Southeast Regional Carbon Sequestration Partnership
Early Test at Cranfield
Status 2015

Susan Hovorka
Seyyed Hossieni
Changbing Yang
Gulf Coast Carbon Center
Bureau of Economic Geology
The University of Texas at Austin

Introduction by Kimberly Sams Gray
Southern States Energy Board

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Carbon Storage R&D Project Review Meeting
Transforming Technology through Integration and Collaboration
August 18-20, 2015

Acknowledgements

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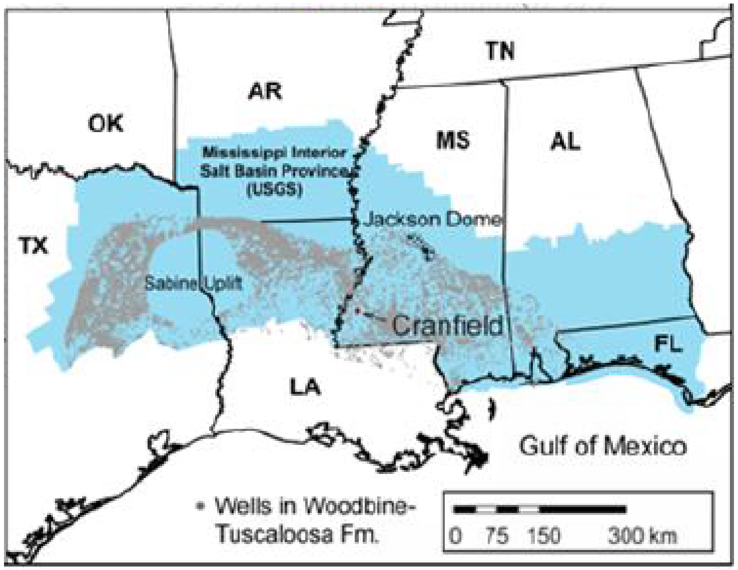
- Cost share and research support provided by SECARB/SSEB Carbon Management Partners.

SECARB Phase III



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Anthropogenic Test

Capture: Alabama Power 's Plant Barry, Bucks, Alabama

Transportation: Denbury

Geo Storage: Denbury's Citronelle Field, Citronelle, Alabama

Early Test

Denbury Resources' Cranfield Field Near Natchez, Mississippi

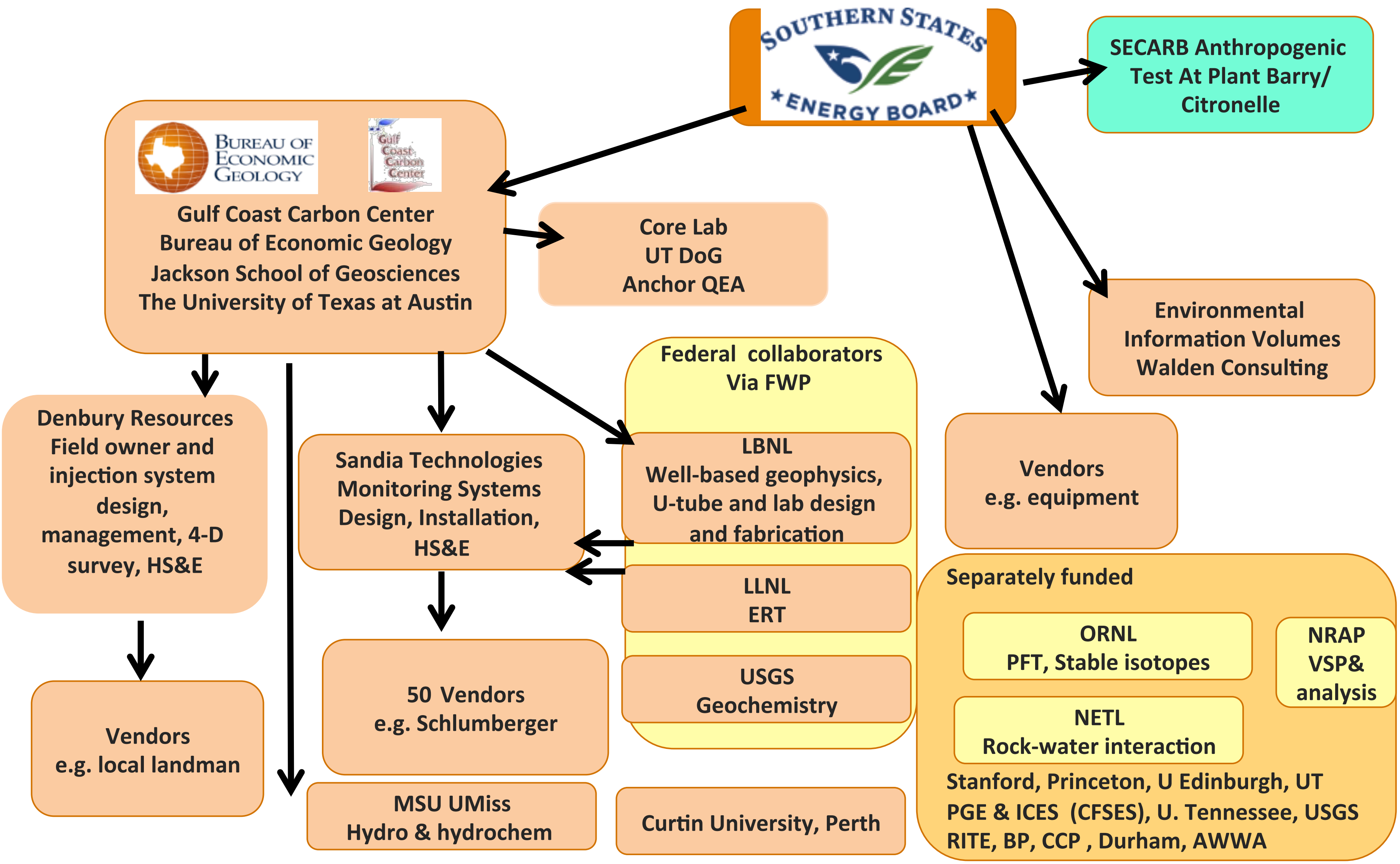
CO_2 Source: Denbury

CO_2 Transportation: Denbury

Saline MVA: GCCC

Gulf Coast Carbon Center

Cranfield Organization



Highlights

- Project status – fieldwork completed (Hovorka)
- Modeling status – history match to 4-D seismic (Hossieni)
- Assessing Impacts of CO_2 Leakage on Groundwater Quality and Monitoring Network Efficiency (Yang)

Fieldwork Completed!

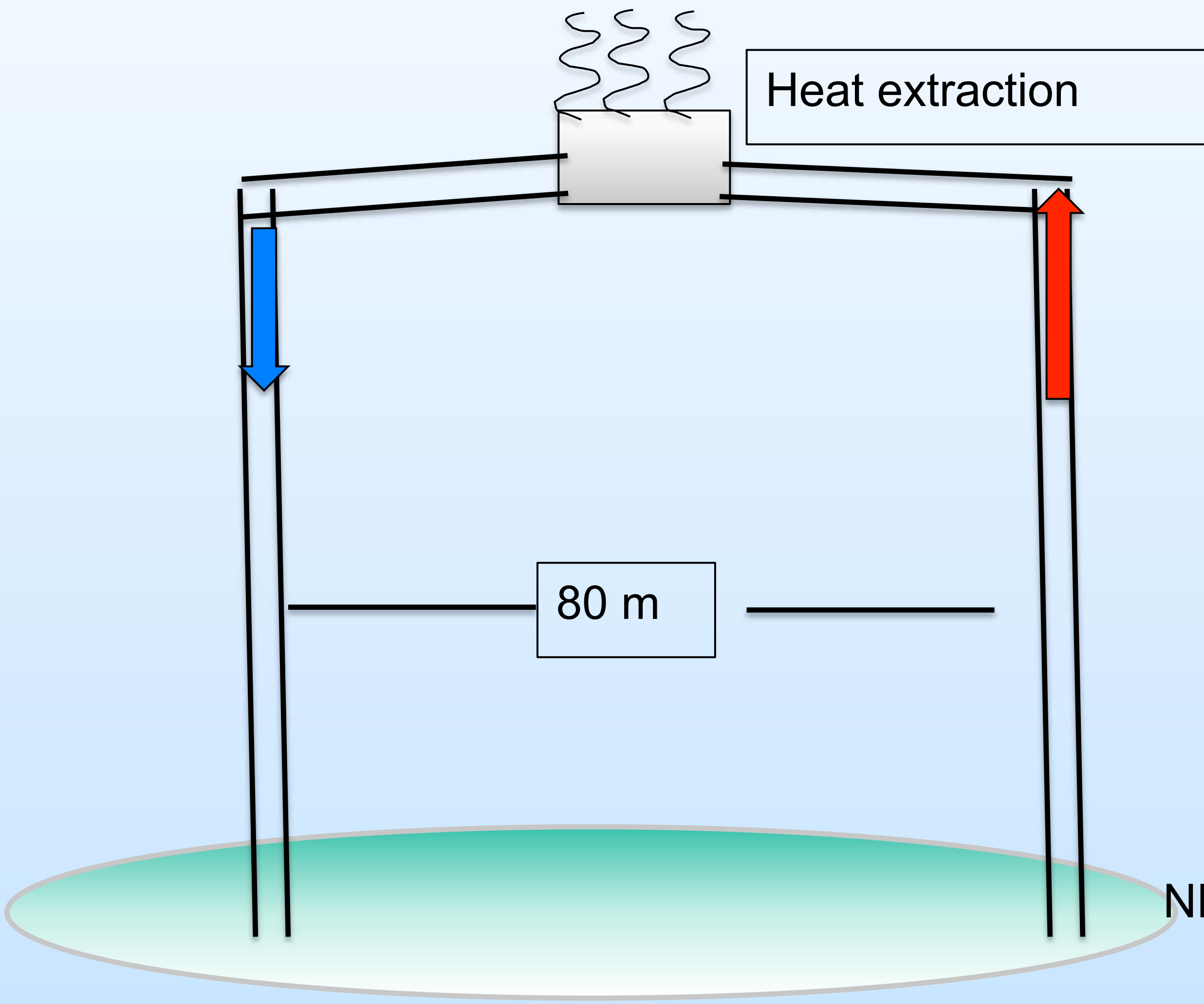
- Last stages of project:
  - Pulse testing (Sun) and thermosyphon (Freifeld, LBNL) completed in January 2015
  - Well integrity data collected (Duguid/Schlumberger/ Battelle)
  - P&A and final data collection completed in April, 2015
- This concludes field phase of Early Test
  - Denbury commercial EOR will continue
  - DOE program work will extract lessons learned and conduct technology transfer

Heat exchanger

Vent system

Photos by Lu

Thermosyphon (Barry Freifeld)

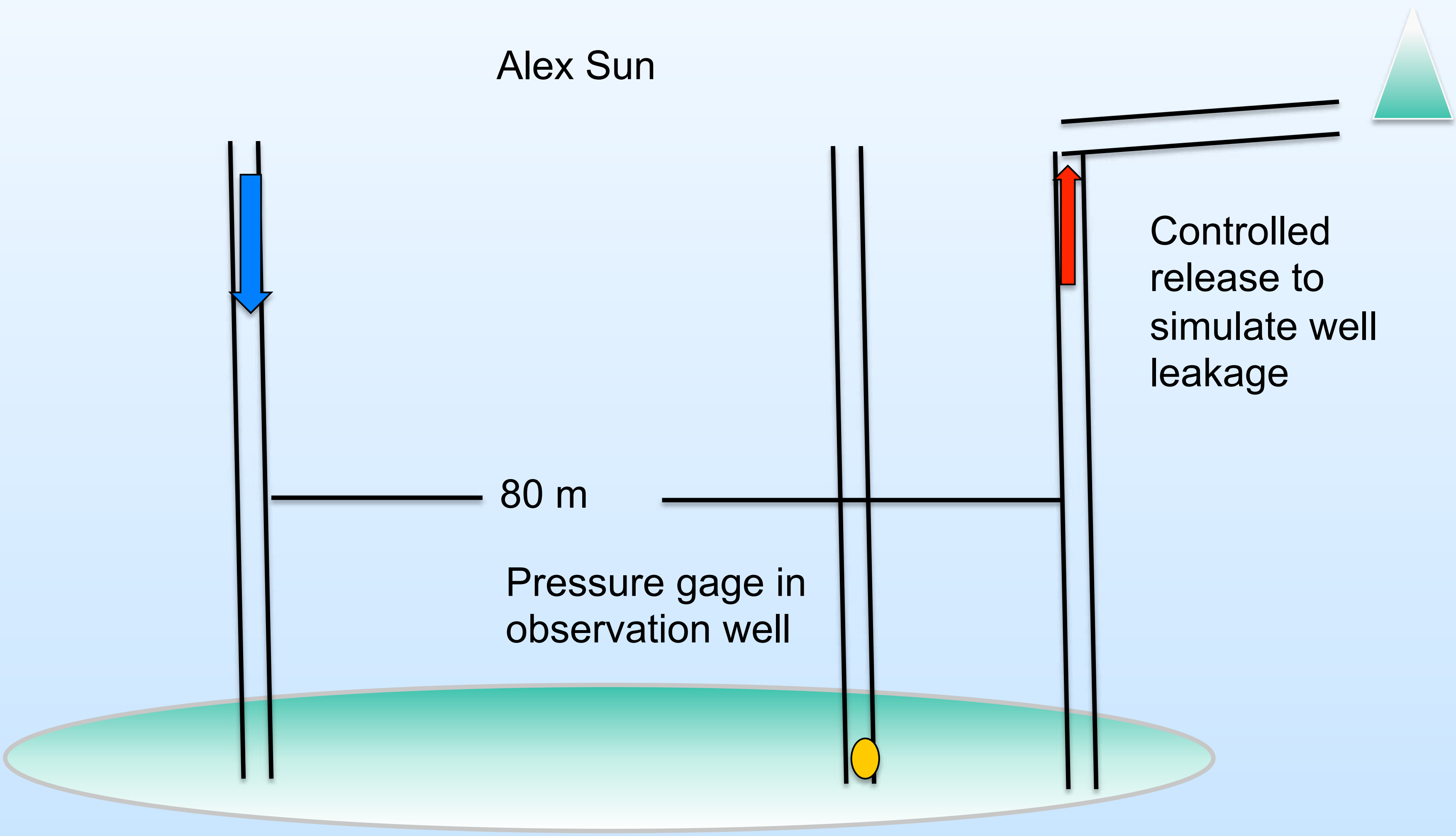


NETL Geothermal program

DOE program combining CCUS and geothermal; LBNL lead

Harmonic Pulse testing for Leakage (PIDAS)

Alex Sun



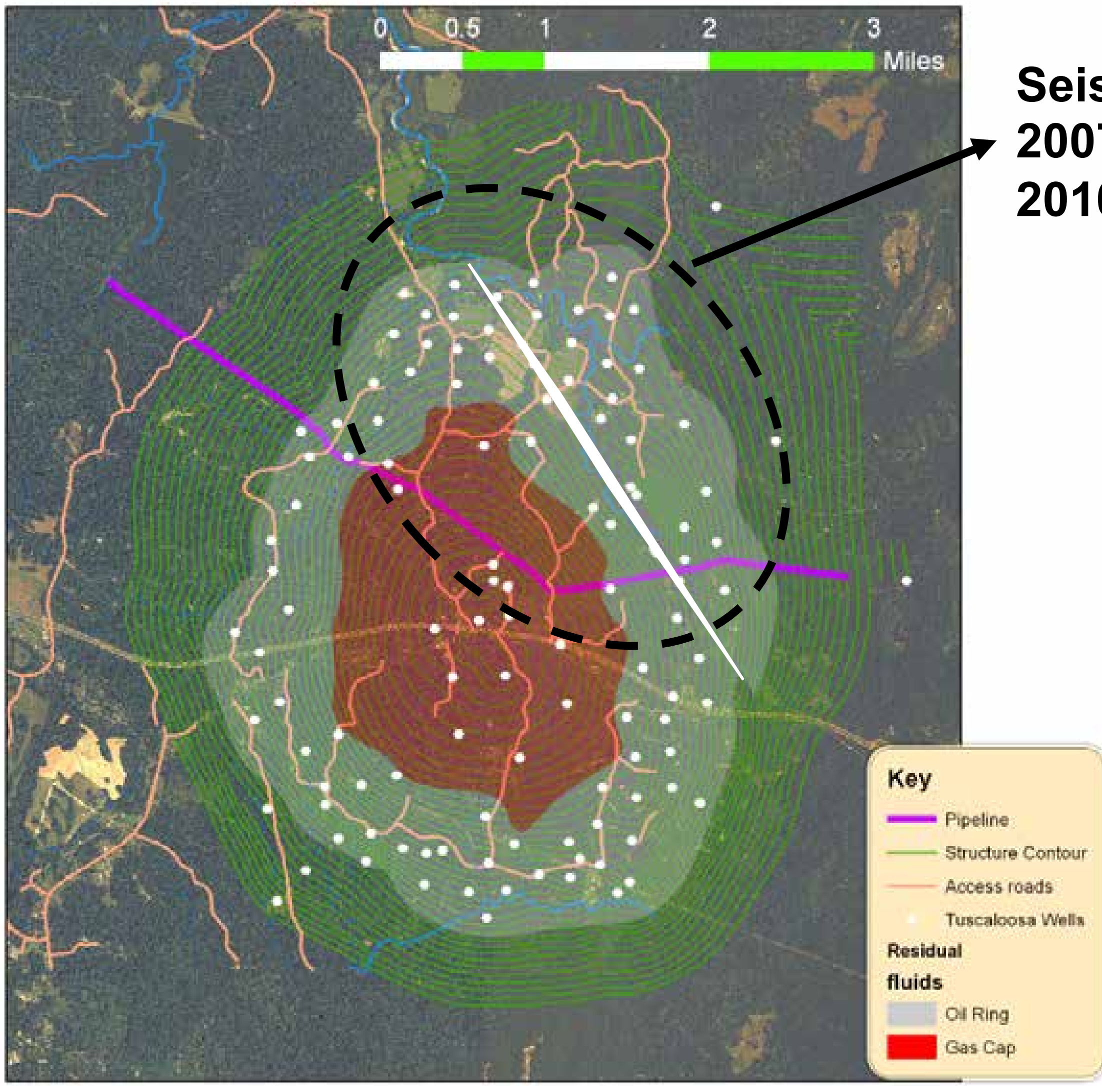
Plugging Procedure Overview

- Final Repeat RST
- “Kill” F2 and F3 wells
- Remove packers
- Squeeze Tuscaloosa perforations, test
- Logging, Sonic, USIT, gyro
- Schlumberger sidewall cores
- Fluid sampling and hydro tests in AZMI
- Squeeze AZMI perforations
- Cement and abandon according to MO&G Board rules

Next steps

- Analysis of data collected – value and best practices to commercial CCUS monitoring
  - Publications
- Technology transfer
  - Current commercial projects
  - International collaborators

History matching and reservoir simulation

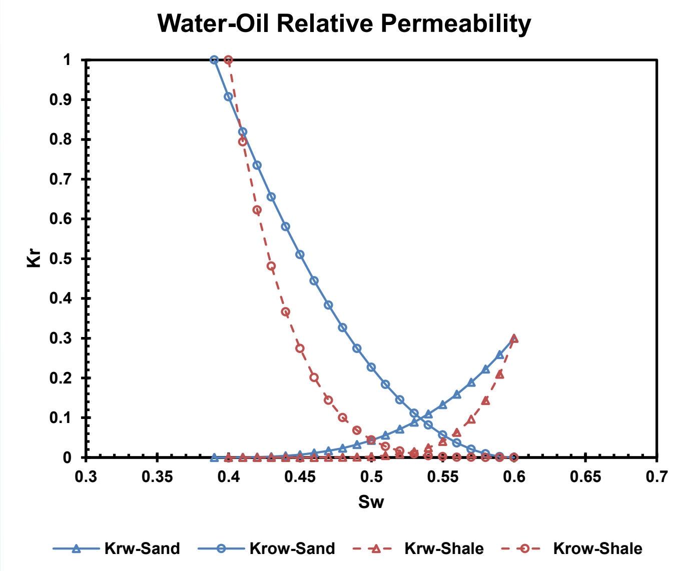


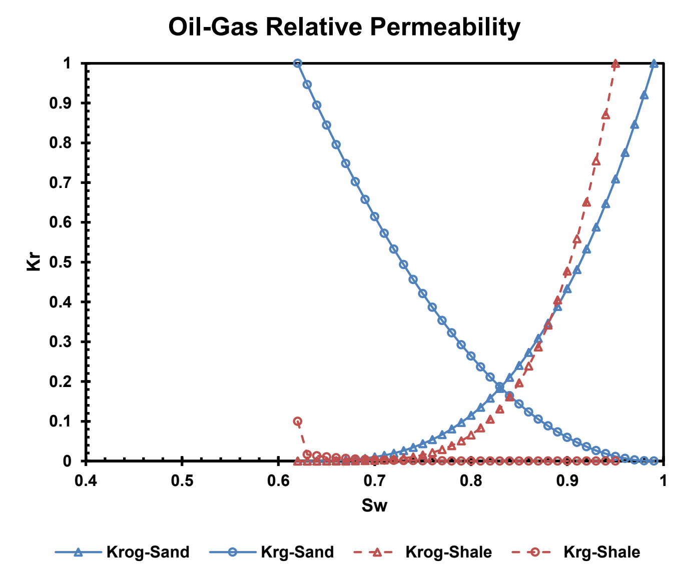
Seismic Surveys
2007 Baseline
2010 Repeat

Simulation parameters

Parameter	Value
Pressure	32 MPa
Temperature	125 C
Thickness	24 m
Depth	3060-3193 m
Historical production	1943-1966
CO_2-EOR	2008-2011

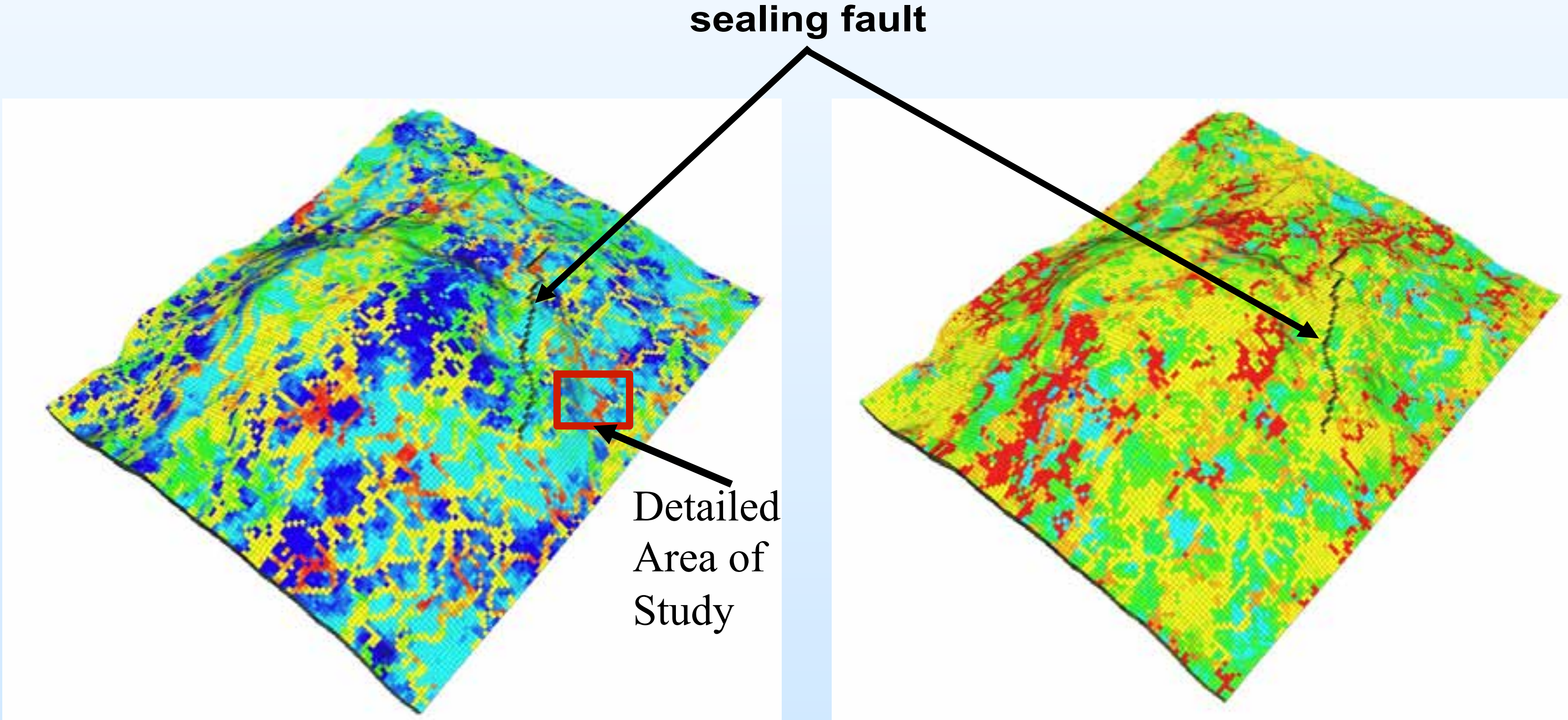
Parameter	Value
Reservoir Simulator	CMG
Number of grids	124 ×149×20
Grid size	61×61×1.2 m
Total number of grids	369,520
Boundary condition	Active aquifer
Facies	Sand/shale
Geochemistry	neglected





Static model development

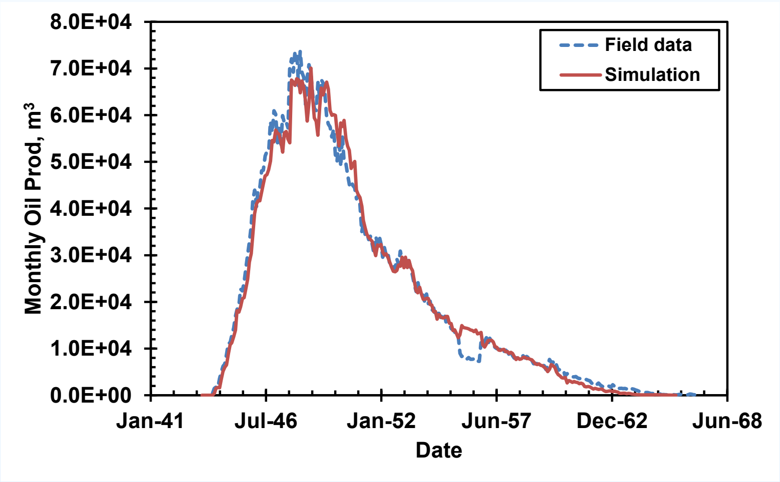
Permeability range is 0.01-4400 md and porosity range is 0.0002- 0.45.



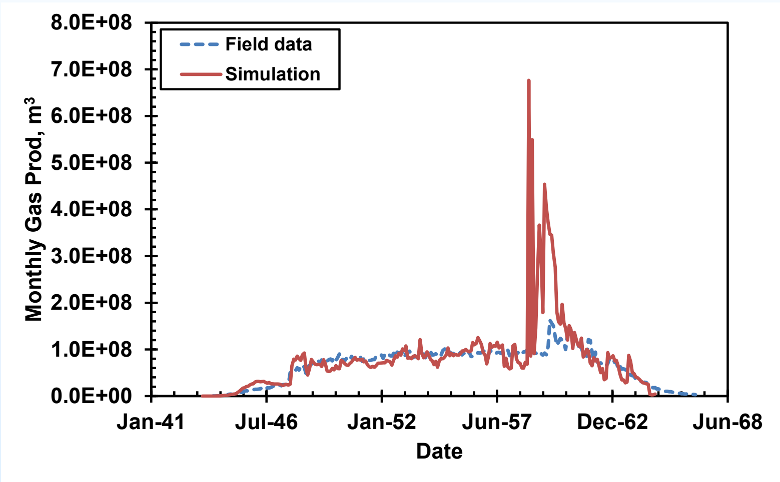
Porosity map **Permeability map (log scale)**

Hosseini, S. A., Lashgari, H., Choi, Jong-Won, Nicot, J. -P., Lu, Jiemin, and Hovorka, S. D., 2013, Static and dynamic reservoir modeling for geological CO2 sequestration at Cranfield, Mississippi, U.S.A.: International Journal of Greenhouse Gas Control, v. 18, p. 449-462.

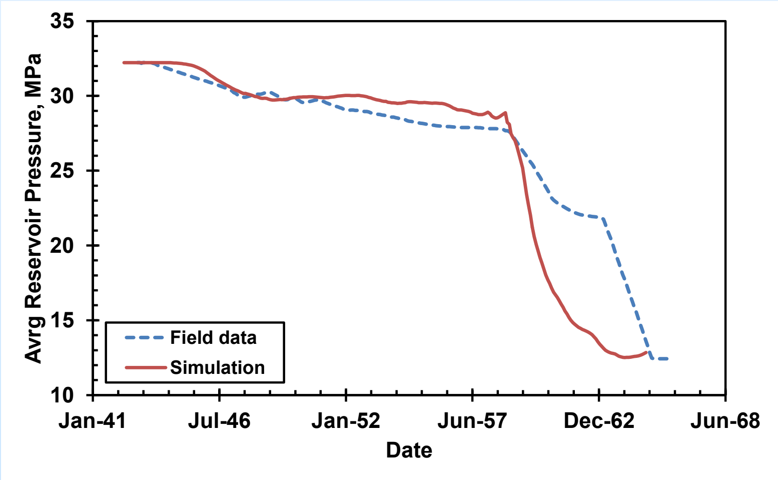
History Matching of Historic Production



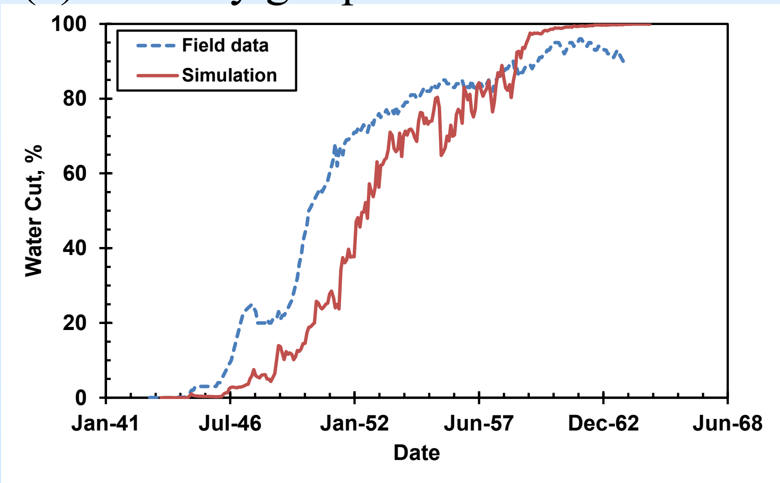
(a) Monthly oil production rate



(b) Monthly gas production rate

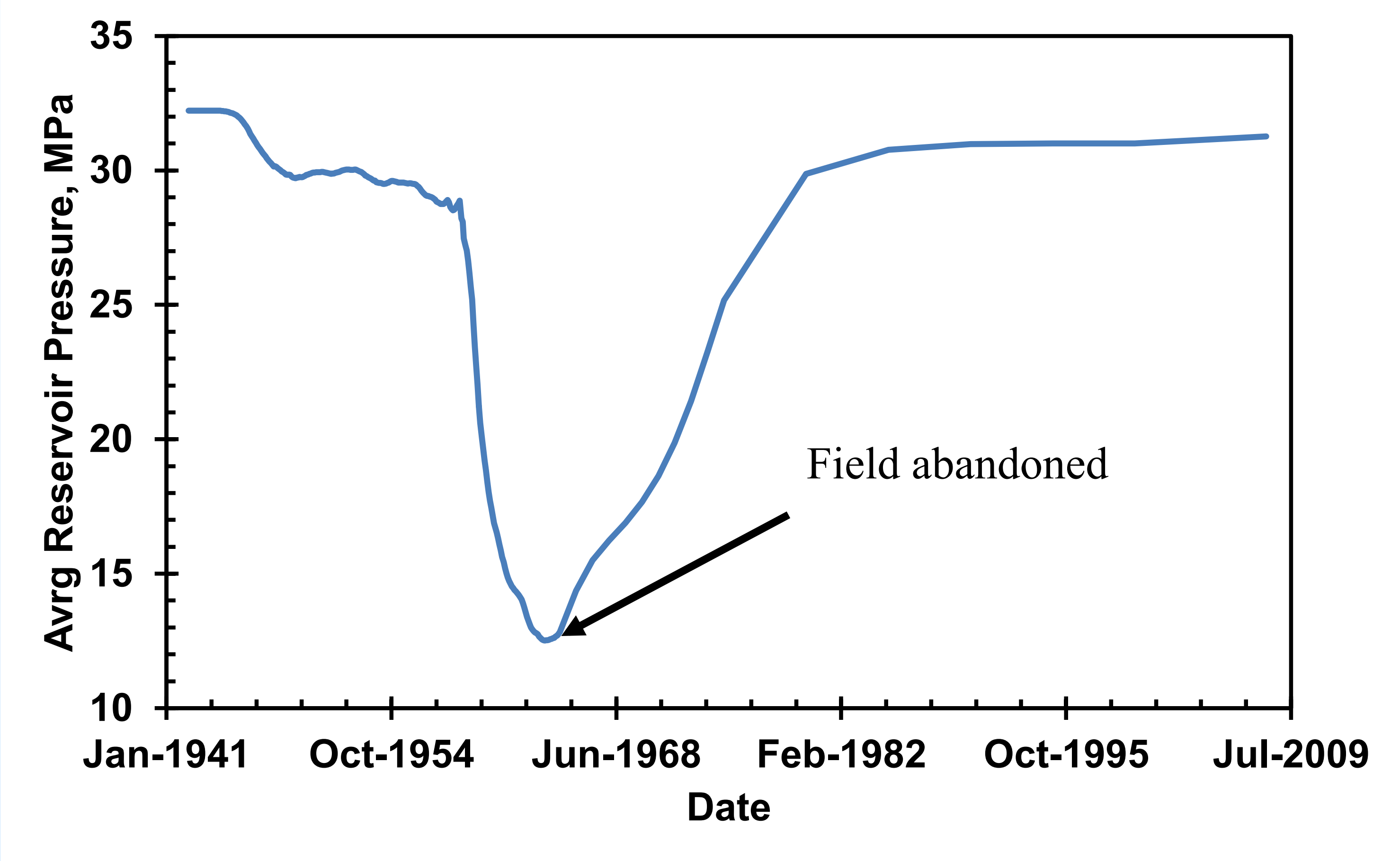


(c) Average reservoir pressure

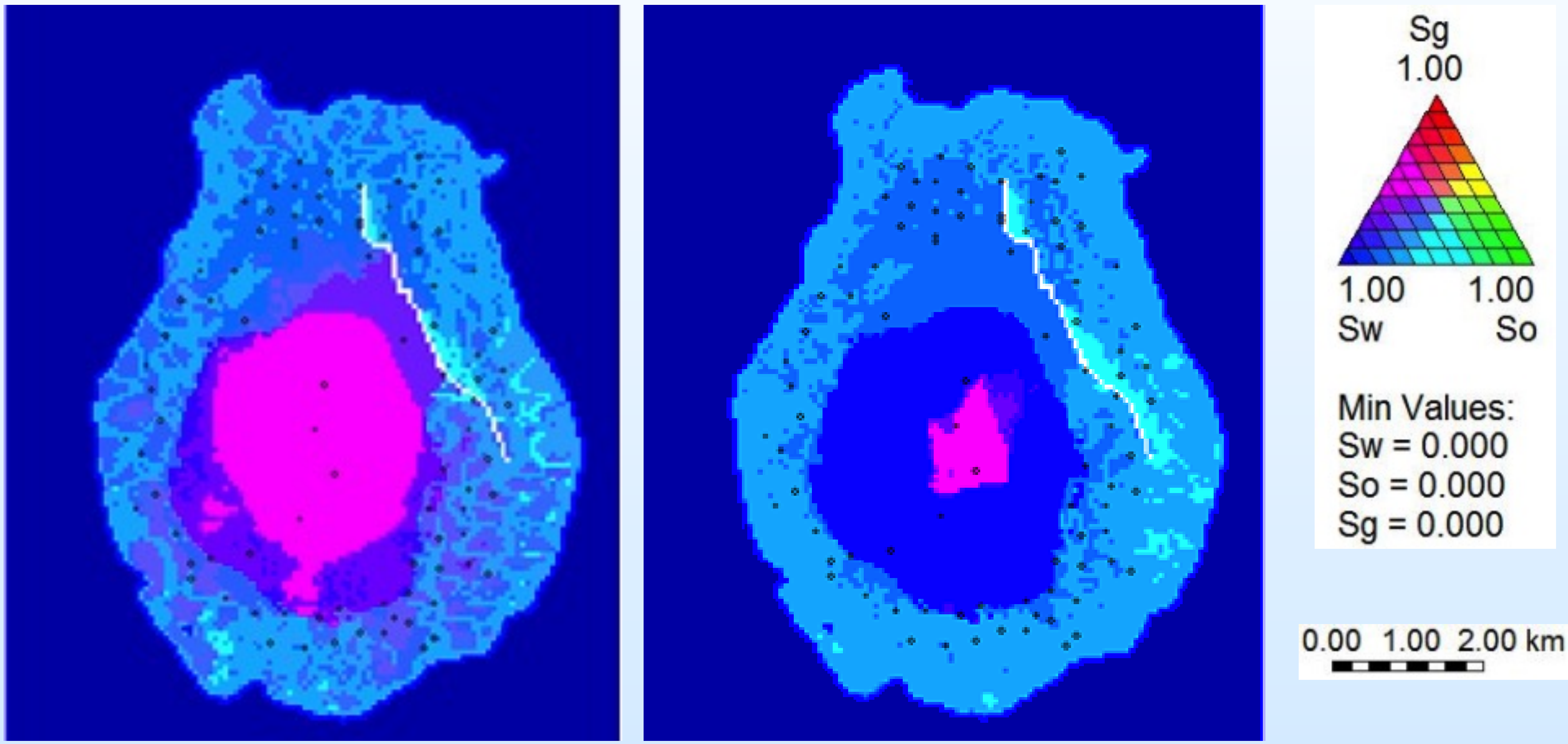


(d) Water cut

Pressure restores 1966-2008

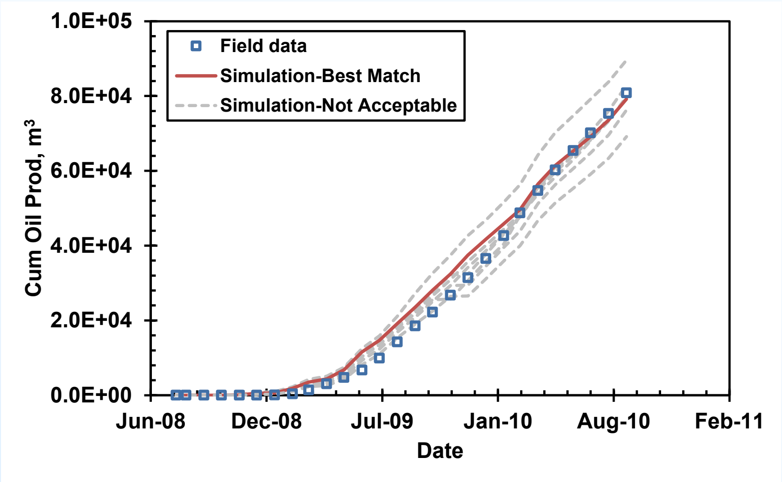


Saturation distribution

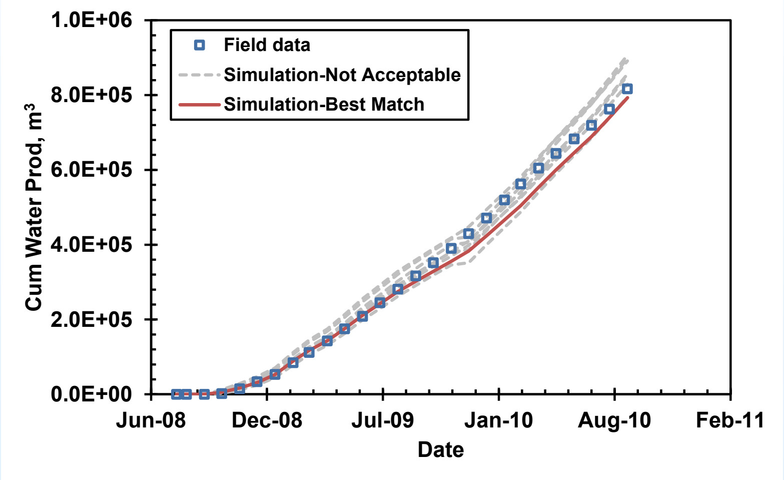


1966 **2008**

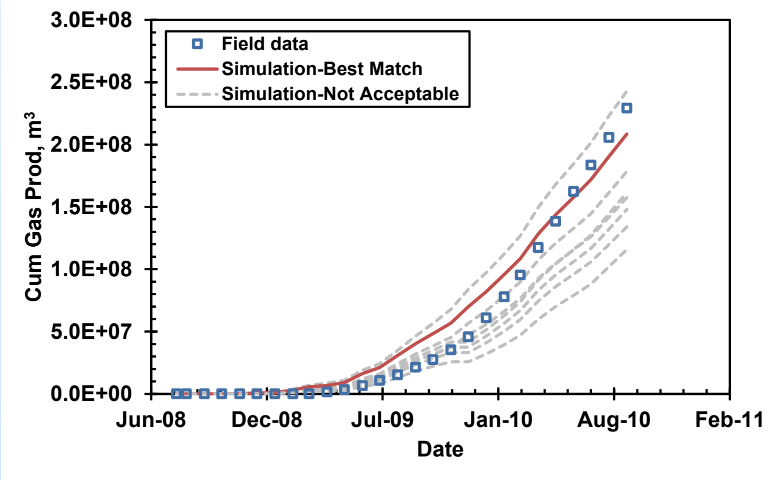
History matching of CO_2-EOR



(a) Cumulative oil production

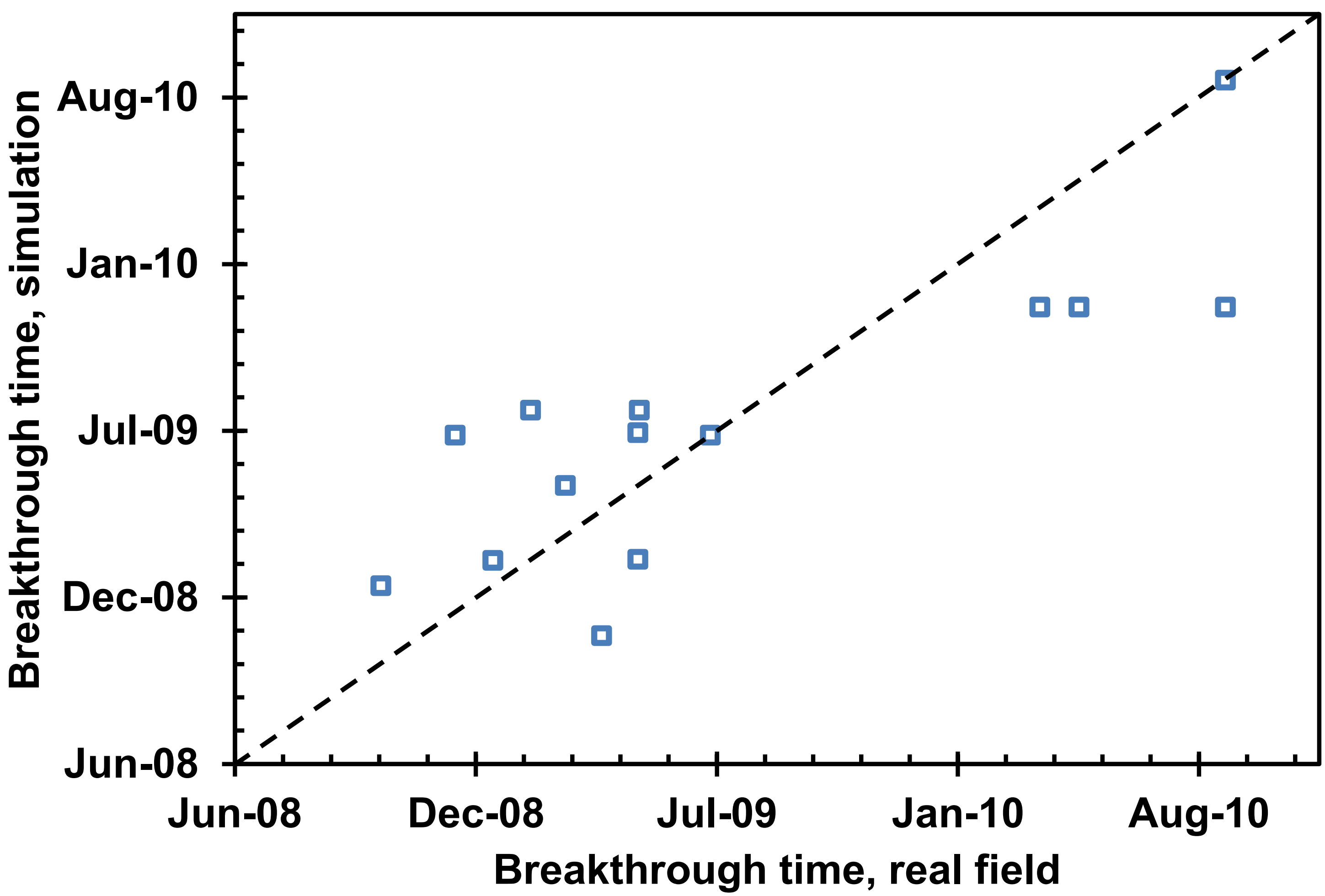


(b) Cumulative water production



(c) Cumulative gas production

Performance of fluid flow model



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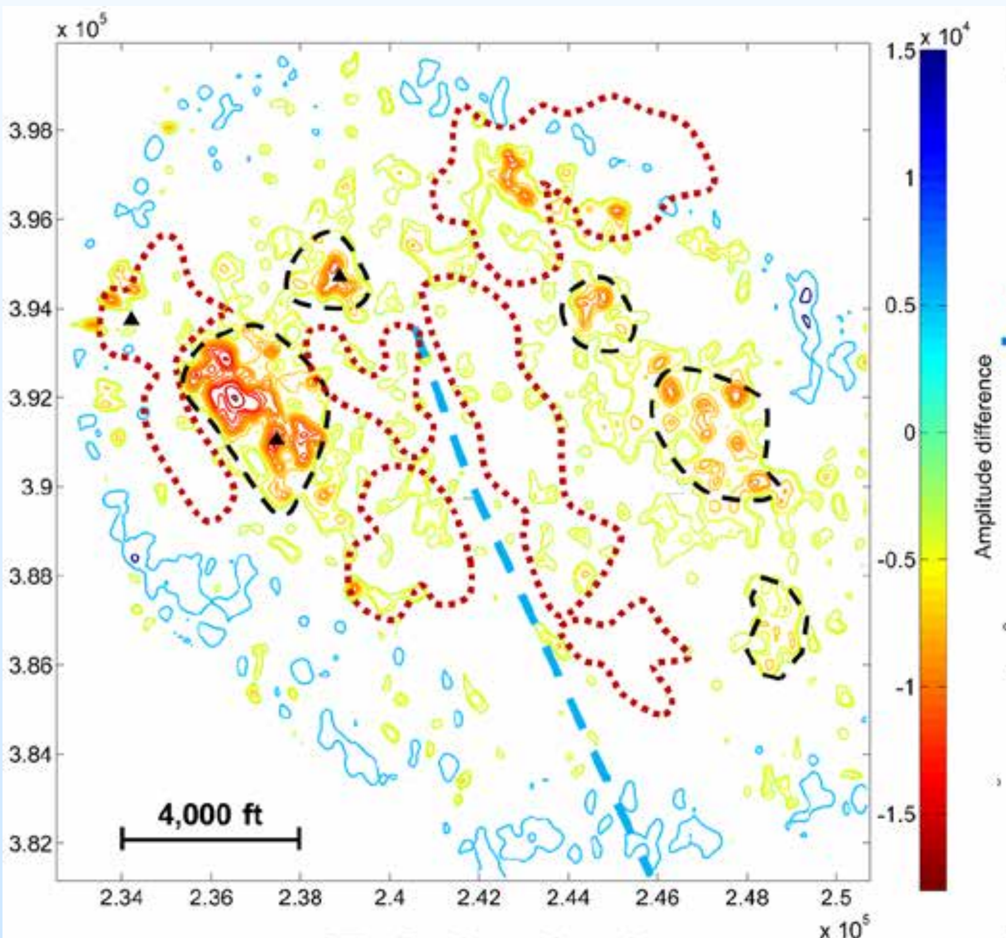
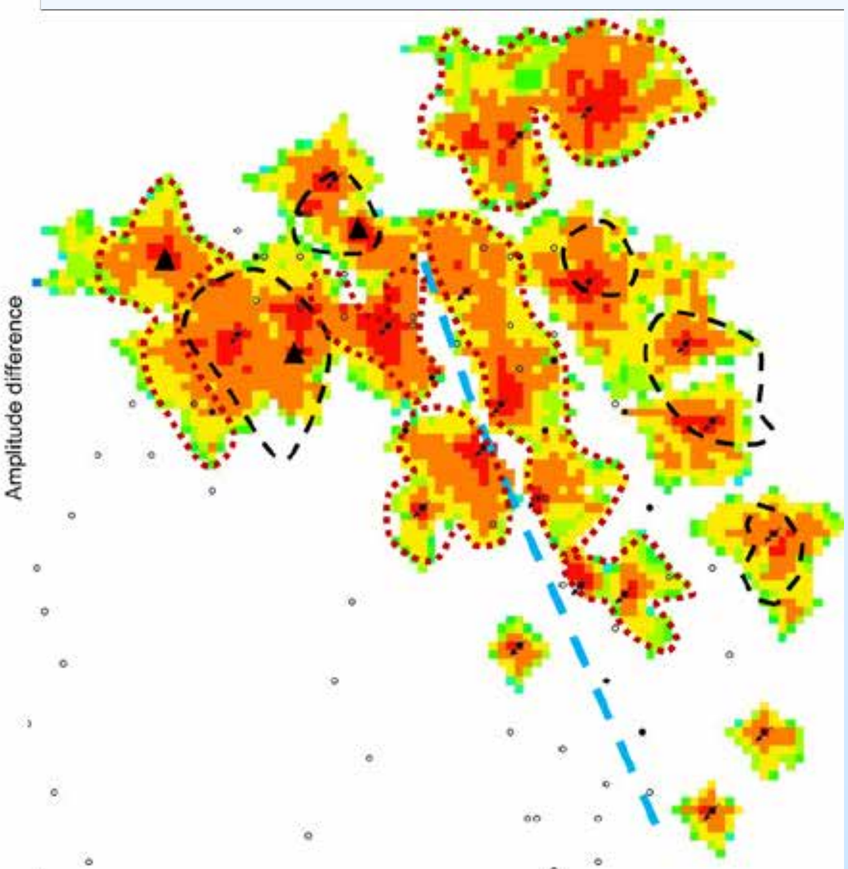
4D seismic vs fluid flow simulation



4D Seismic data



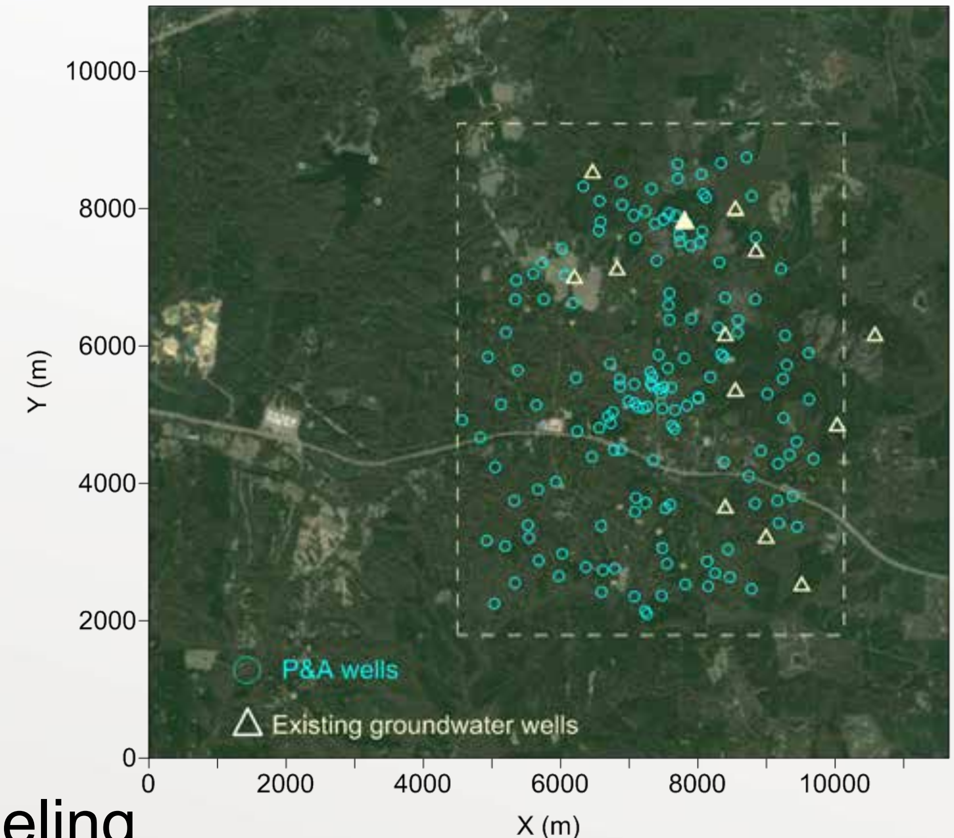
Simulation results

Future Modeling

- Investigate residual gas distribution in more detail (adjust bubble point, better match for blowdown)
- Extending forecast simulation
- Investigating effect of development strategies on reservoir response
  - Continue CO_2-EOR
  - Transition into pure storage
- Post injection simulations

- Field campaigns for groundwater sampling
- Lab experiments of water-rock-CO_2 interactions
- Single-well push-pull test

No CO_2 leakage signals have been detected.



Objectives

Use reactive transport modeling

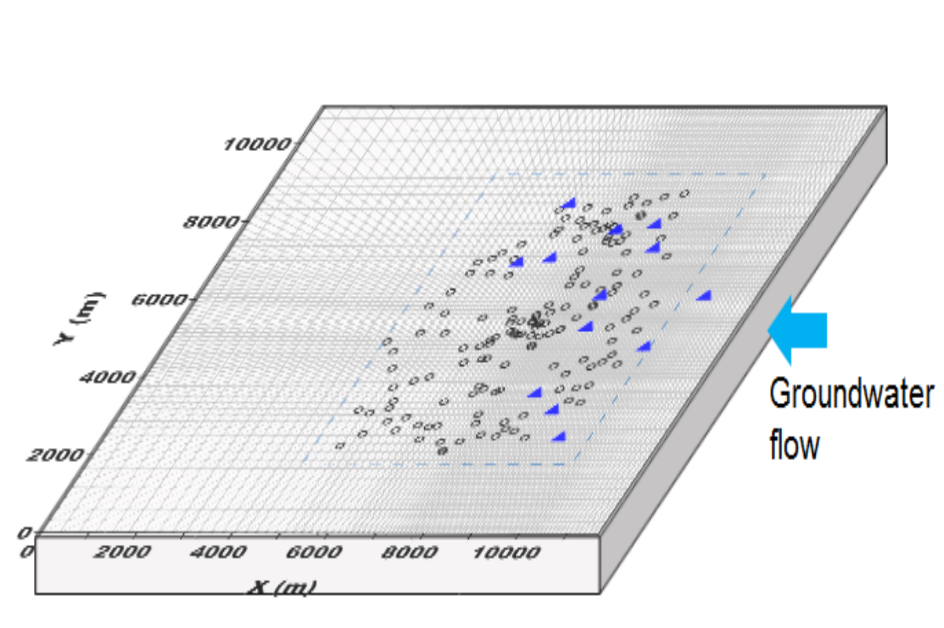
- Assess impacts of CO_2 leakage on groundwater chemistry
- Evaluate monitoring network efficiency

Yang, C.; S. D. Hovorka; R. H. Treviño; J. Delgado-Alonso, Integrated Framework for Assessing Impacts of CO2 Leakage on Groundwater Quality and Monitoring-Network Efficiency: Case Study at a CO2 Enhanced Oil Recovery Site. Environ Sci Tech 49: 8887-8898 (2015).

Yang, C; R. H. Treviño; S. D. Hovorka; J. Delgado-Alonso, Semi-analytical approach to reactive transport of CO_2 leakage into aquifers at carbon sequestration sites, Greenhouse Gas: Science and Technology, accepted.

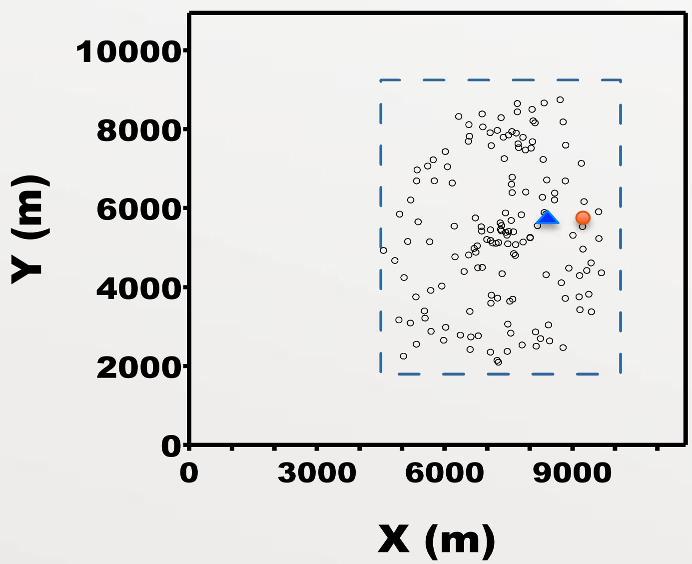
Regional-Scale Reactive Transport Modeling (RSRTM)

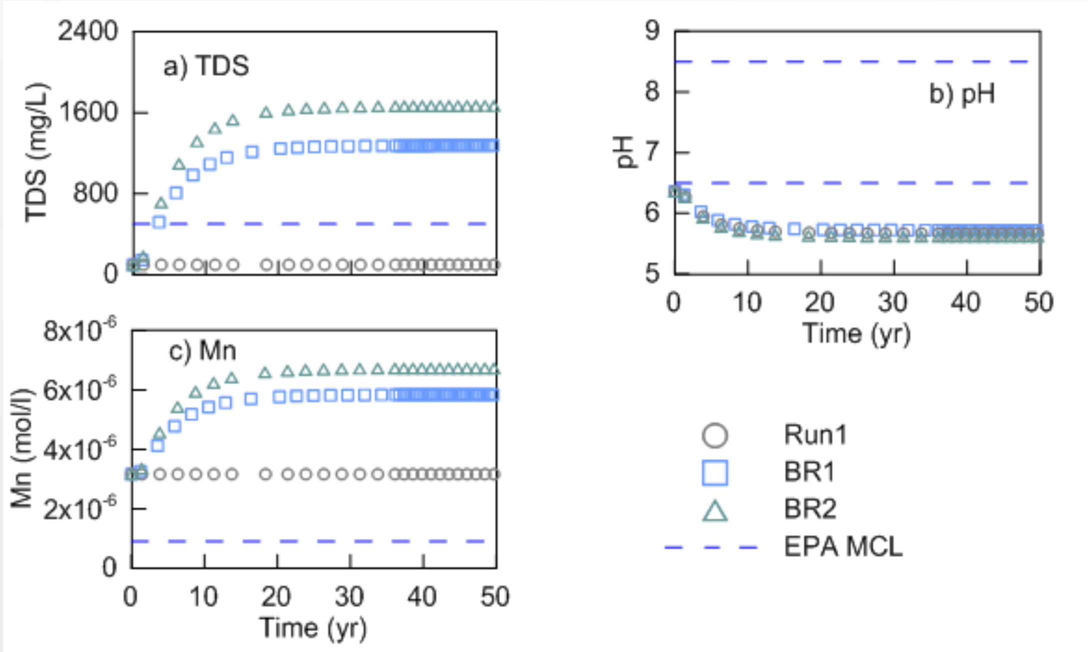
- Aquifer simplification (shallow, confined, homogeneous, groundwater flows from right to left);
- Geochemical interactions of water-rock-CO_2 tested and validated with laboratory experiments & the field test



- CO_2 as dissolved phase in either fresh groundwater or brine
- CO_2 leakage rate from 0.9 to 100 metric ton/yr

Potential impacts of CO_2 leakage on groundwater chemistry





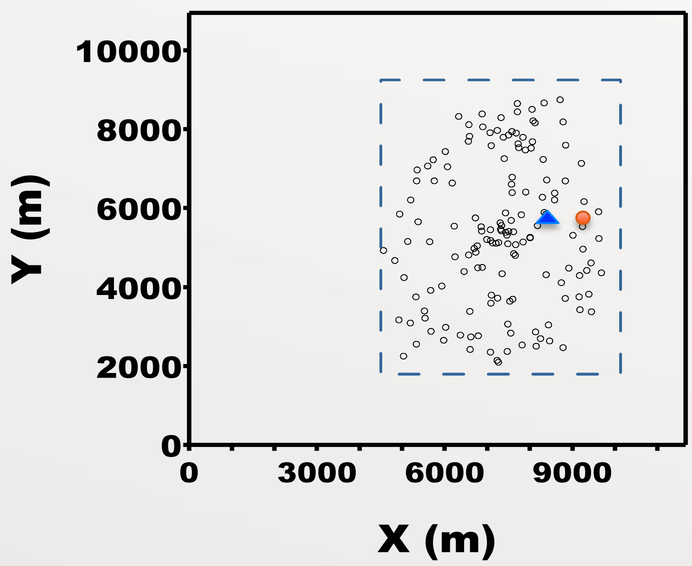
Leakage rate
metric ton/yr

Run1: 50.3
BR1: 37.3
BR2: 50.3

J=0.5%

- TDS exceeds the EPA MCL if brine is leaked;
- pH degradation
- Mn is a concern

Potential impacts of CO_2 leakage on groundwater chemistry



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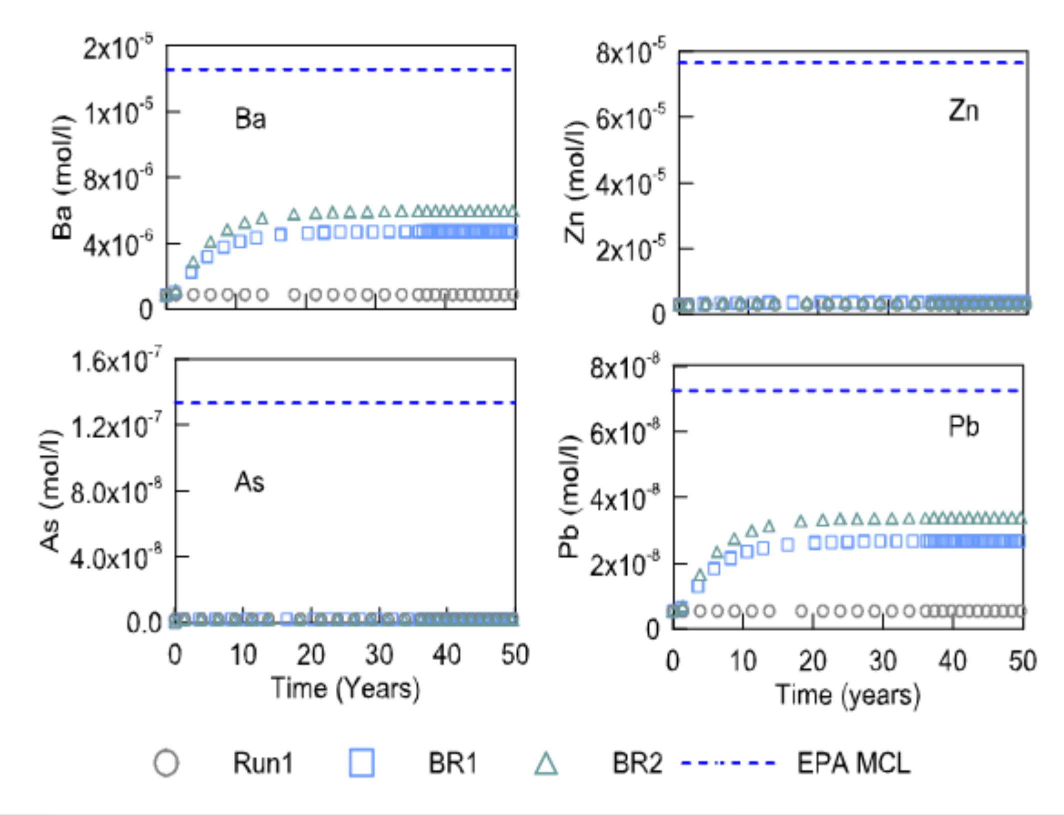
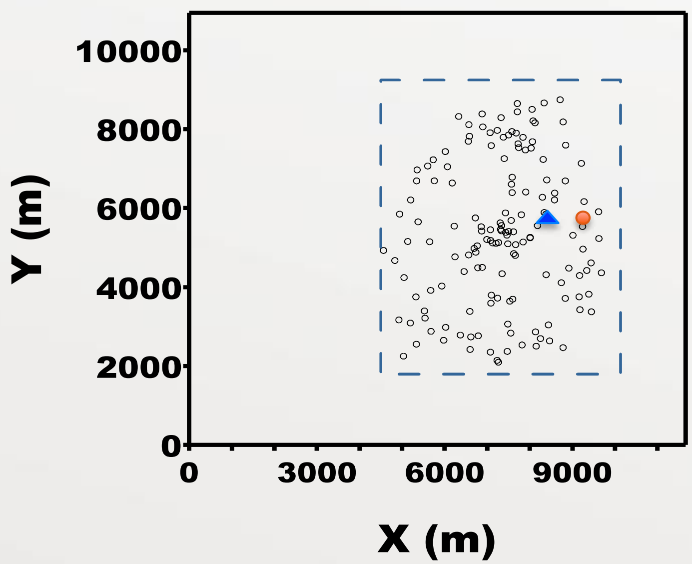
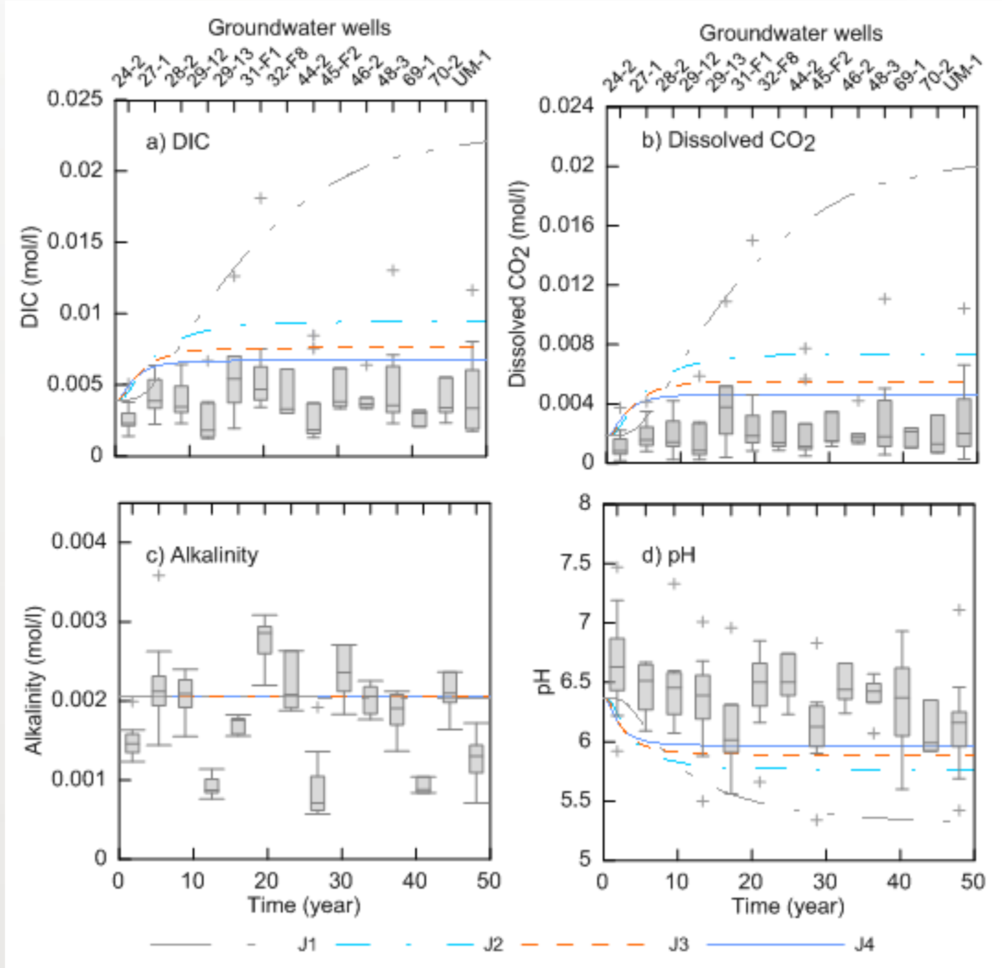


- Simulated conc. < EPA MCL
- Ba and Pb increase caused by brine leakage

Potential impacts of CO_2 leakage on groundwater chemistry



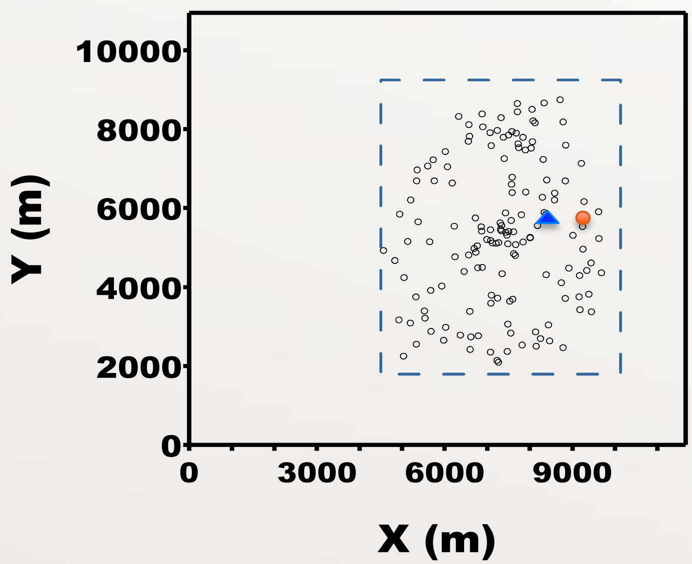


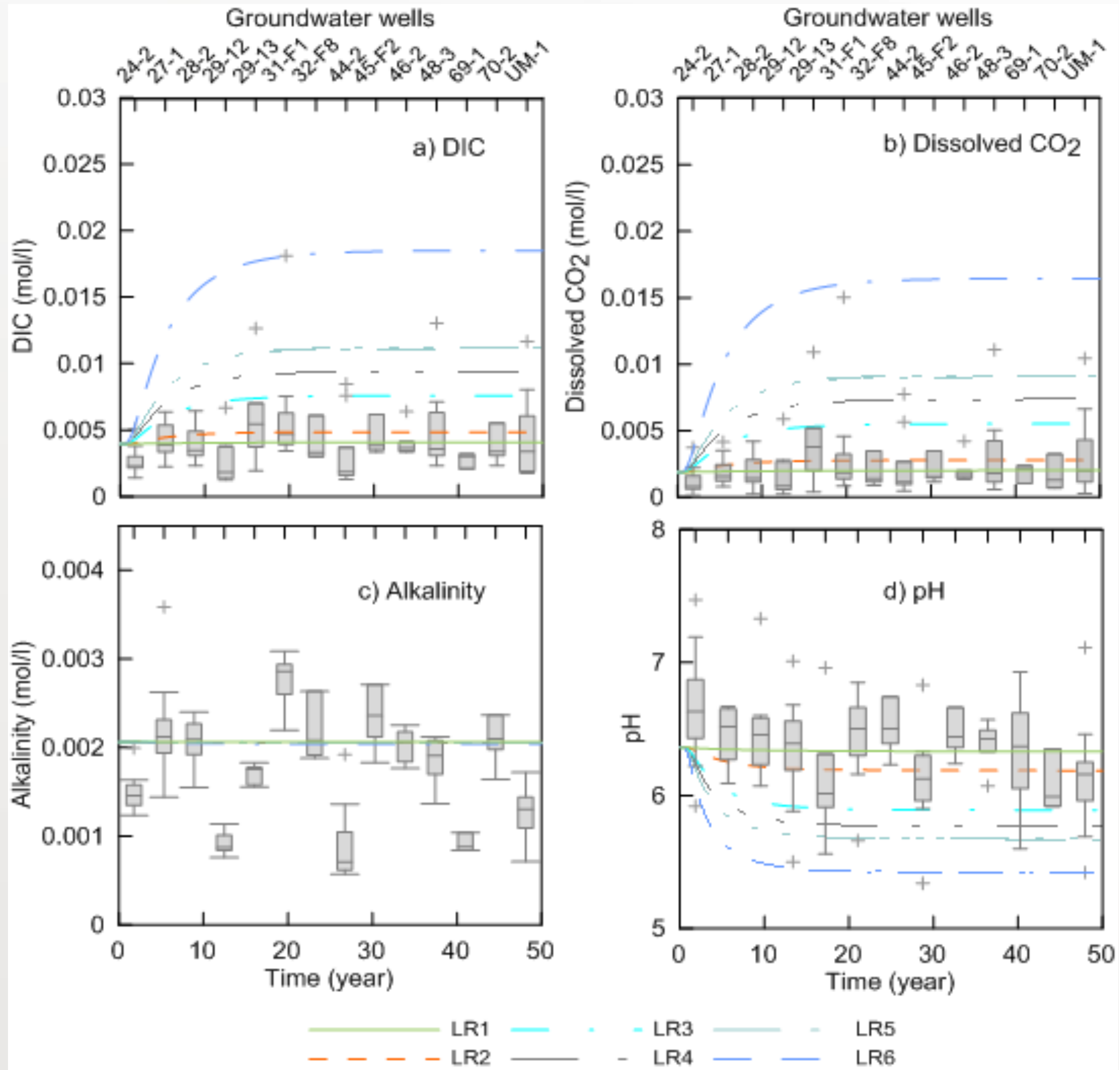
Regional hydraulic gradient

J1: 0.1%
J2: 0.5% (in the shallow aquifer)
J3: 0.8%
J4: 1.0%

Leakage rate: 37.7 metric ton/yr

Potential impacts of CO_2 leakage on groundwater chemistry





Leakage rate: metric ton/yr

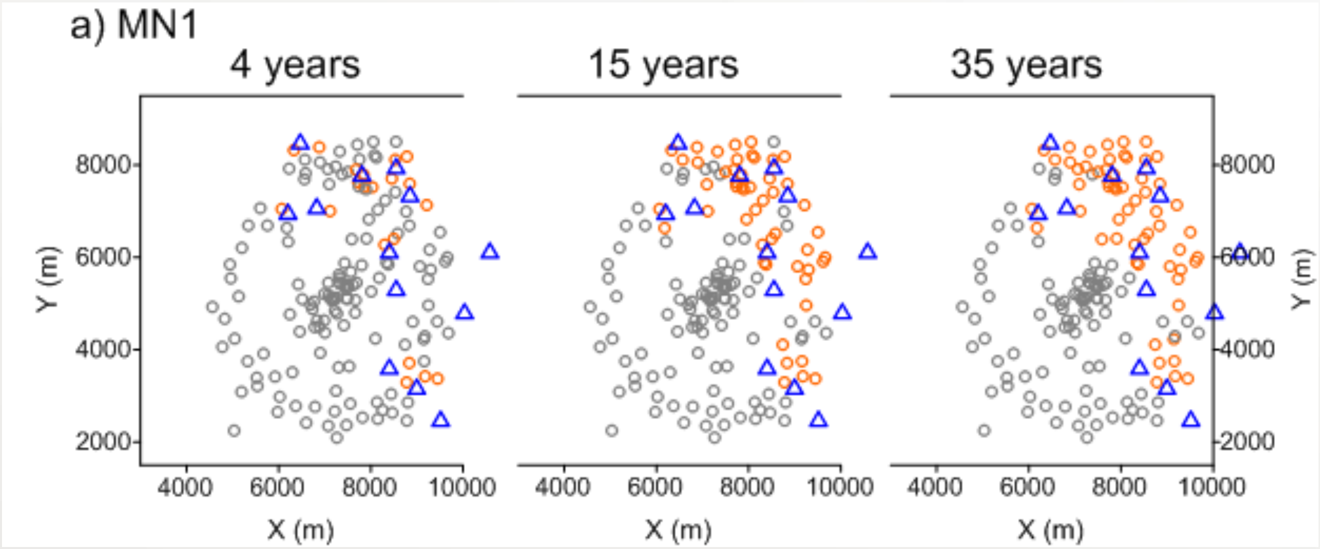
LR1: 0.94
LR2: 6.28
LR3: 25.1
LR4: 37.7
LR5: 50.3
LR6: 100

J=0.5%

Monitoring Network Efficiency

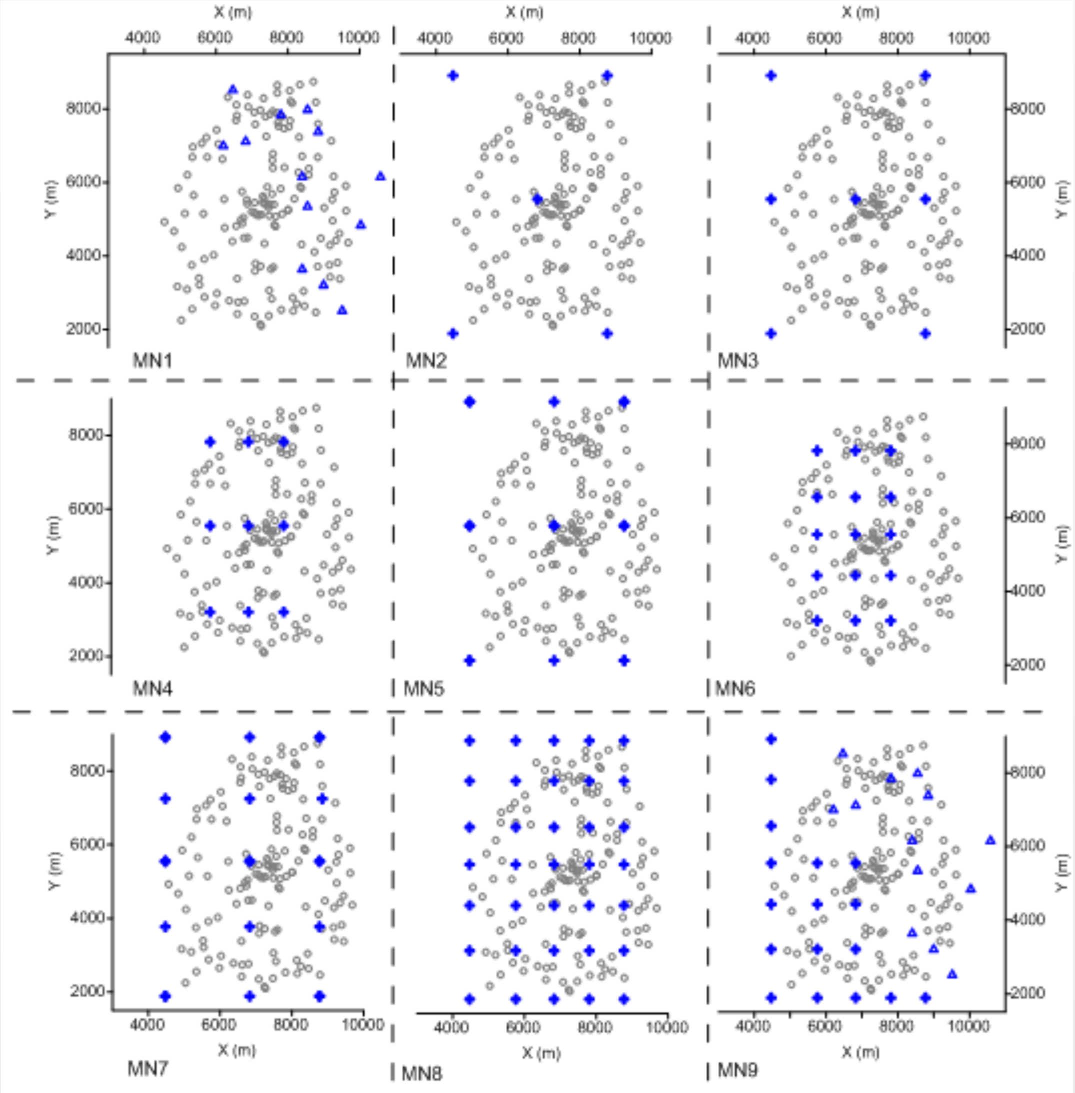
$$ME = W\uparrow d / W\uparrow T$$

- 20/151=0.13 by 4 years
- 50/151=0.33 by 15 years
- 58/151=0.38 by 35 years



CO$_2$ leakage from a P&A well is detected by a monitoring net work if change in DIC, dissolved CO_2, or pH in any one of wells of the monitoring network is higher than one standard deviation of the groundwater chemistry data collected in the shallow aquifer over the last 6 years.

Monitoring Network Efficiency

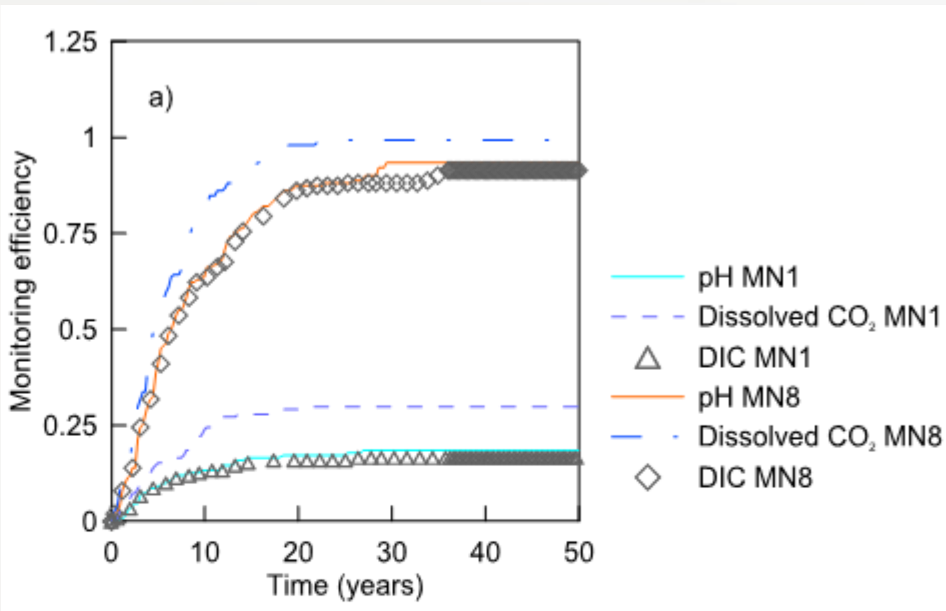


Unit: wells/km^2

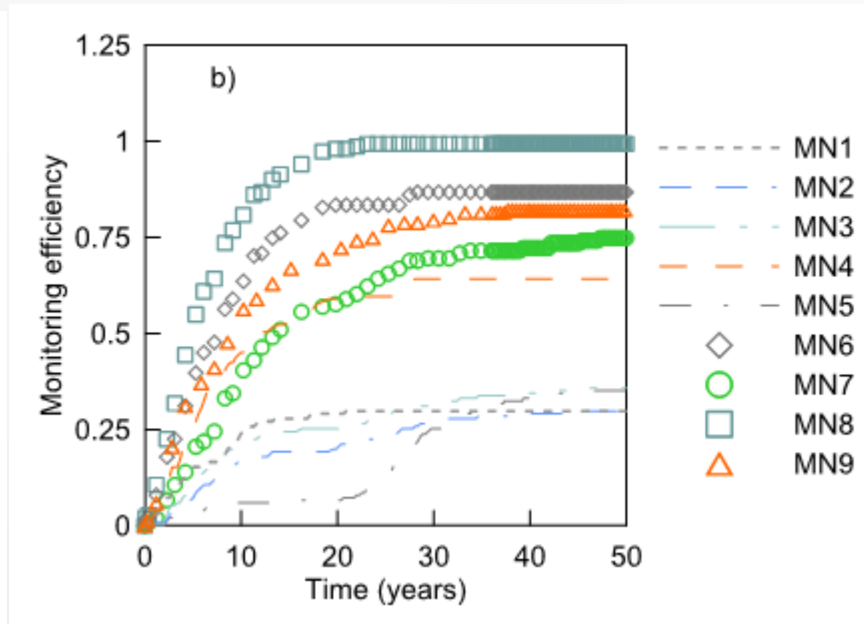
MN1: 0.322
MN2: 0.124
MN3: 0.173
MN4: 0.223
MN5: 0.223
MN6: 0.371
MN7: 0.371
MN8: 0.866
MN9: 0.742

Monitoring Network Efficiency

Leakage rate=37.7 metric ton/yr; J= 0.5%



Comparison of ME for a) with pH, dissolved CO_2 and DIC as indicators for the two monitoring networks, MN1 and MN8



- Comparison of ME with dissolved CO_2 as indicator for the 9 monitoring networks
- Well densities for MN4 and MN5 are 0.223 wells/km2; ME of MN4 is ~2 times of ME of MN5, suggesting well locations are important

Monitoring Network Efficiency

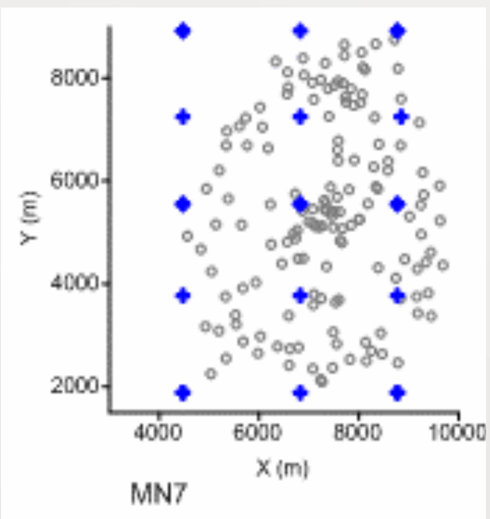
Leakage rate: metric ton/yr

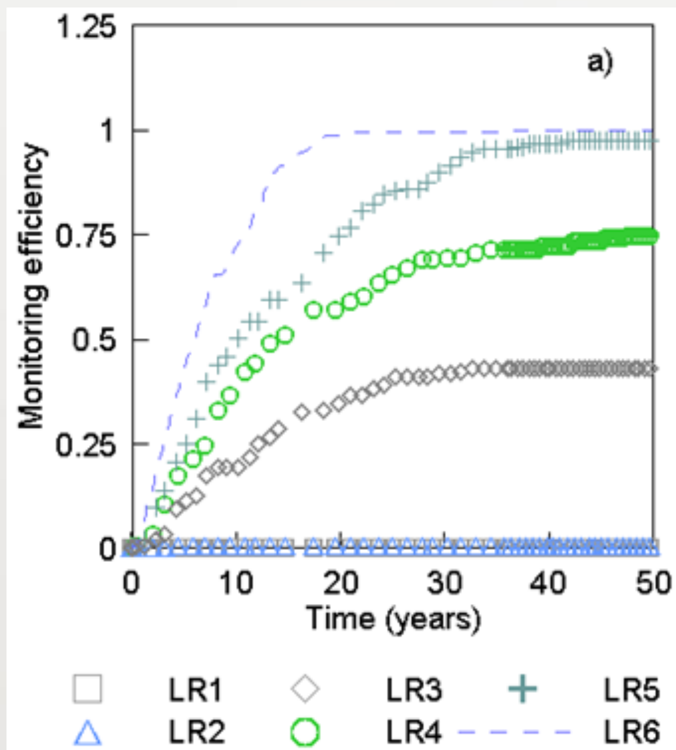
LR1: 0.94, LR2: 6.28
LR3: 25.1, LR4: 37.7
LR5: 50.3, LR6: 100

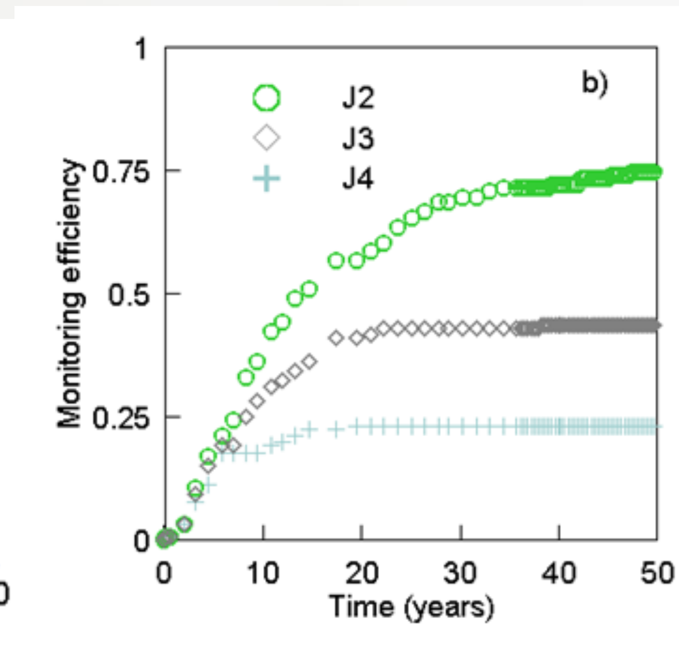
Regional hydraulic gradient

J2: 0.5% , J3: 0.8%
J4: 1.0%

Monitoring efficiency of MN7 with dissolved CO_2 as an indicator







Summary

- Model outcome: No obvious degradation in groundwater quality (except degradation in pH) if only CO_2 is leaked. Salinization would be problematic if brine+CO_2 are leaked.
- Dissolved CO_2 appears to be a better indicator than DIC, pH, alkalinity for CO_2 leakage detection at the CO_2-EOR site, however, dependent on regional hydraulic gradient, leakage rate.
- Monitoring network efficiency depends on regional hydraulic gradient, leakage rate, flow direction, and also aquifer heterogeneity. Impact of dispersion coefficient could be neglected.

Summary

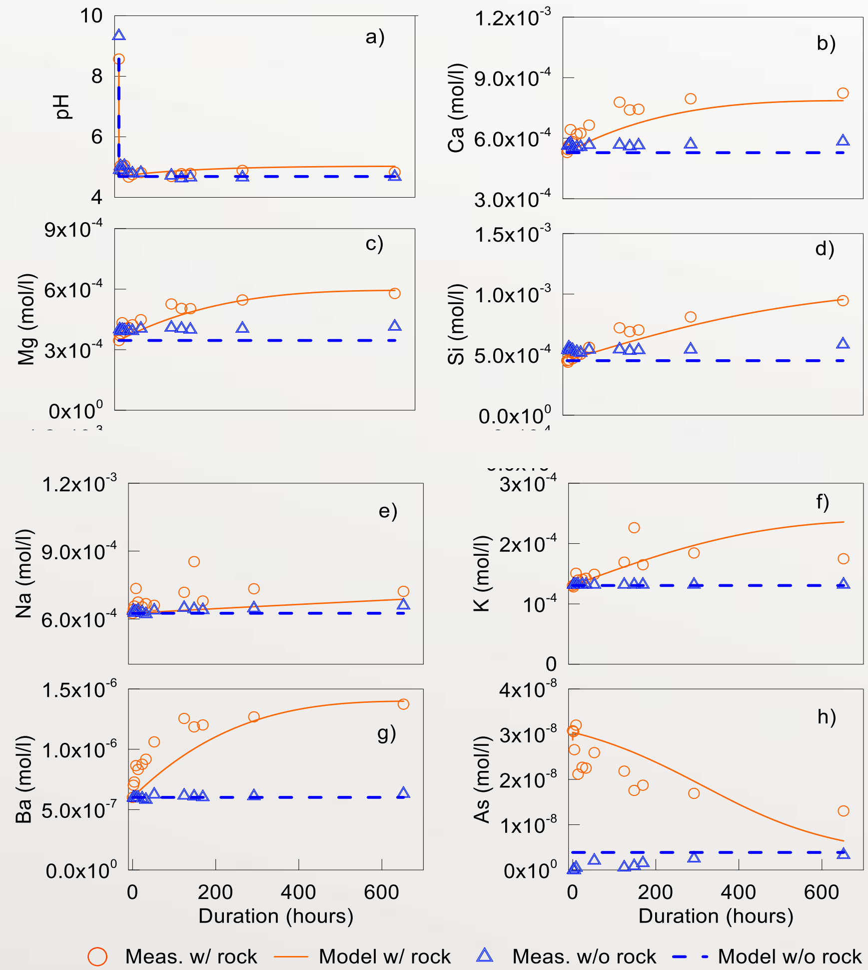
- The existing groundwater wells can monitor CO_2 leakage from up to 60 P&A wells and MN8, the ideal monitoring network which consists of 35 water wells can detect CO_2 leakage from almost all P&A wells.
- Site characterization + lab experiments + single-well PPTs + RTM could be enough for risk assessment.

Thanks!

Gulf Coast Carbon Center
Bureau of Economic Geology
NETL
Denbury
Southern States Energy Board
SECARB Southeast Regional Carbon Sequestration Partnership

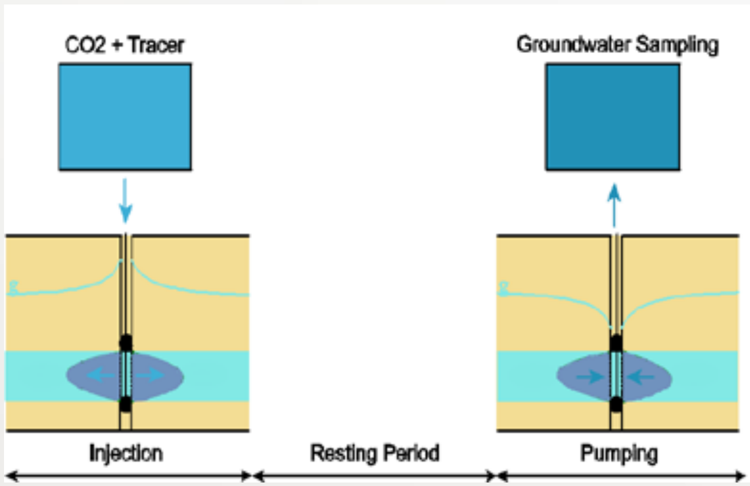
Model calibration with laboratory and field tests

To understand responses of groundwater chemistry to CO_2 leakage under laboratory conditions

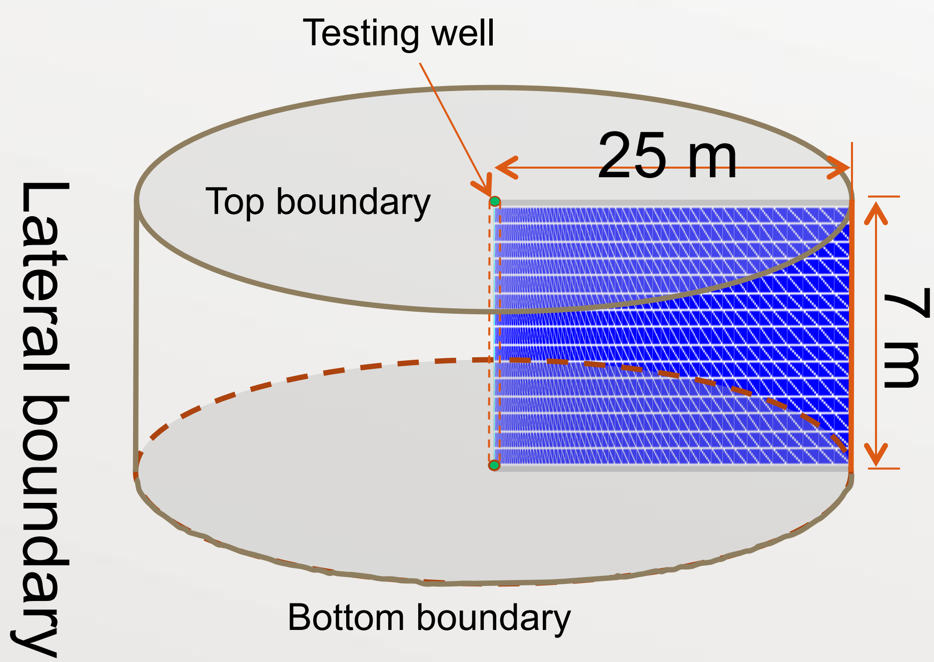


- 106 g of sedimentary samples and 420 ml groundwater from the Cranfield shallow aquifer
- bubbled with Ar for a week, then with CO_2 for ~half year

Model calibration with laboratory and field tests



Single well push-pull test



Model calibration with laboratory and field tests