PNNL-SA-147201

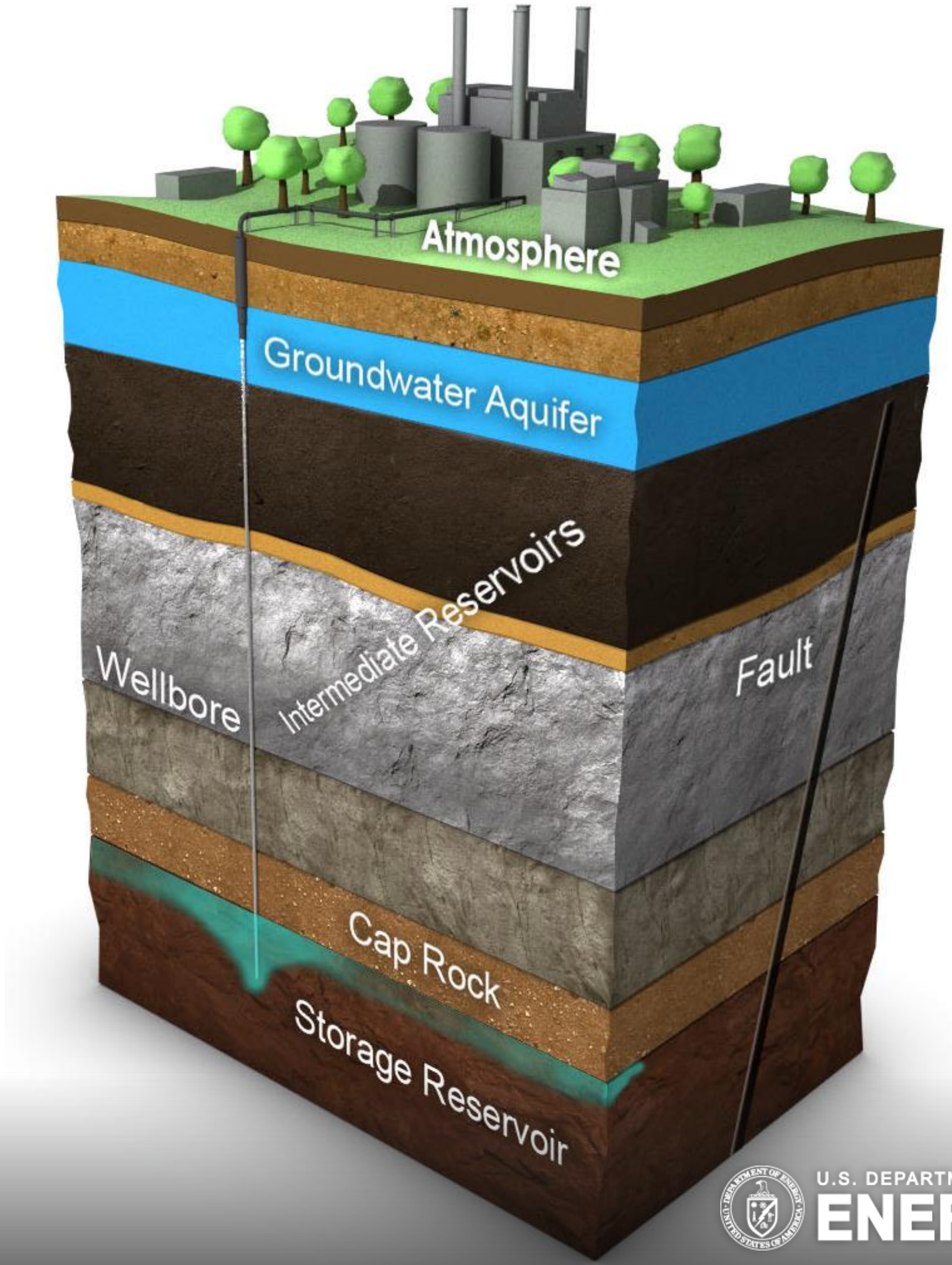
Evaluating the Risk to Groundwater from Geologic Carbon Storage Projects

Diana Bacon, Ph.D., LHG
Pacific Northwest National Laboratory

Ground Water Protection Council Annual Forum
September 16, 2019

NRAP
National Risk Assessment Partnership

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

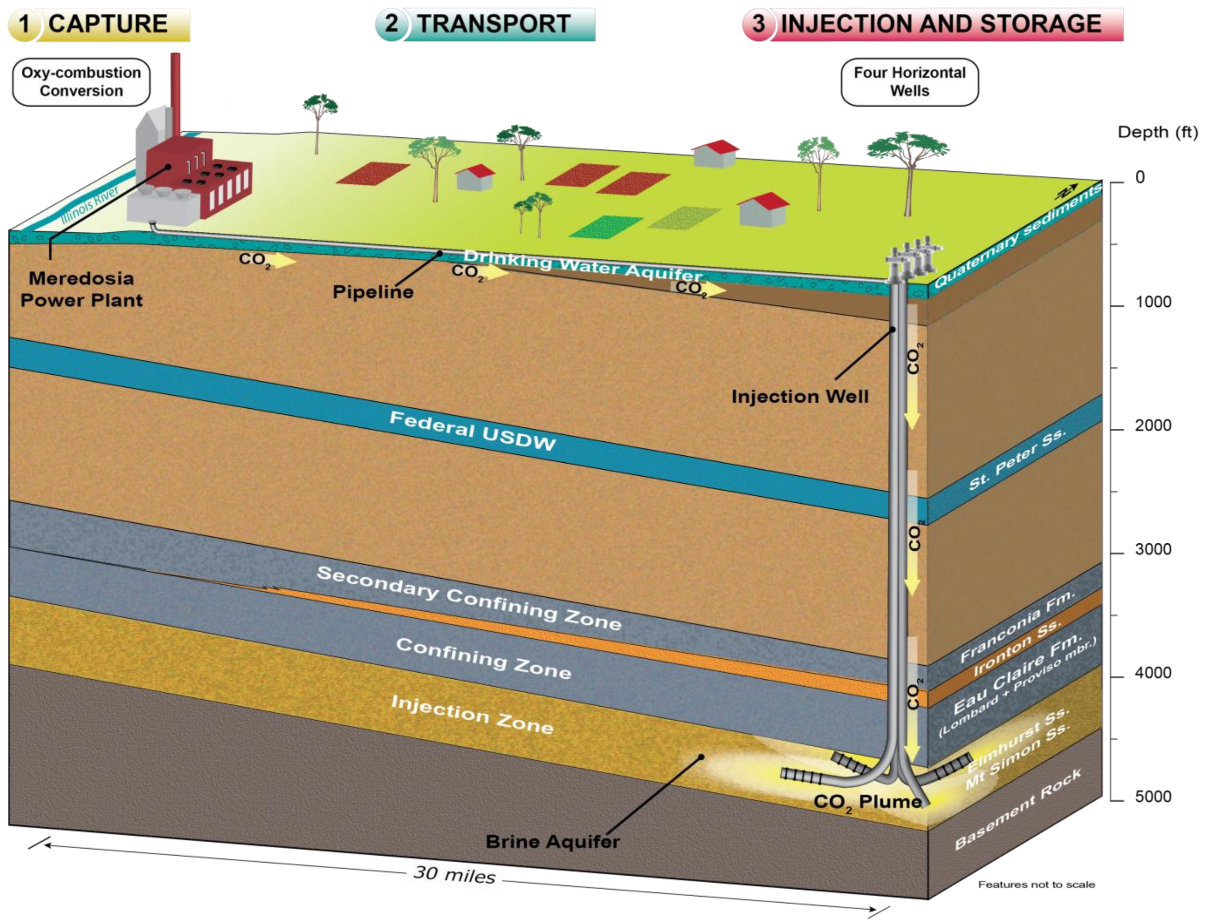


U.S. DEPARTMENT OF ENERGY

FutureGen 2.0 Case Study

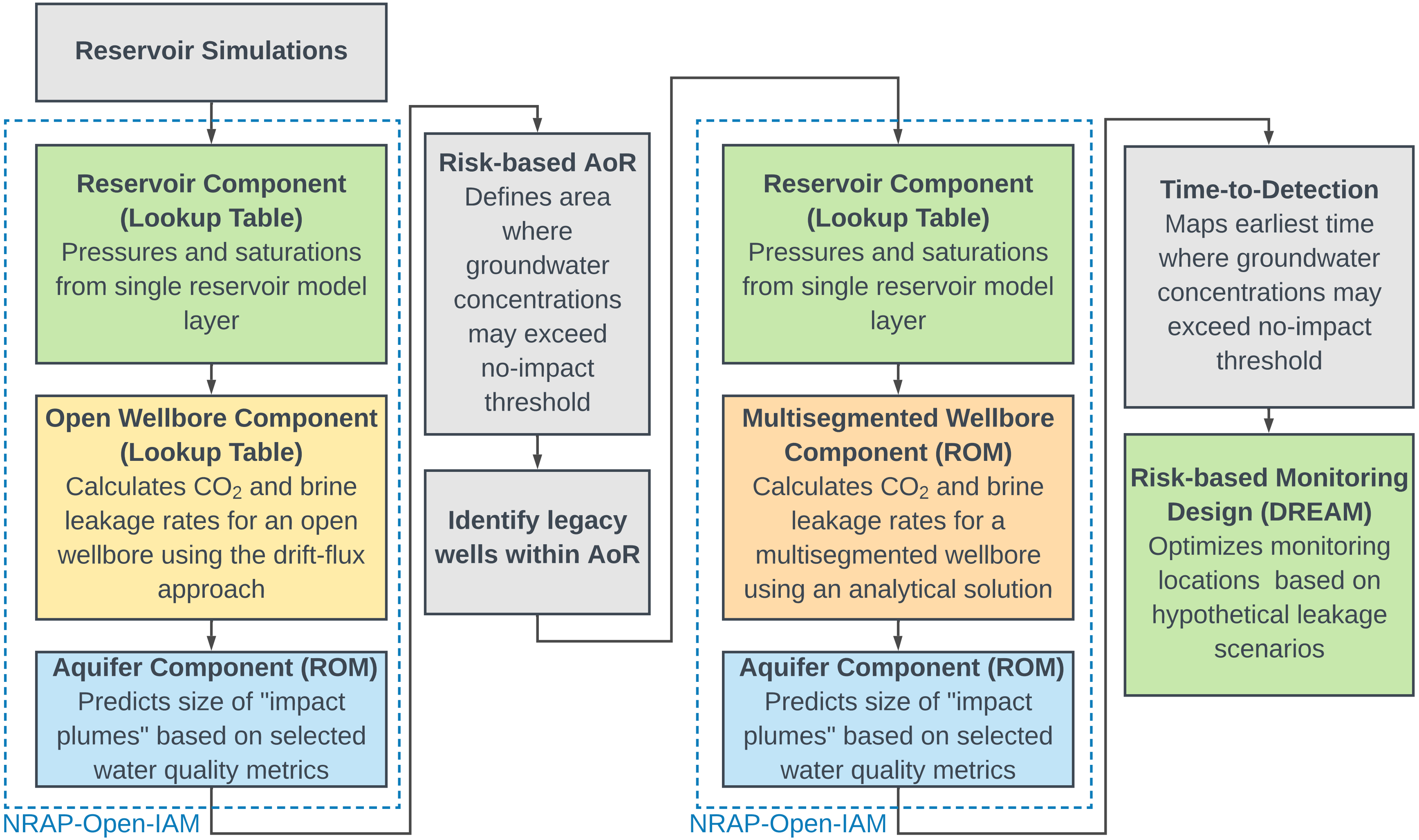
UIC Class VI Permit Application

- **Revisit characterization data and modeling from Class VI permit application**
- **Apply NRAP tools to determine risk-based**
  - Area of Review
  - Monitoring Design
  - Post-Injection Site Care Period



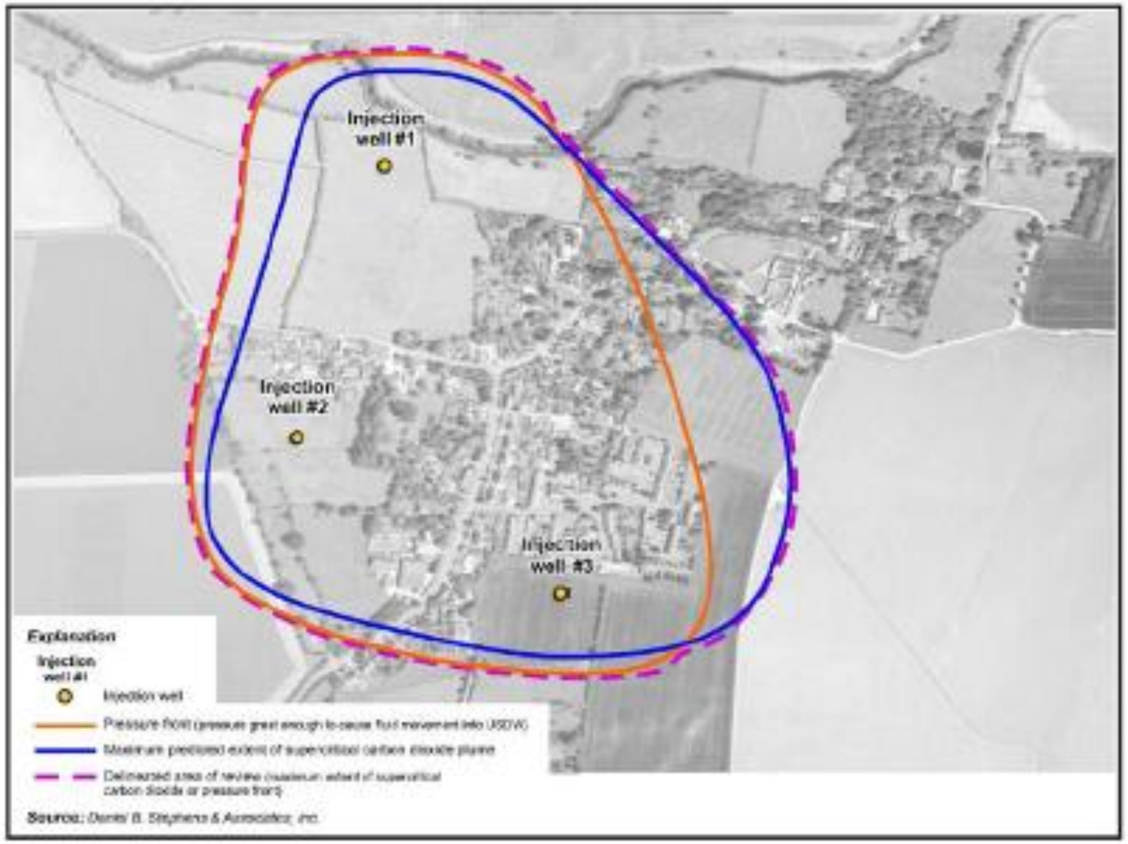
Risk-based AoR and Monitoring Design

Using NRAP-Open-IAM and DREAM



Area of Review (AoR) for CO_2 Storage Sites

- The area surrounding the injection project where groundwater resources may be endangered by the activity (i.e., project risk area)
- EPA requires operators applying for a Class VI CO_2 injection permit to determine the AoR based on the separate-phase CO_2 plume/pressure evolution predictions from physics-based computational modeling
- AoR is delineated by the maximum extent of CO_2 plume and pressure front over the lifetime of the project to account for risks associated with both CO_2 and/or brine leakage into the overlying groundwater aquifer



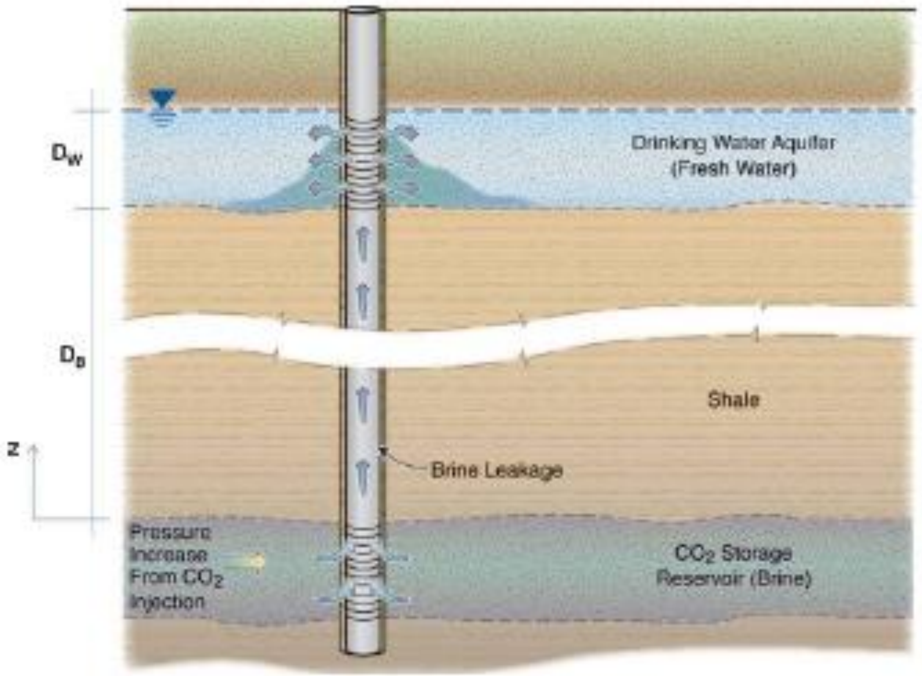
Pressure Front (Under-Pressurized or Hydrostatic Conditions)

- **The critical pressure that can cause fluid flow from injection zone into the groundwater aquifer through a hypothetical conduit**
- **Under-pressurized conditions:**
  - Simple mass balance calculation (Birkholzer et al., 2011) assumes density of the fluid in the wellbore is uniform and equal to the density in the injection zone

$$\Delta P_{if} = P_u + \rho_i g \cdot (z_u - z_i) - P_i$$

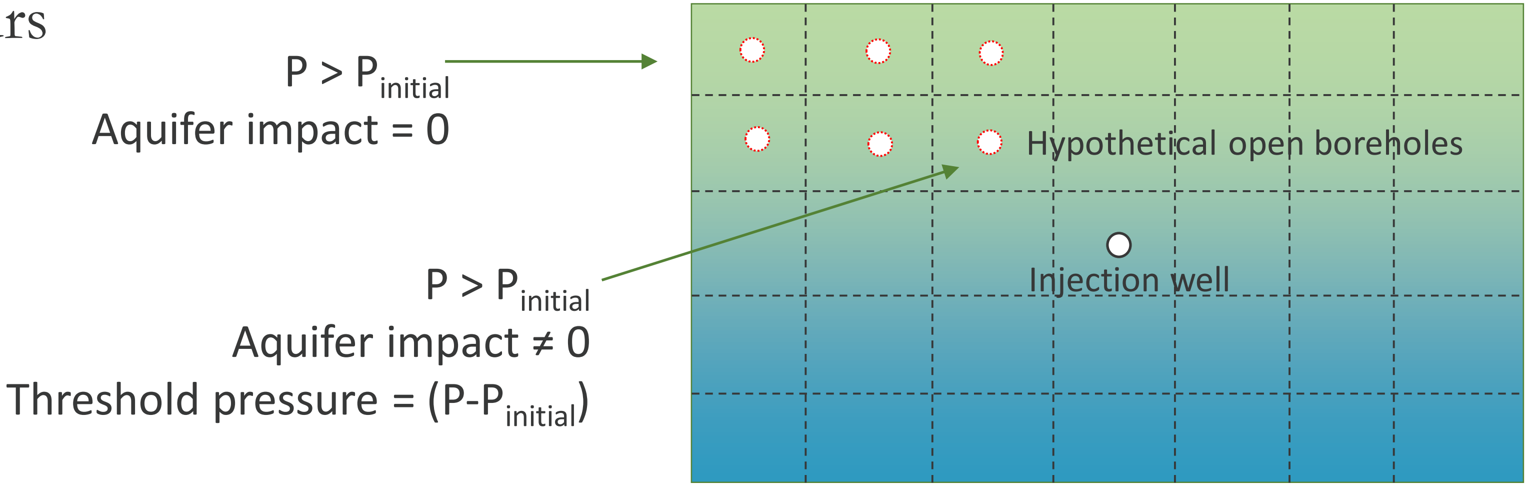
- **Hydrostatic conditions:**
  - Displacement of the existing fluid in the borehole (Nicot et al., 2009)

$$\Delta P_c = \frac{1}{2} \cdot g \cdot \xi \cdot (z_u - z_i)^2 \quad \xi = \frac{\rho_i - \rho_u}{z_u - z_i}$$



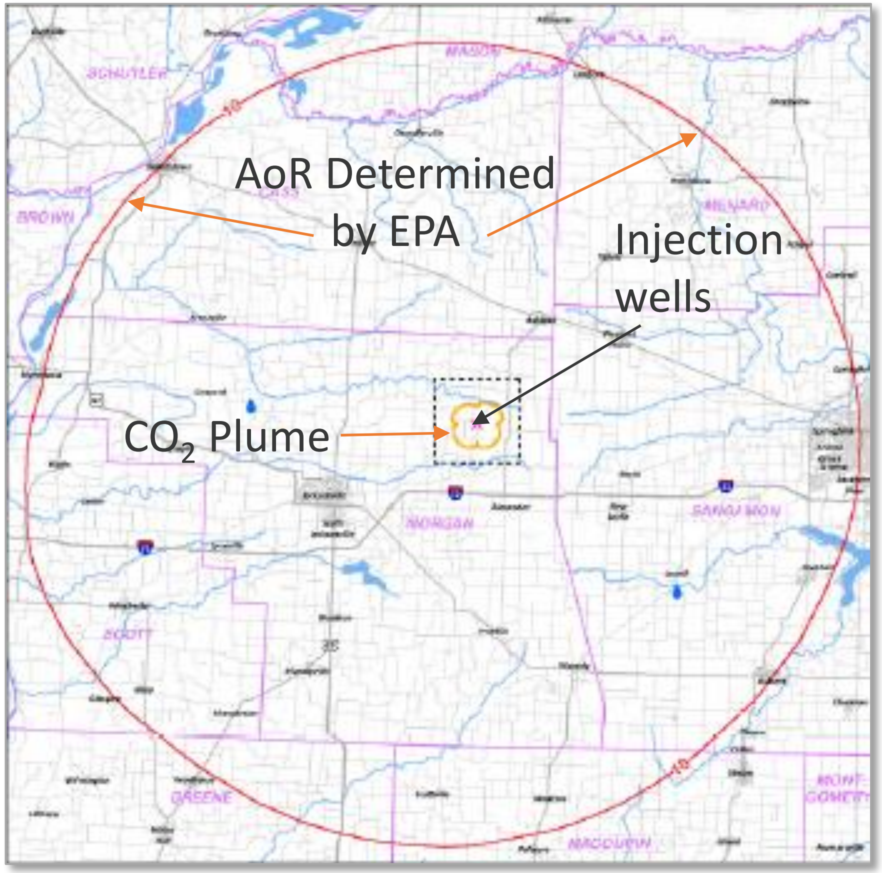
Pressure Front (Over-Pressurized Conditions)

- **Determination of an "allowable pressure increase" (EPA Guidance) that prevents fluid leakage into the aquifer and impact on the water quality**
- **Calculated based on:**
    - A multiphase numerical model designed to model leakage through wellbore(s)
    - A numerical or analytical approach to determine the threshold above which an impact to aquifer occurs



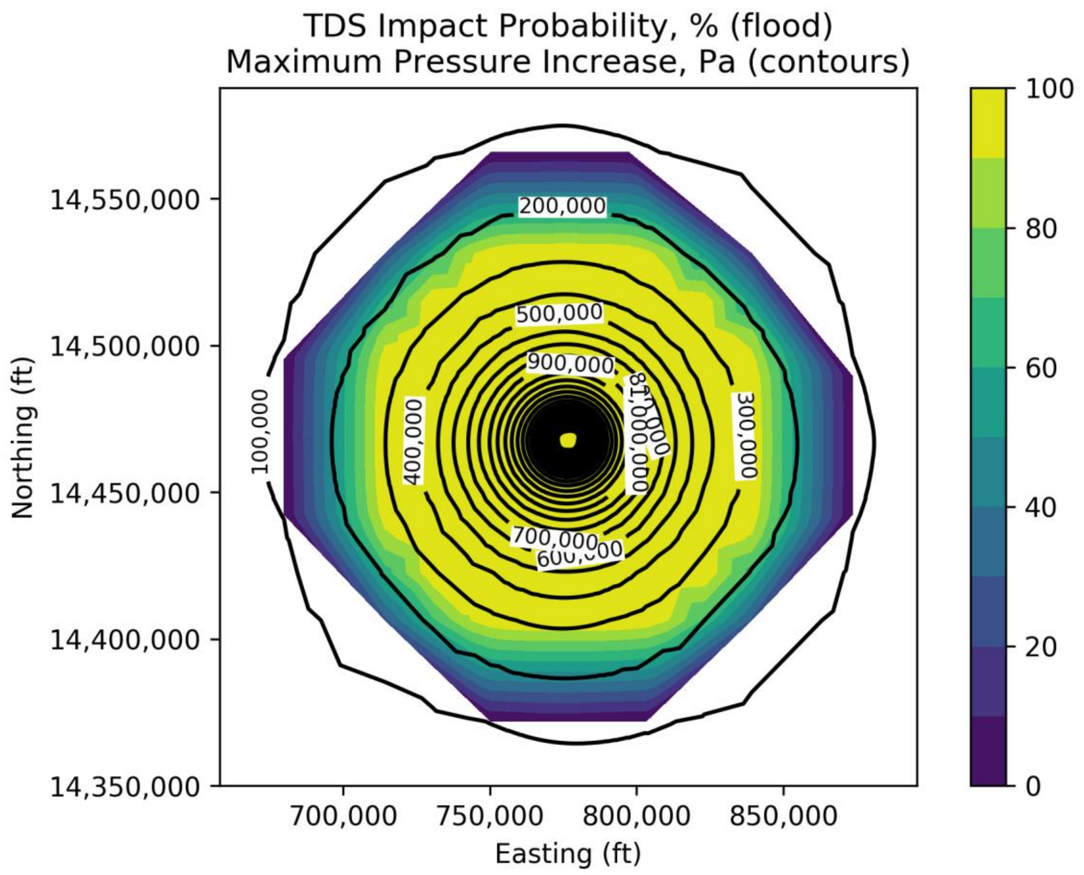
Area of Review Determination at FutureGen 2.0 Site

- **Mt. Simon: Over-pressurized reservoir with respect to the lowermost USDW**
- **Pressure front and AoR determined by EPA**
  - Based on 10 psi critical pressure



AoR Determination Using NRAP-Open-IAM

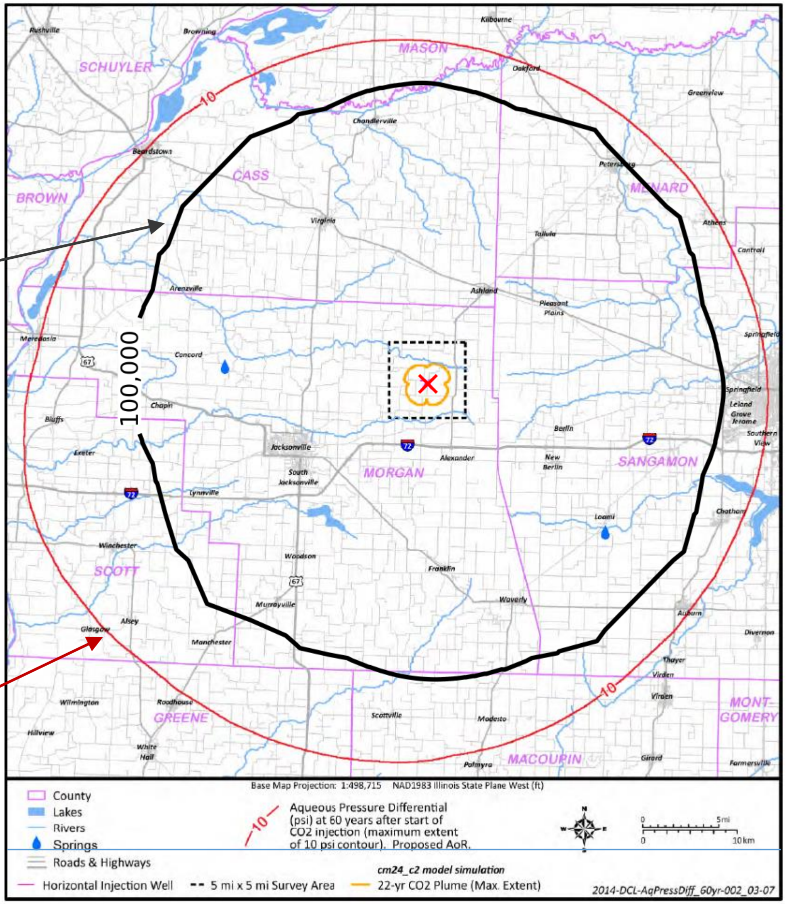
- **Base AoR delineation on impact to the aquifer if a well is placed at a particular location**
- **Loop through all X,Y locations in reservoir model layer**
  - Find pressure and saturation in reservoir model
  - Use Open Wellbore model to determine CO_2 and brine leakage rates to aquifer
  - Calculate pH and TDS impact volumes vs. time and location
- **Map maximum pH and TDS impact volumes on X,Y grid for each realization**
- **Calculate probability of aquifer impact for each grid location**



AoR Comparison

Risk-Based AoR (100,000 Pa / 14.5 psi (black)
Class VI Permit AoR 68,974 Pa / 10 psi (red)

Risk-based AoR



AoR determined by EPA using 10 psi critical pressure

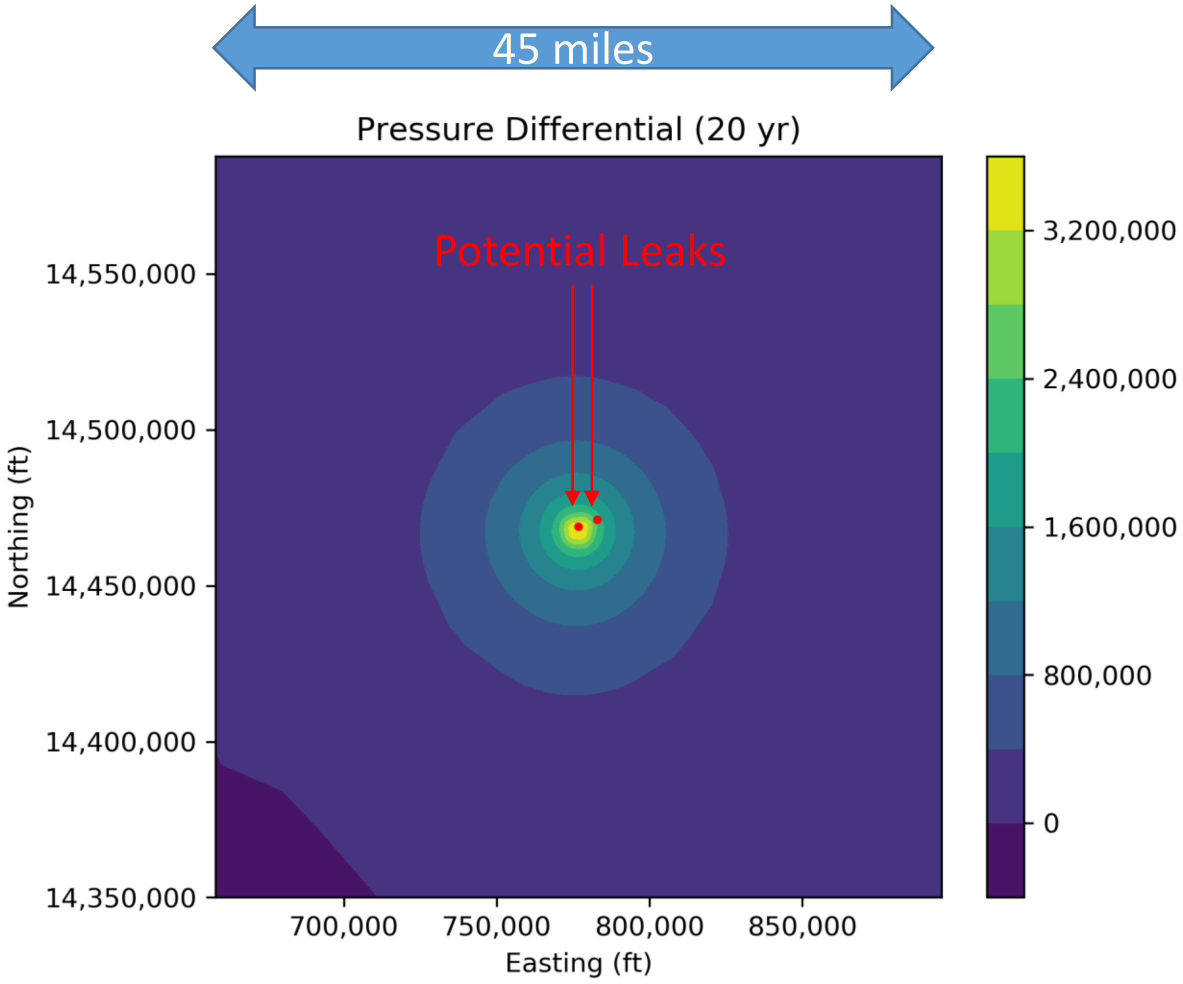
- Area of potential aquifer impact predicted to be smaller than AoR based on 10 psi critical pressure
- Results sensitive to model assumptions
  - wellbore diameter
  - impact threshold
  - duration of leak

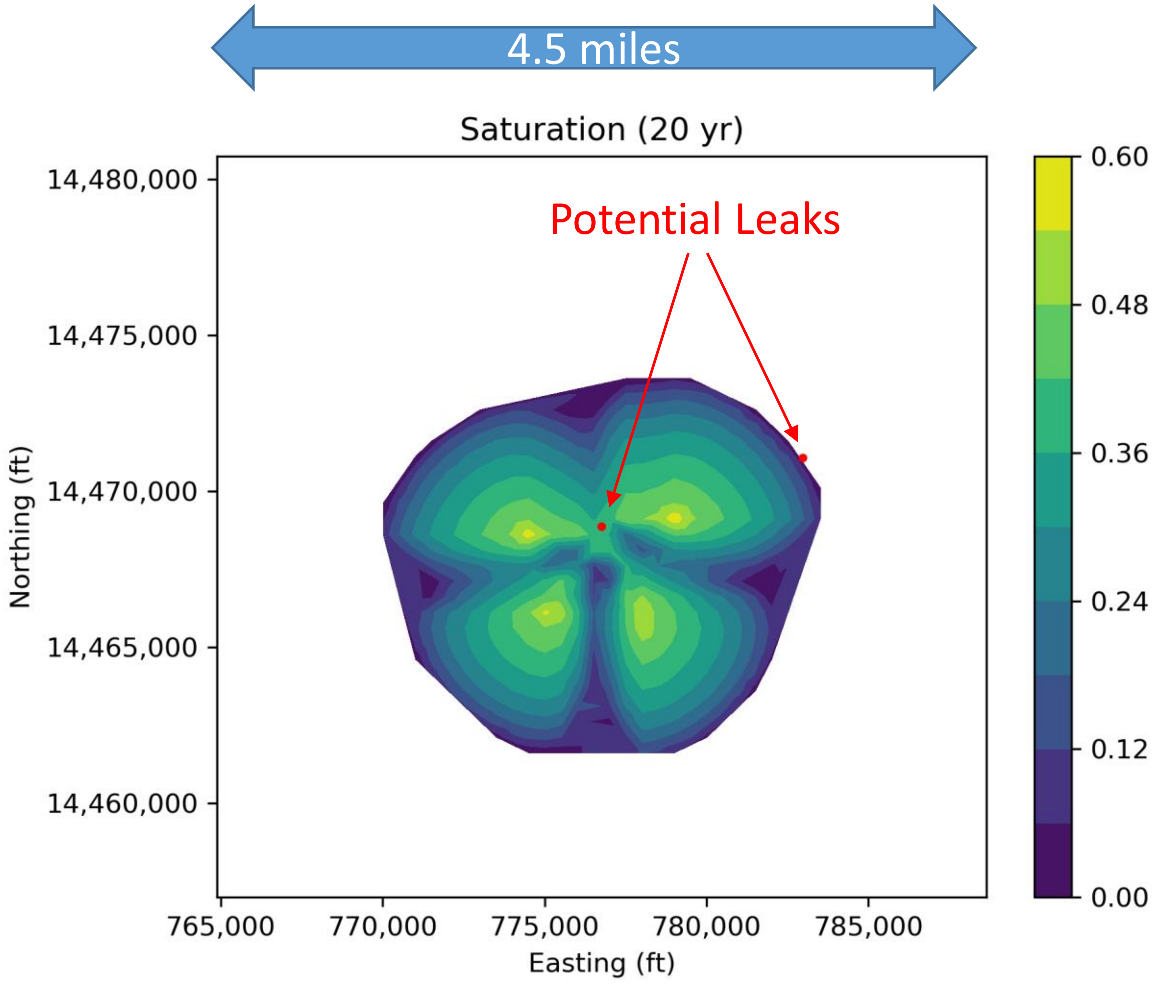
Detection Thresholds

	Analytical Detection Range and Precision*		
Parameter	**Min**	**Max**	**Precision +/-**
Pressure, psi	0	2500	0.065%
Temperature, F	0	150	0.03%
DIC, mg/L	0.2	--	20%
pH	2	12	0.2
TDS, mg/L	10	--	10%

*From UIC Permit application, Attachment C, Tables A.5 & A.7

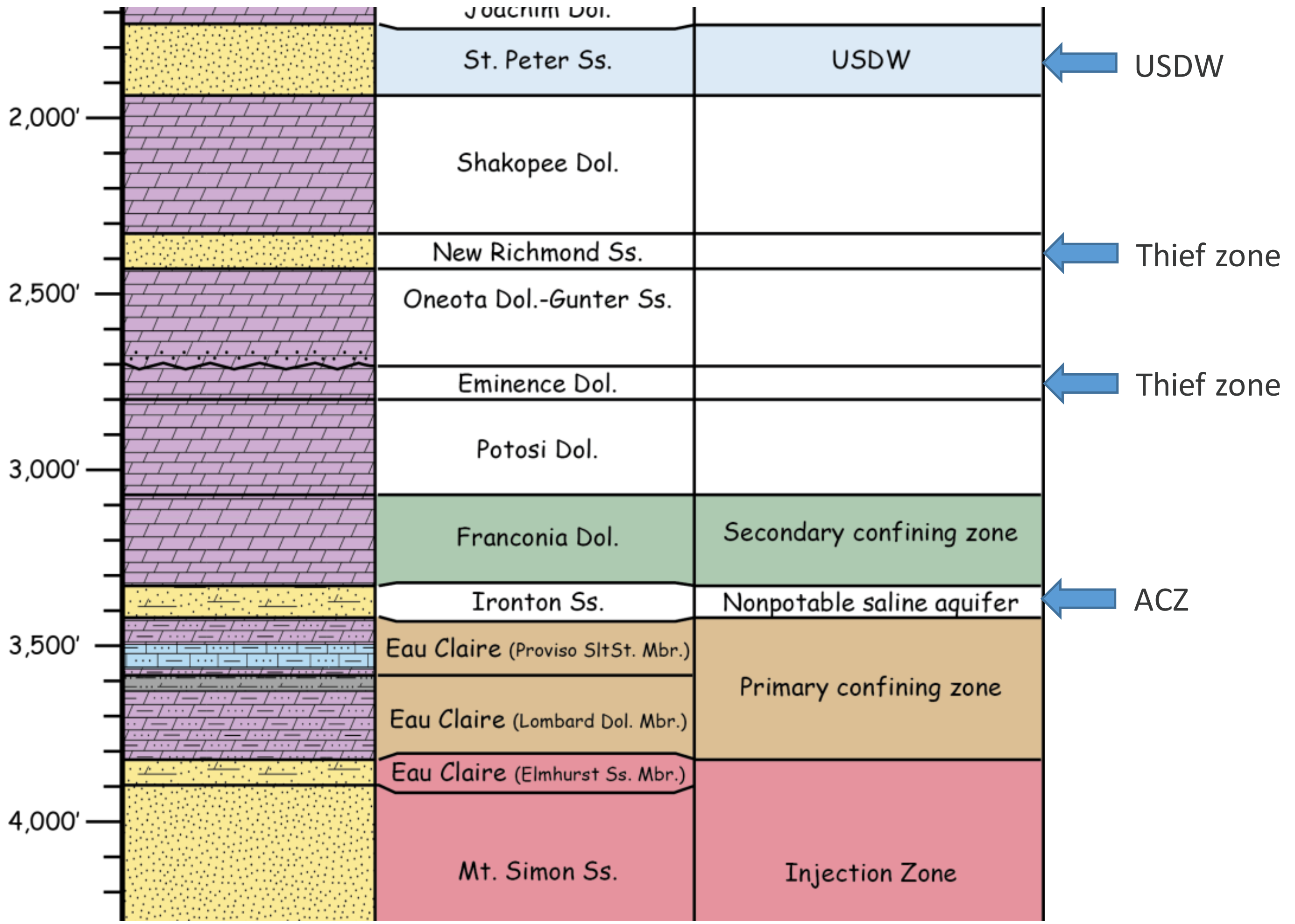
Identify Potential Leakage Paths within AoR





Risk-based Monitoring Design

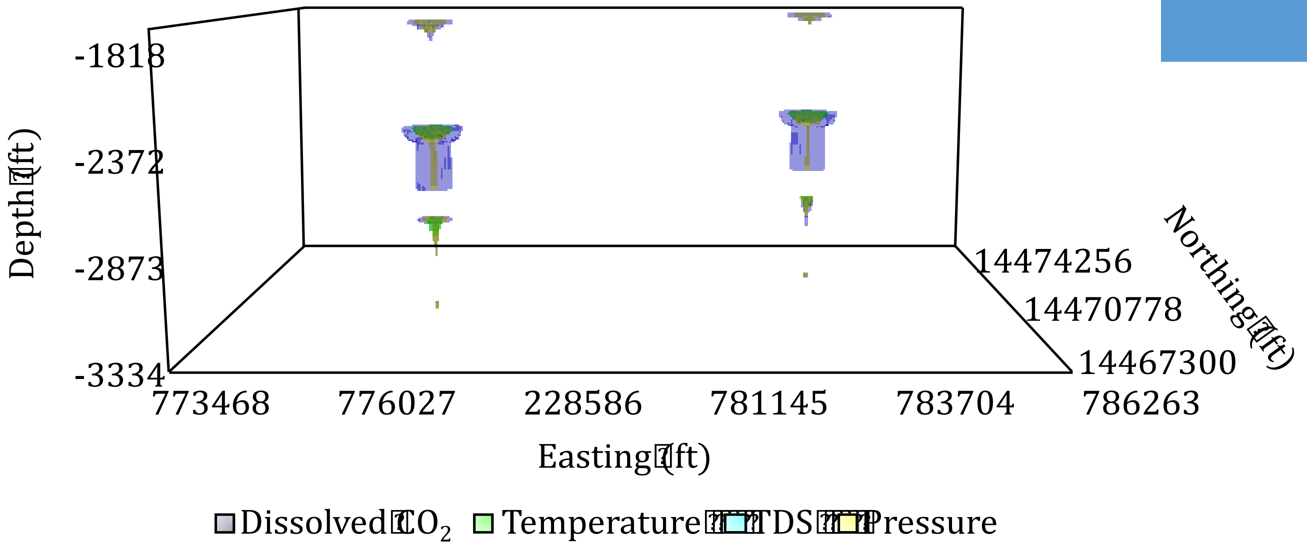
- Several potential leakage paths, which is optimal monitoring location for earliest detection?
- Assume wellbore permeability distribution based on observed values for legacy wells



Monitoring Design

Summary & Conclusions

- Original monitoring plan: 2 ACZ wells and 1 USDW
- DREAM optimized monitoring plan: 2 ACZ wells

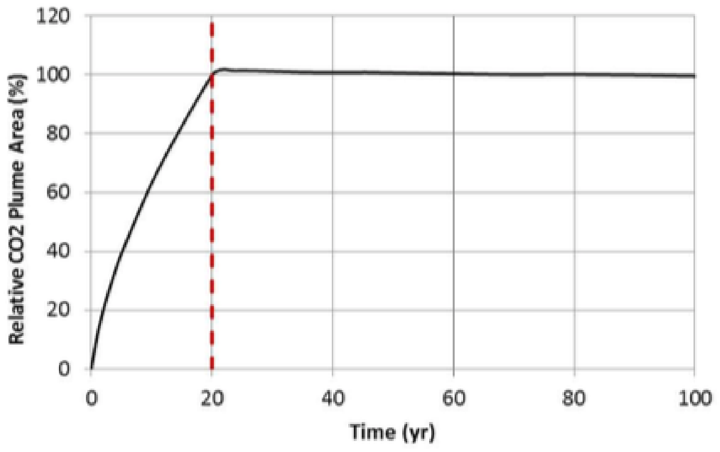


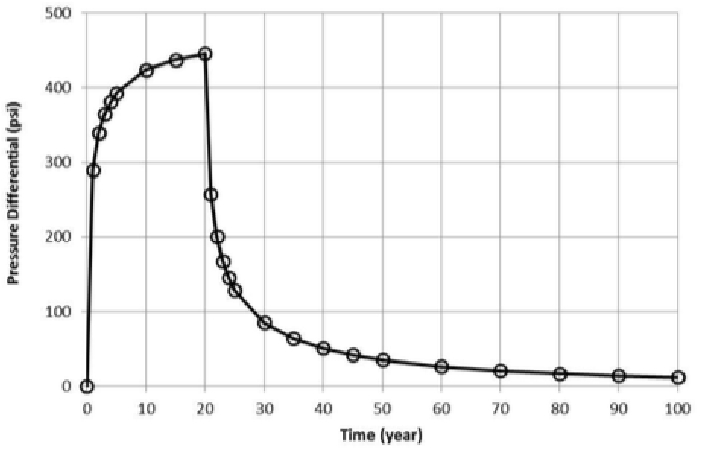
Monitoring Unit	Injection Well	Stratigraphic Well
	TTD (y)	TTD (y)
St. Peter	4.9	16.7
New Richmond	3.9	15.7
Potosi	2.9	14.7
Ironton	1.6	12.6

- Over $10M in avoided costs for installation, sampling, and decommissioning of the third well
- Potential leaks much smaller in USDW than thief zones

Opportunity to demonstrate performance-based PISC

- **As a first-of-its-kind project, U.S. EPA recommended the use of the default 50-year PISC period for the UIC Class VI permit application**
- **To close a site the Class VI regulations require demonstration of non-endangerment**
- **FG 2.0 did not take credit for projected reservoir performance in determining a PISC period**
  - CO_2 plume projected to stabilize 2 years after injection stops
  - Reservoir pressure projected to decline rapidly post-injection

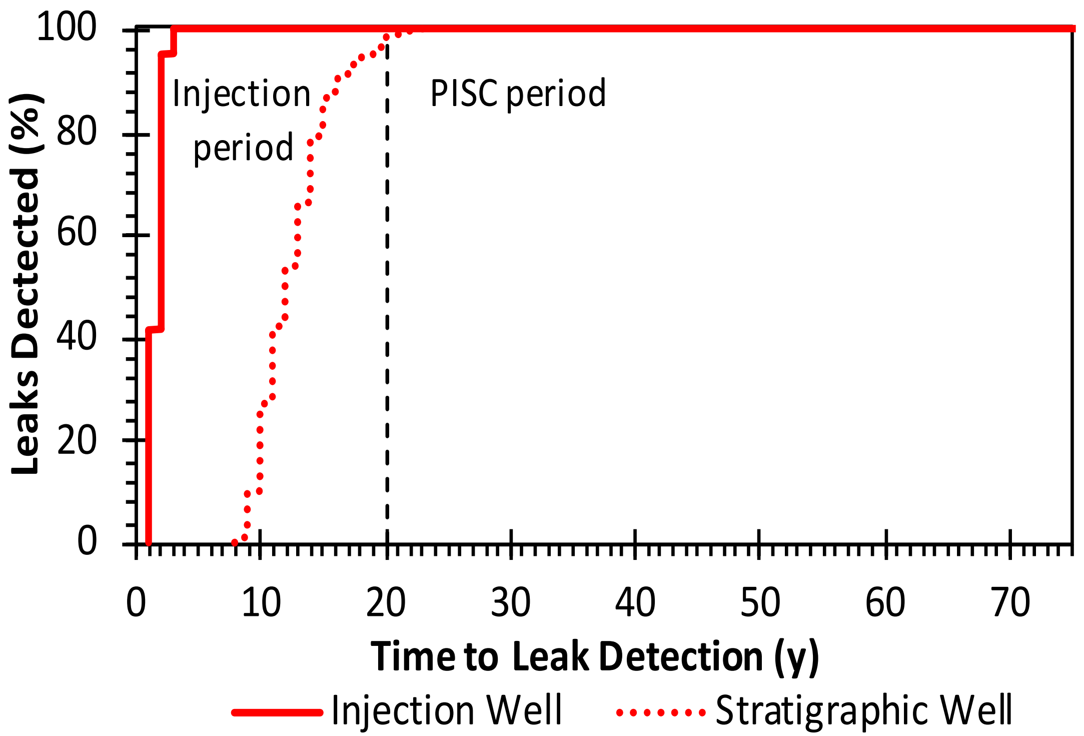




PISC Period

Summary & Conclusions

- **NRAP-Open-IAM realizations indicate that the majority of risk of endangerment to USDWs occurs during injection period**
- **A 10 year PISC period would still lead to a net PISC period reduction of 40-years and an operational cost reduction in excess of $50M for the project**



Summary

Application of NRAP-Open-IAM and DREAM to FutureGen 2.0

- Risk-based Area of Review calculated using NRAP-Open-IAM based on potential aquifer impacts
- Risk-based monitoring design using DREAM resulted in simpler monitoring well design
- NRAP-Open-IAM can be used to define a risk-based, and substantially shorter, PISC period for the site

Acknowledgements

NRAP Phase I Groundwater Group

- **PNNL**
  - Diana Bacon
  - Chris Brown
  - Inci Demirkanli
  - George Last
  - Amanda Lawter
  - Chris Murray
  - Nik Qafoku
- **LLNL**
  - Susan Carroll
  - Kayyum Mansoor
  - Yunwei Sun
  - Hari Viswanathan
- **LANL**
  - Elizabeth Keating
  - Zhenxue Dai
  - Dylan Harp
- **LBNL**
  - Liange Zheng
  - Marco Bianchi
- **NETL**
  - Ale Hakala
- **West Virginia University**
  - Maneesh Sharma

NRAP Phase II IAM Developers

- **NETL**
  - Veronika Vasylskiva
  - Greg Lackey
  - Ernest Lindenmeyer
- **LANL**
  - Dylan Harp
- **LLNL**
  - Kayyum Mansoor
- **LANL**
  - Dylan Harp
- **LBNL**
  - Yinqi Zhang
- **PNNL**
  - Diana Bacon

DREAM Developers

- **PNNL**
  - Catherine Yonkofski
  - Jonathan Whiting
  - Jason Gastelum

Bibliography

Application of NRAP Tools to FutureGen 2.0

- 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.