Lessons Learned During Numerical Simulations of a CO_2 Sequestration Field Demonstration Project

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Why do we use simulations?

- **Understand past performance and predict future performance of a reservoir based on the available information**
- **Predictions can be used to make decisions**
  - Reservoir management
  - Monitoring strategies
  - HSE/economic risk analysis

Oil reservoirs are more complex compared to other geologic reservoirs

- **Need to take into account at least three components (CO_2, water, oil) that can exist in multiple phases (gas, immiscible liquids, super-critical):**
  - Compositional simulations need more components to be taken into account
- **Multiple simultaneous thermodynamic interactions:**
  - Multi-component oil & CO_2, Water & CO_2
- **Oil and hydrocarbon gas make reservoir dynamics complicated**

Oil reservoir parameter space is larger than other geologic reservoirs

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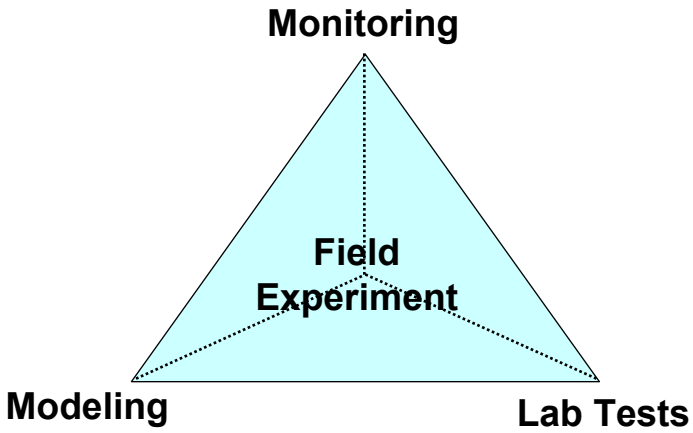
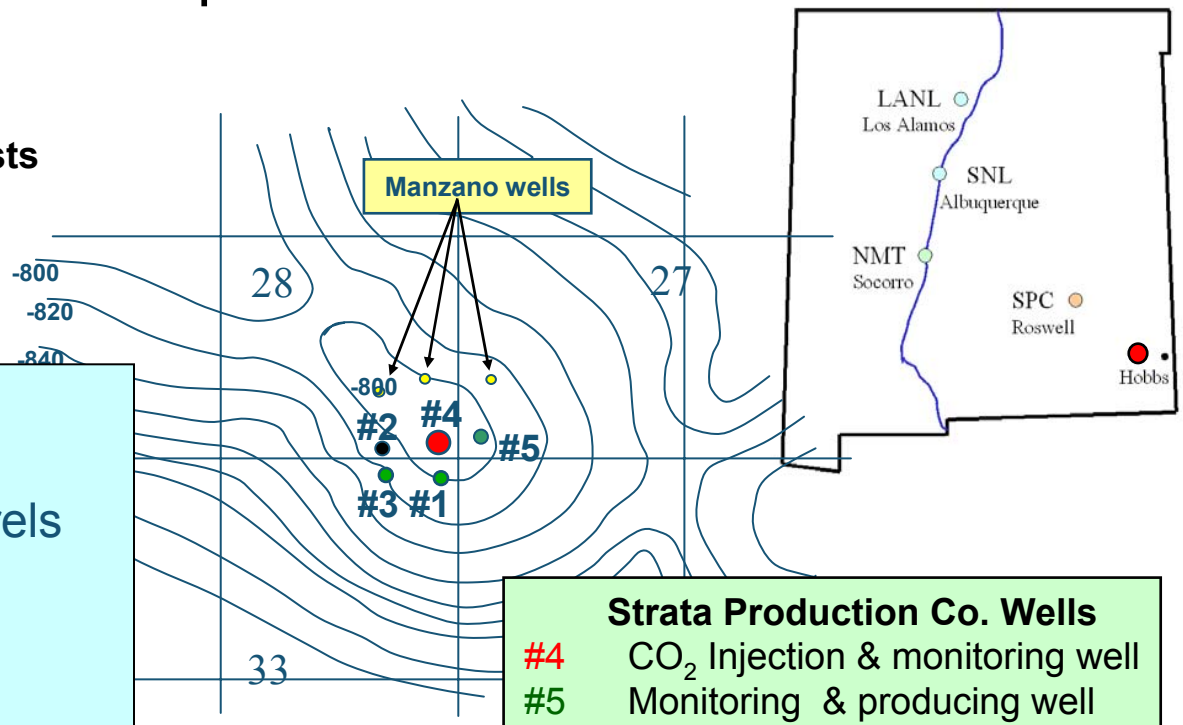
West Pearl Queen Project



- A multi-disciplinary project centered around field demonstration in a depleted oil reservoir.



West Pearl Queen reservoir:
- First Production in 1984.
- Produced about 250000 barrels of oil till 2000.
- No enhanced oil recovery operations.

Strata Production Co. Wells

#4	CO_2 Injection & monitoring well
#5	Monitoring & producing well
#1&3	Waste water injector well
#2	Plugged well

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West Pearl Queen Project Overview

Phase I – Pre-Injection Studies

- Geology
- Geophysics
  - » Logs, Crosswell & Surface 3D/9C
- Geochemistry
- Core analysis
- Modeling

Phase II - CO_2 Injection Test

- 2100 ton Injection @ ~7 gpm
- 6 Month soak
- 3 Week blow down
- Continuous production thereafter

Phase III - Post-Injection Studies

- Surface Seismic
  - » Surface 3D/9C
- Integration

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Numerical Simulations: Approach

- **Develop a reservoir model based on available data**
  - Validate the model through production history match
- **Perform pre-injection characterization calculations**
  - Predict reservoir response to CO_2 injection
  - Predict CO_2 migration subsequent to injection
- **Integrate with field observations**
  - Validate the model through field observations
  - Understand fluid flow dynamics
  - Predict long-term capacity of reservoir and long-term fate of CO_2

Pre-injection Geologic Interpretation

- **Available Geologic Data**
  - Logs : gamma ray, neutron, density, resistivity
  - Core data : porosity, permeability from core
  - Outcrop
  - Geophysical logs:
    - » Crosswell tomogram between Stivason Federal #4 and Stivason Federal #5
    - » High resolution 3-dimensional, surface seismic survey (prior to start of injection, not available for pre-injection characterization)
- **Geologic Interpretation:**
  - Layered reservoir, with three continuous, high-porosity zones separated by shaley units
  - Best matrix permeabilities are on the order of 100 md, porosities about 15-20%
  - No known faults

Pre-injection Simulations

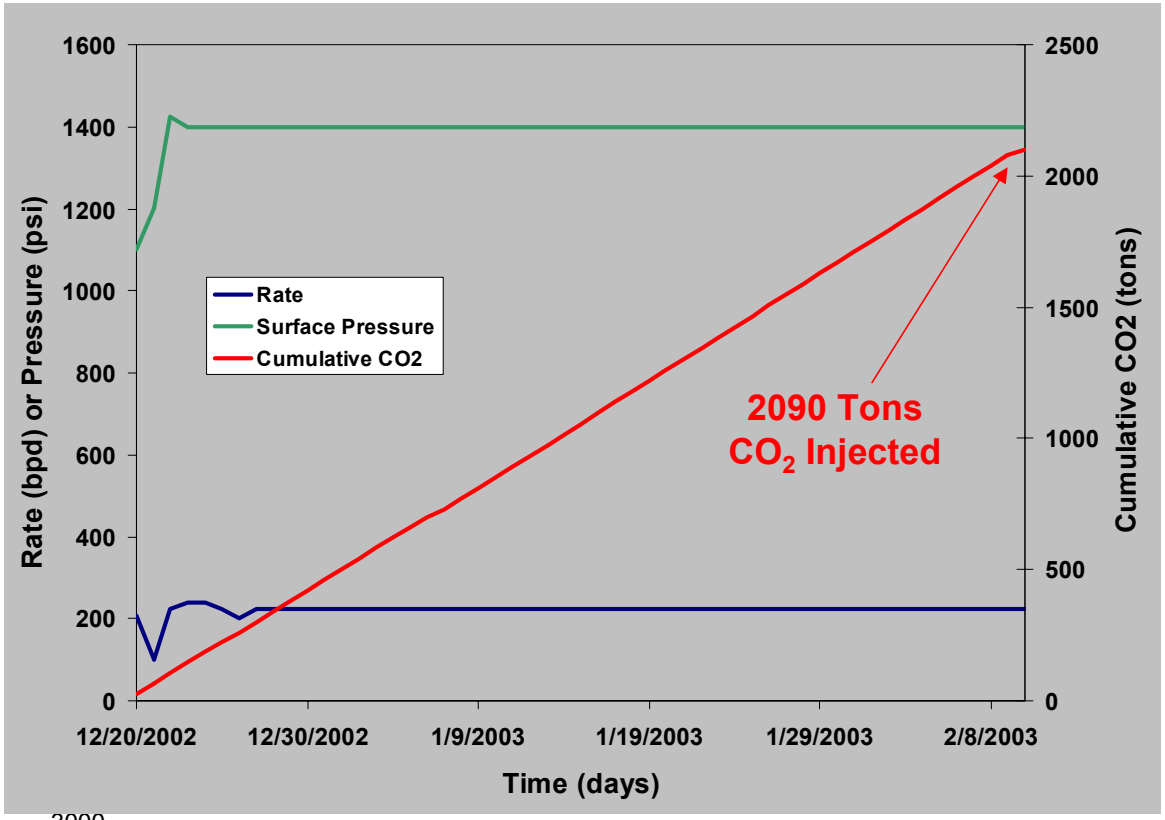
- **Available Data**
  - Oil, water, gas production data (monthly volumes)
  - No reservoir pressure data
    - » Field operator estimated pressure ~ 100-200 psi based on observed production
  - Limited 2-phase relative permeability data from laboratory experiments
- **Production History Match**
  - Reservoir parameters derived from geologic model
  - Multi-phase flow behavior estimated from production history match
  - Pressure matched to operator estimate
  - Commercial code: ECLIPSE
- **CO_2 Injection Simulations**
  - Compositional simulation
  - Multicomponent oil (C1 to C7+), gas thermodynamics
  - Variable CO_2 injection rates (1000-10,000 tons/month)
  - Regulatory BHP constrained injection

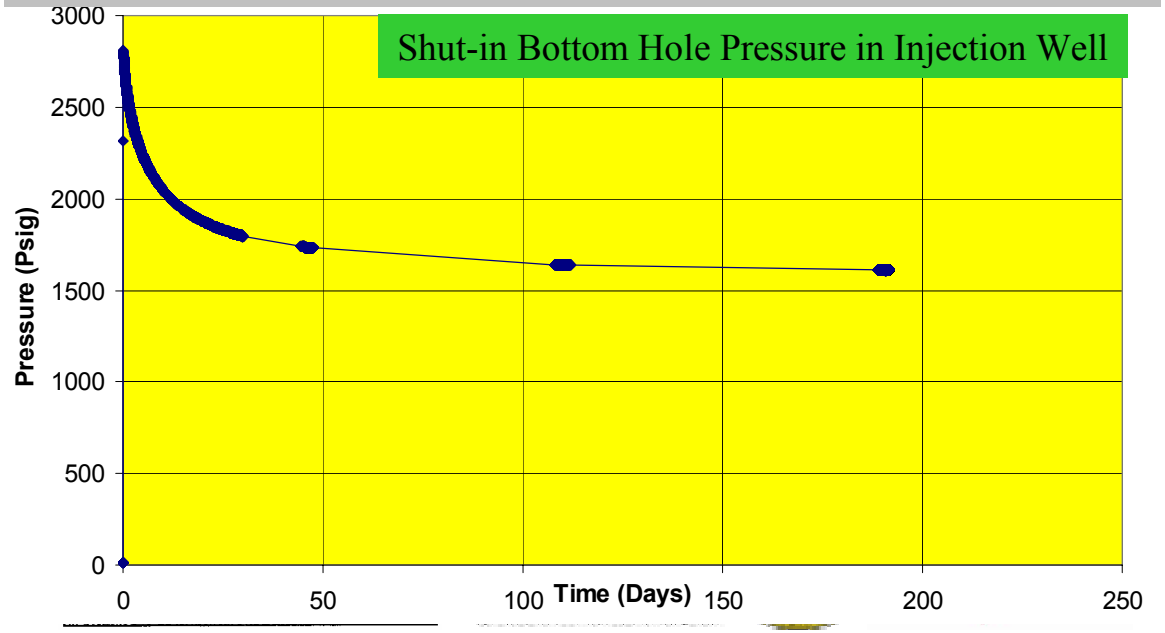
Pre-injection Simulation Results

- Estimated CO_2 injection rate : ~ 100 tons/day without exceeding BHP constraint.
- Estimated CO_2 plume extent : migration upto monitoring well (Stivason #5) during soak period.
- Post-injection reservoir pressure within vicinity of injection well : ~ 700 psia.

Field Observations

- Field injection rates significantly lower than simulation results
- Reservoir pressure significantly higher than previous assumption





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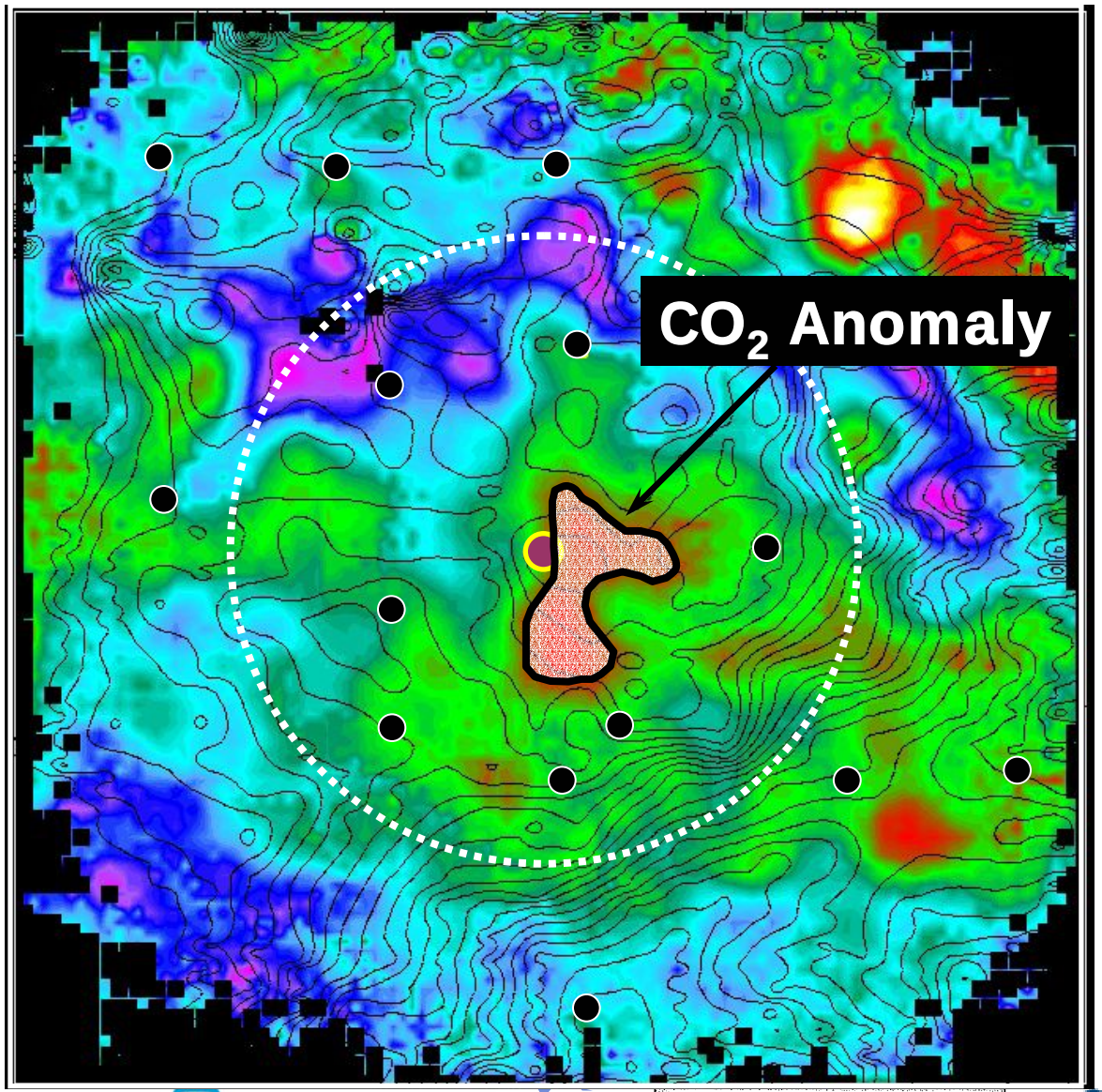
CO_2 Plume Extent : Seismic Interpretation



RMS Amp. Difference
Base - Monitor

- 1
- 0
- -1

Depth Structure Overlay
Top of Queen
CI = 4 ft

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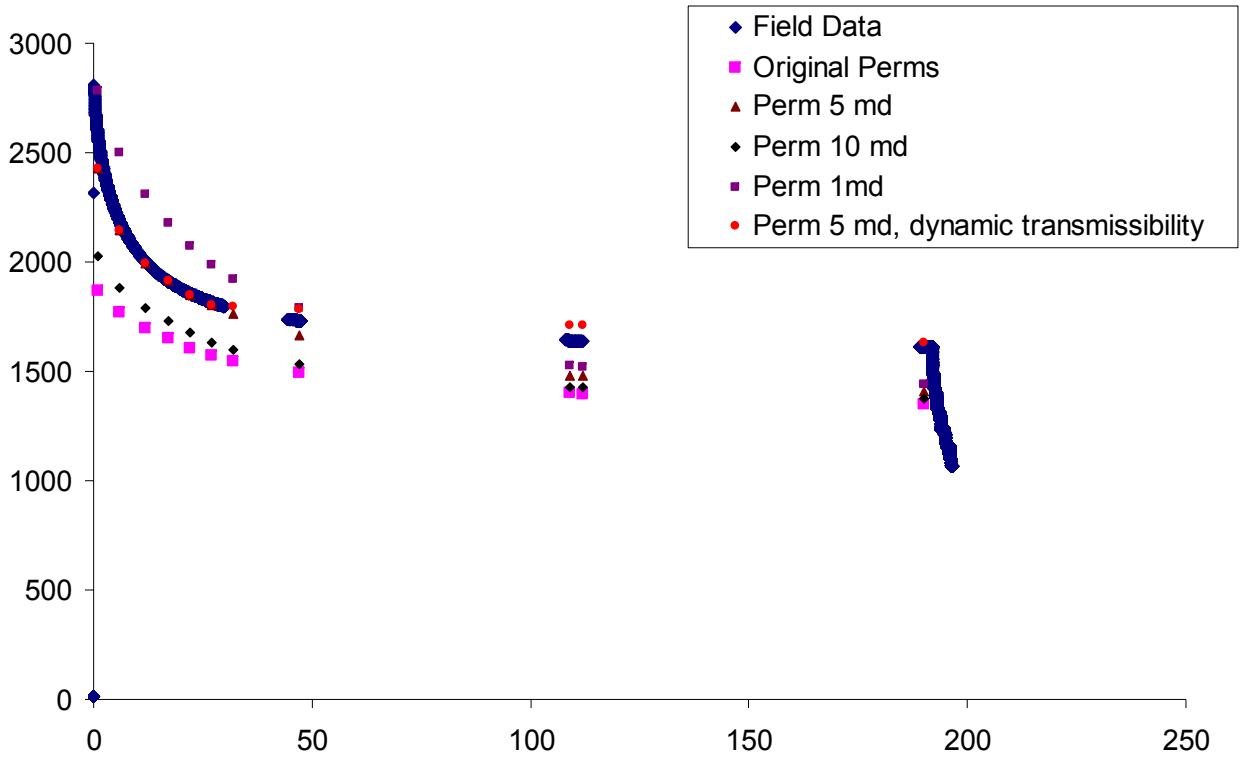
Iteration based on field observations

- Rigorous calculation of bubble point from laboratory compositional analysis of field oil & gas samples
- Local permeability varied near injection well to match observed injection rate and reservoir pressure



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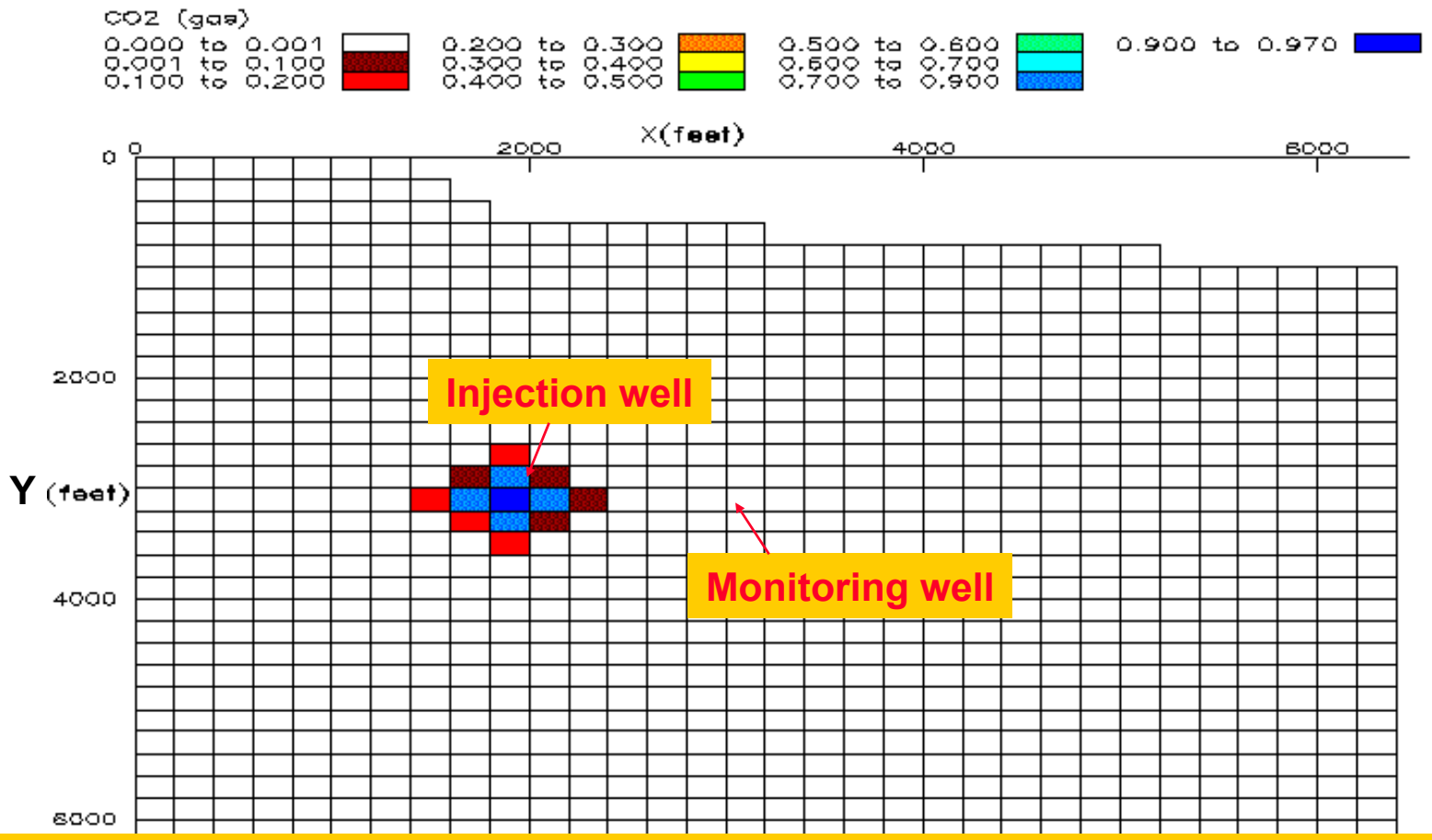
Predicted CO_2 Plume Extent



Plume extent qualitatively similar to seismic observations.

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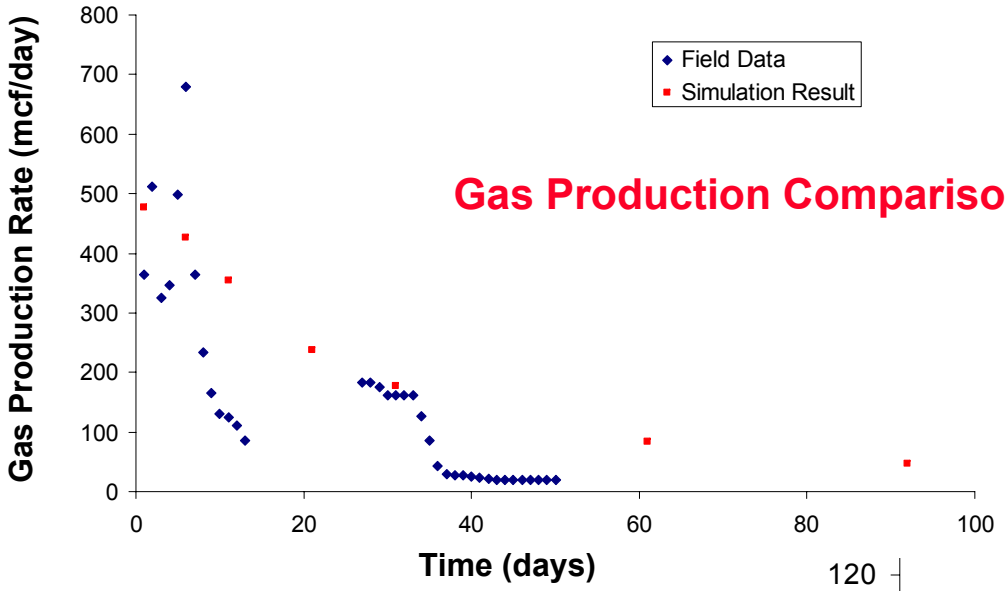
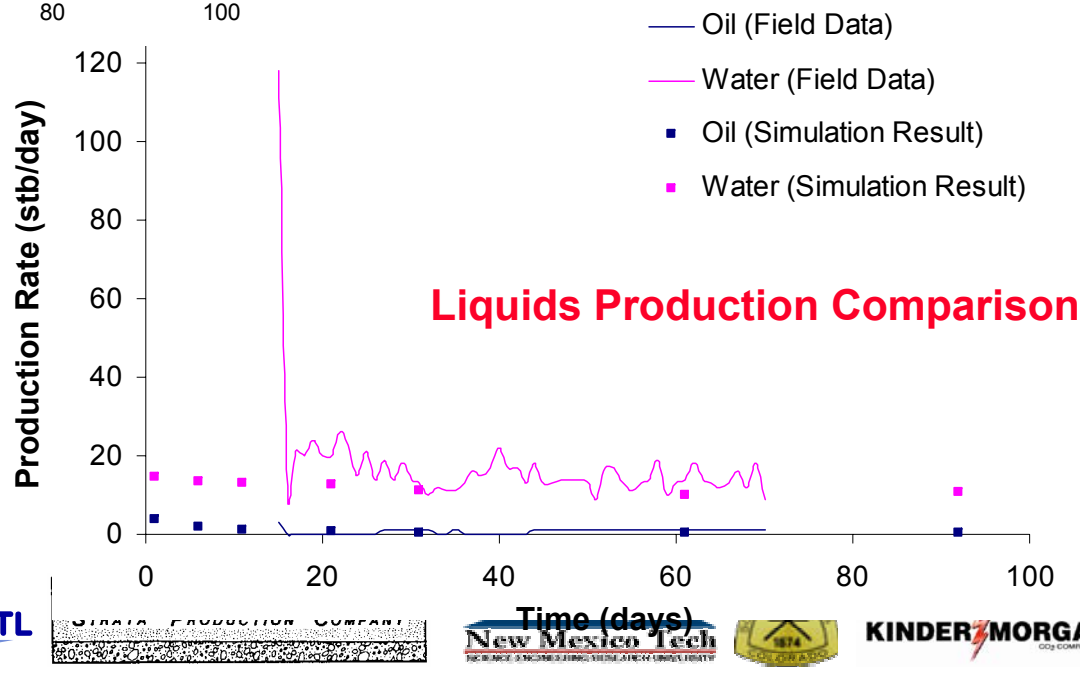
Post Soak Fluids Production Comparison



Gas Production Comparison

- **Relative permeability relationships modified: higher residual CO_2 saturations**



Liquids Production Comparison

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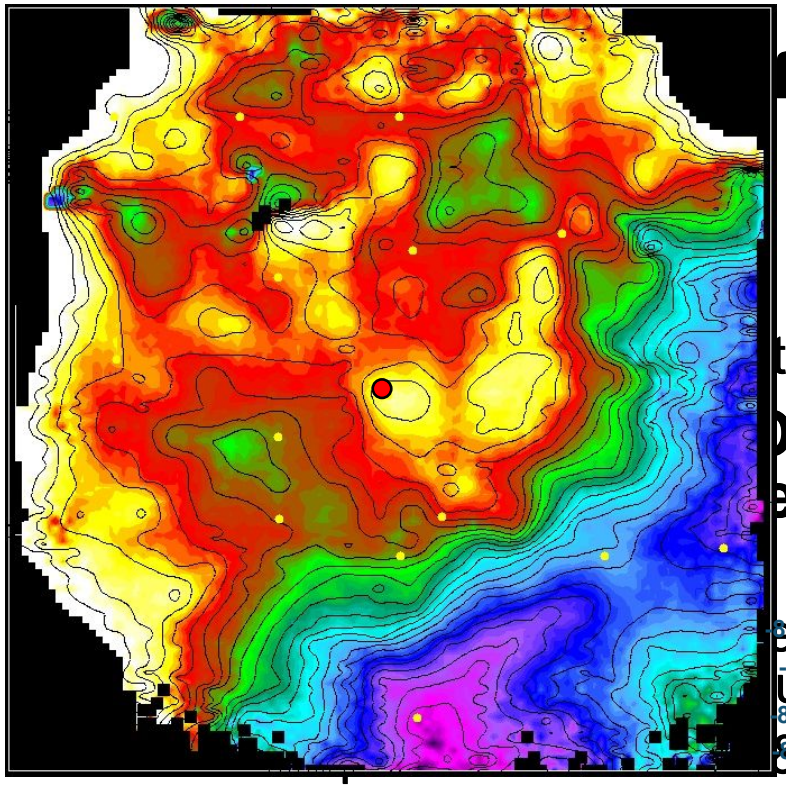
Conclusions



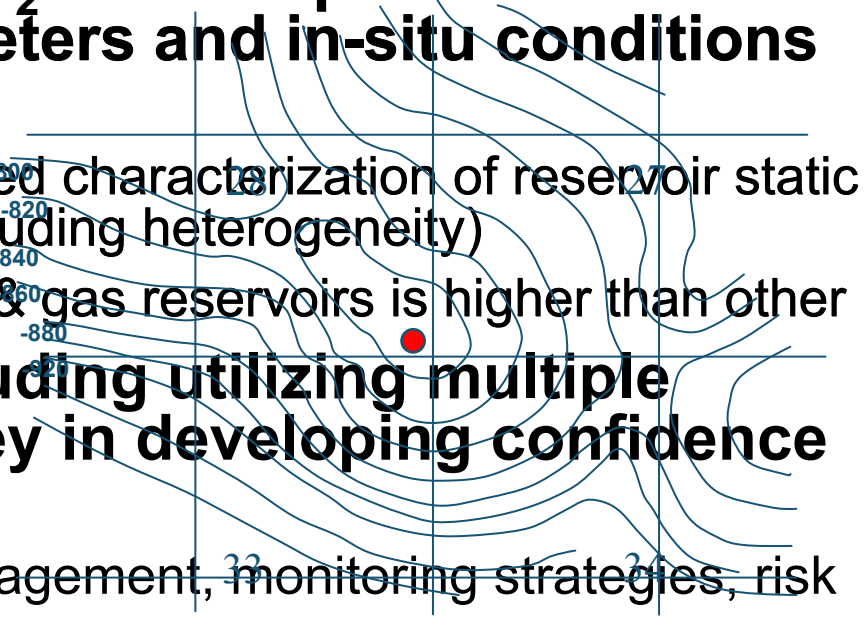
- **f reservoir dynamics had to field observations.**

Interpretation of geology based on seismic data

tual models

Interpretation of geology based on log data

- **O_2 is a complex interaction eters and in-situ conditions**



ed characterization of reservoir static uding heterogeneity)

& gas reservoirs is higher than other

- **Uncertainty analysis including utilizing multiple conceptual models are key in developing confidence in predictions**
  - Implications on reservoir management, monitoring strategies, risk analysis

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