Modeling and Monitoring Associated CO_2 Storage at the Bell Creek Field

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Presentation Outline

- Overview of Plains CO_2 Reduction (PCOR) Partnership Program
- Overview of Bell Creek project
- PVT (pressure, volume, temperature) modeling
- History matching
- Predictions
- Value of simulation

Regional Carbon Sequestration Partnerships

EERC
Putting Research into Practice

NETL PCOR Partnership

PCOR Partnership

5/14

Project Overview: Project Components

- **Bell Creek project**
- Fort Nelson project
- Aquistore project
- Zama project
- Basal Cambrian project
- Regional characterization
- Public outreach
- Regulatory involvement
- Water Working Group

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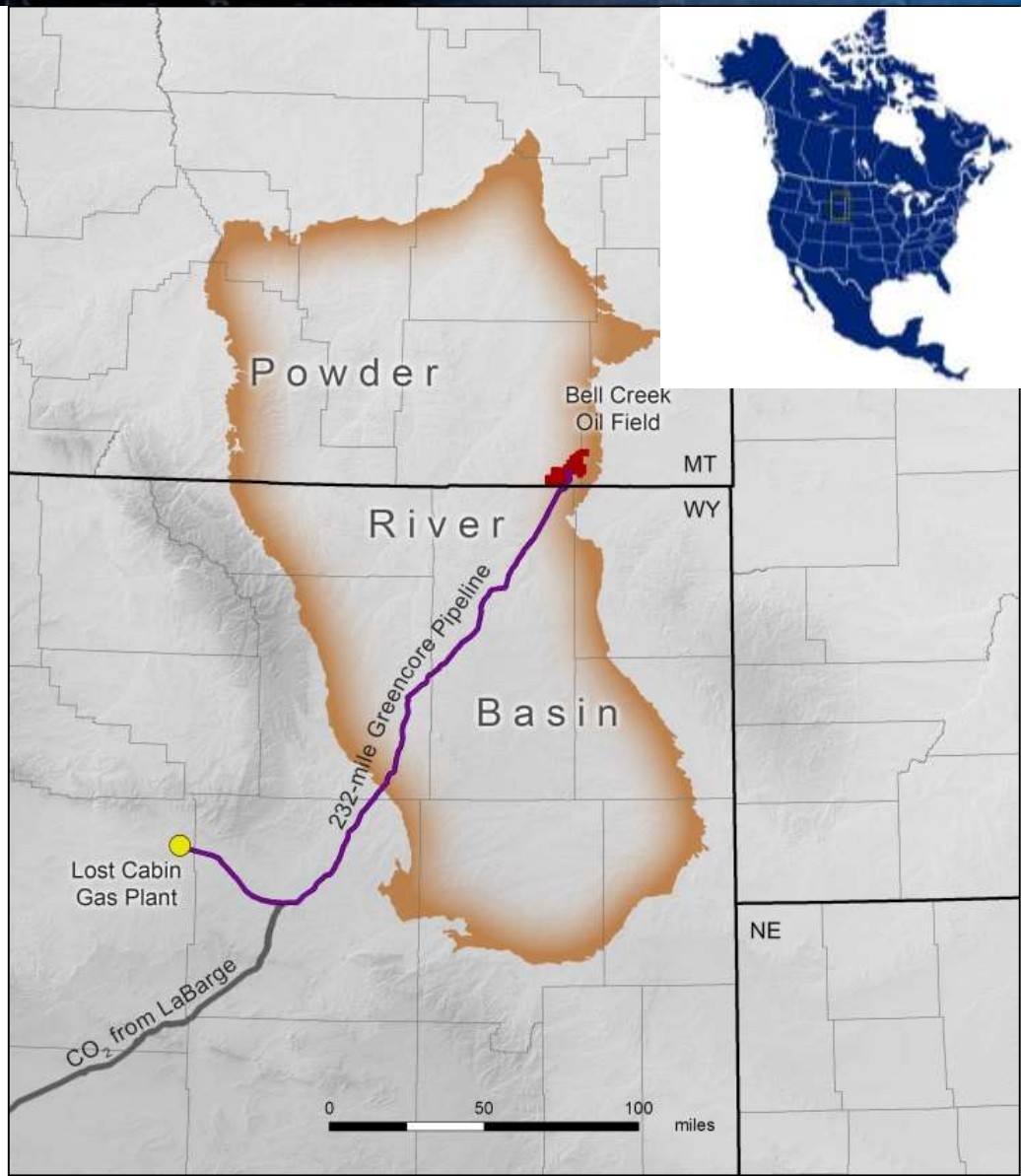
Bell Creek Project Overview

- The Bell Creek oil field is operated by Denbury Onshore, LLC (Denbury) which is conducting a commercial enhanced oil recovery (EOR) project.
- CO_2 is sourced from ConocoPhillips' Lost Cabin natural gas-processing plant and Exxon's Shute Creek gas-processing plant.
- The EERC is studying the interrelationship between EOR and associated CO_2 storage at a commercial-scale project.



Bell Creek History

- **Discovered in 1967 (21,771 acres)**
- **Peak production 56,000 barrels of oil per day (August 1968)**
- **Stock tank original oil in place (STOOIP) 353 million barrels of oil (MMbo)**
- **Cumulative production 133 MMbo (~38% recovery)**

CO_2 Injection Is Ongoing!!!

- Pipeline completed November 2012
- Pipeline filled February/March 2013
- First injection May 2013
- Facilities commissioned August 2013
- 997,392 tonnes injected through June 2014 (1,098,369 U.S. short tons)

(source: Montana Board of Oil and Gas Database)

- An estimated 40–50 million incremental bbl of oil will be recovered.
- An estimated 14 million tons of CO_2 will be stored.

Phased Development Approach

Phase 7
Phase 3
Phase 6
Phase 5
Phase 1
Phase 4
Phase 2
Phase 8
Phase 9

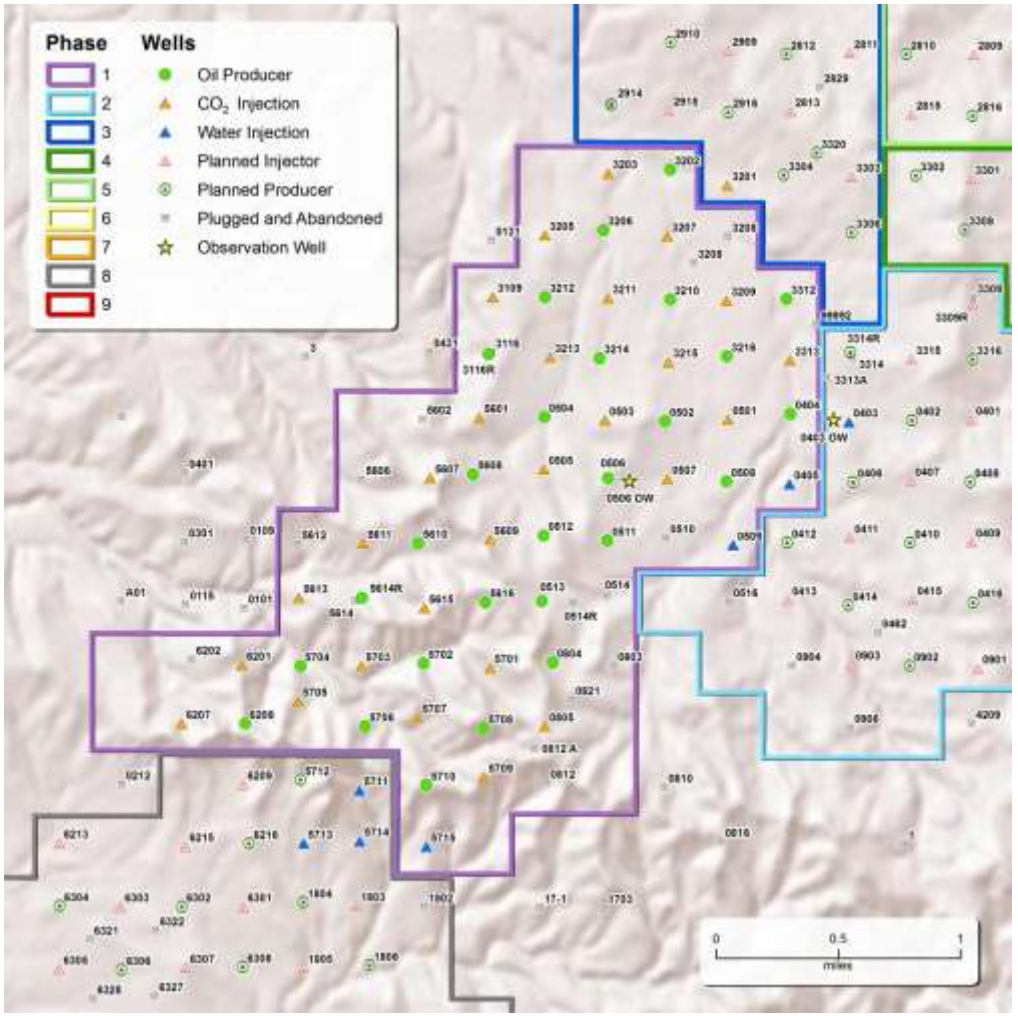
Powder River County
Carter County
MONTANA
WYOMING
Campbell County
Crook County

0 2 4
miles

Operation Plan

Denbury's Field Operations

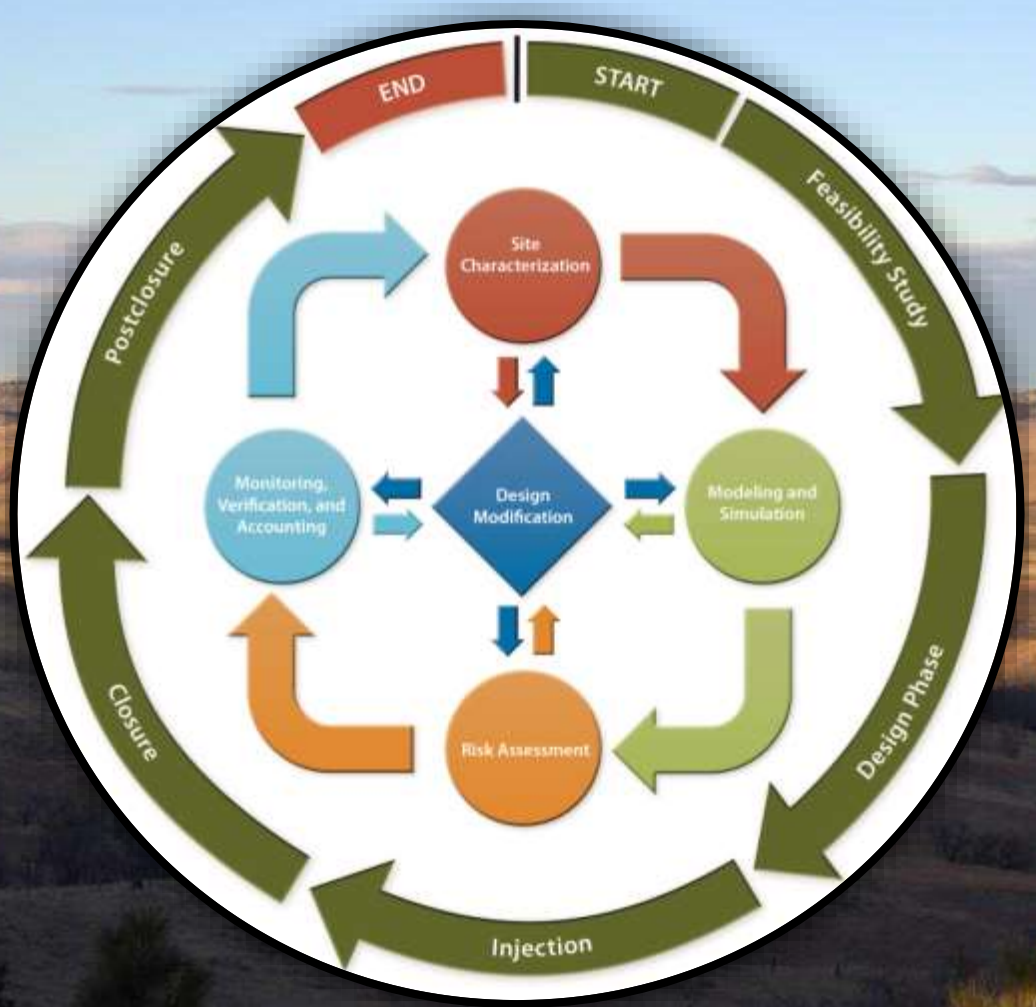
- CO_2 EOR in a five-spot pattern.
- Operate the field in a phased approach.
- 26 injectors and 26 producers in the Phase 1 area.
- Production with no artificial lift.
- Reservoir pressure between 2200 and 2800 psi.
- Produced gas will be recycled.



The PCOR Partnership

Integrated Approach to Program Development

Focused on site characterization, modeling and simulation, and risk assessment to guide MVA strategy

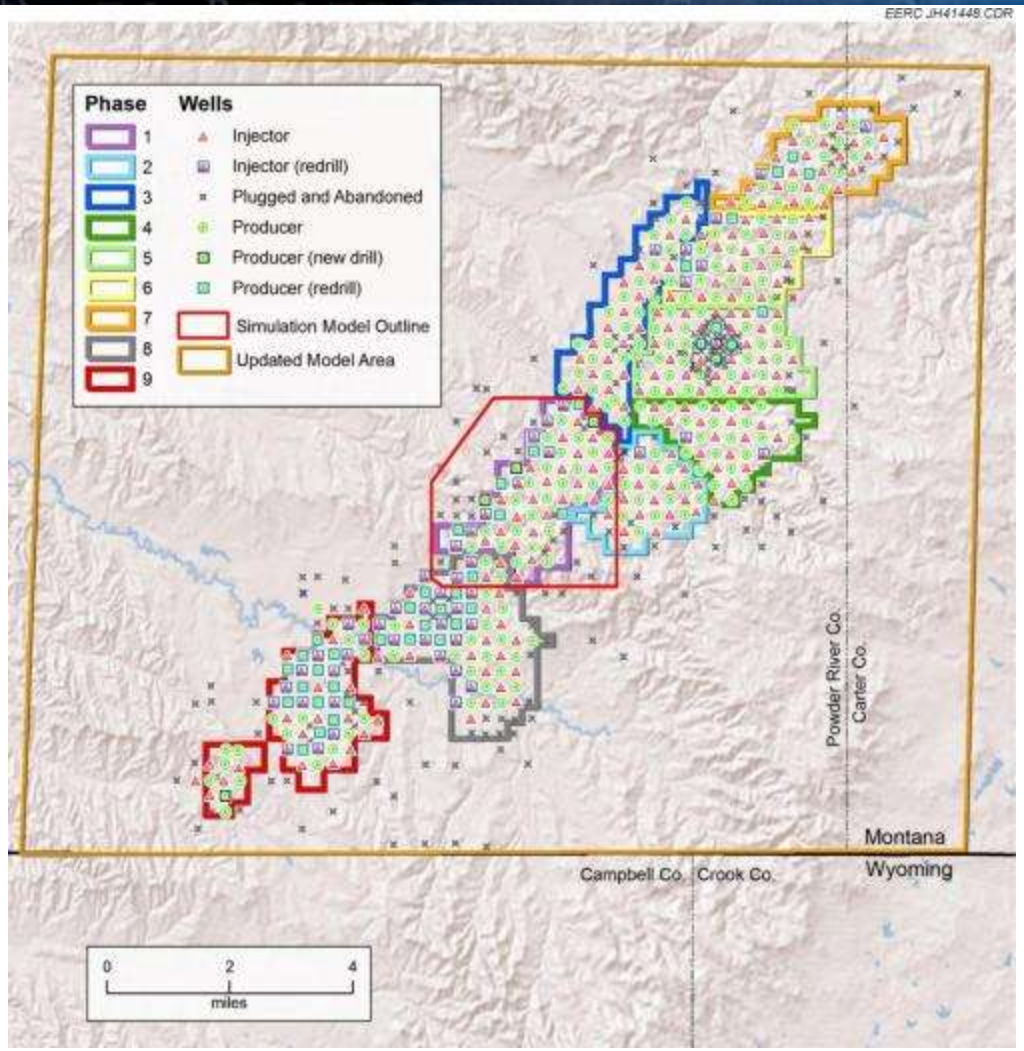


Completed Site Characterization Activities

- Well file integration
- Lidar (light detection and ranging) collection
- Outcrop investigations
- Drilling characterization wells
- New core collection and analysis
- SCAL (special core analysis) and PVT testing
- Existing core analysis
- 40-mi^2 3-D seismic survey
- Baseline 3-D vertical seismic profiles (VSPs)
- Pulsed-neutron logs (PNLs)

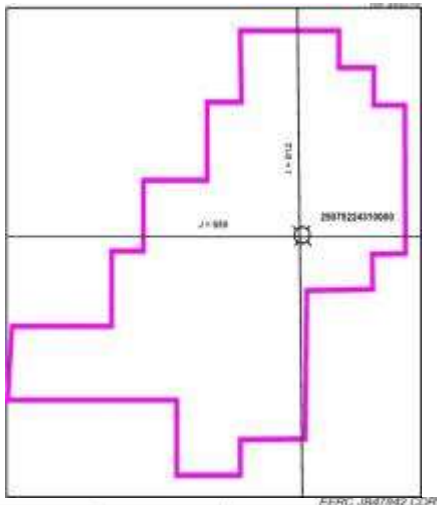
Modeling and Simulation Efforts

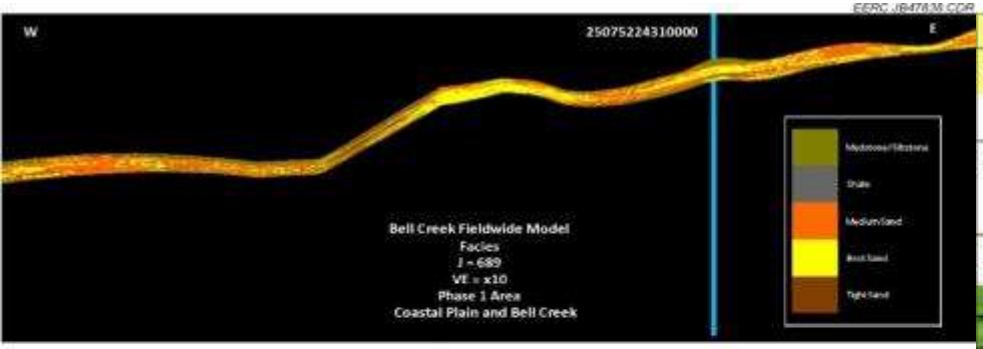
- 200-mi^2 domain models
  - Surface through Madison Formation
  - Mowry Formation through Skull Creek Formation
  - 3-D Mechanical Earth Model (MEM)
- 7.75-mi^2 multiphase flow numerical simulation models
- PVT and equation-of-state modeling
- 1-D MEM
- Shallow subsurface geochemical modeling

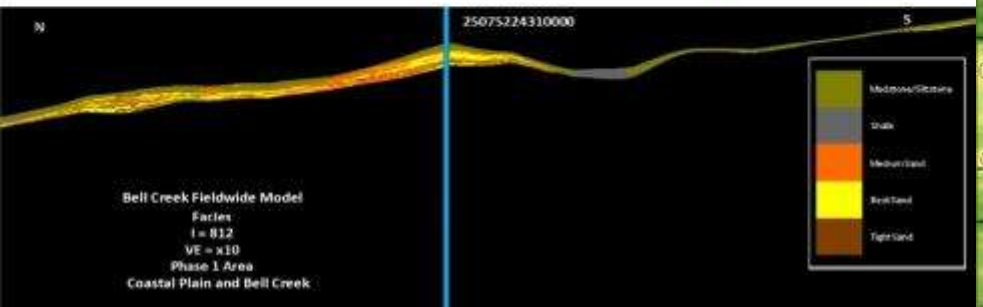


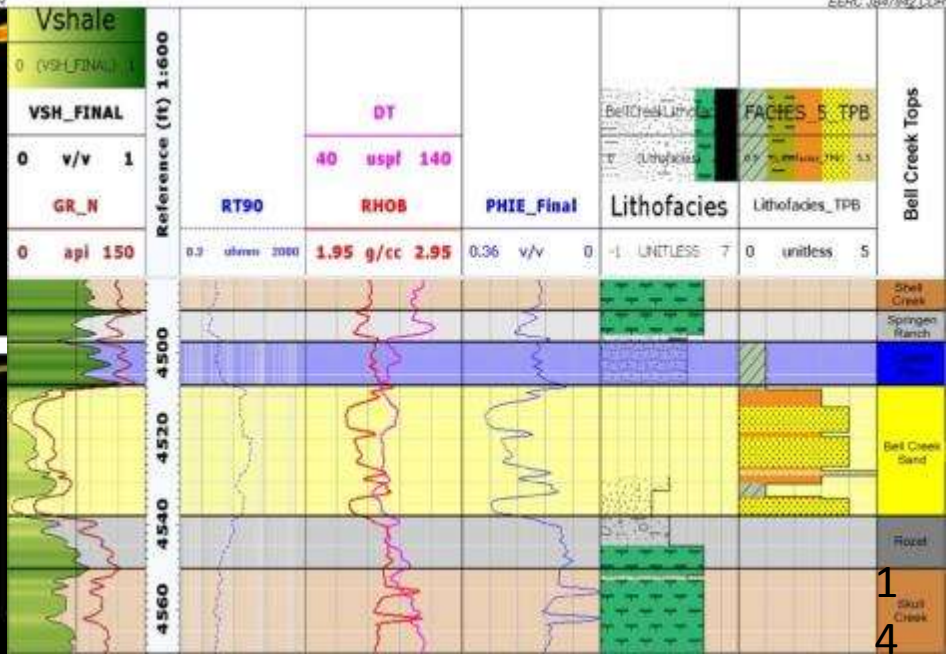
Detailed Geologic Model

- Includes updated PETRA database
  - Lidar-corrected well locations and elevations
  - QA/QC of well logs from 748 wells
  - Core data from 25 wells
- 200 mi^2 (100 million cells in static model)
- Populated with lithofacies, porosity, permeability, and water and oil saturation









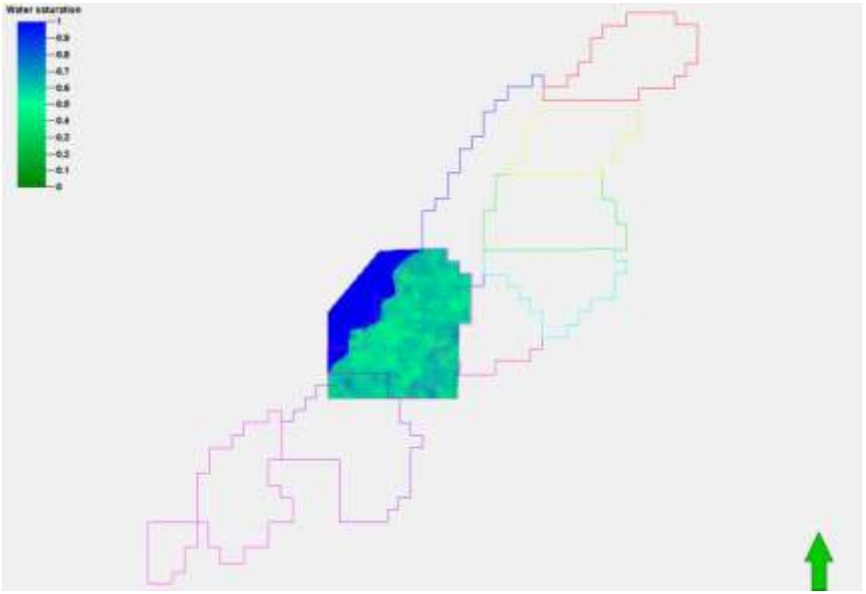
Numerical Simulation Model

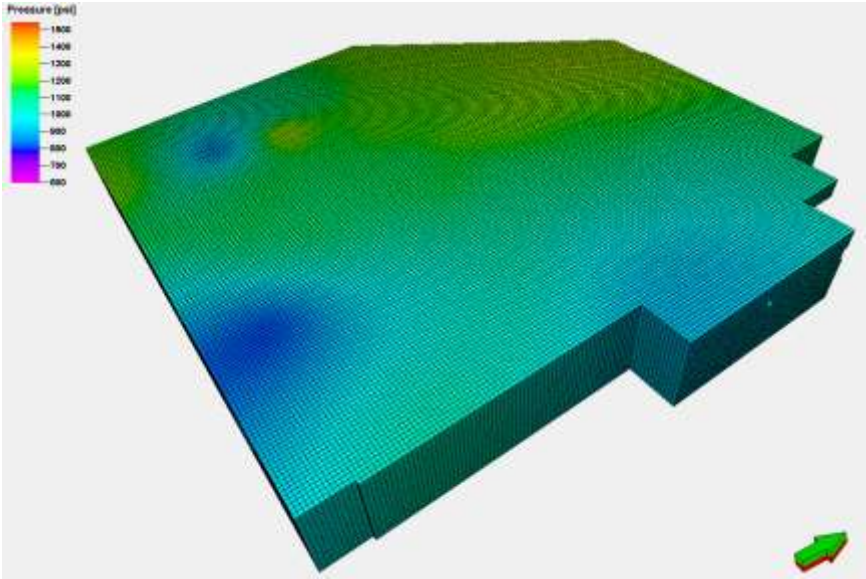
Characteristics

- 520,926-cell model clipped from regional model (7.75 mi^2).
- Coastal Plain and Bell Creek reservoir zones are included.
- Incorporates 75 production wells and 35 converted injection wells.
- Incorporates SCAL and PVT data.

Applications

- Used to determine breakthrough times at wells, optimal times for repeat monitoring, verification, and accounting (MVA) techniques.
- Used to predict storage capacity, sweep efficiency, recovery factor, and utilization factor.



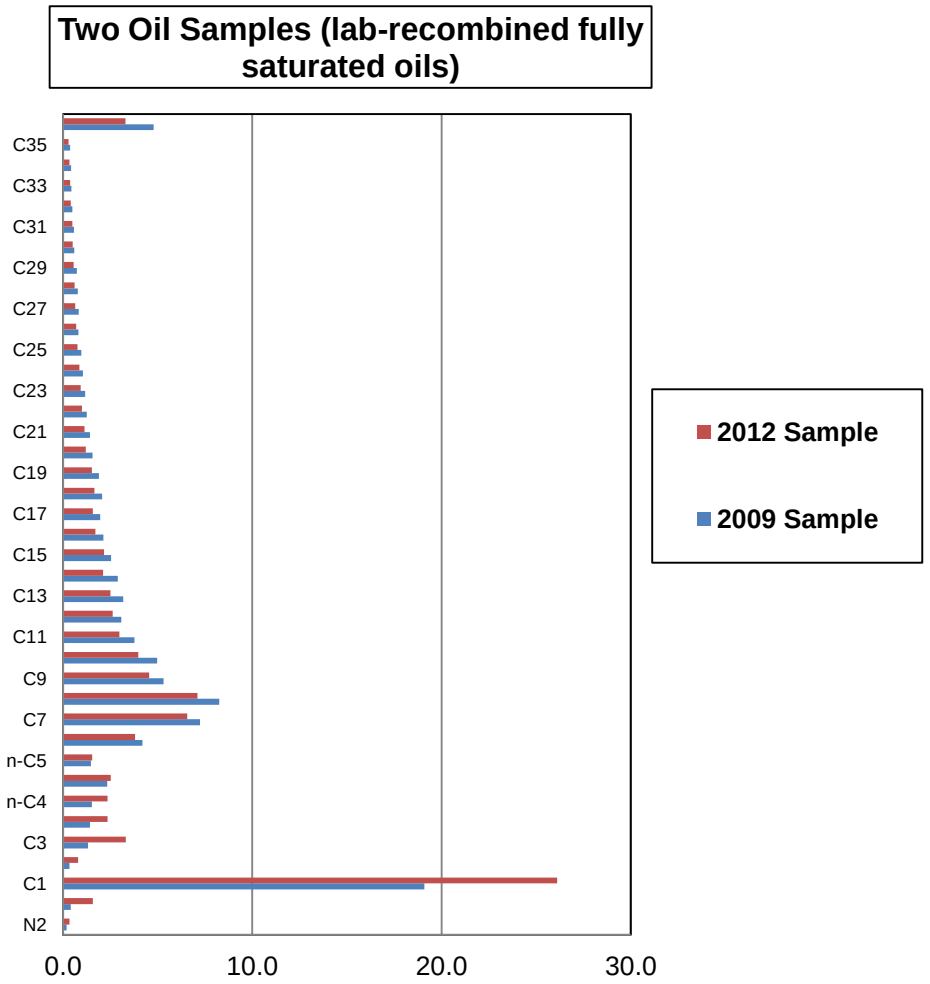


EERC

PVT Modeling

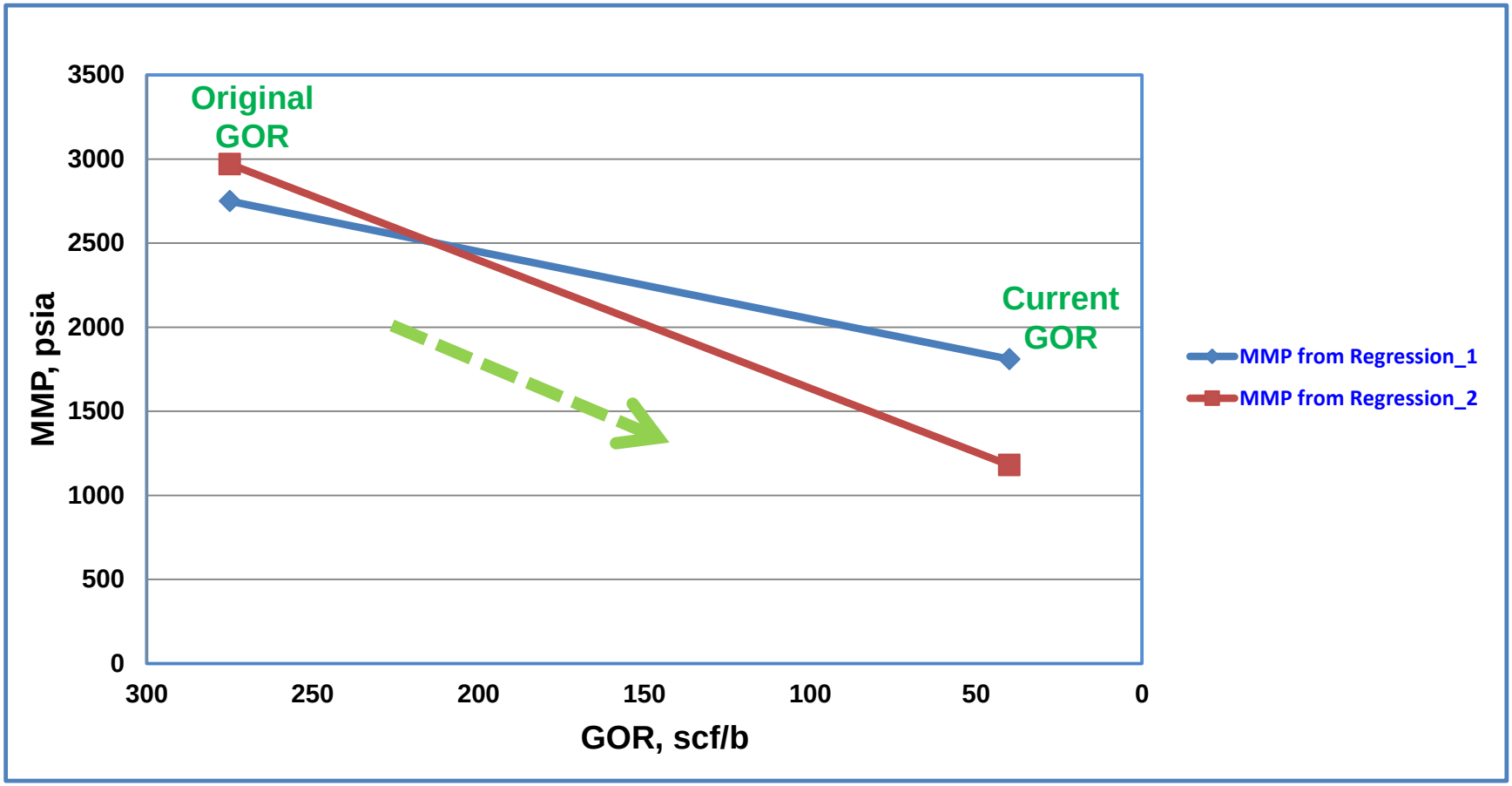
Equation of State (EOS) and Slim-Tube Simulations

- Seven-component EOS.
- EOS was initially tuned to original oil and GOR.
- Slim-tube simulation had excellent agreement.
- Numerically flashed EOS resulted in MMP ranging from 1200 to 1800 psi.



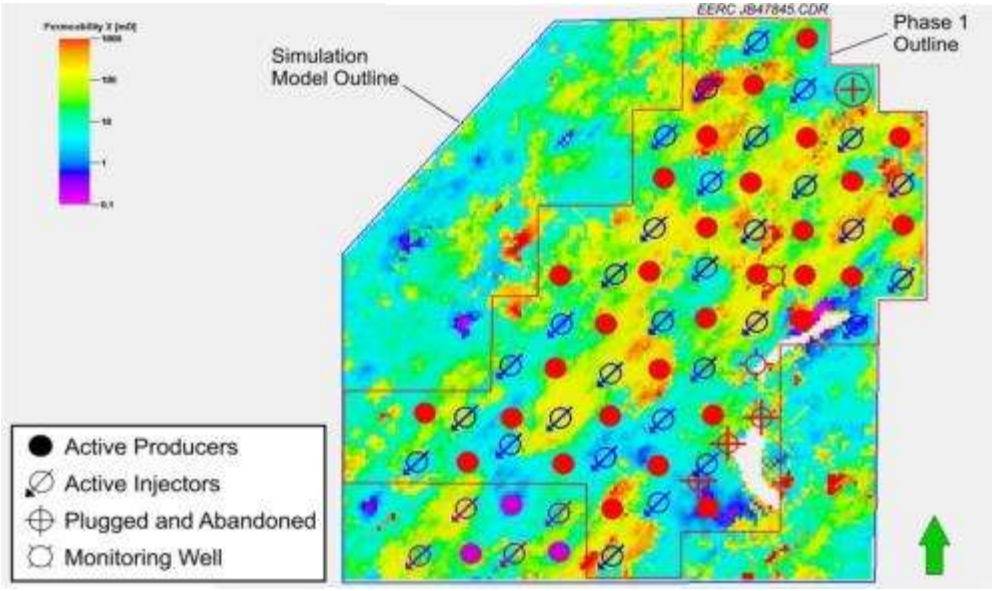
Effect of Variable GOR on MMP

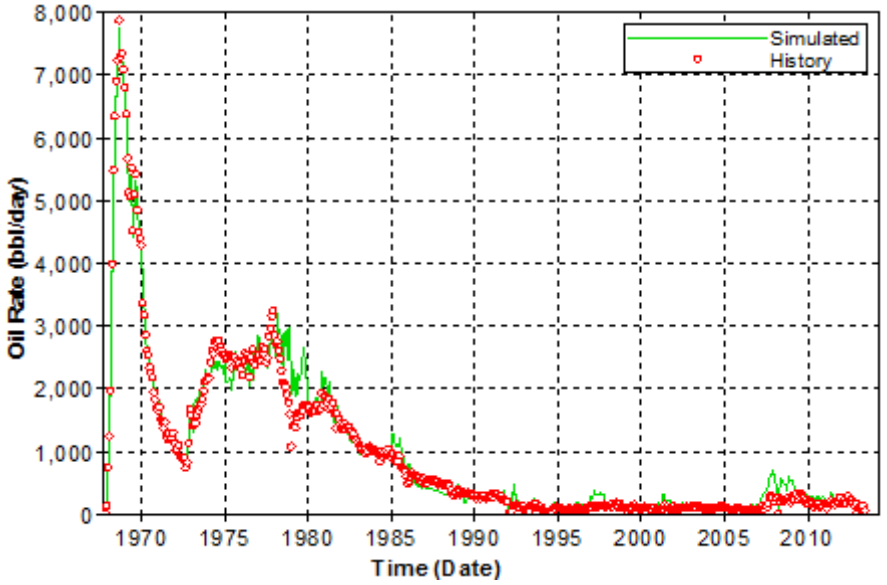
- **EERC Simulated MMP vs. pressure depletion**

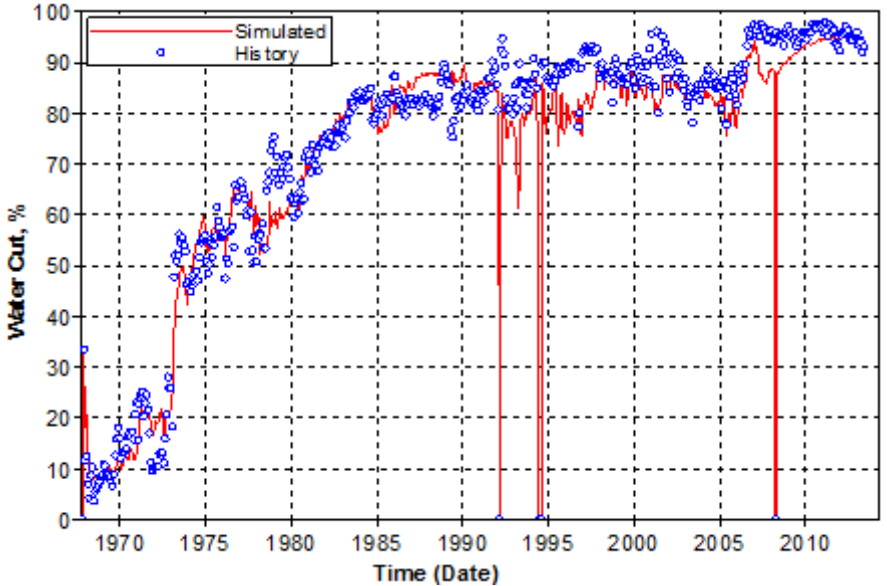


History Match

- Historical production, injection, and water cut rates were matched.
- Used total liquid rate as a control for history match.
- A good match also achieved for pressure; however, little historical pressure data were available.

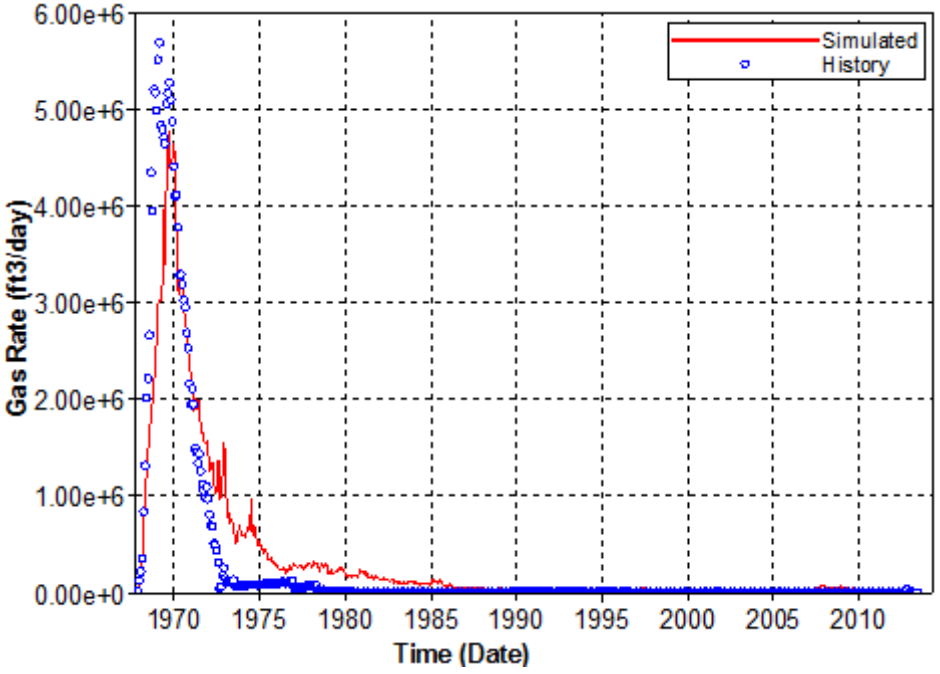


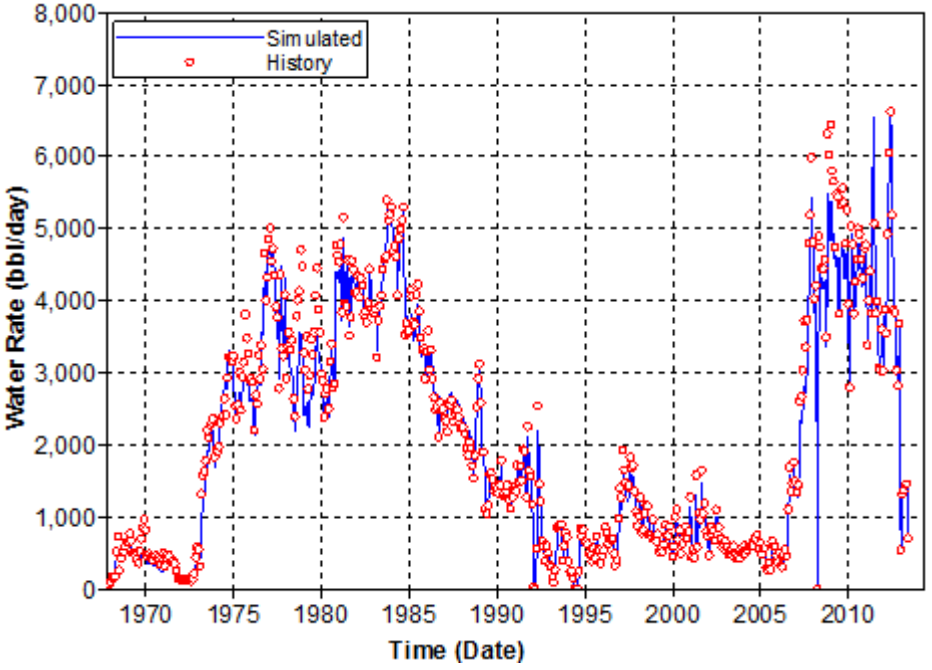




History Match

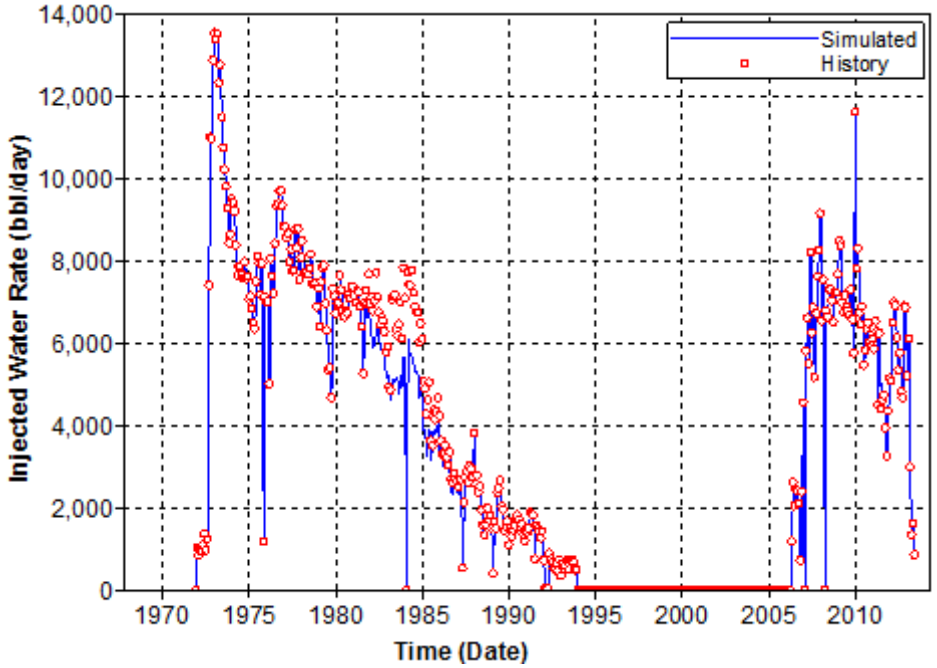
- Gas and water production rates

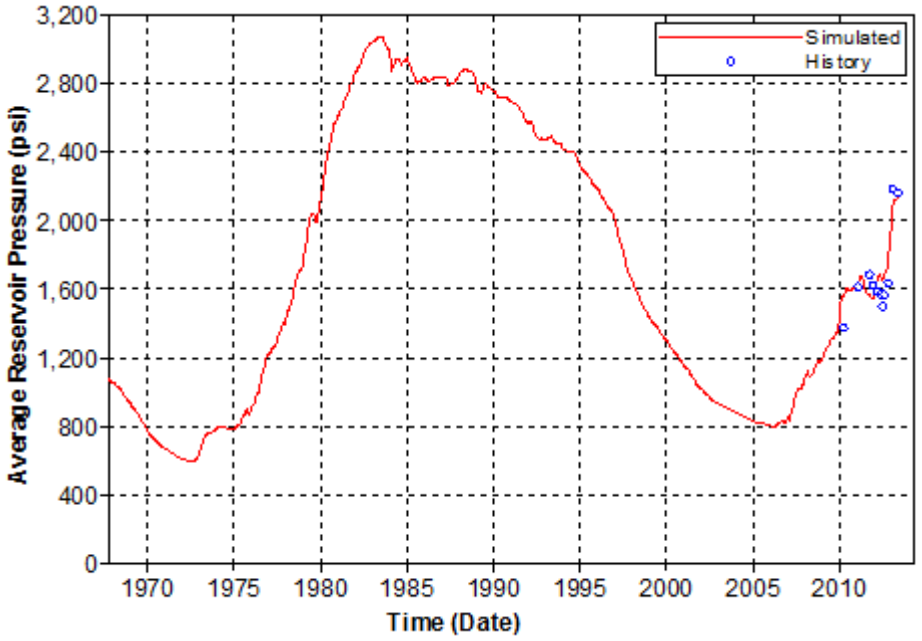




History Match

- Water injection rate and average reservoir pressure

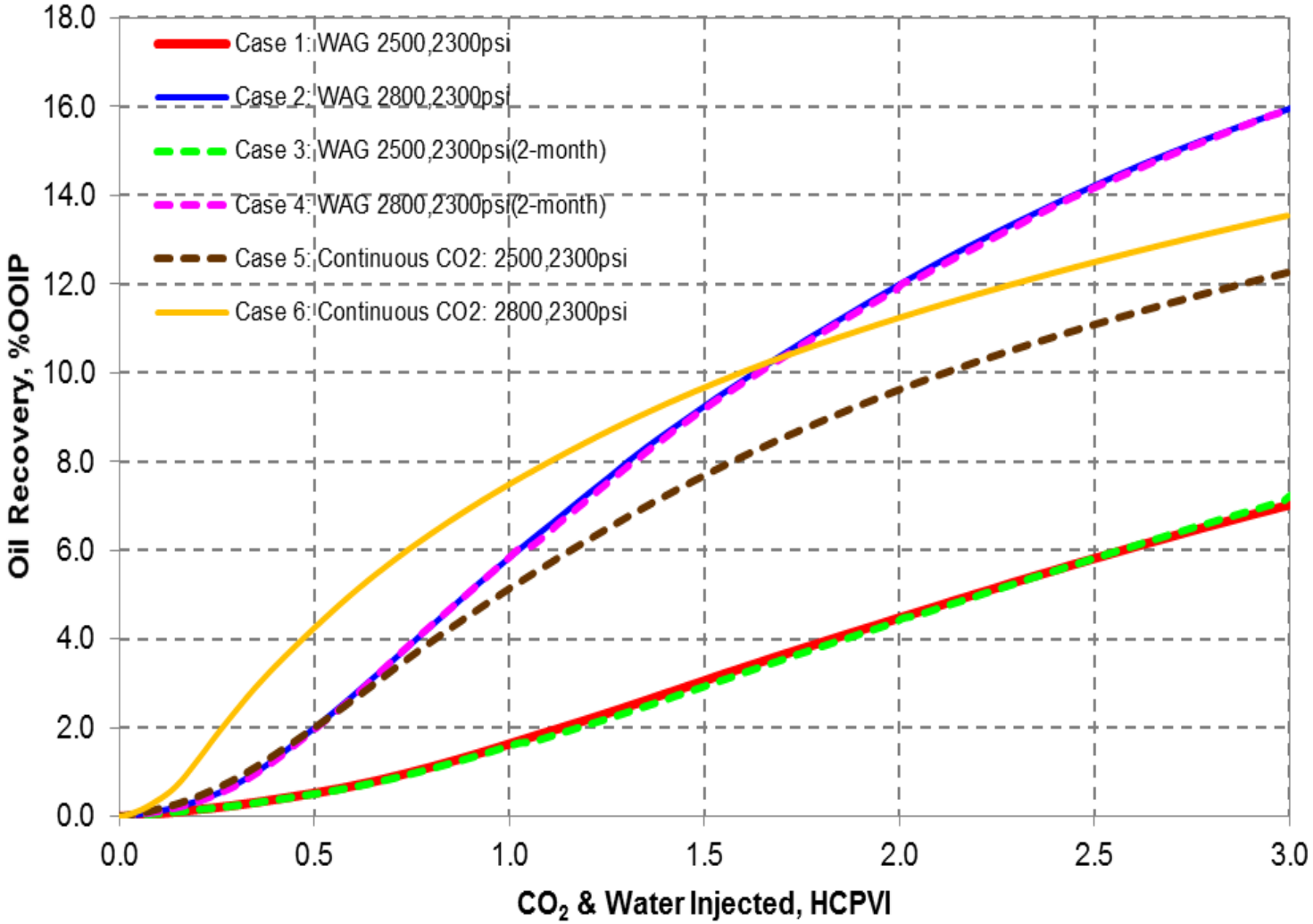




Predictive Simulations

- Case 1: water alternating gas (WAG) 3-month cycle (2500, 2300 psi)
- Case 2: WAG 3-month cycle (2800, 2300 psi)
- Case 3: WAG 2-month cycle (2500, 2300 psi)
- Case 4: WAG 2-month cycle (2800, 2300 psi)
- Case 5: continuous CO_2 injection (2500, 2300 psi)
- Case 6: continuous CO_2 injection (2800, 2300 psi)

Predictive Simulations – Oil Recovery vs. Hydrocarbon Pore Volume Injected (HCPVI)



Recoveries are based on the EERC's analysis and estimates.

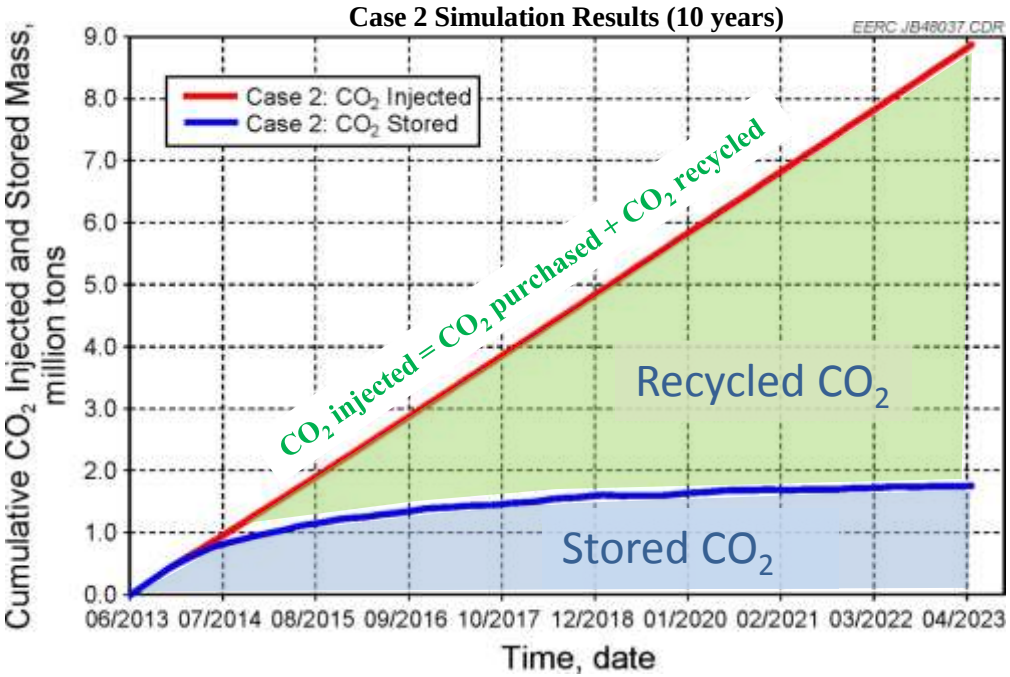
Predictive Simulation – CO_2 Utilization Factors

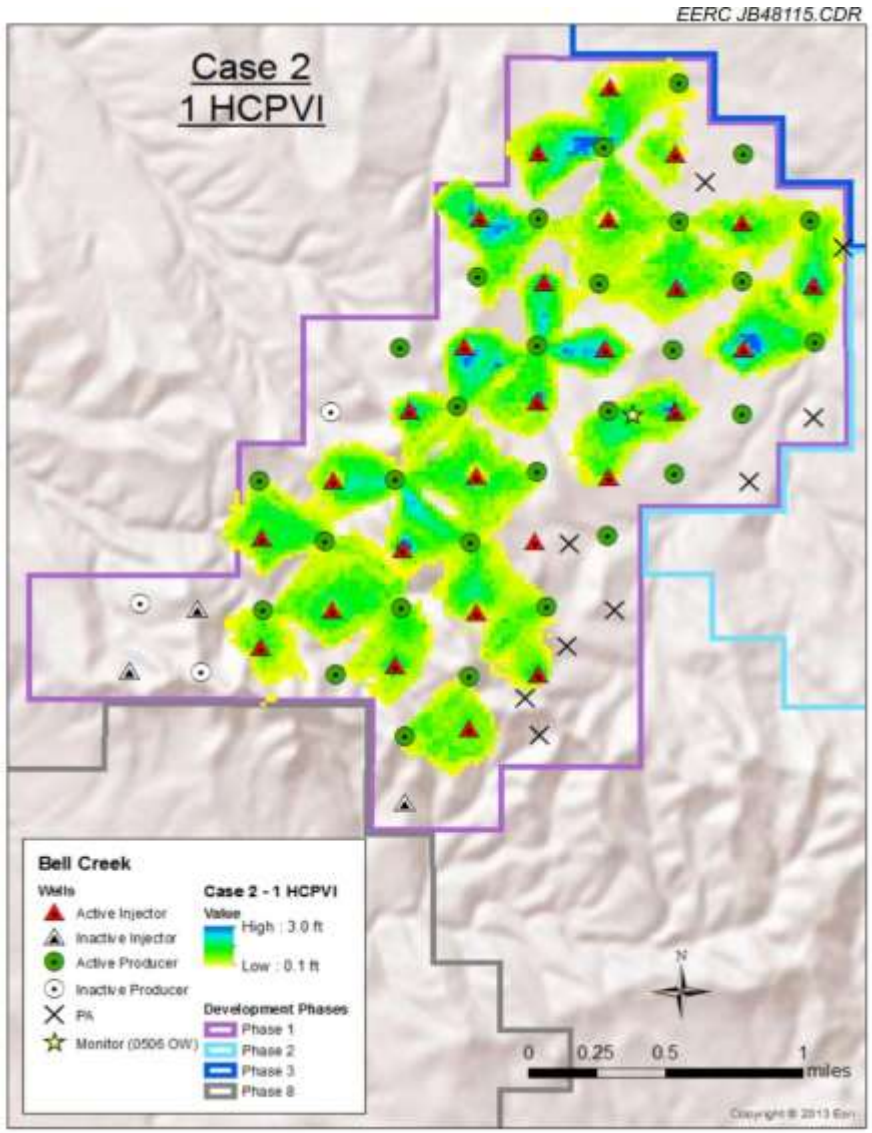
Case No.	HCPVI	Gross CO_2 Utilization Factor, MMscf/bbl	Net CO_2 Utilization Factor, MMscf/bbl
1	1.0	23.31	18.72
	2.0	17.97	10.33
	3.0	18.42	7.84
2	1.0	15.60	8.85
	2.0	16.02	5.30
	3.0	18.72	4.27
3	1.0	22.96	18.42
	2.0	17.38	10.17
	3.0	17.69	7.62
4	1.0	15.22	8.77
	2.0	15.68	5.31
	3.0	18.24	4.18
5	1.0	29.93	14.49
	2.0	39.75	10.72
	3.0	49.71	9.75
6	1.0	33.06	11.72
	2.0	44.92	9.72
	3.0	56.04	8.39

Case 2 – WAG Predictions

Prediction Observations

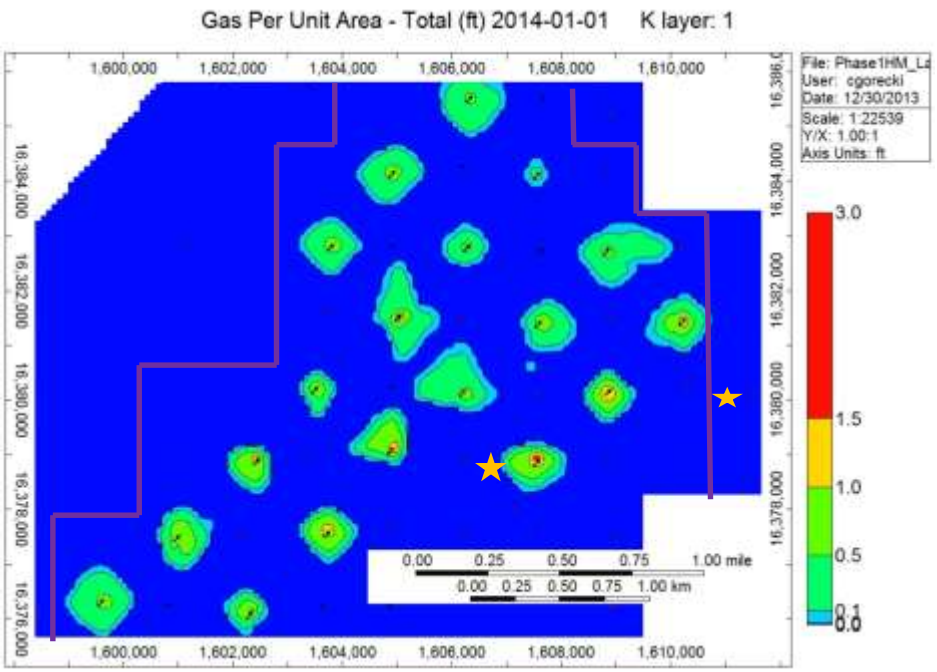
- First breakthrough at production wells expected after 3 months of production and 5 months at the monitoring well.
- By September 30, 2017, approximately 4 million tons of CO_2 will be injected in Phase 1, with approximately 1.5 million tons stored.
- Results used in risk assessment and MVA planning.





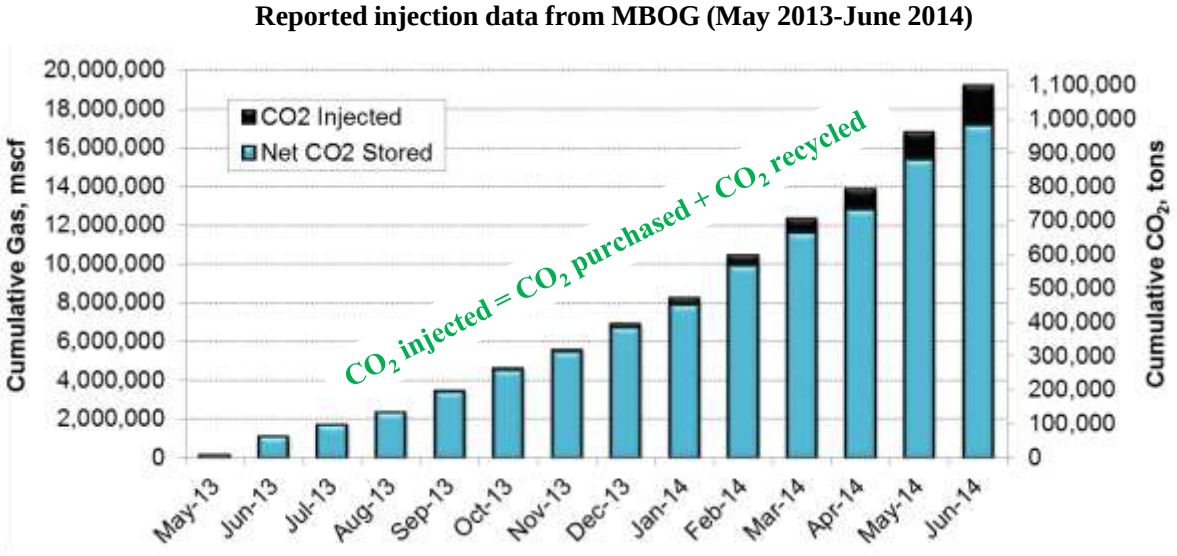
Predictive Simulation Summary

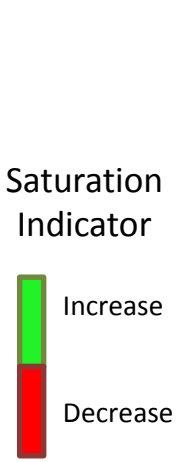
- Predicted MMPs had good agreement with lab results.
- MMP showed a strong relationship to GOR.
- WAG scenarios at 2800 psi and 3 pore volumes injected (recycle + purchase) appear to give the best recovery results.
- CO_2 breakthrough for these cases with different operating injection pressure was predicted to be approximately 3–6 months.

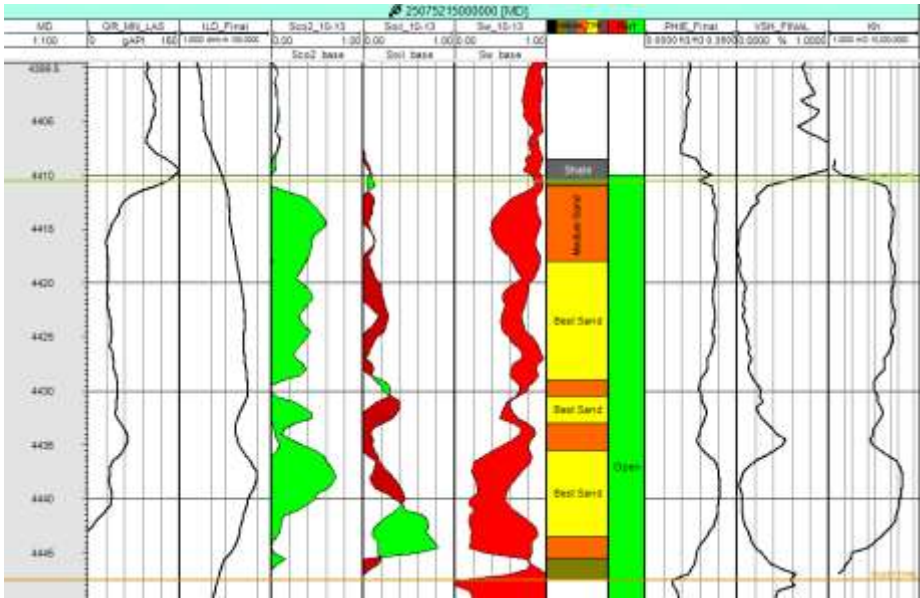


Field Observations and Initial Monitoring Results

- CO_2 breakthrough in the field occurred after about 3–4 months.
- Injected and retained (stored) CO_2 roughly matches predictions after 1 year of injection.
- Work is under way to evaluate how well observed CO_2 saturations from PNL repeats match-predicted saturations at both injectors and producers.

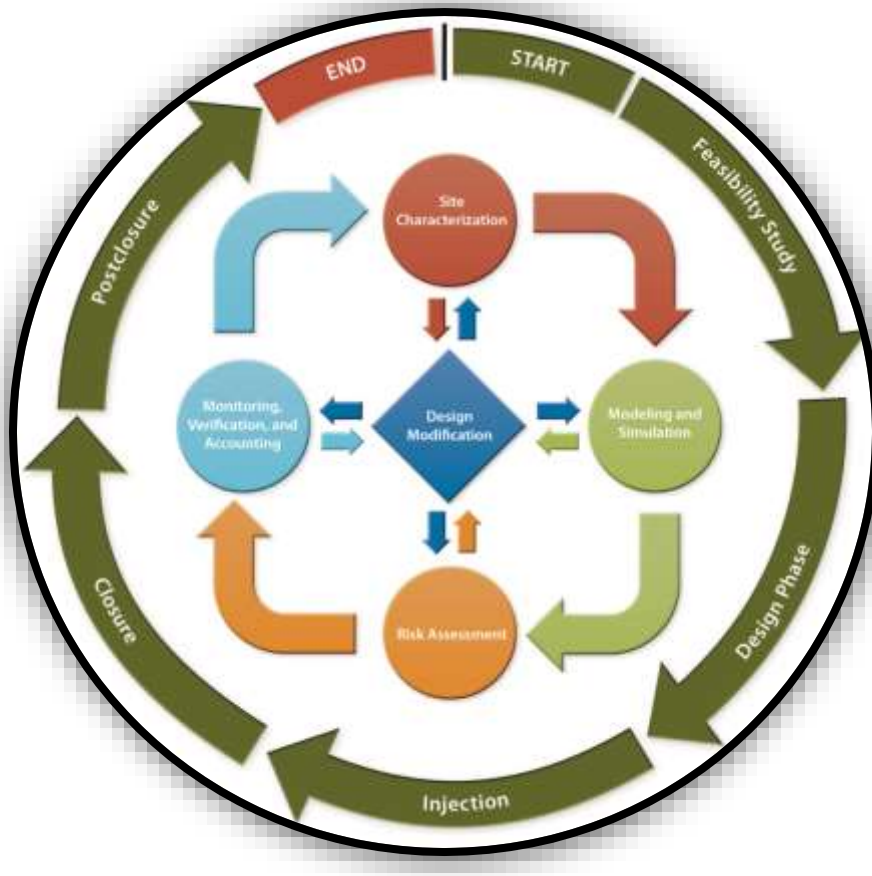






Value of Simulation

- Identify characterization needs.
- Identify potential technical risks.
- Determine timing and type of repeat monitoring.
- Evaluate different injection scenarios.
- Predict associated CO_2 storage.
- Coupled with monitoring, stored mass could be verified.
- Plus many more from an EOR perspective.



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