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Overview of Internal Research on Geological Sequestration of CO_2 at ORD

Midwest Carbon Sequestration Conference
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Traditional Role of ORD in Regulatory Programs (e.g., CERCLA, RCRA, and UST)

- Assistance to program offices in rule making and development of guidance
- Internal and External (e.g., grants) Research
- Technical assistance to EPA regional offices and States

Internal Research ⟷ Technical Assistance

Technical Assistance to EPA Regional Offices and States in CERCLA and RCRA

- Systematic program in place for over 20 years
- Activities include document review, training, on-site field work, etc.
- Activities performed by EPA employees and outside groups (e.g., academia, consultants)
- Funded by ORD and Program Offices

EPA regional offices consistently value this over anything else ORD does. This type of program will eventually be needed for geologic sequestration.

Figure from Birkholzer et al., 2008

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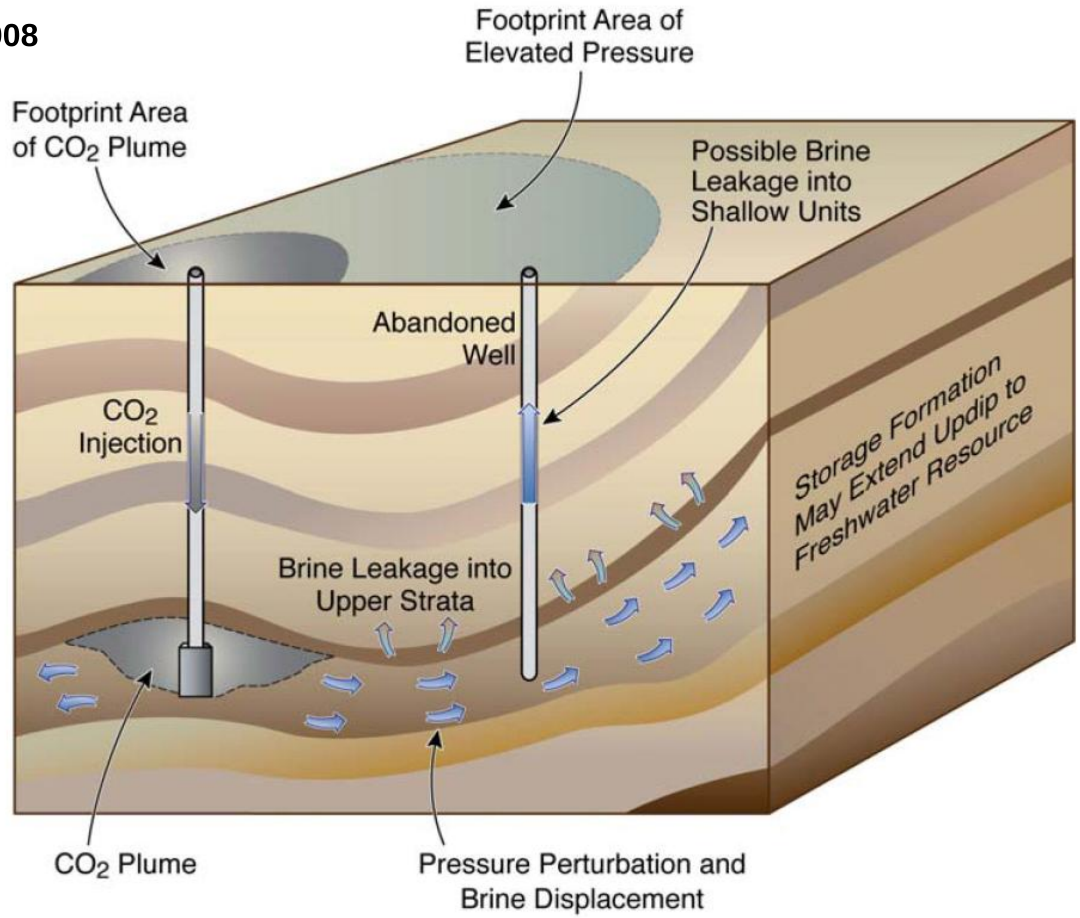
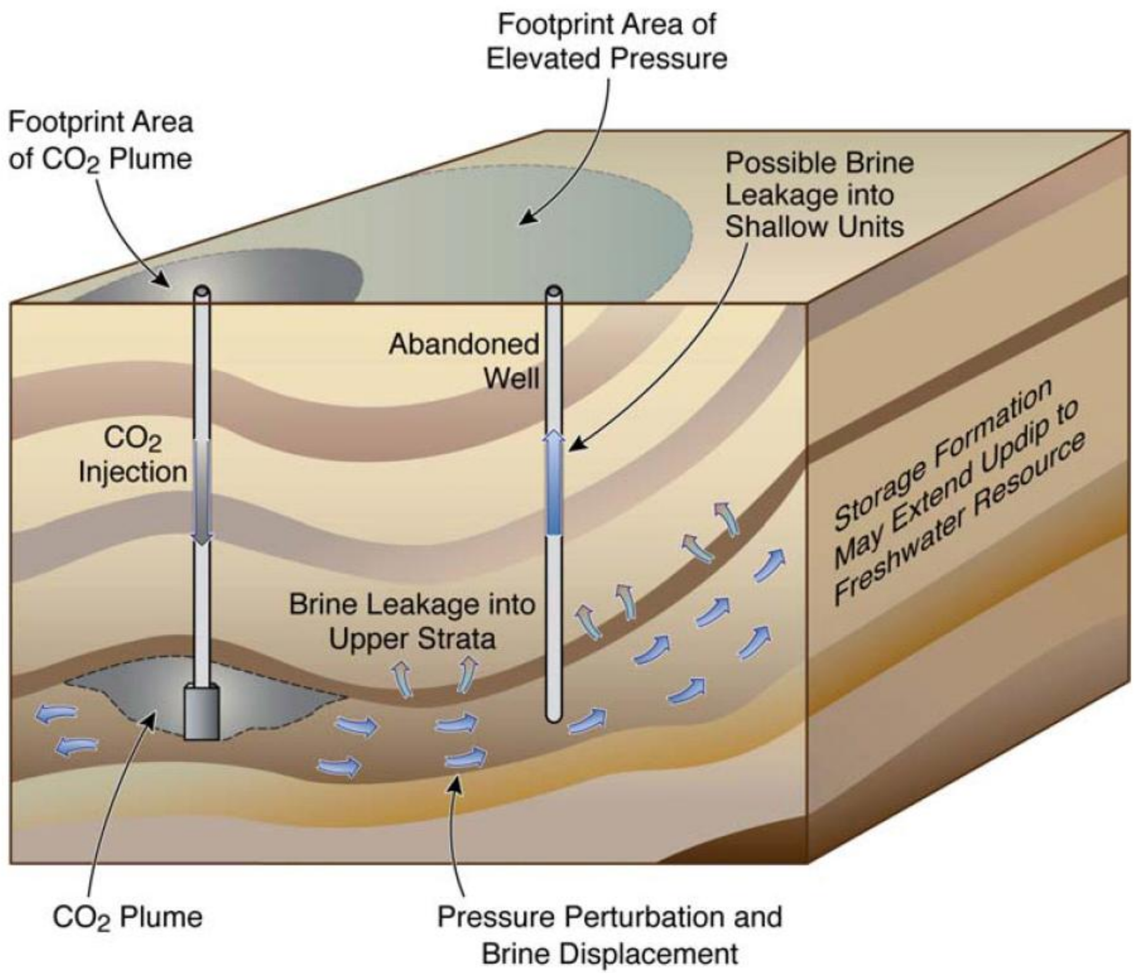
1. Semi-analytical solutions to allow first-order determination of the Area of Review (AoR) (Steve Kreamer/ Athens, GA and Princeton Univ)

AoR - area surrounding injection wells where injected fluids or displaced fluids such as brine could move into USDWs.



Buoyancy will cause a free-phase CO_2 plume to move upwards and spread out farther beneath a confining unit than expected from the injection volume alone). Mobile free-phase and trapped CO_2 injected from a large-scale (e.g., 500-1,000-MW) coal-fired power plant will over time (e.g., 30 years) extend to radial distances on the order of 10 km or more. The pressure front could extend over hundreds of square kilometers.

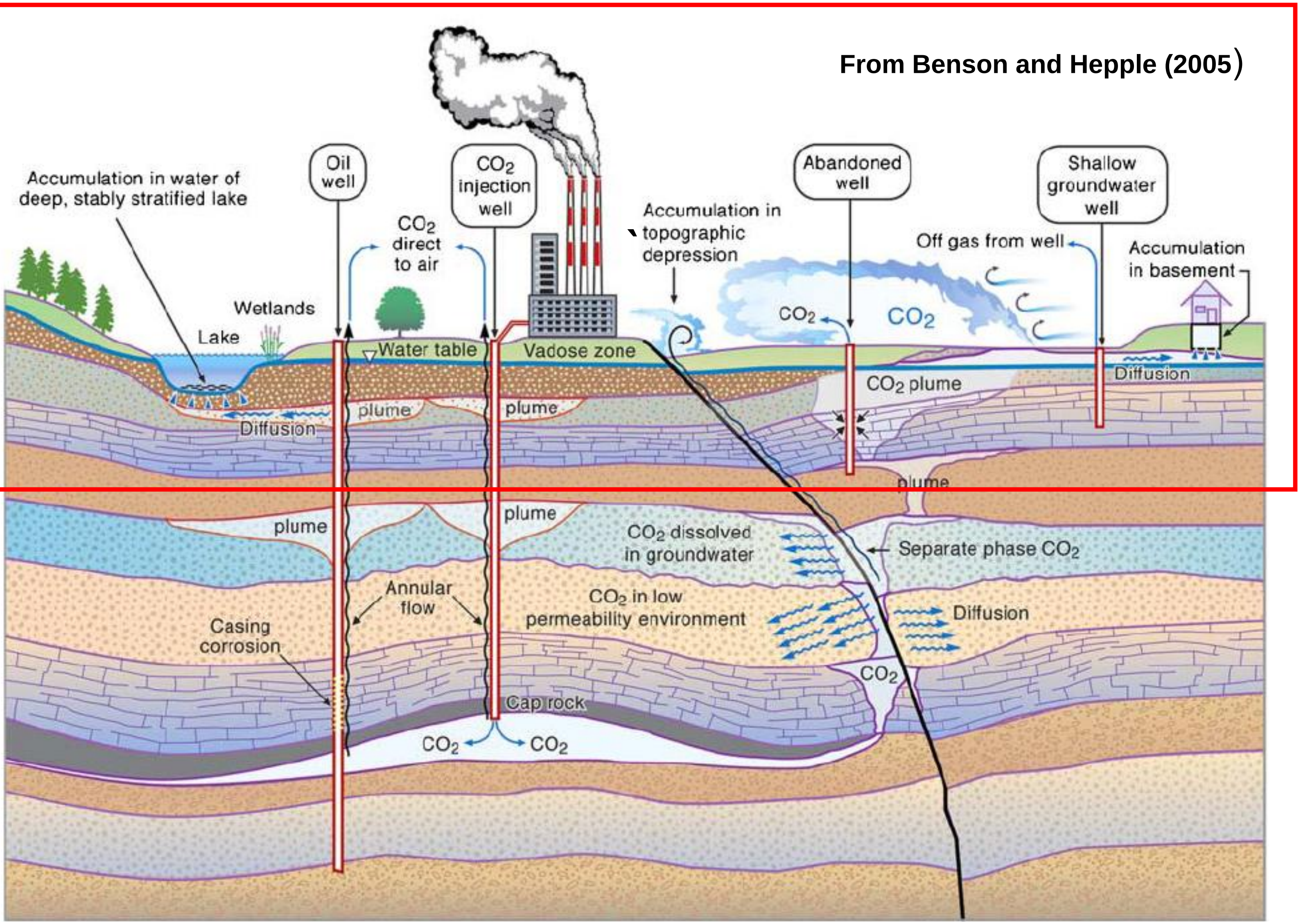


(Solutions by Nordbotten et.al)

Figure from Birkholzer et al., 2008

- Solutions will complement not replace need for numerical analysis.
- Can be used for designing monitoring strategies (e.g., pressure perturbation in overlying permeable formation).
- Computationally more efficient for evaluating leakage through abandoned wells

Current Research at Ada, OK Focused on Biosphere



Research Team for Geological Sequestration in ORD/Ada

- Engineer
- Engineer/numerical modeler (new hire)
- Geochemist
- Geochemist (NRC post-doc)
- Geophysicist (new hire)
- Geologists (2)
- Microbiologist

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2. Determine the feasibility of soil-gas, gas flux, and ground-water monitoring to evaluate the potential for leakage <u>prior</u> to injection and detect leakage <u>during</u> leakage from well penetrations, faults and fractures (Dom DiGiulio and Rick Wilkin, Ada, OK)

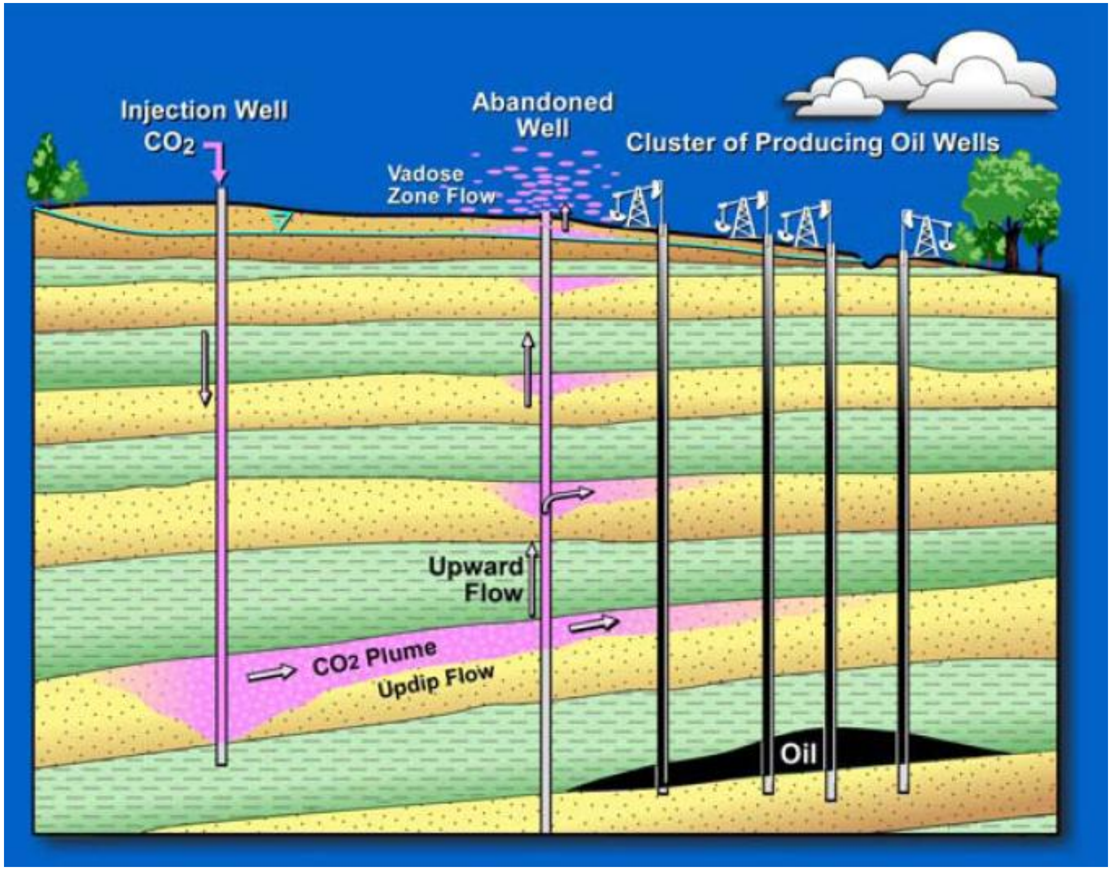


Figure from Celia et al. (2006)

It is widely acknowledged that leakage through transmissive faults (and associated fractures) and well penetrations (operational, non-operational, and abandoned wells) are the most likely potential pathways for CO_2 release from a storage formation at a properly selected site for GS. Emphasis is on wells that have been plugged and not “reworked”.

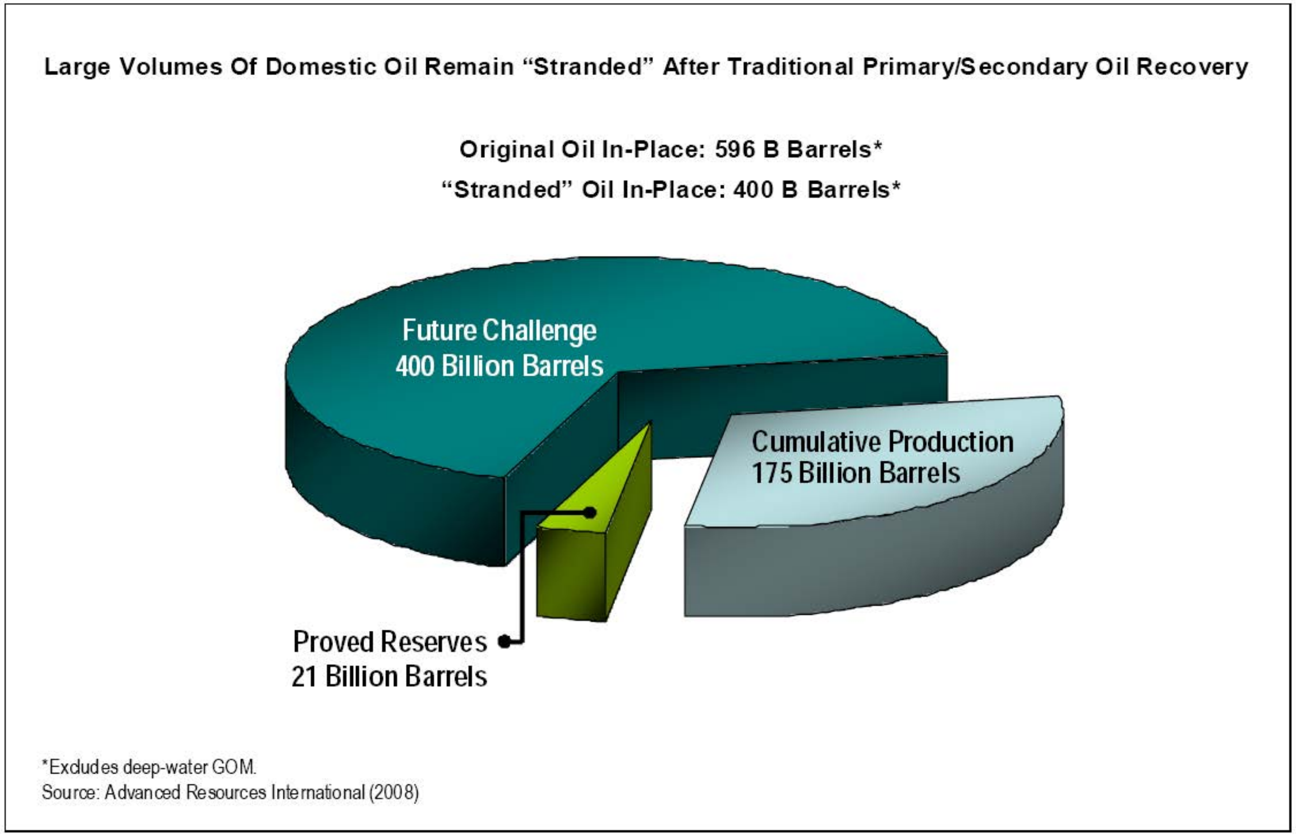
Density of Well Penetrations

Summary of statistics for the number of wells impacted by a typical CO_2 injection.

	Mean	Median	Range
High-density clusters	241.5	216	45-721
Medium-density clusters	62.6	61	8-144
Low-density Background	17.8	11	0-130

From Nordbotten et al., 2004

Focus is on Enhanced Oil Recovery Because of Well Penetrations and Potential for Growth



- Revenue for petroleum + carbon credits
- Tax revenue for States
- Infrastructure
- Mineral Rights.
- Site Characterization
- CO_2-EOR is 70% carbon neutral.100% possible.

Figure from: Storing CO2 with Enhanced Oil Recovery, DOE/NETL-402/1312/02-07-08

CO2-EOR could add 85 billion barrels of incremental domestic oil supply ~ (**4X current proved reserves**).

Research Strategy

Concept of advective gas flow to surface through faults and fractures is well established in geochemical and reservoir exploration and gas migration in active seismic areas. Gas migration through production or abandoned wells would have a spot anomaly near the surface, whereas gas migration through faults and fractures would be expressed as a linear trend or diffuse anomaly.

Release of CO_2 or brine into a USDW would likely be accompanied by measurable alteration in pH, major ions, and potential mobilization of hazardous inorganics. Release of CO_2 into the vadose zone would be accompanied by compositional changes in soil gas and flux to the atmosphere.

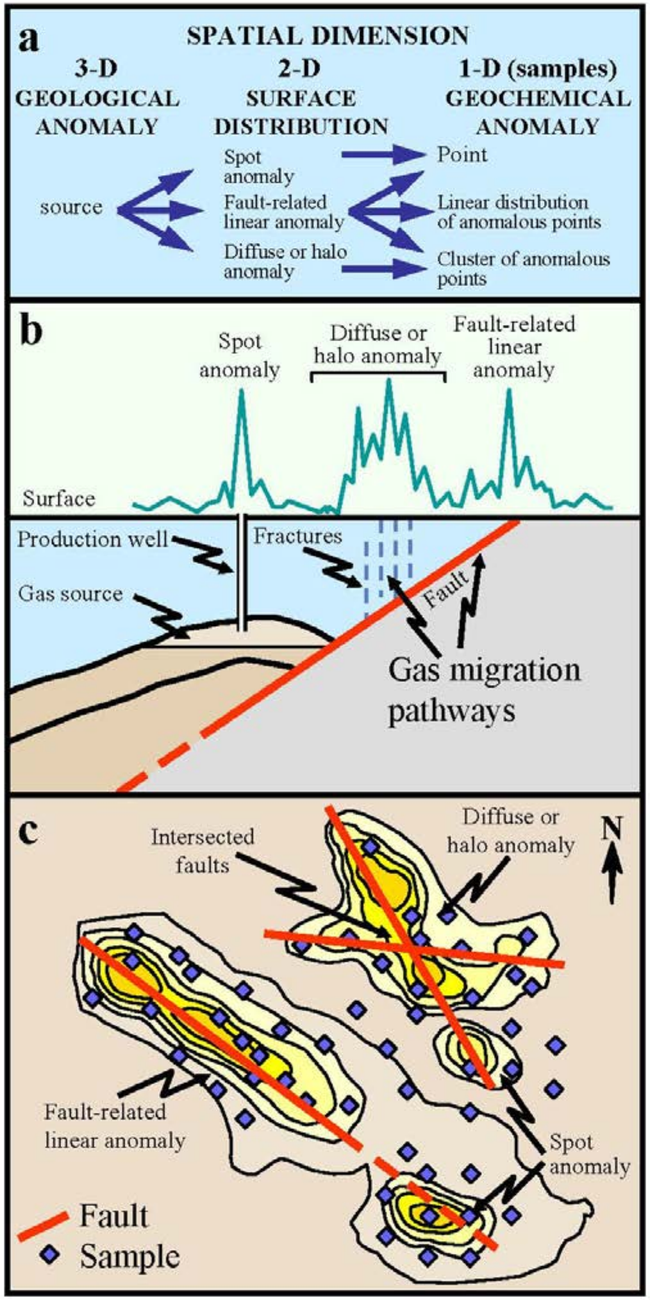


Figure modified from Ciotoli et al., (2004).

Research Strategy

Monitoring parameters: CH_4, C2-C4 hydrocarbons, CO_2, δ13C, Δ14C, H_2, He, H_2S, ^{222}Rn, major ions, pH, and inorganics.

Use of sensors for real-time monitoring and data acquisition.

Need a site, preferably EOR

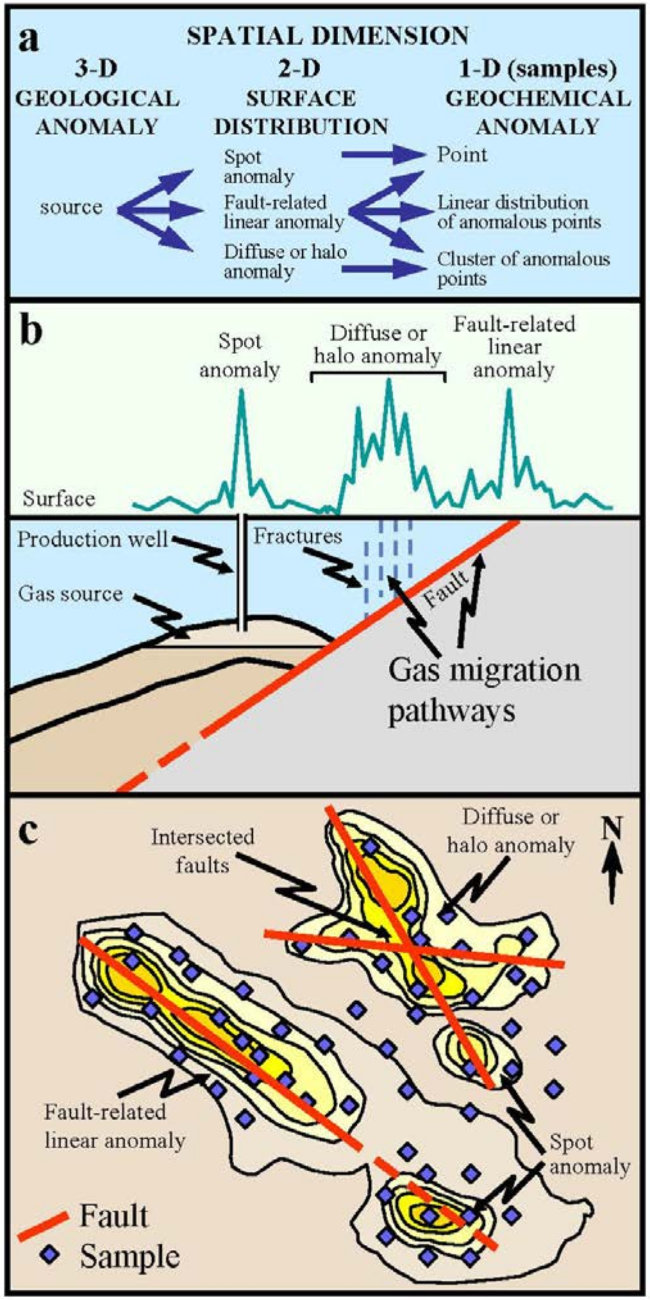
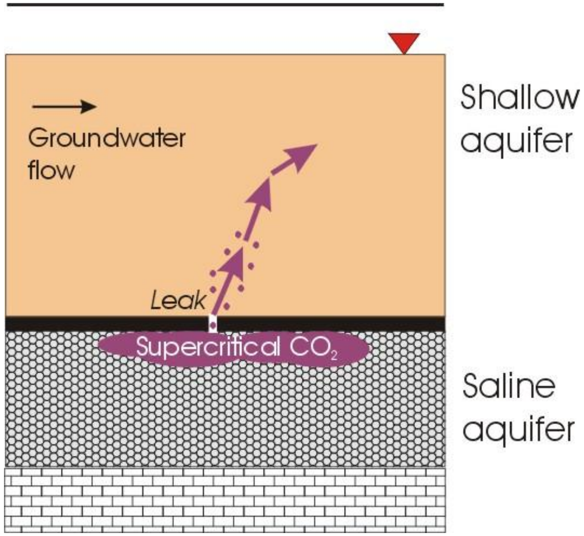


Figure modified from Ciotoli et al., (2004).

3. *Evaluate Impacts to USDWs due to CO2 Release from Geologic Sequestration Projects: Modeling and Experimental Studies (Rick Wilkin and NRC post-doc, Ada, OK)*

- pH decrease: $CO_2(g) + H_2O = H_2CO_3 = HCO_3^- + H^+$
- Trace metal solubilization
- Trace metal precipitation/sorption
- Interactions with aquifer matrix
- ➢ Monitoring strategies

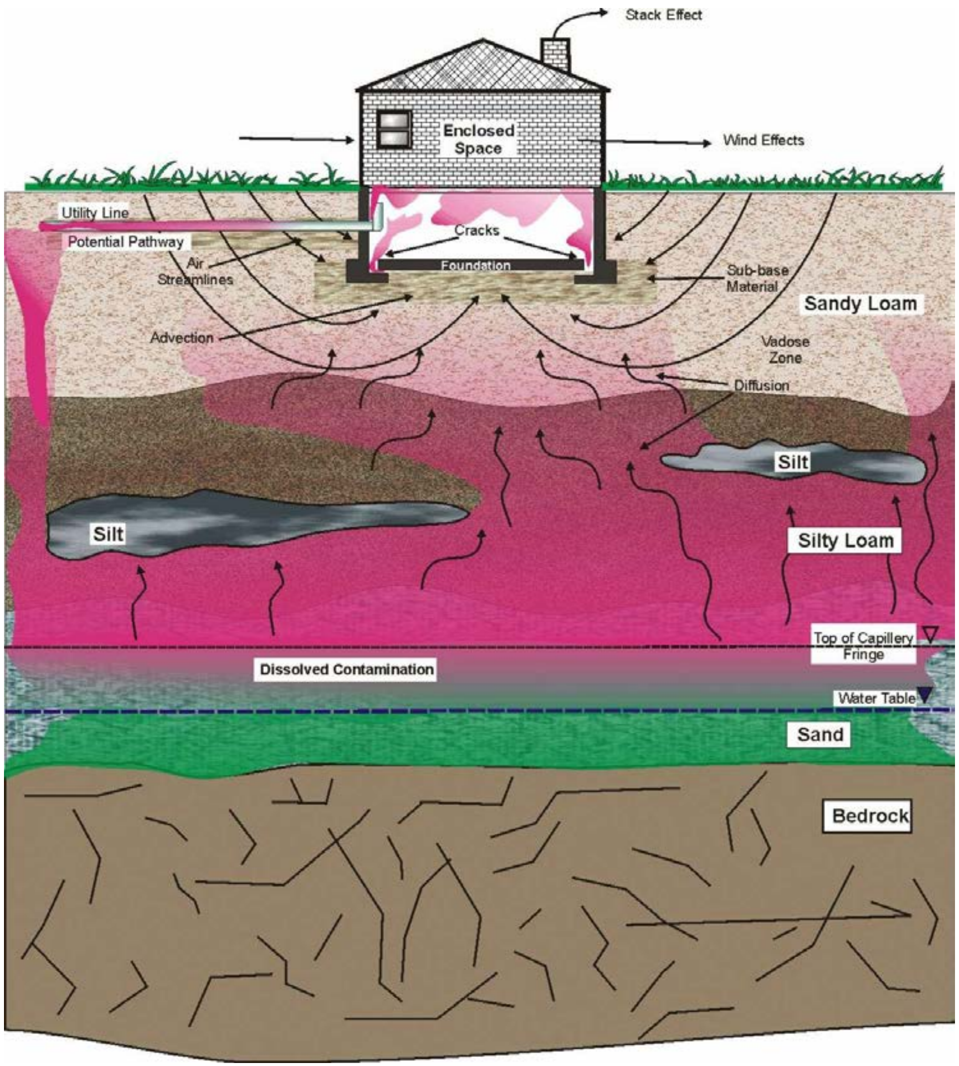


Evaluate Impacts to USDWs due to Carbon Dioxide Release from Geologic Sequestration Projects: Modeling and Experimental Studies

- Conduct column and batch-scale studies from formation (USDW) samples collected from test sites.
- Examine and simulate element partitioning and associated kinetics between the solid and aqueous phase over a range of CO_2 partial pressures.
- Where appropriate, modify geochemical databases with the most current thermochemical data.
- Use results to prepare sampling strategies for a controlled CO_2 injection field study.

4. CO_2 Intrusion into Buildings (Dom DiGiulio and Rick Wilkin, Ada,OK)

- It has already happened at an EOR facility (unpublished).
- If GS application causes elevated levels of CO_2 in the vadose zone, gas intrusion into buildings will occur.
- Elevated levels of CO_2 in buildings due to natural causes may be common. A protocol to enable rapid evaluation is needed to avoid public panic and unnecessary shutdown of a GS project if it is not the cause.



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Gas Intrusion Study in Valley Center, KS

During a period of heavy precipitation on September 13, 2008, dangerously low O_2 and elevated CO_2 levels were measured in indoor air in a number of homes in and around the Prairie Lakes Addition, near Valley Center and north of Wichita, Kansas. The lowest and highest O_2 and CO_2 concentration measured in indoor air was 10% and 7%, respectively.

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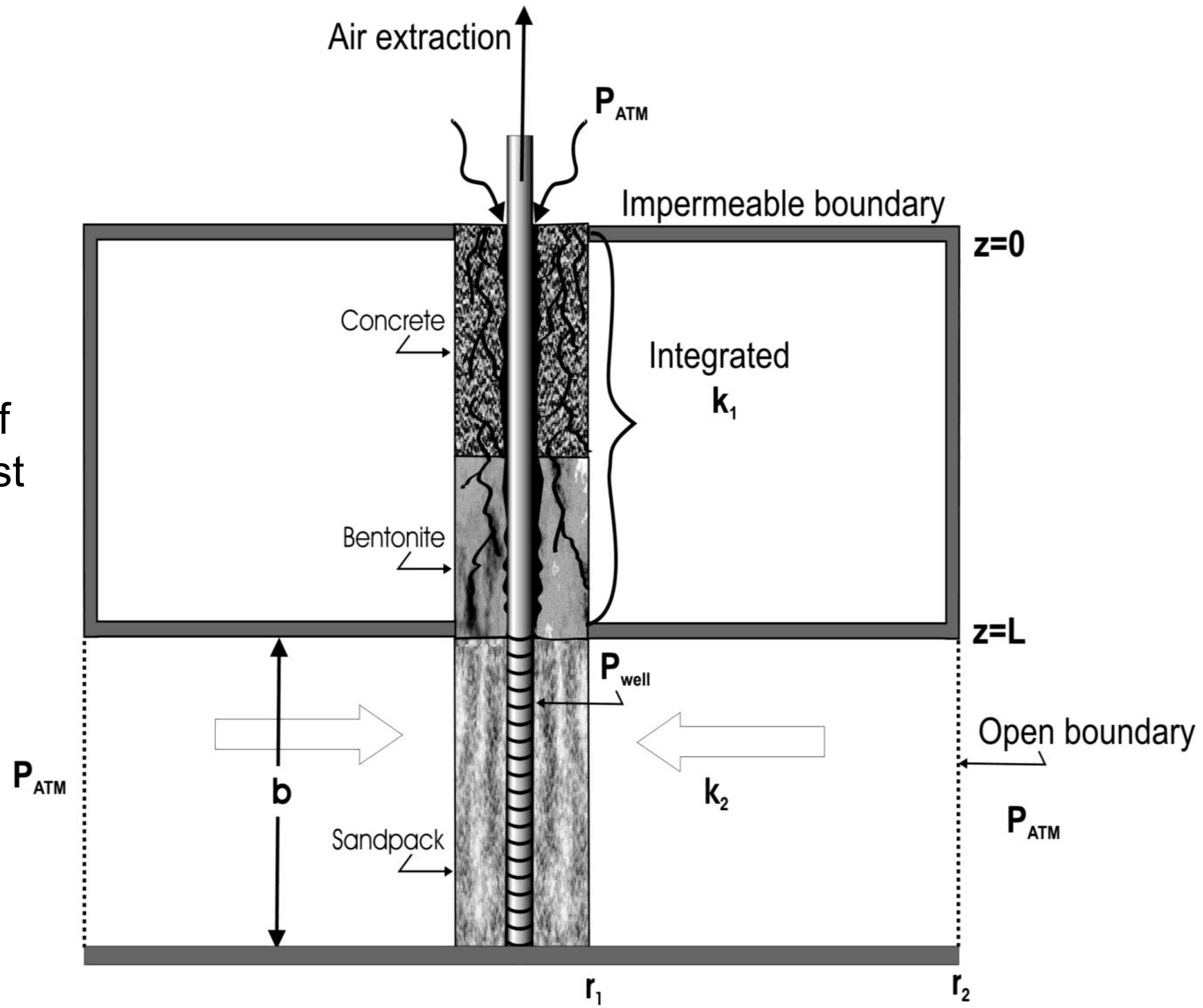
Gas Intrusion Study

- Funded by RARE money
- Supported by a Regional Research Partnership Program (RRPP) (3 month rotation to ORD + 12K per diem and 2K travel)

5. Soil-Gas Sampling Quality Assurance (Dom DiGiulio, Ada, OK)

Heuristic Analysis of leakage.

Leakage is a function of the permeability contrast between the borehole and surrounding media and geometric factors.



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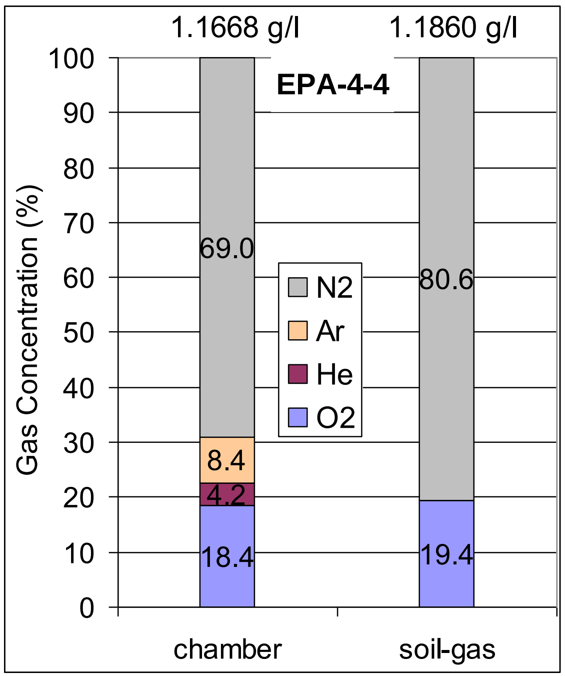
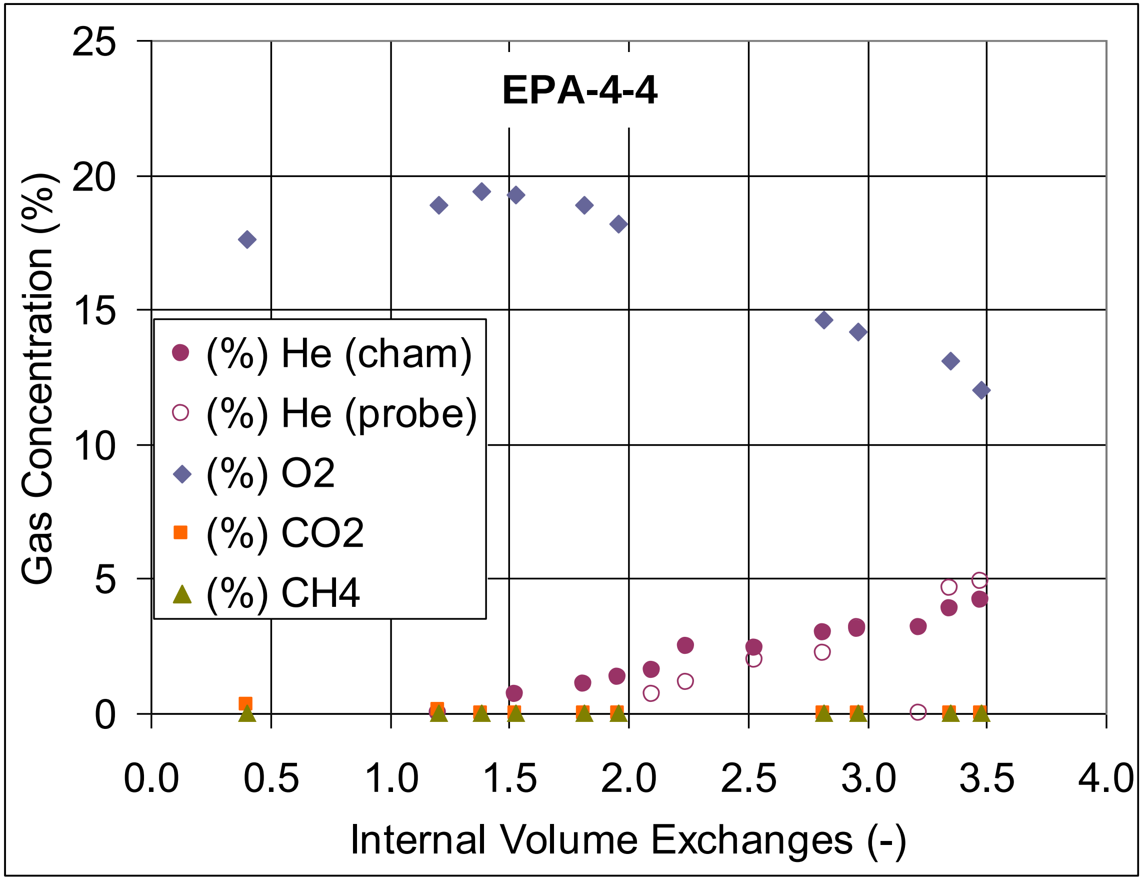
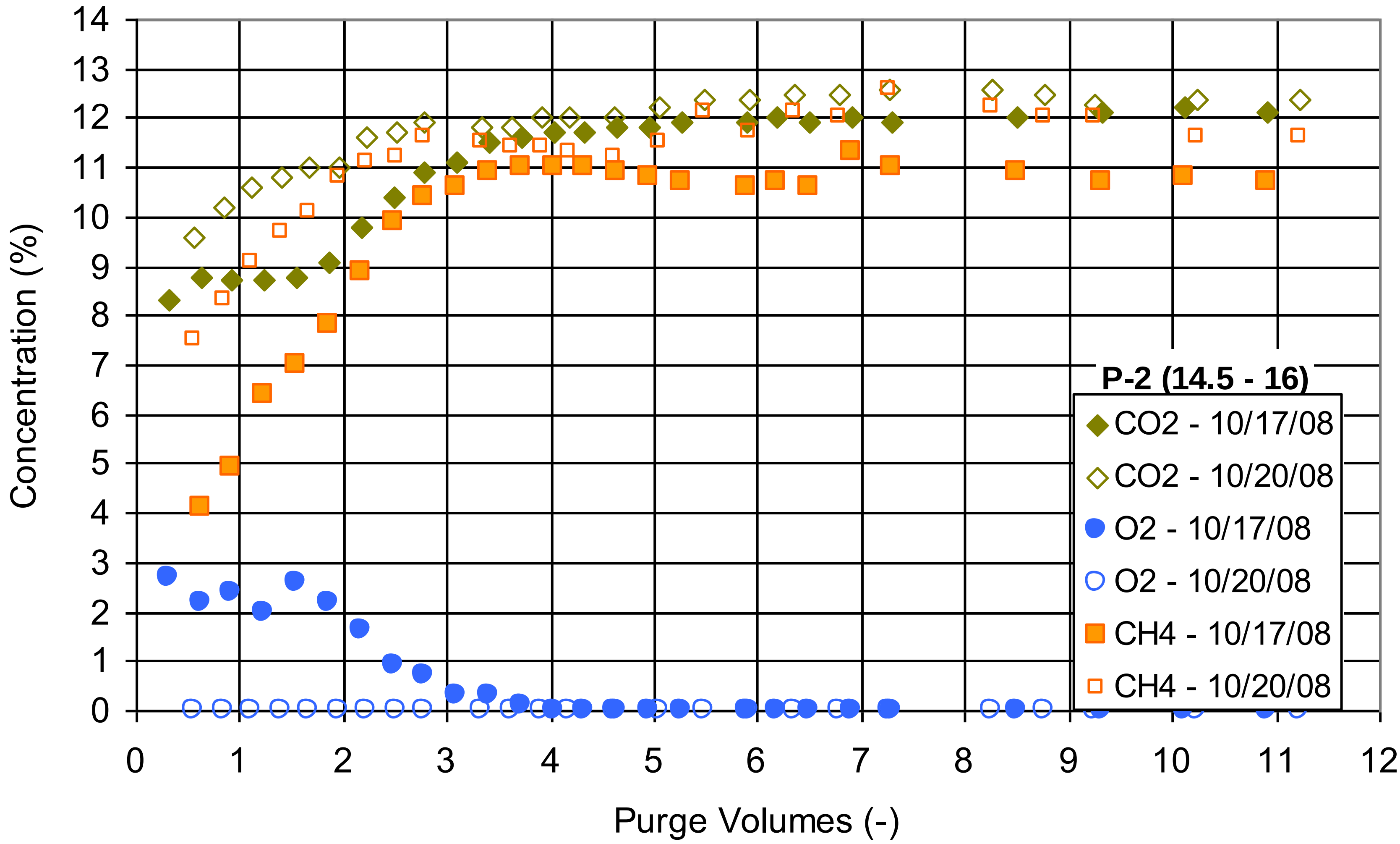
Sample Train Near Well Penetration

Leak Testing in Probe at Green River, Utah



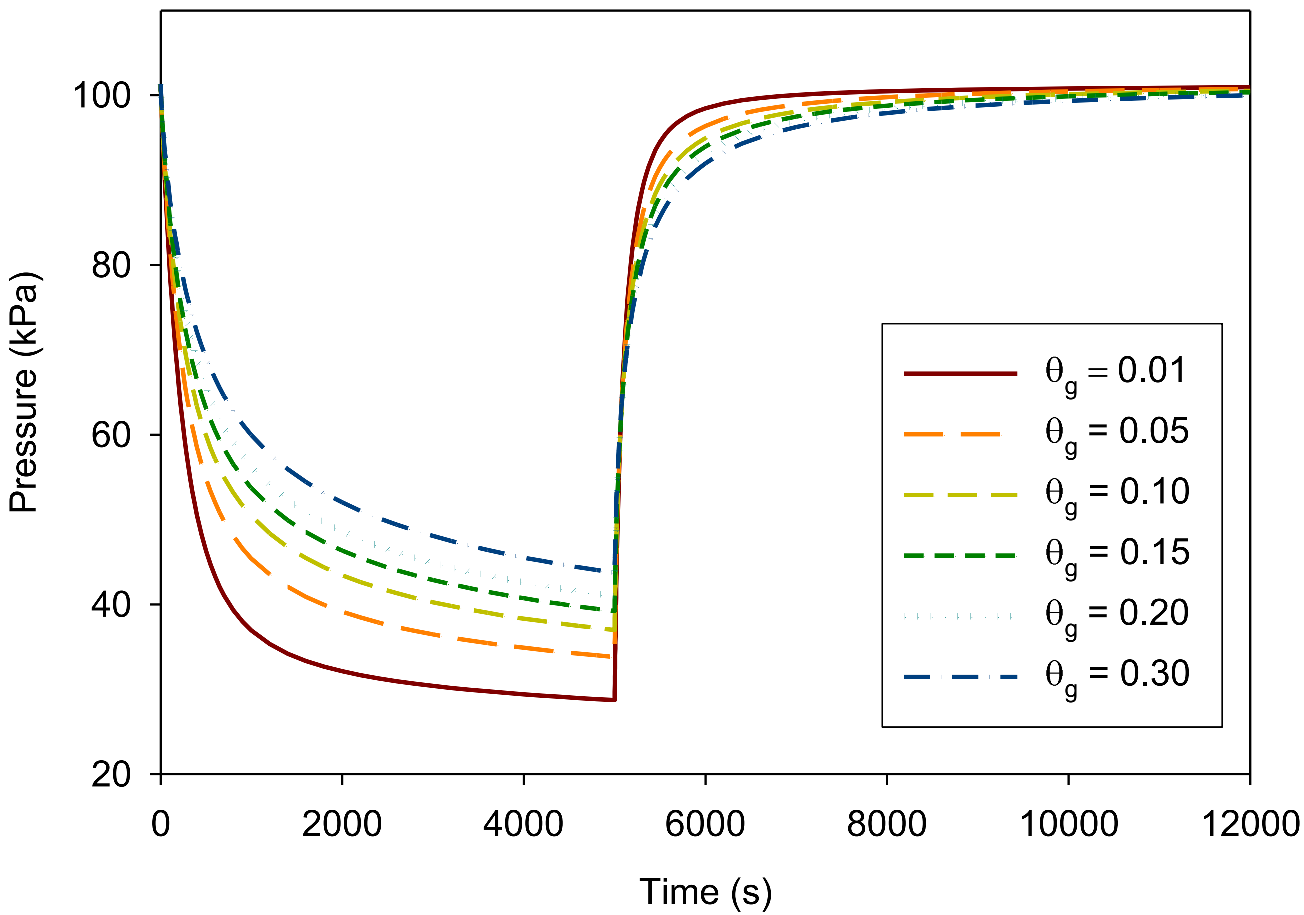


Purge Testing



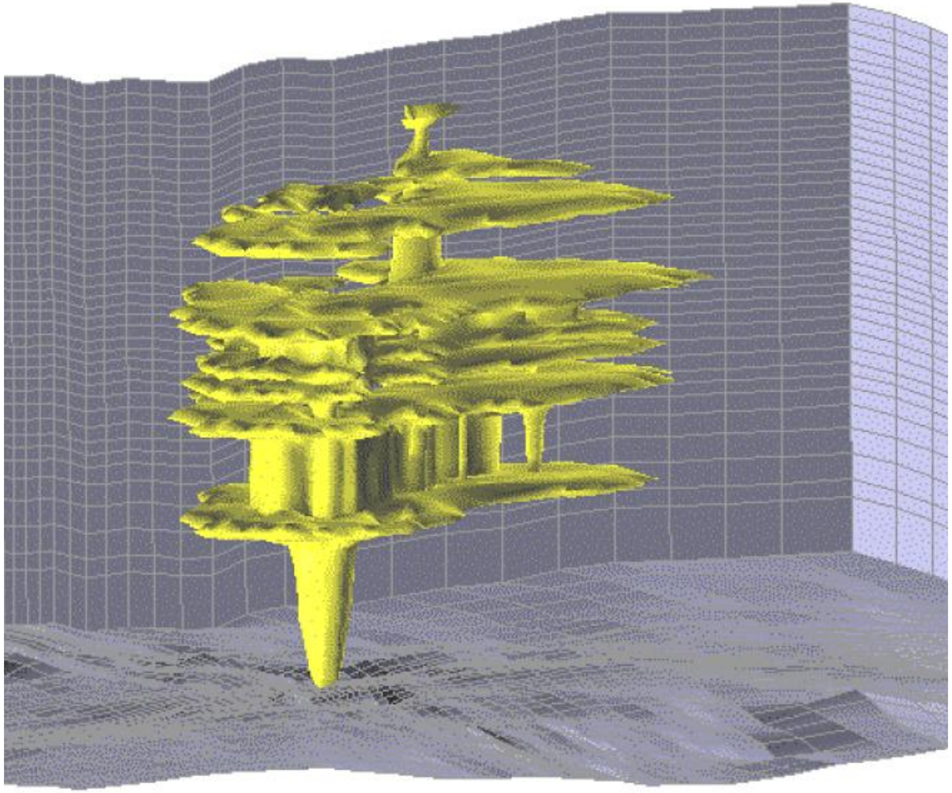
Transient Gas Permeability Testing

Axi-symmetric, finite radius, transient solution with borehole storage (Varadhan and DiGiulio, 2000)



New Project? Modeling-Monitoring Interplay

- Modeling assists in subsurface conceptualization and identifies variables that control CO_2 migration and pressure increase.
- Measurements made over a short time frame and small distance ensure use of reasonable values for these variables.
- Calibrated models can then be used to develop larger scale and longer time frame injections



3D flow simulation of the 1999 Sleipner plume from Best Practice for the Storage of CO2 in Saline Aquifers

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New Project?

Controlled Injection of CO_2 into Ground Water

Monitor geochemical perturbation and return to baseline conditions.

<u>Source</u>: Ji, W., A. Dahmani, D. Ahlfeld, J. Lin, and E. Hill. 1993. Laboratory study of air sparging: Air flow visualization. *Groundwater Monitoring and Remediation*, v.13, no. 4, p. 115-126.

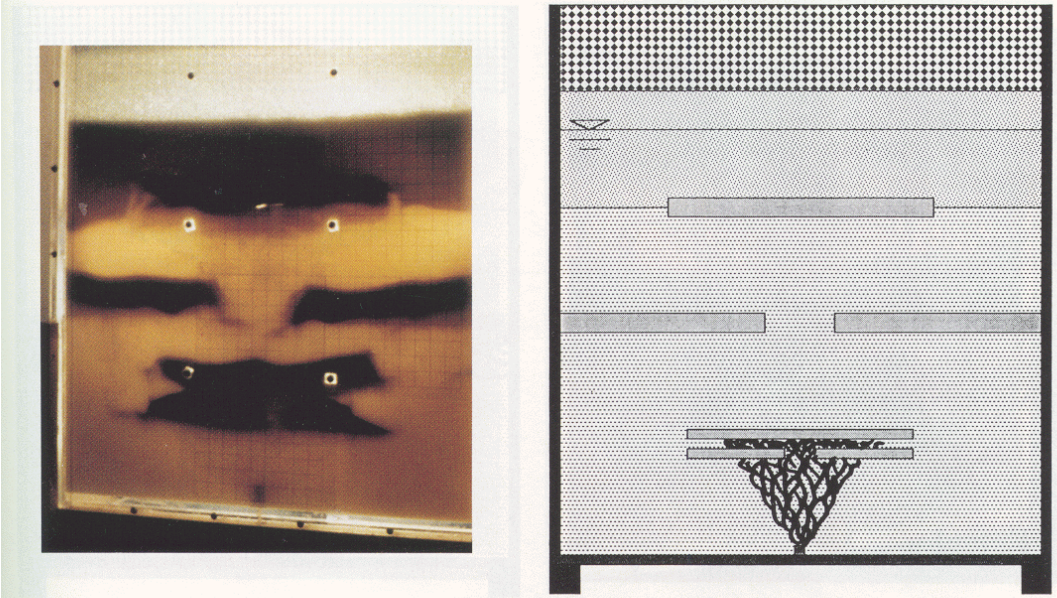

Figure 14. Air channel pattern at start of air injection in a stratified medium: (a) photograph; (b) drawing.

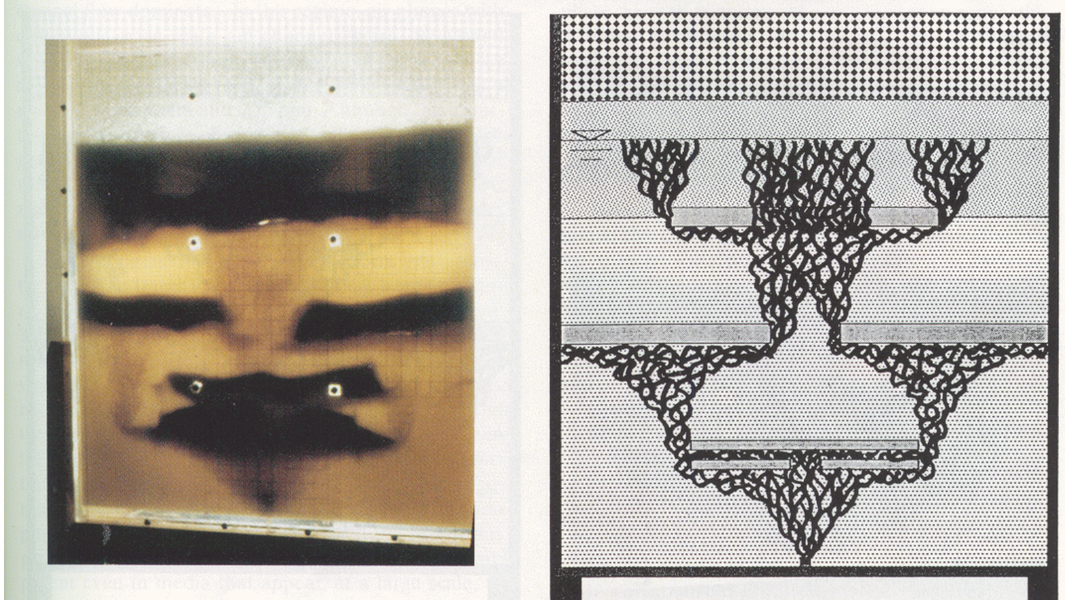

Figure 15. Air channel pattern in a stratified medium at lower air injection rates: (a) photograph; (b) drawing.

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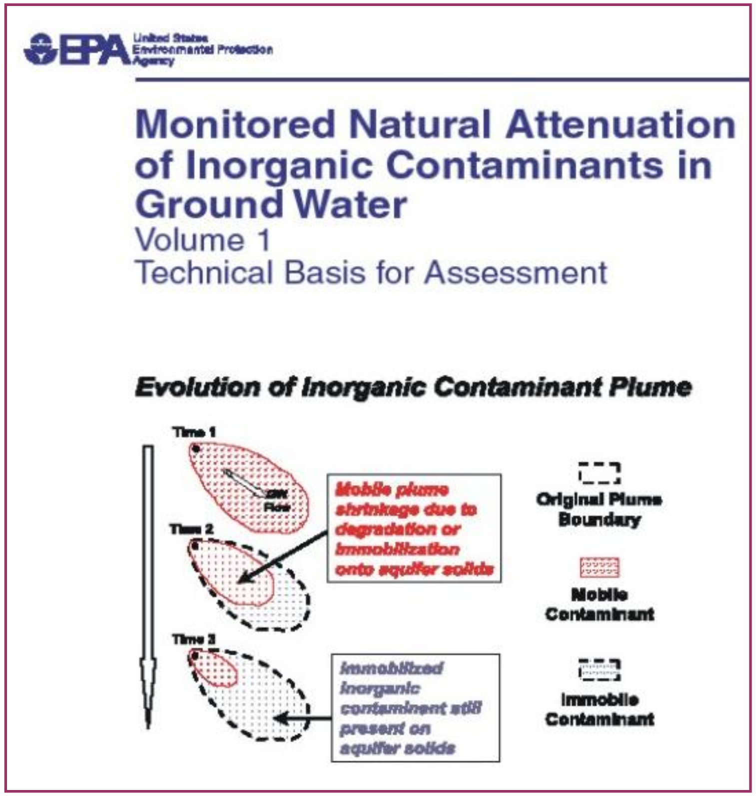
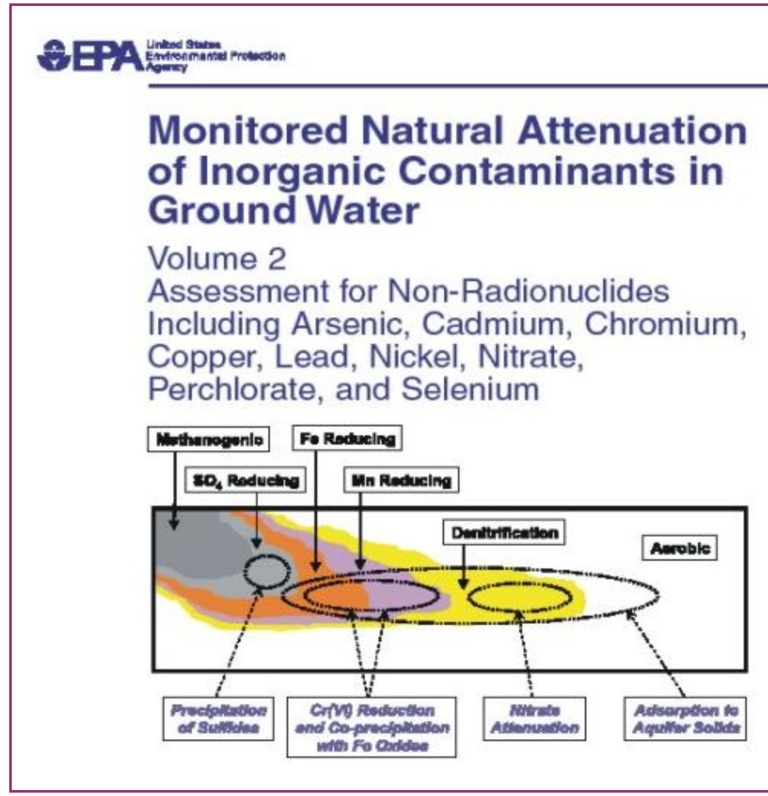
Recent EPA Reports on Monitored Natural Attenuation of Inorganics





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