Frio Brine Pilot: Lessons Learned and Questions Restated

GCCC Digital Publication Series #05-04j

S. D. Hovorka
S. Benson
L. Myer

Keywords:
Site Characterization, Residual Saturation, Permanence Monitoring, Tool Selection, Surface Environments, Groundwater Monitoring,

Cited as:
Hovorka, S.D., Benson, S., and Myer, L., Frio Brine Pilot: lessons learned and questions restated: presented at the National Energy Technology Laboratory Fourth Annual Conference on Carbon Capture and Sequestration, Alexandria, Virginia, May 2-5, 2005. GCCC Digital Publication Series #05-04j, pp. 1-22.

Frio Brine Pilot: Lessons Learned and Questions Restated

Susan D. Hovorka, Bureau of Economic Geology, Jackson School of Geosciences, The University of Texas at Austin
Sally Benson and Larry Myer, GEO-SEQ Project, Lawrence Berkeley National Lab

Abstract

An important product of this study is recommendations to the next generation of developers of geologic CO_2 injection pilot projects. We highlight the value of interactive modeling before and during project development. Numerical simulation of flow strongly guided site selection, well design, and tool selection, and was key in designing a successful project. The two-well design was effective in reaching project goals. We directly detected CO_2 breakthrough at the observation well, sampled formation waters as CO_2 interacted with rock and brine, and recovered tracers to quantify CO_2 saturations and CO_2 dissolution. We used two well hydrologic approaches for evaluating multi-phase flow parameters and cross-well EM and seismic imaging. The observation well provided access during injection for logging CO_2 saturation and "ground truthing" indirect geophysical methods for monitoring. Research team integration is critical but time and labor intensive and required vigorous e-mail communication, phone conferences, in-person meetings, and field coordination. Effective data exchange within the research team was challenging. Engineering designs and the experimental time-lines had to be redone to reduce conflicts between optimal conditions for each instrument, risk of failure, and cost. Redesign eliminated tools with low probability of success or those that could not be effectively implemented under experimental conditions, and substitute tools that would accomplish the required tasks. Even if cost was not an issue, it is impossible to create optimal conditions for each instrument in a single test; compromises must be made, and success is dependent on making thoughtful compromises.

Principle experimental results

(1) Field detection of a small volume of CO_2 using
- U-Tube sampler and in-line gas analysis
- Field geochemistry (pH, alkalinity, metals)
- Stable isotopic signature
- Introduced tracers
- Neutron wireline log
- VSP
- Cross well seismic
- Casedhole, cross-well EM

(2) Good match between modeled and observed CO_2 distribution
(3) Post injection retention by "two phase trapping" of CO_2 limits migration

<u>Recommendations and lessons learned</u>

(1) Numerical modeling strongly guided site selection, well design, and tool selection, and was key in designing a successful project.
(2) Two-well design was effective in sampling a representative radius of the plume.
(3) Research team integration is critical but time and labor intensive
(4) Groundwater monitoring using a standard contaminated –site approach is effective in improving public acceptance
(5) Interference between tests was significant and is an area where improvement of tools should be considered.

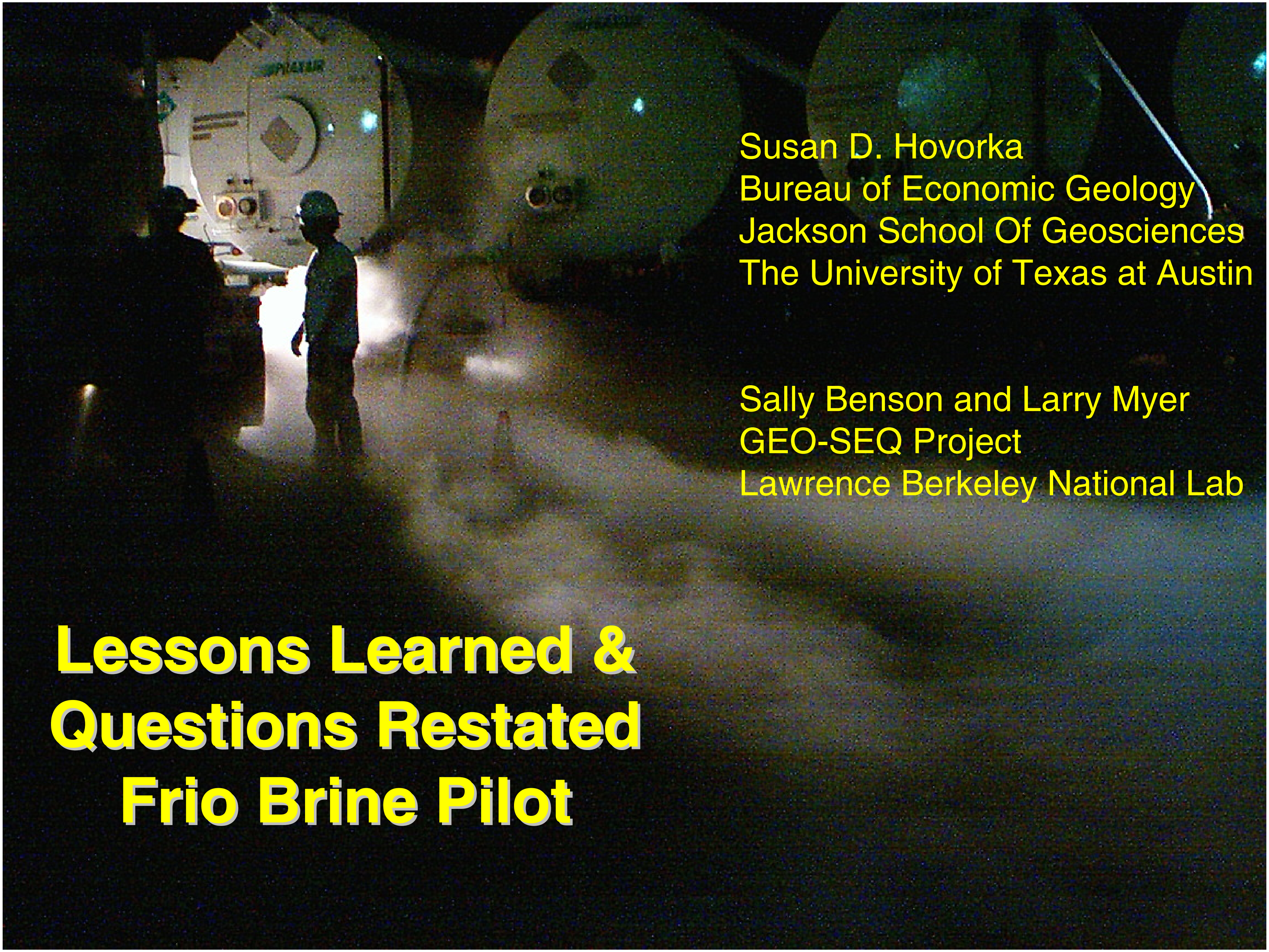
Fourth Annual Conference on Carbon Capture & Sequestration

Developing Potential Paths Forward Based on the Knowledge, Science and Experience to Date

Lessons Learned and Questions Restated
Frio Brine Pilot

Susan D. Hovorka

May 2-5, 2005, Hilton Alexandria Mark Center, Alexandria Virginia

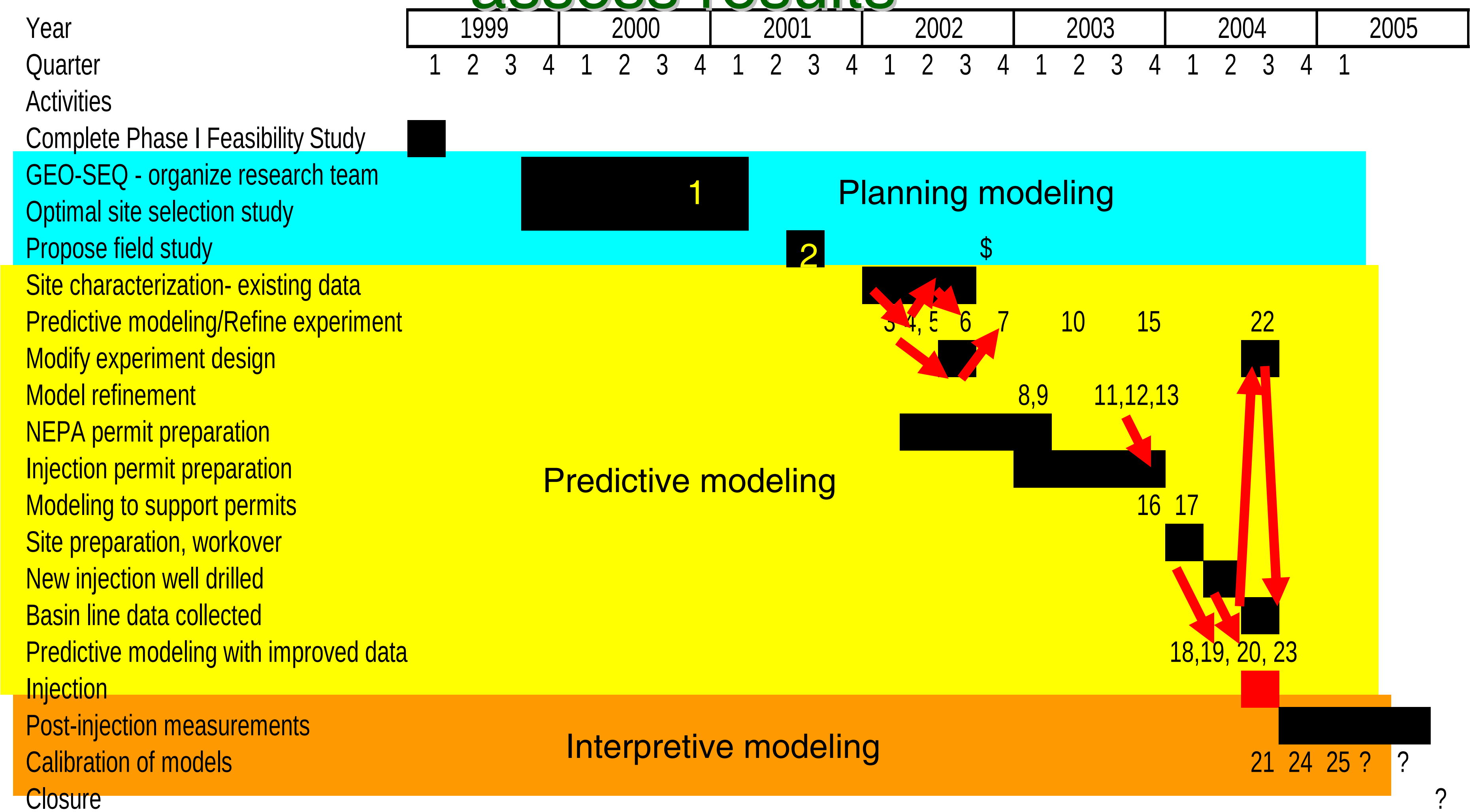


Susan D. Hovorka
Bureau of Economic Geology
Jackson School Of Geosciences
The University of Texas at Austin

Sally Benson and Larry Myer
GEO-SEQ Project
Lawrence Berkeley National Lab

Lessons Learned & Questions Restated Frio Brine Pilot

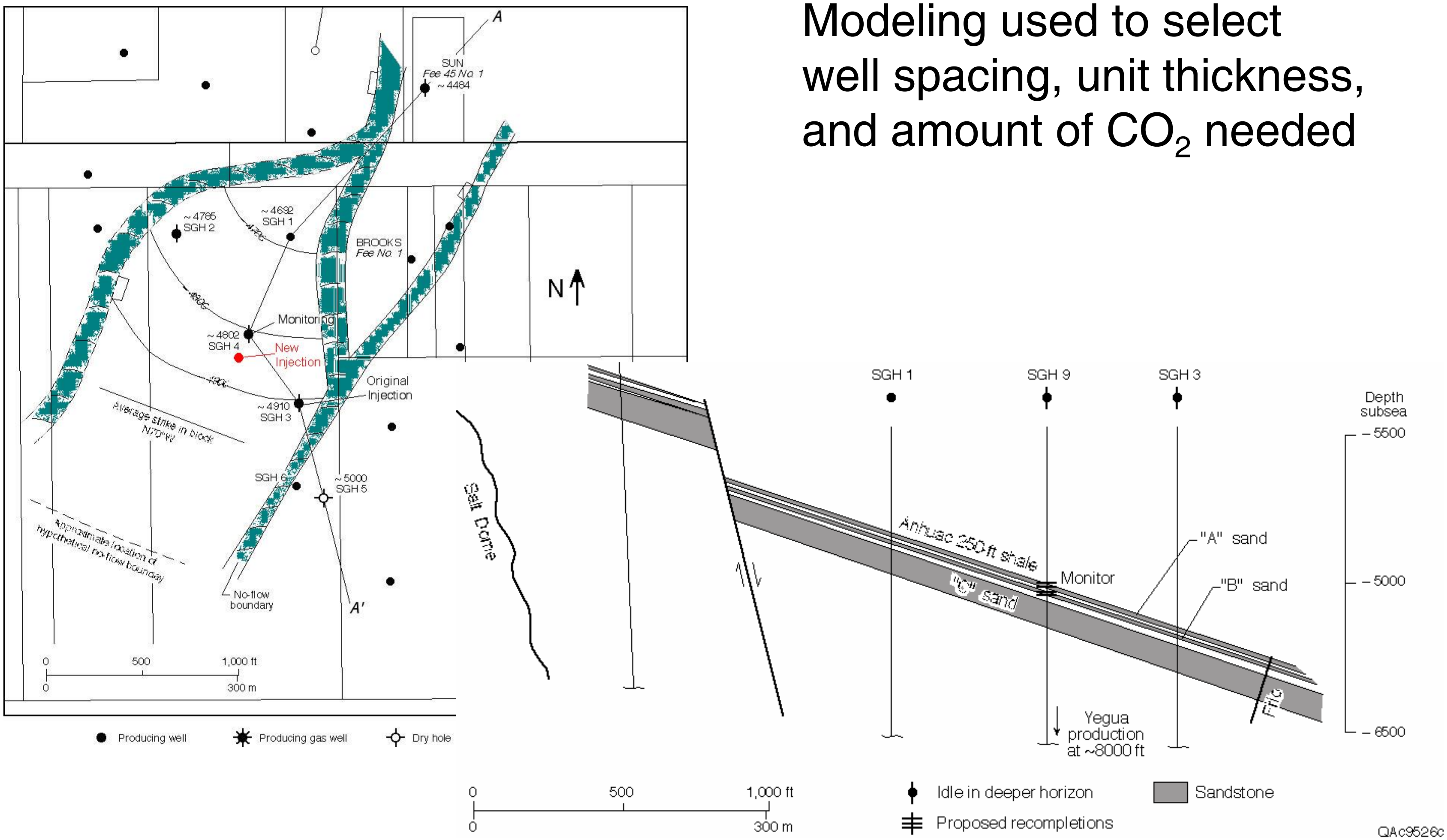
Modeling for proposal, during design, and to assess results



1-25 TOUGH2 model sets, Christine Doughty, LBNL

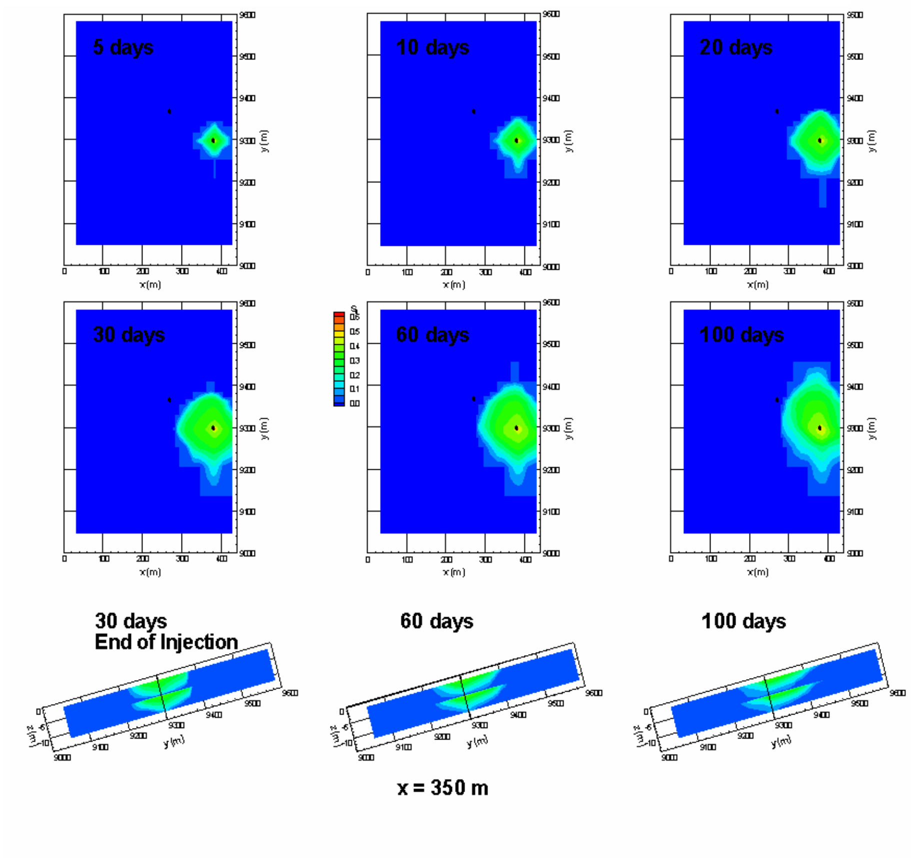
Simple Characterization for Proposal

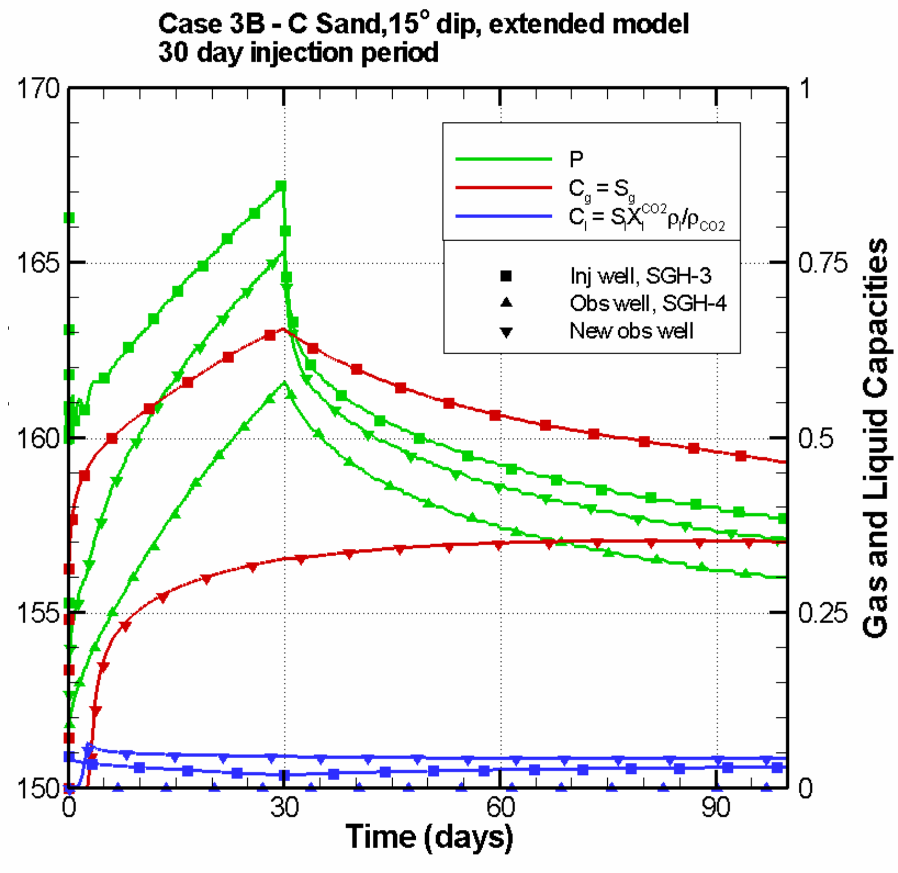
Modeling used to select well spacing, unit thickness, and amount of CO_2 needed



Will CO2 arrive?

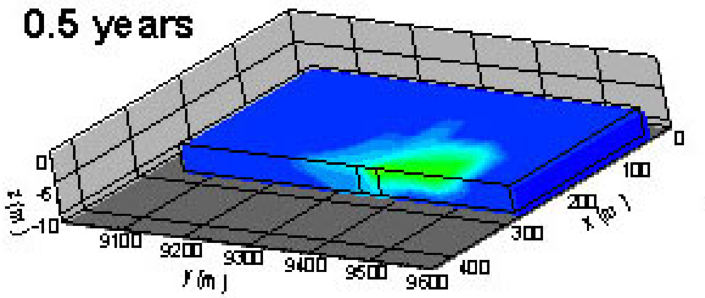
Experimental design interaction with geologic uncertainties



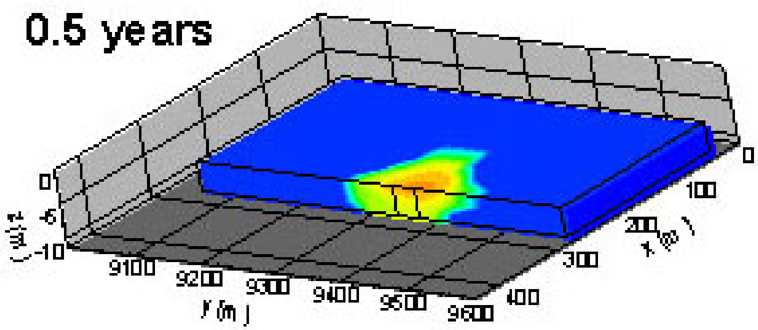


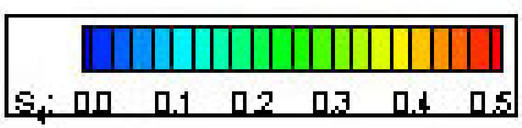
How Modeling and Monitoring Demonstrate Permanence

Residual gas saturation of 5%



Residual gas saturation of 30%

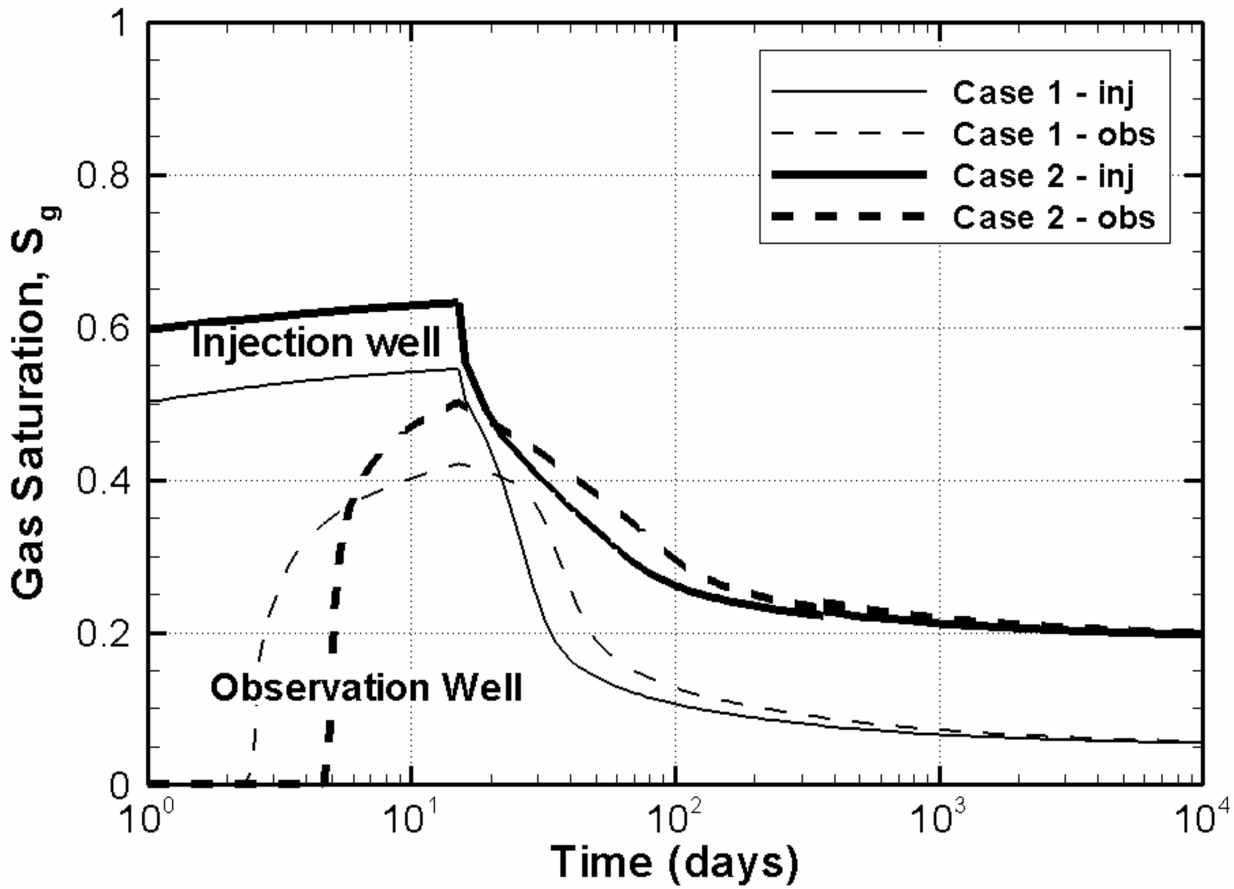




- Modeling has identified variables which appear to control CO_2 injection and post injection migration.
- Measurements made over a short time frame and small distance confirm the correct value for these variables
- Better conceptualized and calibrated models will now be used to develop larger scale longer time frame injections

TOUGH2 simulations
C. Doughty LBNL

Predicted Saturation for History Match – Sensitivity to Residual Saturation

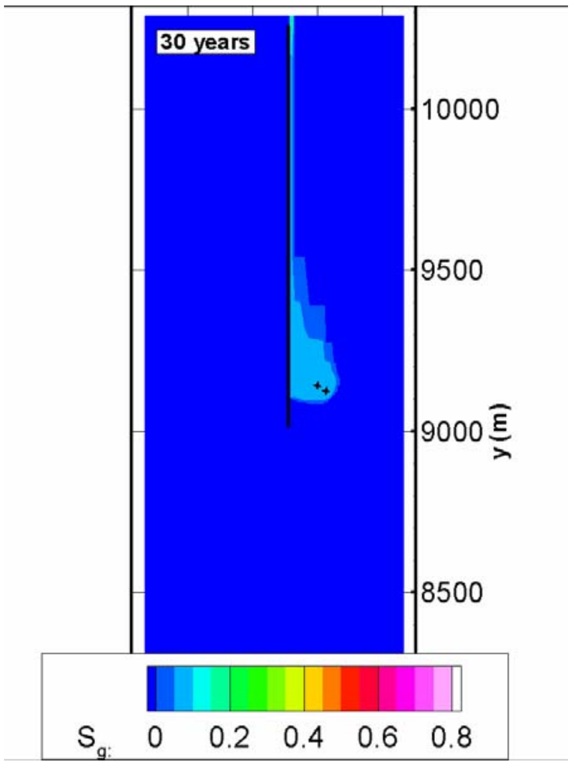


Case 1 Slr=0.30; Sgr=0.05

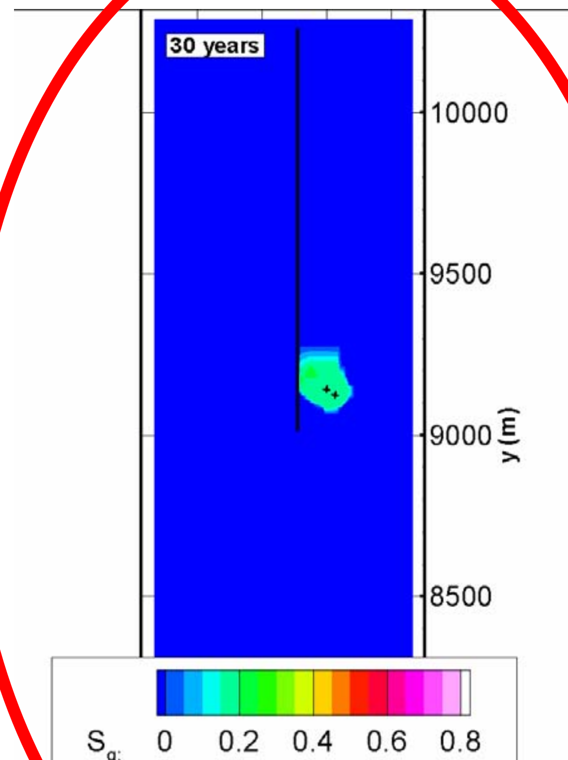
Case 2; Slr varies, ~ 0.10,
Sgr varies, ~0.25

TOUGH2 model

Modeled Long-term Fate
30 years based on observed post-injection saturation



Minimal Phase trapping



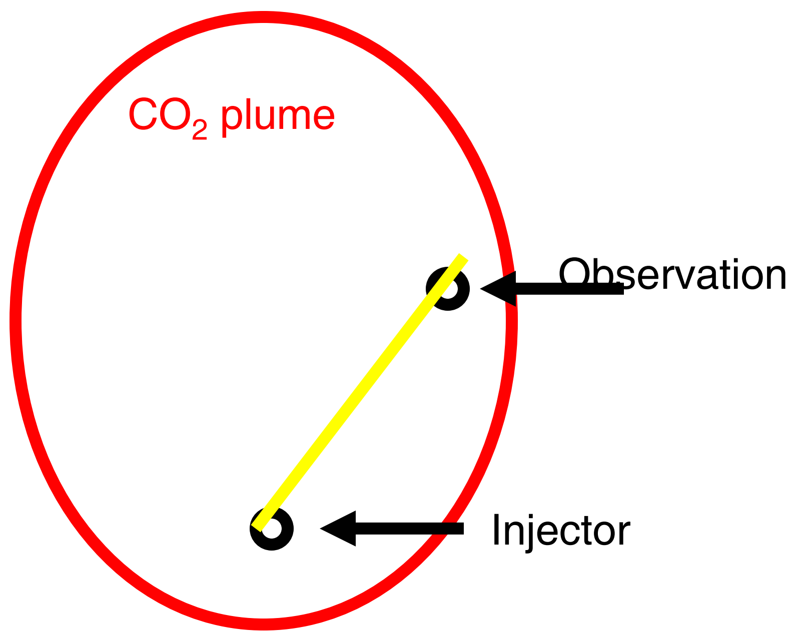
Predicted significant phase trapping

Define Clear and Achievable Goals

Project Goal: Early success in a high-permeability, high-volume sandstone representative of a broad area that is an ultimate target for large-volume sequestration.

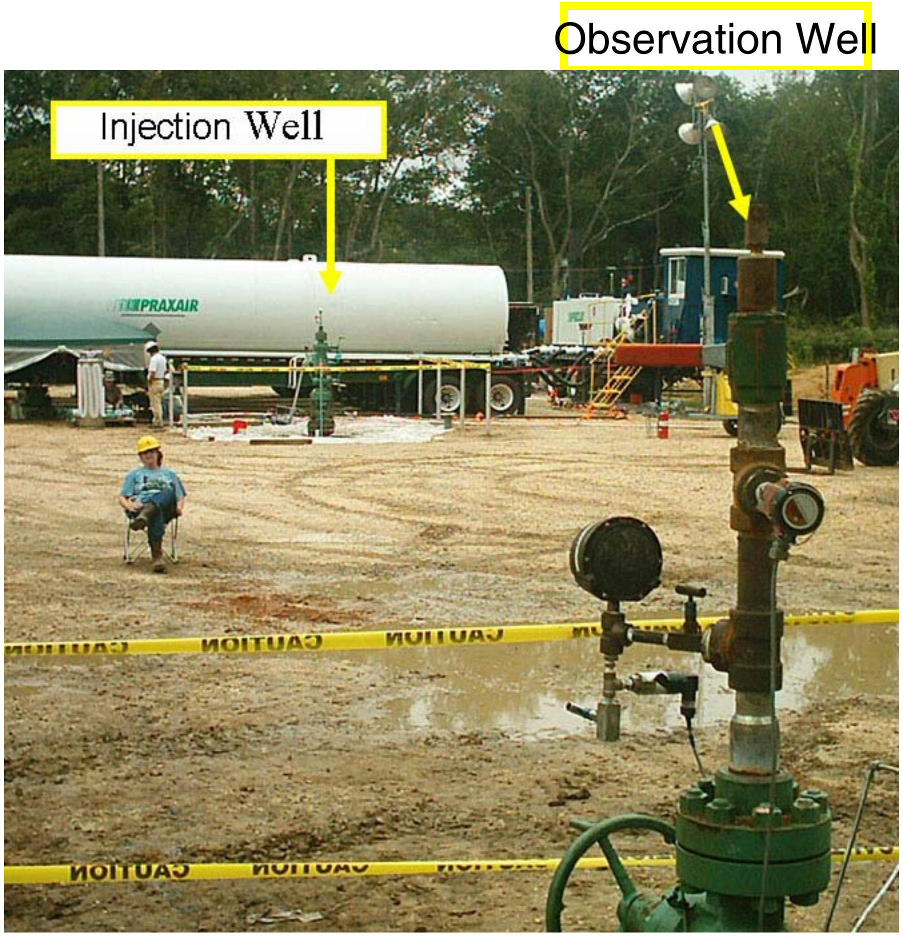
- **Demonstrate that CO_2 can be injected into a brine formation without adverse health, safety, or environmental effects**
- **Determine the subsurface distribution of injected CO_2 using diverse monitoring technologies**
- **Demonstrate validity of conceptual and numerical models**
- **Develop experience necessary for success of large-scale CO_2 injection experiments**
- **Does not say assure storage of CO_2 for long periods of time, or measure distribution with high precision, or not leak, or do it at low cost.**

Usefulness of a two well-design



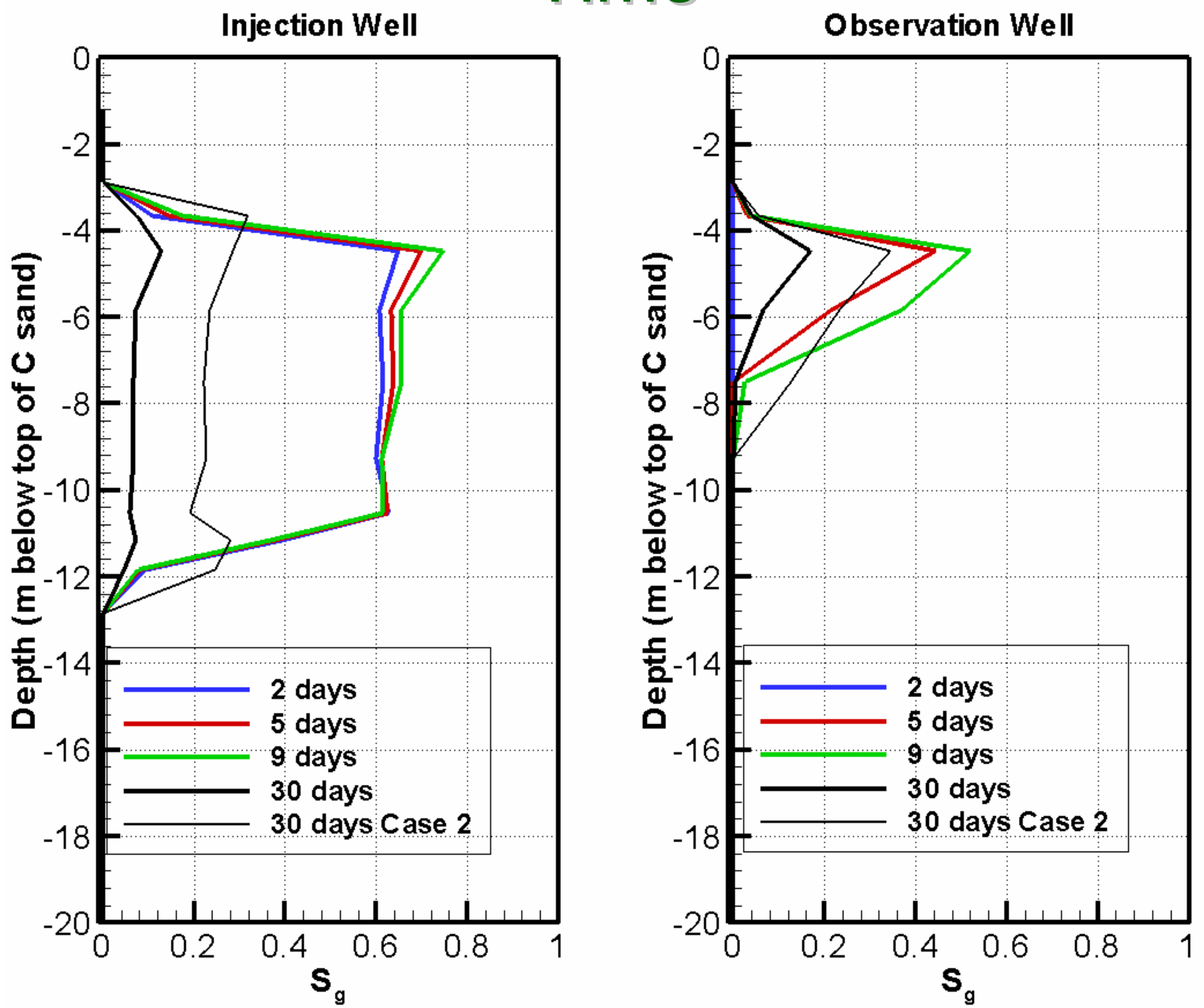
Spatial, temporal information on concentration, chemistry, cross well techniques

Small is Beautiful

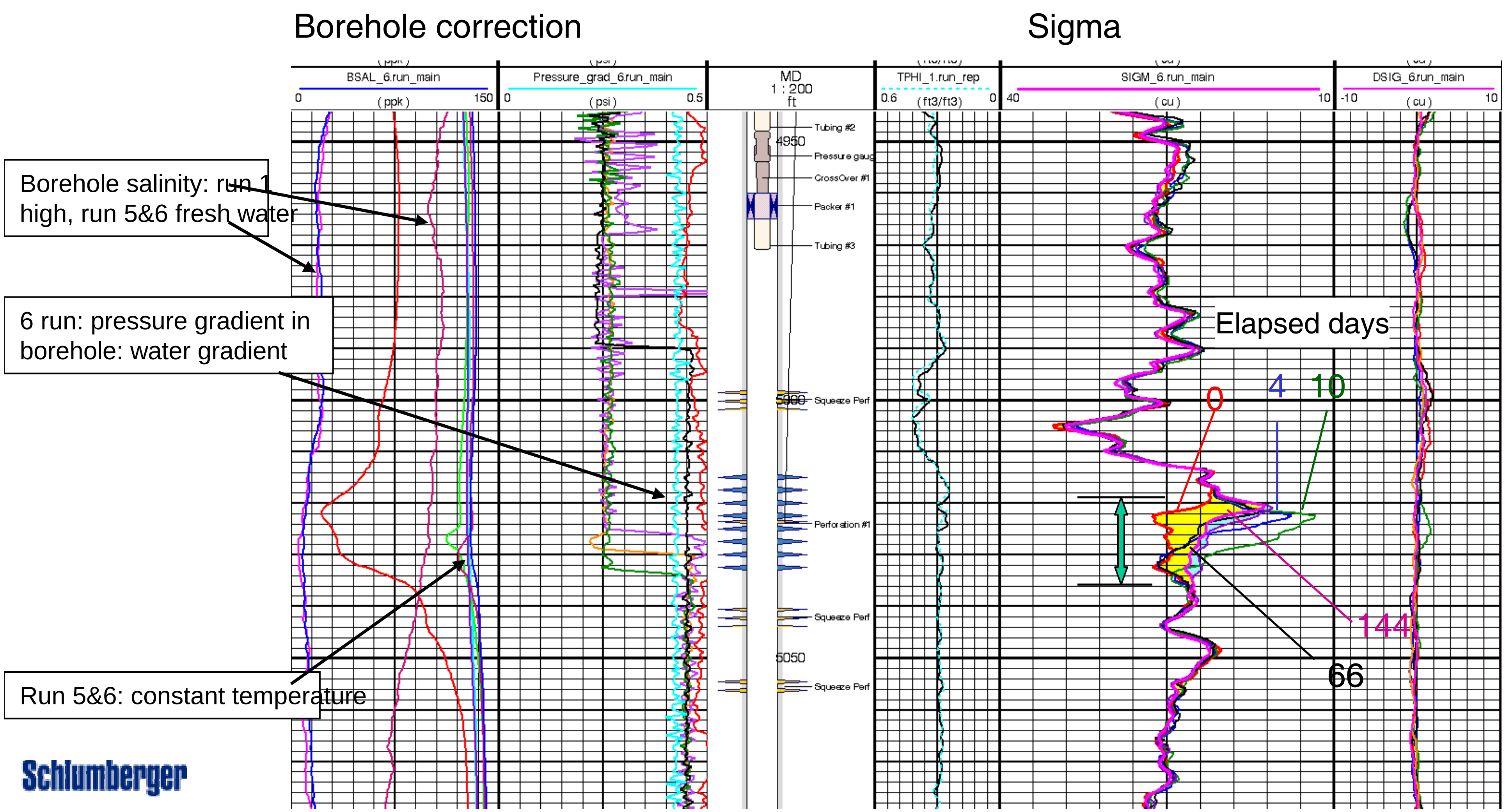


- Closely spaced measurements in time and space
- Emphasis on post-injection period
- High science, low risk

Predicted Saturation Distribution Through Time



Observed Saturation Distribution Through Time-Injection Well



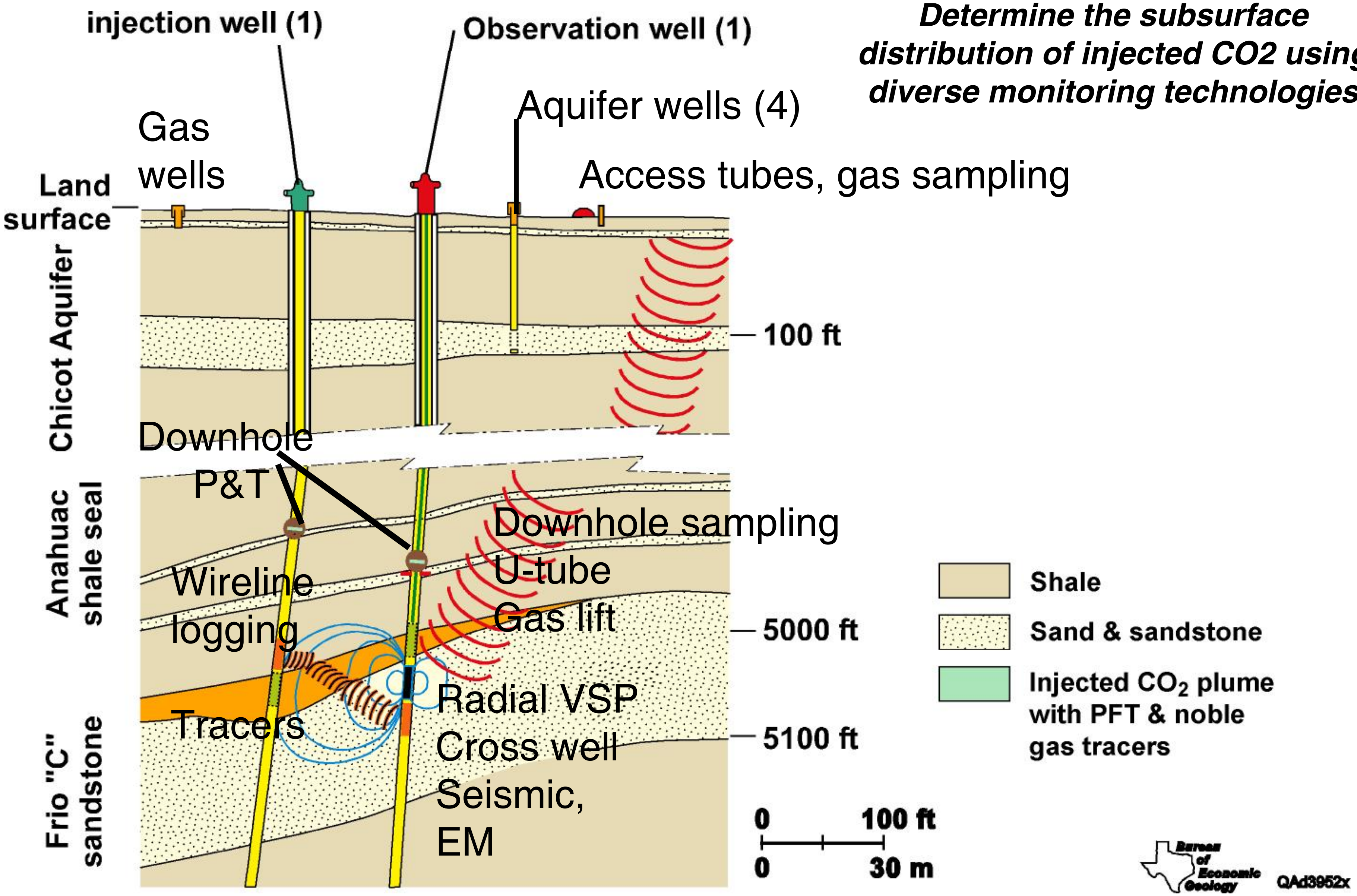
Schlumberger

Tool Selection Appropriate for Goals and Subsurface Environment

- No one tool is "Best"
  - Case specific
    - what is needed?
    - What is possible?
- Interference among tools
  - Geophysics vs. sampling
  - Surface monitoring vs. subsurface sampling

Monitoring at Frio Pilot

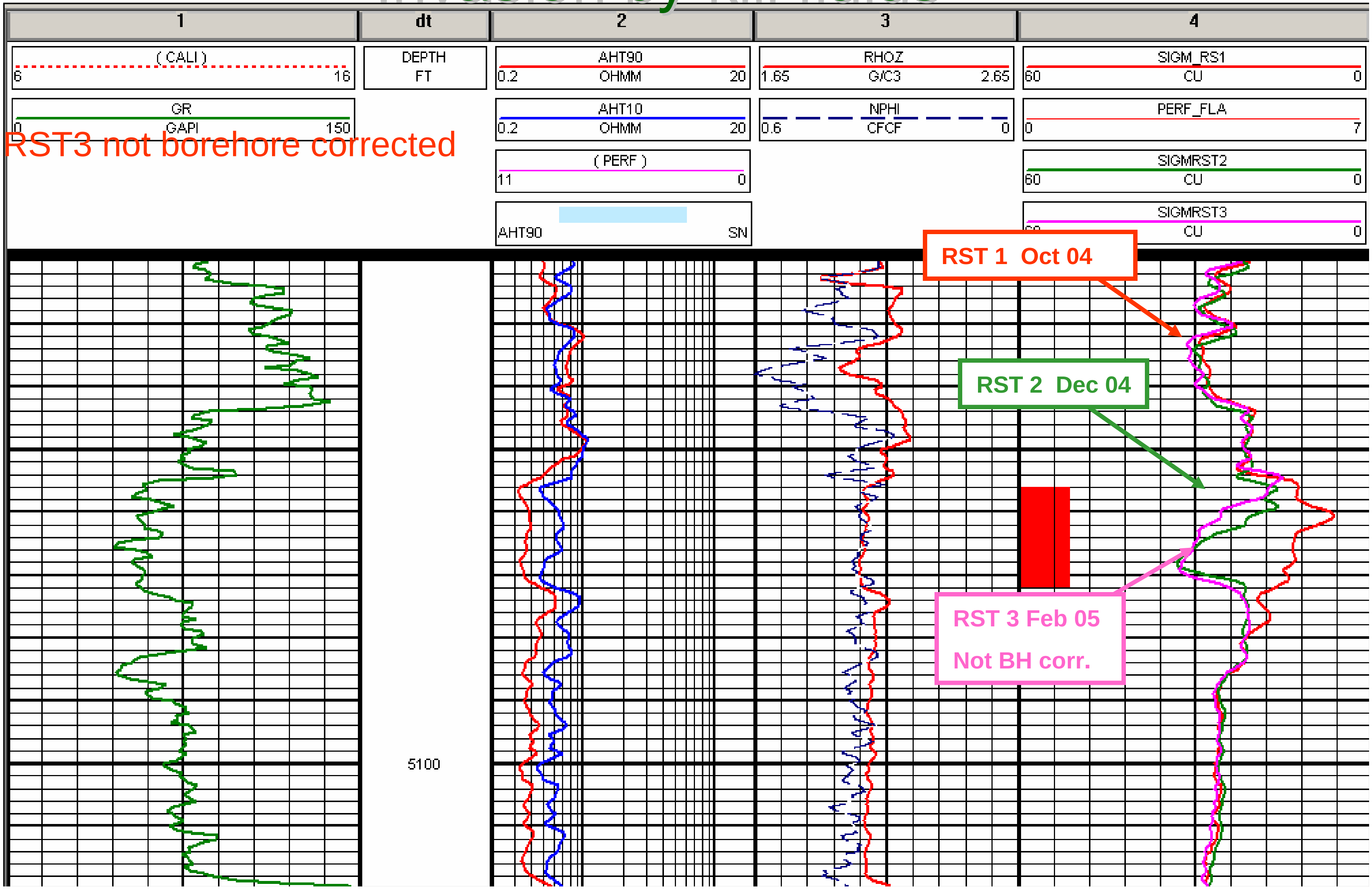
Determine the subsurface distribution of injected CO2 using diverse monitoring technologies



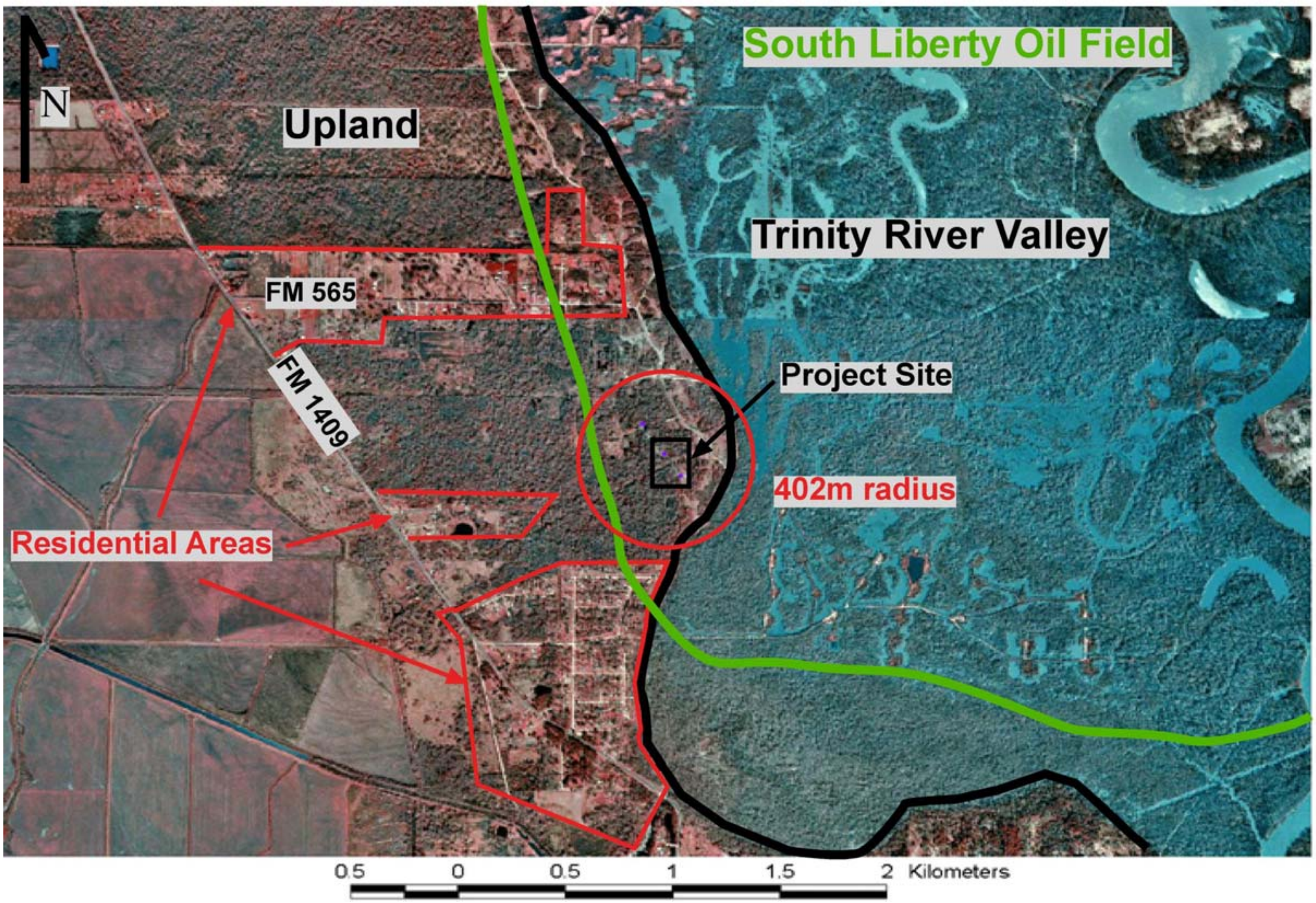
Interference among tests

- Sampling and pressure measurements require wells (open to formation, those in plume produce CO_2, and acid fluid). Geophysics require boreholes, control of wellbore fluids and pressures
- Surface monitoring should be sensitive to detect very small seepage (using tracers for example). Other operations such as surface activities and production of downhole fluids produce large perturbations).

Interference among tests
Invasion by kill fluids

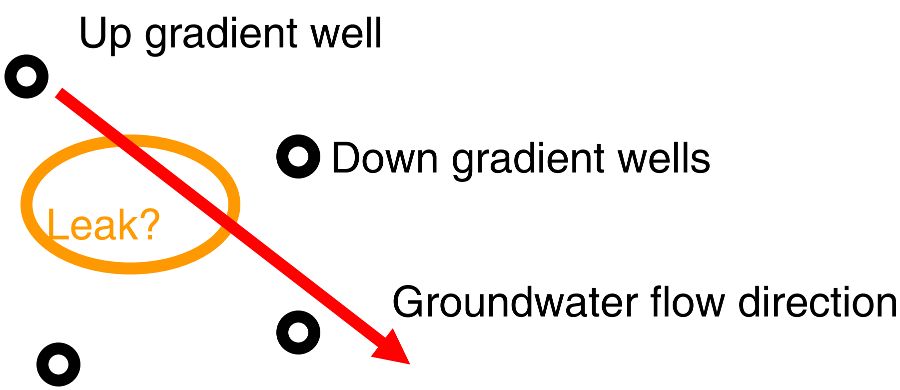


Complexity: Surface Environments



Groundwater Monitoring

- A standard test = high public assurance
- A low-cost test
- An effective test – reduced complexity, integrator of multiple leakage paths



More work needed: experiments not done at Frio

Experiment	why not done?
Large volume of CO_2	Risk, $
Interaction with faults	Risk, complex, premature
4-D survey	Problematic, $
Observation well array in zone	$
Tilt	Problematic, $
Microseismic array	Problematic,$
WAG	Interference
EOR	interference
EGR	interference
Streaming potential	$
Ecosystem impact survey	Problematic, $
Massive pre-project PR	Problematic
Legal/regulatory system test case	Problematic

Experiment	why not done?
During experiment pressure monitoring in overlying brine aquifers, fresh aquifers	Interference
Ecosystem CO2 flux towers	Problematic, $
Surface CO2 monitoring lasers	Problematic, $
Airborne/ satellite monitoring	Problematic
Dealing with dissolved methane	no plan
Exhaustive logging	Problematic, $
Other edgy down hole monitoring	
(e.g. non-conductive wells)	$
Long-term monitoring	problematic, $
Pipeline issues	premature
Complex gas injection	interference
Inject low, recover high	$
Well integrity, special cement	premature
Long-term geochemistry	$

Problematic = estimated to be unlikely to collect useful measurements at Frio scale, duration, site specific conditions

Interference = interferes with success of another experiment

$ = cost prohibitive in total project context. Might be used in a larger budget project