Ensuring CO_2 Storage and Groundwater Protection Through Water Monitoring: Applying Geochemical and Statistical Tools

James Gardiner
Research Scientist
Research & Innovation Center

Conference on Innovations in Climate Resilience

March 29-30, 2022

Disclaimer

This project was funded by the U.S. Department of Energy, National Energy Technology Laboratory an agency of the United States Government, through a support contract. Neither the United States Government nor any agency thereof, nor any of its employees, nor the support contractor, nor any of their employees, makes any warranty, express 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.

Authors

James Gardiner[1,2], Wei Xiong[1,2], Jiaan Wang[3], Mitchell Small[3], Brian Stewart[4], Rosemary Capo[4], Brandon McAdams[1,2], J. Alexandra Hakala[1], R. Burt Thomas[5]

[1] National Energy Technology Laboratory, Pittsburgh, PA 15236

[2] NETL Support Contractor, Pittsburgh, PA 15236

[3] Carnegie Mellon University, Pittsburgh, PA 15213

[4] University of Pittsburgh, Pittsburgh, PA 15260

[5] National Energy Technology Laboratory, Albany, OR 97321

Carbon Sequestration

NATIONAL ENERGY TECHNOLOGY LABORATORY

Importance of Monitoring

- Ensures CO_2 storage
- Protects valuable assets
- Provides assurance to community

Geochemical Monitoring for MVA

- Utilizes existing infrastructure
- Employs developed tools
- Provides source attribution

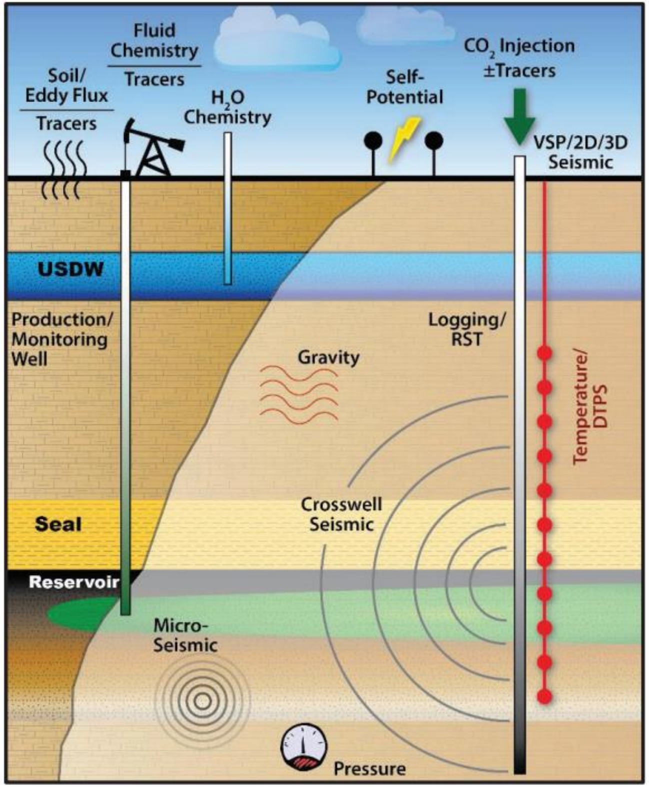
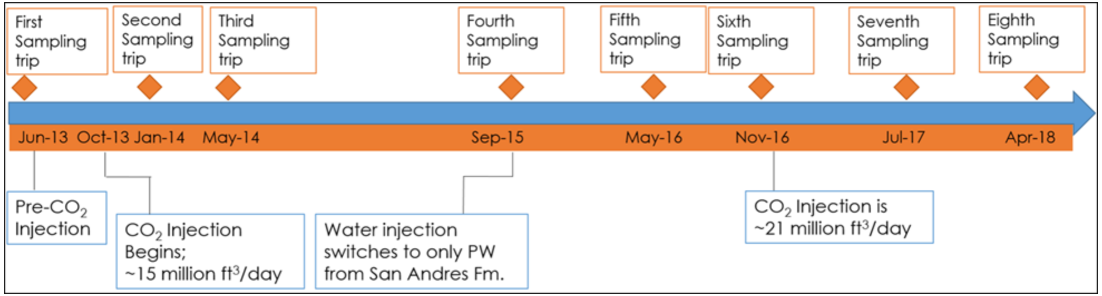
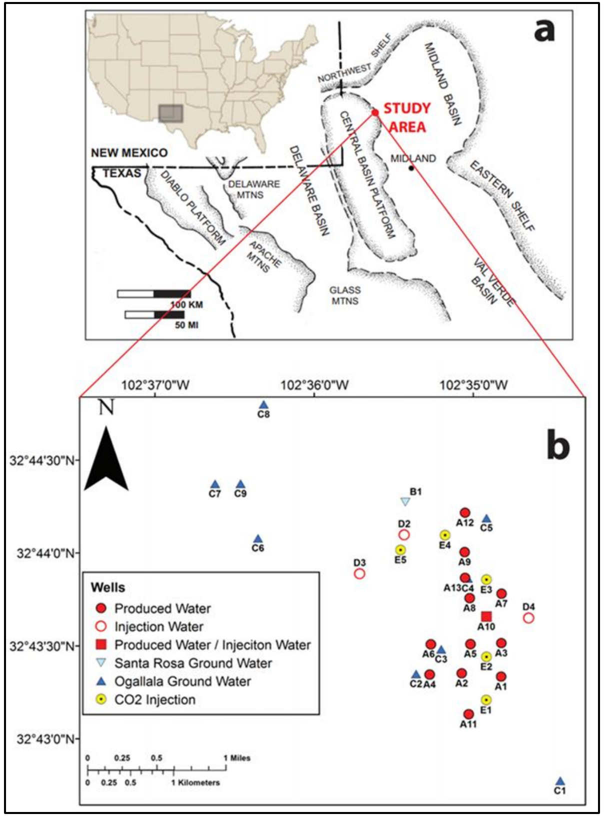


Figure from Balch et al., 2017

Field Area

- **CO_2 EOR as an analog**
- **Sampled oil field in Permian Basin, West Texas**
  - June 2013 to April 2018
    - Eight field sampling events
  - CO_2 EOR: October 2013
    - One pre-CO_2 injection event

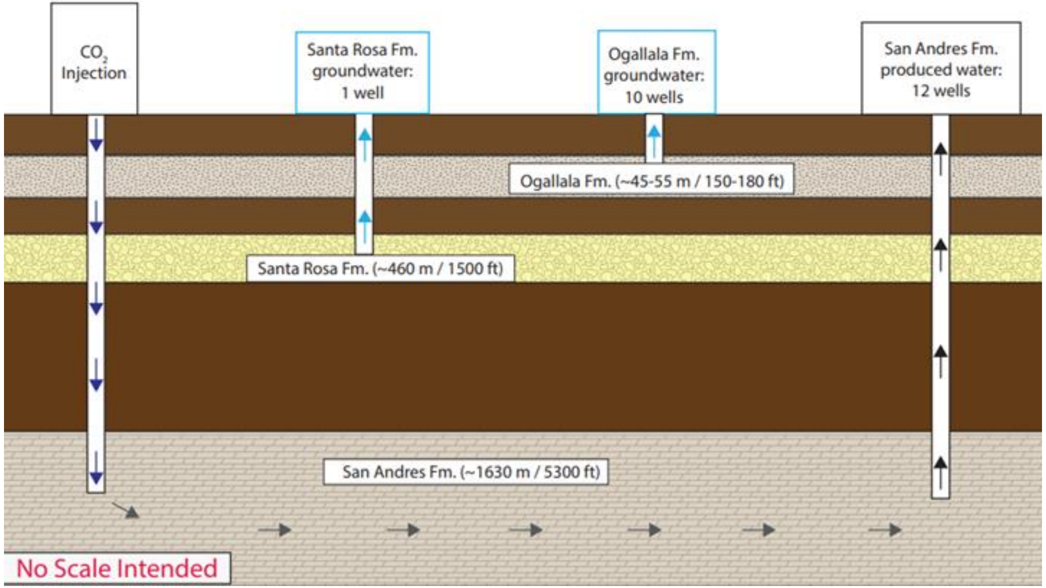




Field Area

Samples

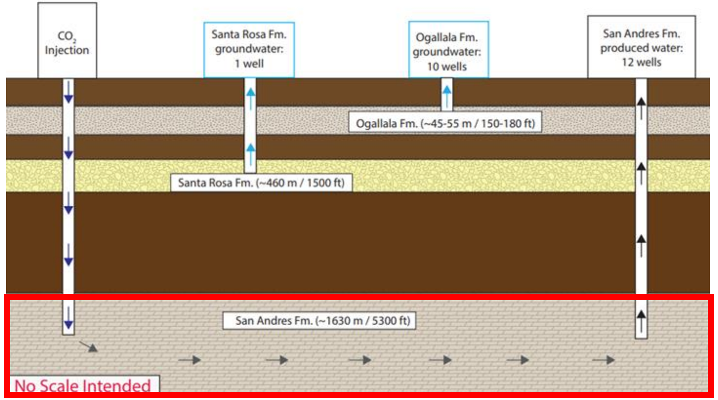
- Ogallala Fm. groundwater
- Santa Rosa Fm. groundwater
- San Andres Fm. produced water

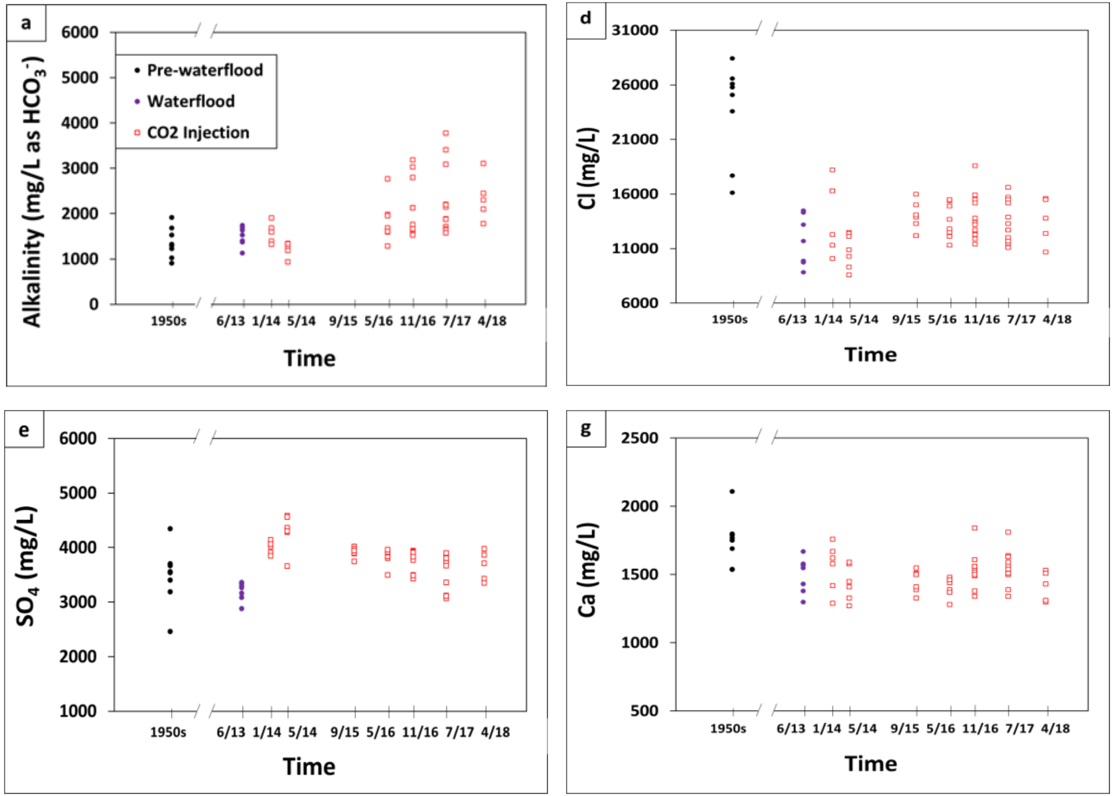


- **Developed analytical process for fossil fuel wastewaters**
  - **Miller et al., 2022**

Results: Producing Formation

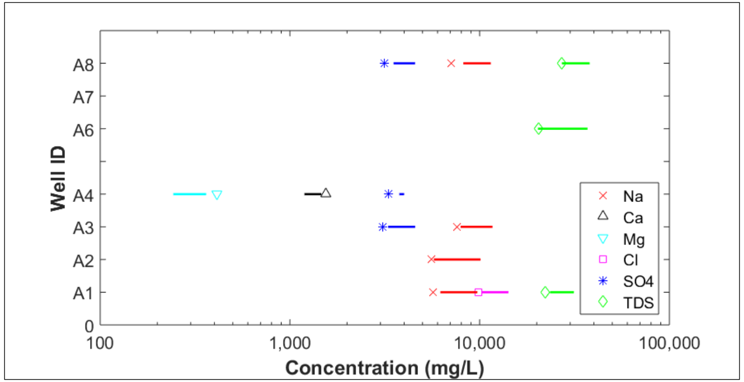
- **Focus on alkalinity and dissolved inorganics**
- **Following CO_2 Injection**
  - Increases in certain parameters
  - Statistical significance

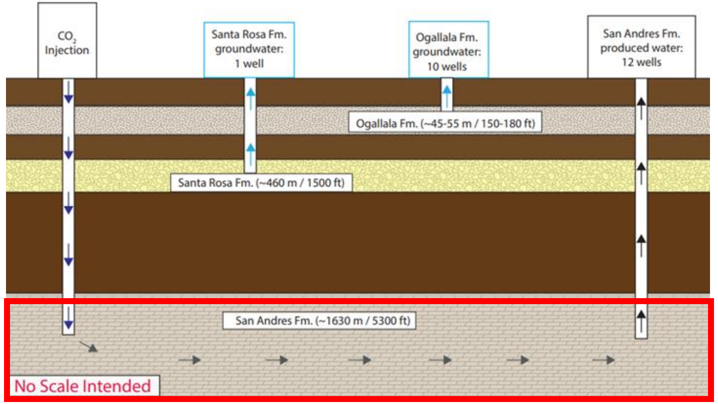




Results: Producing Formation

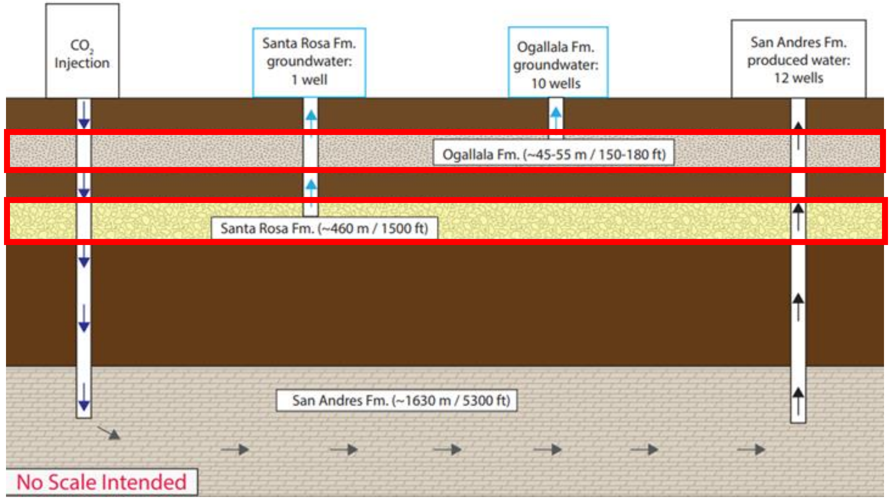
- **Statistical analysis**
  - Generated prediction intervals
  - Significant change: alkalinity, TDS, Na^+, Cl^-, and SO_4^{2-}
- **Interpretation**
  - CO_2 injection caused significant changes in produced water parameters
  - However, CO_2 injection did not result in significant carbonate dissolution
  - Therefore, reservoir integrity was preserved during injection

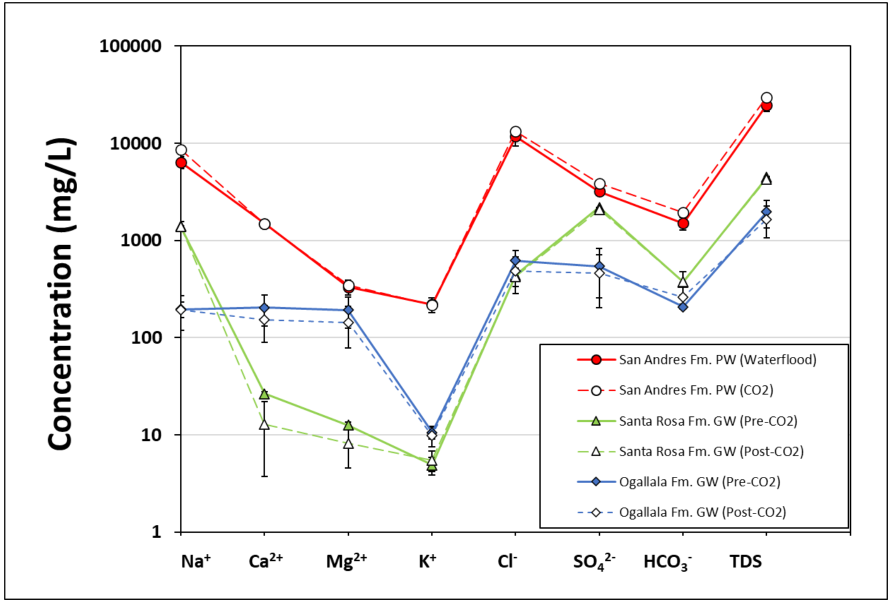




Results: Groundwaters

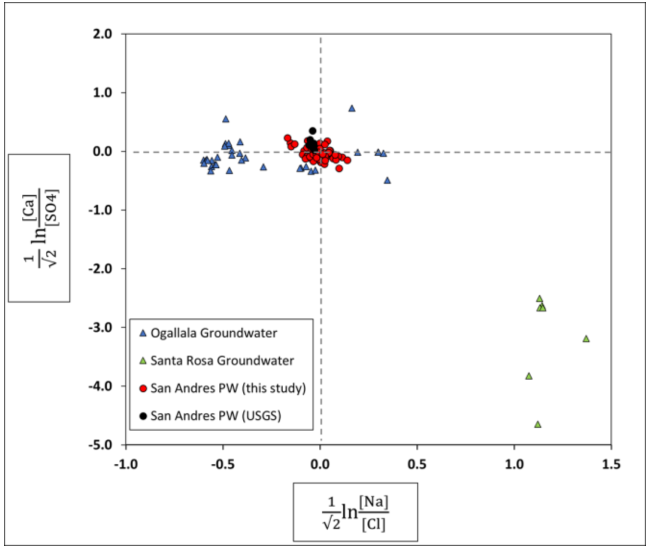
- **Ogallala and Santa Rosa Fm. groundwaters**
  - Did not see significant change following CO_2 injection

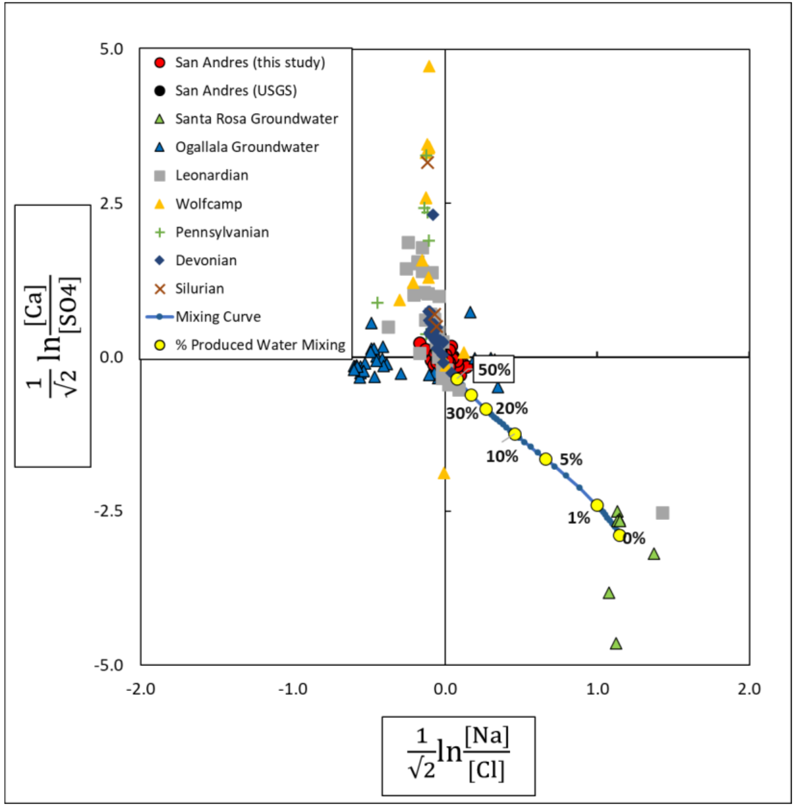




Results: Groundwaters

- **Ogallala and Santa Rosa Fm. groundwaters**
  - **Generated hypothetical mixing curve**
    - Scenario: produced water migration into Santa Rosa Fm.



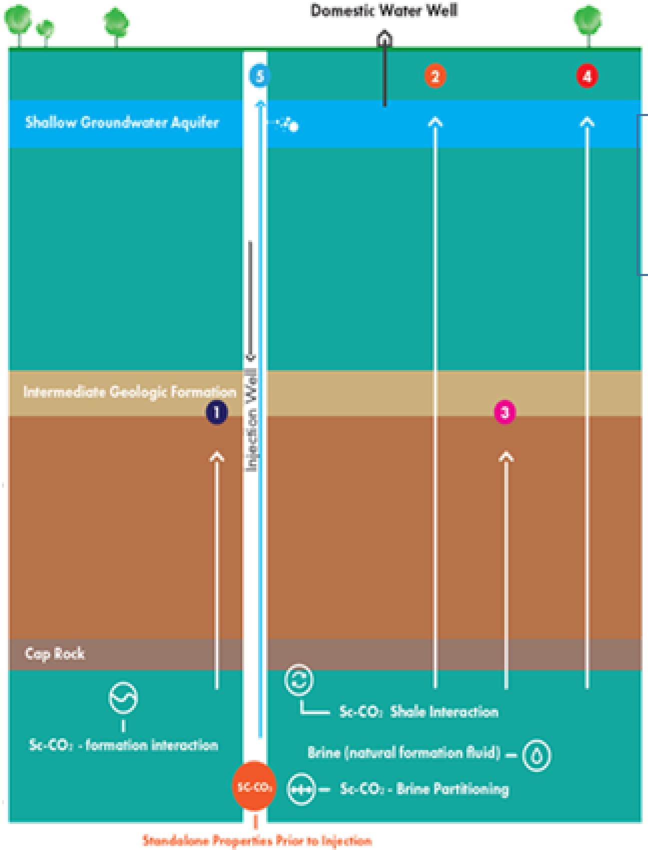


Application of Field Results: GILD

- **Problem definition**
  - Need for a low-cost, easily implementable monitoring strategy for carbon storage reservoir leak detection

- **Proposed solution**
  - Geochemically Informed Leak Detection (GILD)

GEOCHEMICALLY INFORMED · LEAK DETECTION ·
GILD



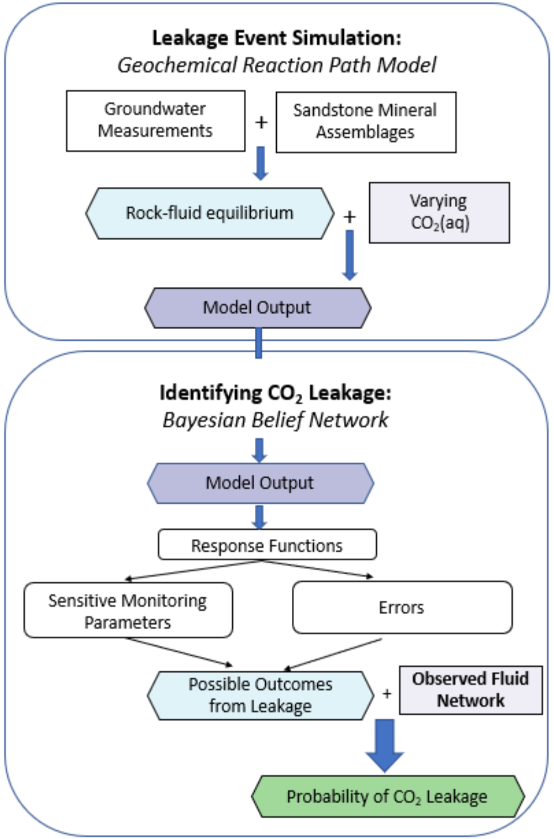
Leakage Pathways

1. Wellbore to intermediate formation
2. Wellbore to shallow groundwater
3. Geologic conduit to intermediate formation
4. Geologic conduit to shallow groundwater
5. Well to shallow aquifer

GILD Overview

Geochemically Informed Leak Detection (GILD)

1) Assess fluid chemistry and mineral compositions of monitoring formation
2) Simulate leakage events with a geochemical reaction path model
3) Identify CO_2 leakage with a Bayesian Belief Network (BBN)



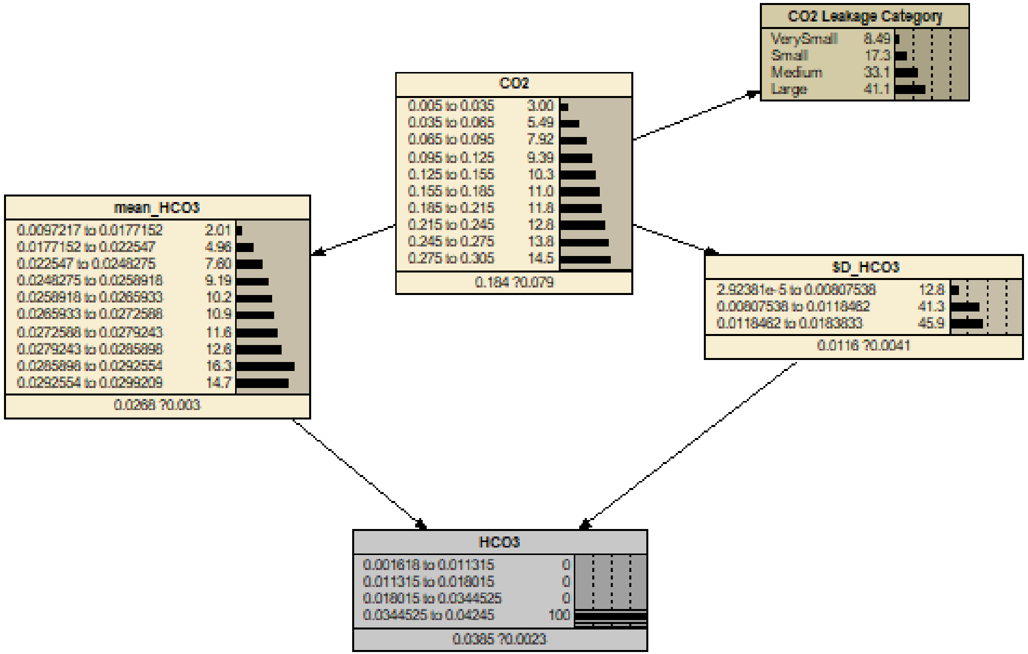
Bayesian Belief Network (BBN)

- Decision support tool
- Probabilistic inference from multiple sources of evidence
- Application for leak detection: given monitoring parameters, compute the probabilities of the presence of leakage

Bayesian Belief Network (BBN) for Leak Detection

NATIONAL ENERGY TECHNOLOGY LABORATORY

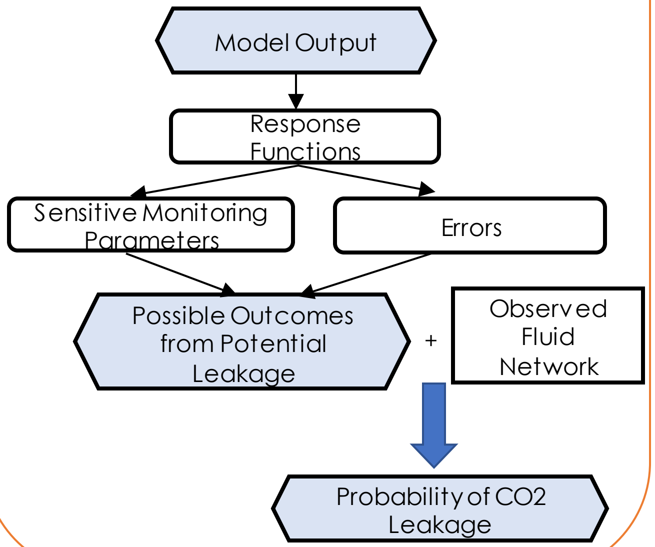
- **Upstream node**
  - CO_2 added concentration
- **Arrows**
  - Causal effect
- **Downstream nodes**
  - Monitoring parameters
- **Bars of each node**
  - Probability of a particular range
- **Conditional probability**
  - Probability of downstream given upstream
- **Purpose**
  - Back inference



BBN Setup for Leak Detection

- **Observation parameters**
  - Inorganic geochemistry
    - Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, SO_4^{2-}, Br^-, alkalinity as mg/L HCO_3^-
- **Analytical techniques**
  - Fit response functions
  - Identify sensitive parameters
  - Include uncertainty
  - Predict possible outcomes from potential leakage
  - Compare with observed fluid network
  - Compute probability of CO_2 leakage

Identifying CO_2 Leakage: Bayesian Belief Network



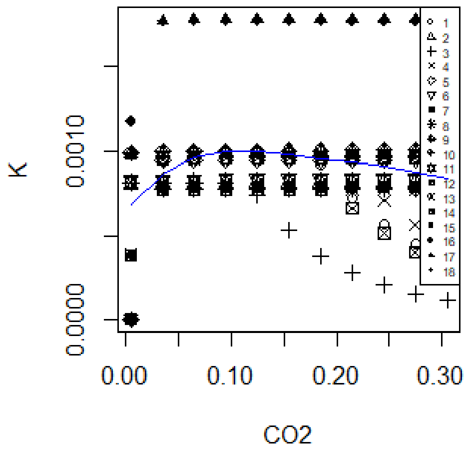
Construction of BBN-Response Functions & Sensitive Parameters

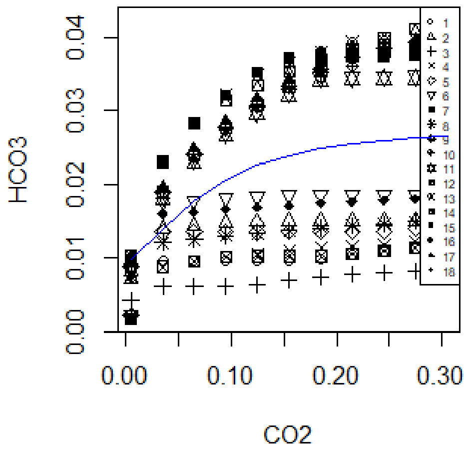
NATIONAL ENERGY TECHNOLOGY LABORATORY

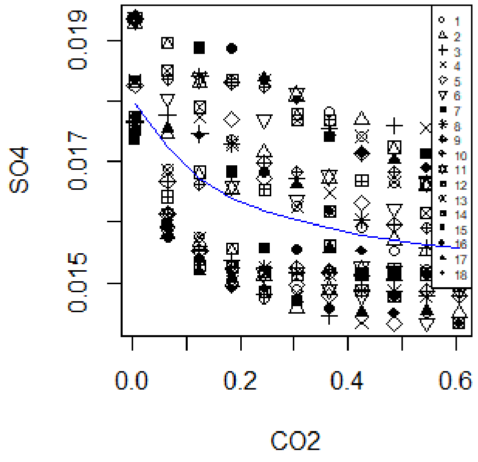
- **Response functions**
  - Output of the geochemical model
  - Relationship of ion concentrations (mol/kg) and CO_2 added concentrations (mol/kg)

→

- **Sensitive Parameters**
  - Selection Criterion
    - Monotonic relationship

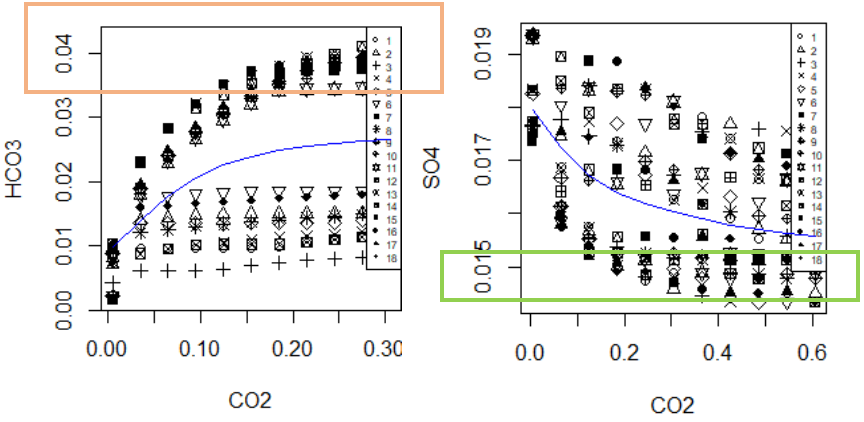


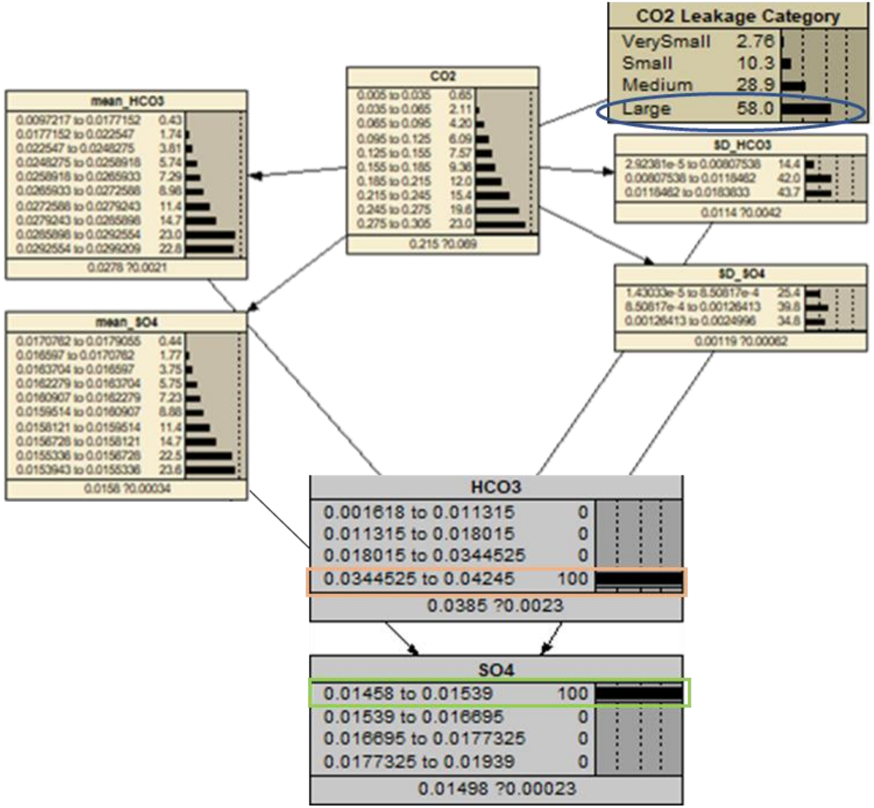




Application of BBN-Combining Evidence

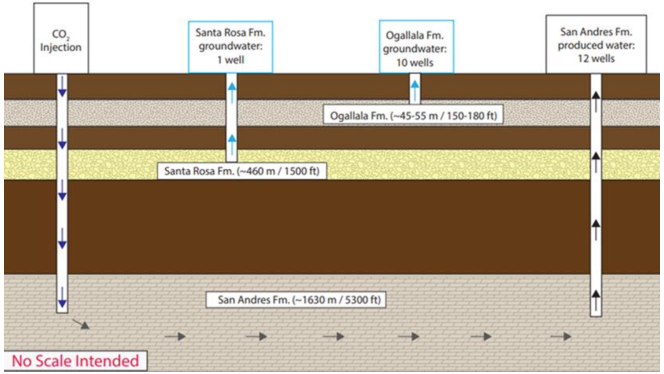
- Evidence from high HCO_3 and low SO_4

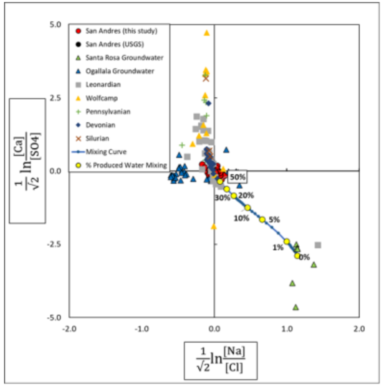




Conclusions

- **Geochemical monitoring provides insight into groundwaters and target formation reactions**
  - No significant dissolution of storage reservoir
  - No produced water migration detected in groundwaters
- **Geochemical-statistical model (GILD) can provide CO_2 leakage detection via robust statistical analysis**
  - Current model applies user input via licensed software and researcher knowledge
  - Goal is to create standalone version that groundwater observers can use





Publications & References

References

- Balch, R., McPherson, B. and Grigg, R., 2017. Overview of a large scale carbon capture, utilization, and storage demonstration project in an active oil field in Texas, USA. Energy Procedia, 114, pp.5874-5887.

Publications from this Field Work

- Pfister, S., Capo, R.C., Stewart, B.W., Macpherson, G.L., Phan, T.T., Gardiner, J.B., Diehl, J.R., Lopano, C.L. and Hakala, J.A., 2017. Geochemical and lithium isotope tracking of dissolved solid sources in Permian Basin carbonate reservoir and overlying aquifer waters at an enhanced oil recovery site, northwest Texas, USA. Applied Geochemistry, 87, pp.122-135.
- Gardiner, J., Thomas, R.B., Phan, T.T., Stuckman, M., Wang, J., Small, M., Lopano, C. and Hakala, J.A., 2020. Utilization of produced water baseline as a groundwater monitoring tool at a CO2-EOR site in the Permian Basin, Texas, USA. Applied Geochemistry, 121, p.104688.
- Miller, J.D., Stuckman, M.Y., Means, N., Lopano, C. and Hakala, J.A., 2022. Determination of transition metal ions in fossil fuel associated wastewaters using chelation ion chromatography. Journal of Chromatography A, p.462924.

Acknowledgement

NATIONAL ENERGY TECHNOLOGY LABORATORY

- We would like to thank the operating company and its employees for helping us to sample the wells featured in this study.
- We would also like to thank the landowners who allowed us to sample their groundwater wells.

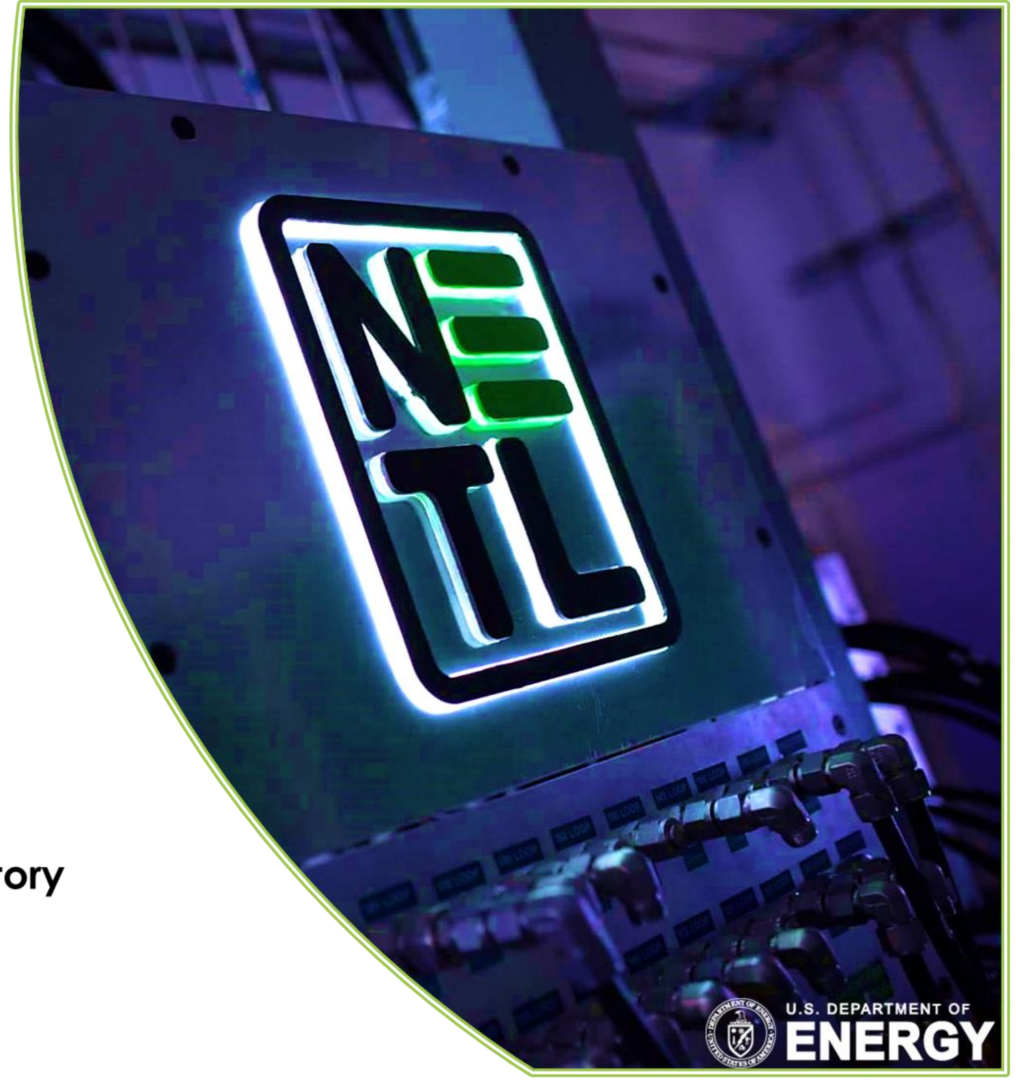
NETL RESOURCES

VISIT US AT: **www.NETL.DOE.gov**

@NETL_DOE

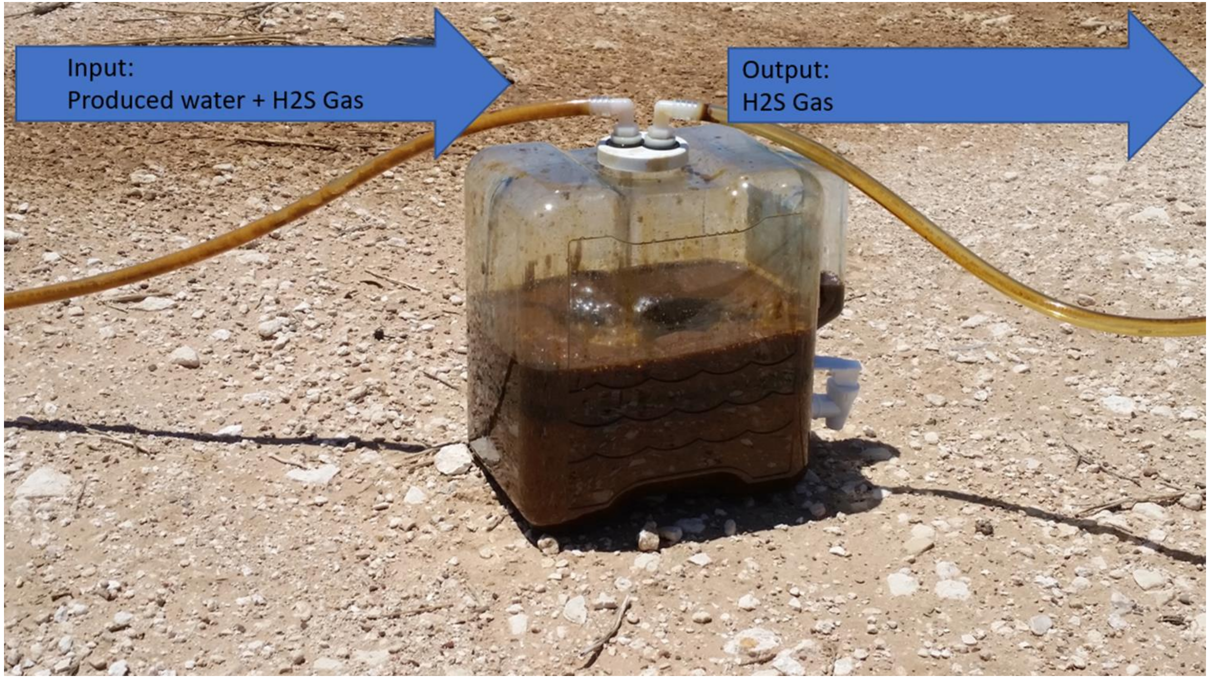
@NETL_DOE

@NationalEnergyTechnologyLaboratory



Supplemental Slides

Field Sampling



Fluid from the well (e.g. oil, gas condensate, produced water, H_2S gas) flows into the carboy and excess gas flows out.

Construction of BBN-Regression Results

- Mean-predicted value from the response function for each CO_2 level
- SD-standard deviation of residuals (geochemical model output-predicted values)
- Ion concentration-normally distributed with mean and SD