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
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

Reservoir Simulations

Reservoir Component (Lookup Table)
Pressures and saturations from single reservoir model layer

Open Wellbore Component (Lookup Table)
Calculates CO₂ and brine leakage rates for an open wellbore using the drift-flux approach

Aquifer Component (ROM)
Predicts size of "impact plumes" based on selected water quality metrics

Risk-based AoR
Defines area where groundwater concentrations may exceed no-impact threshold

Identify legacy wells within AoR

Reservoir Component (Lookup Table)
Pressures and saturations from single reservoir model layer

Multisegmented Wellbore Component (ROM)
Calculates CO₂ and brine leakage rates for a multisegmented wellbore using an analytical solution

Aquifer Component (ROM)
Predicts size of "impact plumes" based on selected water quality metrics

Time-to-Detection
Maps earliest time where groundwater concentrations may exceed no-impact threshold

Risk-based Monitoring Design (DREAM)
Optimizes monitoring locations based on hypothetical leakage scenarios

NRAP-Open-IAM
NRAP-Open-IAM
Area of Review (AoR) for CO₂ 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 CO₂ injection permit to determine the AoR based on the separate-phase CO₂ plume/pressure evolution predictions from physics-based computational modeling

- AoR is delineated by the maximum extent of CO₂ plume and pressure front over the lifetime of the project to account for risks associated with both CO₂ 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)
  \[ \Delta P_c = \frac{1}{2} \cdot g \cdot \xi \cdot (z_u - z_i)^2 \]
  \[ \xi = \frac{\rho_i - \rho_u}{z_u - z_i} \]
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

\[
P > P_{\text{initial}}
\]
\[
\text{Aquifer impact} = 0
\]

\[
P > P_{\text{initial}}
\]
\[
\text{Aquifer impact} \neq 0
\]

Threshold pressure = \(P - P_{\text{initial}}\)
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 CO₂ 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

• 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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Max</th>
<th>Precision +/-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure, psi</td>
<td>0</td>
<td>2500</td>
<td>0.065%</td>
</tr>
<tr>
<td>Temperature, F</td>
<td>0</td>
<td>150</td>
<td>0.03%</td>
</tr>
<tr>
<td>DIC, mg/L</td>
<td>0.2</td>
<td>--</td>
<td>20%</td>
</tr>
<tr>
<td>pH</td>
<td>2</td>
<td>12</td>
<td>0.2</td>
</tr>
<tr>
<td>TDS, mg/L</td>
<td>10</td>
<td>--</td>
<td>10%</td>
</tr>
</tbody>
</table>

*From UIC Permit application, Attachment C, Tables A.5 & A.7
Identify Potential Leakage Paths within AoR

Pressure Differential (20 yr)

Saturation (20 yr)
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

<table>
<thead>
<tr>
<th>Monitoring Unit</th>
<th>Injection Well</th>
<th>Stratigraphic Well</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TTD (y)</td>
<td>TTD (y)</td>
</tr>
<tr>
<td>St. Peter</td>
<td>4.9</td>
<td>16.7</td>
</tr>
<tr>
<td>New Richmond</td>
<td>3.9</td>
<td>15.7</td>
</tr>
<tr>
<td>Potosi</td>
<td>2.9</td>
<td>14.7</td>
</tr>
<tr>
<td>Ironton</td>
<td>1.6</td>
<td>12.6</td>
</tr>
</tbody>
</table>

• 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
  - CO₂ plume projected to stabilize 2 years after injection stops
  - Reservoir pressure projected to decline rapidly post-injection
• 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

- LBNL
  - Yinqi Zhang

- PNNL
  - Diana Bacon

DREAM Developers

- PNNL
  - Catherine Yonkofski
  - Jonathan Whiting
  - Jason Gastelum