Role of geochemical monitoring in geologic sequestration

GCCC Digital Publication Series #10-08

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Keywords:
Monitoring, Overview

Cited as:
Nicot, J.-P., Romanak, K.D., Yang, C., Smyth, R.C., and Hovorka, S., Role of geochemical monitoring in geologic sequestration: presented at the Geologic Carbon Sequestration Site Integrity Workshop – Characterization and Monitoring Science and Technology, Ohio State University, Columbus, OH, June 7-8, 2010. GCCC Digital Publication Series #10-08.

Role of Geochemical Monitoring in Geologic Sequestration

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Geologic Carbon Sequestration Workshop

OSU - Columbus, OH

June 7, 2010

Purposes of Monitoring (*General*)

- Ensure HSE of public and workers
  - injection wells, pipeline – operational phase
  - seismicity, environment, ground water quality
- Verify CO_2 storage (mass balance)
- Confirm predictions of CO_2 migration (plume movement, migration rates, but also pressure distribution)
- Early warnings of storage failure

From IPCC, 2005

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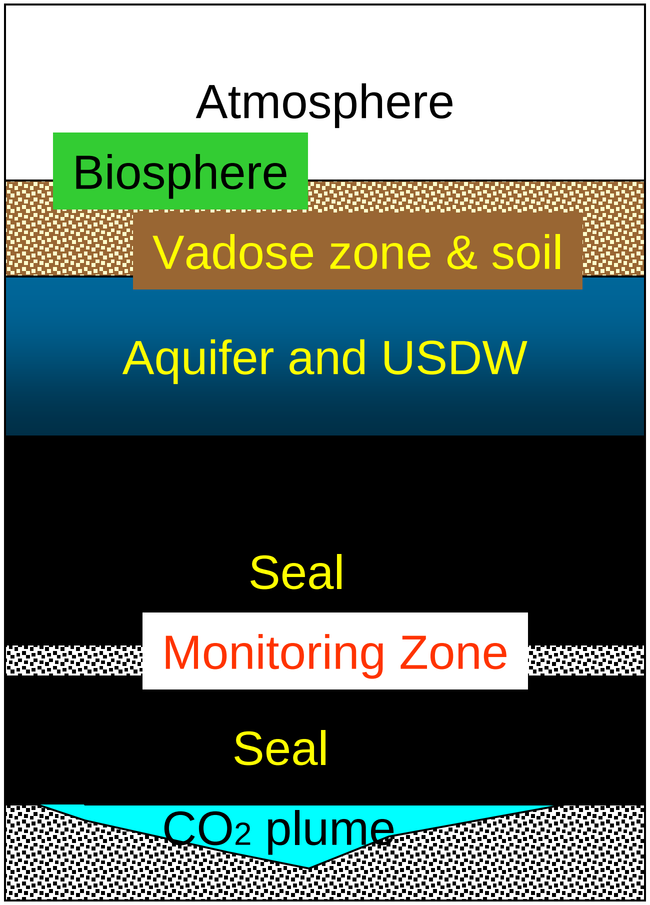
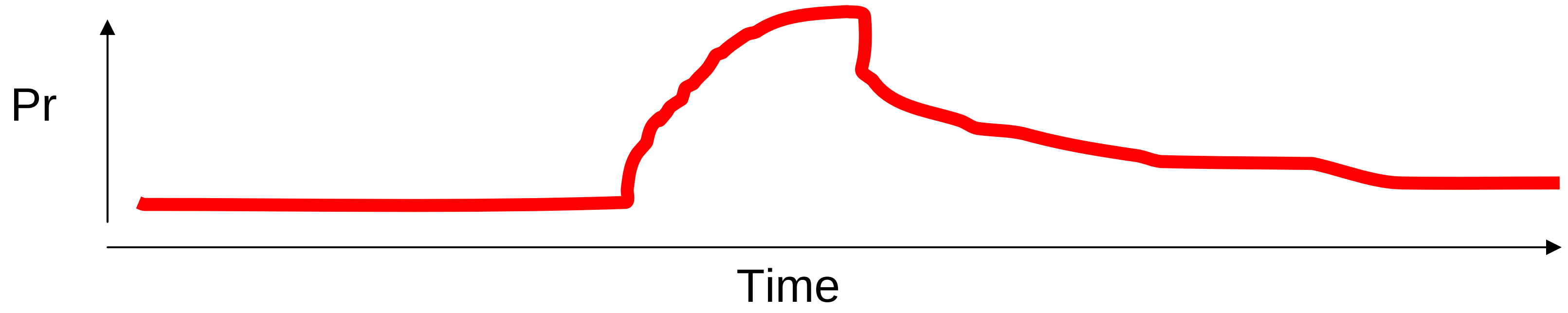
Where: Location of Geochemical Sampling



- **Low pressure, lower cost**
  - Atmosphere (dynamic)
  - Soil gas (dynamic – cumul.)
  - Aquifer (cumul.)
- **Downhole / wellhead – high pressure, higher cost**
  - Above zone (first indicator)
  - Seal
  - In plume
  - Outside plume

From Sue Hovorka



- When: Establish **baseline** (reservoir and injection fluids, aquifer composition, soil gas composition, rock mineralogy, etc.) – **characterization vs. monitoring** – how much, how long before injection? Monitoring occurs during and post-injection
- Mode: **research** vs. commercial:
  - Learn about subsurface processes
  - Provide data for model calibration
  - Compare monitoring methods

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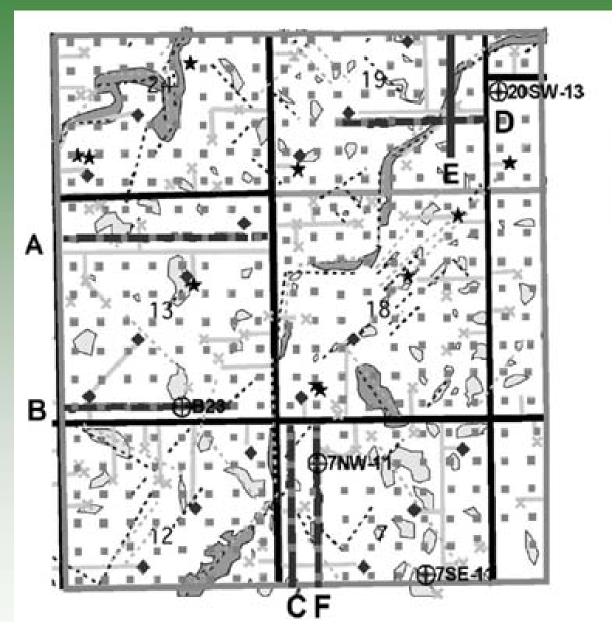
Research vs. commercial

- Weyburn dense grid – not realistic in commercial mode – what is the real value?

Soil-Gas Approach

- Full-field characterization- large spatial area with dense grids.
- Targeted - small spatial area focused on process.



Weyburn soil-gas grid. (Riding and Rochelle, 2009). 14 km^2, 200 m spacing

Romanak, NETL meeting, 2010

What to measure:

- Direct vs. indirect and intrusive vs. non-intrusive, geochemical measurements are necessarily intrusive (bar atmospheric) and mostly indirect
- TDS (EC), major, minor, and trace element concentrations
- pH, alkalinity
- Natural tracers (C, O, H isotopes, noble gases)
- Introduced tracers (SF_6, PFC, noble gas)

Proposed regulations

- Class VI:
  - Monitoring plan must be submitted with application
  - geochemical characterization of rock and water of injection strata, confining zones, above-zone strata, and USDWs §146.82(g)
  - GW monitoring required §146.82(d)
  - Soil gas and atmospheric not required §146.82(h)
  - "monitoring geochemical changes in the subsurface" in preamble – would require monitoring wells in injection Fm.
  - Use of (introduced) tracers not required

Is geochemical monitoring useful?

- It is required by proposed regulations but is it useful?
- Workflow: characterization, modeling, risk assessment, monitoring plan
- Permits dispensed by regulators, they will need standards to assess applications
- Let's monitor pH, alkalinity, and trace elements. Is it this simple?

Ideal (necessary?) attributes of geochemical monitoring

- In addition to efficient (no false >0 <0 at cost), monitoring needs to be:
  1) parsimonious (no redundant techniques) – not sustainable to have many heavily instrumented sites – what is the minimum set of techniques needed
  2) hierarchical (escalate monitoring as indicators go red) – not practical to monitor many parameters all the time – who is going to interpret the data?
  3) simple (no expert guidance needed) – monitoring of numerous sites cannot be done by experts only; clear standards on sampling and interpretation
- Primary, core, basic vs. secondary, additional, enhanced

Shallow aquifer monitoring

- Need to find a parameter sensitive enough
- Increase in DIC and trace metals, decrease in pH?
- Water-rock interactions must be part of the water chemistry interpretation (e.g., Yang, BEG)
- CO_2 concentrations vary spatially and temporally: seasons, land-use changes (change in recharge – Scanlon, BEG) = false positives
- Calcite rock/cement buffers pH but complications with incongruent dissolution of dolomite and gypsum dissolution (Romanak, BEG) = false negatives

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Shallow aquifer monitoring

- Need to find a parameter sensitive enough
- Increase in [illegible] pH?

TDS and possible heavy metal increase if brine leakage

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Laboratory batch experiments

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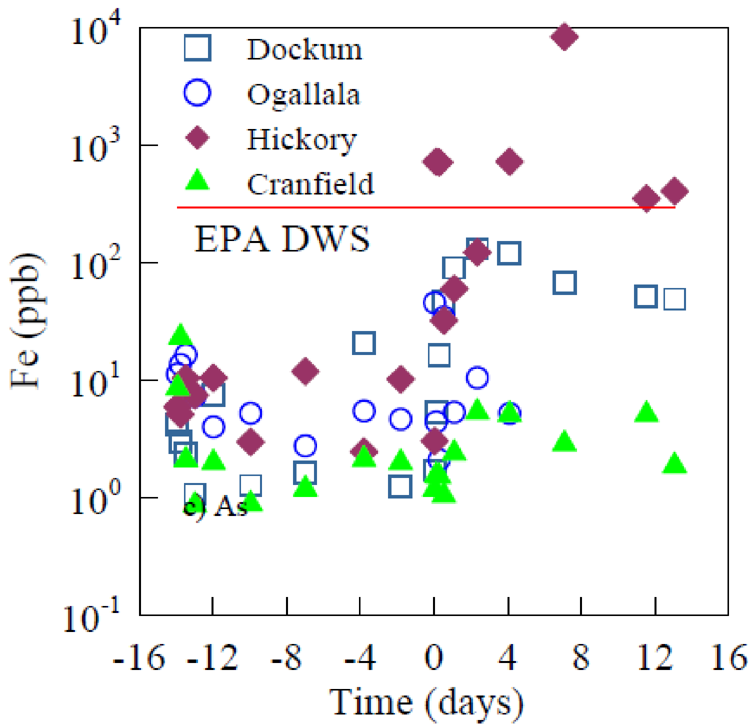
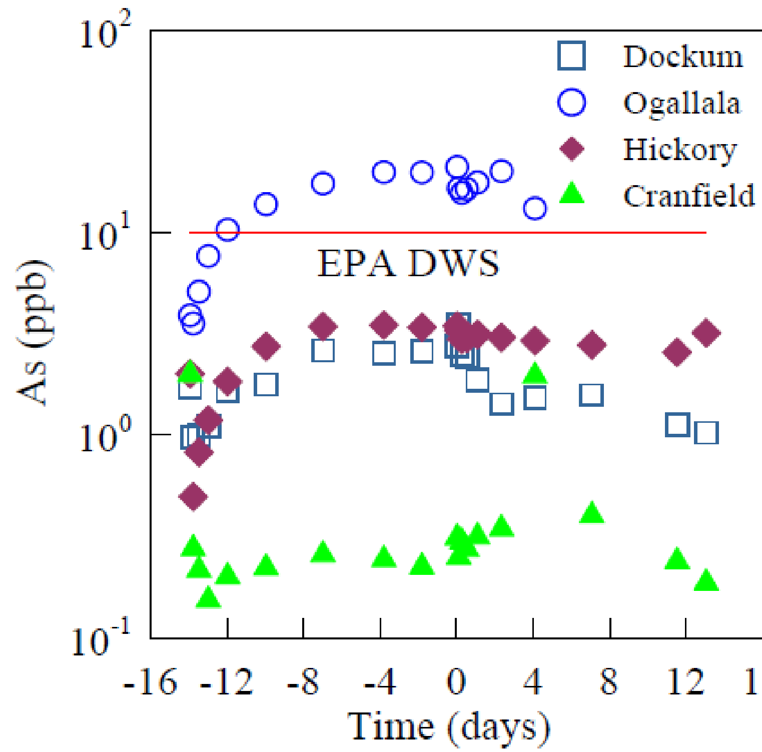
- Ar then CO_2 bubbling (1 atm) in water-rock systems
- Siliciclastic aquifers w/ carb. (Dck, Og) and w/o (Hck, loess)





Lu et al., 2009, EEG; Yang et al., 2010, IJGGC

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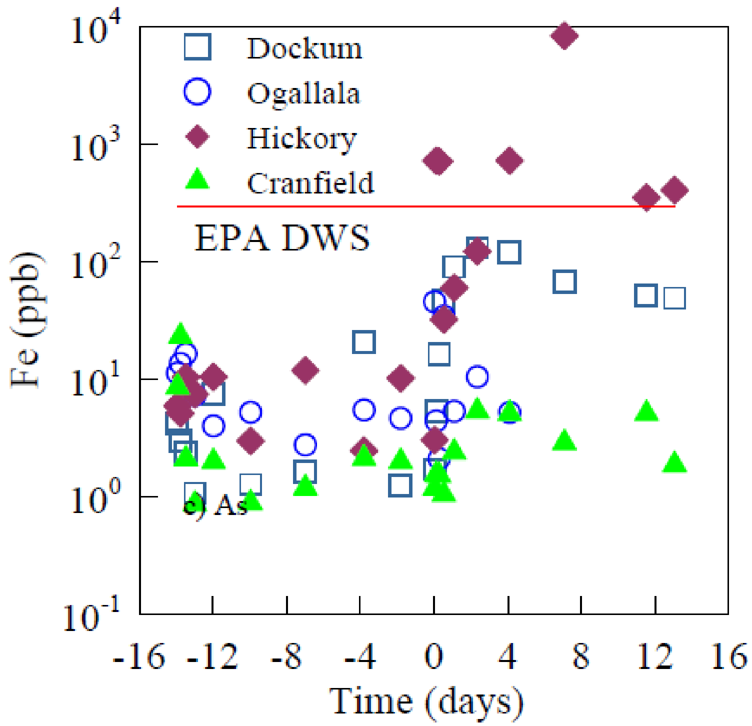
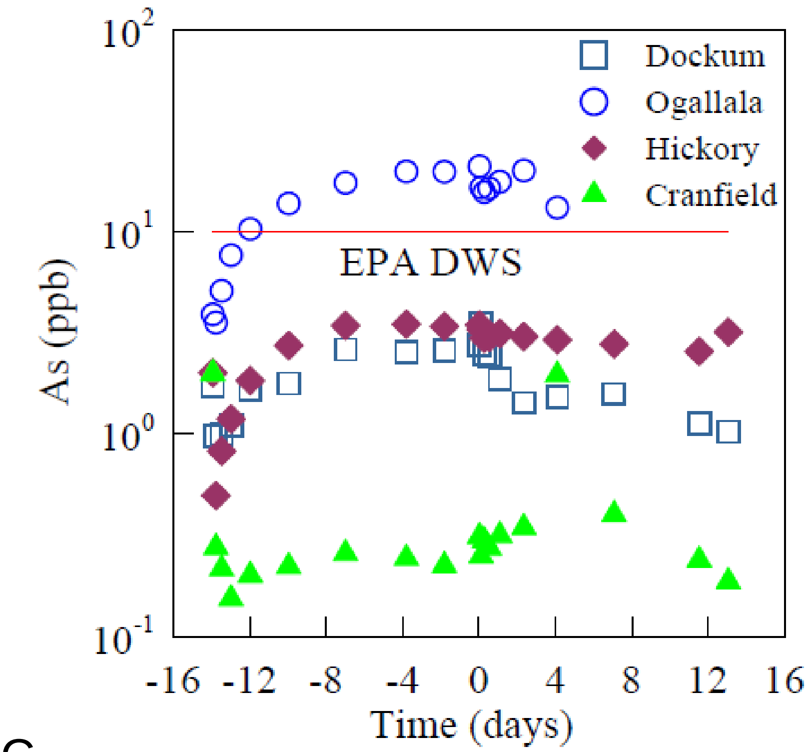
Laboratory batch experiments

- Some decrease in concentration after a few days even as injection continues (are trace metals a good indicator?)
- Increase in As (cation group 2) before injection of CO_2 (is increase necessarily due to CO_2 leakage?)





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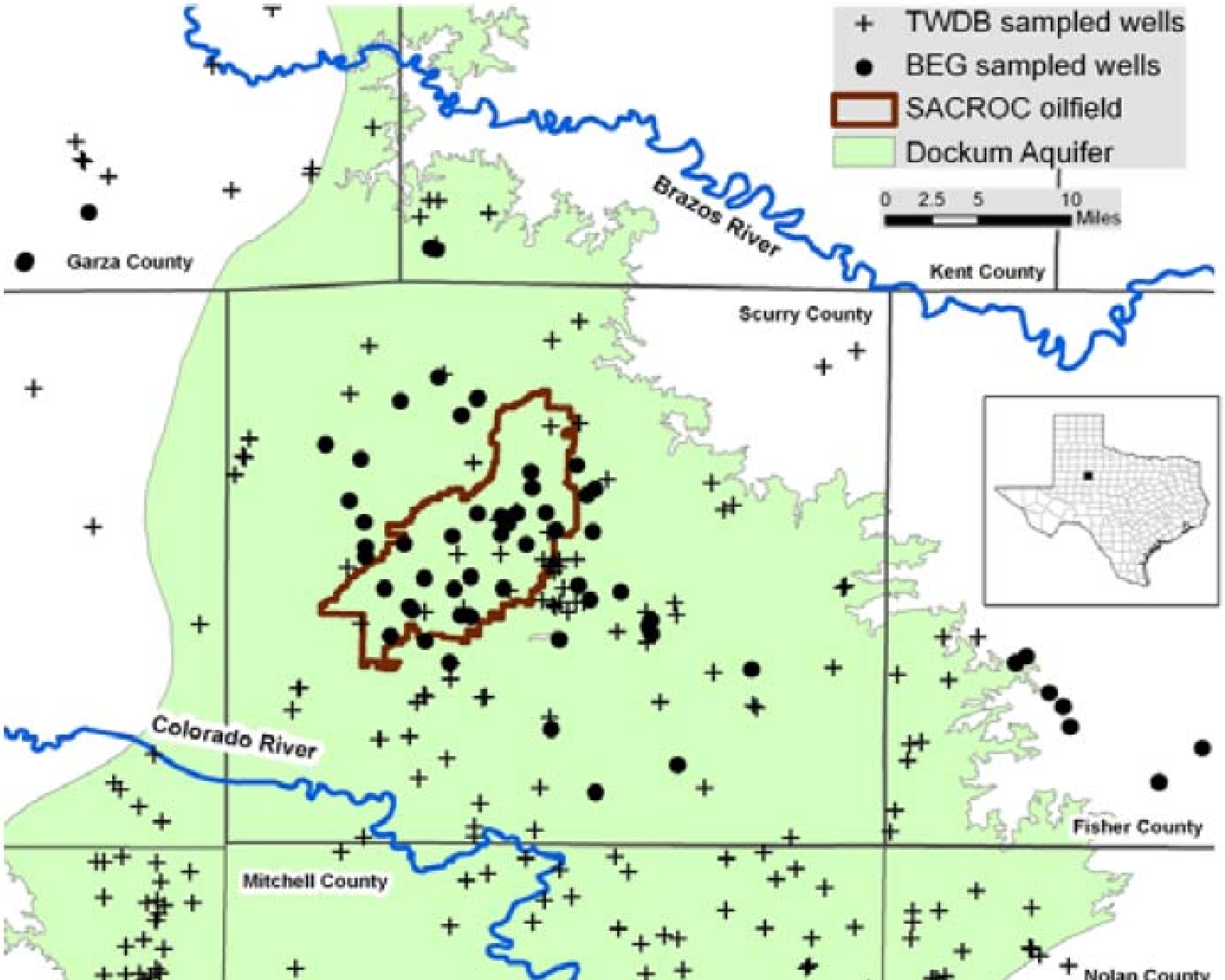
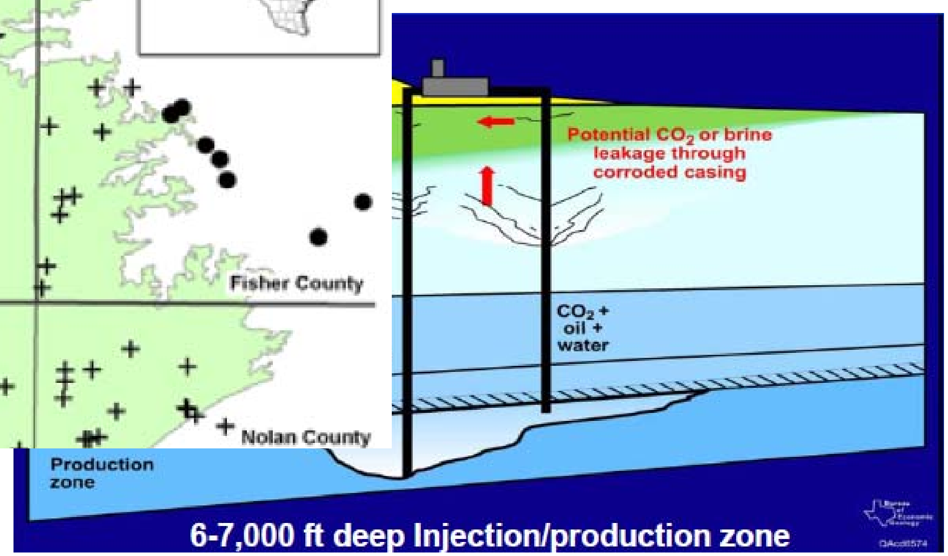
The SACROC case



Sampling points



Smyth et al., 2008

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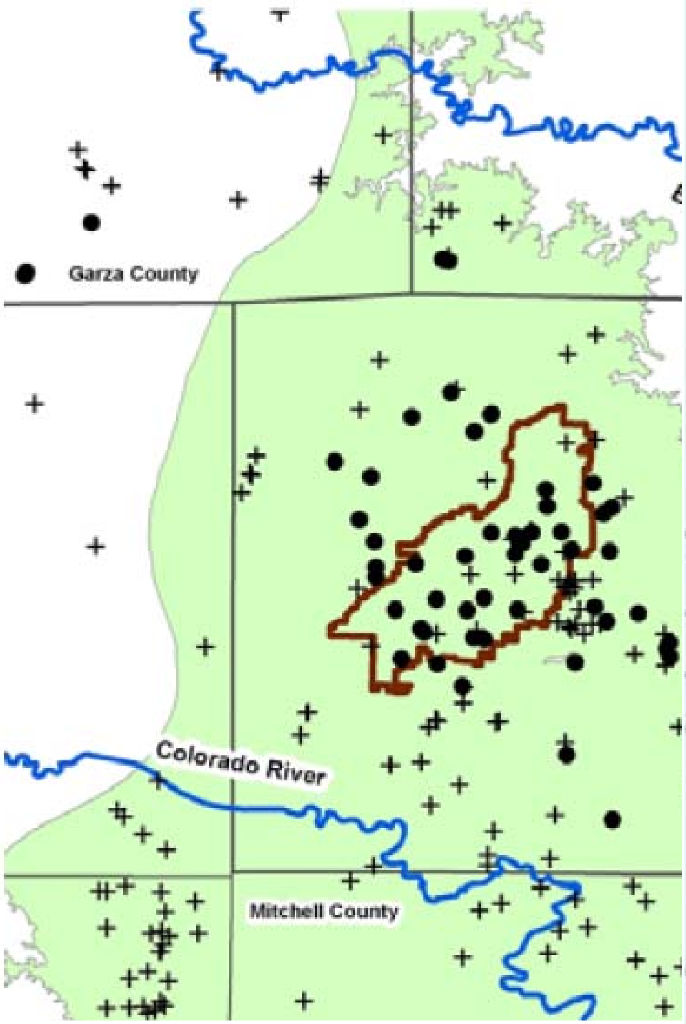

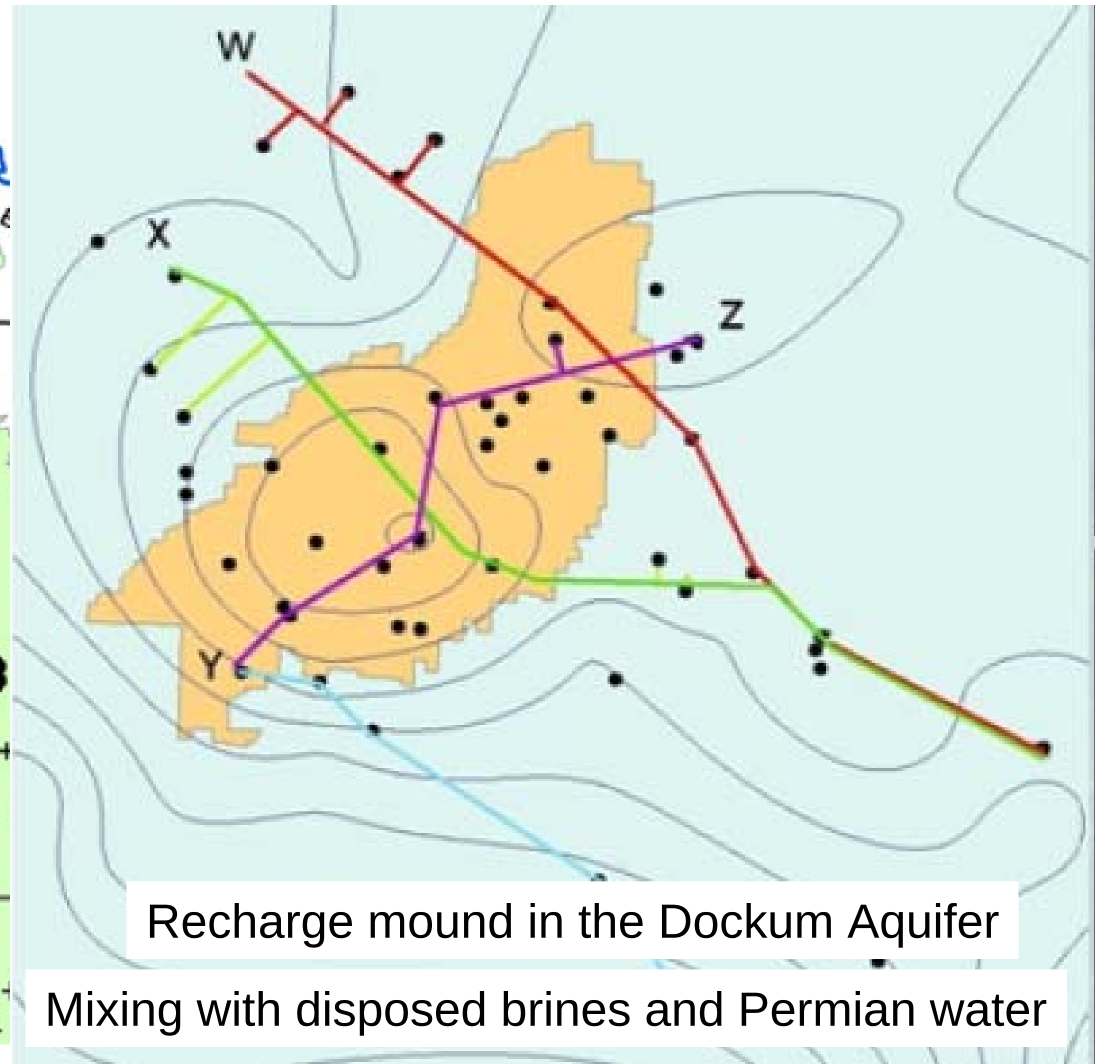

Smyth et al., 2008

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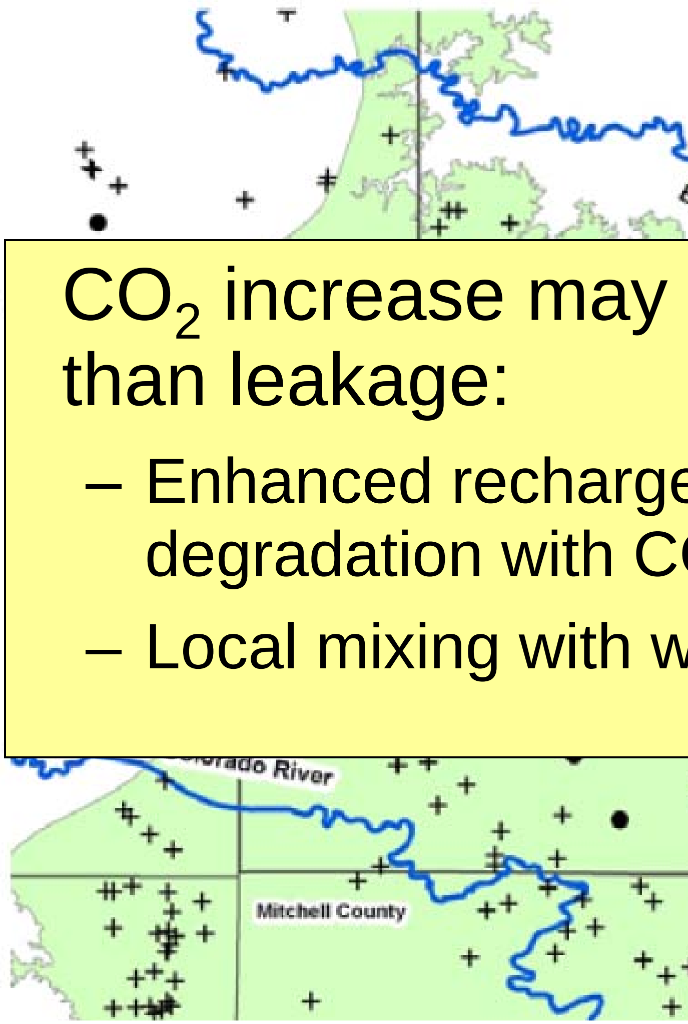
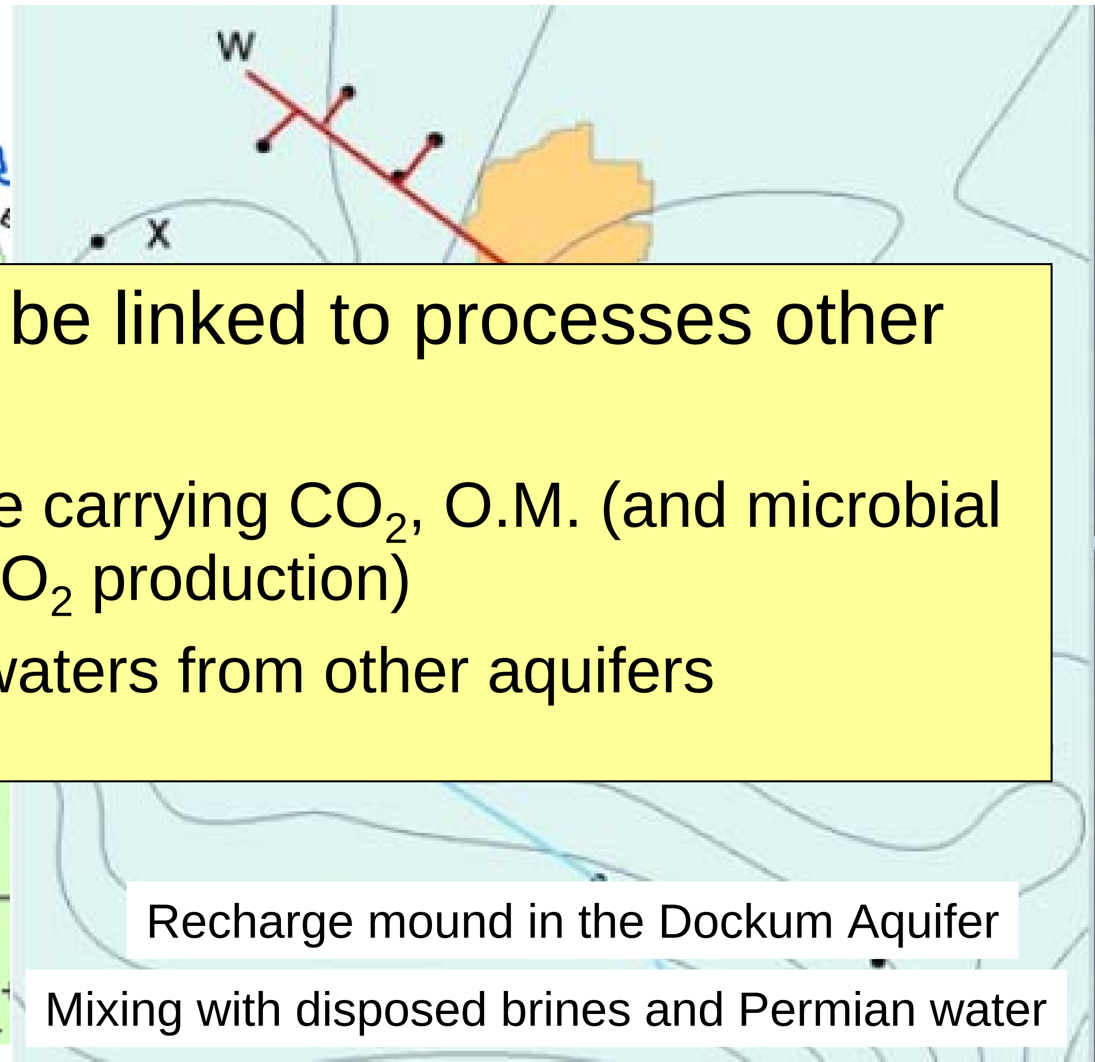
The SACROC case



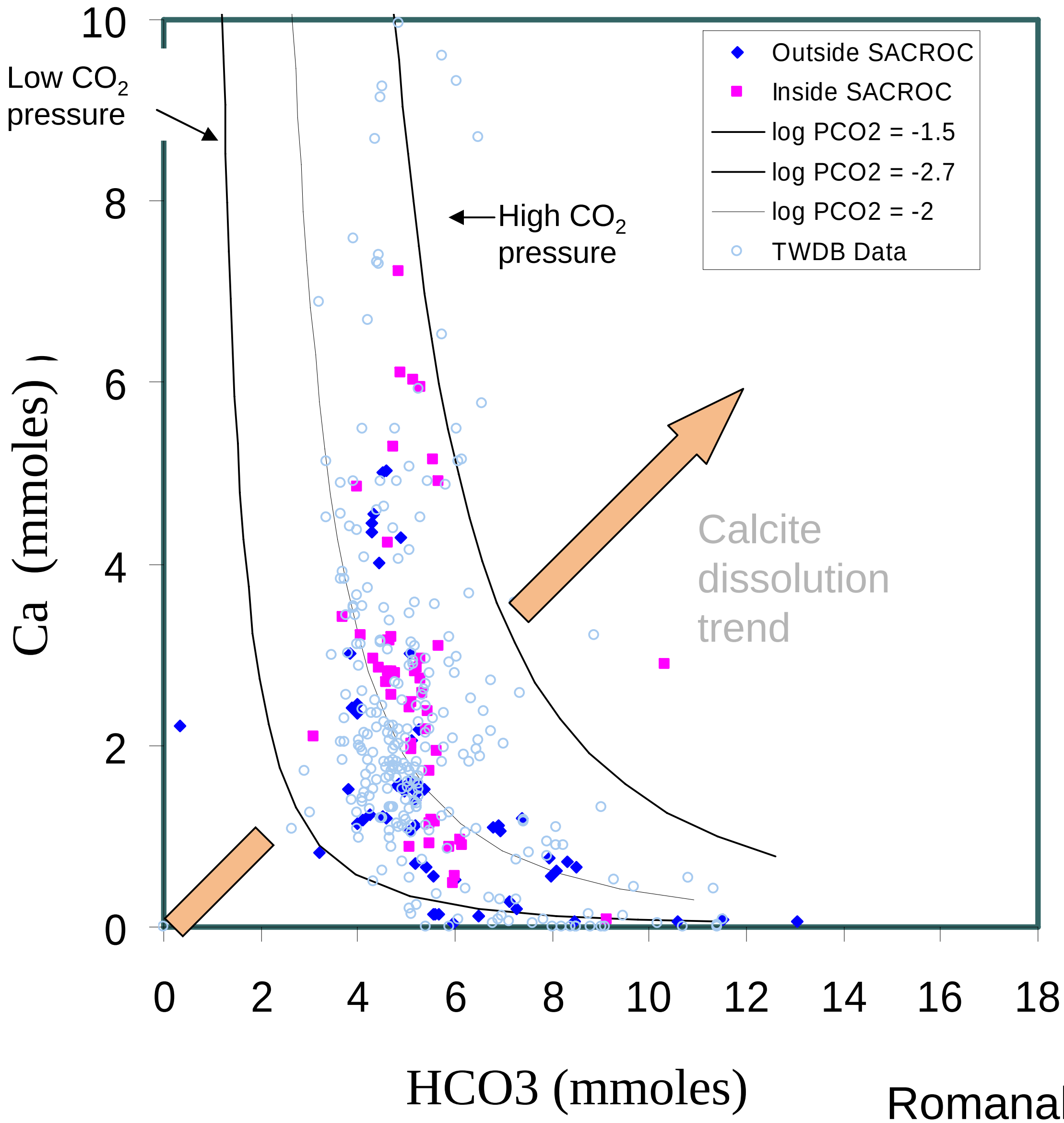


CO_2 increase may be linked to processes other than leakage:

- Enhanced recharge carrying CO_2, O.M. (and microbial degradation with CO_2 production)
- Local mixing with waters from other aquifers

Smyth et al., 2008

Mixing creates a complex carbonate svstem

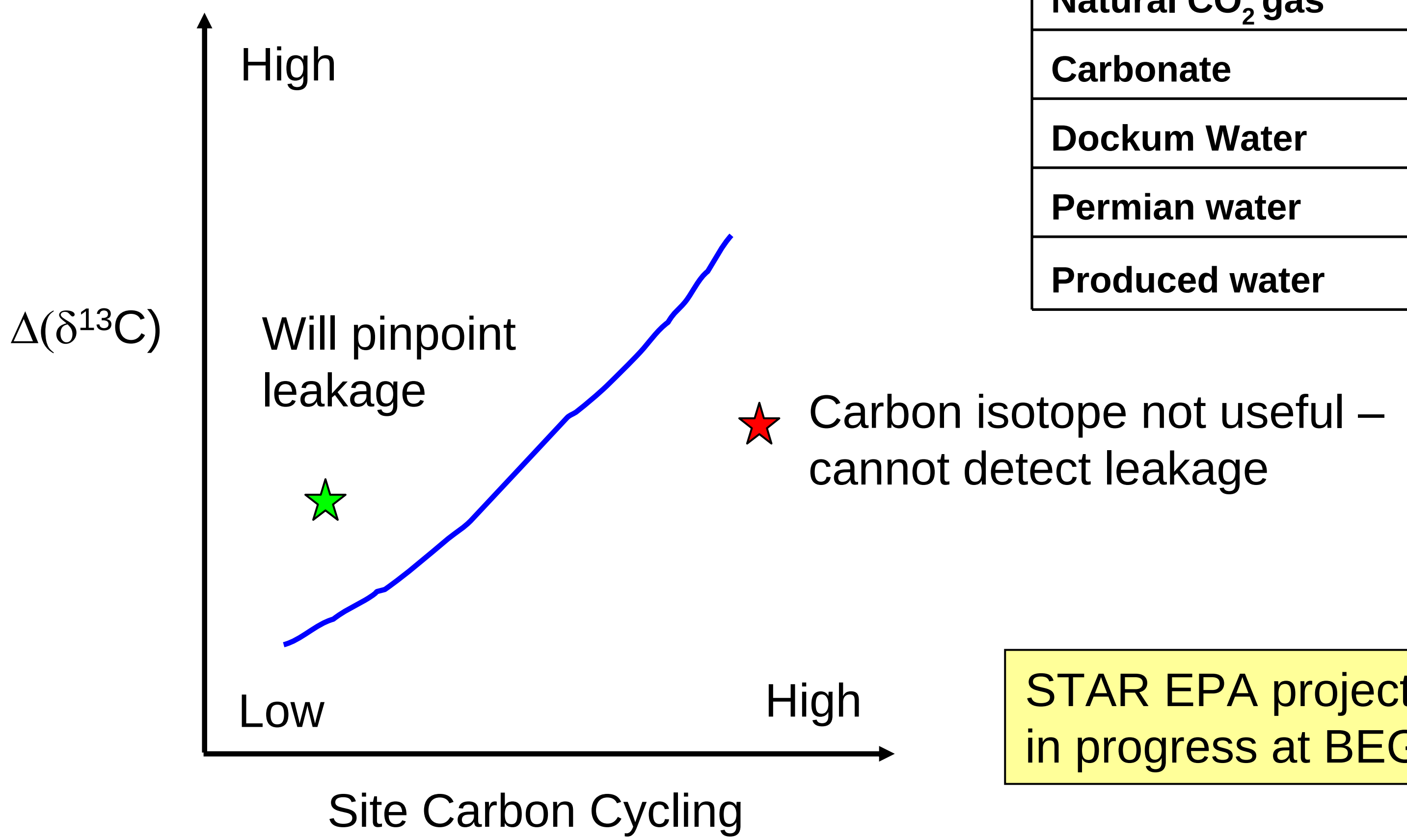


- Look for evidence of CO_2 leakage: do we have calcite dissolution?
- Trends follow dedolomitization rather than calcite dissolution as hypothesized.

Romanak, NETL meeting, 2010

CO_2 Source Identification

End member	$\delta^{13}C$ Range
Injectate CO_2 gas	0 to -6
Natural CO_2 gas	-23 to -29
Carbonate	-2 to -8
Dockum Water	-4 to -13
Permian water	-8 to -10
Produced water	+1 to +9



STAR EPA project in progress at BEG

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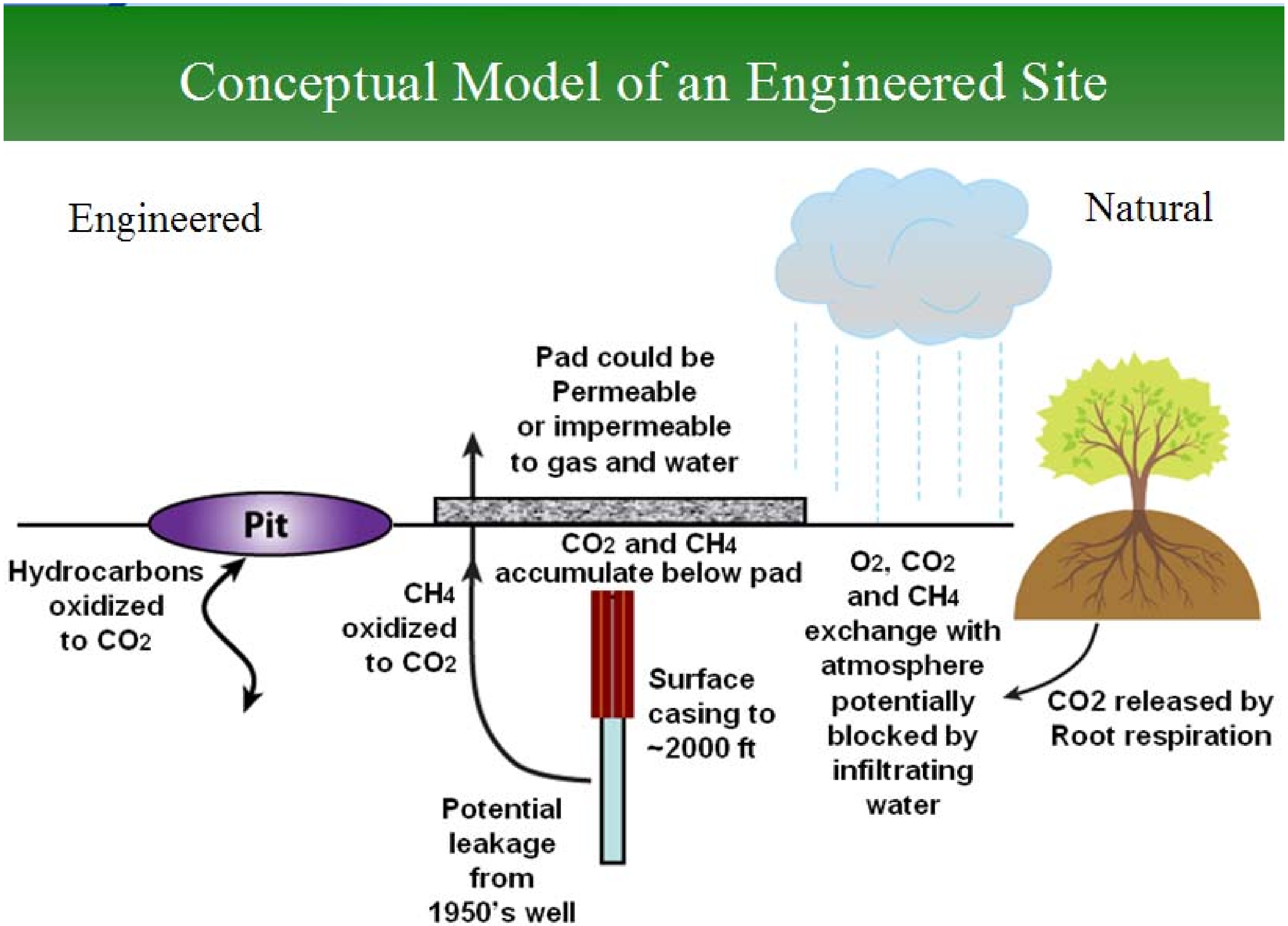
Soil gas monitoring



Romanak, NETL meeting, 2010

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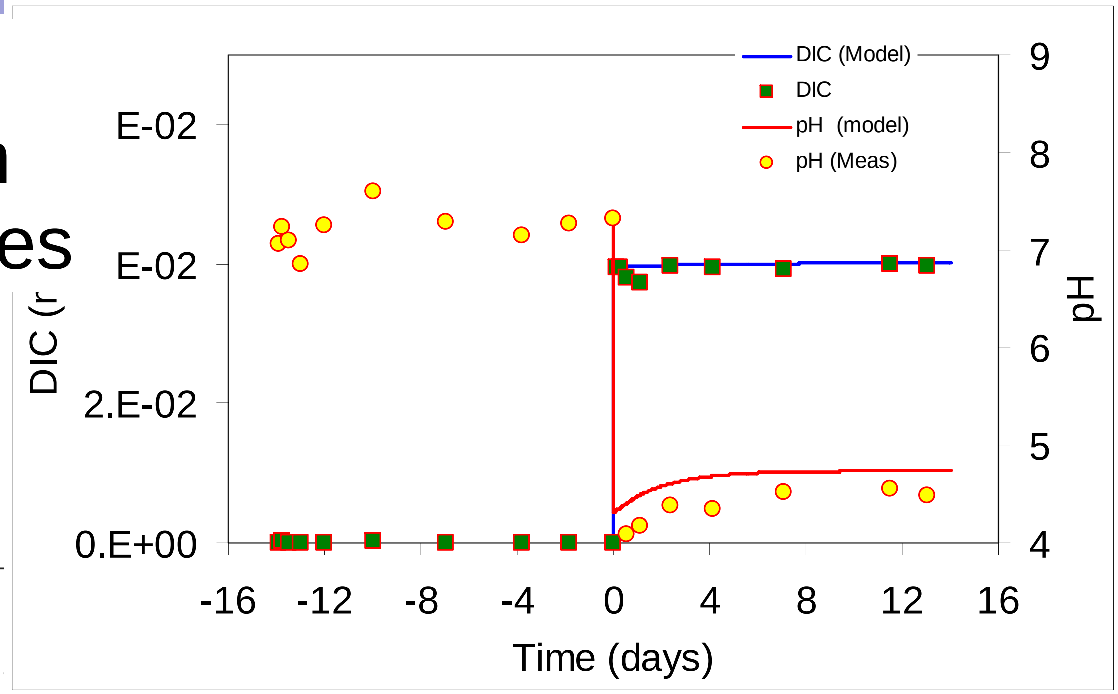
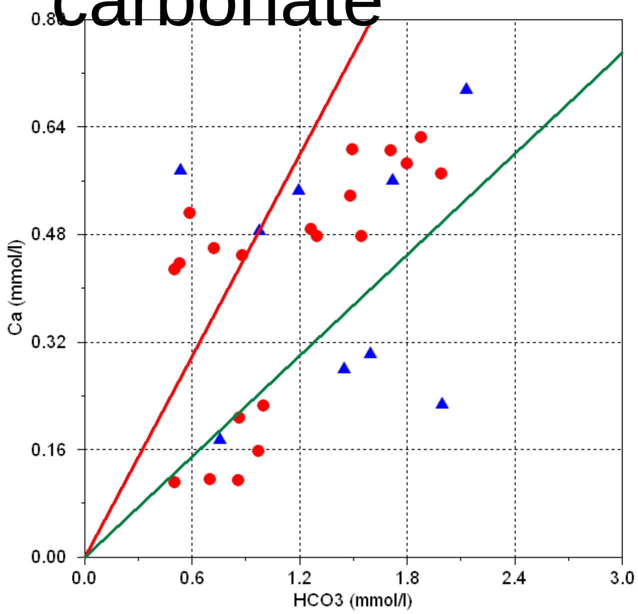
SACROC take-away points

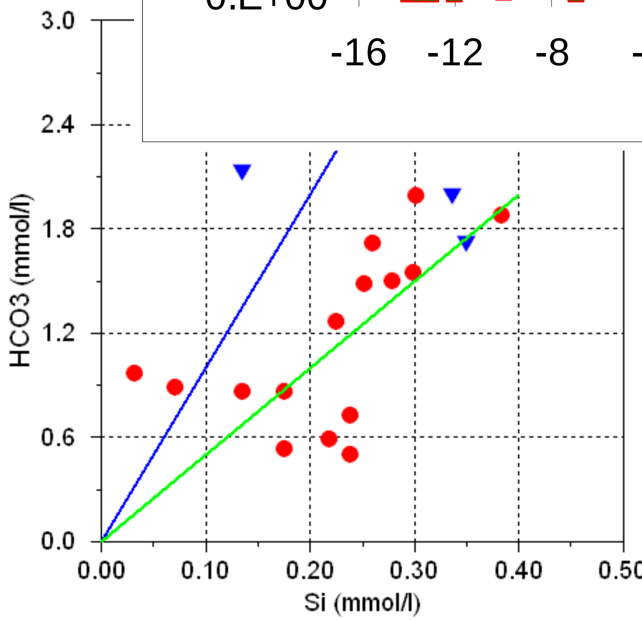
- No evidence for injectate CO_2 in the Dockum aquifer.
- Simple carbonate systems cannot be assumed and carbonate parameters may be unreliable indicators. A complex system may not yield an unequivocal response
- Monitoring of natural parameters (pH, alkalinity, etc.) in shallow aquifers may be impractical and/or ineffective for evaluation of CO_2 storage permanence
- Carbon isotopes may have limited use for identifying CO_2 sources in shallow groundwater.
- Site-specific context is critical.
- How much leakage do we need to catch a leak? How many sampling points?

Cranfield, MS

- Very shallow aquifer:
  a less complex system
  pH drops, DIC increases
- Silicate weathering dominant, very little carbonate







Yang, 2010
NETL Meeting

Tentative standard program for geochemical monitoring

- Characterization:
  - Sampling of formations during well construction/well testing, use of tracers
- First line = Core = Basic = Primary
  - Mandatory sampling of USDWs (quarterly, continuous)
  - Occasional, non-systematic, opportunistic sampling of injection and above-zone formations
  - No introduced tracers
- If Primary parameter (geochem. or not) over agreed-upon limit
  - Systematic sampling of all wells
  - Soil gas sampling

Conclusions – Food for thought – 1/2

- It comes down to a cost/benefit analysis in terms of funding and manpower
- The challenge: how little cost-effective (geochemical) monitoring can we afford? Do we need redundant techniques?
- Geochemical monitoring could be useful at some sites but the interpretation may be too complex at others – it may simply inform other techniques

Conclusions – Food for thought – 2/2

- It is more important to know how much CO_2/brine leaves the "box" than the details of processes within the "box"
- How much of the geochemical monitoring done at research sites is needed for commercial sites?
- Is there a role for geochemical modeling (prediction then observation – batch, RTM) for commercial sites?
- Because focus is on USWDs in onshore settings, geochemical monitoring not as important for offshore sites

What is needed?

- Need more field (push-pull) tests in various settings in research mode to increase confidence for commercial sites
- Develop standards / streamlined flow-charts for regulators and non-experts
- Explore emerging issues:
  - Impact of impurities (pH)
  - Investigation of redox changes (impurities, microbes)
  - ?