressure decline and stability
4. Containment demonstration

(Van Voorhees, 2019)

Keys to demonstrating non-endangerment

For Class VI wells

1. **Site selection / characterization**
2. History matching / conformance
3. Pressure decline and stability
4. Containment demonstration

of commercial CCS projects, and the process by whic
maturity (readiness for commercial injection) of a proje

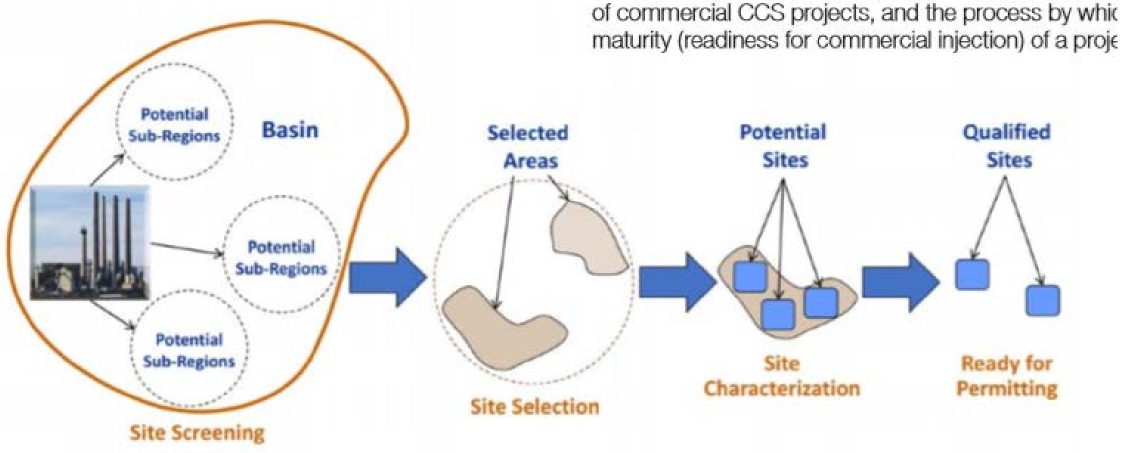


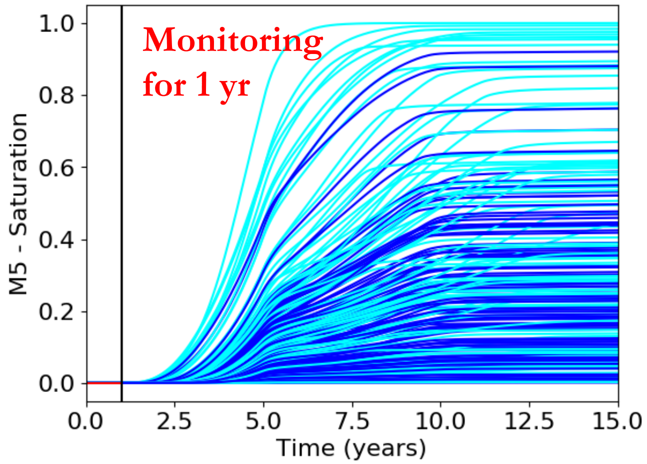
Figure 1.2: Illustration of the Relationship Between Scale of Investigation and Major Steps in Process of Finding and Developing Qualified Sites

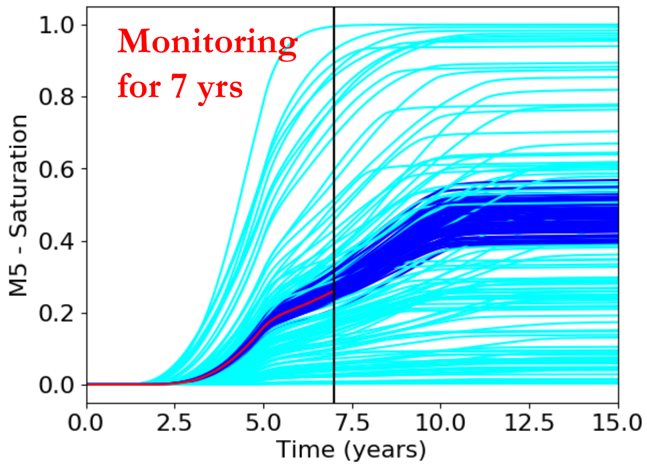
(Van Voorhees, 2019)

Keys to demonstrating non-endangerment

For Class VI wells

1. Site selection / characterization
2. **History matching / conformance**
3. Pressure decline and stability
4. Containment demonstration





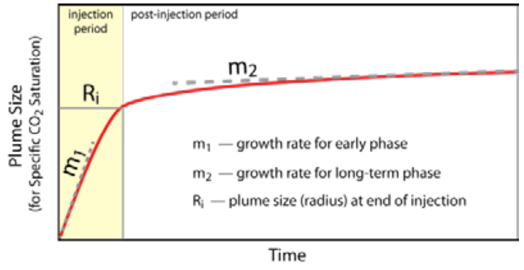
(Harp et al., 2019)

Keys to demonstrating non-endangerment

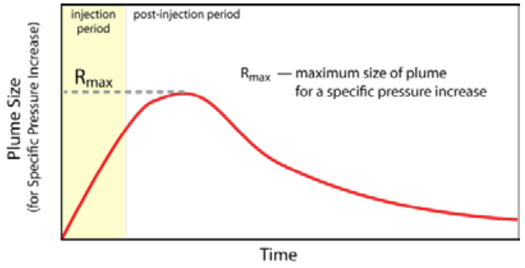
For Class VI wells

1. Site selection / characterization
2. History matching / conformance
3. **Pressure decline and stability**
4. Containment demonstration

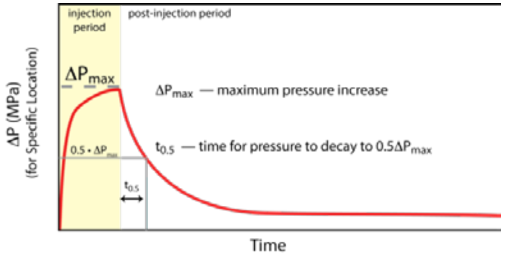
Size of CO_2 Plume



Size of Pressure Plume



Pressure at a Location



(Bromhal et al., 2014)

Keys to demonstrating non-endangerment

For Class VI wells

1. Site selection / characterization
2. History matching / conformance
3. Pressure decline and stability
4. **Containment demonstration**

Greenfield case study

FutureGen 2.0

- Site characterization data and modeling from Class VI permit application for FutureGen 2.0
- Determine risk-based PISC period using NRAP tools

International Journal of Greenhouse Gas Control 90 (2019) 102784

Contents lists available at ScienceDirect

International Journal of Greenhouse Gas Control

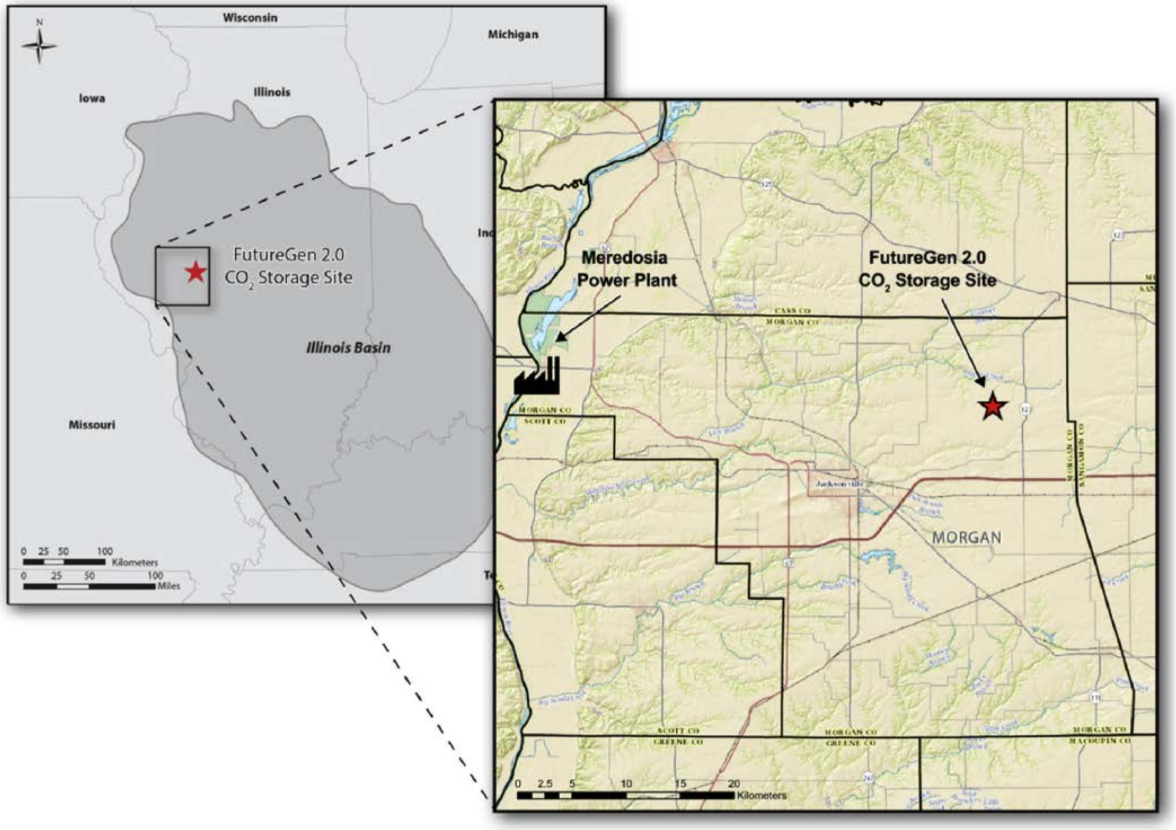
journal homepage: www.elsevier.com/locate/ijggc

ELSEVIER

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

Diana H. Bacon*, Catherine M.R. Yonkofski, Christopher F. Brown, Deniz I. Demirkanli, Jonathan M. Whiting

Pacific Northwest National Laboratory, P.O. Box 999, Richland, WA, 99352, United States

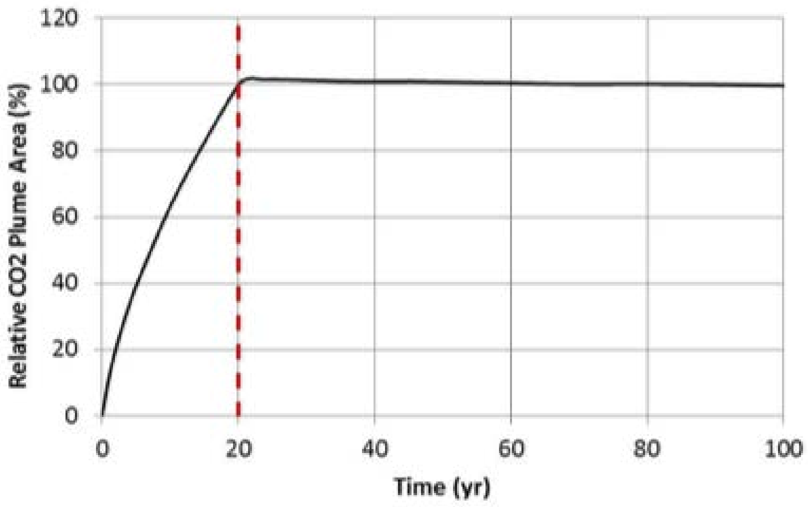


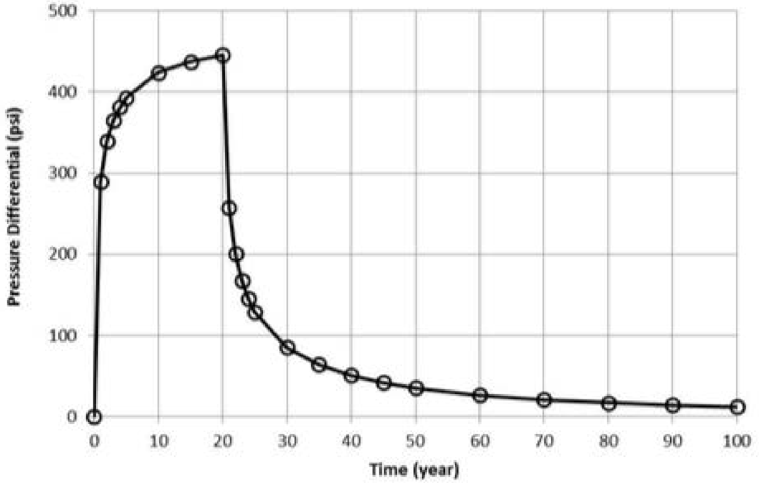
(Bacon et al., 2019)

Greenfield case study

Class VI permit

- 1.1 Mt injection of CO_2 into the 1,240 m deep Mt. Simon sandstone.
- Default 50-year PISC for the permit application.

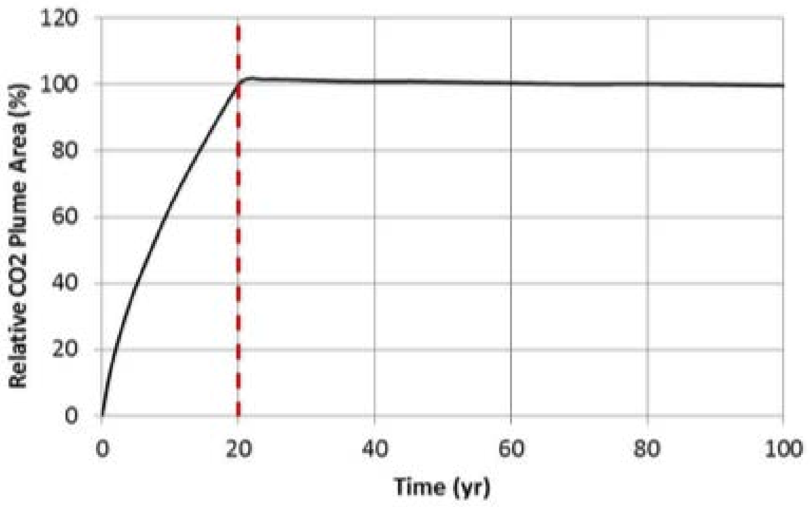


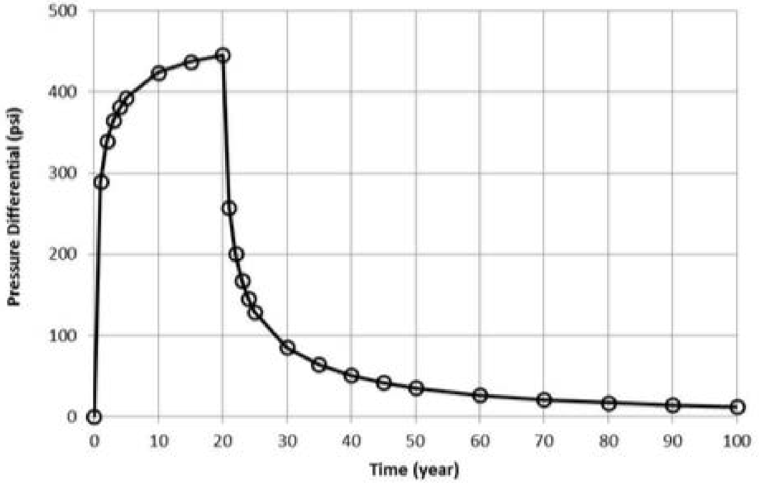


Greenfield case study

Class VI permit

- **1.1 Mt injection of CO_2 into the 1,240 m deep Mt. Simon sandstone.**
- **Default 50-year PISC for the permit application.**
- **Did not account for:**
    - Stabilization of CO_2 plume 2 years post-injection
    - Rapid reservoir pressure decline post-injection

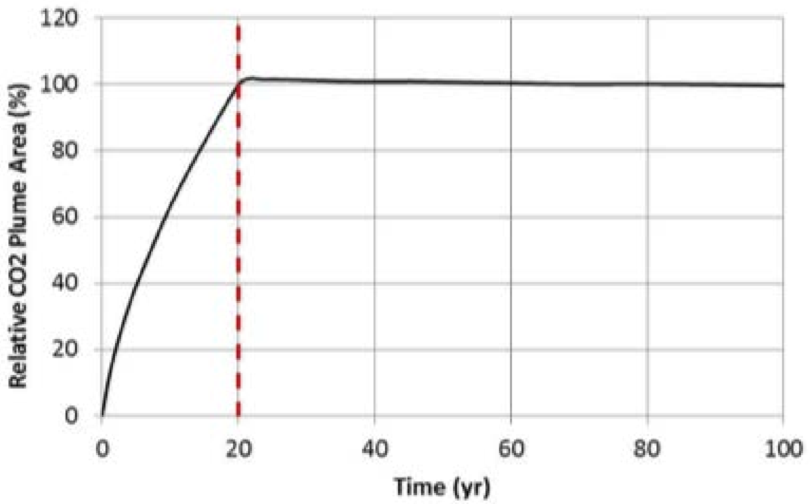


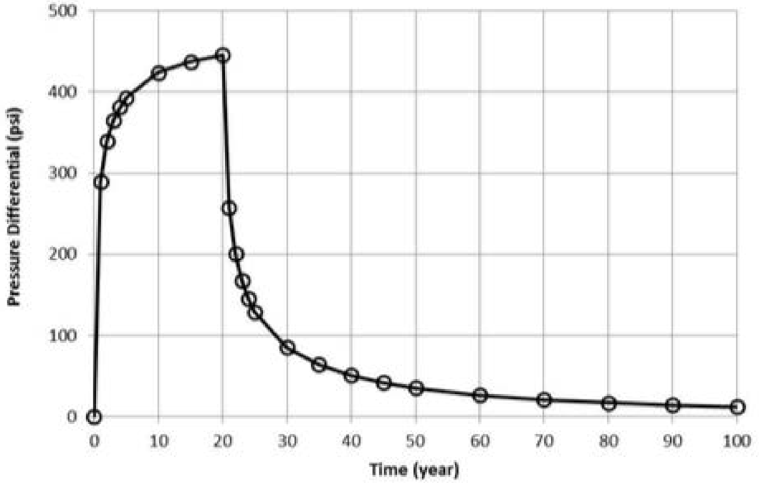


Greenfield case study

Class VI permit

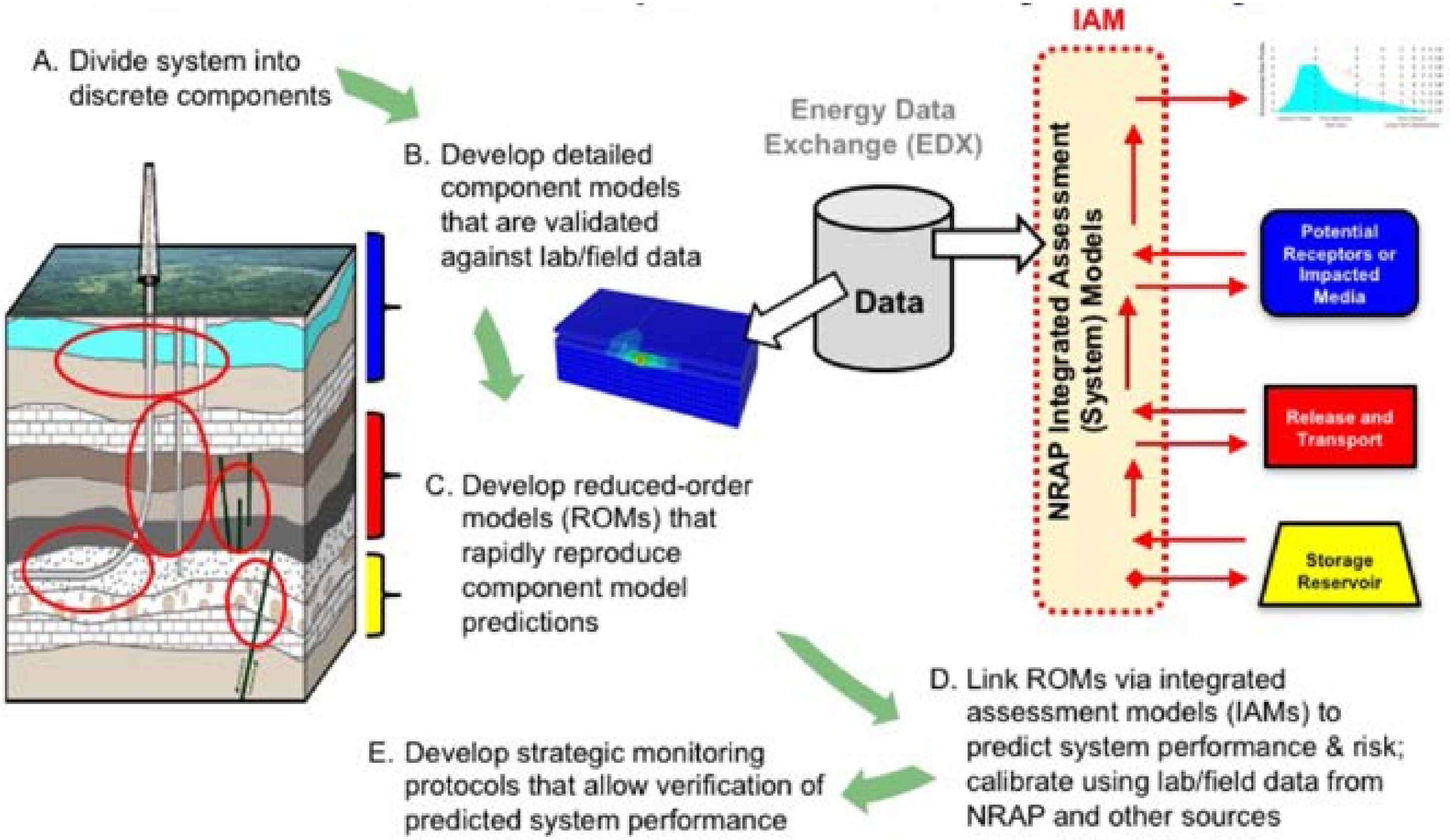
- **1.1 Mt injection of CO_2 into the 1,240 m deep Mt. Simon sandstone.**
- **Default 50-year PISC for the permit application.**
- **Did not account for:**
  - Stabilization of CO_2 plume 2 years post-injection
  - Rapid reservoir pressure decline post-injection
- **Study approach:**
  - Characterize leakage risks along injection and stratigraphic wells at the site using NRAP Open-IAM
  - Use DREAM to optimize well monitoring network
  - Demonstrate containment and non-endangerment to determine a risk-based PISC period





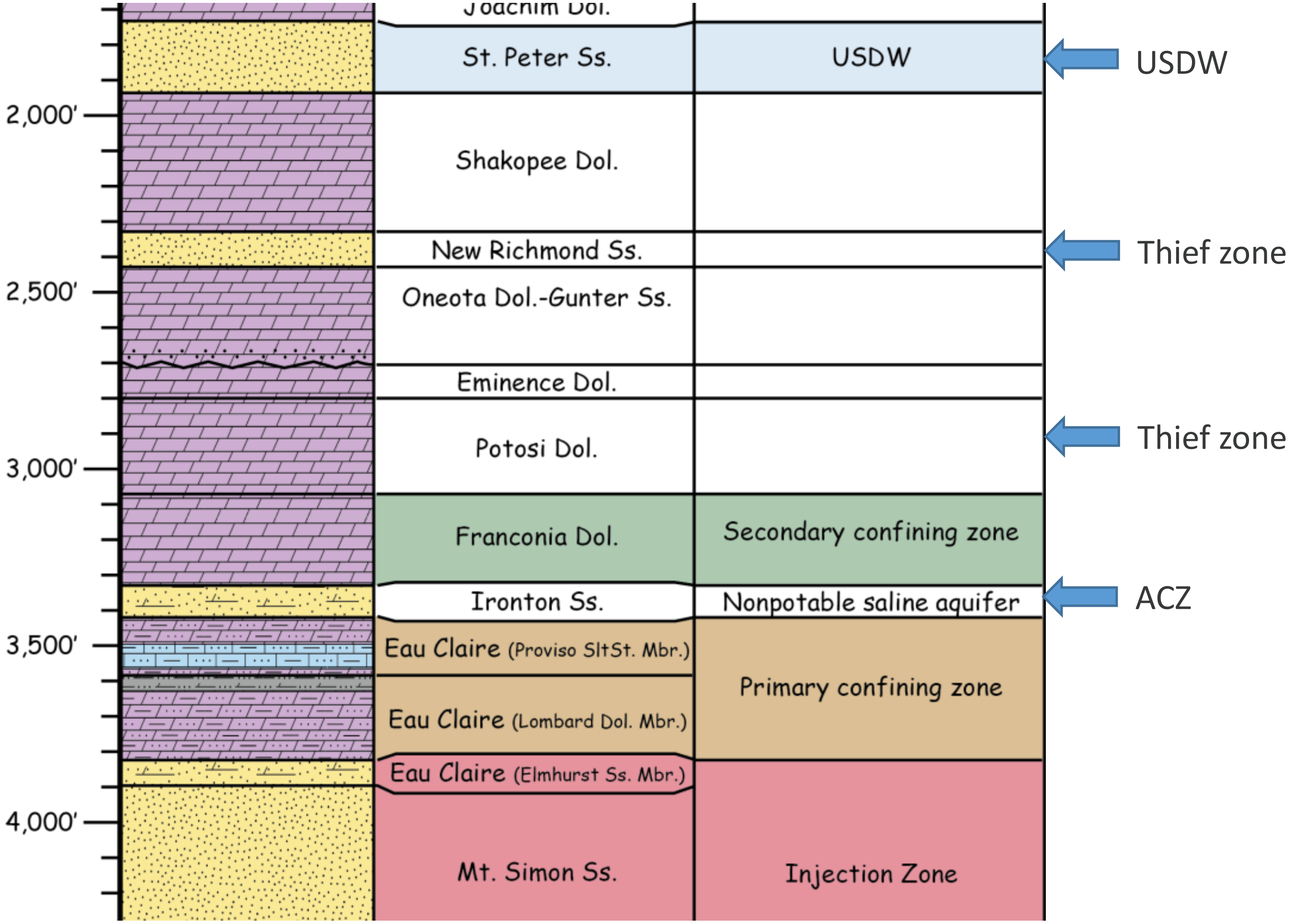
NRAP-Open-IAM

- Open-source integrated assessment is a system model used for modeling leakage risk at GCS sites

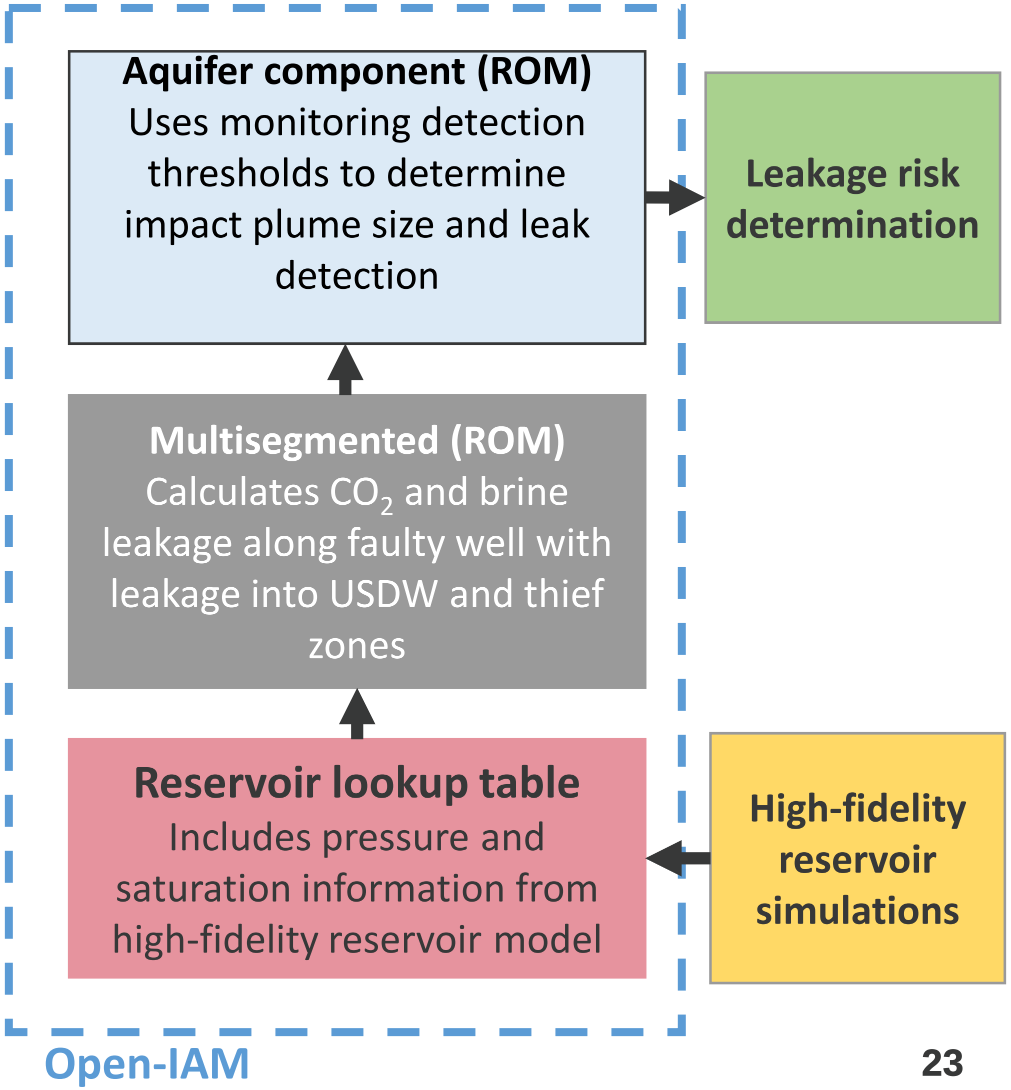


NRAP Open-IAM Model

Overview



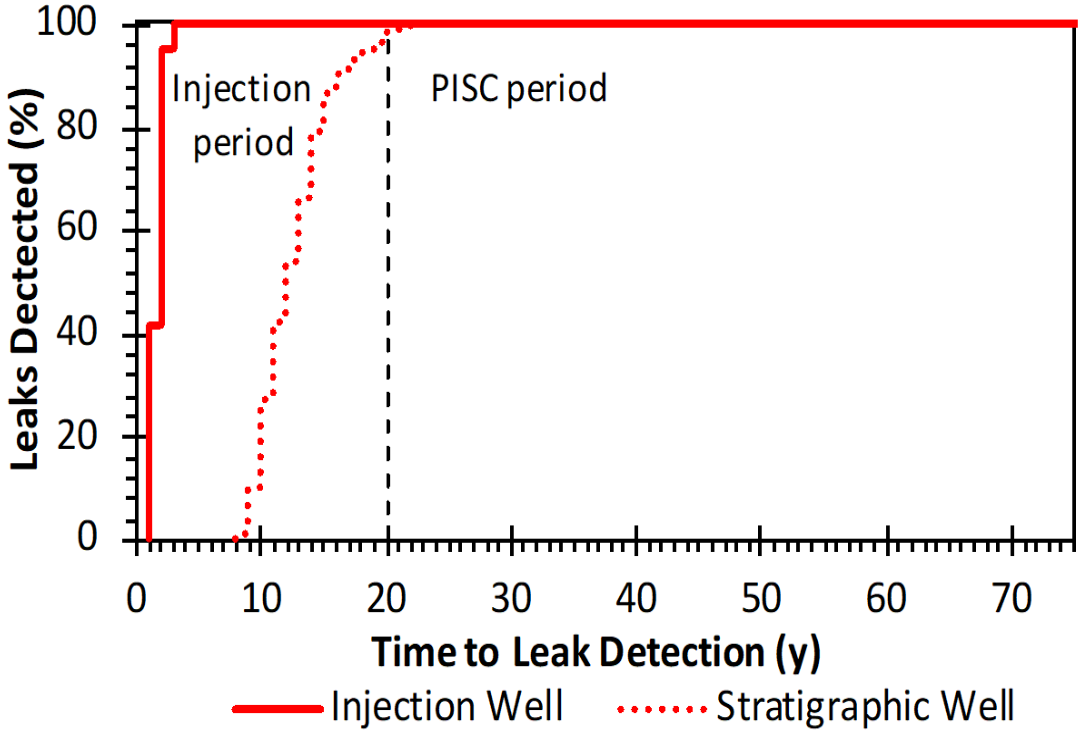
(Bacon et al., 2019)



Greenfield case study results

Risk-based PISC period

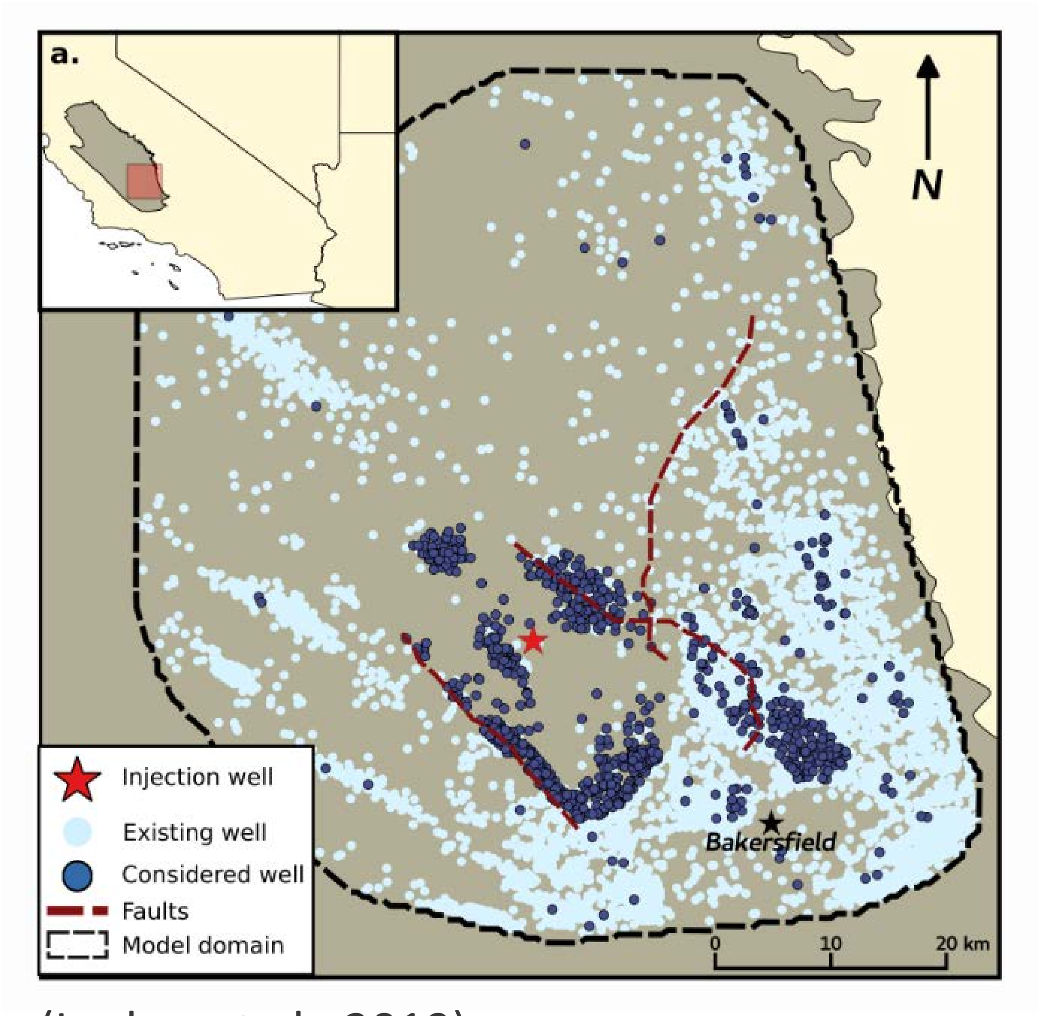
- Majority of leakage risk to USDWs occurred during injection
- 98% of leaks detected during injection period
- The final 2% detected within first 3 years of PISC period
- A 10 year PISC period would reduce the default period by 40 years and save $50M



(Bacon et al., 2019)

Brownfield case study

Kimberlina



(Lackey et al., 2019)

- Hypothetical basin-scale injection of 250 Mt of CO_2 over 50-year period
- 1,000 legacy wells penetrate storage reservoir
- Characterize well leakage risk
- Assess ability to manage leakage risks at site during injection and after injection

International Journal of Greenhouse Gas Control 88 (2019) 182–194

Contents lists available at ScienceDirect

International Journal of Greenhouse Gas Control

journal homepage: www.elsevier.com/locate/ijggc

ELSEVIER

Managing well leakage risks at a geologic carbon storage site with many wells

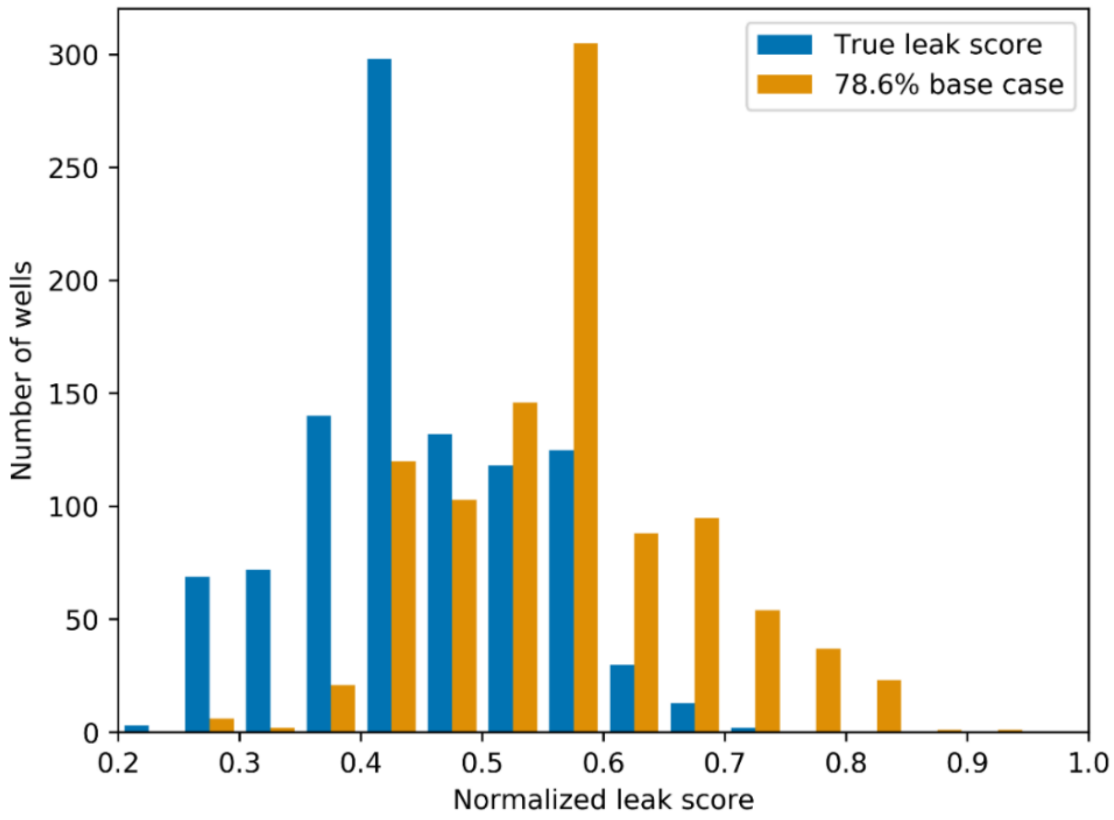
Greg Lackey[a,d,*], Veronika S. Vasylkivska[b,e], Nicolas J. Huerta[b,f], Seth King[c,e], Robert M. Dilmore[a]

[a] U.S. DOE National Energy Technology Laboratory, 626 Cochran Mill Road, Pittsburgh, PA 15236, USA
[b] U.S. DOE National Energy Technology Laboratory, 1450 SW Queen Ave, Albany, OR 97321, USA
[c] U.S. DOE National Energy Technology Laboratory, 3610 Collins Ferry Rd, Morgantown, WV 26505, USA
[d] Oak Ridge Institute for Science and Education, 1299 Bethel Valley Rd, Oak Ridge, TN 37830, USA
[e] Leidos Research Support Team, 626 Cochran Mill Road, P.O. Box 10940, Pittsburgh, PA 15236-0940, USA
[f] Pacific Northwest National Laboratory, P.O. Box 999, Richland, WA 99352, USA

Brownfield case study

Management scenarios

- **Well attribute data from CalGEM**
- **Calculated well-specific leakage risk score (Duguid et al., 2017).**
- **NRAP Open-IAM**
- **Application of well inspection and remediation strategy**
    - Risk-based
    - Distance-based
    - Hybrid



(Lackey et al., 2019)

Open-IAM model

Hypothetical Kimberlina GCS stie

Open-IAM

Reservoir lookup table
Includes pressure and saturation information from high-fidelity reservoir model

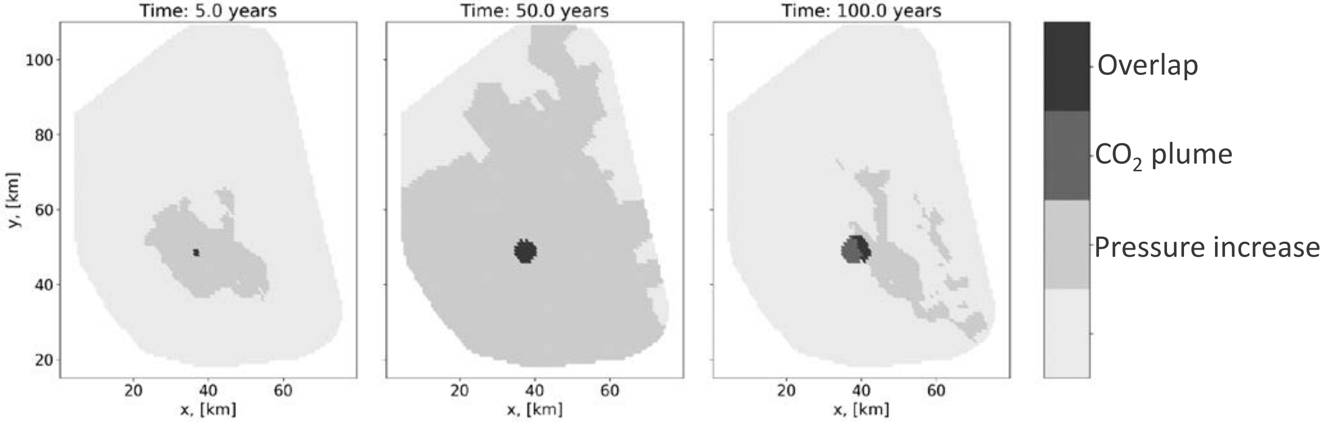
→

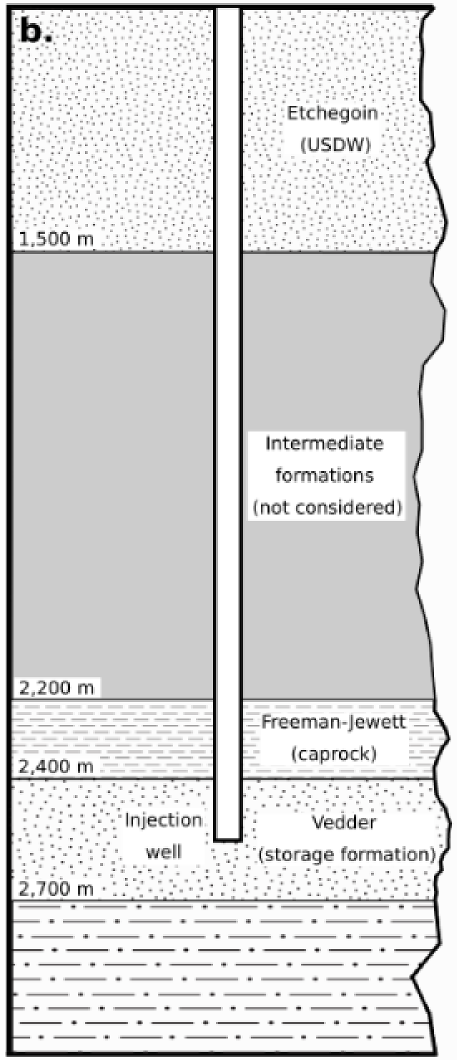
Multisegmented (ROM)
Calculates CO_2 and brine leakage along faulty well with leakage into USDW and thief zones

→

Leakage risk determination

Reservoir simulations





(Lackey et al., 2019)

Brownfield case study results

Leakage risk management

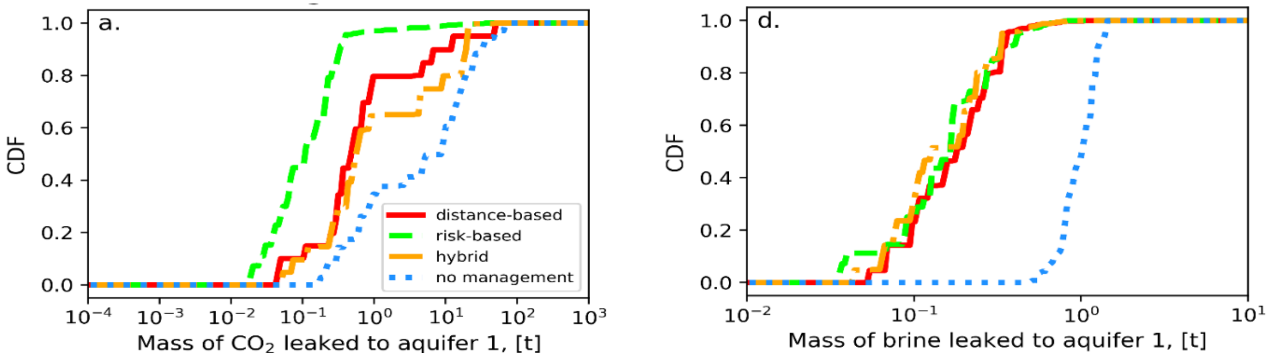
- **Small degree of leakage even in worst-case scenario**
  - 102.1 t (4.08×10^{-5}% of the 250 Mt of CO_2 injected)

(Lackey et al., 2019)

Brownfield case study results

Leakage risk management

- **Small degree of leakage even in worst-case scenario**
  - 102.1 t (4.08×10^{-5}% of the 250 Mt of CO_2 injected)
- **Well monitoring and remediation reduced leakage in all scenarios considered.**
- **Risk-based approach most effective with uncertain reservoir behavior.**

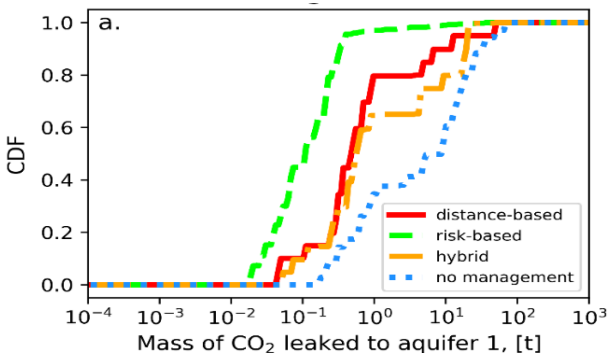


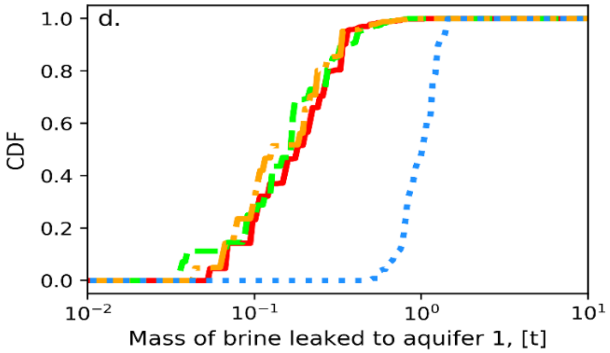
(Lackey et al., 2019)

Brownfield case study results

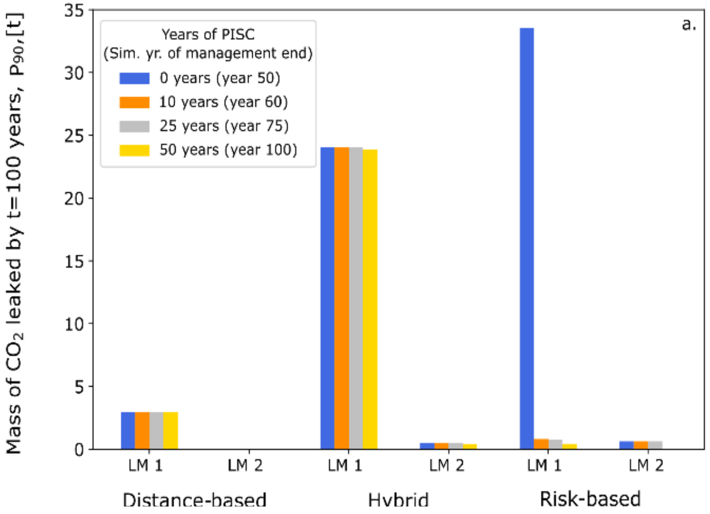
Leakage risk management

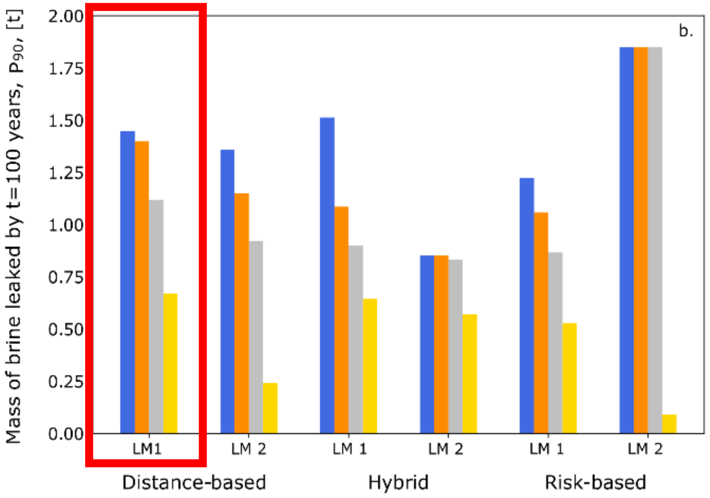
- **Small degree of leakage even in worst-case scenario**
  - 102.1 t (4.08×10^{-5}% of the 250 Mt of CO_2 injected)
- **Well monitoring and remediation reduced leakage in all scenarios considered.**
- **Risk-based approach most effective with uncertain reservoir behavior.**
- **Increasing PISC period length reduced brine leakage but had very little impact on CO_2 leakage**





(Lackey et al., 2019)





Summary

- **Four keys to demonstrating non-endangerment**
    1. Site selection / characterization
    2. History matching / conformance
    3. Pressure decline and stability
    4. Containment demonstration

Summary

- **Four keys to demonstrating non-endangerment**
  1. Site selection / characterization
  2. History matching / conformance
  3. Pressure decline and stability
  4. Containment demonstration
- **Containment demonstration with the NRAP Open-IAM:**
  - Characterize leakage risks by stochastically varying uncertain parameters
  - Simulate CO_2 plume size and detectability in a shallow aquifer
  - Identify time required for leak detection in all possible scenarios
  - Explore and understand the benefits of applying various leakage risk management plans

Summary

- **Four keys to demonstrating non-endangerment**
  1. Site selection / characterization
  2. History matching / conformance
  3. Pressure decline and stability
  4. Containment demonstration
- **Containment demonstration with the NRAP Open-IAM:**
  - Characterize leakage risks by stochastically varying uncertain parameters
  - Simulate CO_2 plume size and detectability in a shallow aquifer
  - Identify time required for leak detection in all possible scenarios
  - Explore and understand the benefits of applying various leakage risk management plans
- **Iterative process where predictions are updated and uncertainties in reservoir performance, leakage response, potential impacts, and leakage detectability are constrained**
- **Develop adaptive site monitoring plan and weight the incremental costs of additional PISC against the associated risk and uncertainty benefits.**

Selected References

- Bacon, D.H., Demirkanli, D.I., S.K. White, Probabilistic Risk-based Area of Review (AoR) Determination for a Deep-Saline Carbon Storage Site, International Journal of Greenhouse Gas Control (in revision).
- Bacon, D.H., C.M.R. Yonkofski, C.F. Brown, D.I. Demirkanli, J.M. Whiting, 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, 2019, International Journal of Greenhouse Gas Control, Volume 90, available at: https://doi.org/10.1016/j.ijggc.2019.102784.
- Chen, et al., "On Reducing Uncertainty in Geologic CO_2 Sequestration Risk Assessment by Assimilating Monitoring Data," submitted to *International Journal of Greenhouse Gas Control.*
- Doughty, C.A., and Oldenburg, C.M., "CO_2 Plume Evolution in a Depleted Natural Gas Reservoir: Modeling of Conformance Uncertainty Reduction Over Time," submitted to *International Journal of Greenhouse Gas Control*, special NRAP 2019 issue
- Harp, D., Oldenburg, C., Pawar, R. A metric for evaluating conformance robustness during geologic CO2 sequestration operations. IJGGC, Volume 85, June 2019, Pages 100-108
- Harp, D., Ohishi, T., Chu, S., Chen, S., Pawar, R. Development of quantitative metrics of plume migration at geologic CO_2 storage sites. Greenhouse Gases Science & Technology Volume 9, Issue 4. https://doi.org/10.1002/ghg.1903
- Lackey, G., Vasylkivska, V.S., Huerta, N.J., King, S., Dilmore, R.M. Managing Well Leakage Risks at a Geologic Carbon Storage Site with Many Wells. *International Journal of Greenhouse Gas Control*, Volume 88, September 2019, Pages 182-194.
- Pawar, R., Chu, S., Makedonska, N., Onishi, T., Harp, D. Assessment of relationship between post-injection plume migration and leakage risks at geologic CO2 storage sites. submitted to IJGGC
- Yang, X., Buscheck, T.A., Mansoor, K., and Carroll, S.A., "Assessment of Geophysical Monitoring Methods for Detection of Brine and CO_2 Leakage in Drinking Aquifers," *International Journal of Greenhouse Gas Control*, 90:102803, https://doi.org/10.1016/j.ijggc.2019.102803
- Zhang, Y., King, S., Harp, D.R., Vasylkivska, V., Bacon, D., Chen, B., and Mansoor, K., "NRAP-Open-IAM: A Flexible Open Source Integrated Assessment Model for Geologic Carbon Storage Risk Assessment and Management," submitted to *Computers and Geosciences*.

NRAP workshop

- Introduction
- Fluid Migration Characterization
- State-of-stress Characterization
- Risk-based Area of Review
- U.S. DOE's SMART Initiative
- Plume Dynamics and Conformance
- Induced Seismicity Management
- Monitoring for Leak Detection
- Site Closure
- Discussion