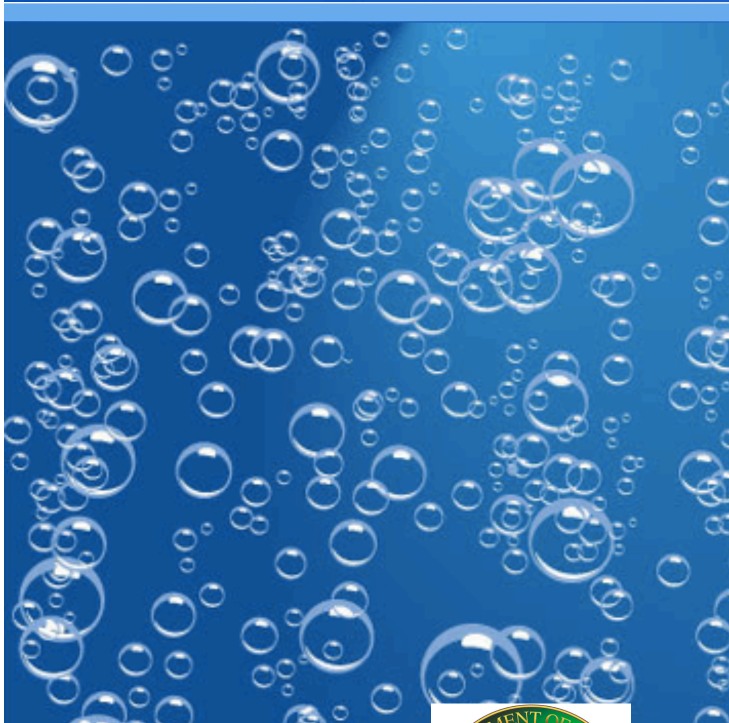
An overview of the potential impacts of CO_2 leaks on shallow drinking water aquifers



Elizabeth Keating

Los Alamos National Laboratory, Los Alamos, NM

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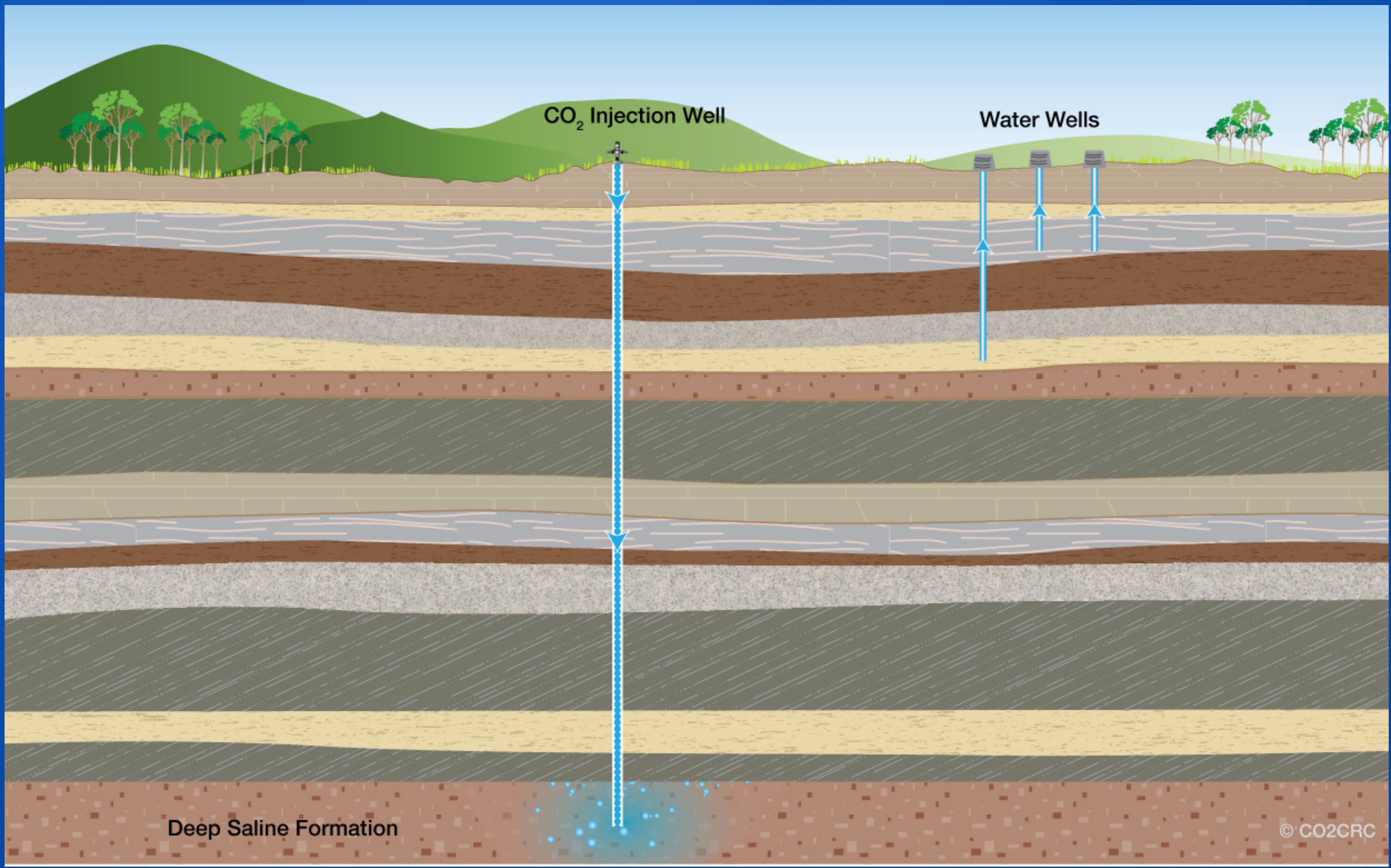
Risk to drinking water aquifer=

The *probability* that injected CO_2 would breakthrough to the aquifer X

The *impact* leaked CO_2 would have on water quality



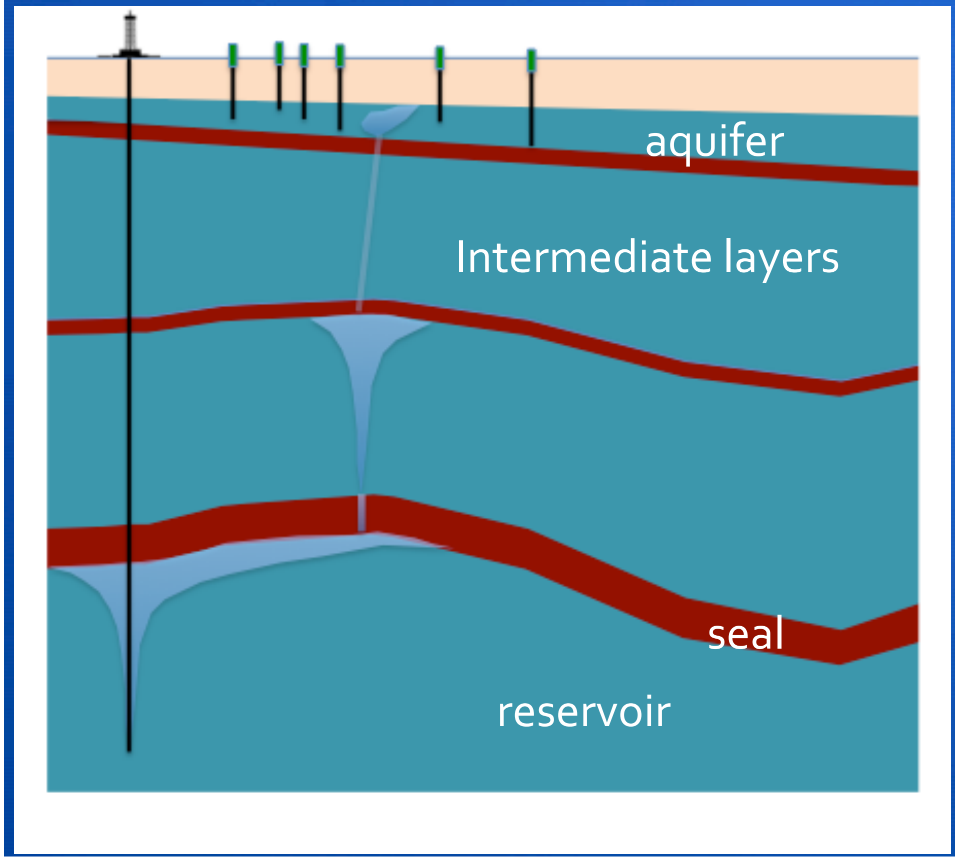
Presentation outline

- Likelihood of CO_2 breakthrough
- Potential impacts of CO_2 leakage on shallow groundwater quality
- Risk assessment
- Concluding remarks

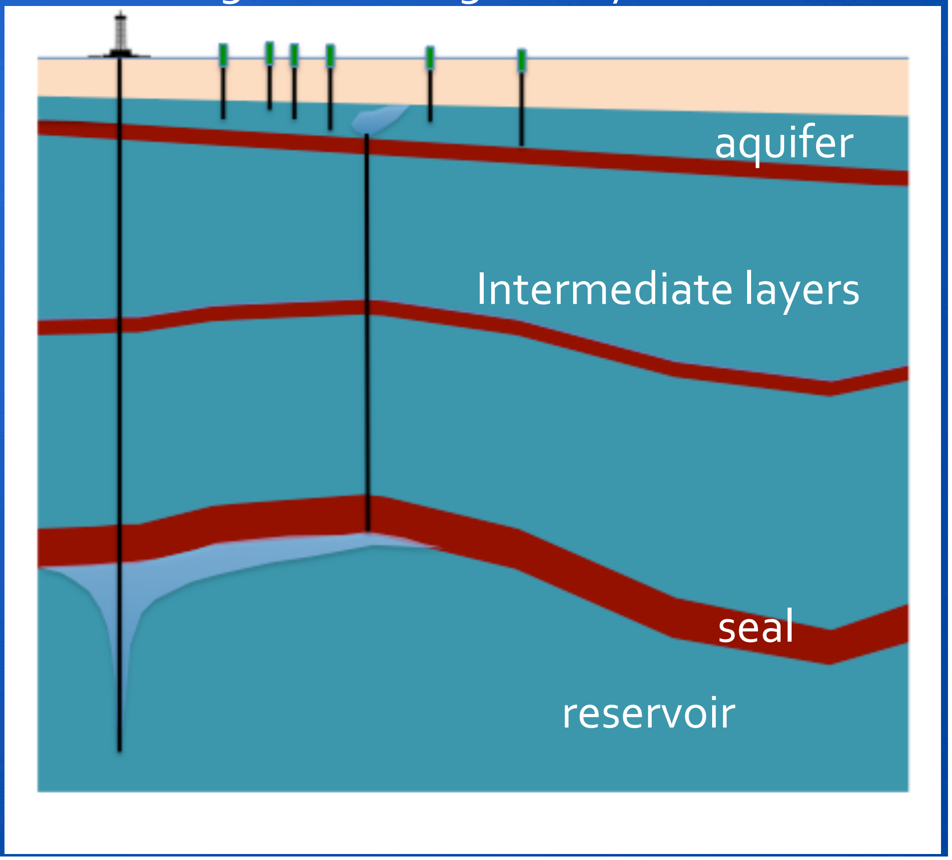
There are multiple scenarios that could result in CO_2 leaking to a shallow aquifer. All require two elements:

- **A sustained permeable pathway through seals and intermediate zones**
- **Sufficient upward driving force**

Multiple seal failures, diffuse upward leakage



Focused migration along a leaky wellbore / fault

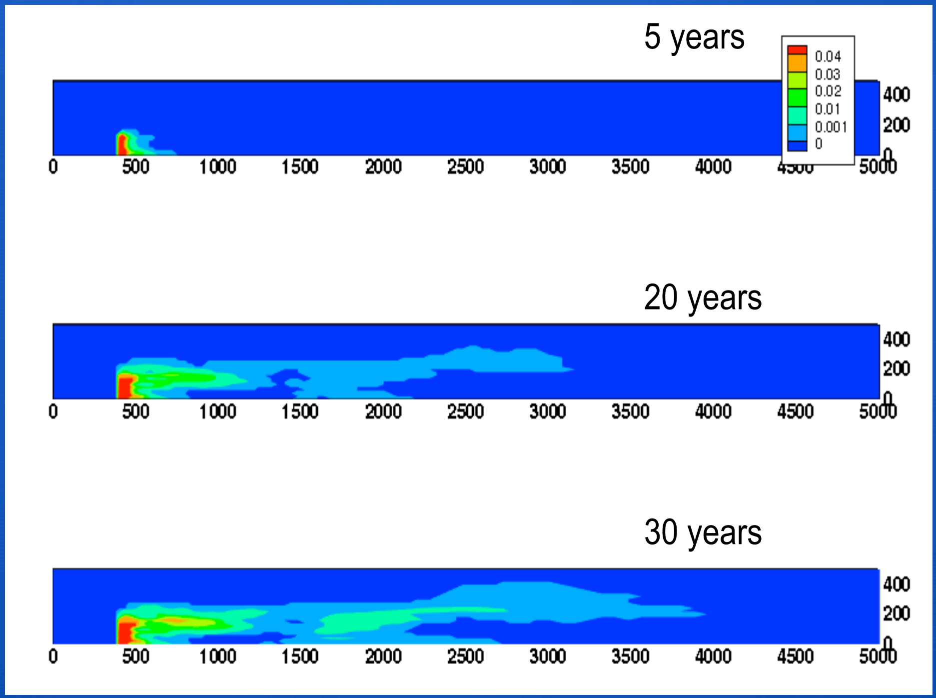


There is substantial evidence that a carefully selected and managed site will have a *very* low probability of containment failure and breakthrough to shallow aquifers

- Studies of natural analogs (oil and gas reservoirs, CO_2 reservoirs)
- Experience with industrial analogs
- Experience with CO_2 storage projects
- Studies of CO_2 migration along faults & old wellbores (field, laboratory, simulations)
- Risk assessment studies

Potential impacts of CO2 leakage on shallow groundwater quality

Simulated groundwater pH (Bacon et al., 2013)



What constitutes a CO_2 impact?

Two perspectives:

1. CO_2 causes concentrations of any solute to exceed maximum contaminant levels (MCLs), as defined by U.S. EPA.

2. CO_2 causes concentrations of any solute to change more than would be expected as 'natural variation' (U.S. EPA Class VI well permitting regulations)

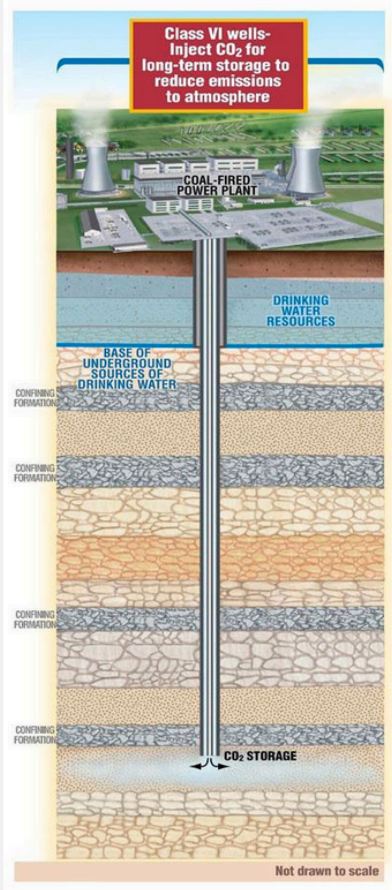
Factors to consider regarding the "maximum contaminant levels (MCLs)" perspective

- Dissolved CO_2 is not, by itself, harmful in drinking water.
- CO_2 can change the pH and alkalinity of groundwater, making it more reactive with aquifer rocks. In certain environments, this can cause trace metal concentrations to increase (e.g. As, Pb, U)
- Amount of CO_2 and hydrochemical conditions of the aquifer will control whether or not MCLs would be exceeded

Factors to consider regarding the 'No degradation' perspective

- Dissolved CO_2, in any amount, will change water quality, so

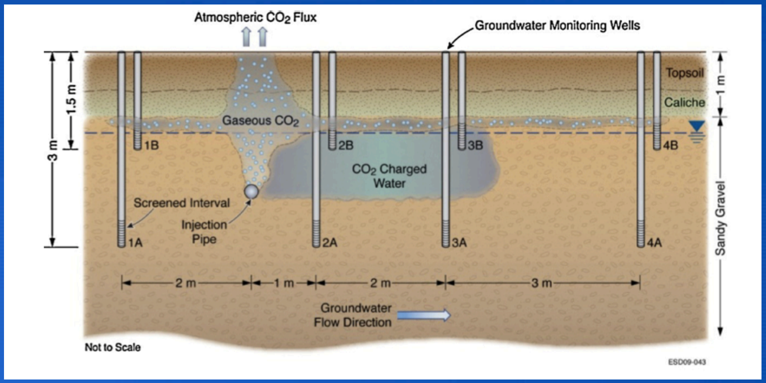
  any LEAK to groundwater == IMPACT
- This could drive a monitoring approach that is designed to detect very small changes in groundwater chemistry. Would this approach be capable of detecting a leak?
  - Monitoring well density
  - Background variability
- What is the expected rate of false positives? false negatives?



UIC Class VI wells inject CO2 for long-term storage to reduce emissions to the atmosphere.

Research methods used for studying groundwater impacts from CO2 leaks

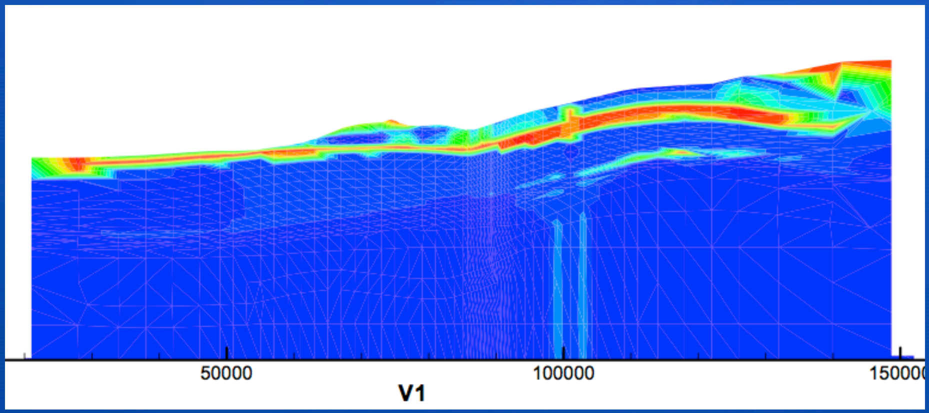
Controlled-release experiments (Spangler et al., 2010)



Bench-scale experiments

Numerical simulations

Allis et al., 2005



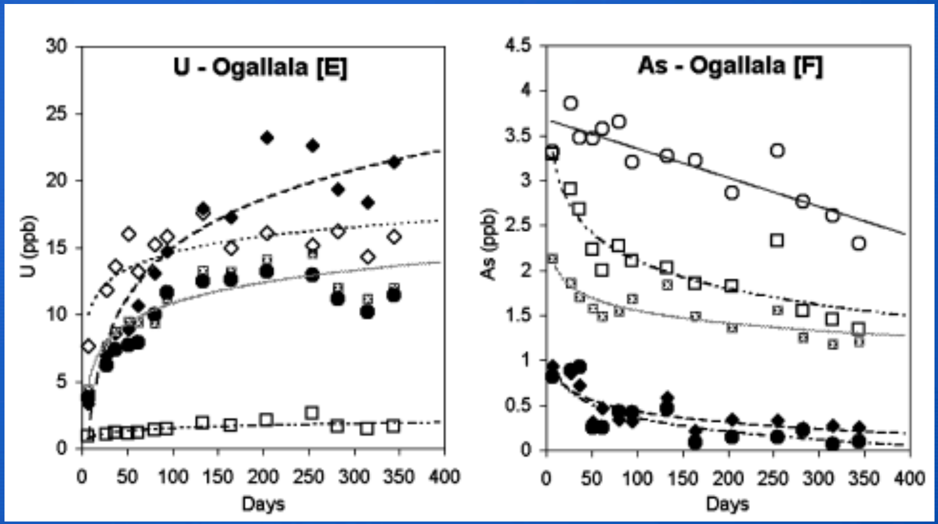
Natural analog studies

Han and others

Crystal Geyser, UT

Research on CO_2-driven trace metal release

Bench scale studies



Little and Jackson, 2010

CO2 controlled release experiment in Bozeman, MT

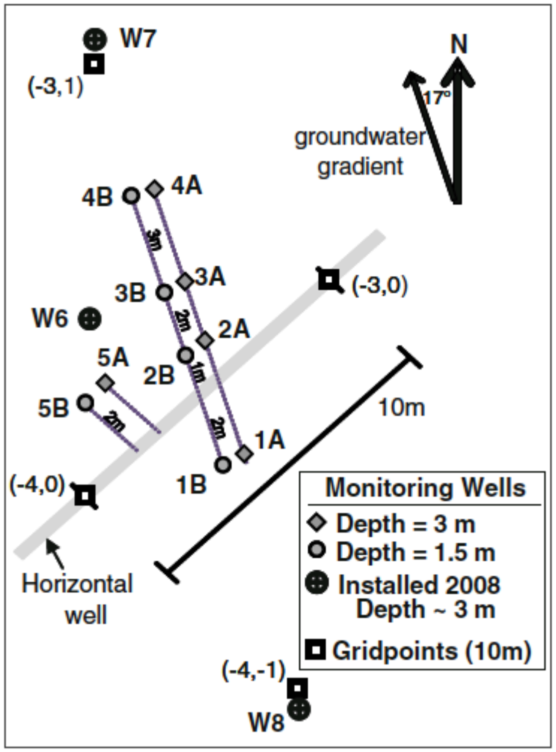
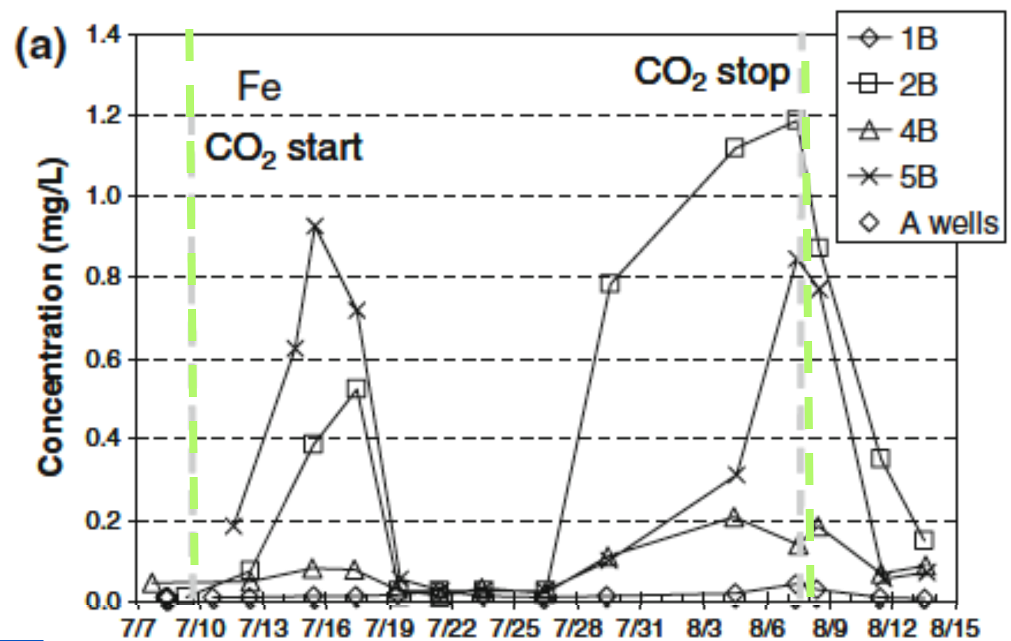


Fig. 1 Location of water-monitoring wells in relation to the surface trace of the slotted horizontal pipe in zone VI of the ZERT site

Dissolved Iron concentration in monitoring wells



Spangler et al., 2010; Kharaka et al., 2010

CO2 controlled release experiment in Bozeman, MT

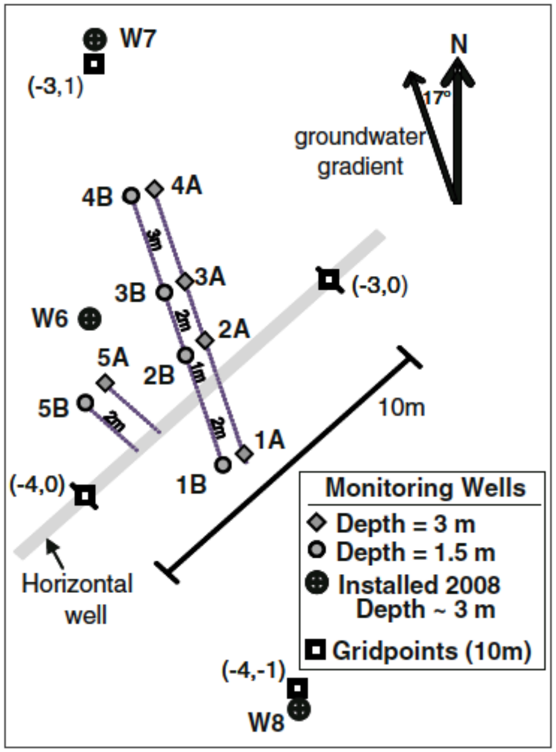
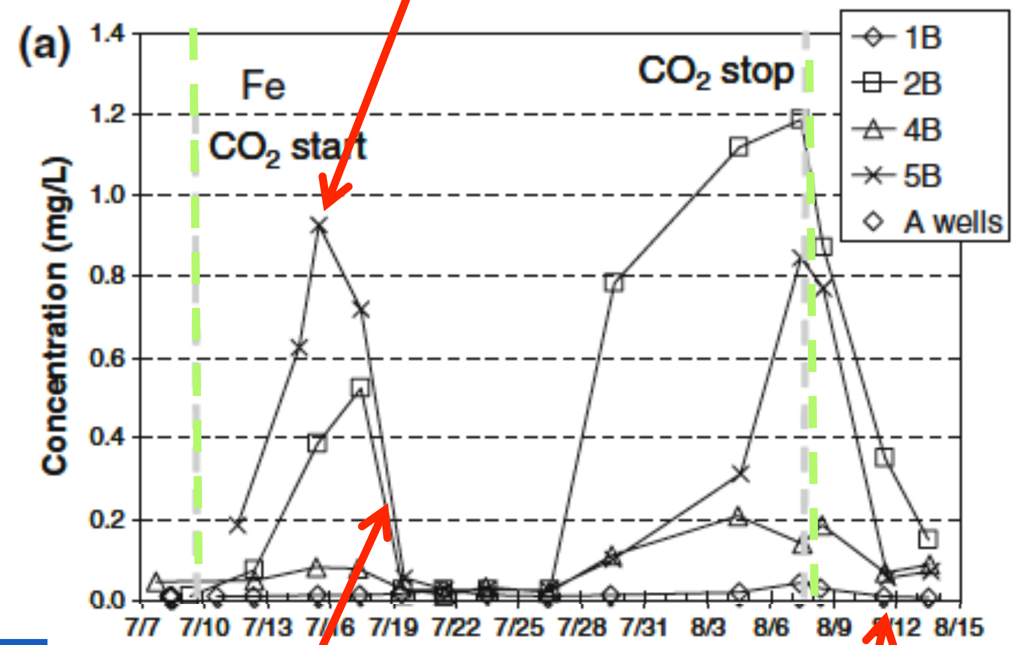


Fig. 1 Location of water-monitoring wells in relation to the surface trace of the slotted horizontal pipe in zone VI of the ZERT site

1. Increase in trace metal concentrations



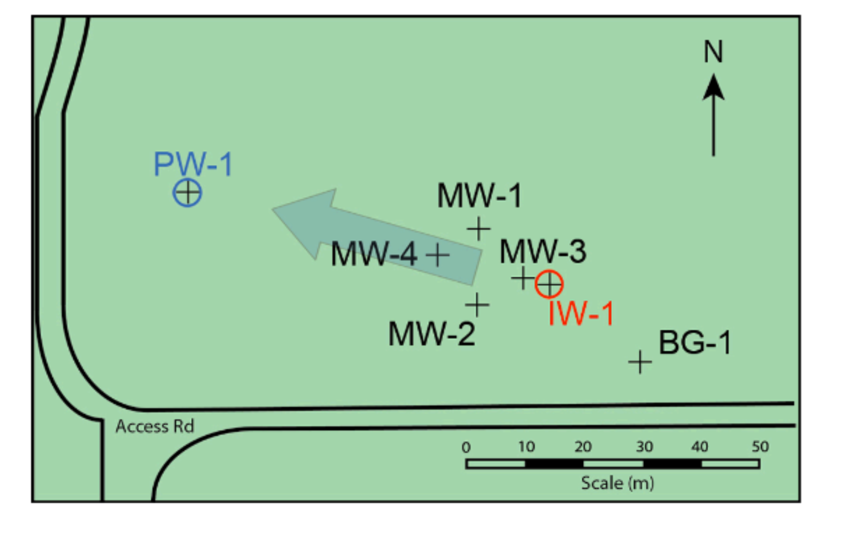
3. Variations unrelated to CO2

2. Fairly rapid recovery

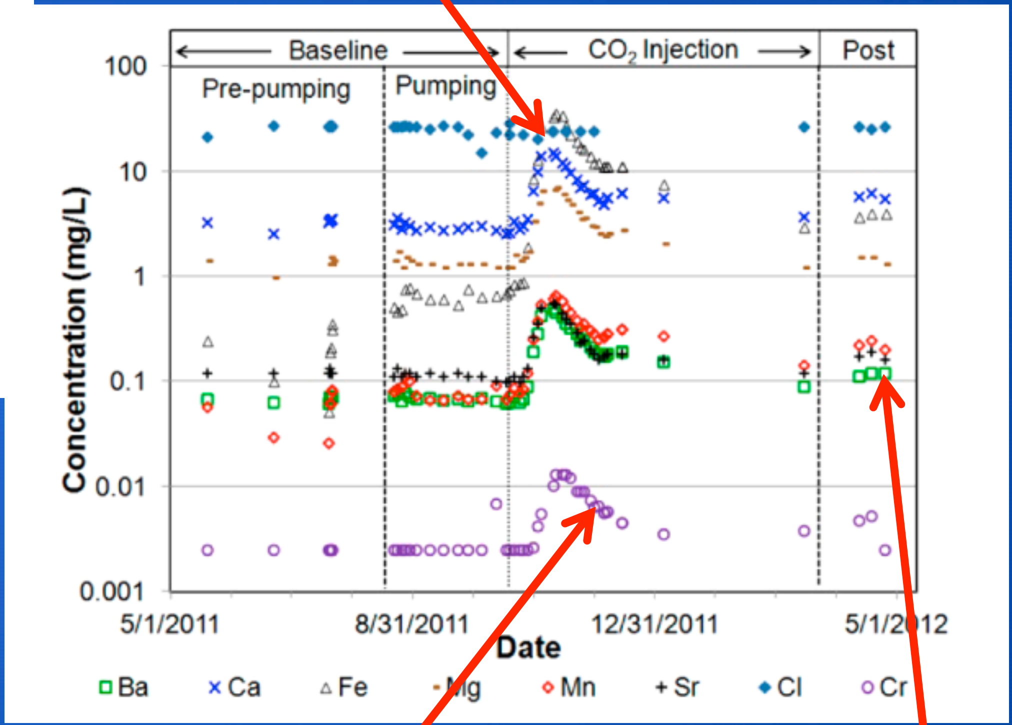
4. MCLs were never exceeded

Spangler et al., 2010; Kharaka et al., 2010

CO2 controlled release experiment in Jackson County, Miss



1. Rapid increase in trace metal concentrations



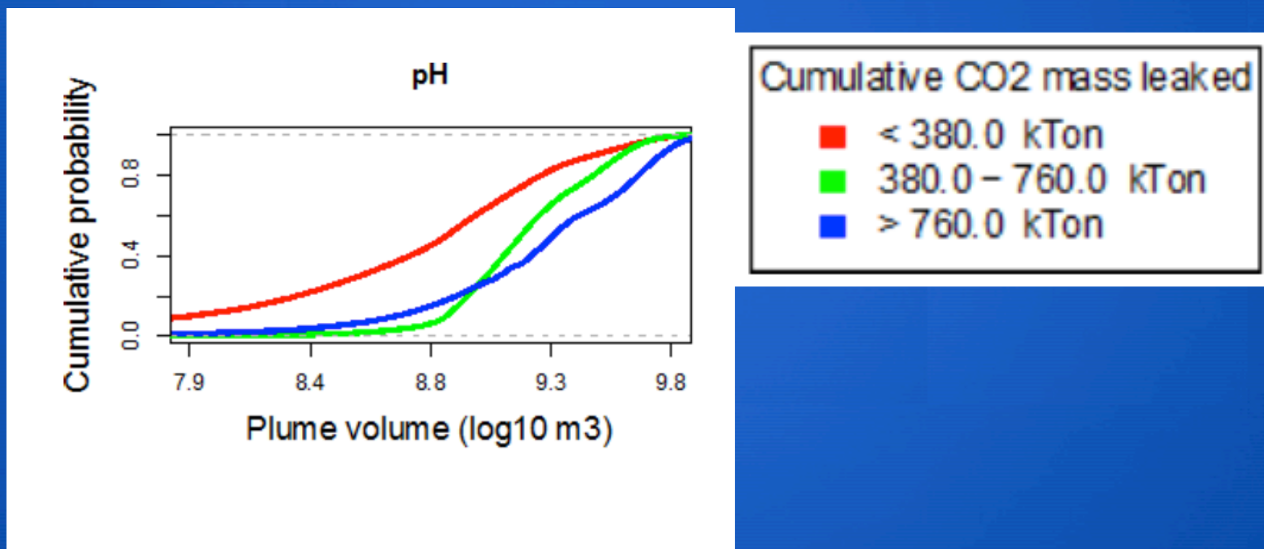
3. MCLs were never exceeded

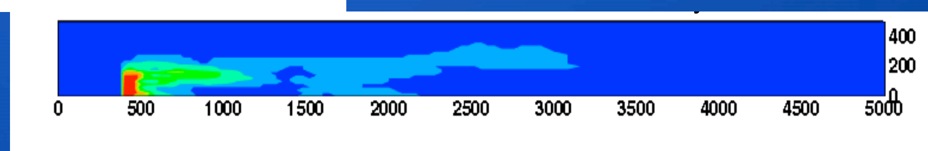
2. Early recovery

4. Post-injection concentrations were slightly elevated

Trauz et al., 2013

- We have a reasonably good understanding about the relationship between size of CO_2 leak and the size of a resulting groundwater quality ‘impact’ plume
- The relationship depends hydrogeochemical characteristics of the aquifer
- This information can be useful for risk assessment and monitoring design



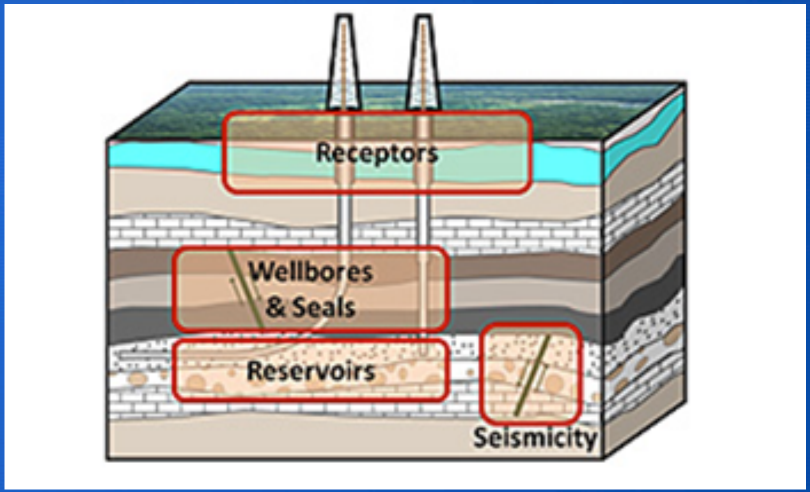


Keating et al., 2016; Carroll et al, 2014; Dai et al., 2014; Keating et al., 2014; Trainor-Guitton et al., 2013

National Risk Assessment Partnership

Science-based tools for

- Assessing and managing risk
- Designing effective monitoring programs



https://edx.netl.doe.gov/nrap/

Concluding remarks

- Risks to groundwater resources
  - At a carefully selected and properly managed site, risk of CO_2 reaching a shallow aquifer will be low
  - If CO_2 does reach the shallow aquifer, the most significant health-related risk would be elevated trace metal concentrations
  - Controlled-release studies suggest concentrations of trace metals would be unlikely to exceed drinking water standards

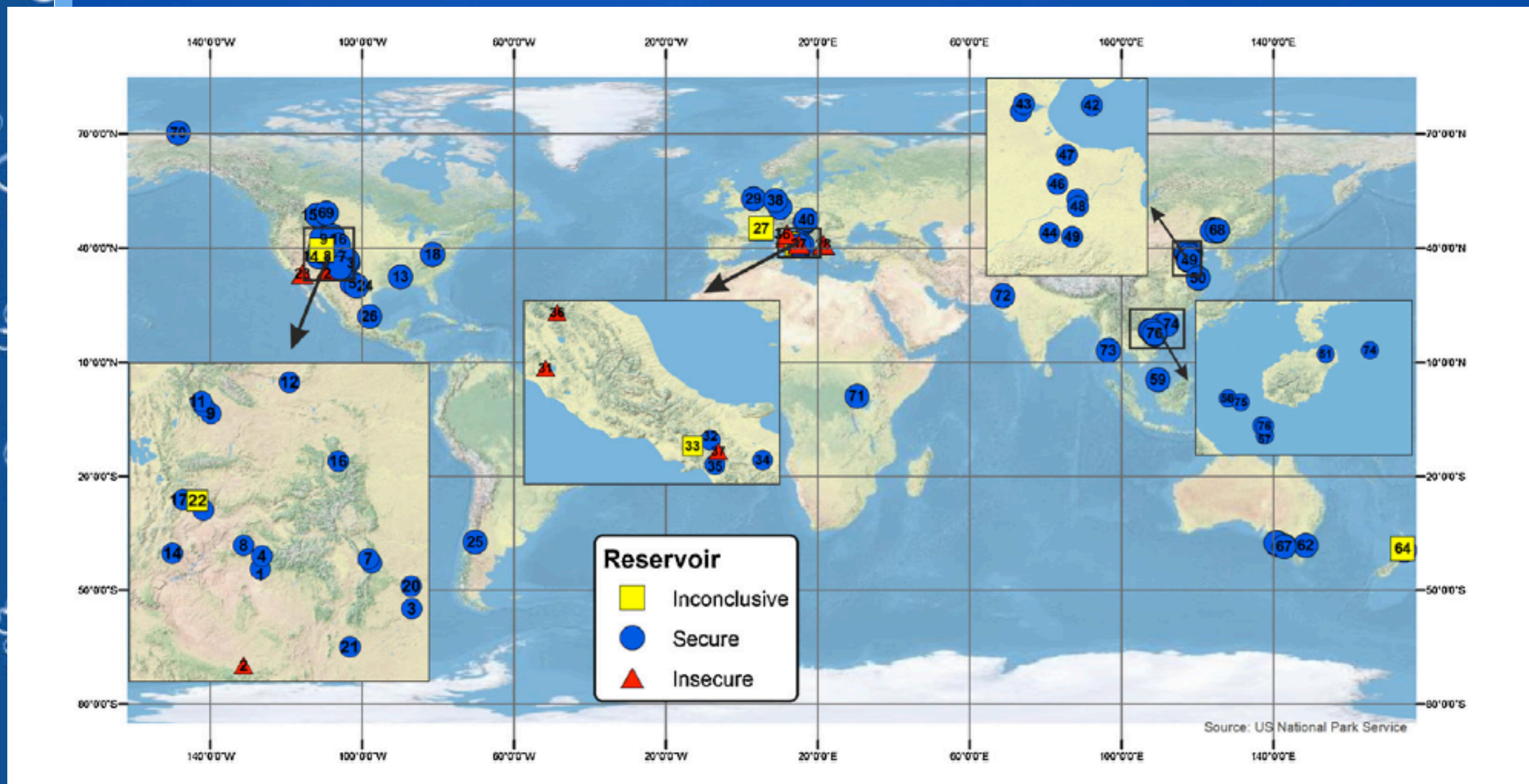
Concluding remarks

- Even small leaks would cause at least a brief and localized water quality changes, and, if these changes are larger than 'natural background variability', they will meet the EPA Class VI criterion for 'impact'.

- In practice, these changes may be subtle, difficult to detect, and difficult to discriminate from changes unrelated to sequestration operations.

- Leak detection using groundwater chemistry changes may be ineffective
  - Time-to-detection would be long
  - High rates of false positives?
  - Extremely high sampling density would be required to achieve high confidence of detection

- Other leakage detection methods (deeper, more spatially integrative) may be more effective



Naturally occurring CO_2 reservoirs, from Miocic et al., 2016