Devising a Framework to Couple Electromagnetic Geophysical Measurements with Reservoir Simulations to Monitor CO_2 Plume Movement

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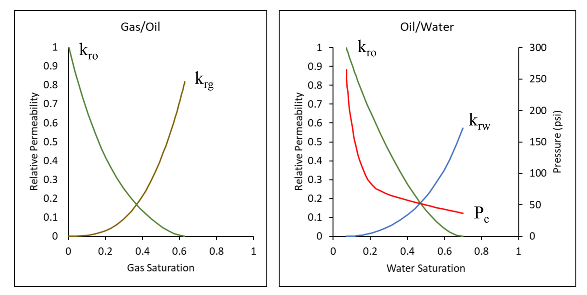
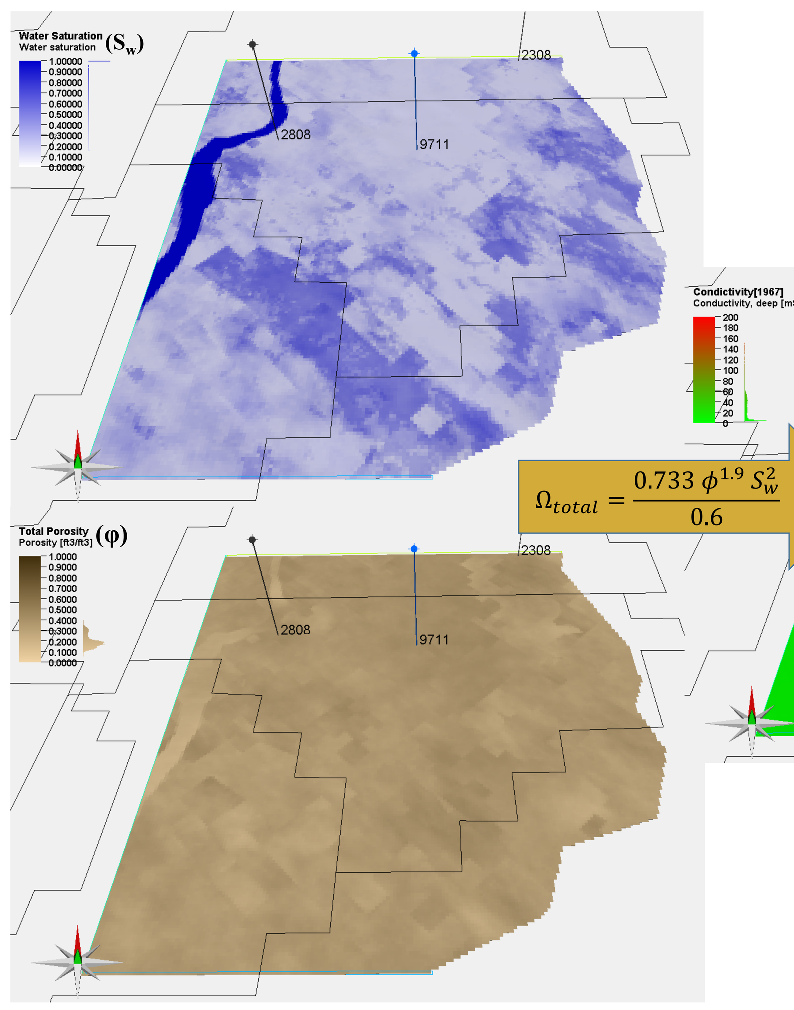
Reservoir Model - History Matching

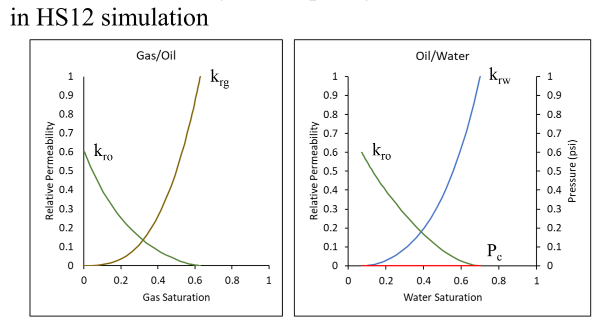
Historical simulations were run using production and injection data from January 1967 to September 2017. The results of these simulations will be used to define the initial conditions in our time-lapse monitoring simulations consistent with the time-frame of the current project period.

Relative Permeability and Capillary Pressure model used in HS11 simulation





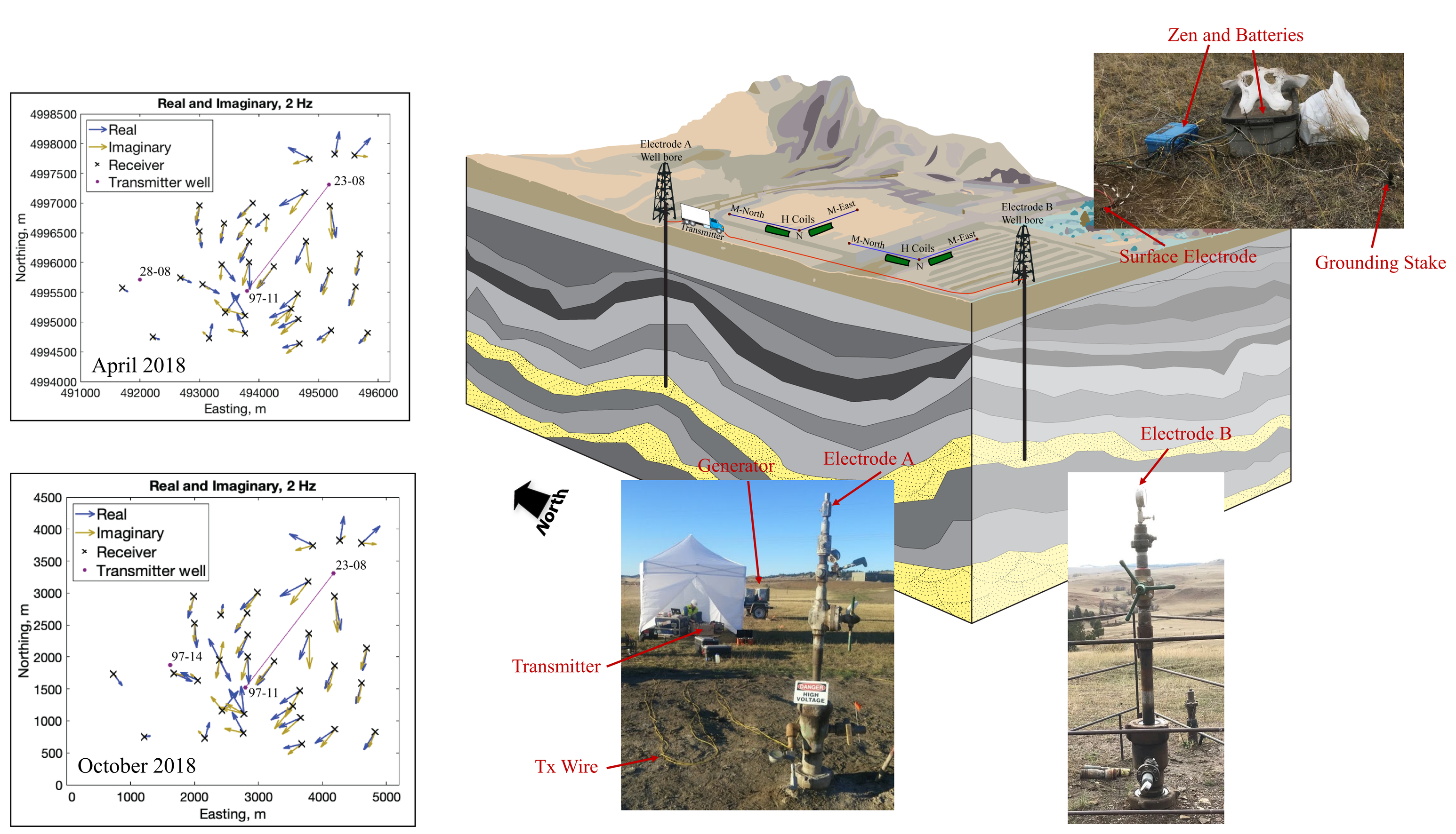
Relative Permeability and Capillary Pressure model used in HS12 simulation



CWC-CSEM & TEM Data Acquisition

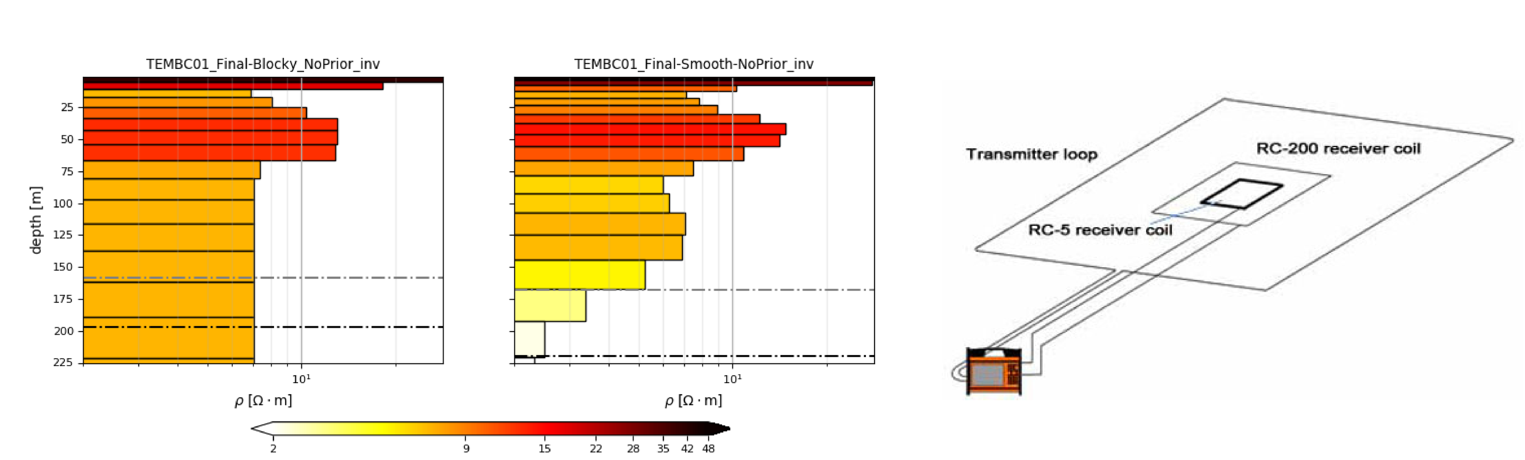
Time-lapse Charged Well Casing - Controlled-Source Electromagnetic Survey (CWC-CSEM)

CWC-CSEM is time-lapse geophysical monitoring based on a controlled-source electromagnetic method using charged well casing as the energizing sources and measuring both E- and B-fields at the surface. Two Boreholes are utilized as long electrodes to generate the EM fields by using a transmitter to inject 25 Amps and 250 Volts. This creates a current path between the wells that is then measured at the surface by the Zens data collection system. It is connected to receiver electrodes placed 100 meters from the base receiver location along the north and east bearings and H-coils measuring the magnetic moment in the northing, easting, and vertical principal directions.



Transient Electromagnetism Survey (TEM)

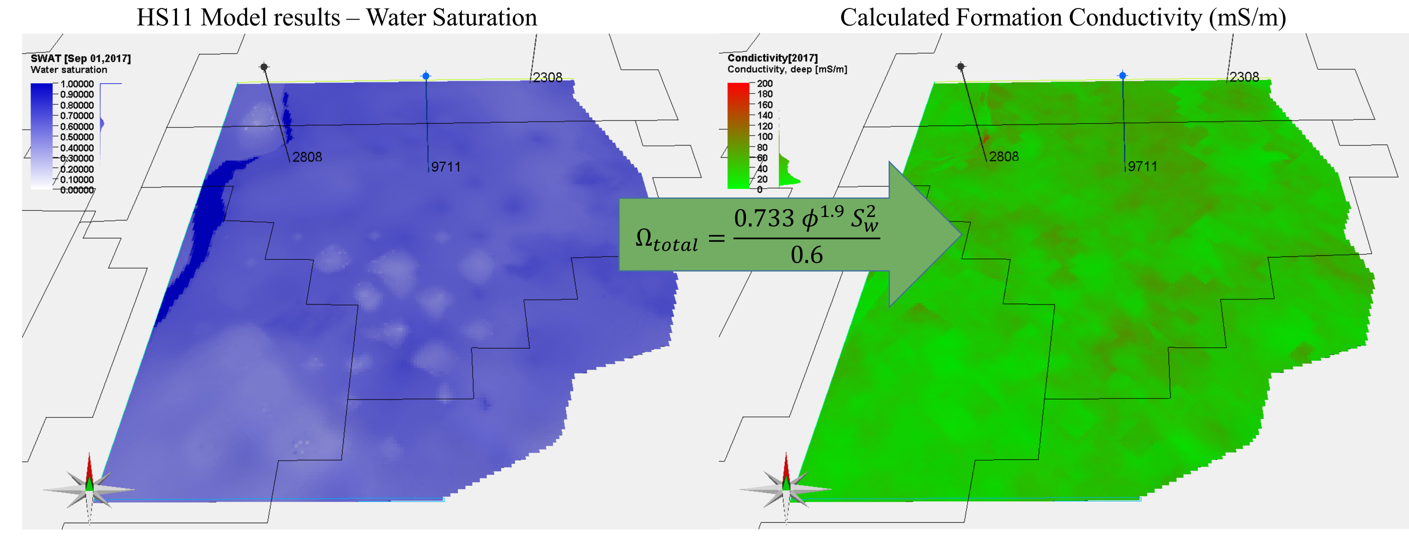
The data collected from the near surface EM survey will be used to characterize the near surface heterogeneity and identify near surface infrastructure such as pipelines. This data will be used as a static correction for the CSEM data, there by improving the resolution of the signal from the reservoir.

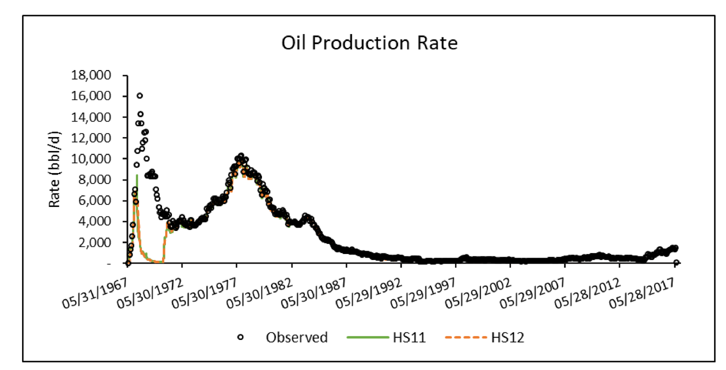


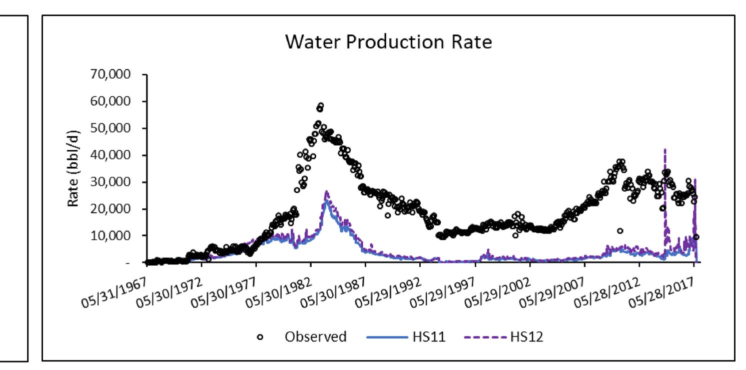
Results – History Matching

There is no unique solution to the history matching problem. Similar results can be produced using different inputs (relative permeability and capillary pressure). We think that using CWC-CSEM to measure the reservoir conductivity we can constrain the possible water saturations in our reservoir model.

HS11 Model results – Water Saturation / Calculated Formation Conductivity (mS/m)







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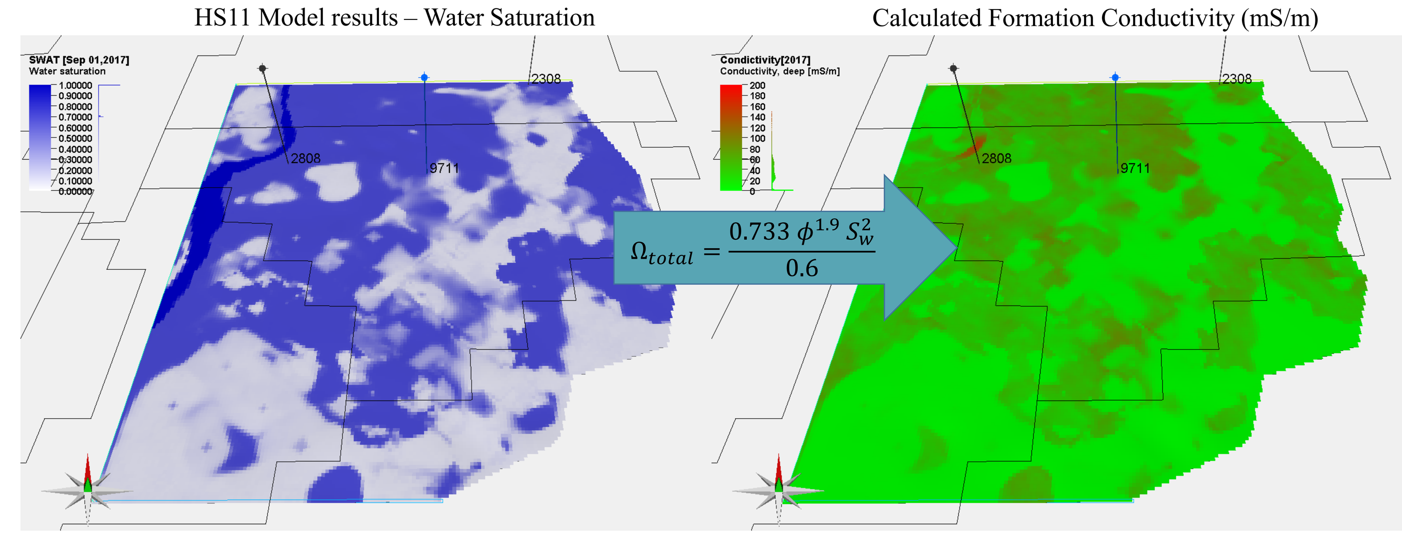
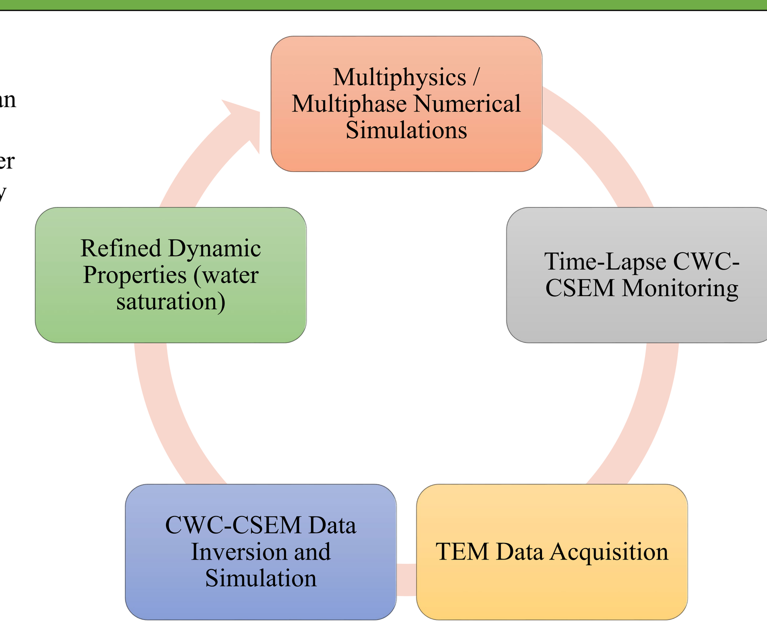


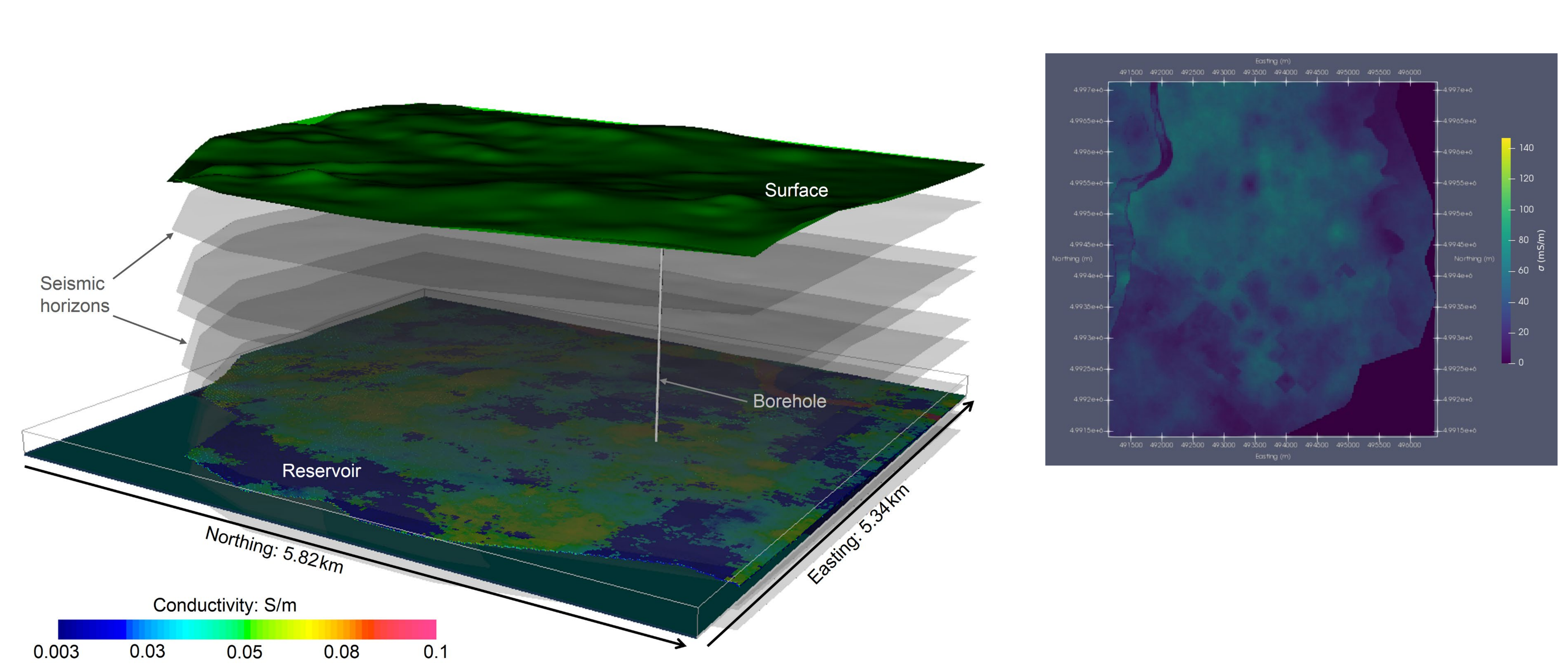
Guidance and Feedback

The goal of this project it to couple field measurements to numerical models to improved predictions of CO_2 behavior in an active oil field undergoing CO_2-EOR. We will use the field data to constrain the water saturation in the numerical model, there by improving the accuracy of future forward modeling.



EM Modeling

The EM model extends the reservoir model domain to include all of the geologic layering from the surface through the target reservoir, incorporating the stratigraphy extending down to the basement rock. Within these layers are assign conductivity distributions calculated from fluid saturations (water, oil, and CO_2) in the dynamic reservoir model. Available data from the CWC-CSEM and TEM surveys will be used to 'tune' the conductivity distribution to better constrain properties in the reservoir model. The conductivity model and ability to update it over time provides an essential link between the reservoir model, and the results from the CWC-CSEM surveys.



Abstract

Monitoring CO_2 plume movement and extent is critical to any CO_2 utilization and storage (CCUS) project but can present significant challenges. Downhole measurements (such as cross-well seismic) can give the resolution needed to track the CO_2 plume. That resolution comes at a significant expense in equipment and lost production time, and the resolution is only in the vicinity of that well. Surface seismic is less expensive but has decreasing resolution with depth and may not be sensitive to changes in the CO_2 plume. Conversely, electrical conductivity has been shown to be correlated with changes in phase saturation associated with CCUS operations.

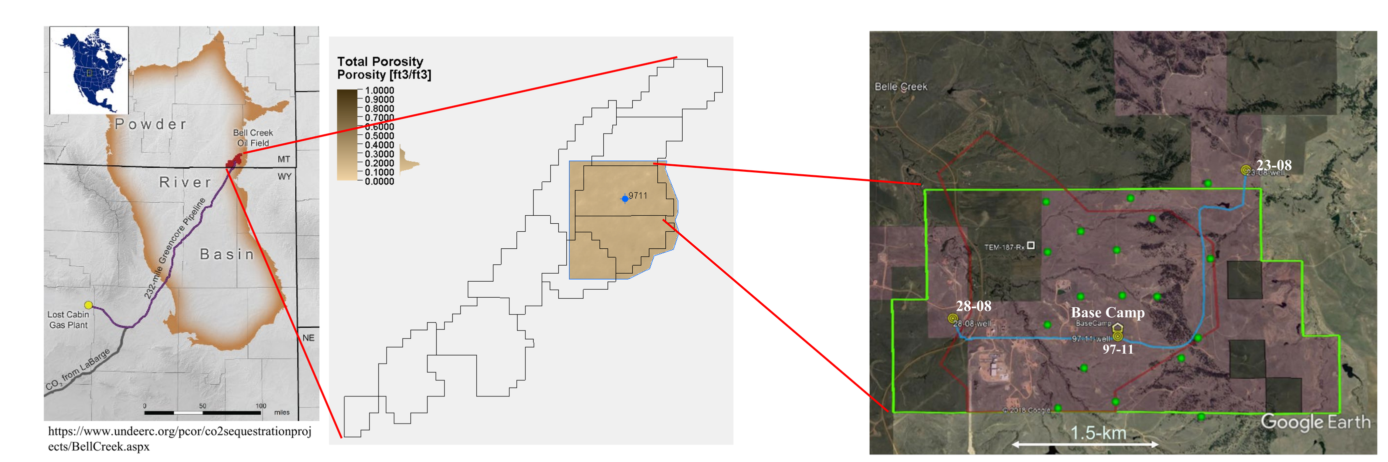
A novel approach for subsurface monitoring that can be applied with minimal expense and operation disruption is charged wellbore casing controlled-source electromagnetics (CWC-CSEM). This technique injects electrical current into two legacy wells. Surface measurements of the induced electric and magnetic fields are obtained with distributed data loggers. Time-lapse measurements are sensitive to changes in CO_2 plume movement, but inversion requires the application of prior knowledge from prior characterization efforts. We propose a methodology where simulations are used to inform CWC-CSEM inversion while simultaneously being validated. As such, uncertainty is reduced, and more robust flow models can be devised.

A three-year study is underway at the Bell Creek Field in southeast Montana to evaluate the effectiveness of CWC-CSEM on an active CO_2-EOR operation. Determining the relationship between electrical resistivity and phase saturations, and coupling that to a reservoir model is the thrust of this project. Initially, the relative permeability/capillary pressure relationship and the compositional oil model were identified as model parameters with high uncertainty. To elucidate the impact of these uncertain parameters, simulations were run for ten years with a single five-spot pattern. Final water saturation distributions were converted into resistivity using Archie's Law and available fluid sampling data to provide an exploration of the time lapse electromagnetic anomaly which can be anticipated using CWC-CSEM methods. This technique has promise as an inexpensive and accurate way to monitor CO_2 injection in a CCUS site.

Study Site

The Bell Creek Field is located along the northeast flank of Power River Basin in southeast Montana. The target reservoir is within the Lower Cretaceous Muddy Formation. It has about a 1 degree dip to the northwest. The field relies on stratigraphic trapping of the hydrocarbons along the up-dip area to the south and east. The producing intervals are made up mainly of southwest to northeast trending nearshore marine sands that were deposited during an overall sea-level fall.[1]

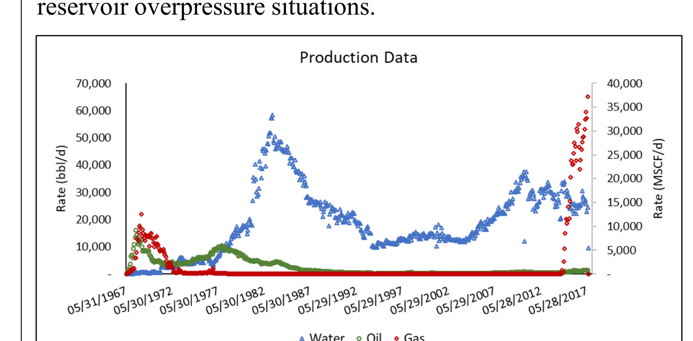
[1 – Exxon Company, Engineering & Geologic Study Bell Creek Consolidated (Muddy) Unit Area]

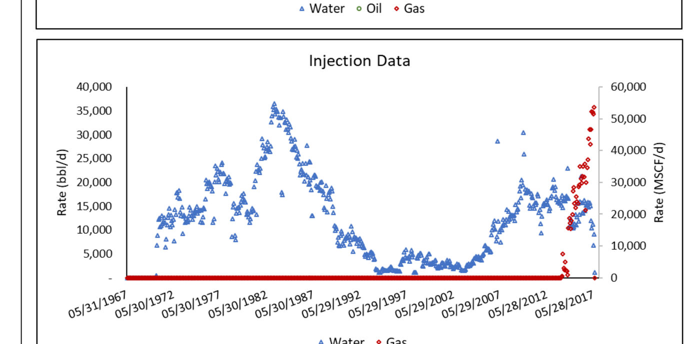


Input data

Production & Injection Data

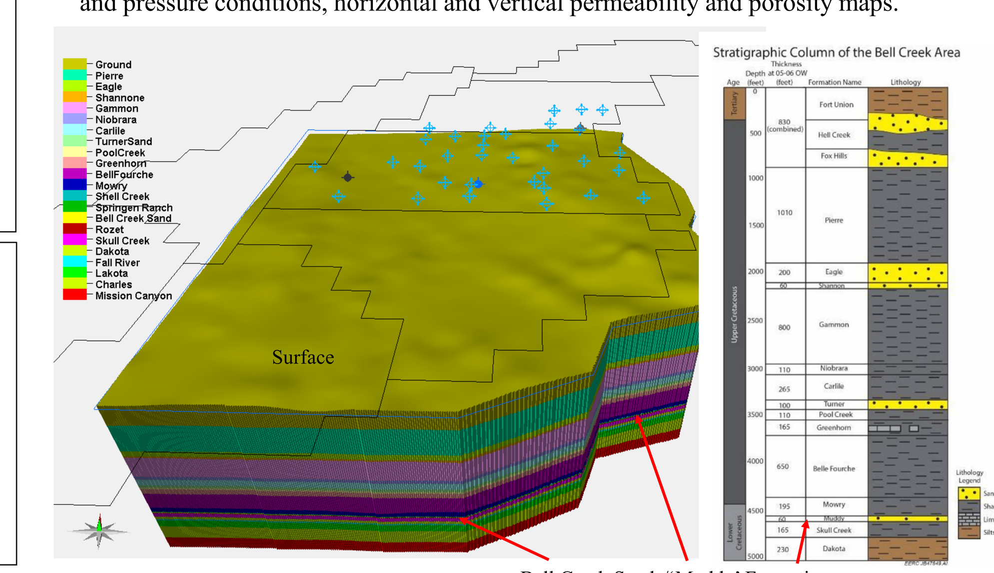
Well schedules and injection and production rates were created from historical field data. Injection wells have a bottom hole pressure limit assigned to 80% lithostatic to avoid simulating reservoir overpressure situations.





Seismic Imaging and Structural Framework

An initial geologic model, provided by EERC, was expanded on to delineate the structural constraints for the EM inversion model. An expanded geologic model incorporates supplementary information from the literature to extend the model from the surface to the base of the Morrison Formation, approximately 6100 feet deep. The target reservoir is within the Muddy Formation/Bell Creek Sands, roughly 4300 feet deep. A dynamic simulation model is extracted from the full geologic model. This model's dimensionality is 174 x 188 x 14 cells, containing 411,152 cells with defined properties; predevelopment oil and pressure conditions, horizontal and vertical permeability and porosity maps.



Archie's Law

Initially we are using Archie's law to analyze resistivity data and convert that to water saturation. We will then calibrate the reservoir model with the measured resistivity data to improve its predictive behavior. Our big question: "Is this method sensitive enough to determine CO_2 changes in the deep subsurface?"

$$\Omega_{total} = \frac{\Omega_w\ \phi^{1.9}\ S_w^2}{\alpha}$$

$\alpha = 0.6$
$\Omega_w = 0.733$

Acknowledgements

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