



GWPC
2009

Evaluation of Groundwater Quality Changes in Response to CO₂ Leakage from Deep Geological Storage

¹ Liange Zheng, ¹Jens T. Birkholzer, ¹ John A. Apps,
²Yousif Kharaka, ² James Thordsen

¹Lawrence Berkeley National Lab, Berkeley, CA; ²USGS, Menlo Park, CA

2009 GWPC Water/Energy Sustainability Symposium
Salt Lake City, Utah September 13-16, 2009

CO₂ Leaks?

There are several key technical risk features, events and processes for geologic CO₂ storage and these include:

- The release of CO₂ from its storage location (e.g., via wellbores, faults or fractures, etc.)

-

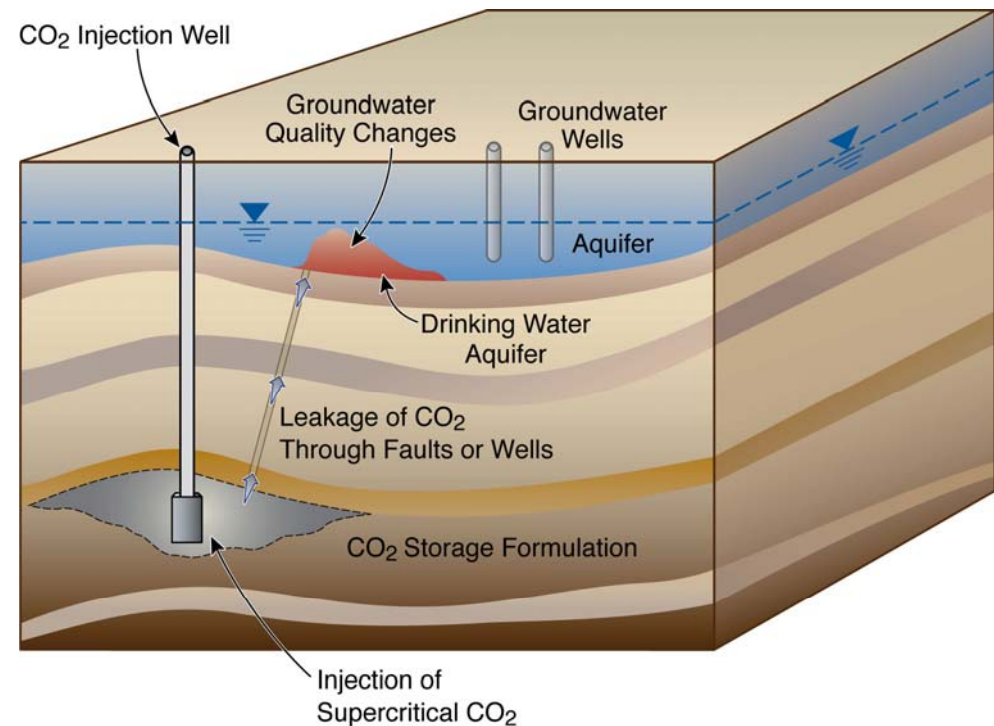
(<http://www.netl.doe.gov>)

“With appropriate site selection informed by available subsurface information, a monitoring program to detect problems, a regulatory system, and the appropriate use of remediation methods to stop or control CO₂ releases if they arise, the local health, safety and environment risks of geological storage would be comparable to risks of current activities such as natural gas storage, EOR, and deep underground disposal of acid gas.”

(Sally Benson, IPCC Special Report on Carbon Dioxide Capture and Storage, 2005)

Water Quality Effects from CO₂ Leakage

- Possibility of leakage pathways such as faults or wells
- CO₂ leakage into aquifers may cause mobilization of hazardous trace elements
- Leakage of CO₂ or brine migration may cause migration of other contaminants (e.g., organics, co-injectants) into aquifers



Selected Work on Groundwater Quality Impacts

- **Wang and Jaffe, Energy Conversion and Management, 45, 2004**
 - Simulation of CO₂ intrusion into shallow groundwater shows increase in lead concentrations, for very simplified host rock mineralogy.
- **Kharaka et al., Geology, 34, 2006**
 - Strong increases in trace metal concentrations following CO₂ injection in a deep storage formation at Frio.
- **Lewicki et al., Environmental Geology, 52, 2007**
 - Natural analogs show acidification of groundwater and changes in chemical composition, but waters remain potable in most cases.
- **McGrath et al., Ground Water Monitoring & Remediation, 27, 2007**
 - Increase in cadmium concentrations in shallow groundwater (above drinking water limits), related to CO₂ releases from a municipal landfill.
- **Smyth et al., Proceedings GHGT-9, 2008**
 - Increases in cation concentrations measured in laboratory batch experiments of diverse aquifer rocks exposed to CO₂-water mix.
- **Carroll et al., 8th CCS annual conference, 2009**
 - Increase in concentrations of various cations in batch experiments when aquifer rocks is exposed to CO₂-charged water.

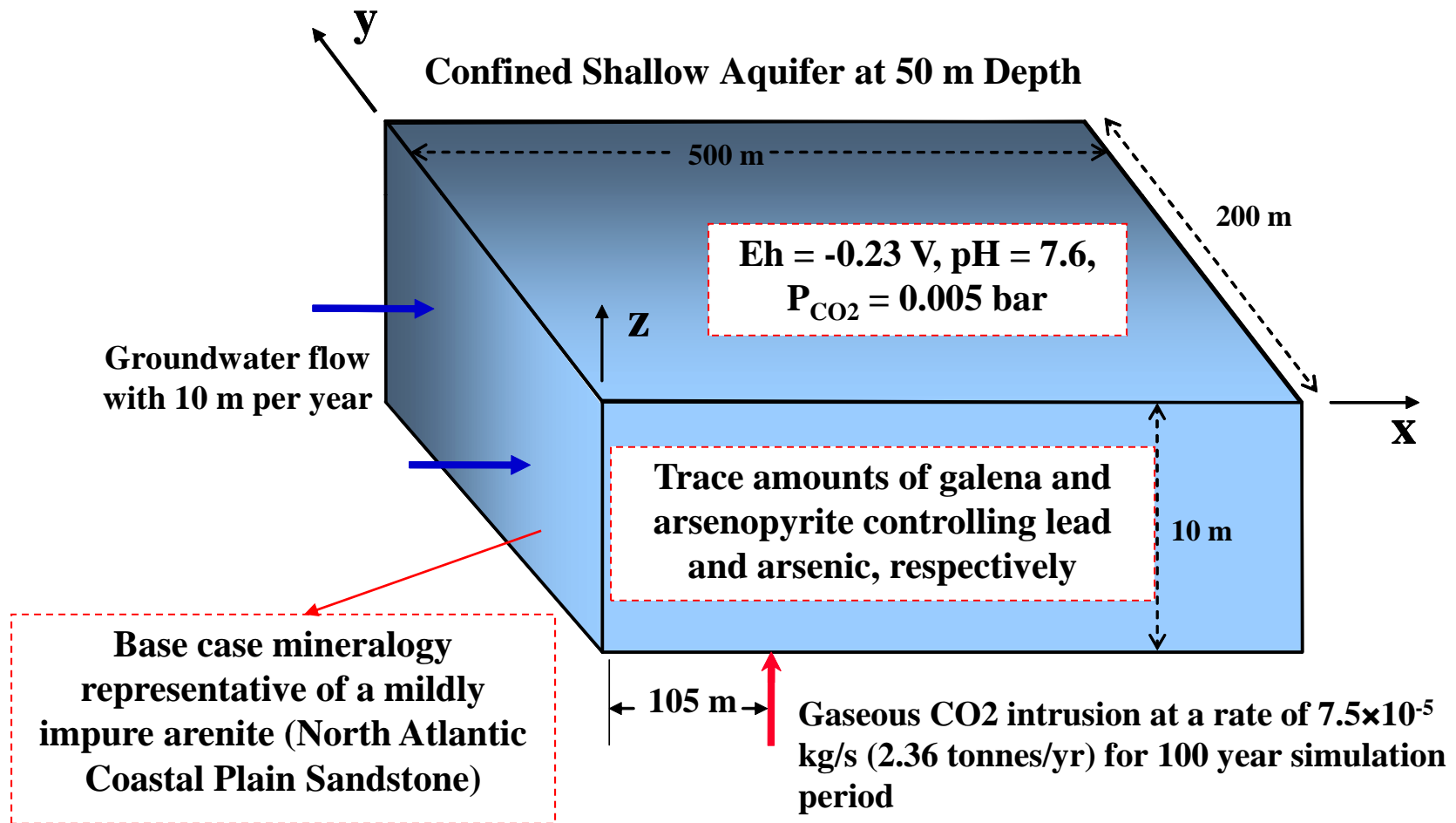
Relevant Research at LBNL

- **Systematic prediction of CO₂-related mobilization of hazardous trace elements in groundwater (finalized)**
- **Field experiment with shallow CO₂ release and measurements of geochemical changes (ongoing ZERT project, funded by EPRI)**
- **Potential impact of organics and co-injectants on groundwater (ongoing project)**

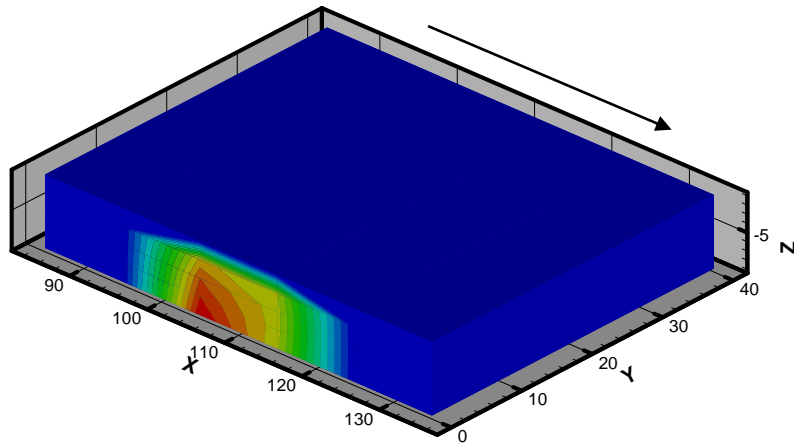
Presented in this talk

CO₂-Related Mobilization of Hazardous Constituents in Groundwater

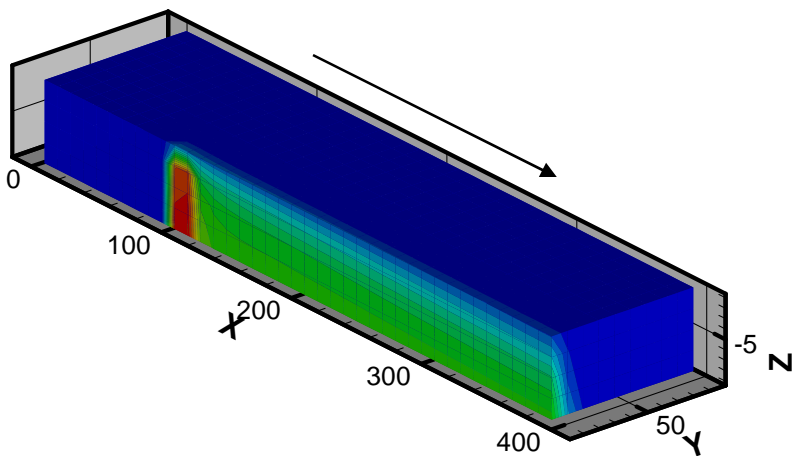
Generic study by reactive transport modeling



Intrusion Rate: 2.4 t/yr

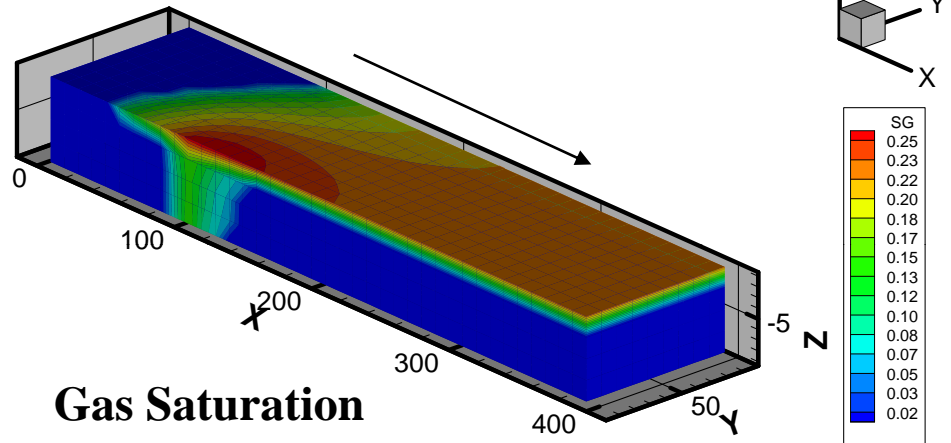


Gas Saturation (Close-up)

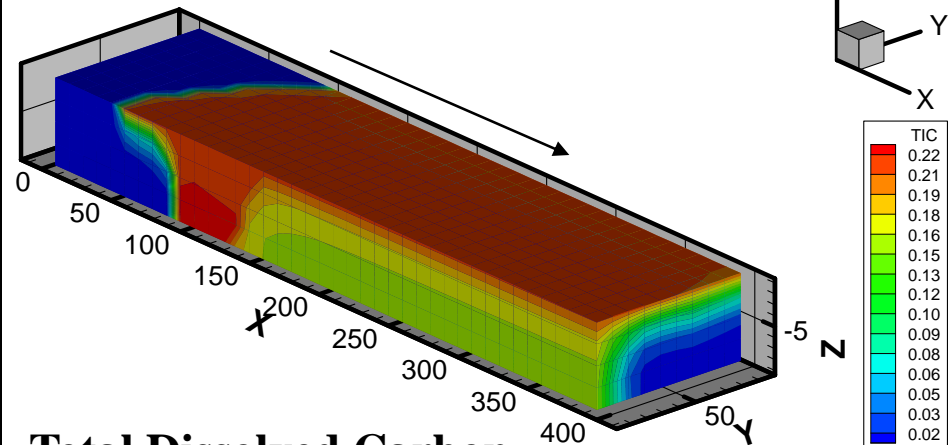


Total Dissolved Carbon

Intrusion Rate: 19 t/yr



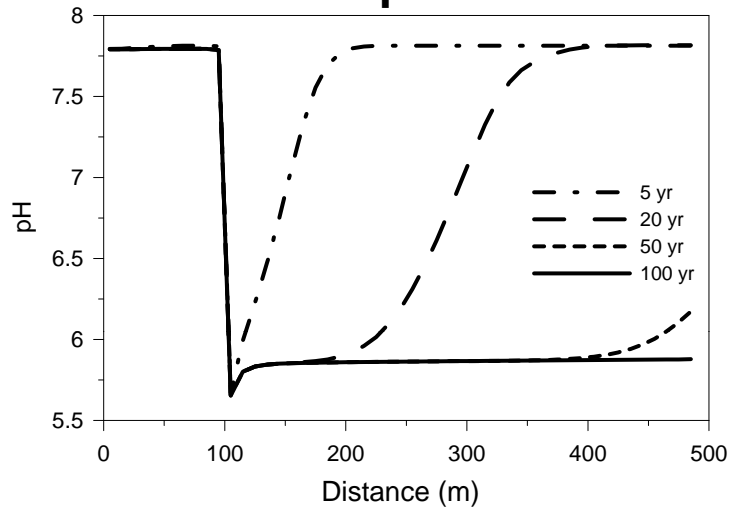
Gas Saturation



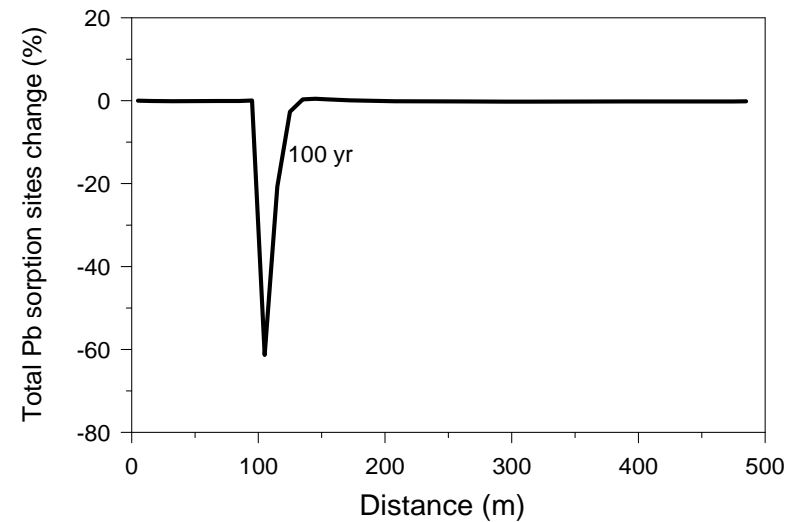
Total Dissolved Carbon

Base Case with 2.4 t/yr

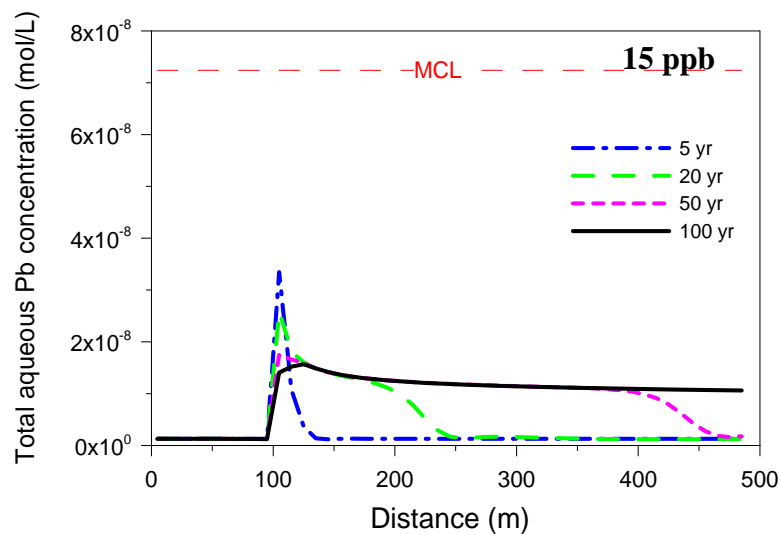
pH



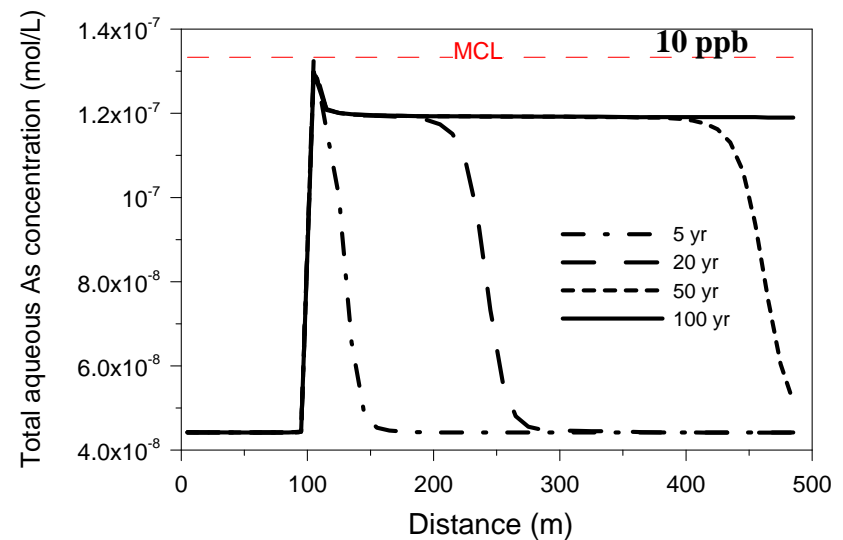
Relative Change of Total Pb Sorption Sites



Lead Concentration



Arsenic Concentration

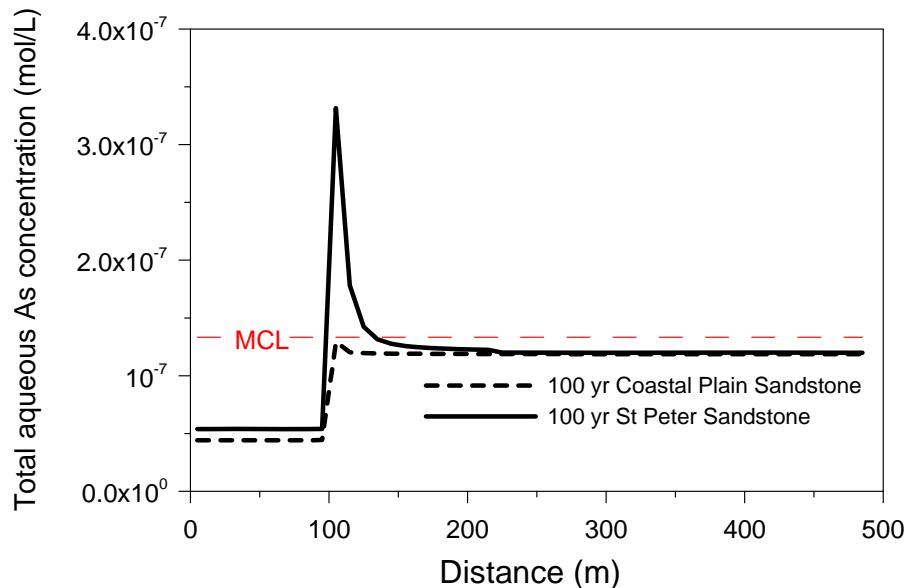


Different Aquifer Mineralogy

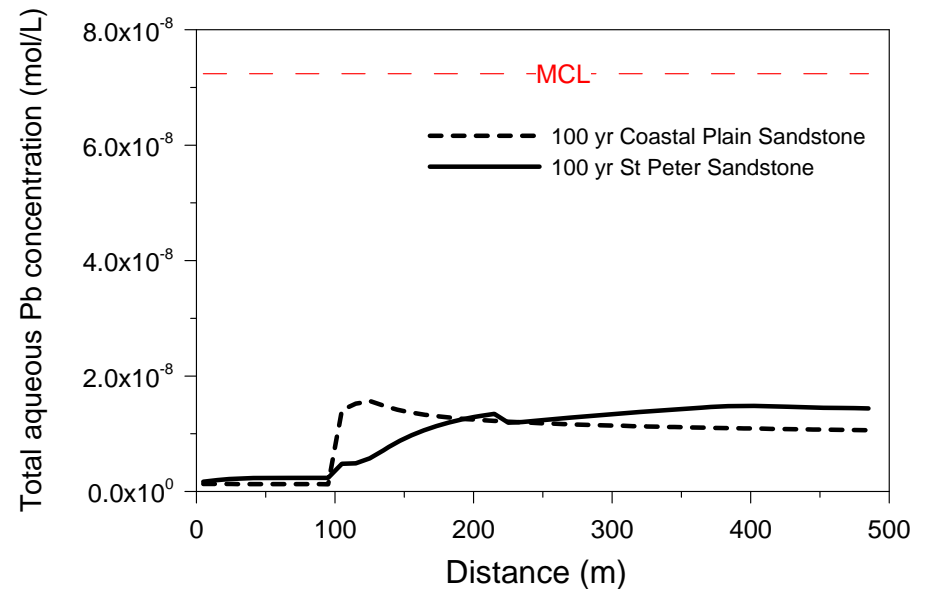
Base case with Coastal Plain Sandstone: aquifer contains enough carbonate minerals to buffer pH.

Sensitivity case with St Peter Sandstone: carbonate minerals in the aquifer are depleted and pH buffering capacity diminishes.

Arsenic Concentration at 100 Years



Lead Concentration at 100 Years



Conclusions from Generic Modeling Study

- While substantial increases in aqueous concentrations are predicted to occur compared to the initial water composition, the maximum contaminant level for arsenic in groundwater has been exceeded in only a few simulation cases, whereas the maximum contaminant level for lead has not been exceeded at all
- Adsorption/desorption via surface complexation is arguably the most important process controlling the fate of hazardous constituents mobilized by CO₂ leakage. The relative importance of dissolution/precipitation versus adsorption/desorption is controlled by many factors, including adsorption parameters and aquifer mineralogy, reaction kinetics, aqueous complexation processes, and mineral solubility constants
- The rate of CO₂ entering an aquifer has small minor effect on the maximum contaminant concentrations. Excess CO₂ remains in the gas phase and migrates elsewhere, thereby changing the spatial distribution of possible groundwater contamination, but the contamination level increasing only slightly.
- Site specific studies are recommended, with model predictions and supplementary laboratory and/or field experiments.

Field Experiment at ZERT Shallow Release Facility

ZERT Field Site (Bozeman, Montana)

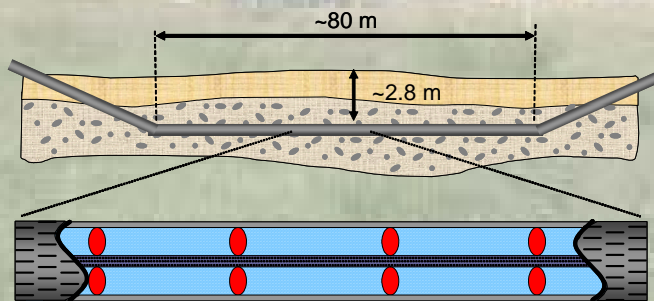


Facility Goals, Rationale, and Design

- Develop a well-characterized site
- Apply known CO₂ injection rates for testing near-surface monitoring
- Use this site to establish detection limits for monitoring technologies
- Use this site to improve flow and transport models

Activities to Date

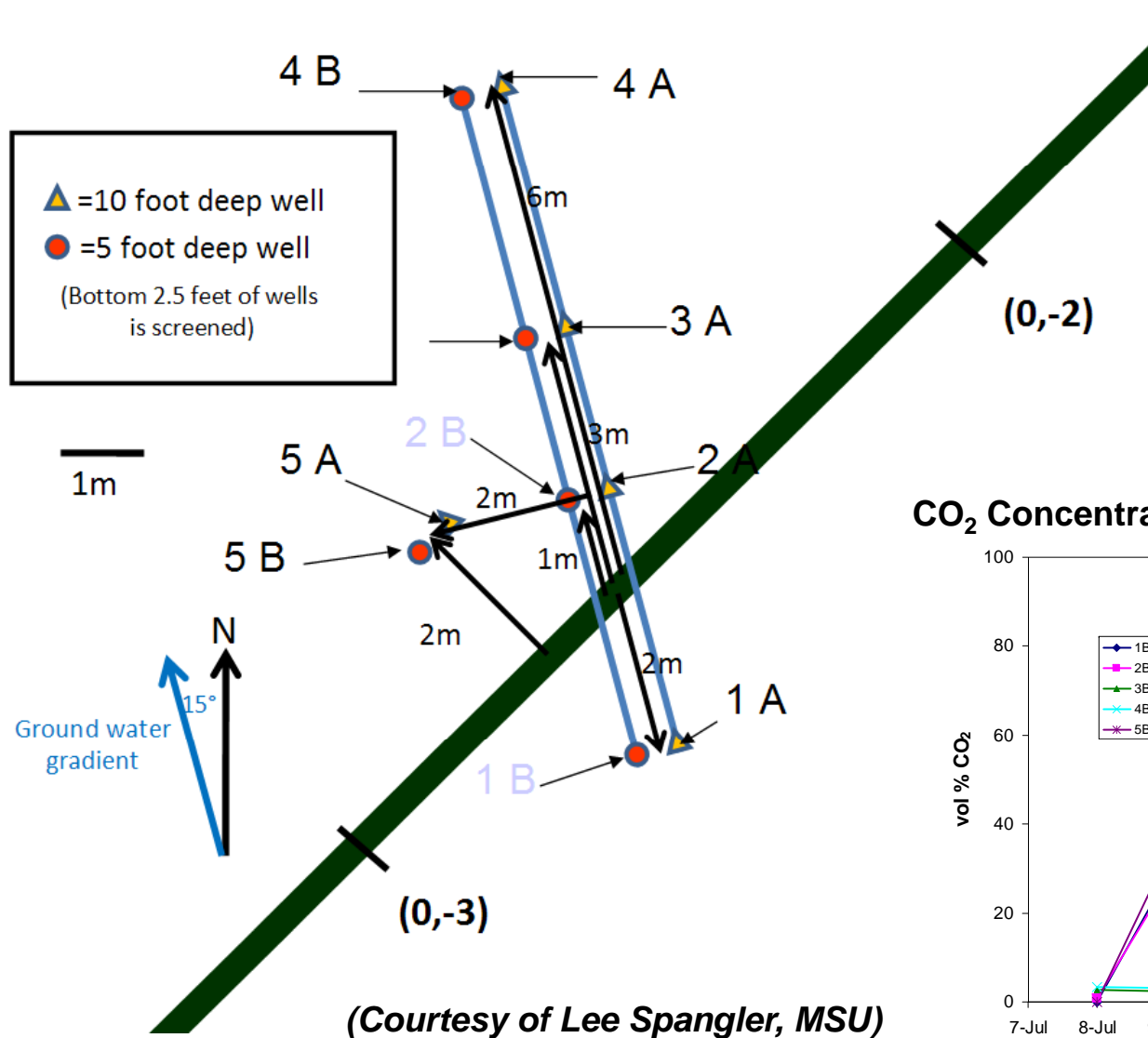
- 2006—Characterization, vertical-well injections, horizontal well installation
- 2007—Year 1 Shallow-release
 - Phase 1 100 kg/day for 10 days
 - Phase 2 300 kg/day for 7 days
- 2008—Year 2 Shallow-release
 - Phase 1 300 kg/day for 30 days



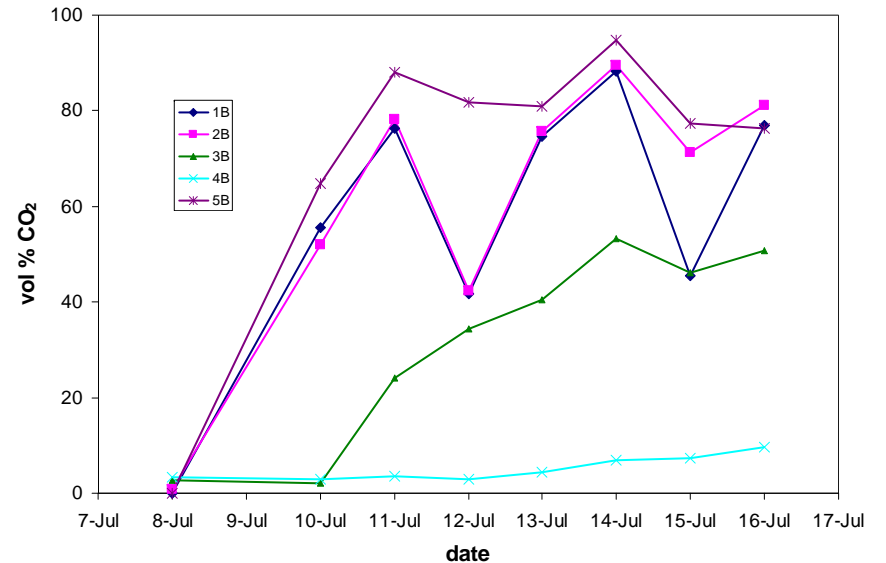
Slotted stainless pipe with internal CO₂ pipe & packer system for even gas distribution

(Courtesy of Lee Spangler, MSU)

Wells for Groundwater Characterization



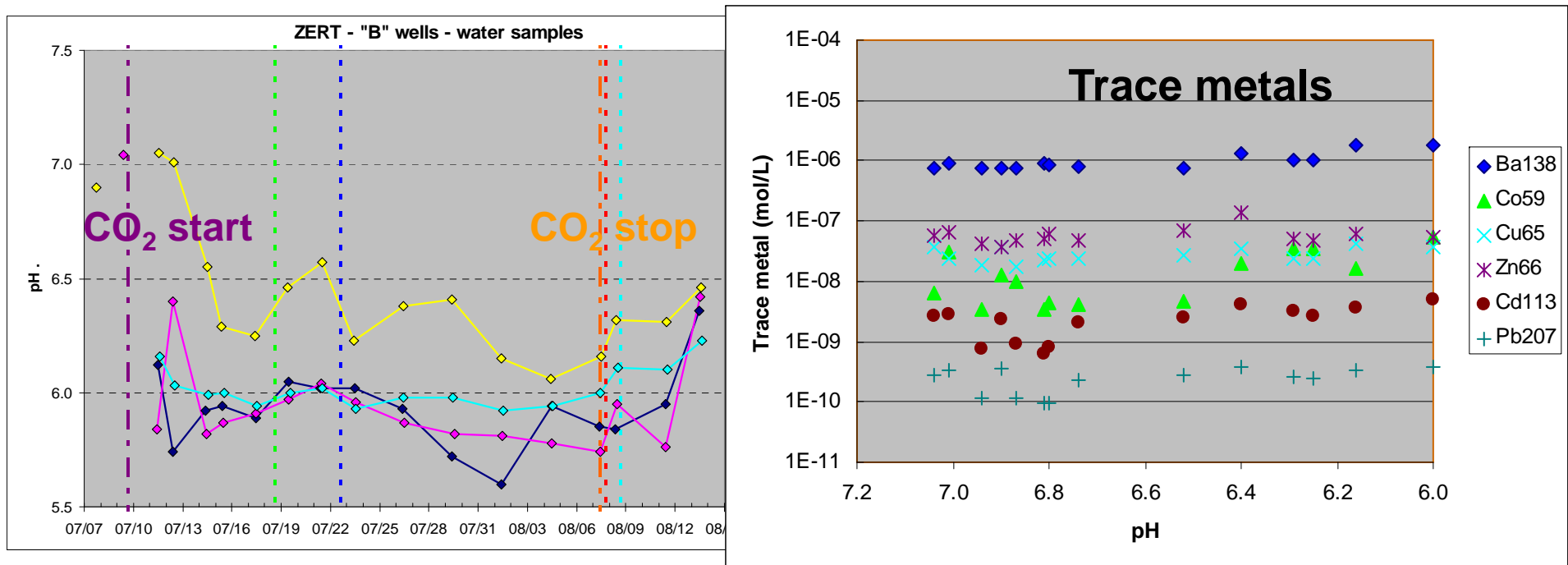
CO₂ Concentrations in Head Space Above Wells



Groundwater Monitoring

Chemical Analyses of Groundwaters by USGS

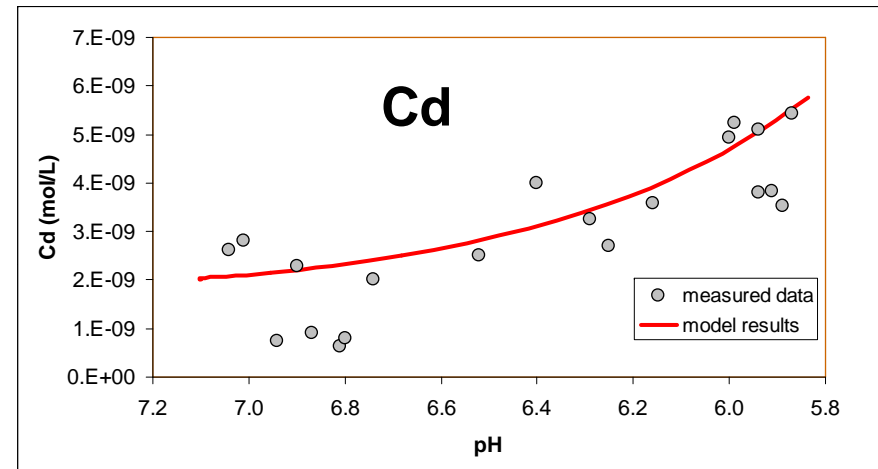
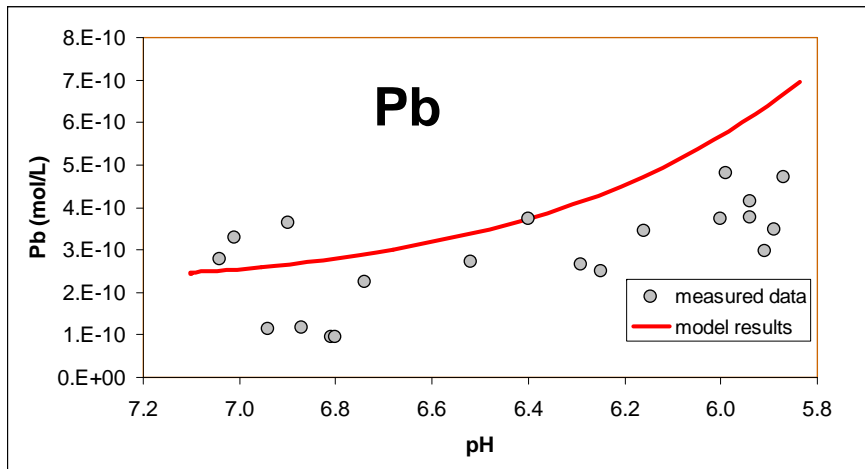
- 62 complete chemical analyses between 7 July 2008 and 13 August 2008
- 30 chemical constituents, T, EC, pH, TDS, Total Cations, Total Anions
- Hazardous constituents include: As, Ba, B, Cd, Cr, Cu, F, Pb, Se, U



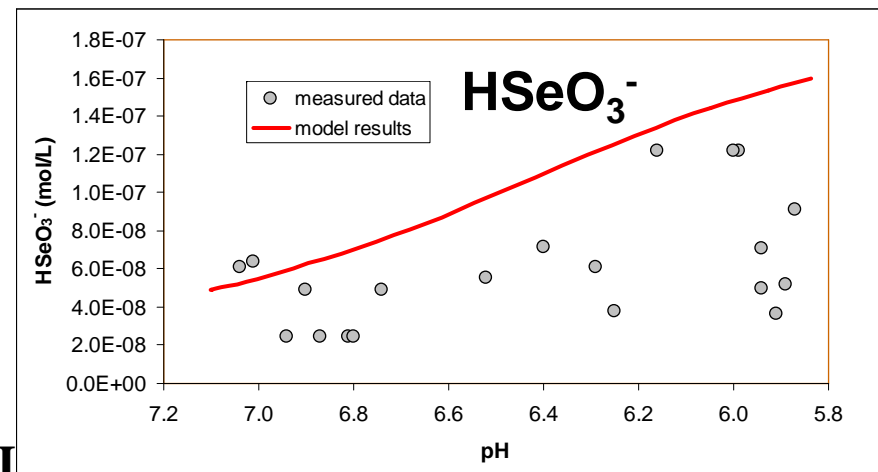
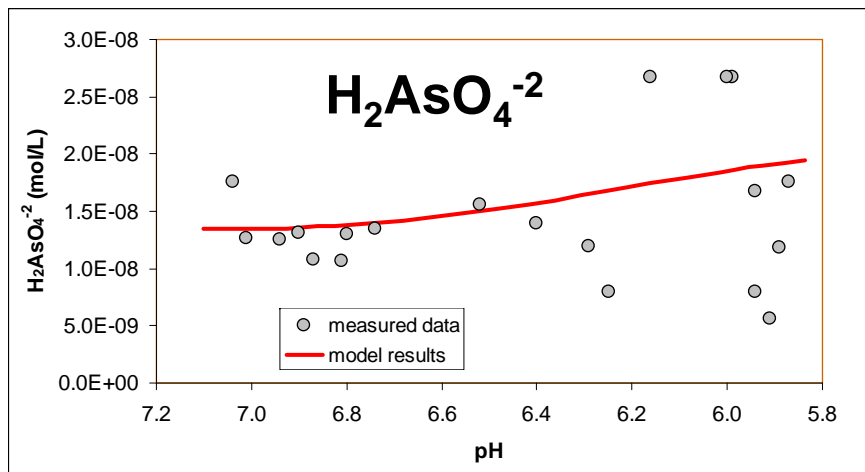
Concentrations of trace metals are below the Maximum Contaminant Levels

Geochemical Process Modeling

Cation exchange could explain the evolution of trace metals.



Adsorption/desorption could explain the evolution of anions.





Concluding from Field Experiment

- The release of CO_2 into shallow groundwater leads to a fast and systematic drop of pH and consequently an increase of the concentration of trace cations and anions.
- Calcite dissolution could be the main pH buffer process.
- The increase in the concentrations of major cations and trace metals could be explained by Ca^{+2} -driven exchange reactions.
- The release of anions from sorption site due to competing adsorption of carbonate could explain the concentration trend of most anions.
- Further characterization of soil mineralogy is ongoing, which will be followed by more precise geochemical interpretation and modeling.
- Findings may not be representative of most groundwater resources because a very shallow system is considered, strongly affected by atmospheric precipitation.



Acknowledgments

The first study was funded by US Environmental Protection Agency, Office of Water and Office of Air and Radiation, under an Interagency Agreement with the U.S. Department of Energy at the Lawrence Berkeley National Laboratory, Contract No. DE-AC02-05CH11231.

This second work was funded by the Electric Power Research Institute, EPRI. We thank the entire ZERT team and all participating organizations for a supportive and exciting research environment

Thank you for your attention