Rejuvenating A Mature EOR Asset: Miscible CO_2 Flooding at SACROC

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Kinder Morgan CO_2 Company, LP

December 7th, 2012

SACROC Unit (Canyon Reef)

- Discovered – Nov, 1948
- Formation – Canyon Reef (Limestone)
- Depth – 6200-7000 ft.
- OOIP – 2.8 BSTB
- Porosity – 9%
- Permeability – 30mD
- Reservoir Temp – 125°F
- Drive – Solution Gas
- Gravity – 42°API

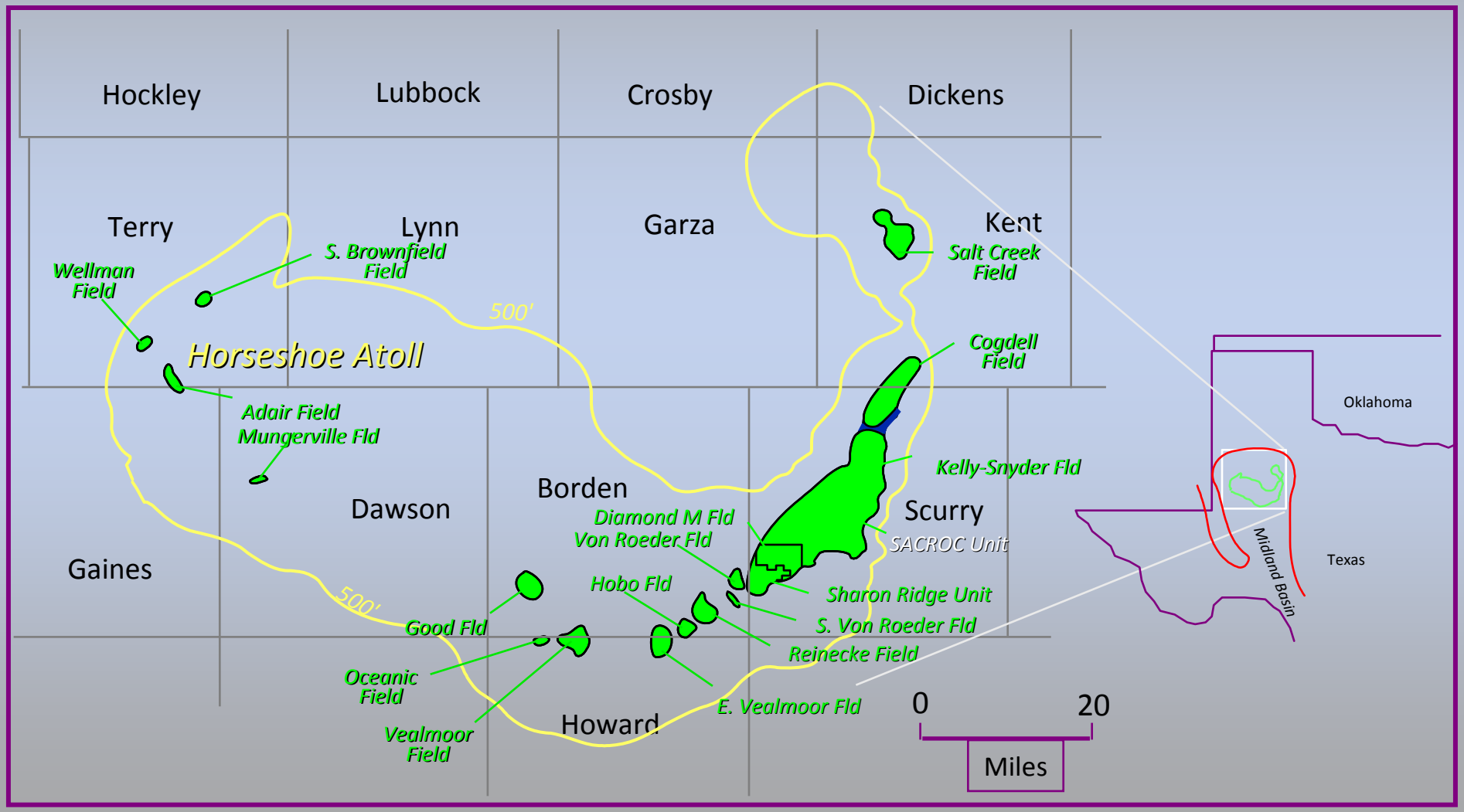
- Disc Pressure – 3300 psig
- P_b – 1800 psig
- R_{si} – 1000 scf/bbl
- B_o – 1.65 rb/stb
- Viscosity – 0.33 cP
- S_{oi} – 80%
- S_{orw} – 35%

- MMP – 1850 psig

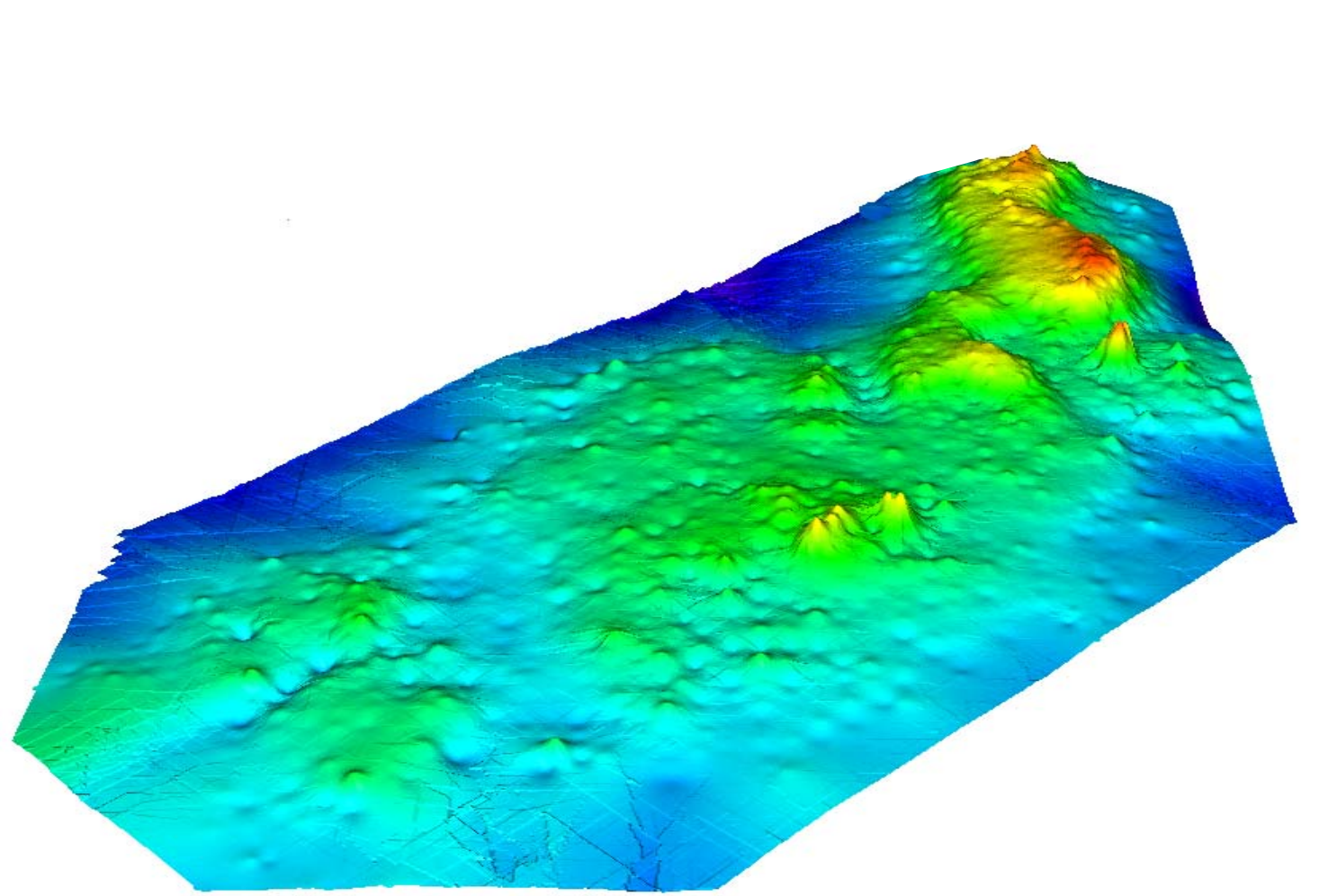
SACROC Unit (Canyon Reef)

- Discovered - Nov 1948
- Formation – Canyon Reef (Limestone)
- OOIP – 2.8 BSTB
- Gravity – 42°API
- Porosity – 9%
- Permeability – 30mD
- Reservoir Temp – 130°F
- Depth – 6200’
- V_{DP} – 0.85
- Disc Pressure – 3300 psig
- R_{si} – 1000 scf/bbl
- B_o – 1.65 rb/stb
- Viscosity – 0.33 cP
- S_{oi} – 80%
- S_{orw} – 36%
- P_b – 1800 psig
- MMP – 1850 psig
- Drive – Solution Gas

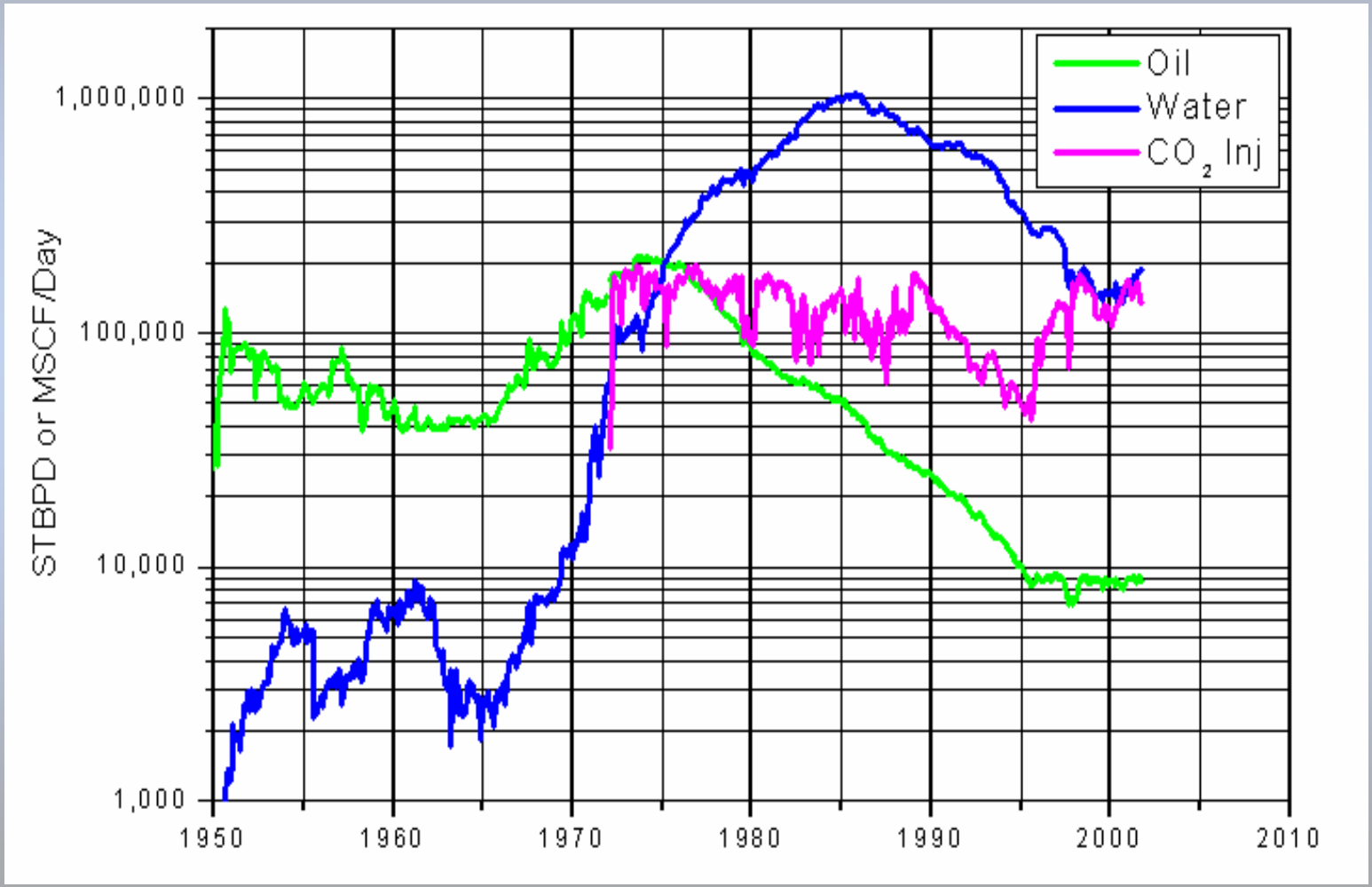
Regional & Geologic Setting



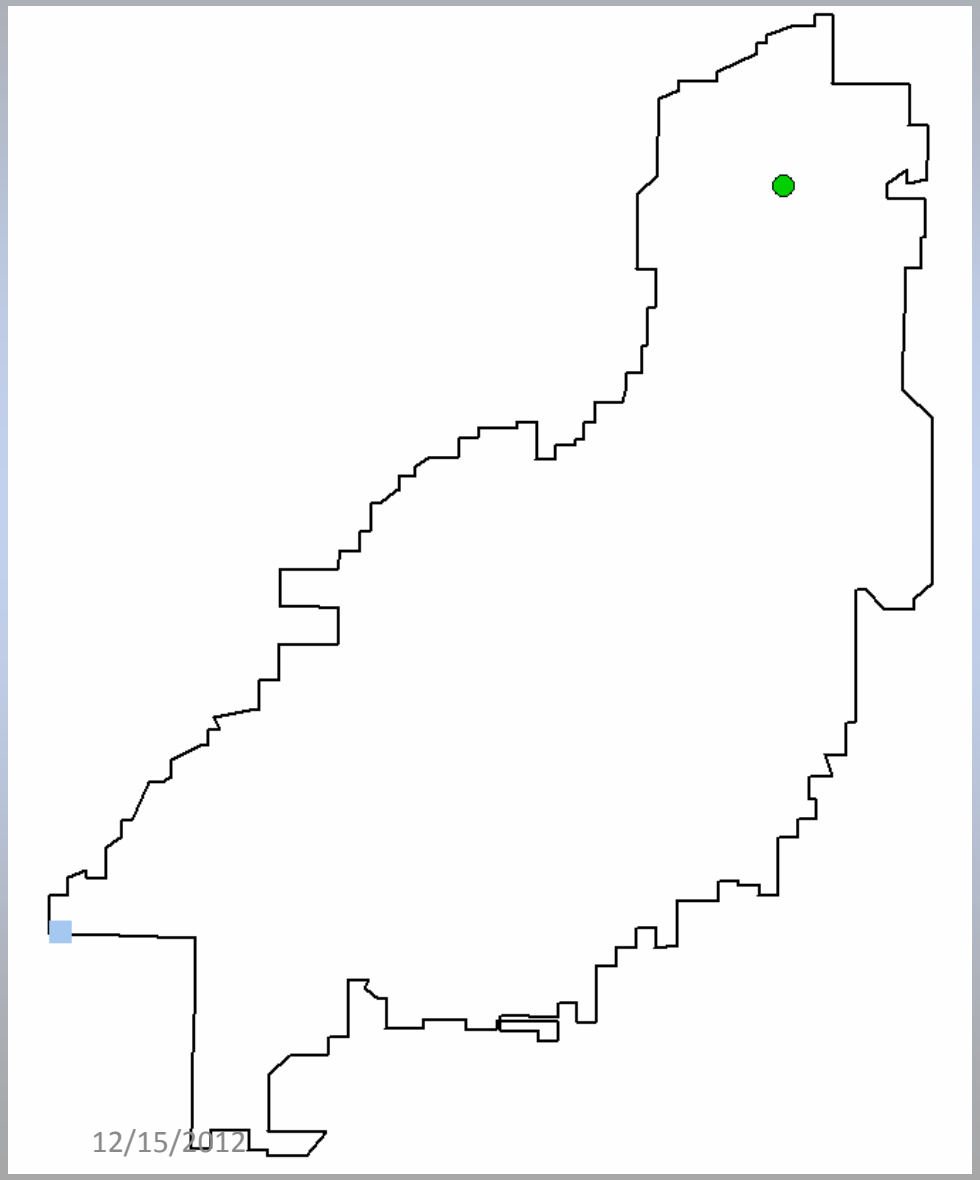
SACROC Unit Structure



SACROC Production Plot to 2001

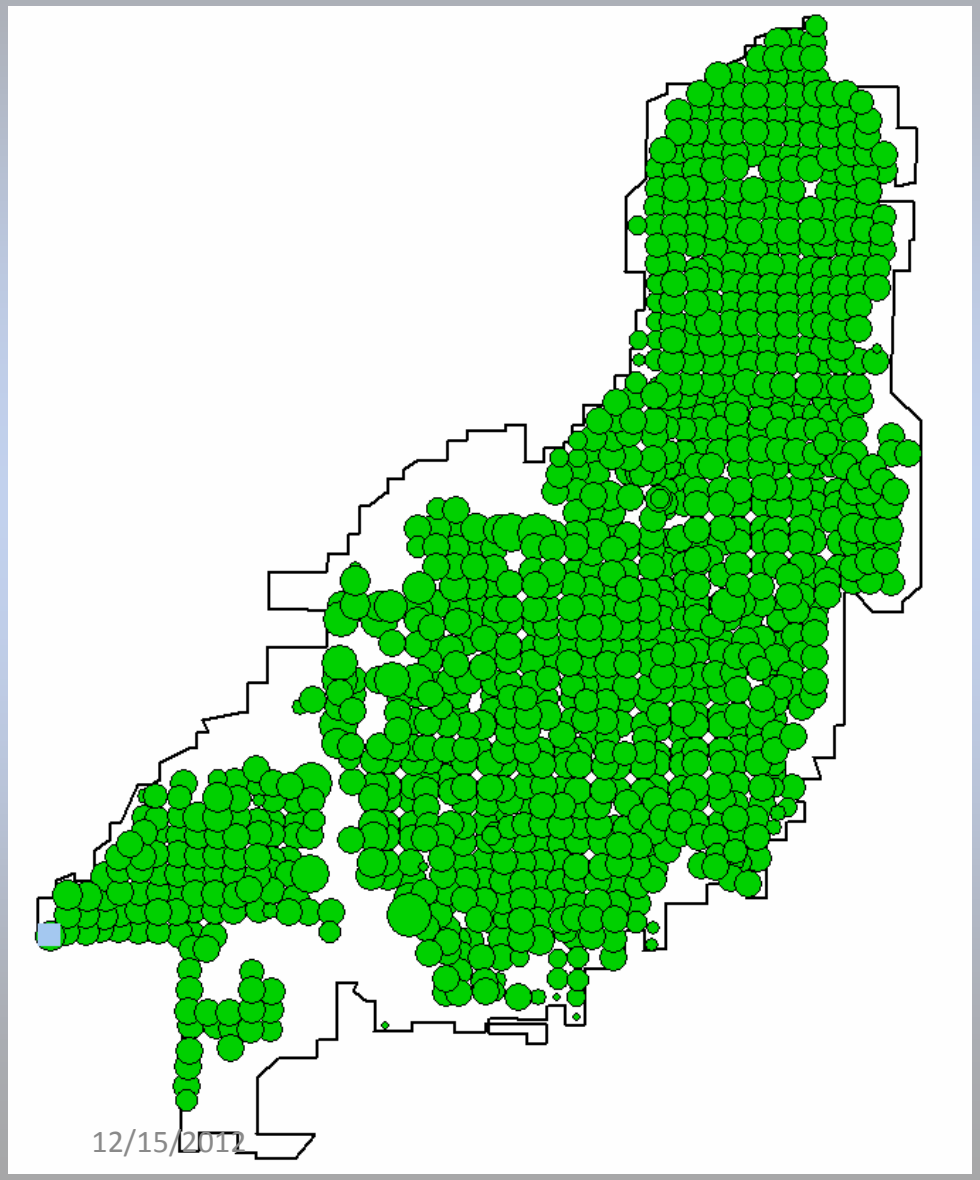


November 1948



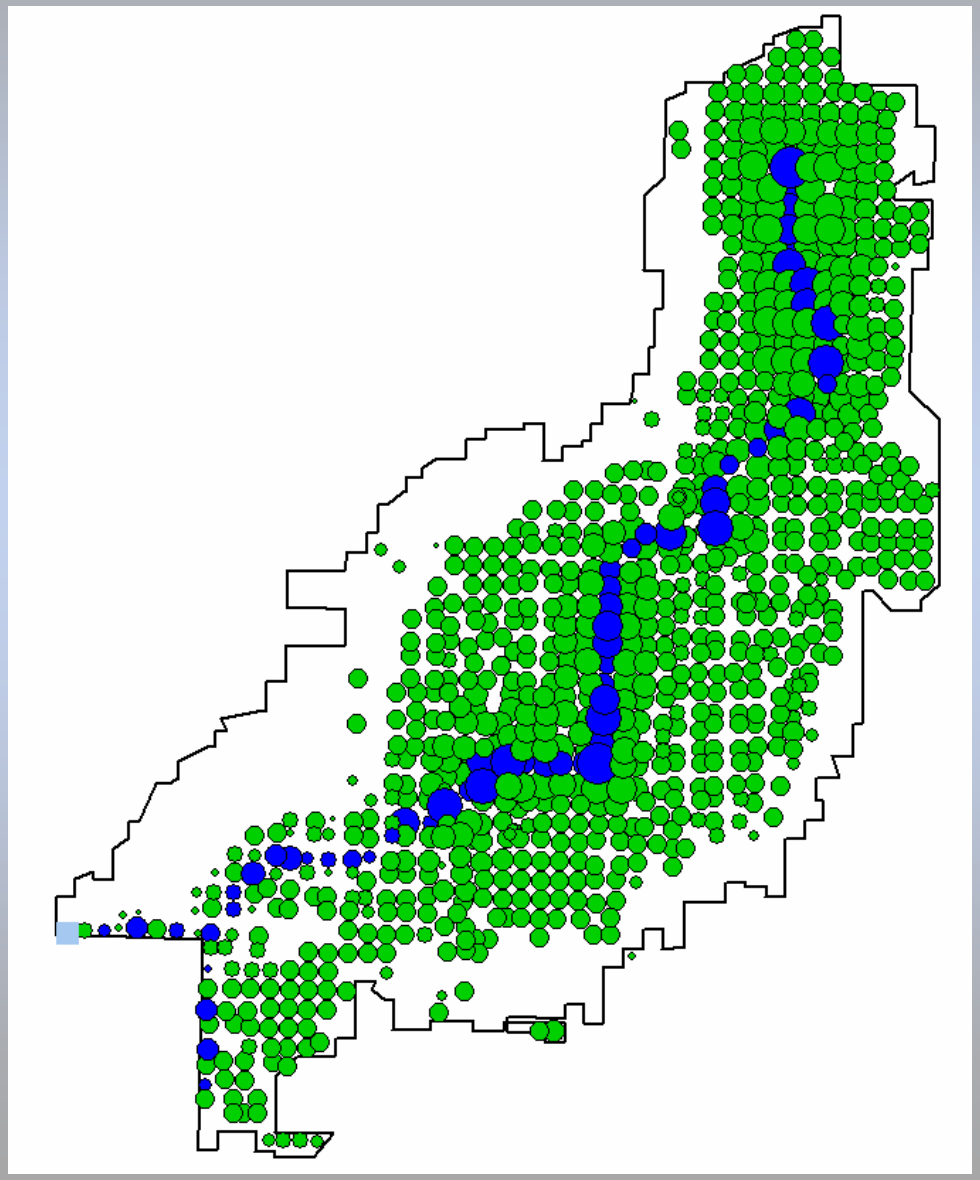
- 66 BOPD
- Water Cut 0%
- N_p - 2,000 STB

November 1950



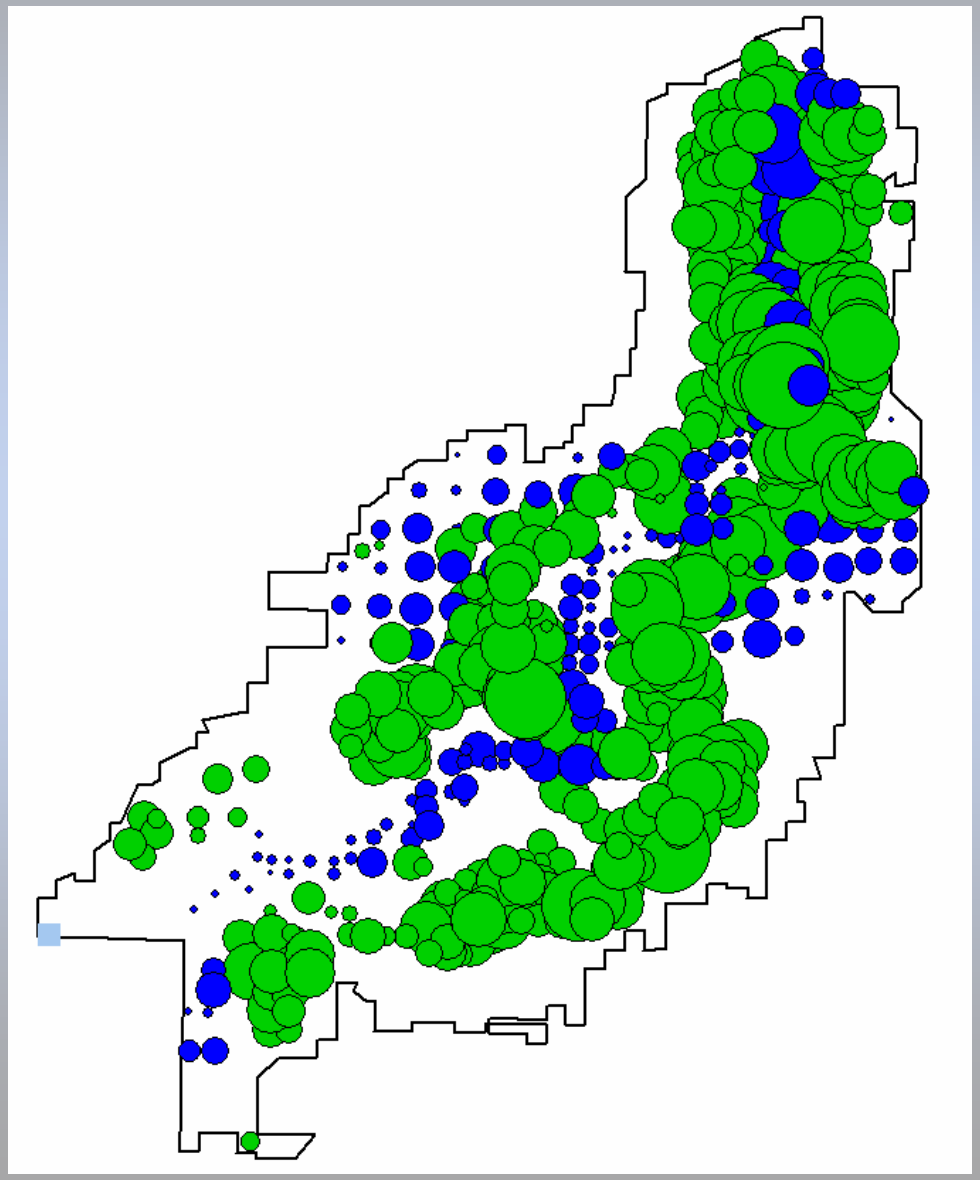
- 112,000 BOPD
- Water Cut 1%
- N_p - 28 MMSTB
- RF - 1%

November 1954



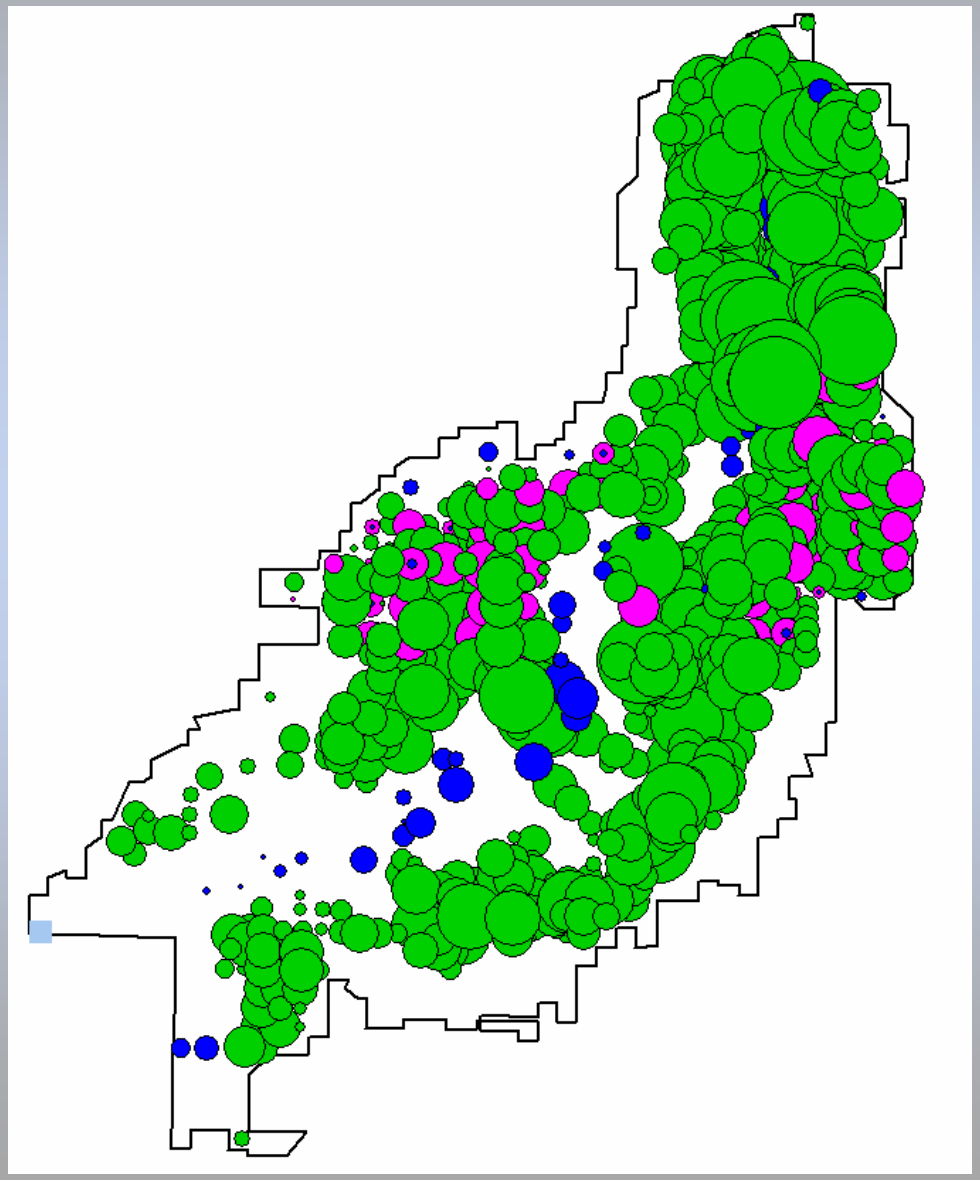
- 52,000 BOPD
- Water Cut 9%
- N_p - 129 MMSTB
- RF – 4.6%

November 1971



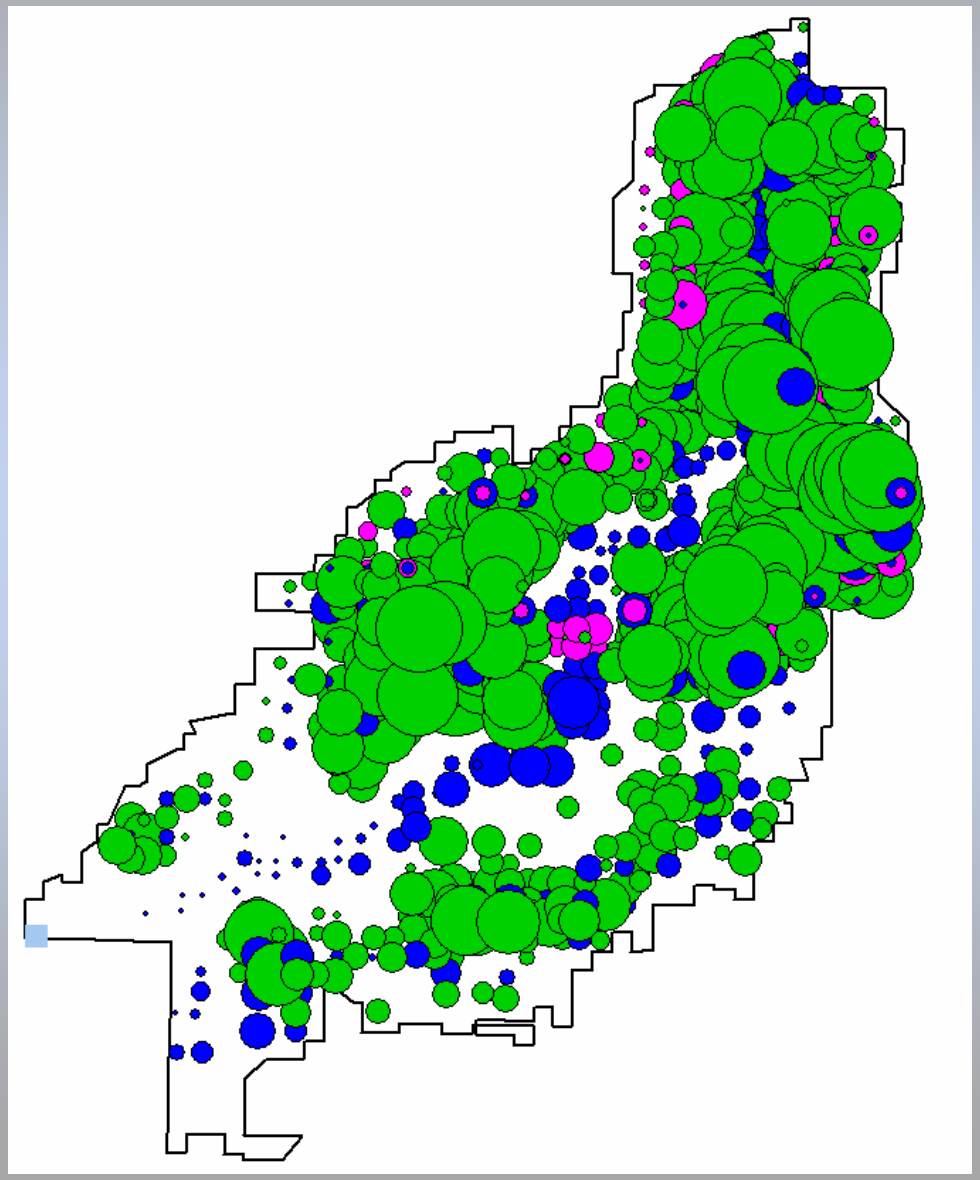
- 134,000 BOPD
- Water Cut 27%
- N_p - 528 MMSTB
- RF – 19%

May 1972



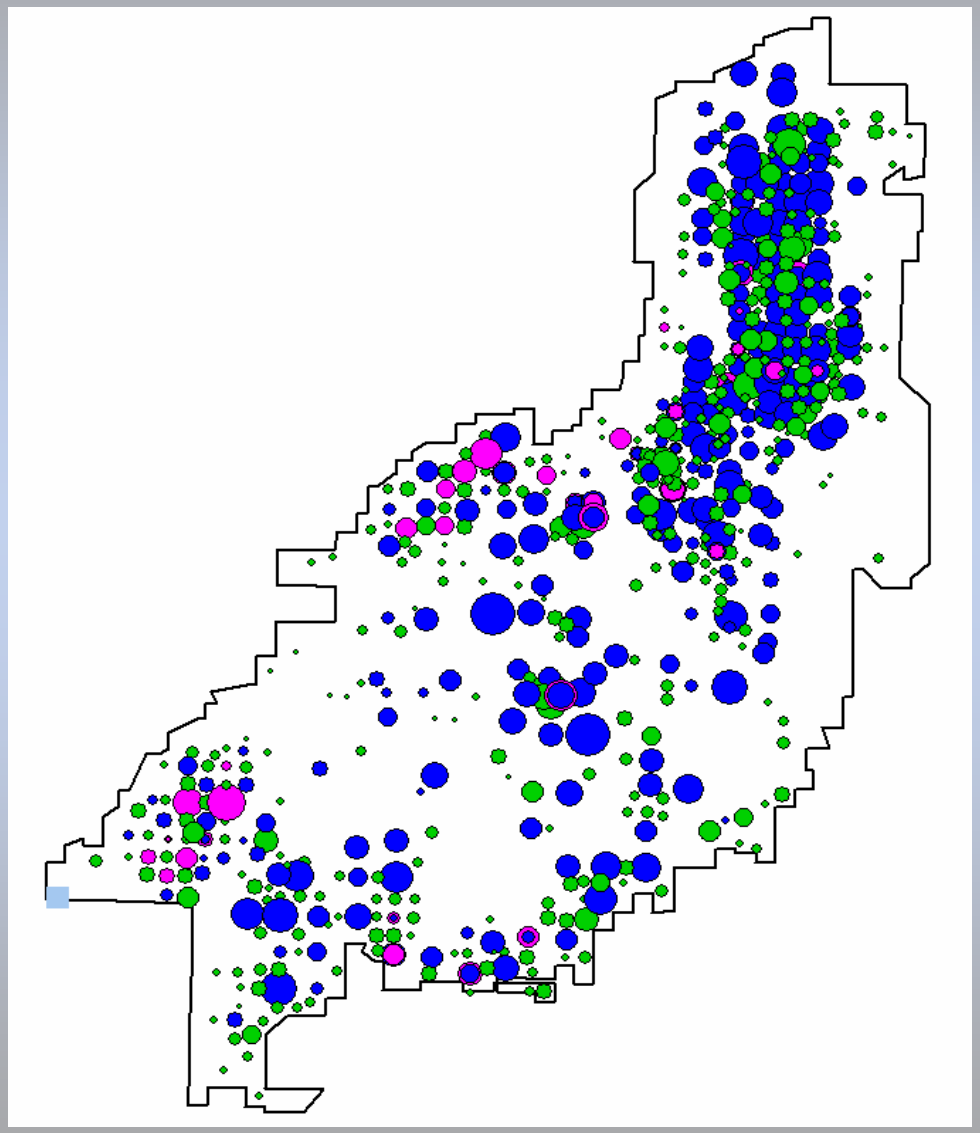
- 175,000 BOPD
- 174 MMSCF CO_2
- Water Cut 36%
- N_p - 552 MMSTB
- RF – 20%

May 1974



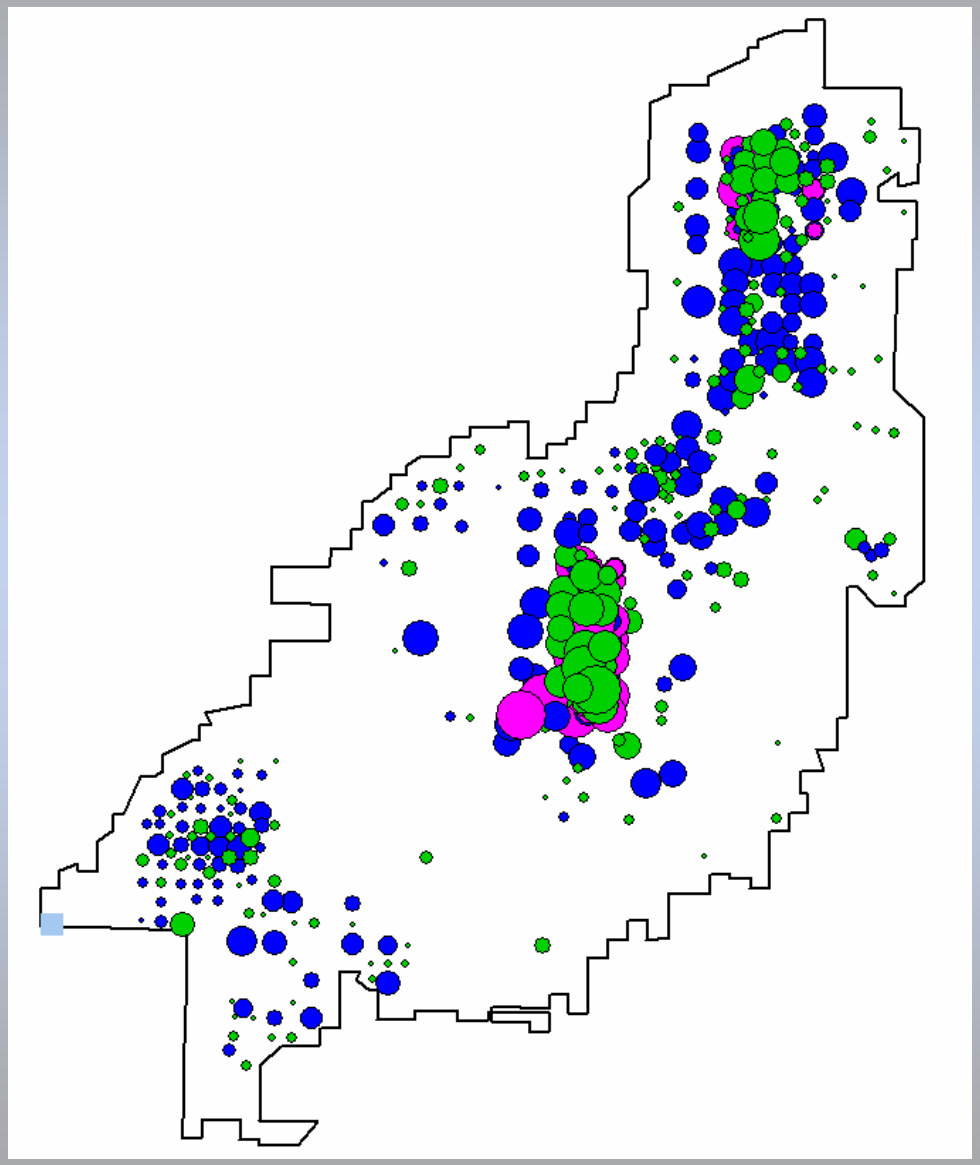
- 211,000 BOPD
- 150 MMSCF CO_2
- Water Cut 36%
- N_p - 680 MMSTB
- RF – 24%

February 1995



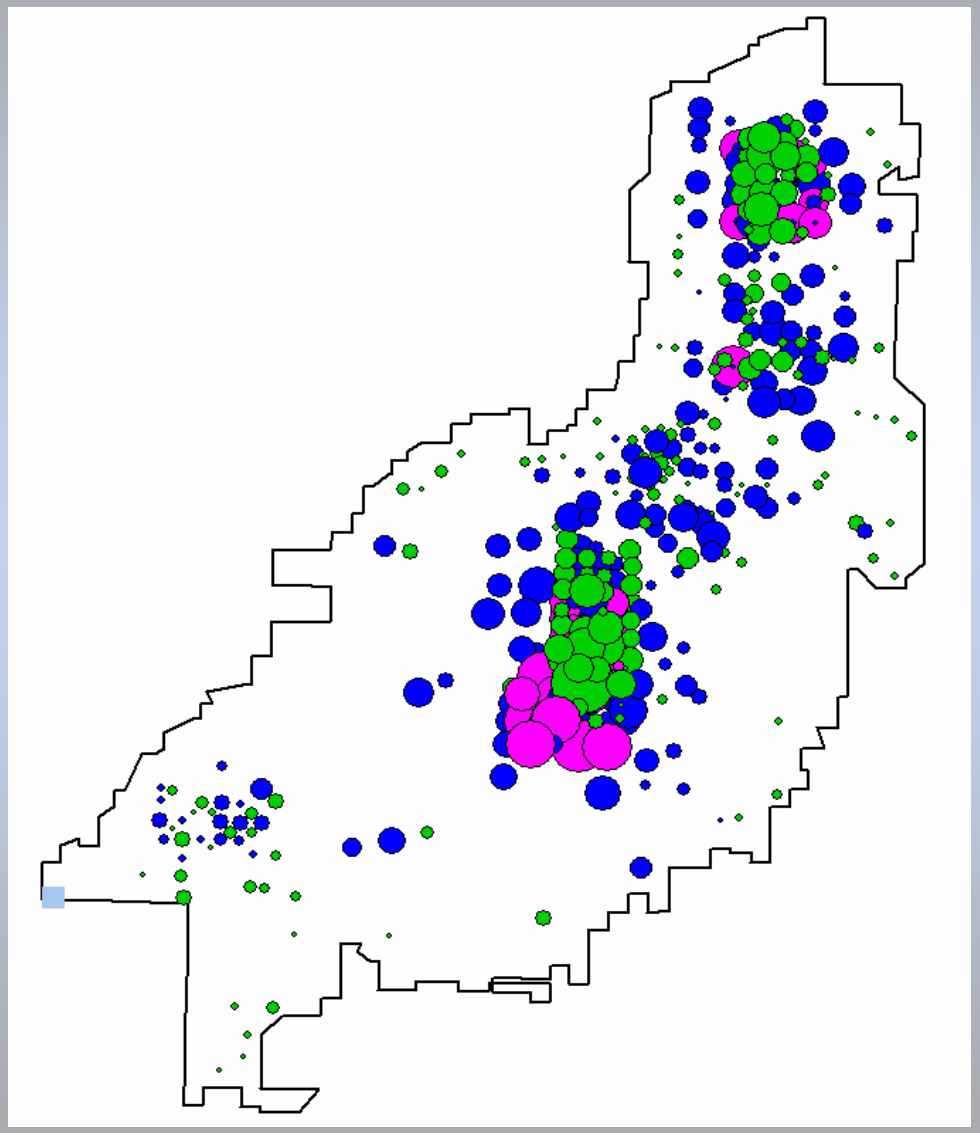
- 10,000 BOPD
- 49 MMSCF CO_2
- Water Cut 97%
- N_p - 1,223 MMSTB
- RF – 44%
- 1st Truly Miscible

April 2000



- 8,400 BOPD
- 118 MMSCF CO_2
- Water Cut 95%
- N_p - 1,239 MSTB
- Cum CO_2 – 1.3Tcf

October 2001

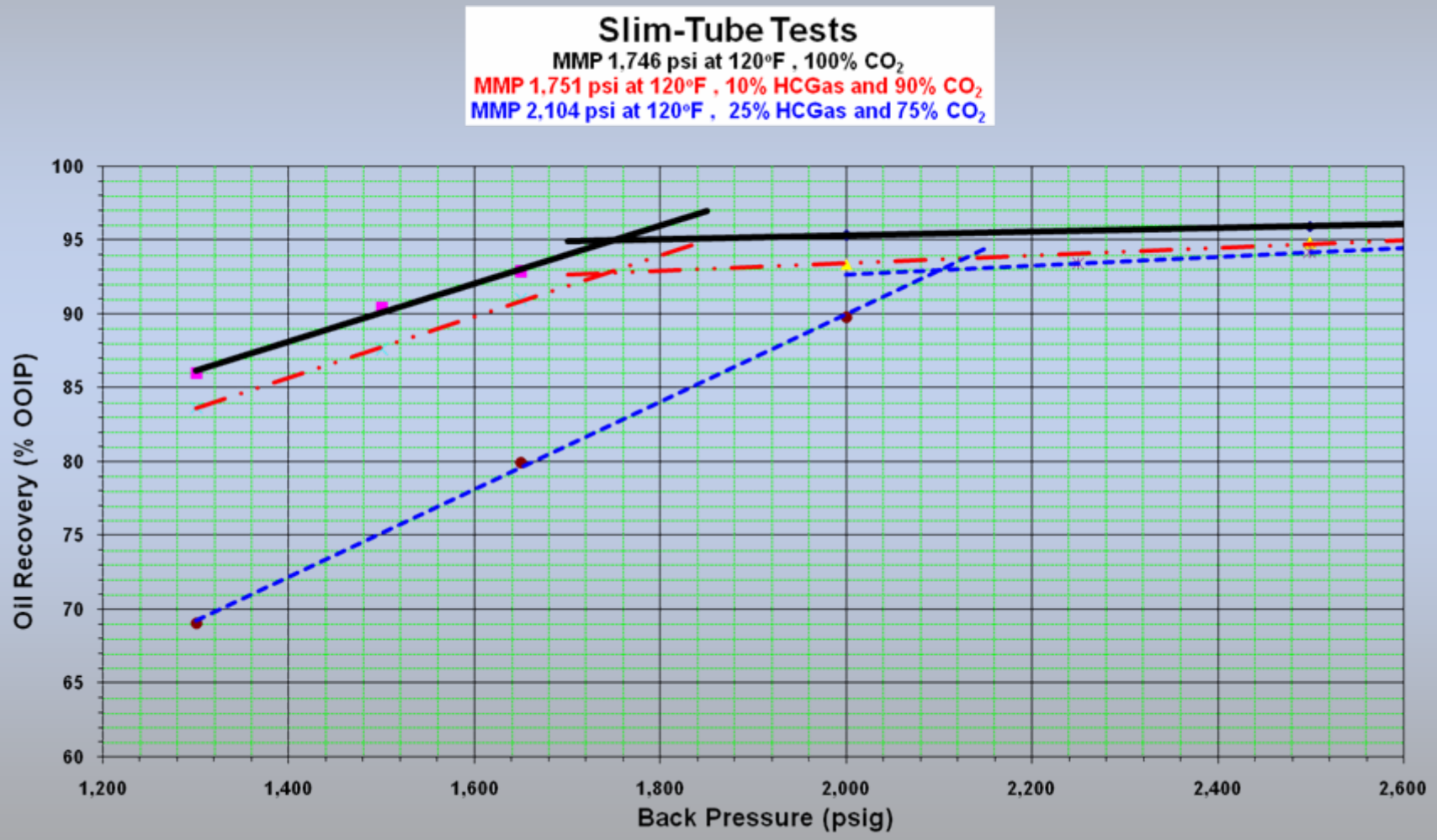


- 9,000 BOPD
- 136 MMSCF CO_2
  Water Cut 95%
- N_p - 1,244 MSTB

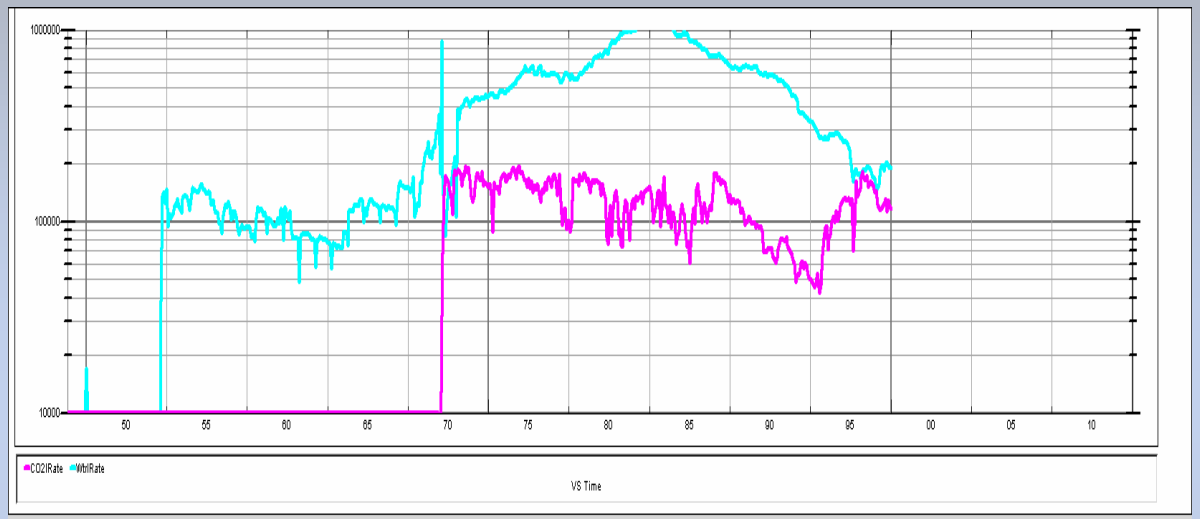
The Opportunity

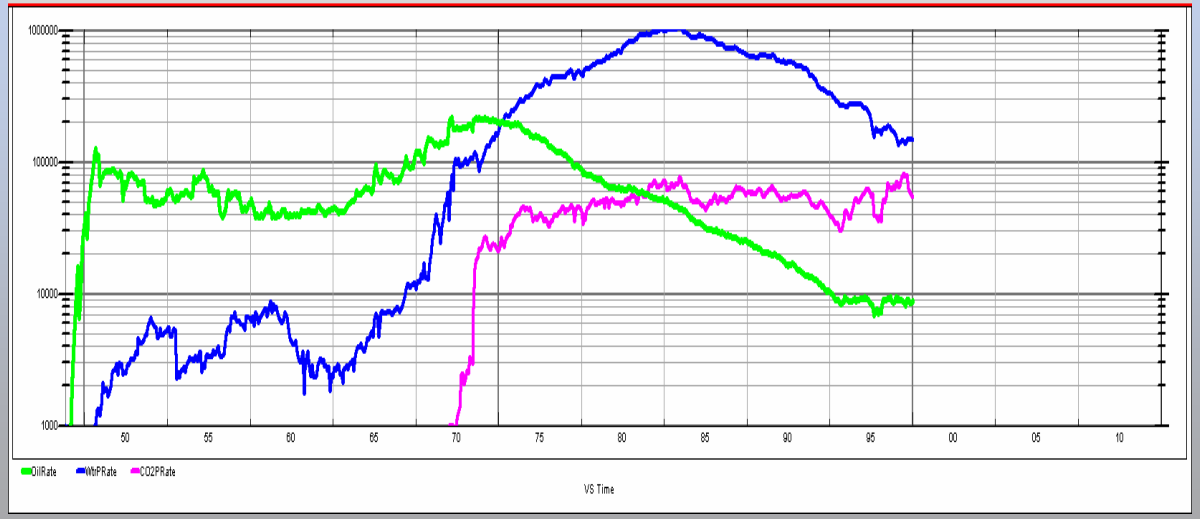
- Saturation, Containment, Pressure, Injectivity, Connectivity
- Low CO_2 Injection Purchases
  - Over-distributed available CO_2
  - Resulted in low injection pressure
- No "Classic" Miscible CO_2 Flood Response
  - Water decreasing & CO_2 increasing
- THE CO_2 WAS NOT MISCIBLE
  - Swelled the Oil
  - Reduced Viscosity
  - IFT $\neq 0$

The Opportunity



The Challenge





At this rate & current oil price the field is uneconomic.

The previous immiscible flood recovered little oil beyond secondary

Can we improve the recovery with a fully miscible CO_2 flood?

Favorable Factors

- High K – means fast processing rates (~25%/yr)
- Low viscosity oil – 0.33 cP (favorable mobility ratio)
- Depth – Deep enough for miscibility, not too hot
- Known lithology – clean limestone, 100% Calcite
- Large unit – able to expand by phases

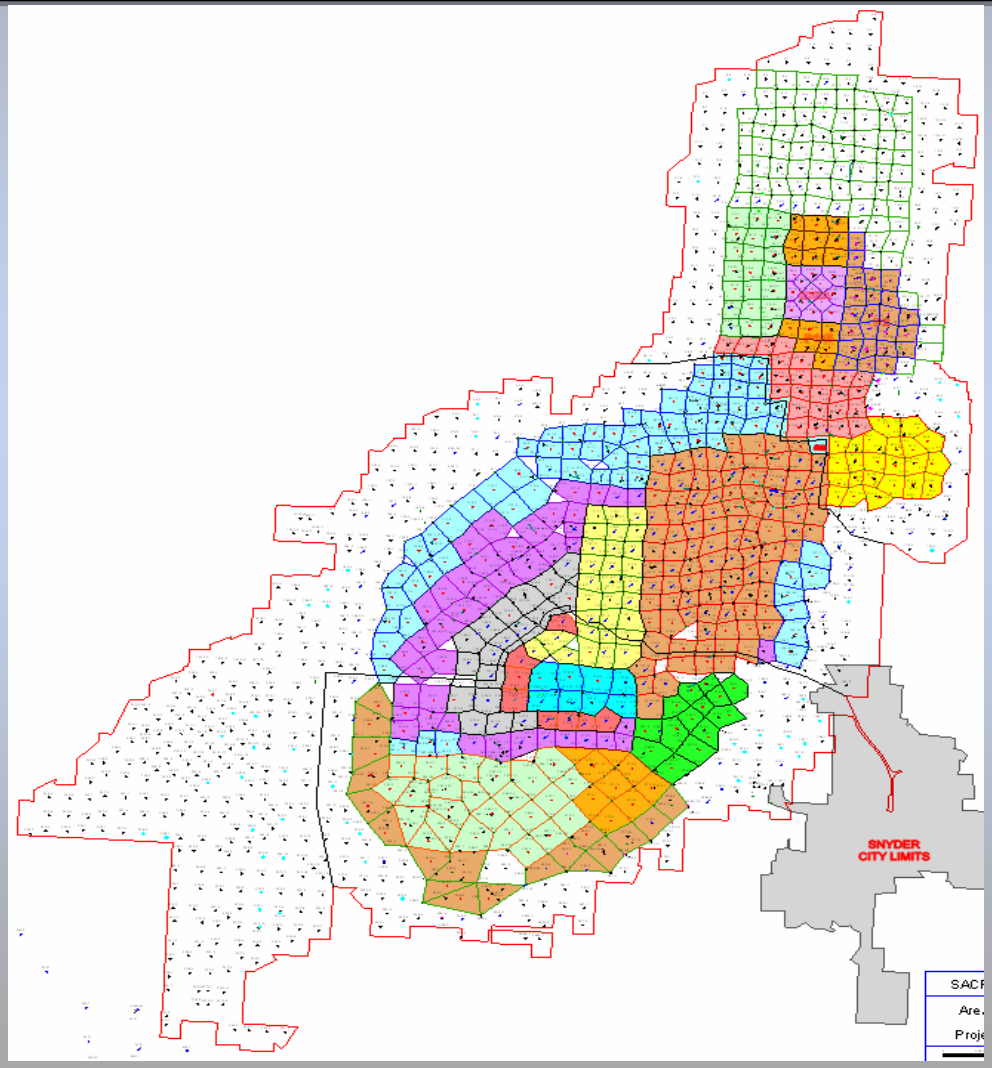
Operational Changes

- Raise average reservoir pressure above MMP
- Convert rod pump to ESP to maintain higher P_{wf} (objective to prevent loss of miscibility near wellbore)
- Use active water curtain to prevent external migration of CO_2

Operational Changes (cont.)

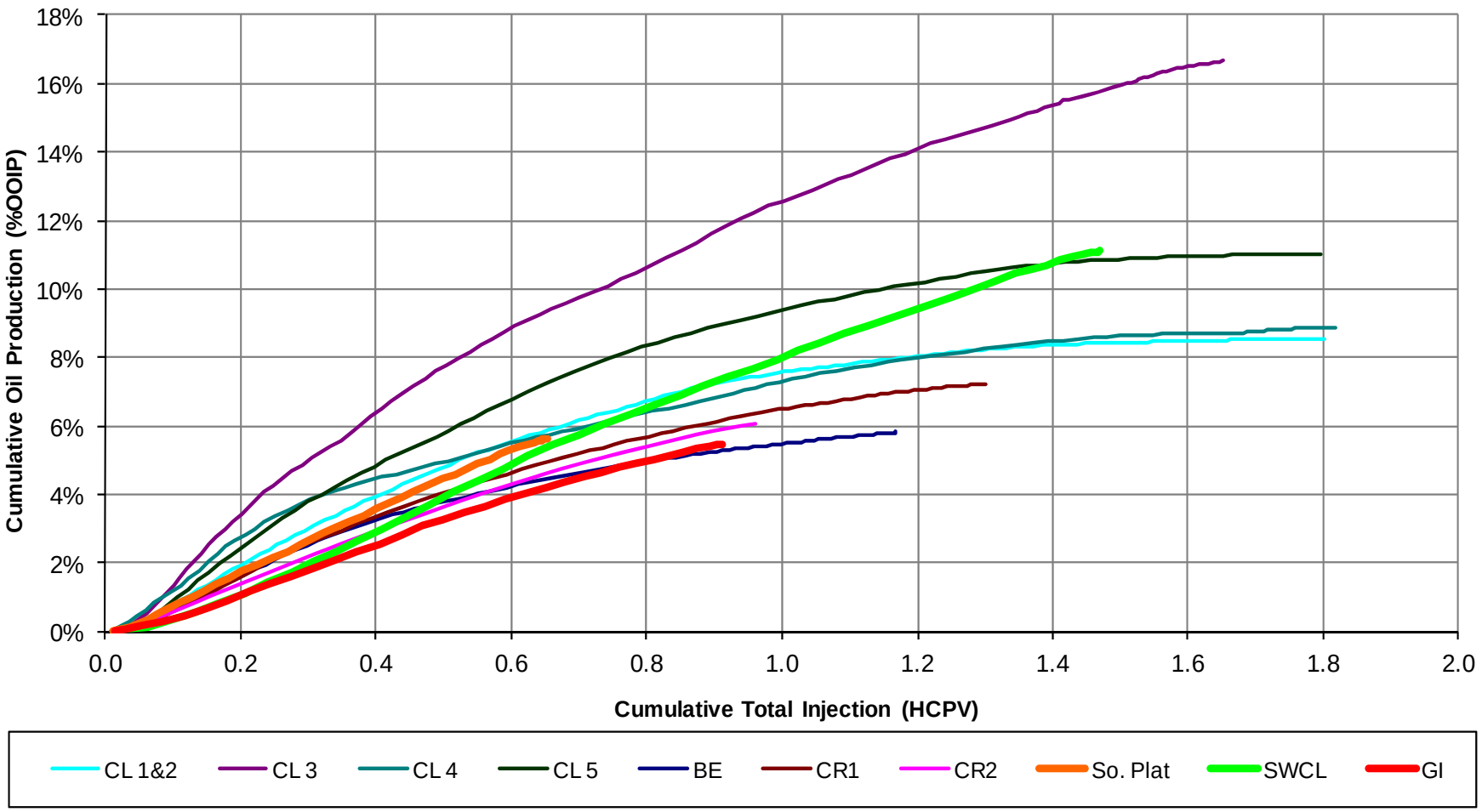
- Extend initial CO_2 slug, follow with dry WAG (many patterns were WAG sensitive and premature water injection led to loss of recovery)
- All injectors completed cased hole to control vertical conformance.
- SIGNIFICANT increase in CO_2 purchases

SACROC CO_2 Project Areas

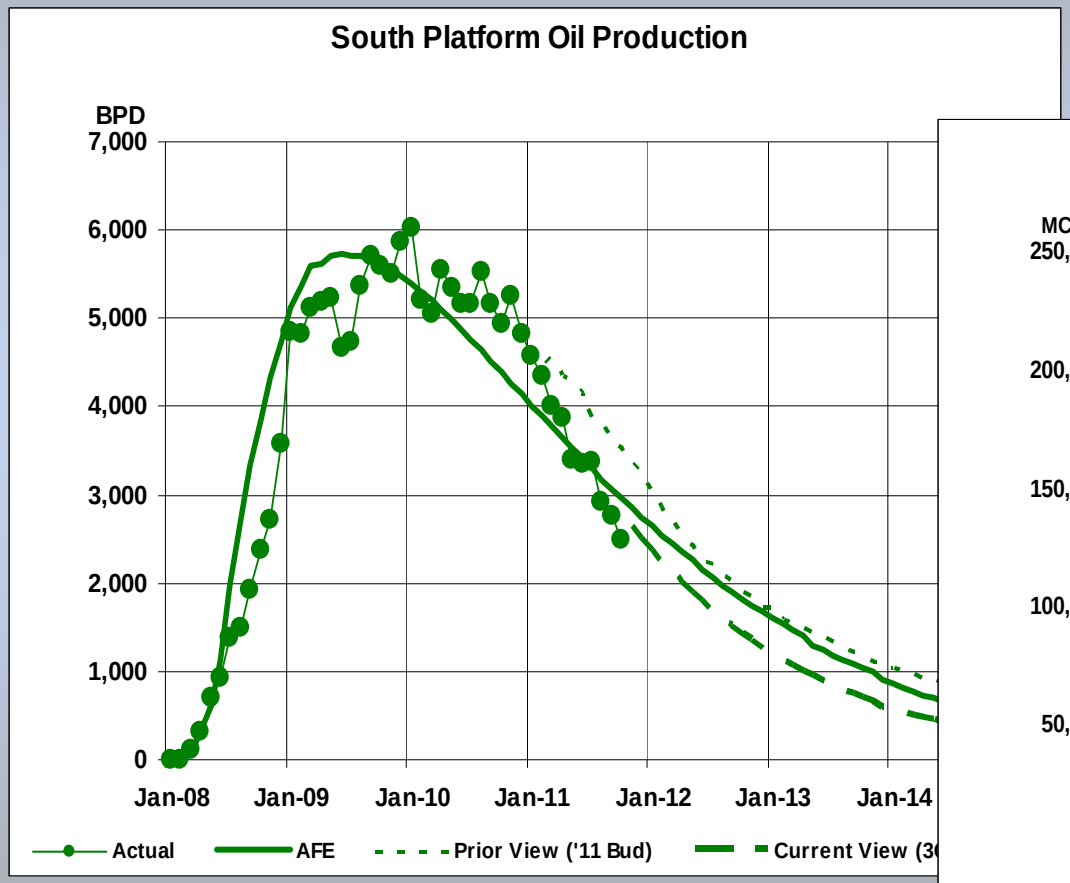


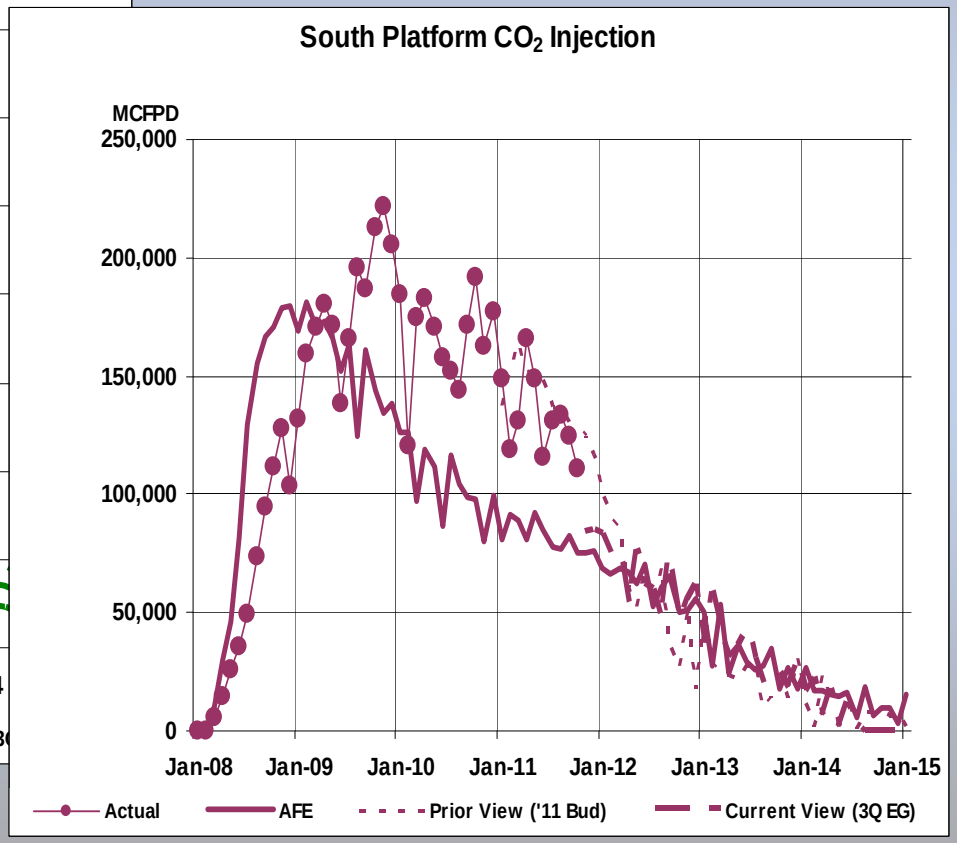
- 16 Phases to date
- Avg. Dim. Oil recovery ~ 8.1%
- Avg dim CO_2 injected ~ 0.55

Dim. Oil Recovery Curves



AFE *vs.* Actual Example



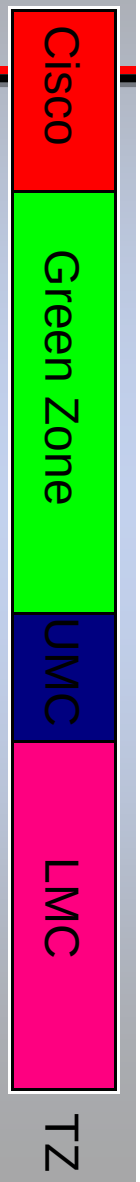


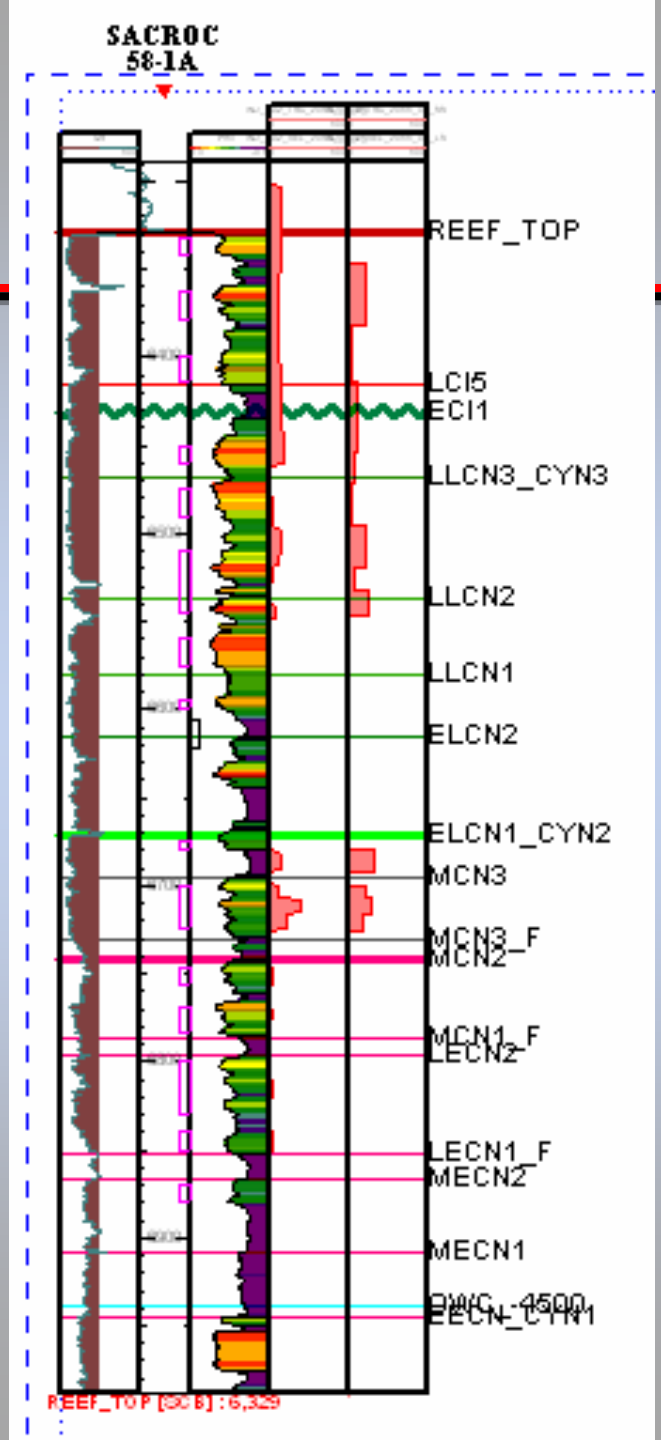
Major Divisions

The Canyon Reef is divided up into four major divisions

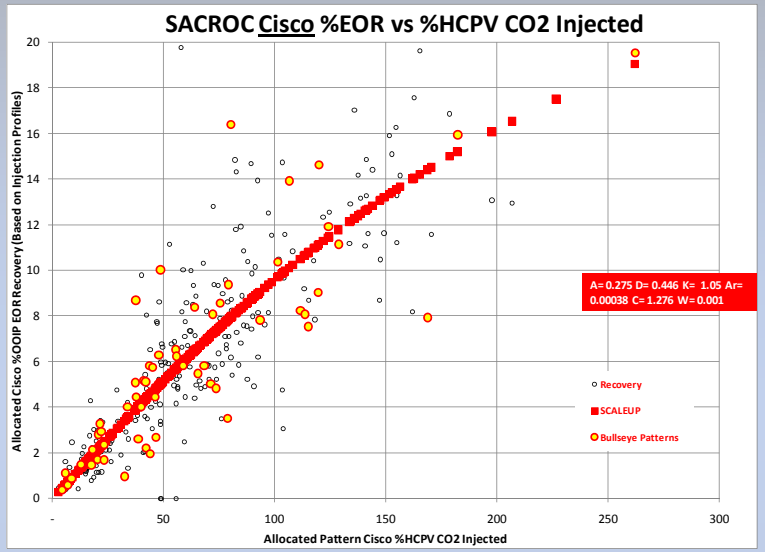
- Cisco
- Green Zone
- Upper Middle Canyon
- Lower Middle Canyon

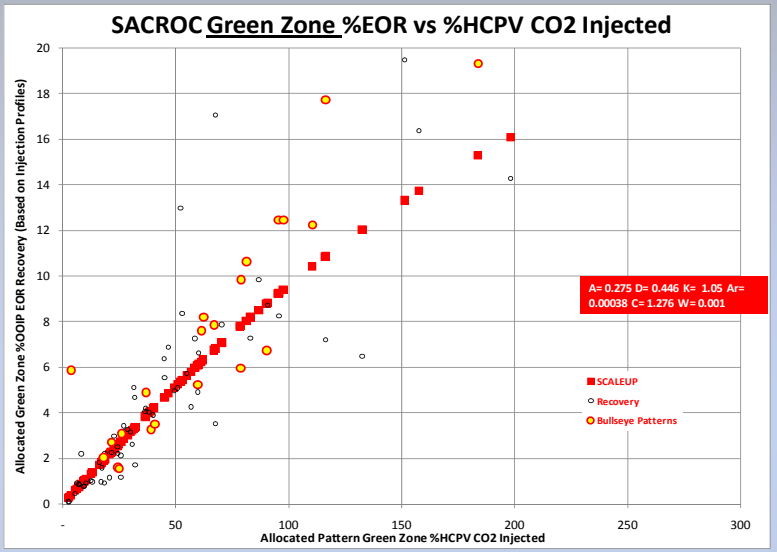
These are further subdivided into zones following the BEG convention

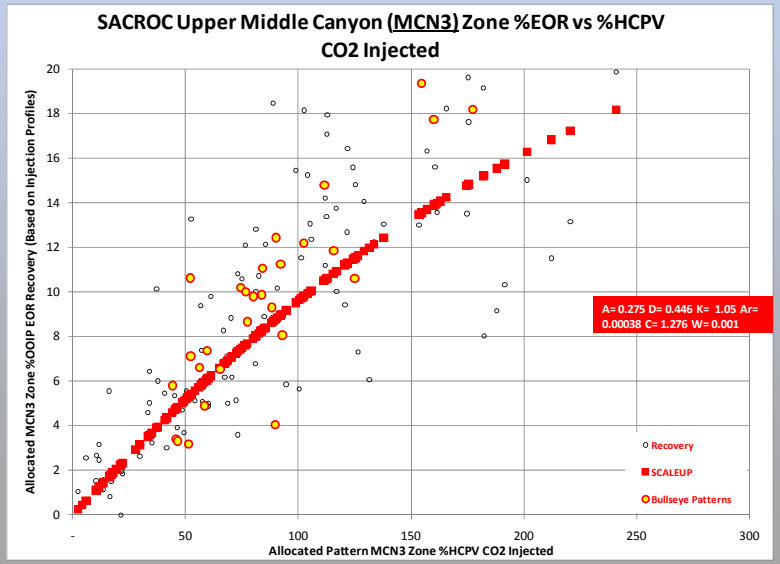


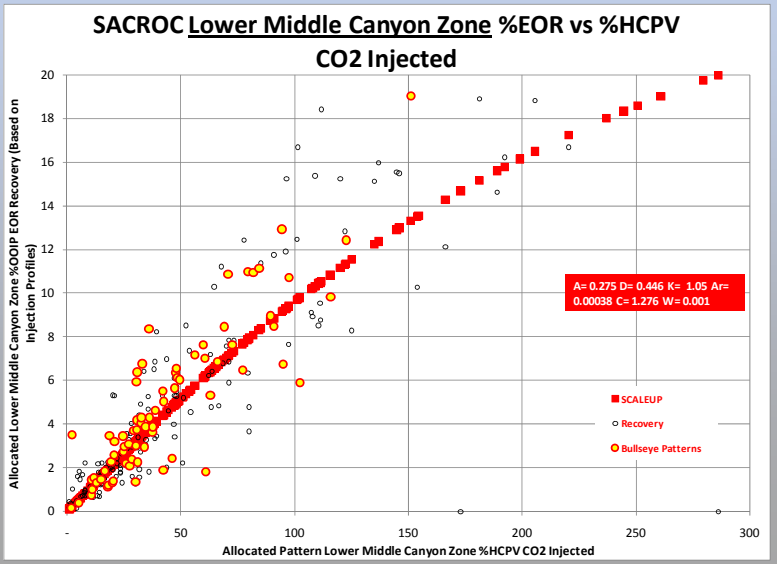


Dim oil Recovery vs. dim CO_2 Inj.

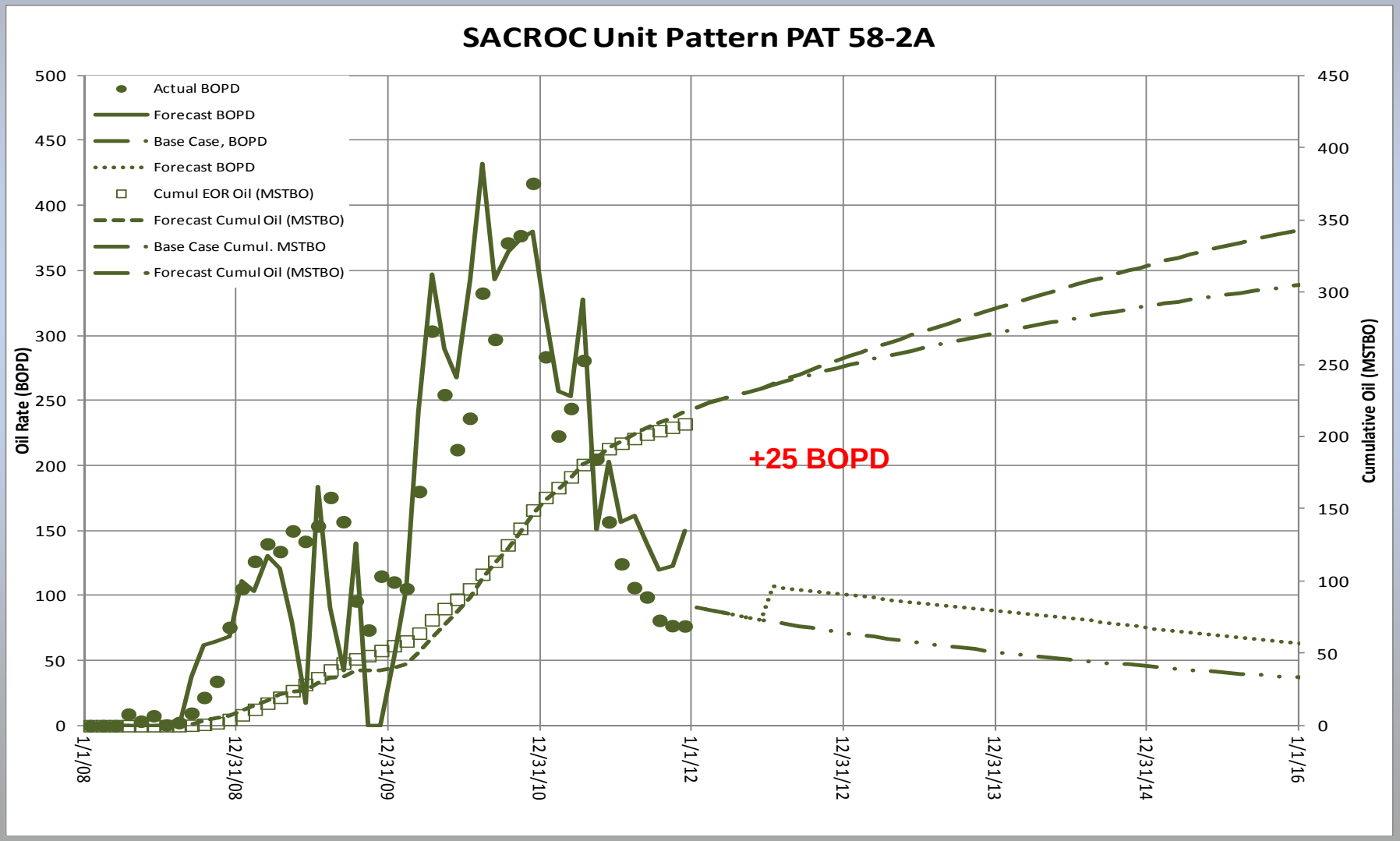




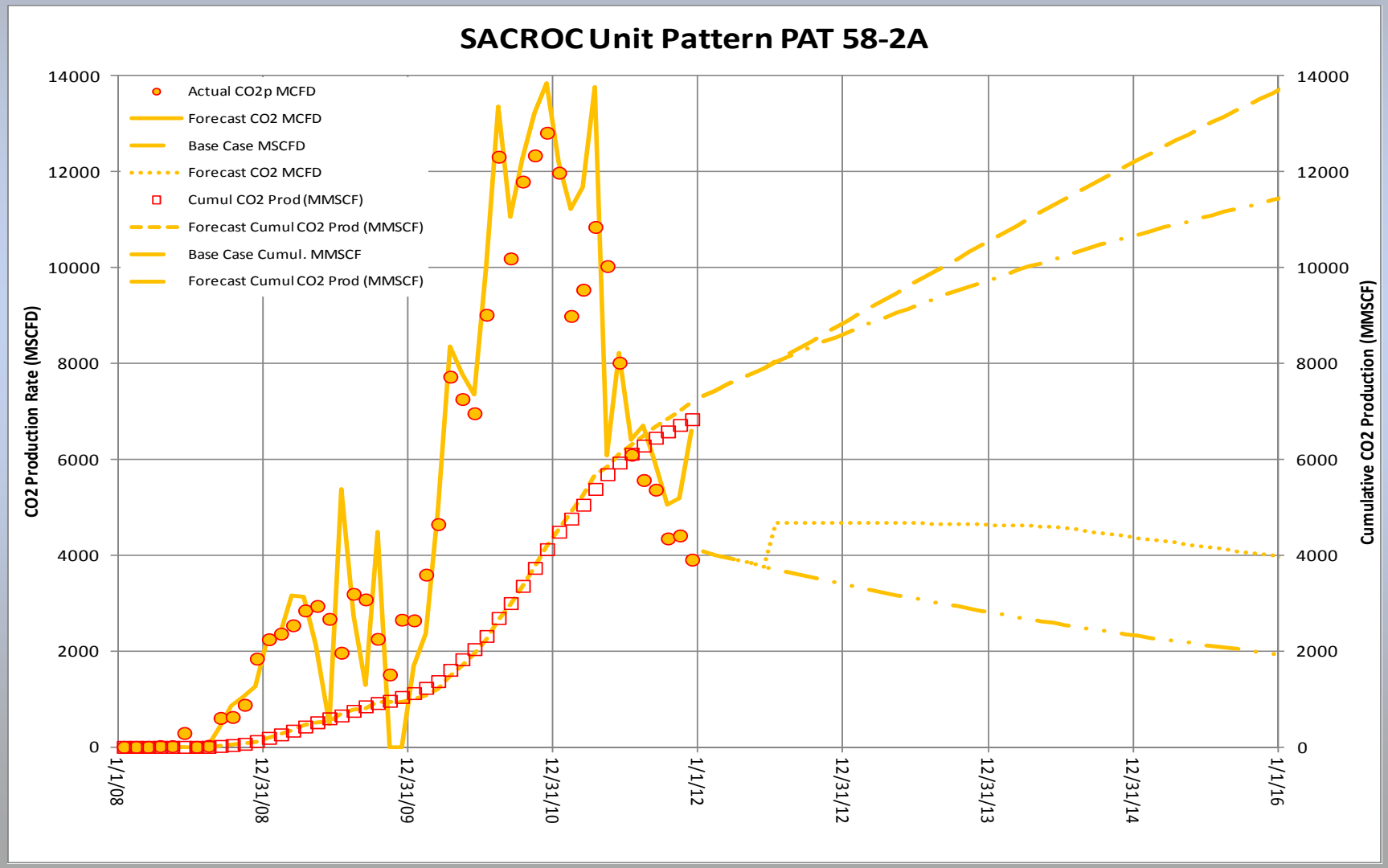




Oil Rate vs. Time



CO_2 Produced vs. Time



Monitoring Tools

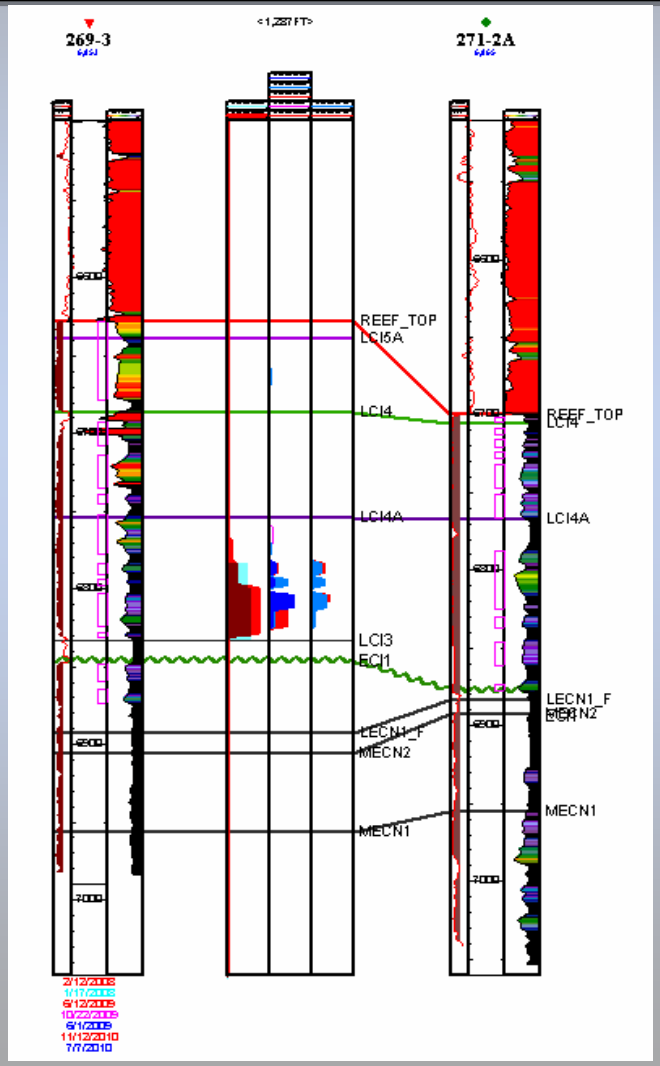
Injection Profiles

- Used to determine zone(s) of injection
- Run once per year on each fluid

Step-rate tests

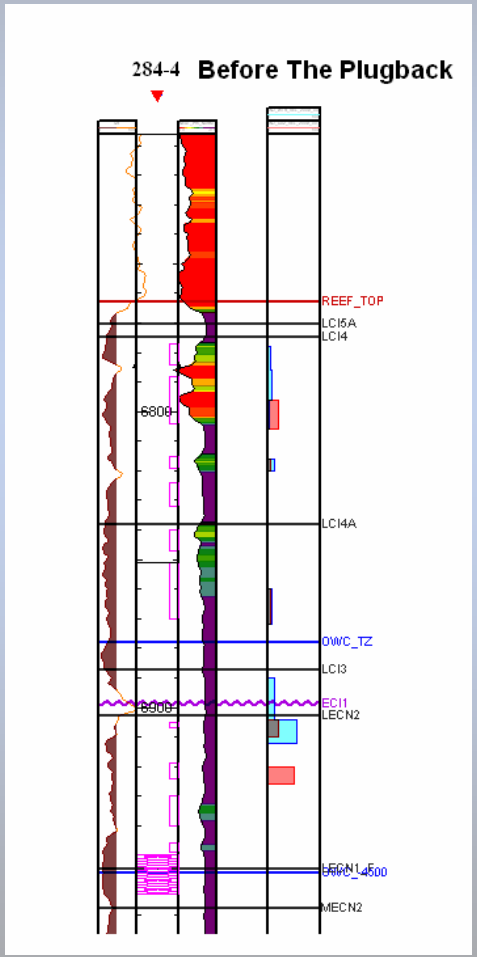
- Used to determine parting pressure
- Run once per year on water injectors

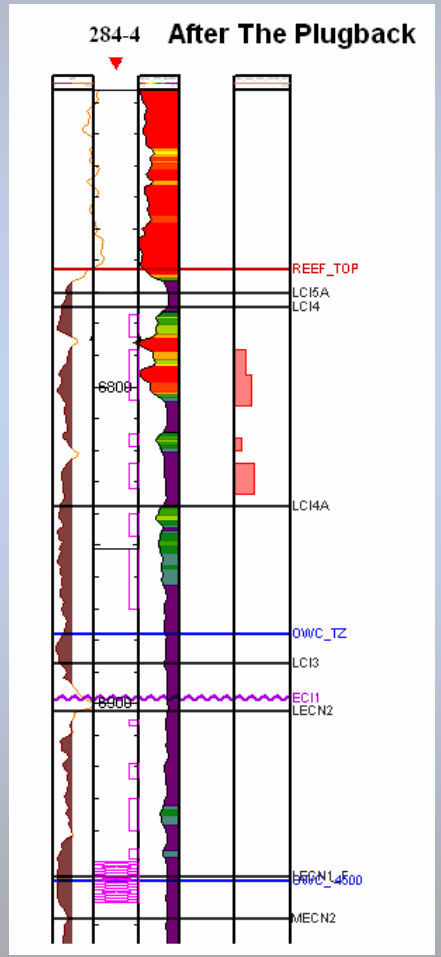
Vertical Conformance



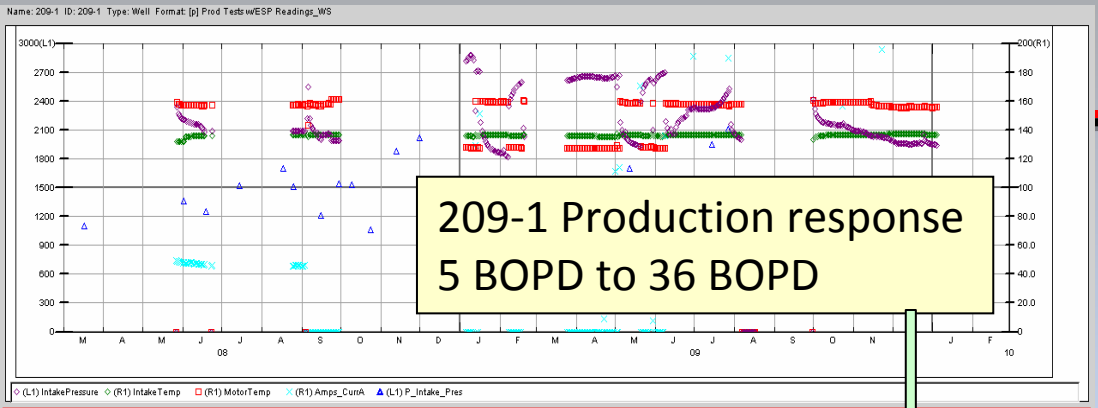
- Injector-Producer cross section showing dominant injection into one zone
- Significant amount of by-passed pay

284-4 Before and After Plugback

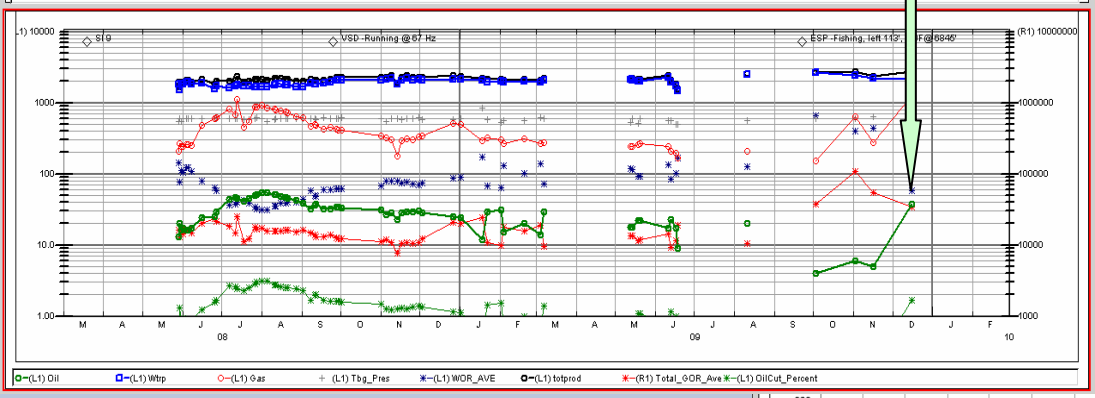


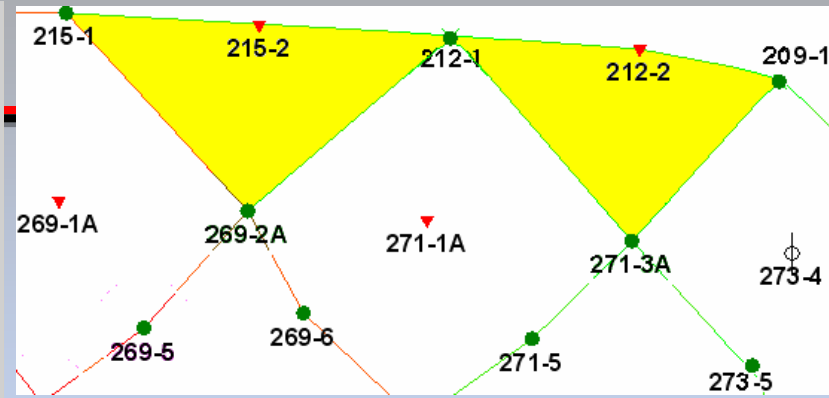


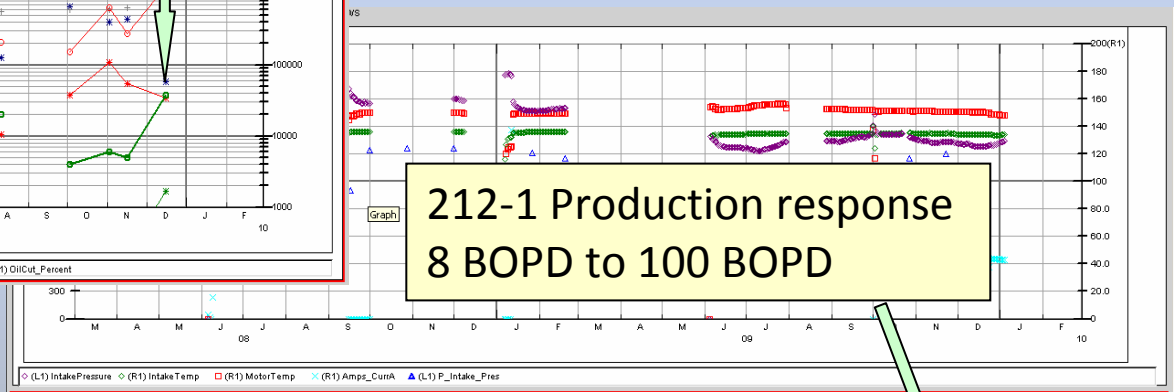
Conformance Response (212-2, 215-2 Polymer Jobs)



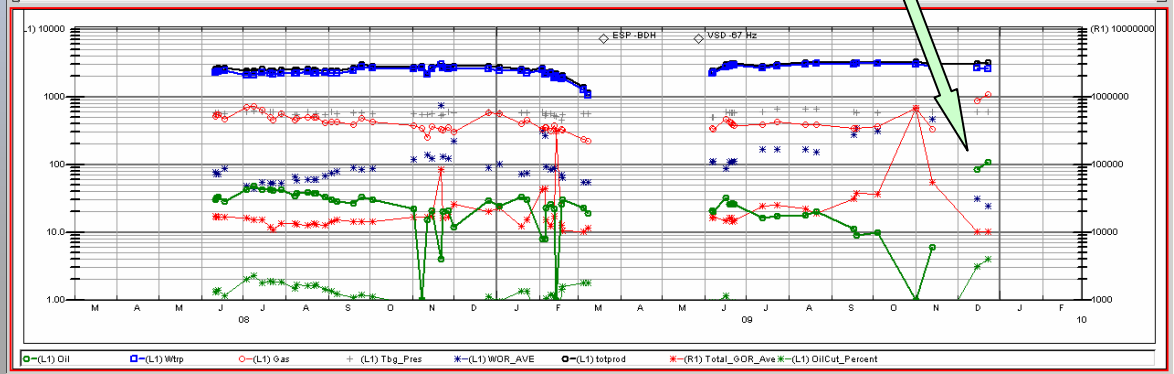
209-1 Production response
5 BOPD to 36 BOPD





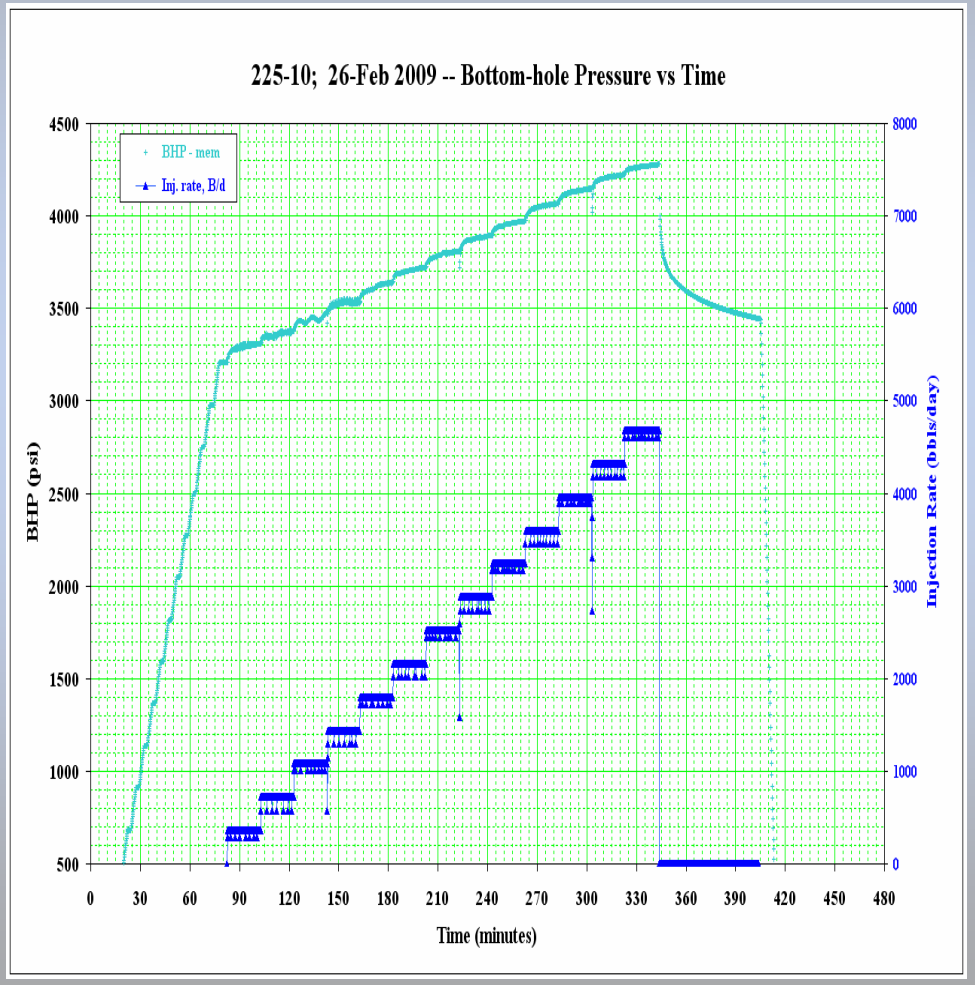


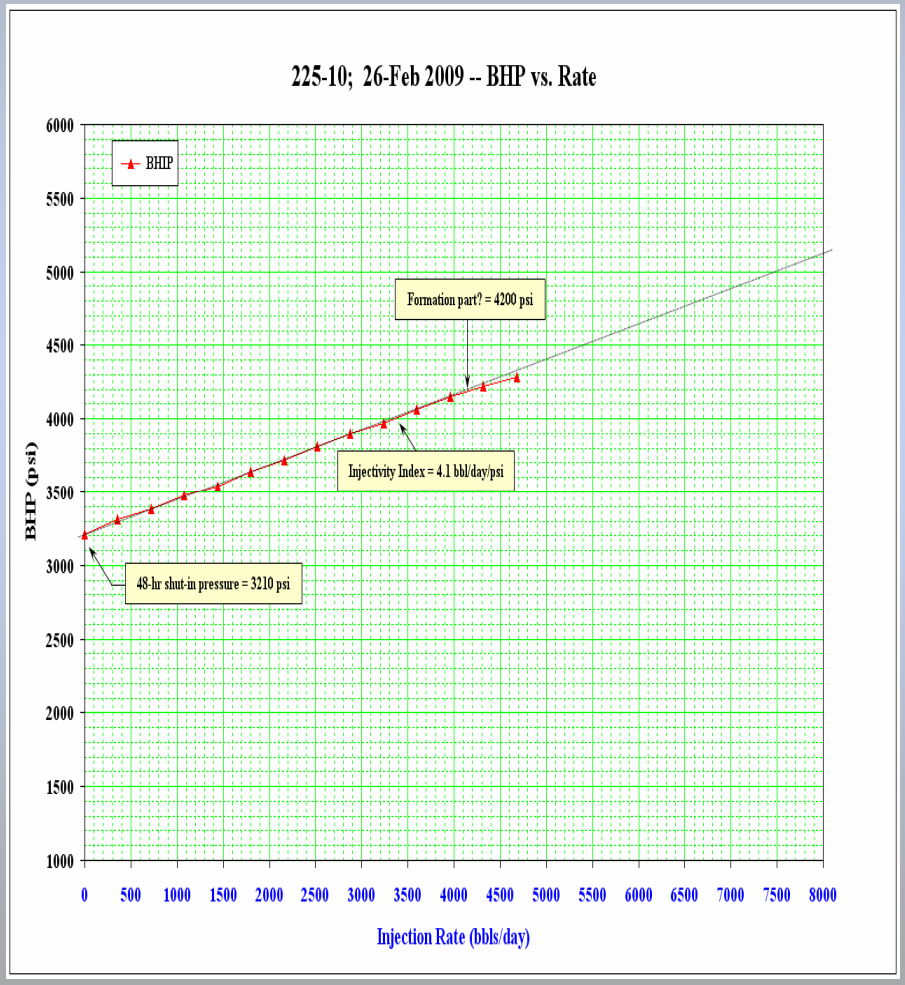
212-1 Production response
8 BOPD to 100 BOPD



212-2 Job cost: $185,025
215-2 Job cost: $405,173

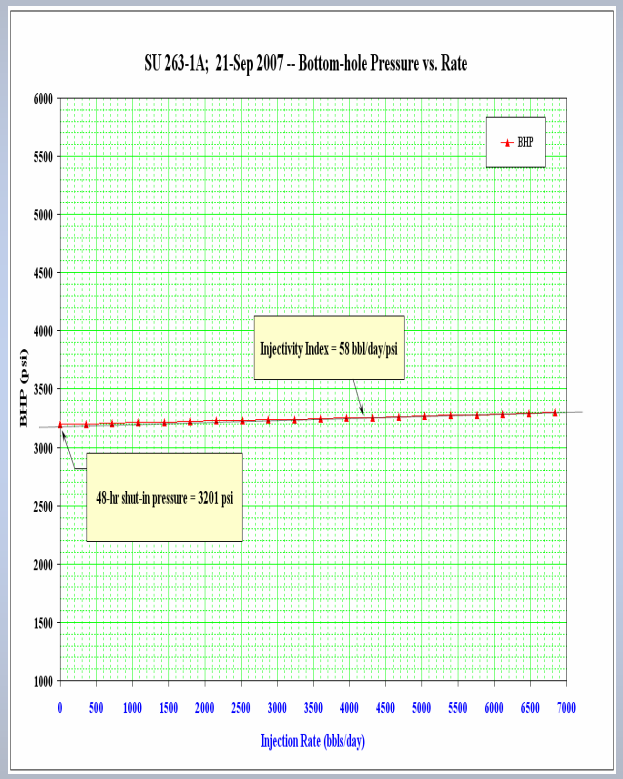
Step-Rate Test

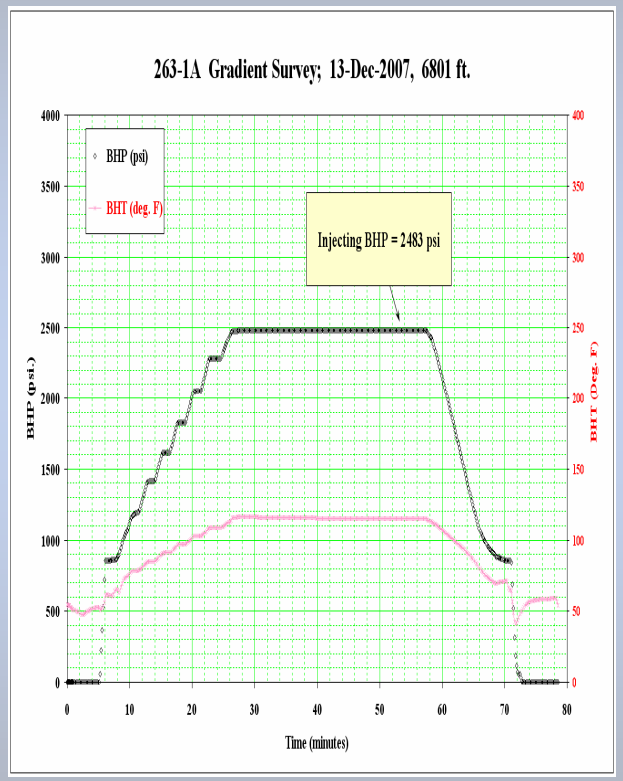




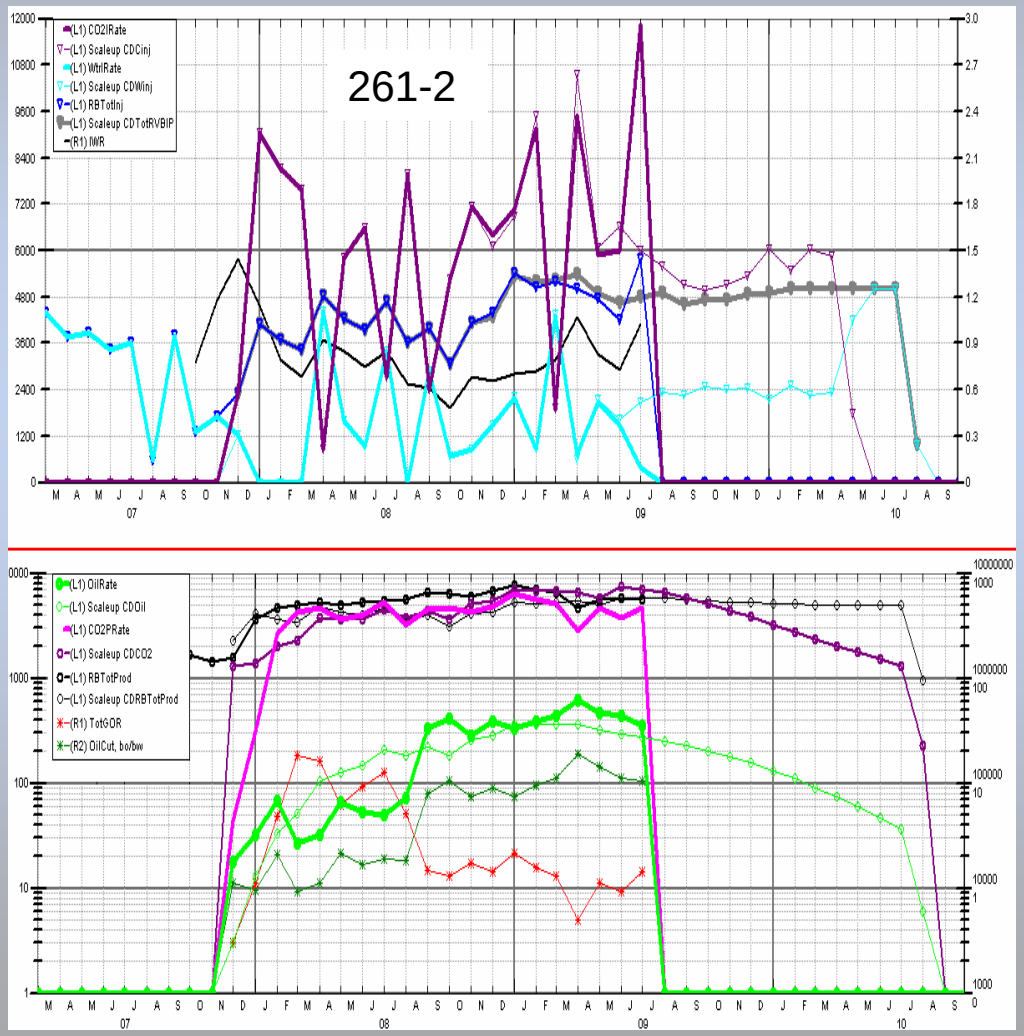
Areal Conformance

- Pressure & Rate re-balancing
- Attempts to viscosify CO_2 – Surfactant pilot project





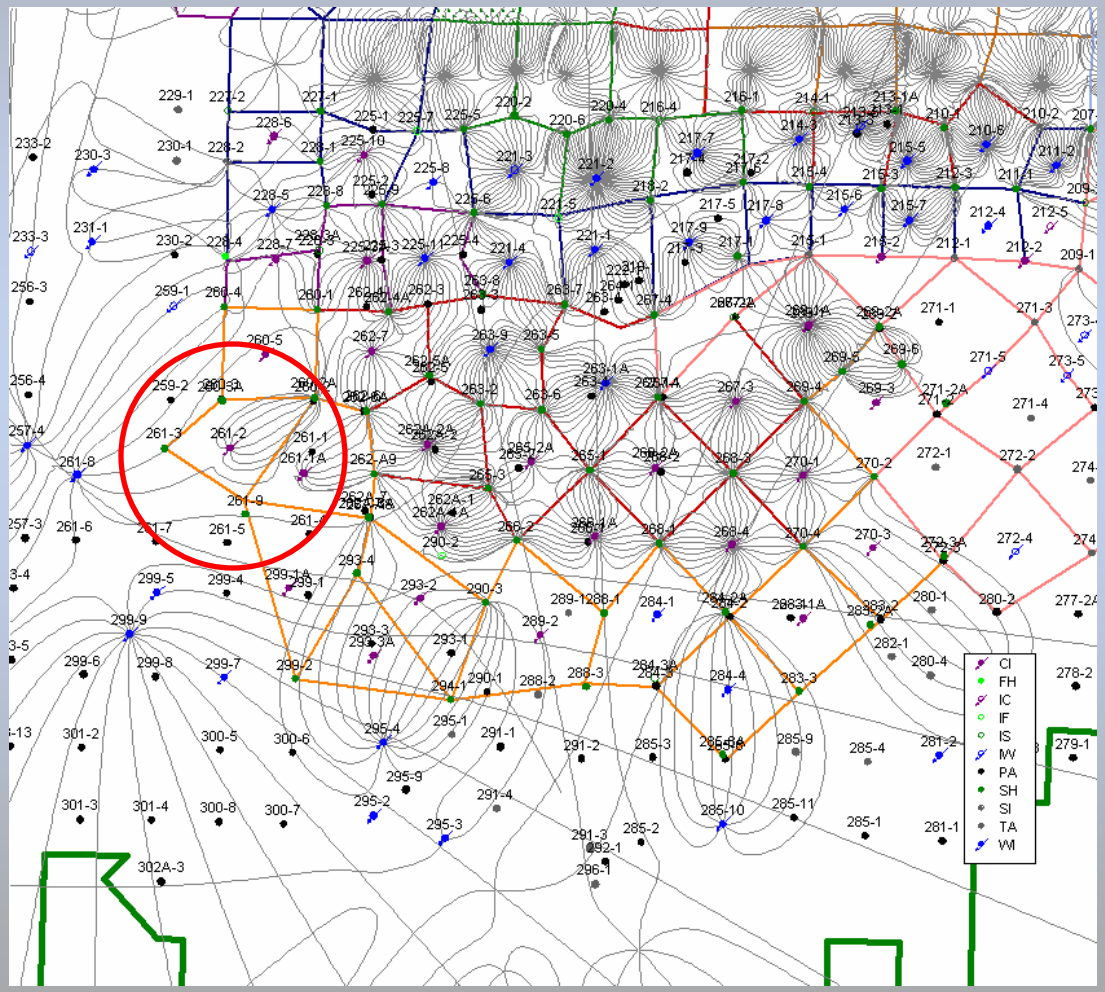
Examples of Pressure Re-balancing



Pattern production responded after 8 months drawdown of prior water curtain

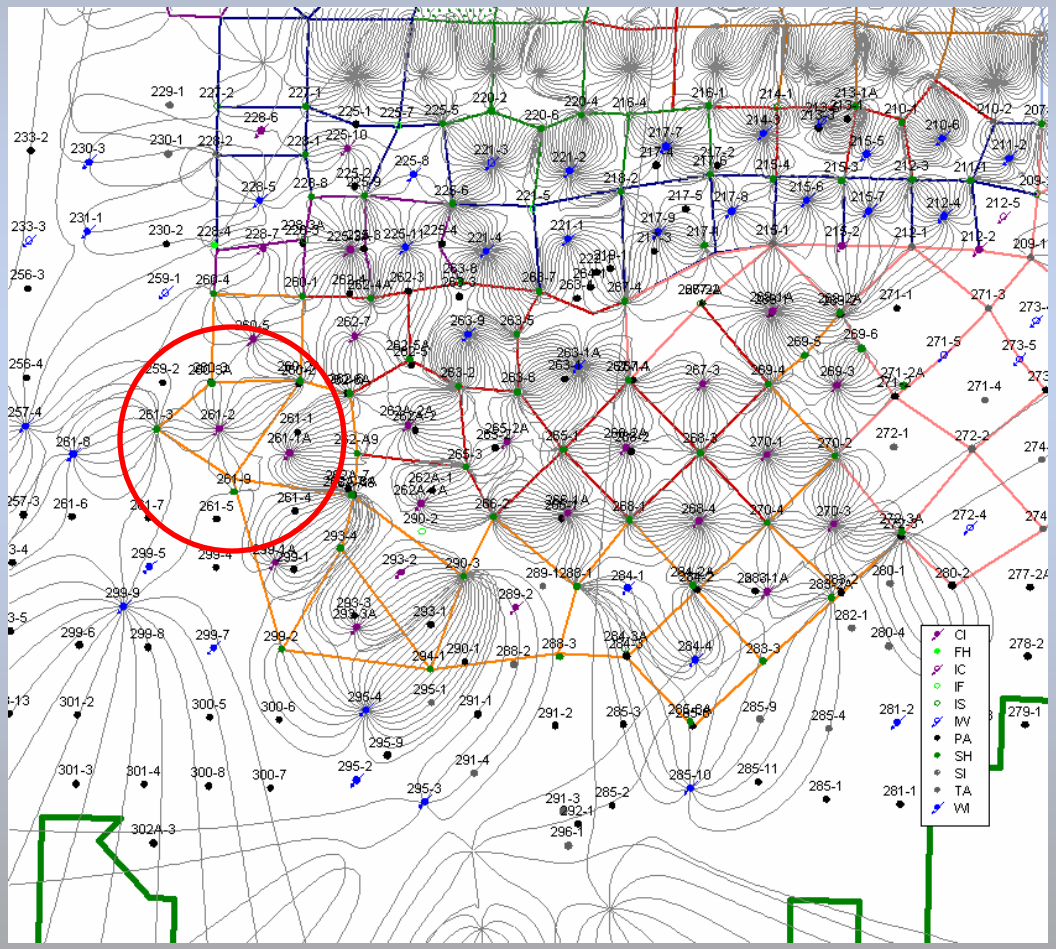
November 2007

Note streamlines show no support to 261-3

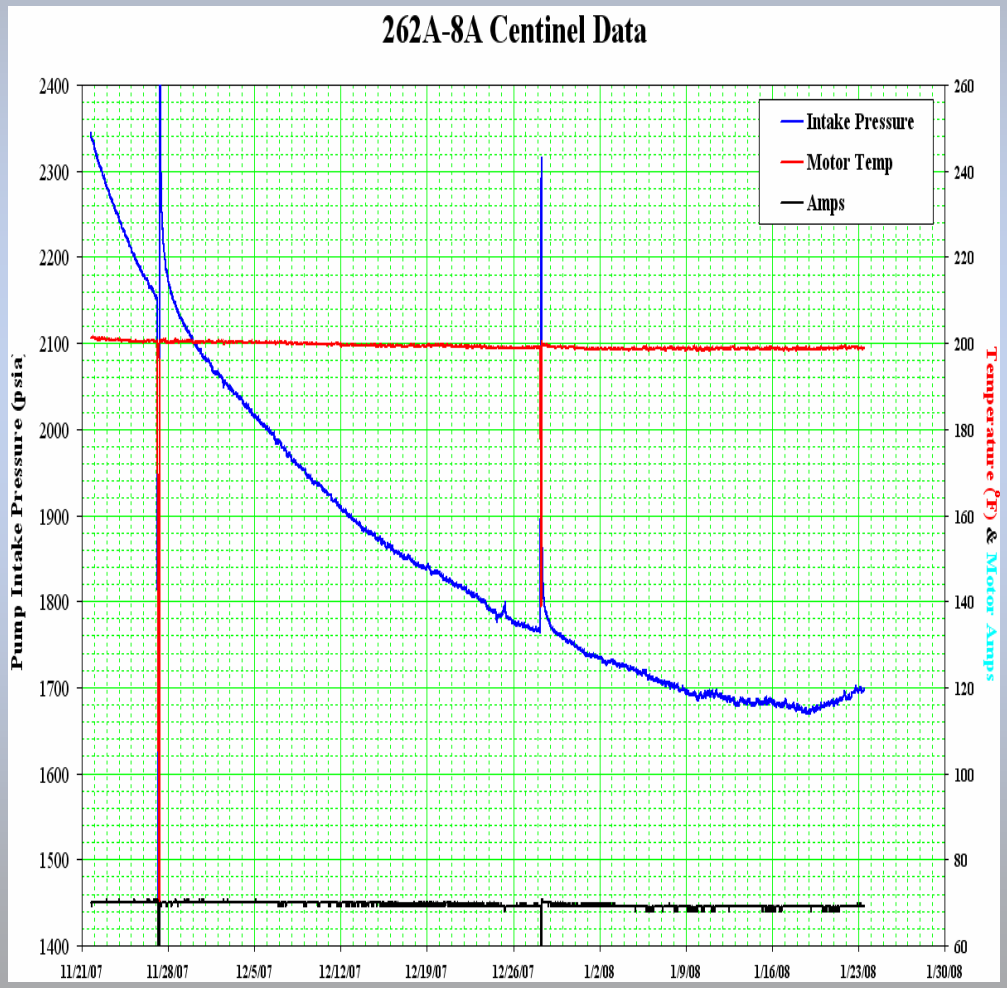


July 2008

Note streamlines now show 261-3 receiving support



BHP Monitoring



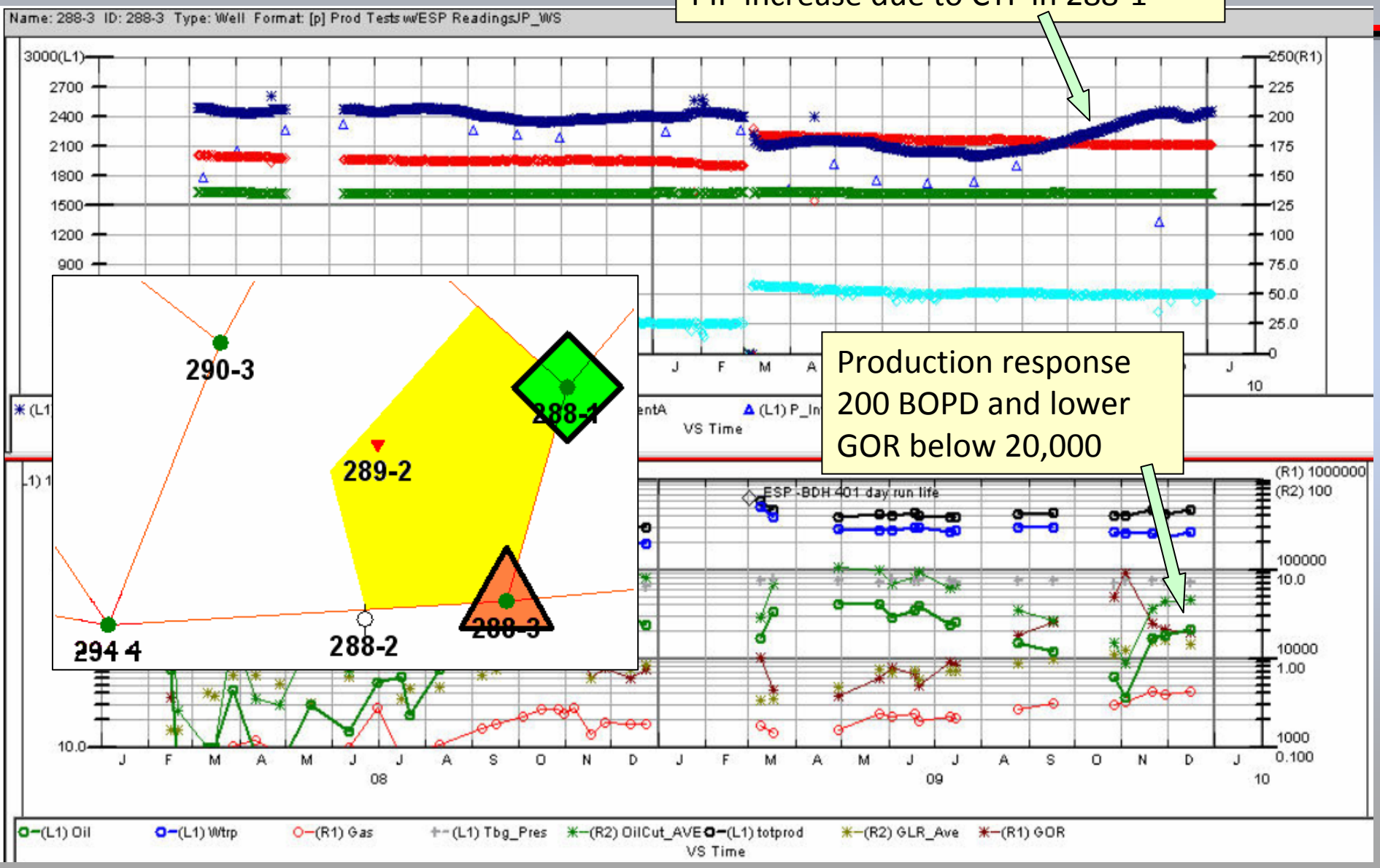
All ESP's are equipped to record P_{wf} and motor temp.

This data is available in real-time and can also be used to track reservoir pressure

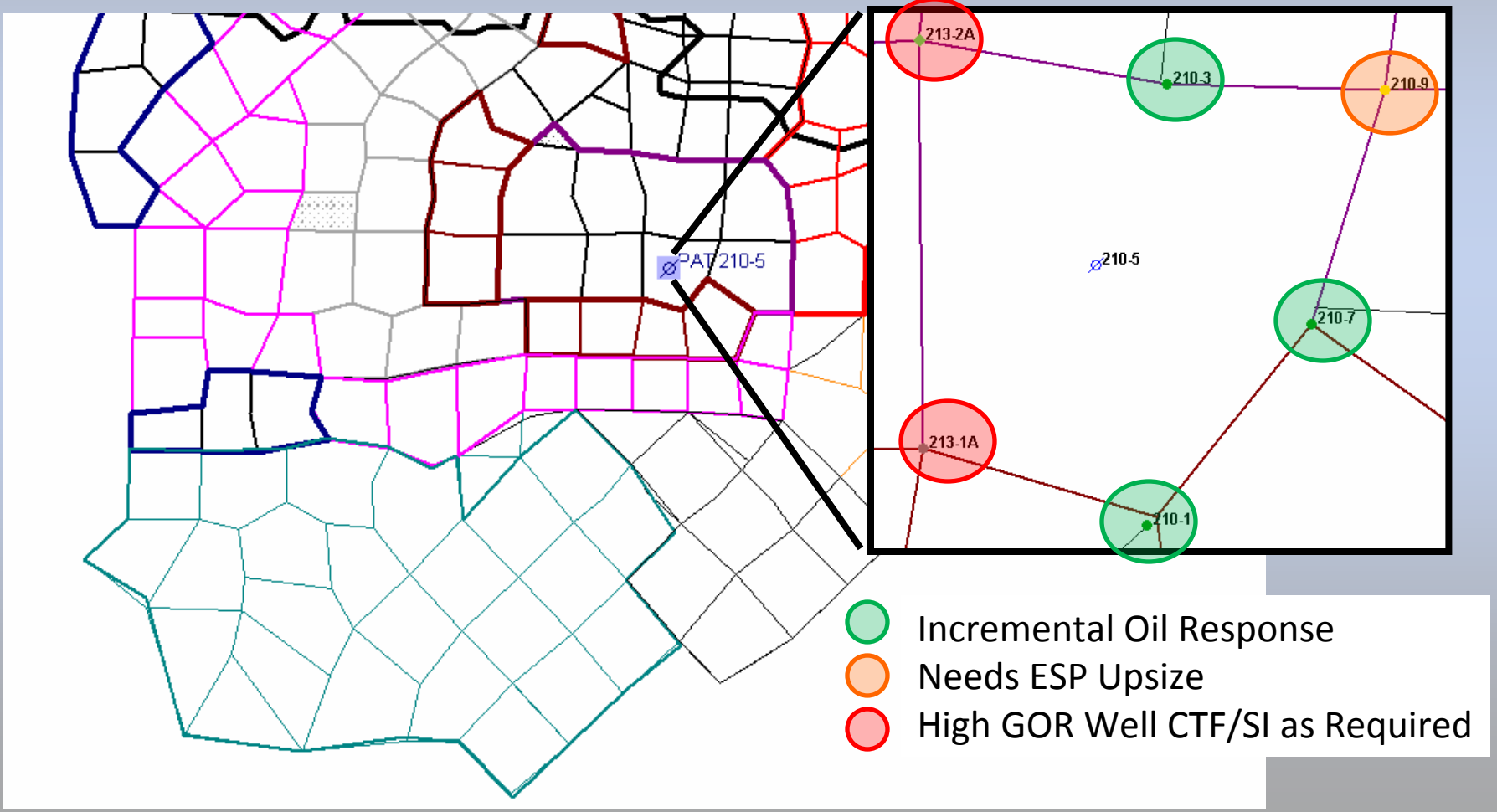
CTF Pressure & Rate Response in Offset Wells

PIP increase due to CTF in 288-1

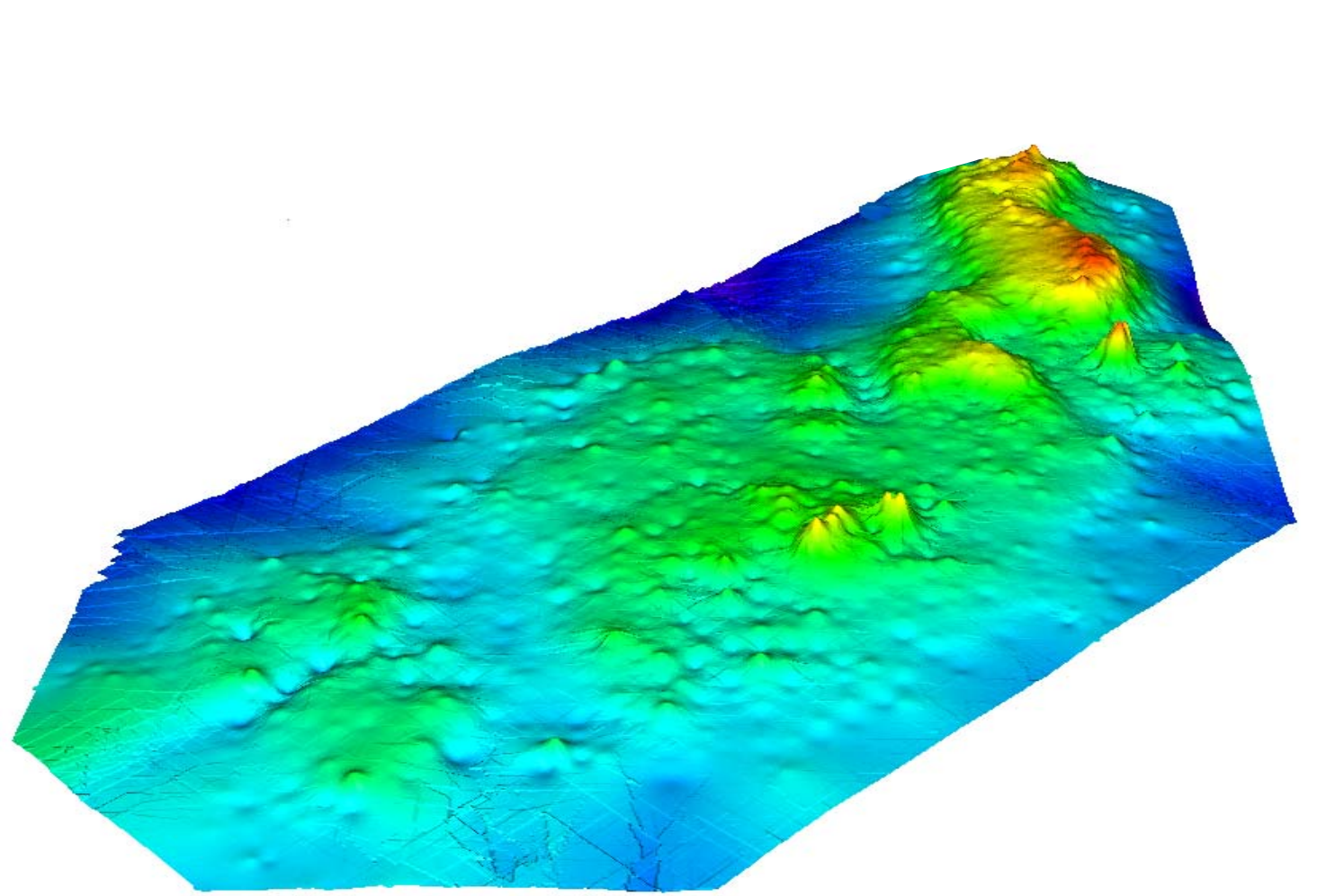
Production response 200 BOPD and lower GOR below 20,000



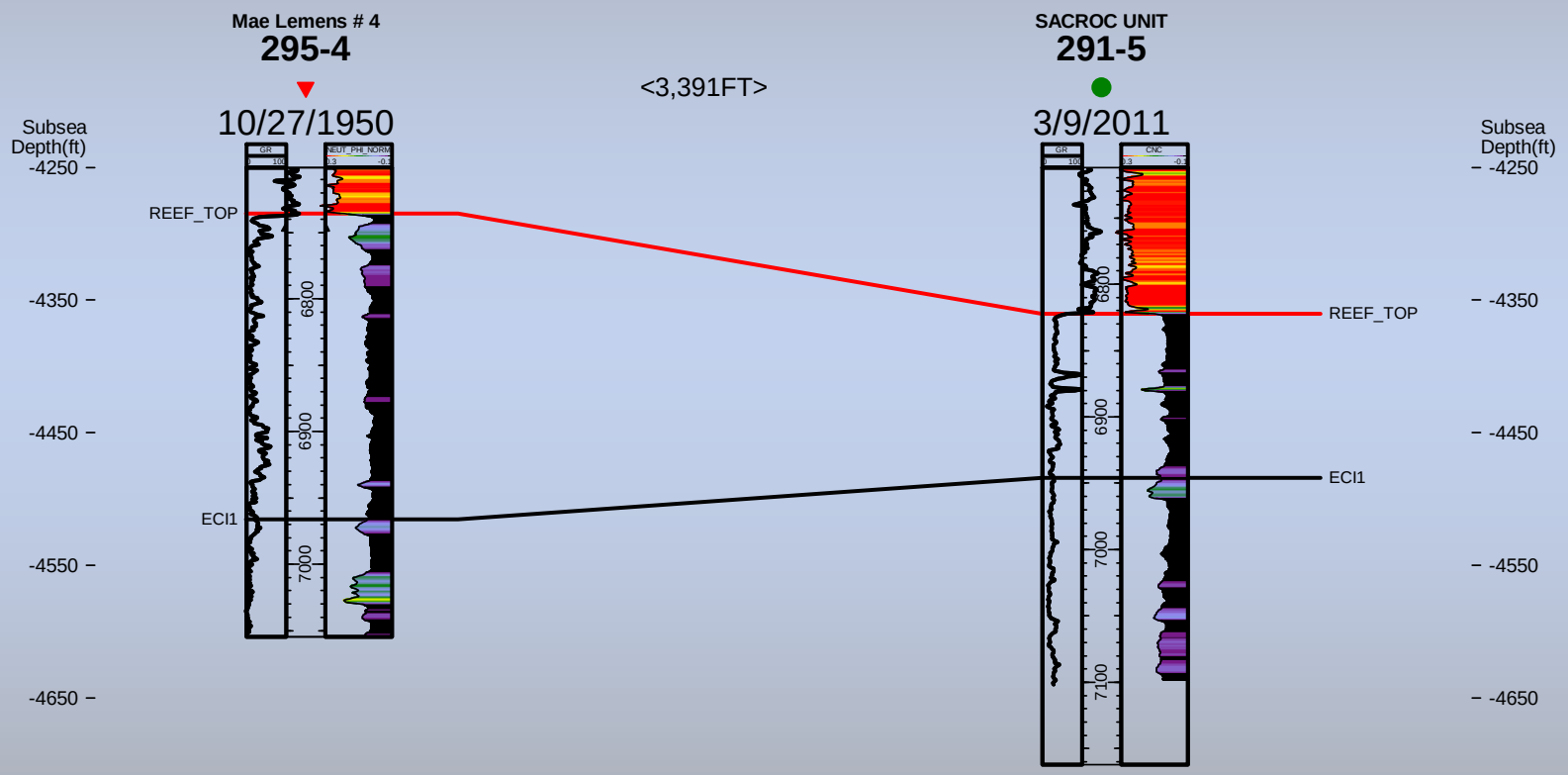
Pattern 210-5 Rebalancing



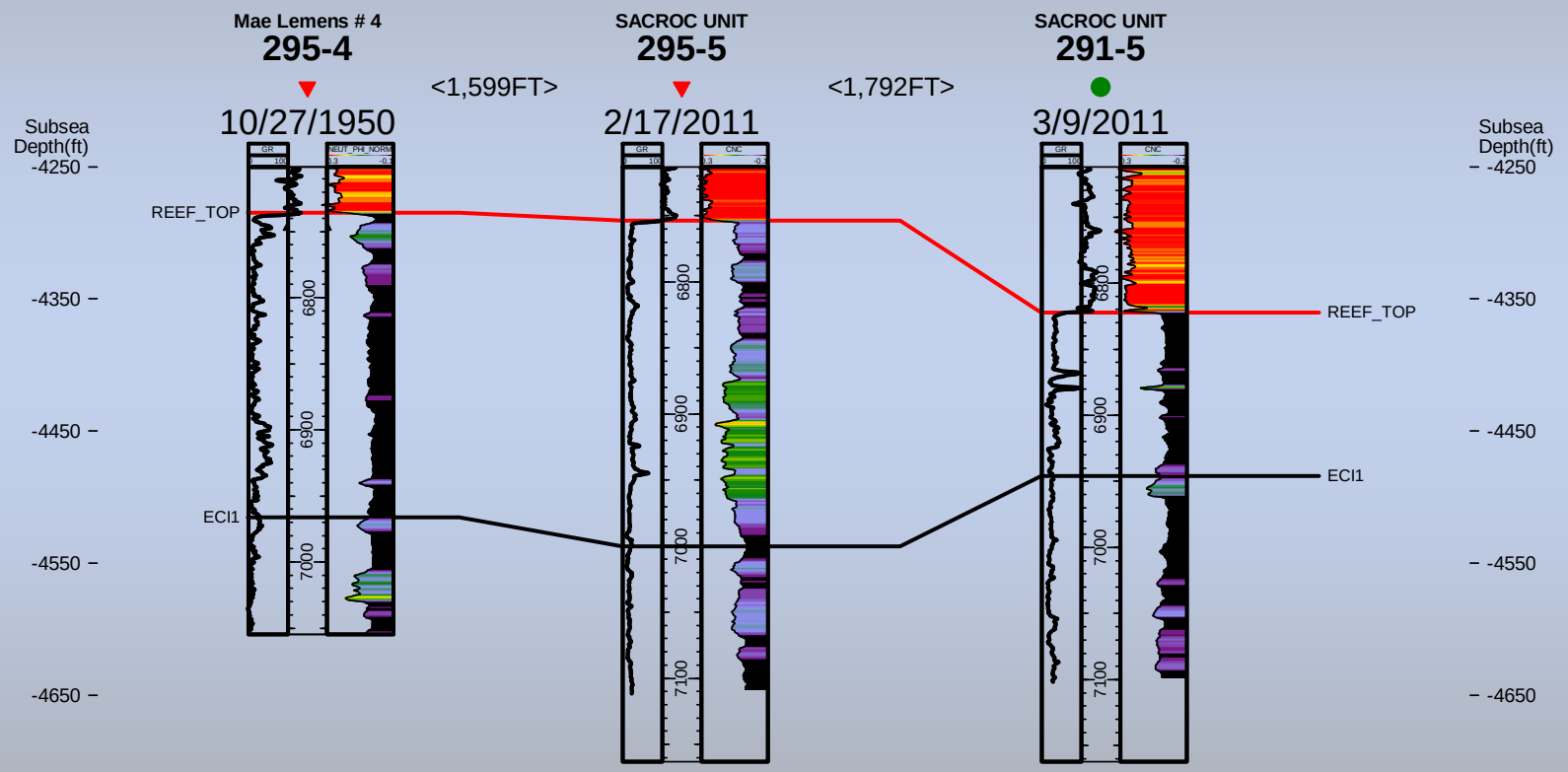
SACROC Unit Structure



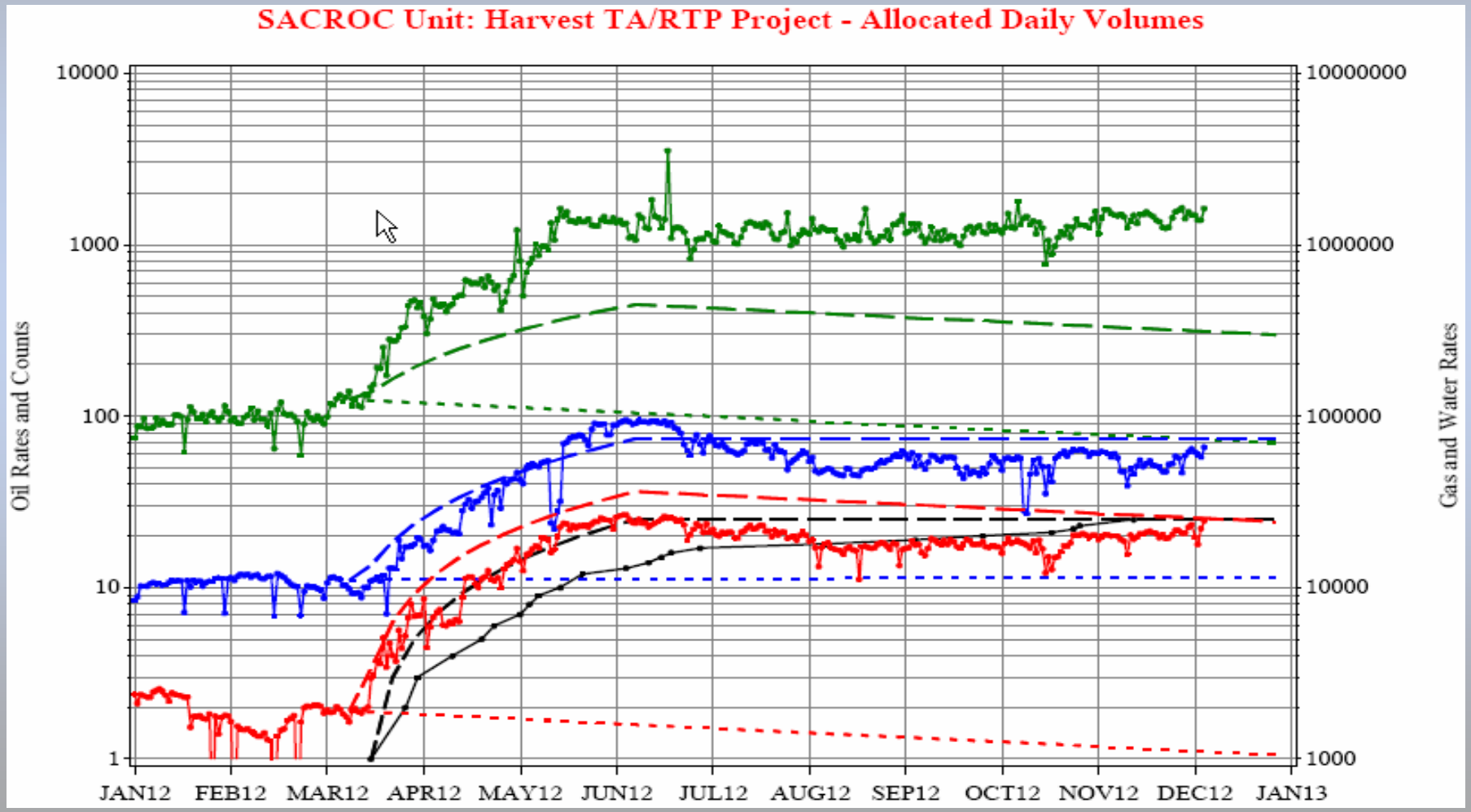
Un-Drained Pinnacles



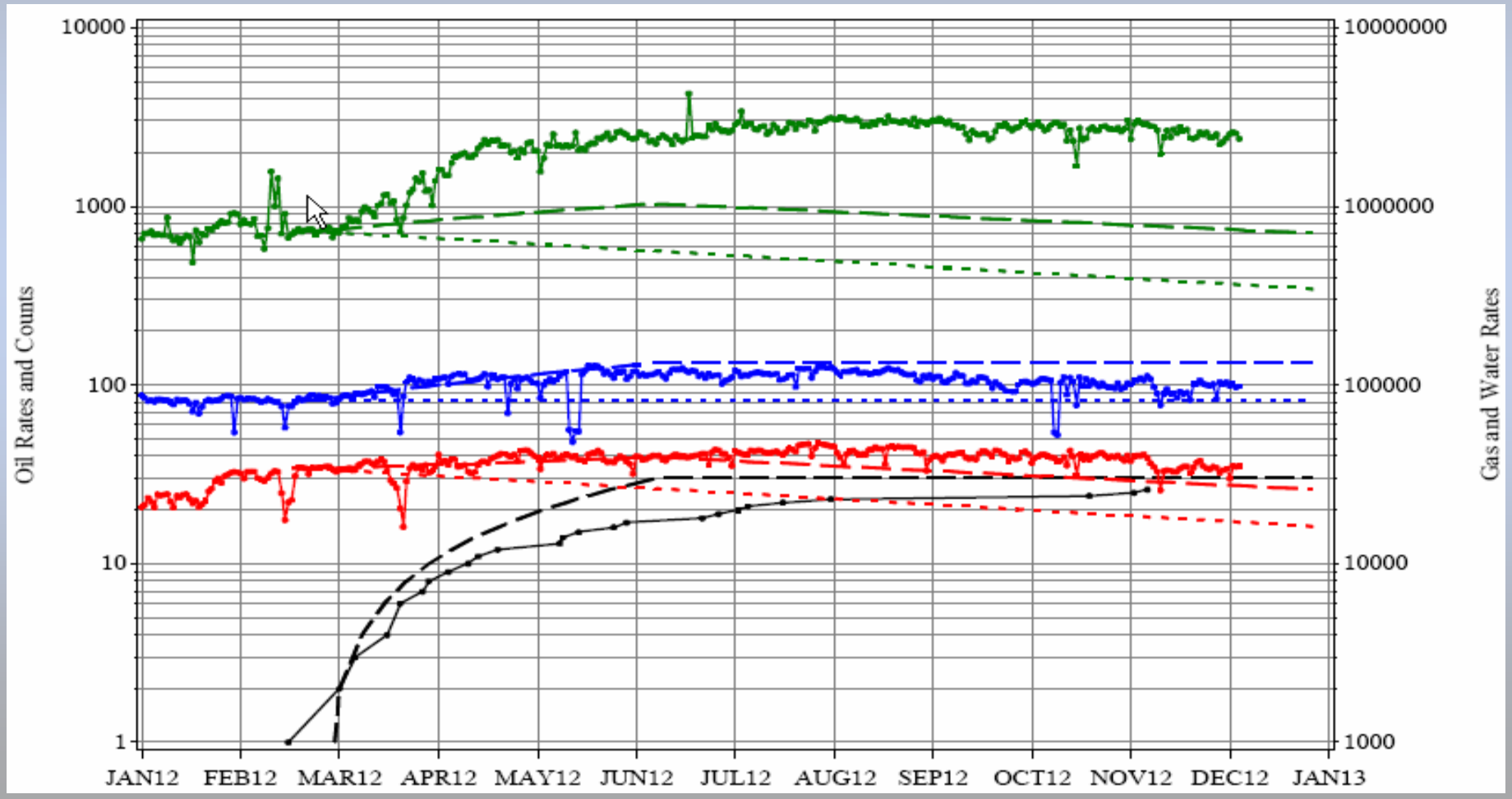
Un-Drained Pinnacles



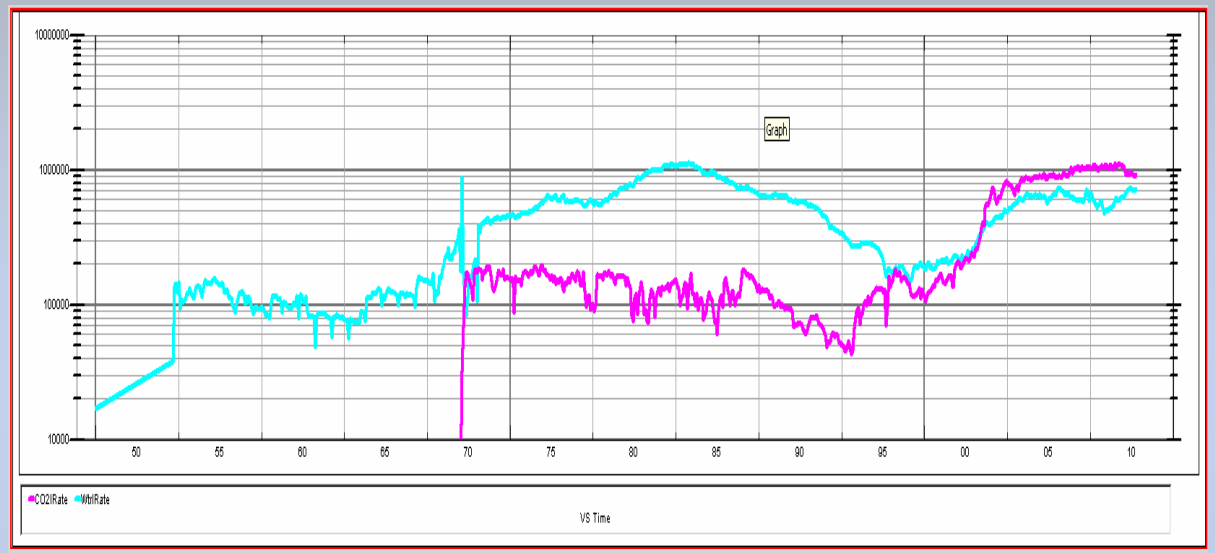
CO_2 "Harvest" -- RTP

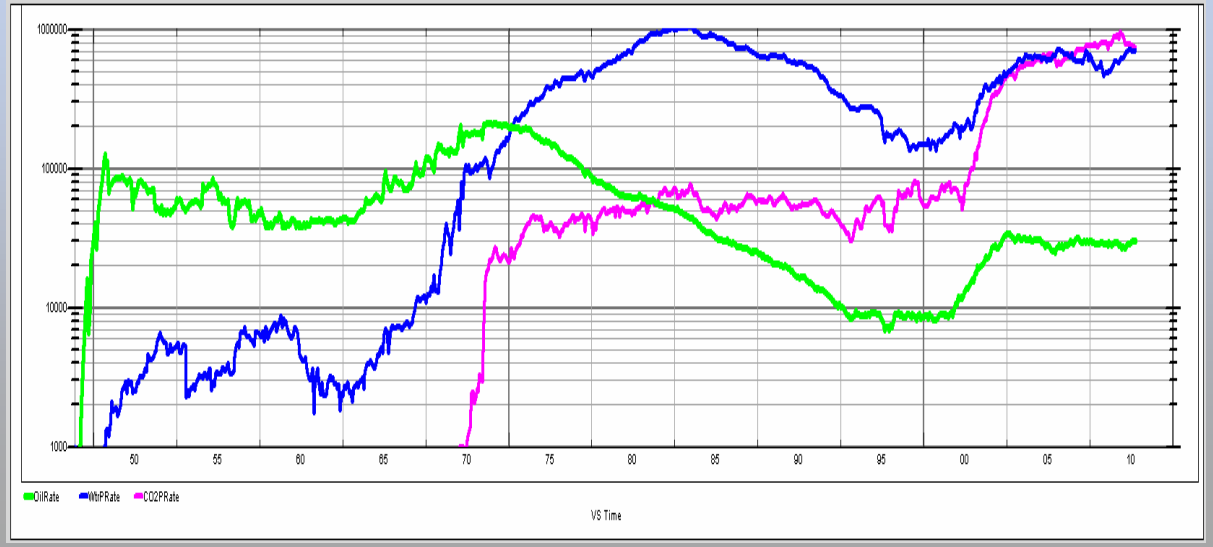


CO_2 "Harvest" -- Upsize



Production Response

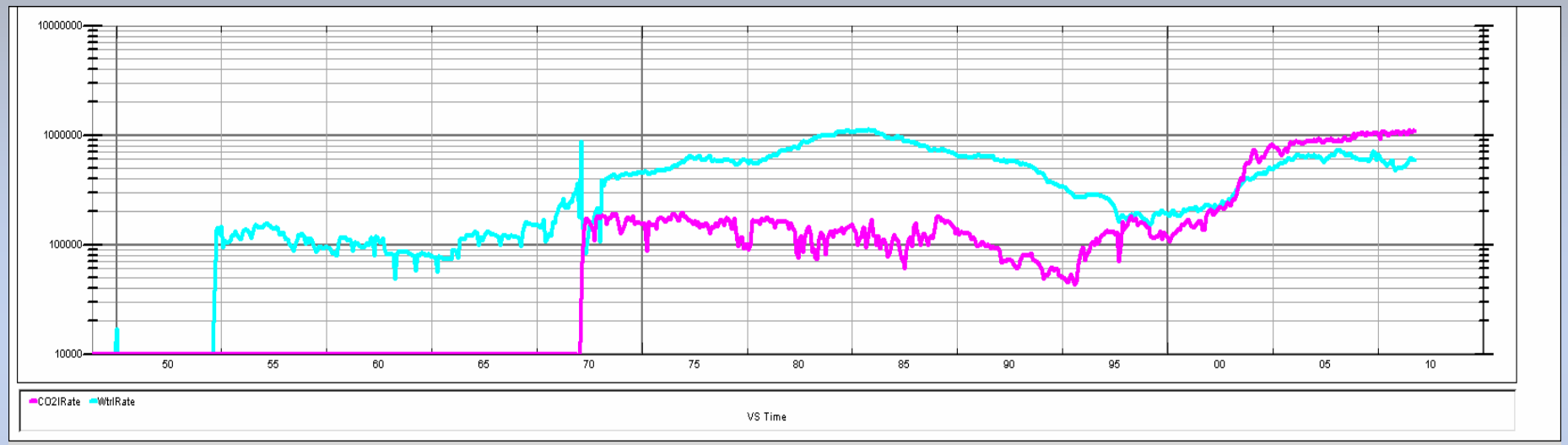


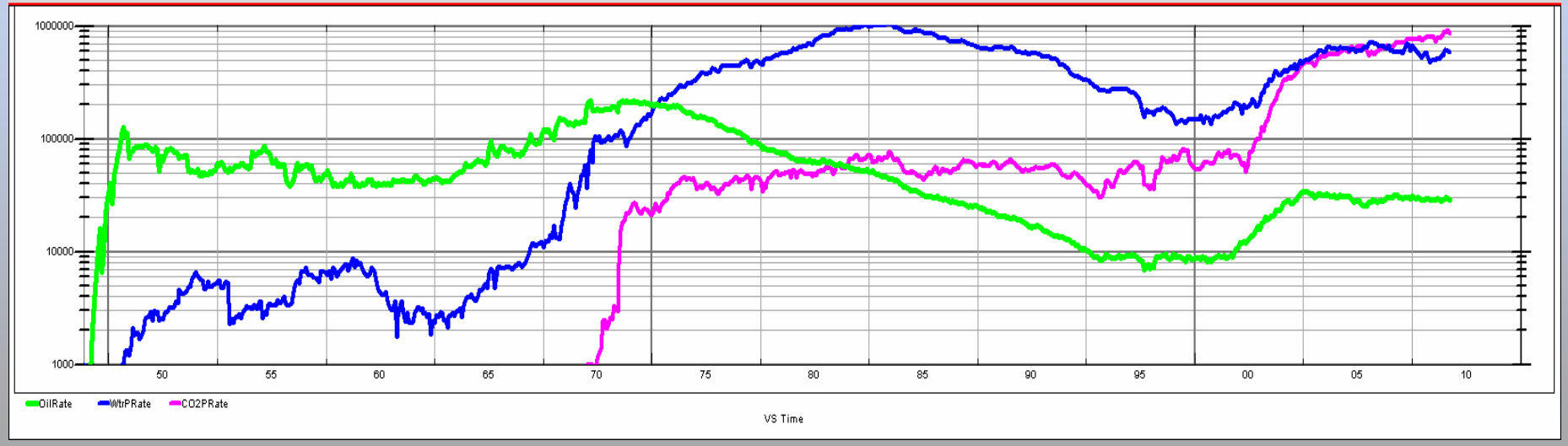


Oil production rate has increased from 8800 BOPD to the current 30,000 BOBD.

Cumulative incremental oil production since year 2001 now exceeds 110 MMSTBO

SACROC CO_2 Response





X

X

X

Layer by Layer Forecasting Process

- Using the historical injection profiles determine the fraction of injected CO_2 entering each layer, and from the injection rate determine the %HCPV CO2 injection with time into each layer
- From the generalized dimensionless recovery curves we calculate the dimensionless oil and CO_2 recoveries for each layer
- The Oil recovery equation "A" value is set to 15% initially, but it occasionally requires changing to "history match" performance
- Calculate the oil and CO2 production rates from the layer allocated CO_2 injection rate and the oil & CO_2 recovery derivatives
- Sum the layer oil & CO_2 production rates to get the pattern oil & CO_2 production. Calculate the water production by material balance

Outline

- Field History
  - Geologic Setting
  - Key Statistics
  - Production History
- The Opportunity
- The Challenge
  - Operational Changes
  - Monitoring
  - Rate Re-Balancing
  - Conformance