Environmental Monitoring Over CO$_2$ Geologic Storage Sites

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GCCC Environmental Monitoring Experience

- SWP SACROC Field
- SECARB Cranfield
- Hastings
- NRG-Petra-Nova/West Ranch
- PI of the IPAC-CO$_2$ Kerr Leakage Claim, Canada
- ZERT Controlled release
- Brackenridge Controlled Release Field lab
- Inform policy within UNFCCC, US Congress
Environmental Monitoring

Presentation Outline

• Overview
• Objectives and components
• Challenges/opportunities for improvement
  – Source attribution of anomalies
  – Baseline comparisons
  – Public engagement
• Example: Kerr Claim
• Transition from concentration-based to Process-based monitoring
• Summary
Overview of Monitoring Zones

"Near-Surface" Monitoring

- Strong variability, dynamic, many challenges, release to atmosphere, biosphere impacts
- Moderate baseline variability, assurance of no damage to drinking water, easy access

"Deep" Monitoring

- Minimal variability, early detection, small signals
- Static, quiet environment, variability is from CO₂ injection, CO₂/brine migration

Figure courtesy of Sue Hovorka
Why Monitor in the Near-Surface?

- Accessible and inexpensive
- Direct observation of environmental resources
  - Groundwater
  - Soil Biosphere
- Regulation & permitting
- Quantification and accounting
- Monitoring remediation efforts
- Fast and targeted response to public concerns
Environmental Monitoring Challenges

• CO$_2$ is naturally everywhere!
• Reactive
• Dynamic over space and time
  • Biologic respiration
    – Weather/Climate
  • Soil conditions
• Land Use (industrial activity, agriculture, groundwater extraction etc.)
• Very difficult to discern leakage from natural variability.
• Critical to understand processes.

Source: DOE, 1999: Carbon Sequestration Research and Development
Components of Near-Surface Monitoring

✓ Locate anomaly
✓ Attribute source
✓ Quantify emissions
✓ Engage stakeholders
Balanced Approach to Locating Anomalies

• Sampling Grids
  – Dense grid of point measurements
  – Expensive and time consuming.
  – Doesn’t cover full area

• Targeted
  – Based on risk assessment,
  – Environmental change
  – Public concern

• Remote Wide-Area Sensing
  – Excellent spatial coverage
  – Interferences/vegetation/wind
IEAGHG Interactive Monitoring Selection Tool

- Description of tool
- Maturity of the technique
- Cost of deployment.
- Case studies
- Bibliography
Determining What is “Anomalous”

- What constitutes an “anomaly (e.g. a potential leakage signal)?
- What parameter should be used to indicate leakage?
- When is action required (e.g. thresholds, trigger points) ?
  - “When measurements of a given parameter exceed natural variability by one standard deviation about the mean”
Current Thinking on “Natural Variability”

- Measure “baseline” CO$_2$ for 1-3 years before project starts to document seasonal variability.
- Monitor CO$_2$ during project and compare to baseline.
- Significant increase from baseline during a project could signal a leak.
What about a “Background Reference” site?

Statistical distribution of soil gas CO$_2$ (sampled in October 2011) at sites within the WMP (Beaubien et al., 2014). The background area (Minard’s Farm) and the Kerr Farm (where leakage was alleged but disproven) are shown along with 5 other sites within the WMP.

Weyburn field soil gas monitoring
Beaubien et al., 2013
“Baselines” are Shifting!

RS = the flux of microbially and plant-respired CO₂ from the soil surface to the atmosphere,

Increased dissolution of CO₂ in groundwater and associated mineral dissolution

RS = \( \text{the flux of microbially and plant-respired CO}_2 \) from the soil surface to the atmosphere,

Increased dissolution of CO₂ in groundwater and associated mineral dissolution
...and at our Monitoring Sites

Background \( CO_2 \) concentrations at Cranfield over 6 years (all depths)
Source Attribution is Critical

- BEG’s experience in attribution: 2 blind anomalies: Cranfield anomaly and Kerr Claim
  - Very difficult
  - The risk of false positives is much greater than the risk of leakage.
  - Fast accurate attribution is CRITICAL for public acceptance

Dixon and Romanak, 2015, Improving monitoring protocols for CO₂ geological storage with technical advances in CO₂ attribution monitoring, IJGGC vol 41
Table 1
Summary of the six main monitoring activities for the CCS regulations discussed in the text.

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<td>GHG accounting</td>
<td>Protection of the environment</td>
<td>Protection of the marine environment</td>
<td>Protection of the marine environment</td>
<td>GHG accounting and protection of the environment</td>
<td>Protection of the environment (underground sources of drinking water)</td>
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<td>Only in terms of pressure and plume extent</td>
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</tr>
</tbody>
</table>

Dixon and Romanak, 2015, Improving monitoring protocols for CO₂ geological storage with technical advances in CO₂ attribution monitoring, IJGGC vol 41
News of a “Leak” at the Kerr Farm Weyburn Field: January 2011

Land fizzing like soda pop: farmer says CO2 injected underground is leaking

By: Rob Weiker and Jennifer Graham, The Canadian Press
Posted: 01/11/2011 10:22 AM | Comments: 9 •
Alleged Land Disturbances
IEAGHG Weyburn-Midale CO₂ Monitoring and Storage Project

- Largest geologic CO₂ monitoring and storage project
- Since 2000 > 24 M tonnes of CO₂ injected
- CO₂-EOR operated by Cenovus Energy
- Studied by an international team of CO₂ storage experts
- Managed by Petroleum Technology Research Centre (PTRC)


www.PTRC.ca
Industry and Government Response

• **1998**: (Operator) Weyburn Pump and Water Conditioning, groundwater test report
• **2002 – 2005**: (Operator) Farm well Inventory Project, regional groundwater analysis
• **2004**: (Operator) KBL Land Use Consulting Ltd., gravel pit water and soil samples
• **2005**: (Operator) Enviro-Test Analytical soil sample
• **2005**: (Government) Saskatchewan Health Provincial Laboratory, gravel pit and domestic well water
• **2006**: (Operator) Aqua Terre Solutions Inc., well and gravel pit water test
• **2006**: (Landowner) MR2 McDonald & Associates, water quality investigation
• **2007**: (Landowner) Consultation with Dr. Malcolm Wilson, Office of Energy & Environment, University of Regina
• **2008**: (Government) Ministry of Environment – Review of studies
• **2008**: (Government) SRC Analytical Laboratories, soil, water and air quality monitoring
• **2008**: (Government) Droycon Bioconcepts Inc., Bacteriological content of water
• **2010-2011**: (Landowner) Petro-Find Geochem Ltd., Soil gas surveys.
Petro-Find Conclusion

“...source of the high concentrations of CO$_2$ in soils of the Kerr property is clearly the anthropogenic CO$_2$ injected into the Weyburn reservoir.”

How To Avoid This?

• High risk of false positives from inaccurate attribution.
• Need protocols and techniques in place before a project begins.
  – Methods,
  – Parameters
  – Trigger points
• Need quick response tools and protocols that do not rely on “background” measurements.
Process-Based Soil Gas Ratios

- Uses simple gas relationships to identify processes.
  - Biologic respiration
  - Methane oxidation
  - Dissolution
  - Leakage
- No need for years of background.
- Method can be applied in any environment regardless of variability

“In a media release, Ecojustice lawyer Barry Robinson, who represented the Kerrs, accepted the IPAC-CO2 study’s findings while emphasizing its necessity, saying that “without a full scale investigation, it has been impossible until now to rule out CO₂ contamination.”

Romanak et al., 2014, Process-based soil gas leakage assessment at the Kerr Farm: Comparison of results to leakage proxies at ZERT and Mt. Etna, IJGGC vol 30
Ramifications for Monitoring

ZERT Controlled Release Experiment, Montana USA

Respiration relationship = “Baseline” or “threshold”
“User-Friendly” for Public Engagement

- Instant data reduction
- Reduces risk of false positives.
- Graphical analysis
- Continuous monitoring capability will give instant real-time leakage detection information.

Katherine Romanak BEG
Translating Ratios into Surface Flux

\[ EF_i = \frac{(C_i)(Q)}{A} \]

\( EF_i = \) emission rate of species i in \( \text{ug/m}^2\text{min} \)

\( C_i = \) measured concentration of species i in vol% converted to \( \text{ug/m}^3 \)

\( Q = \) sweep air flow rate in \( \text{m}^3/\text{min} \)

\( A = \) exposed surface area in \( \text{m}^2 \)
Summary and Recommendations

- Environmental variability is a significant challenge for environmental monitoring.
- Most protocols call for the use of baseline values to determine if variability is from leakage or natural variation.
- Baselines are shifting due to climate change and will not provide accurate “attribution” of anomalies.
- Recognizing the importance of “attribution” is critical to environmental monitoring but most protocols and regulations do not include attribution as a monitoring step.
- Attribution should precede quantification.
- The Kerr claim shows a great need for accurate methods and protocols for attribution to be in place before a project begins.
- The risk of a false leakage claim due to inaccurate attribution is likely higher than the risk of actual leakage.
- A process-based type of approach may give more accurate, immediate, and stakeholder-friendly monitoring results and may be useful for quantification and remediation monitoring.
Thank You

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Isotopic Signature

Background CO$_2$ range (terrestrial)

Data Sources
Andres et al., 1994
Redondo and Yelamos, 2005
Whiticar, 1999

$\delta^{13}$C not always definitive
Groundwater Monitoring Network Efficiency

- For Cranfield case: 1 well/km needed to detect a leak within >20 years of release.
- Monitoring network efficiency depends on regional hydraulic gradient, leakage rate, flow direction, and aquifer heterogeneity.

Yang et al., 2015, *Environmental Science & Technology* 49, 14

Unit: wells/km²

- MN1: 0.322
- MN2: 0.124
- MN3: 0.173
- MN4: 0.223
- MN5: 0.223
- MN6: 0.371
- MN7: 0.371
- MN8: 0.866
- MN9: 0.742
Process-Based Example

- Uses geochemical relationships to identify key processes rather than concentration comparisons