SACROC CO_2 Flood Project Challenges: Past, Present, and Future

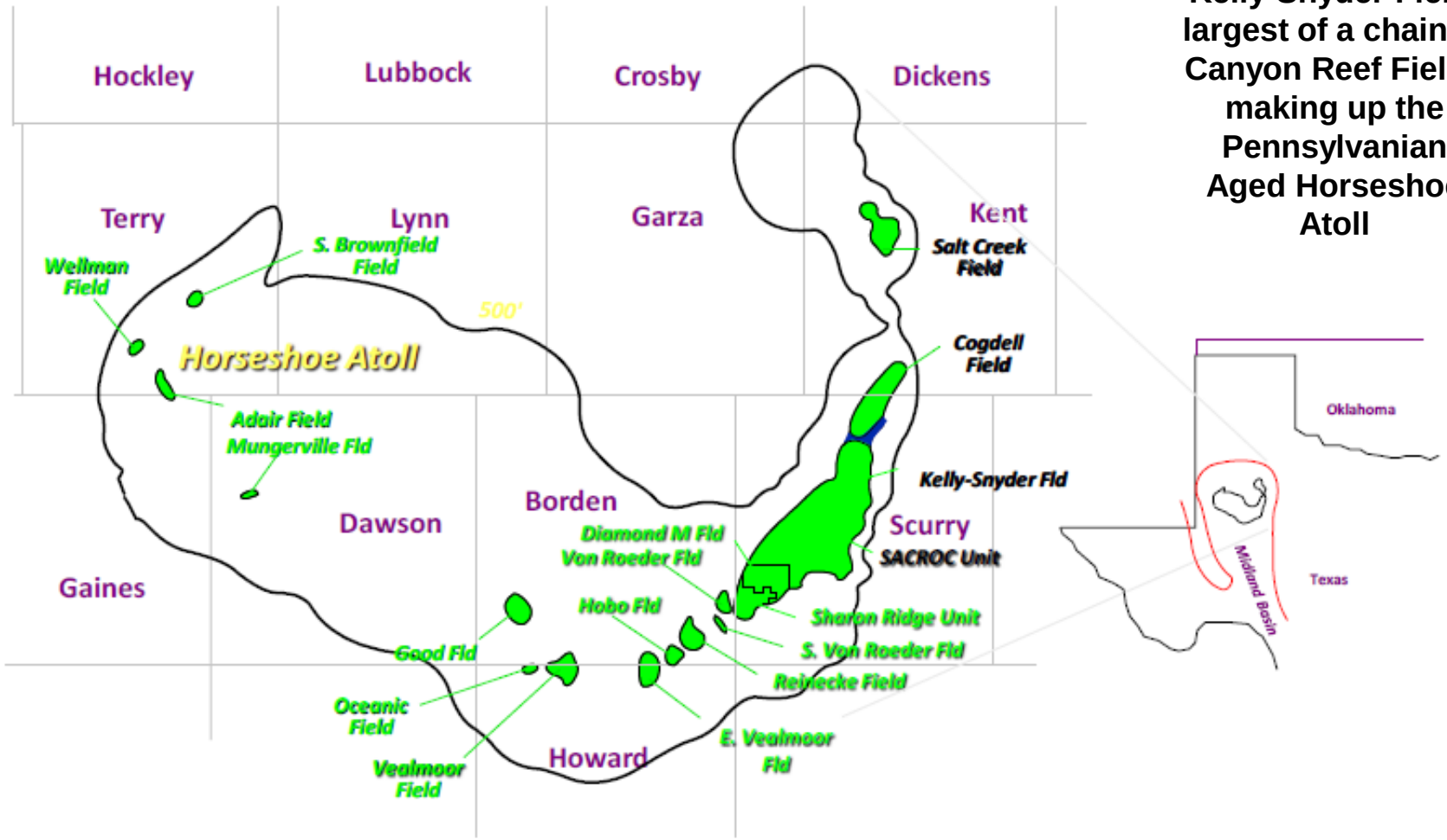
Presented at the 19th Annual CO_2 Flooding Conference

December 11-13, 2013

Midland, Texas

SACROC Location Map

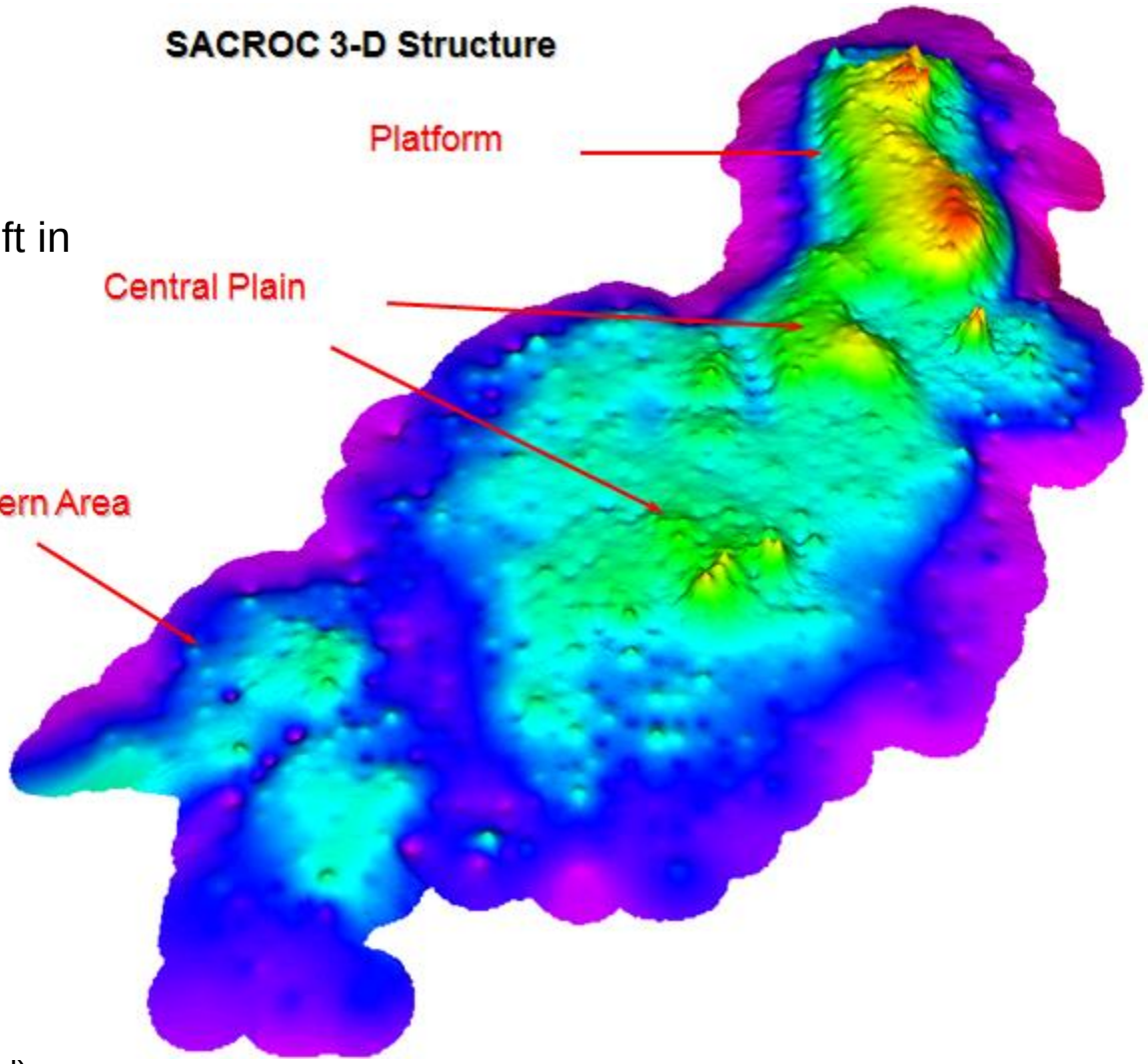
SACROC is in the Kelly-Snyder Field, largest of a chain of Canyon Reef Fields making up the Pennsylvanian Aged Horseshoe Atoll



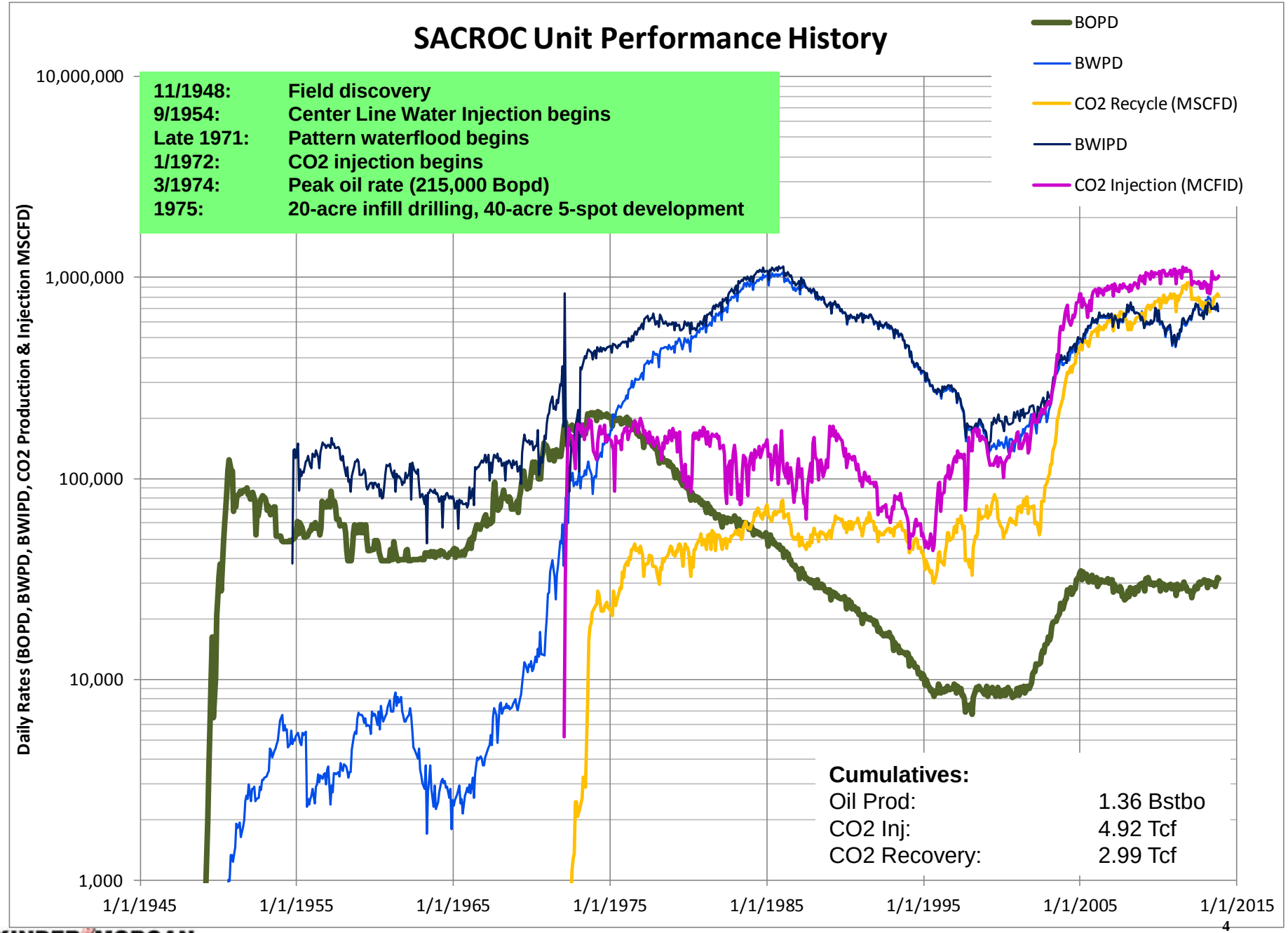
Modified from Vest (1970)

SACROC Unit Information

- Field discovery 11/1948
- Productive area: 49,980 acres
- Formation: Canyon Reef
- OOIP: 2,800 MMSTBO
- Oil column thickness: up to 900 ft in Platform
- Average depth: 6800’
- Discovery pressure: 3122 psi
- Oil gravity: 42 API
- HC GOR:
  - Original: 1000 Scf/Stbo
  - CO2 Flood: 2600 Scf/Stbo
- Rich gas, 230 Bbls NGL/Mmscf HC gas
- Total CO2 Flood Gas GOR: 28,000 Scf/Stbo
- 11/2013 Production & Injection:
  - 31,900 BOPD
  - 18,900 BPD NGL
  - 1,040 MMSCFID CO2 (90% Recycled)



SACROC Unit Performance History



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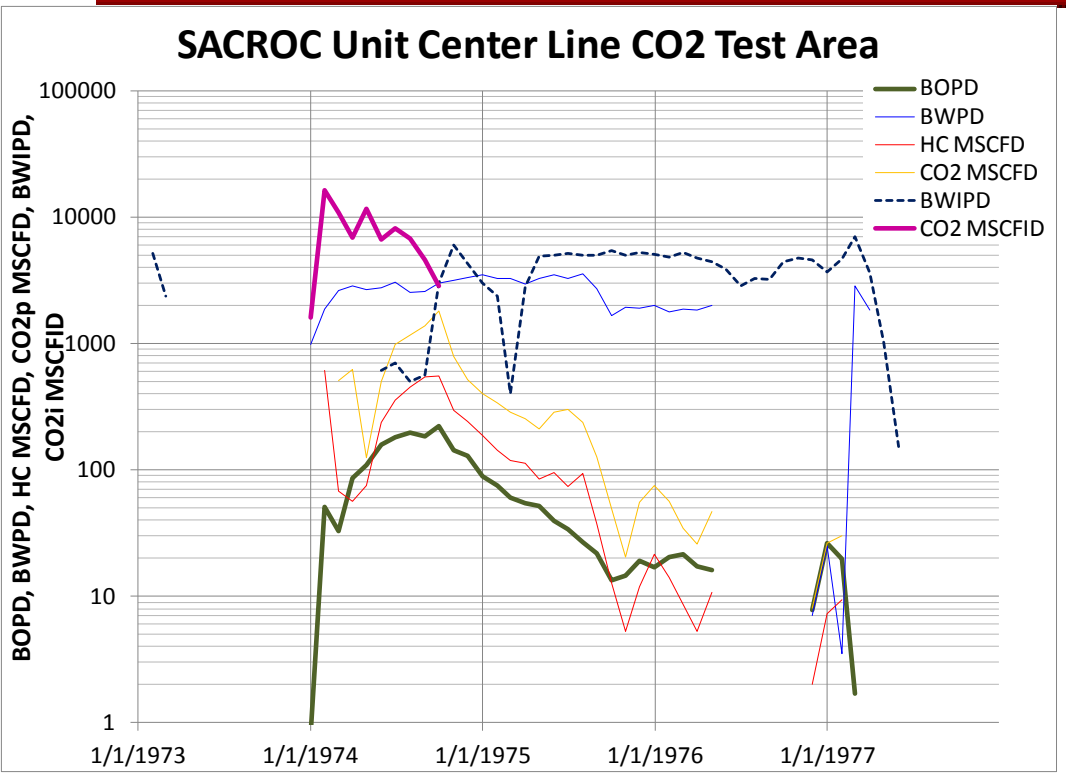
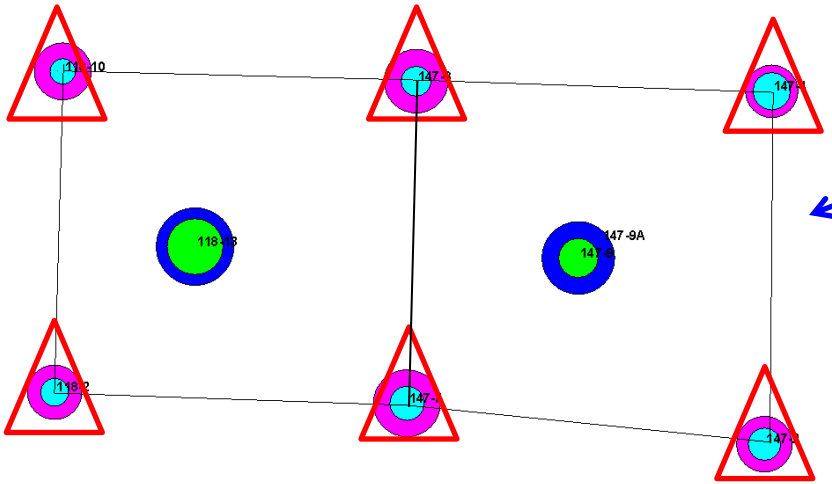
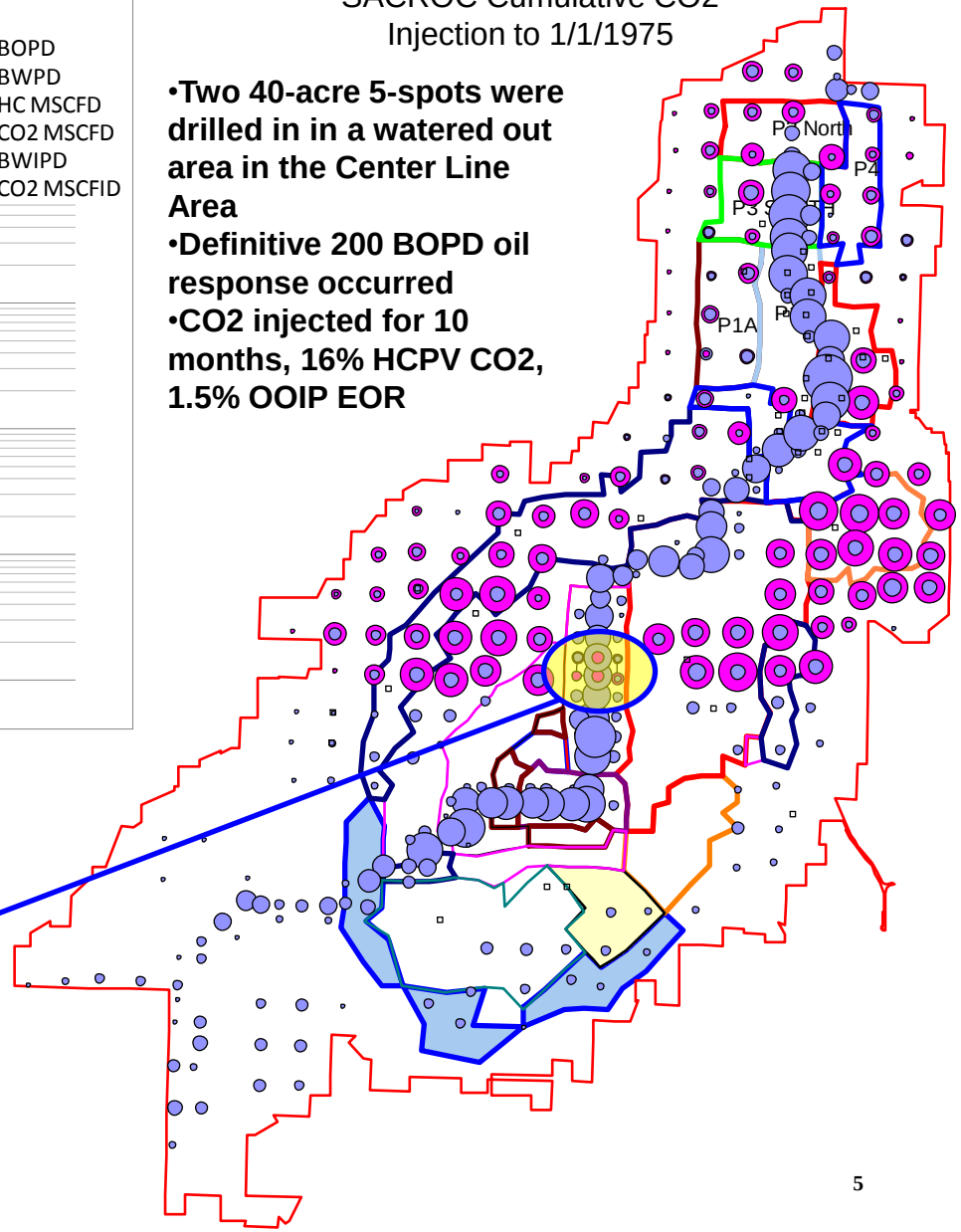
SACROC 1974 Center Line CO2 Injection Test Patterns



SACROC Cumulative CO2 Injection to 1/1/1975

- **Two 40-acre 5-spots were drilled in in a watered out area in the Center Line Area**
- **Definitive 200 BOPD oil response occurred**
- **CO2 injected for 10 months, 16% HCPV CO2, 1.5% OOIP EOR**

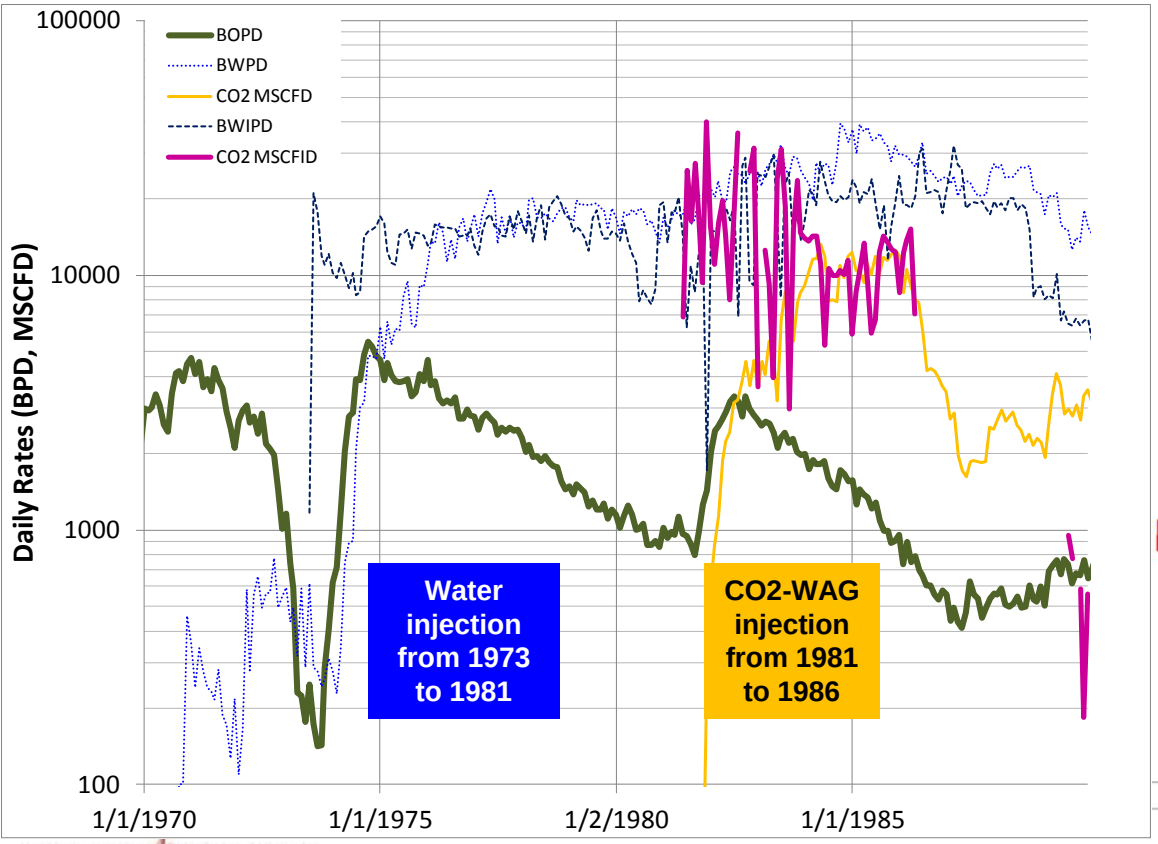


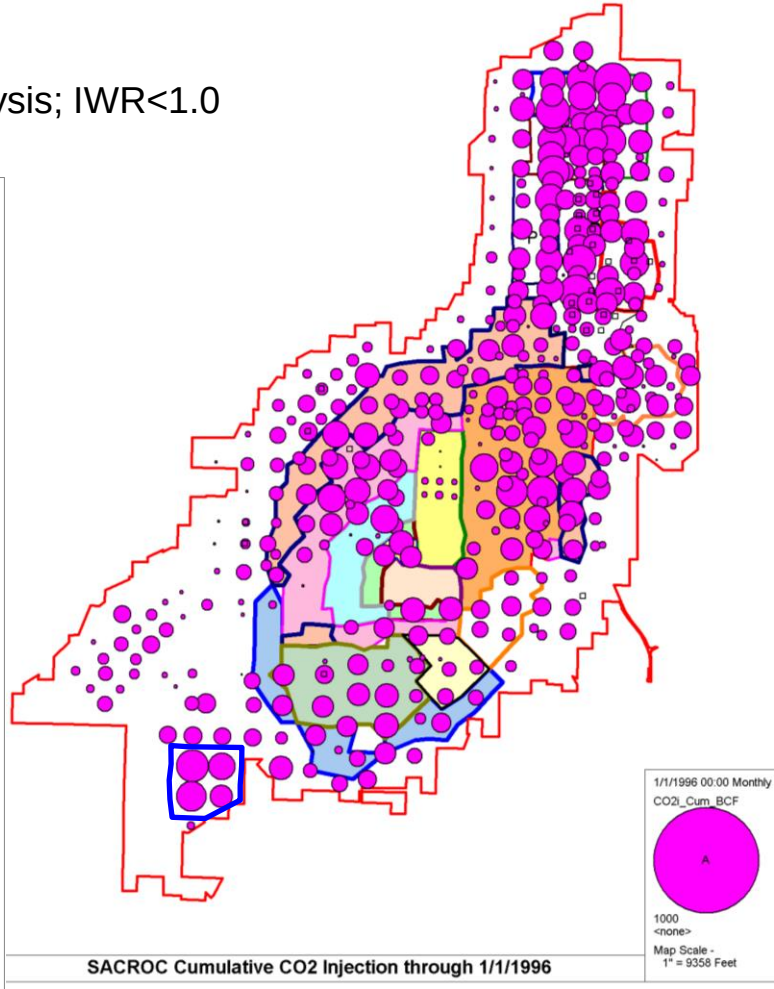


SACROC 4-Pattern Area CO2 Flood Pilot

- Pilot conducted in south part of Unit ahead of the CO2 injection expansion into the south of the Unit
- Pilot made up of four ~160-acre inverted 9-spot patterns
- 2000 BOPD+ of definitive oil response
- EOR was 10% of OOIP after 30% HCPV CO2 injection
- However, oil influx from outside project area complicates analysis; IWR<1.0

Cumulative CO2 Injection Bubble Map through January, 1996





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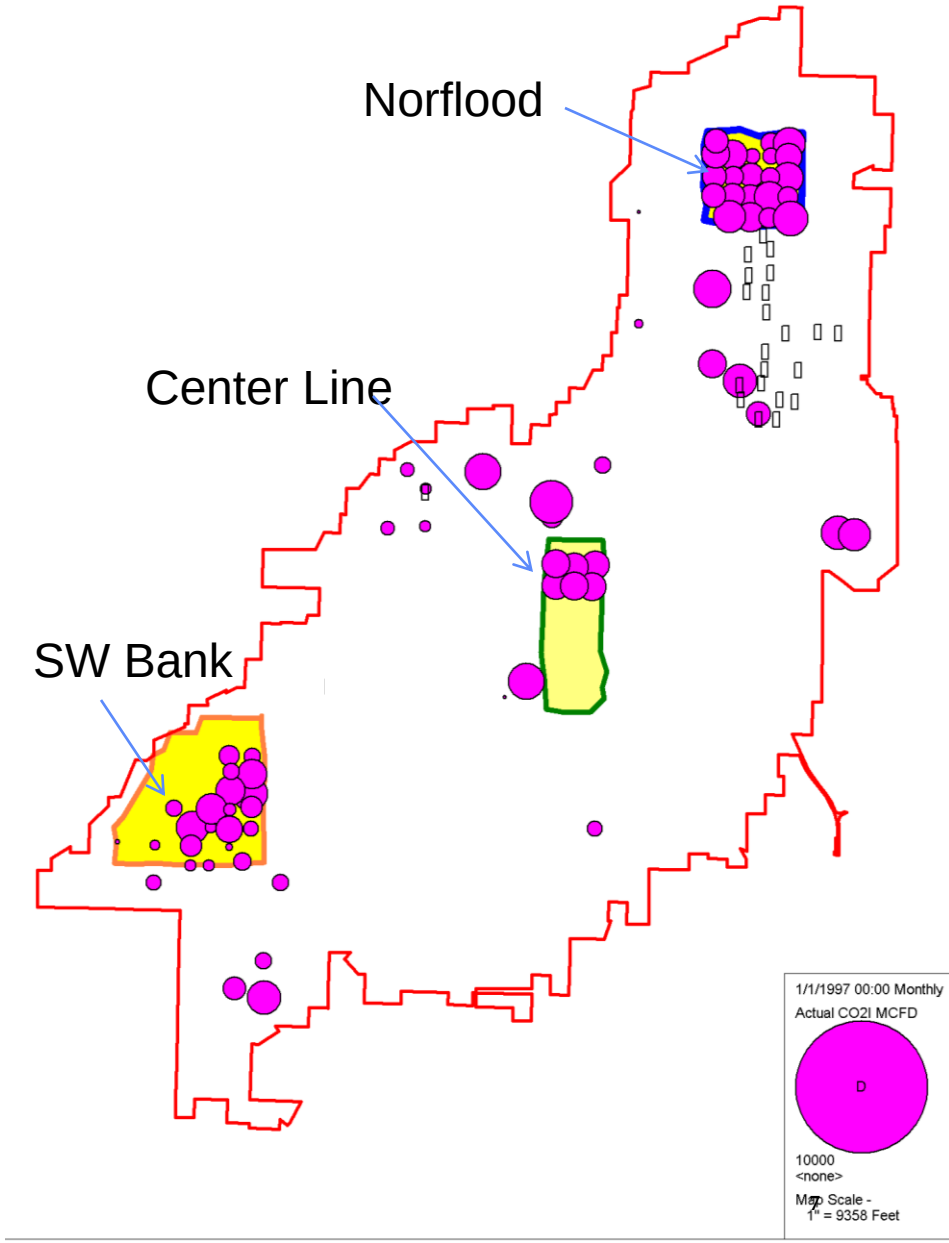
SACROC Early 1997 CO2 Injection Focusing on Center Line, Norflood, & SW Bank Redevelopment Projects

- Pennzenergy suspected that SACROC hadn't been effectively CO2 flooded
  - Other West Texas projects beginning CO2 injection in the 1980's and 1990's had exhibited significant CO2 Flood EOR Wedges
  - SACROC's CO2 injection had been conducted using high WAG ratios, sometimes below MMP

- Three focused CO2 flood test areas were initiated:
  - Norflood
    - Focused on low permeability Middle Canyon
  - Southwest Bank
    - Focused CO2 injection in lower permeability reservoir
  - Center Line
    - Focused 40-acre 5-spot pattern development



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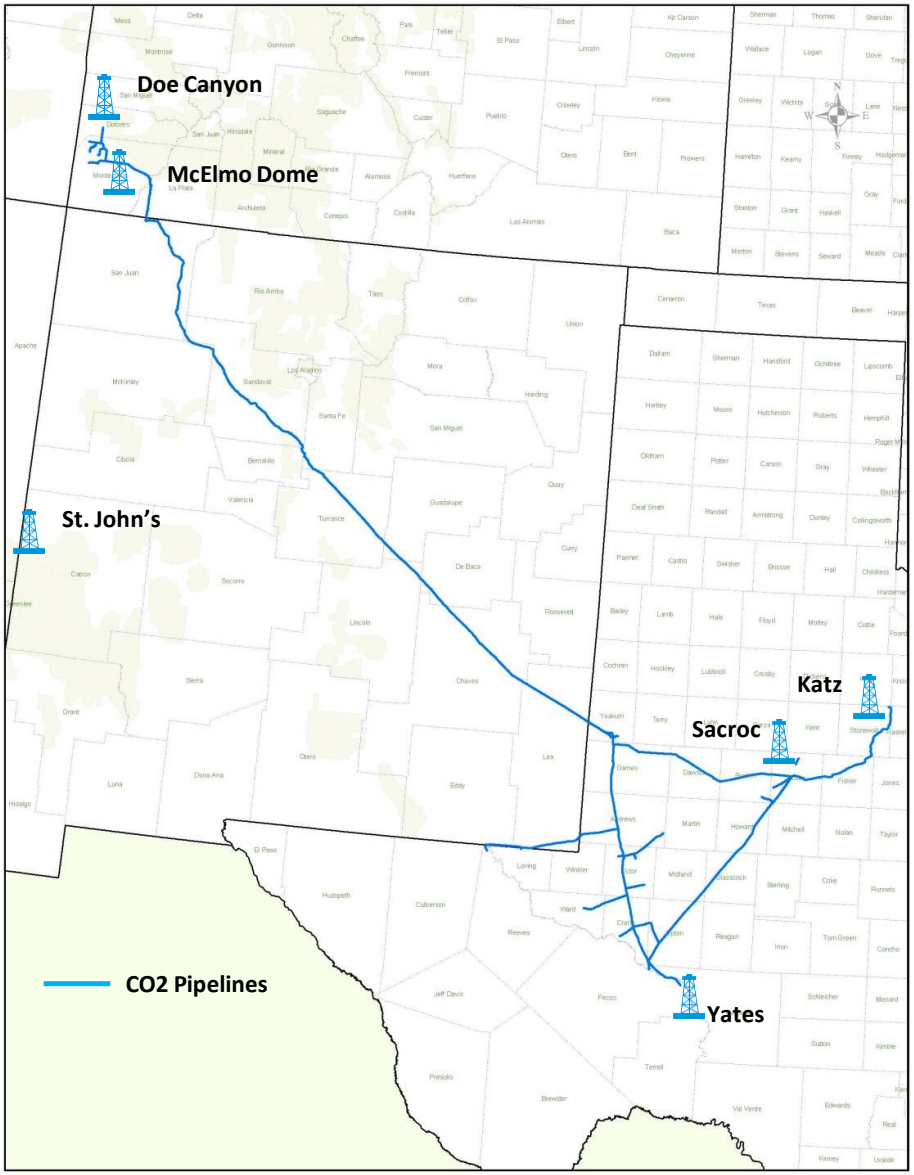
Initial KM CO2 Flood Redevelopment

- KM Purchased SACROC in 2000
- Expanded upon Pennzenergy's successful Center Line CO2 flood project
- KM expanded its CO2 pipeline infrastructure in 2003 by installing the Centerline Pipeline to deliver another 300 MMSCFD to the SACROC area and beyond



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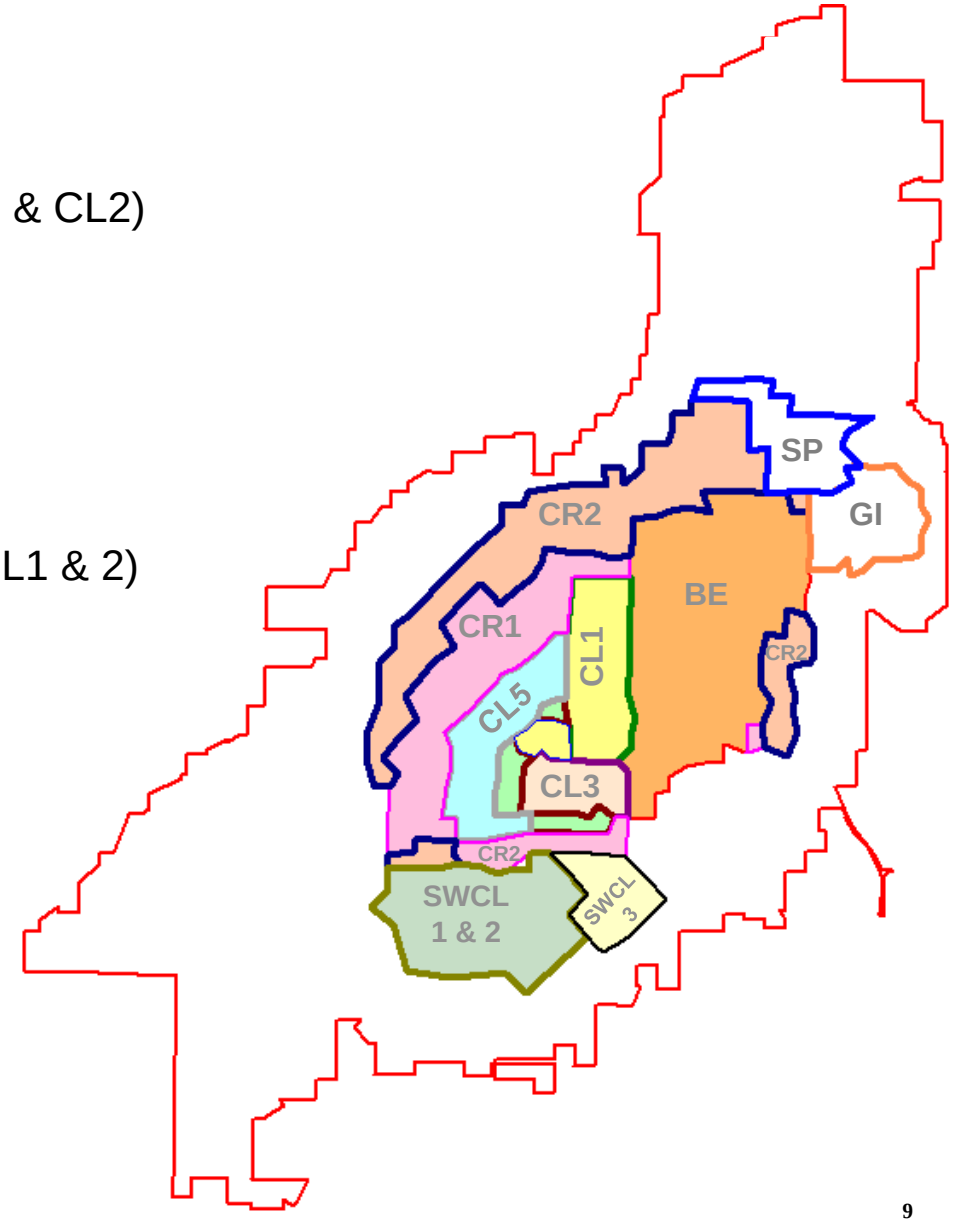
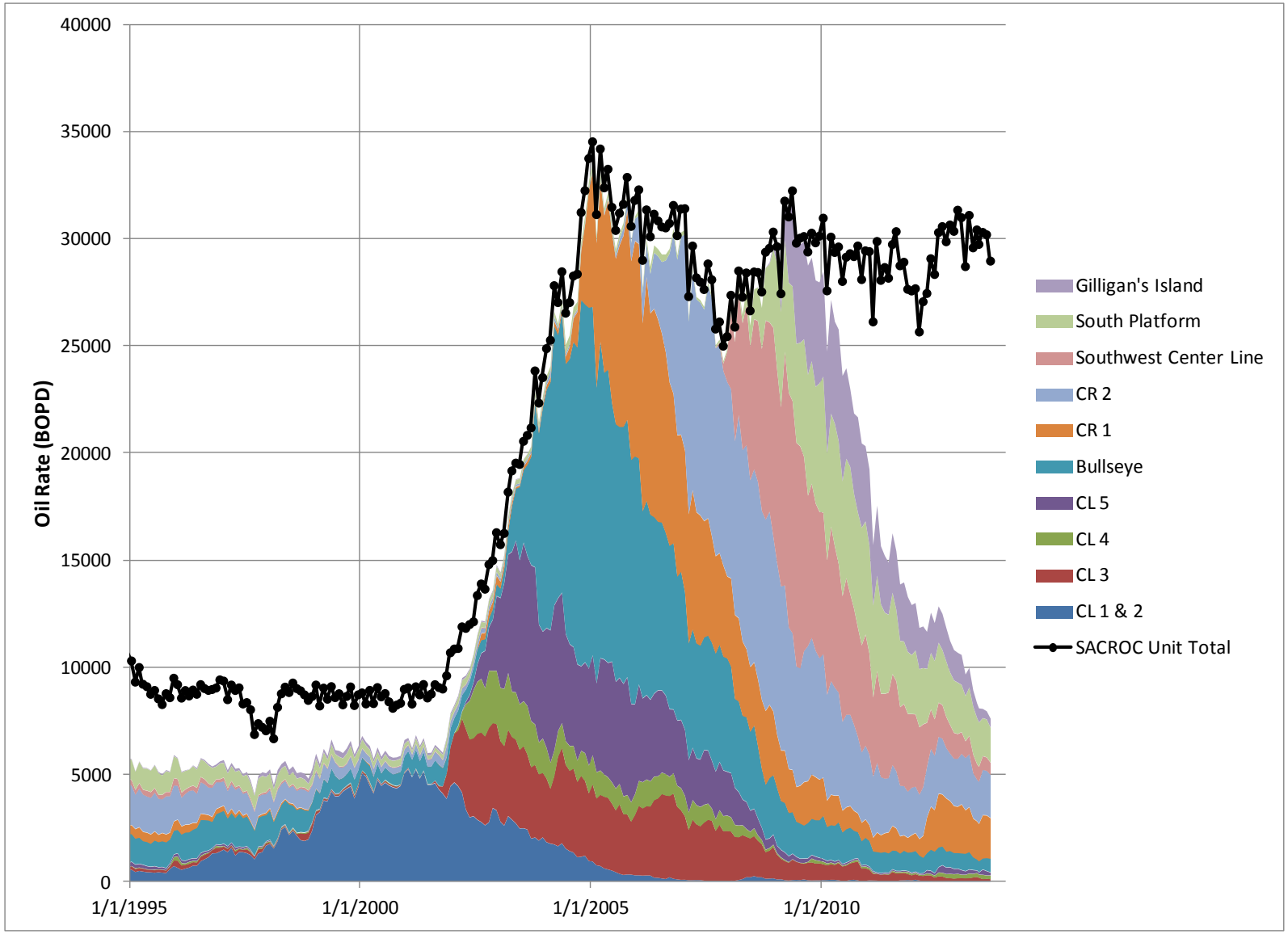
SACROC CO2 Flood Redevelopment Project Areas 1996-2008

Year	Project
1996:	Center Line 1 & 2 Expansions (CL1 & CL2)
2001:	Center Line 3 (CL3)
2002:	Center Line 4 (CL4)
2002:	Center Line 5 (CL5)
2003:	Bull's Eye (BE)
2004:	Center Ring 1 (CR1)
2005:	Center Ring 2 (CR2)
2007:	Southwest Center Line 1 & 2 (SWCL1 & 2)
2008:	Southwest Center Line 3 (SWCL3)
2008:	Gilligan's Island (GI)
2008:	South Platform (SP)

Platform development was deferred until all of the Central Plain areas were completed.



1996-2008 CO2 Flood Project Area Contribution to Total Unit Production



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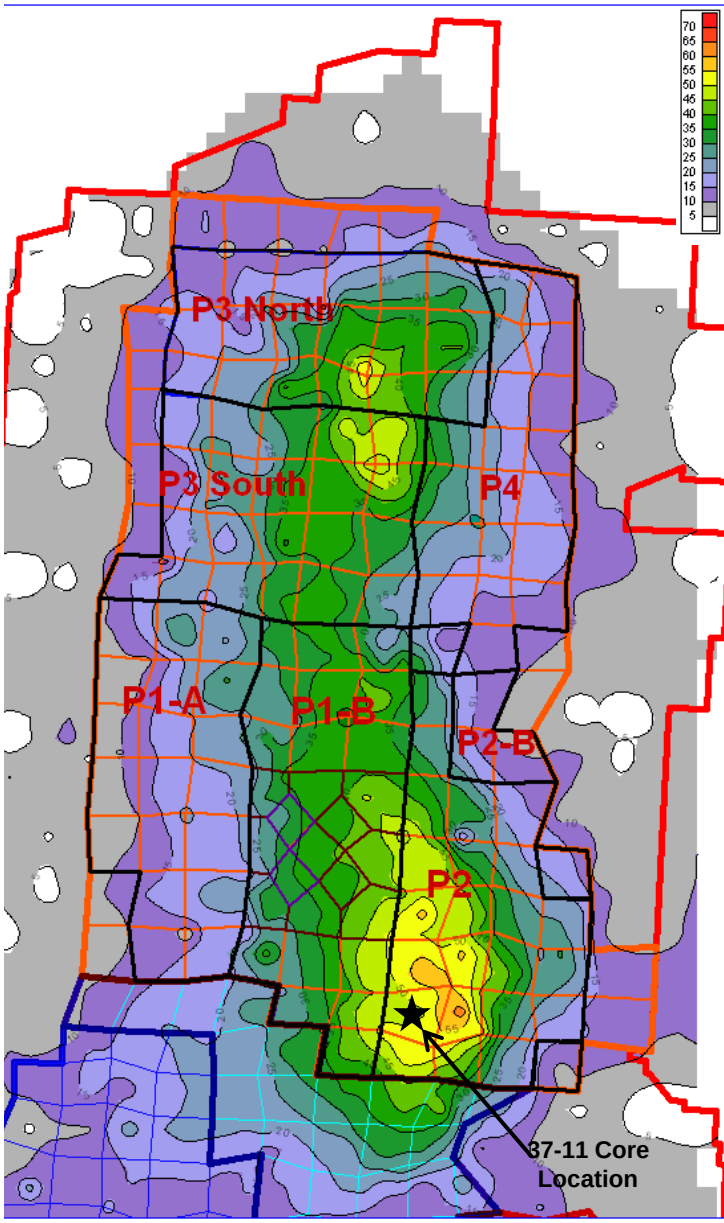
Platform CO2 Flood Development

- SACROC Platform Area has the thickest pay in all of SACROC
  - OOIP: 951 MMSTBO
  - Area: 5700 acres, 145 patterns
- Complex, Highly Heterogeneous Reservoir
  - Some Dual, Triple injection well completions used to better distribute CO2 injection



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SACROC Platform Pay Zone Intervals

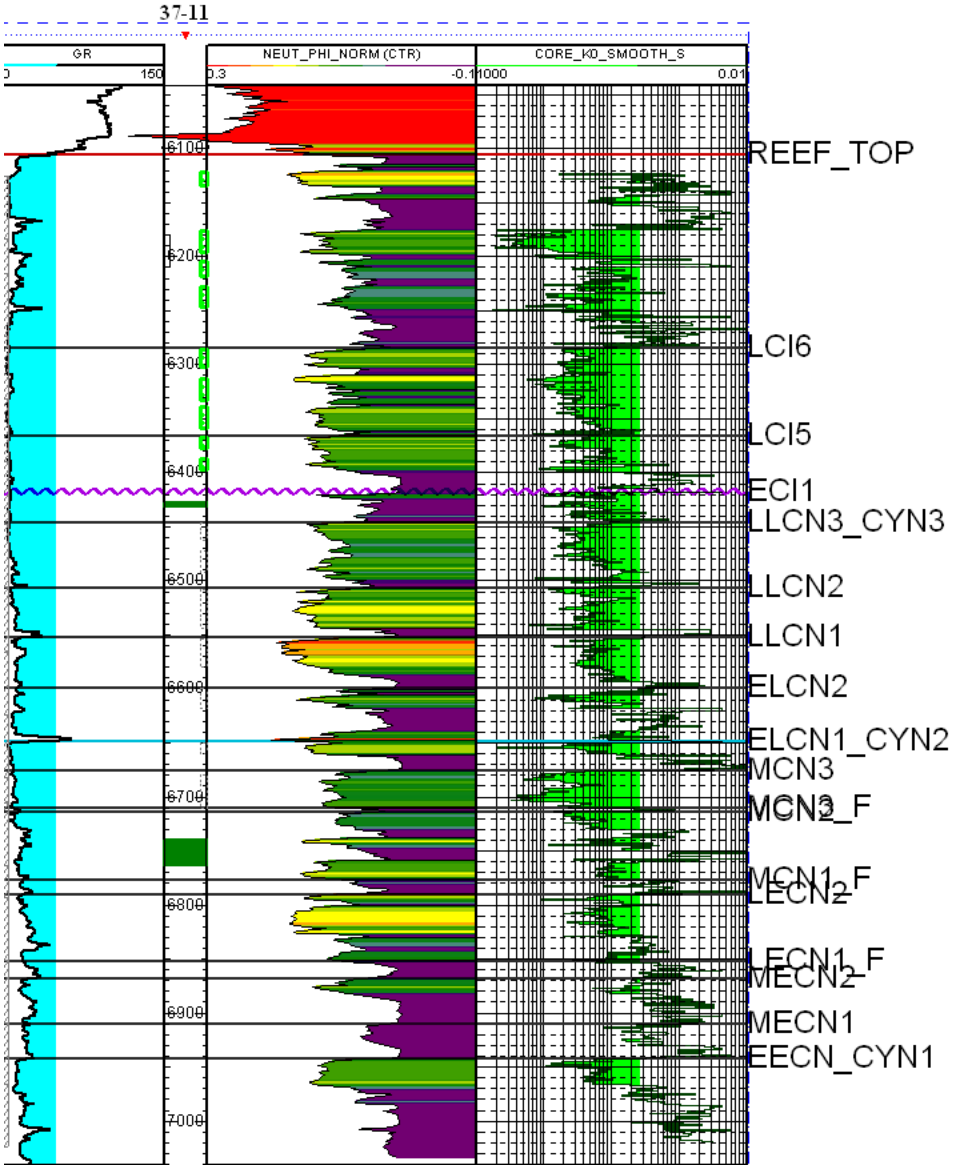
Intervals

Cisco

Green Zone

MCN3

Lower Middle Canyon



Platform Area Green Zone

Navassa Island Modern Day Green Zone Analog

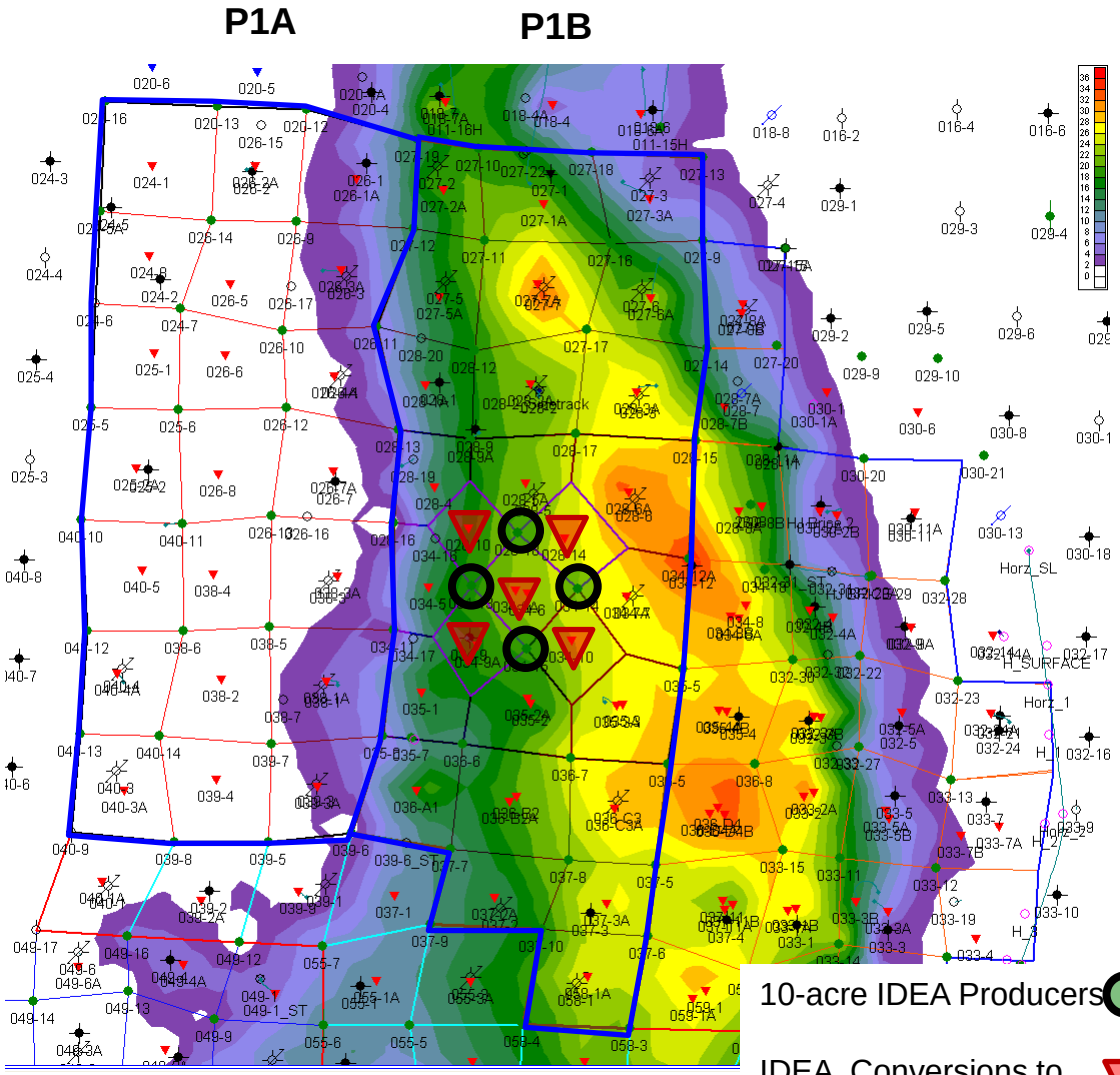
Karsted Core Sample

P1A & P1B 2009 Initial Platform CO2 Flood Project Areas

- **Expanding CO2 Flood into the Platform meant confronting severe CO2 channeling issues**
  - **Several cases of CO2 breaking through within hours of starting CO2 injection**

- IDEA (Infill Development Experimental Area)
  - 10-acre infill drilling & conversion project was implemented to create 20-acre 5-spot patterns
  - Objective was to increase recovery by connecting up discontinuous pay and allow faster processing of lower permeability layers

- **Unfortunately the infill drilling also connected up the high permeability layers/channels**



10-acre IDEA Producers

IDEA Conversions to Injection

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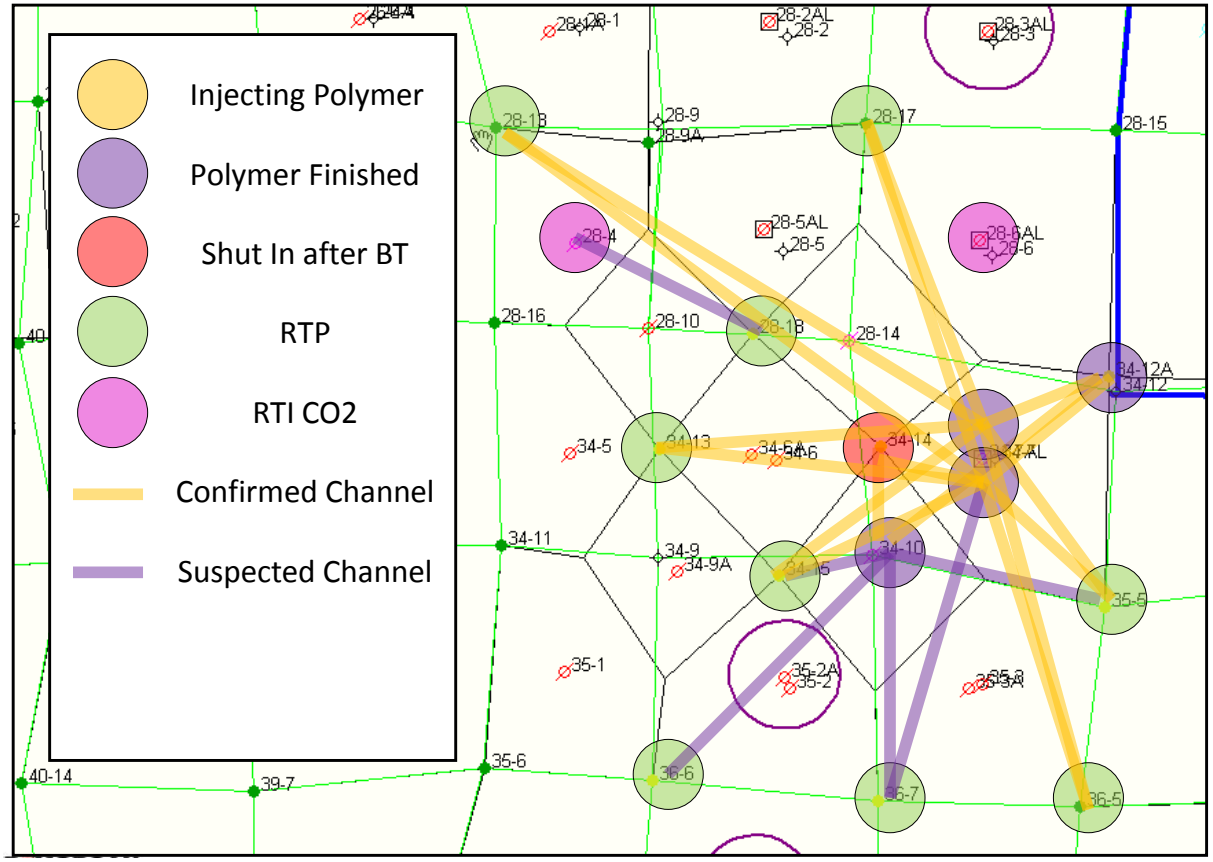
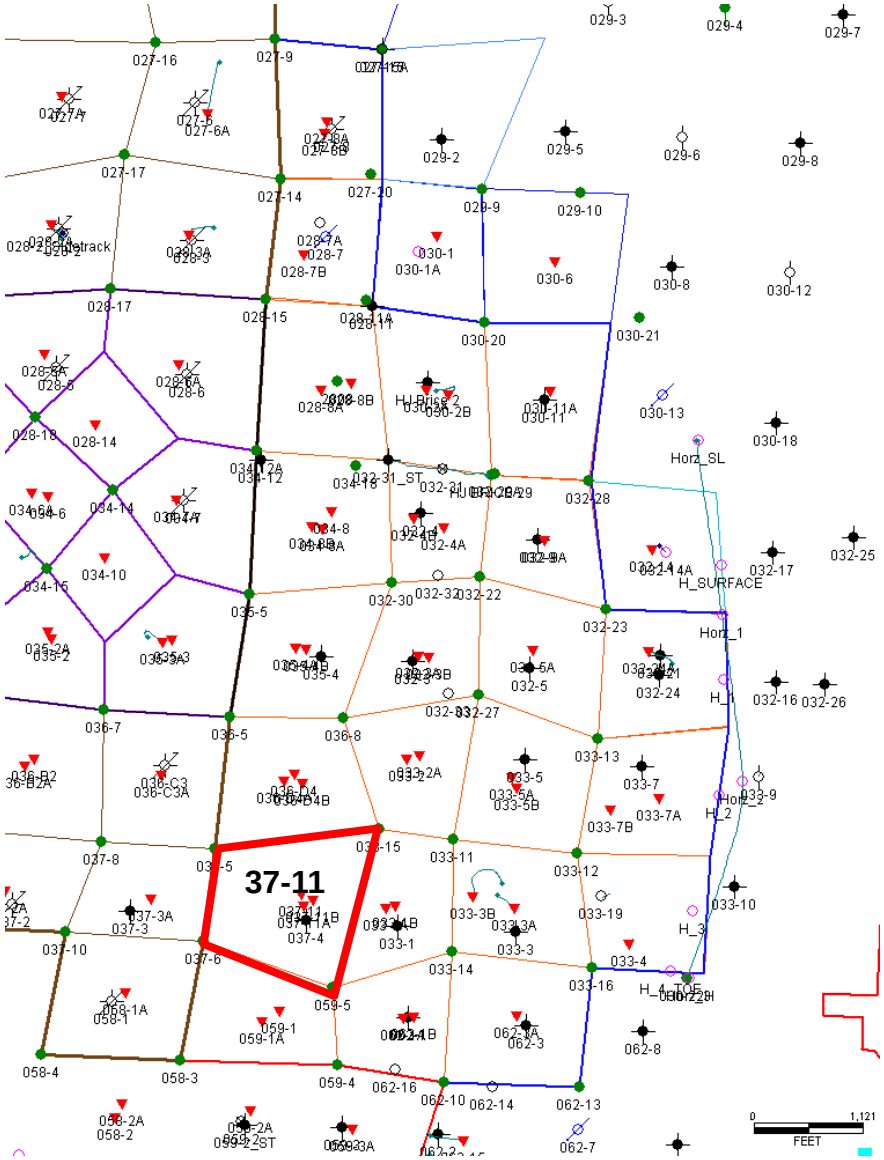
CO2 Channeling Issues

- Early CO2 channeling issues resulted in several patterns having to be shut-in
  - Cross-linked polyacrylate gel treatments successfully controlled many of the problems (except in the most extreme cases)
  - The long pump times required for placing the polymer treatments resulted in substantial production downtime



P2 Project Design Changes

- Pre-Injection Polymer Treatments were pumped
  - Pumping polymer before beginning CO2 injection avoided significant production downtime
- Where economically justified, three injection well completions were implemented to better distribute CO2 injection
- Horizontal producer was drilled on east side of project
  - Replaced drilling 5 vertical wells



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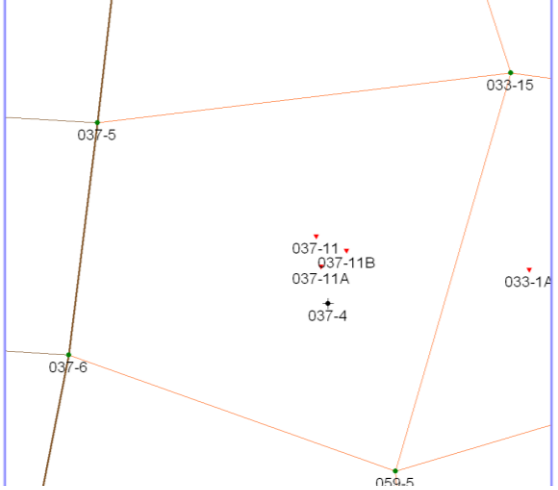
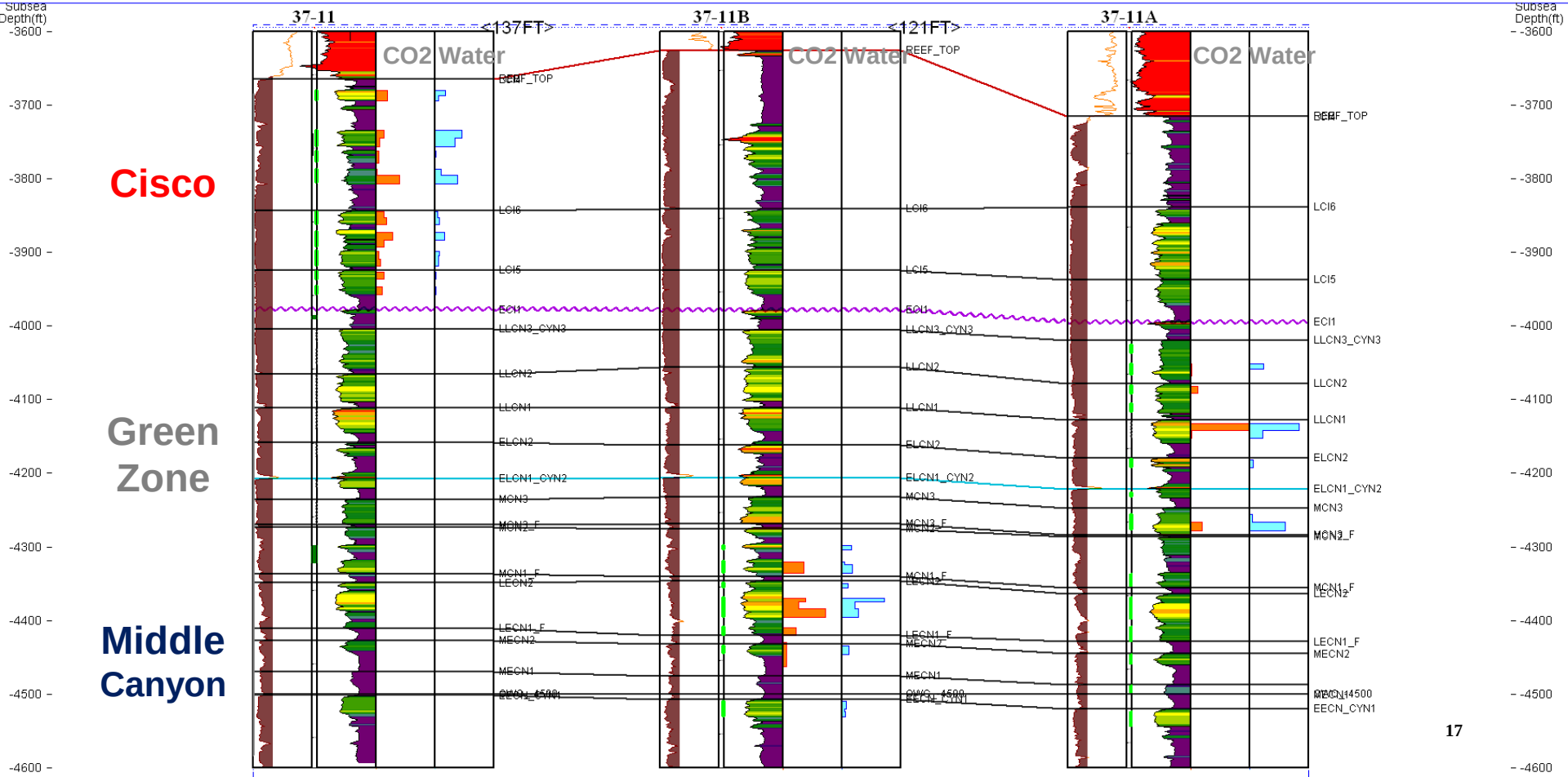
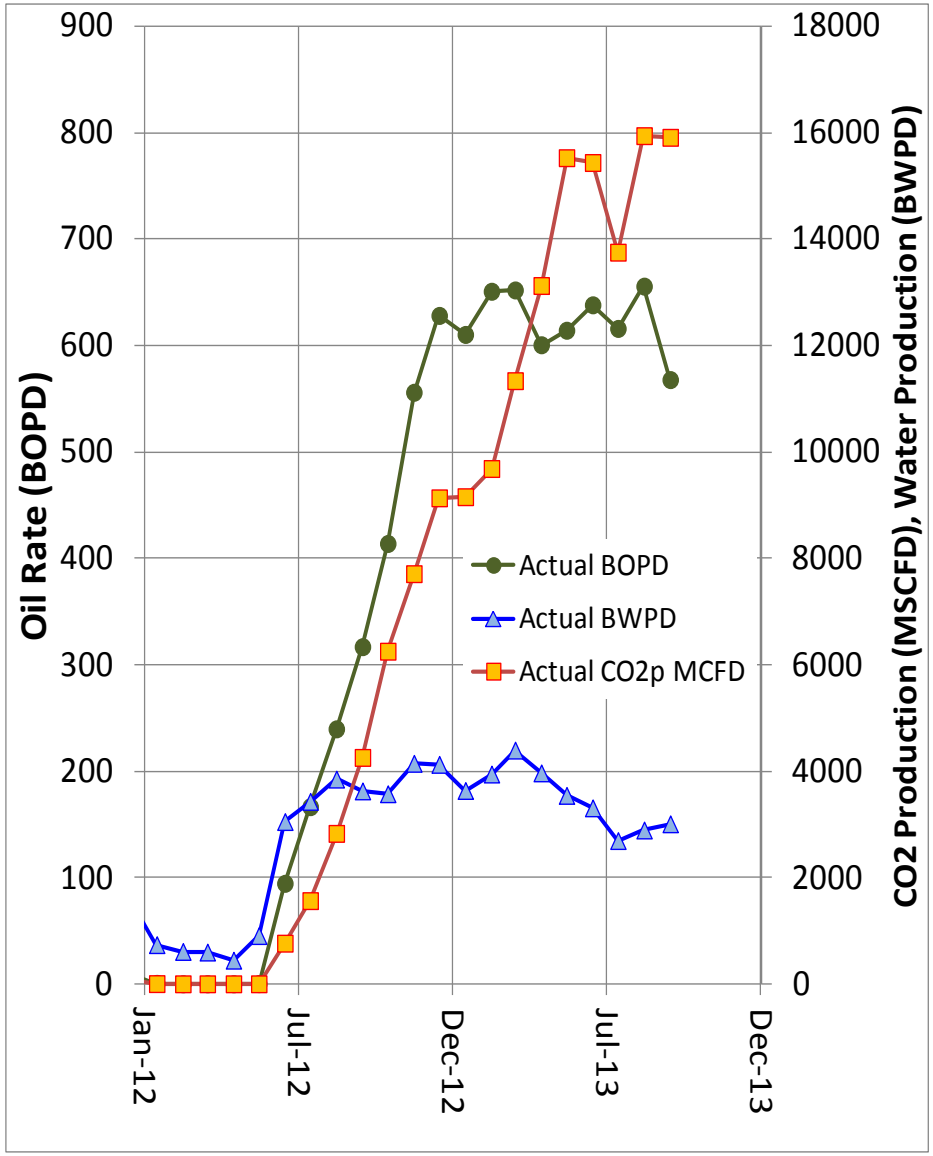
SACROC Pattern 37-11 Triplet Injection Completion

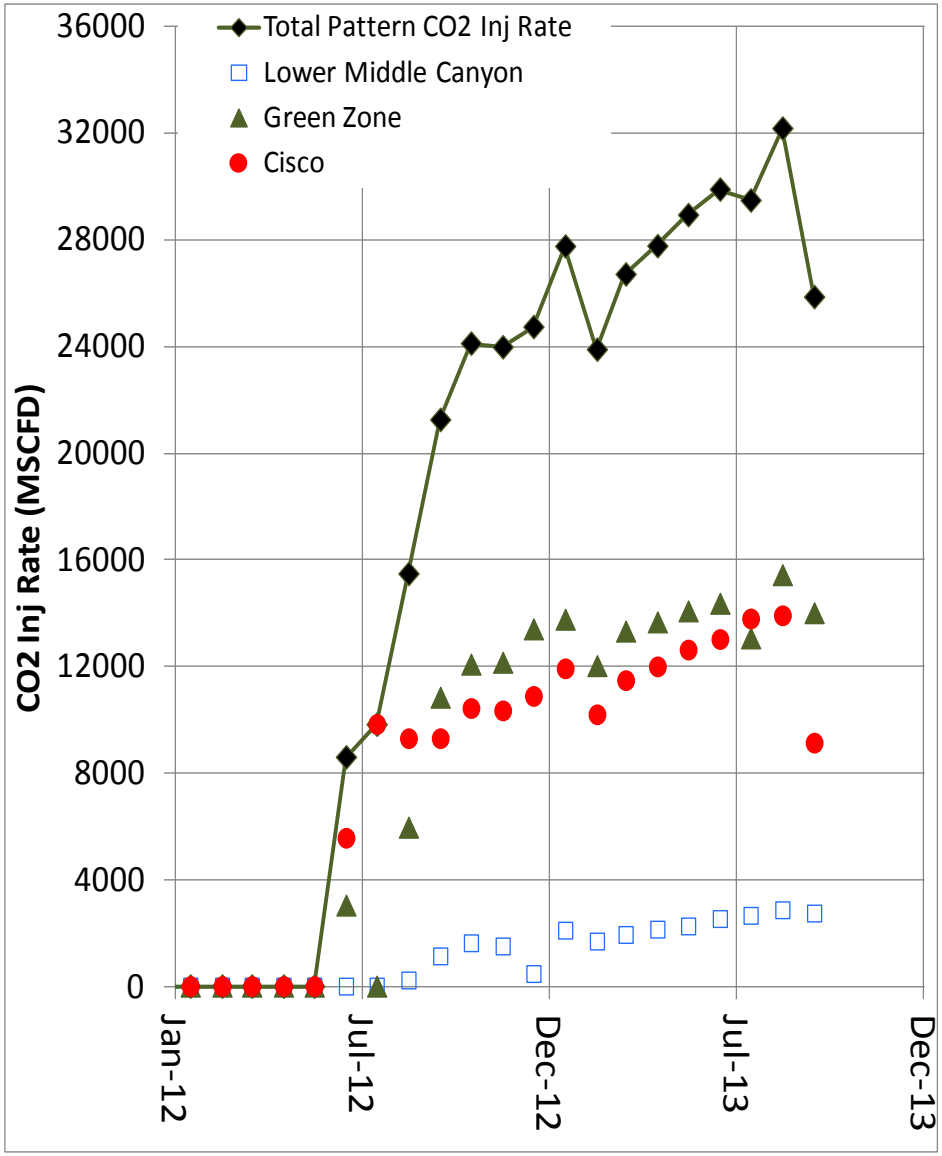
Completion	OOIP (MSTBO)	Average Injection (RBPD)	Processing Rate (%HCPV/Yr)
Cisco	3255	5452	41%
GZ/UMCN	5845	6242	26%
LMCN	3121	1055	8%
Total	12221	12750	25%





SACROC Pattern 37-11





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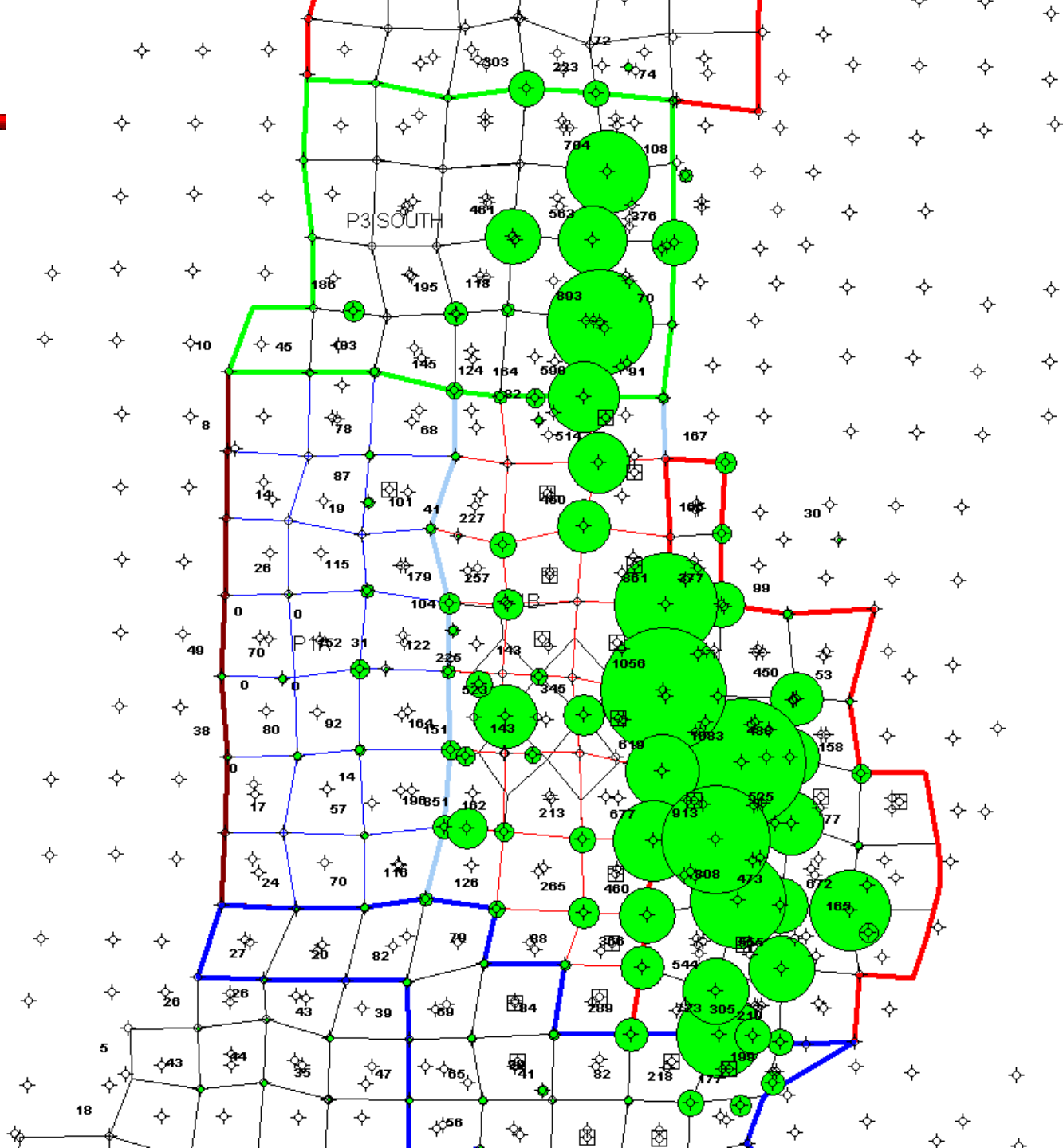
SACROC Platform Oil Rate Tests 12/2013



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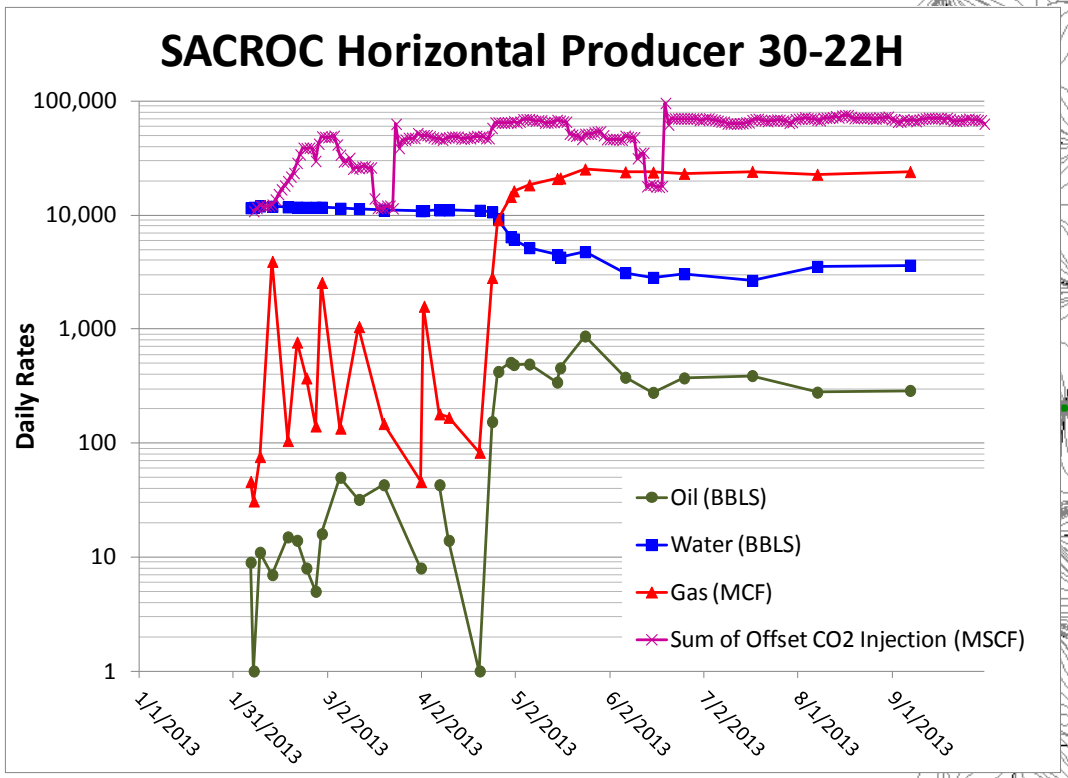
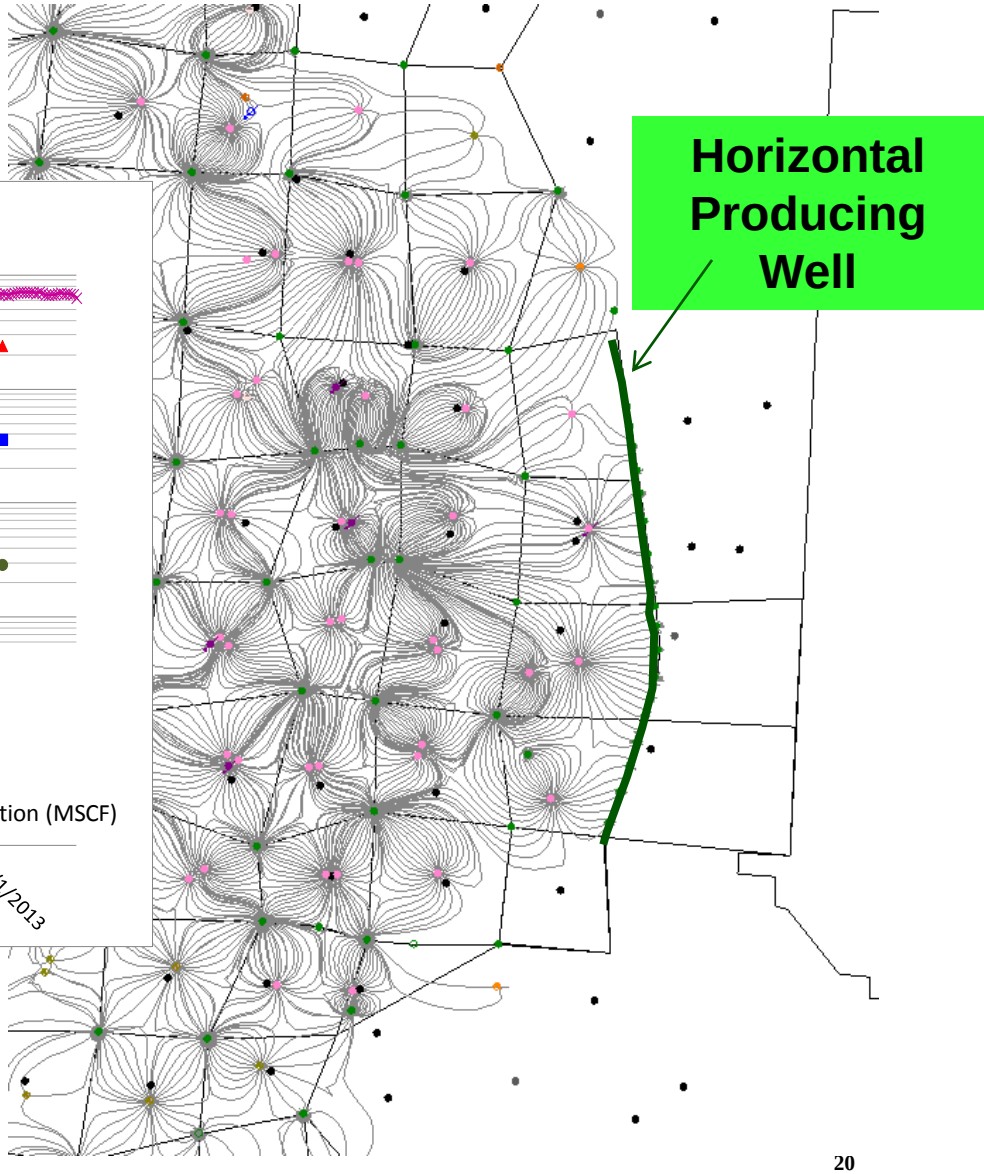
Horizontal Producers

- Drilling a horizontal producer replaced drilling 5 vertical wells
  - Well was completed using 18 cross-linked gelled acid stages





- Being able to drill horizontal producers will reduce the development cost of expanding the CO2 flood project into the thinner patterns along the edge of the field

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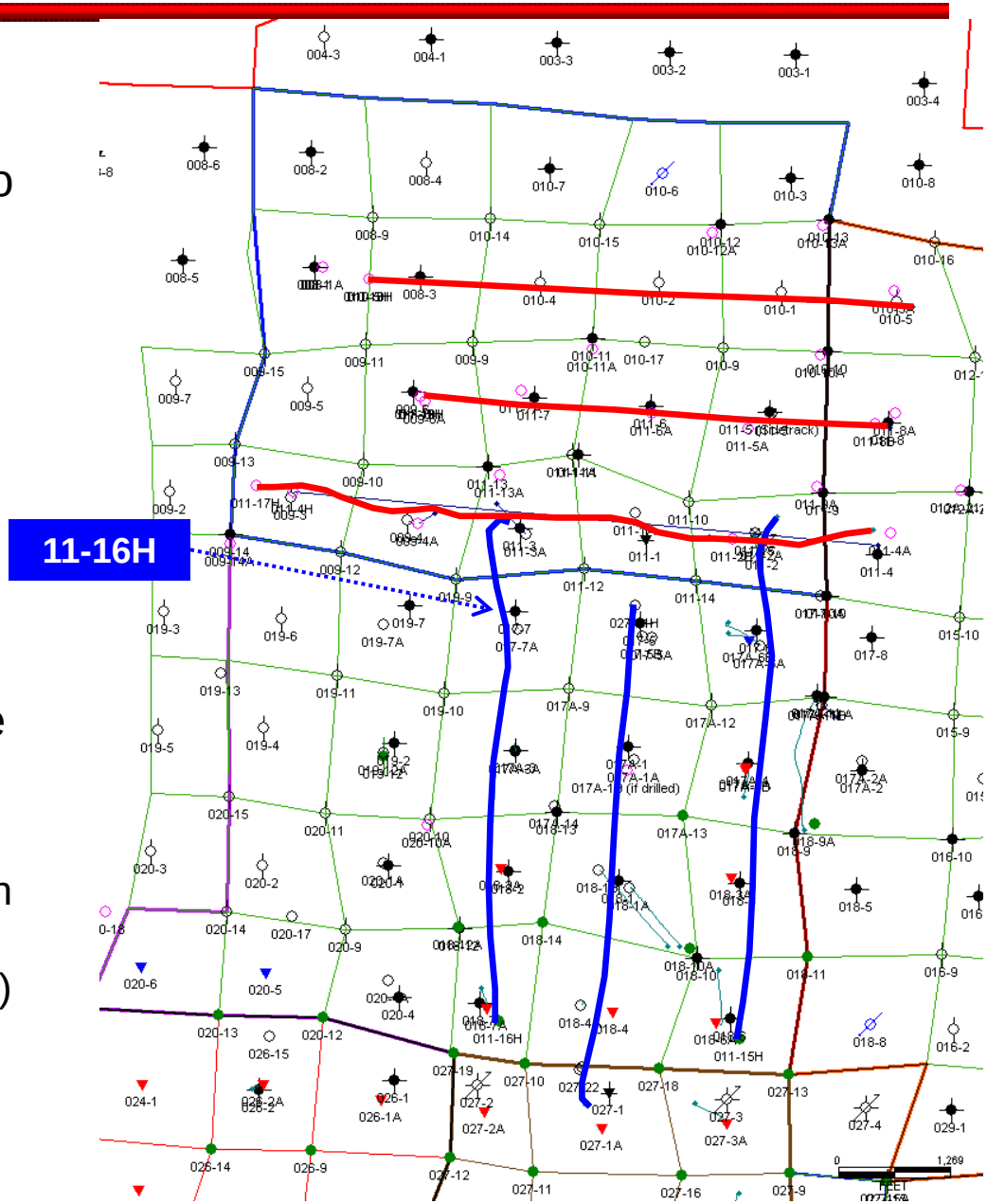
Lower MCN Horizontal Injection Completions

- Concerns over Lower MCN vertical well drilling costs, reservoir processing rates led to approving 6 horizontal injection wells in the P3 South and P3 North CO2 Flood Project Areas
  - Vertical well Lower MCN processing rates estimated to be <10% HCPV/yr
  - Multi-stage acid fractured Lower MCN processing rate expected to be >25% HCPV/yr
- All 3 of the P3 South wells have be successfully drilled and completed
  - 11-16H began CO2 injection on 11/27/13; currently injecting 25,000 MSCFD (30% HCPV/yr)



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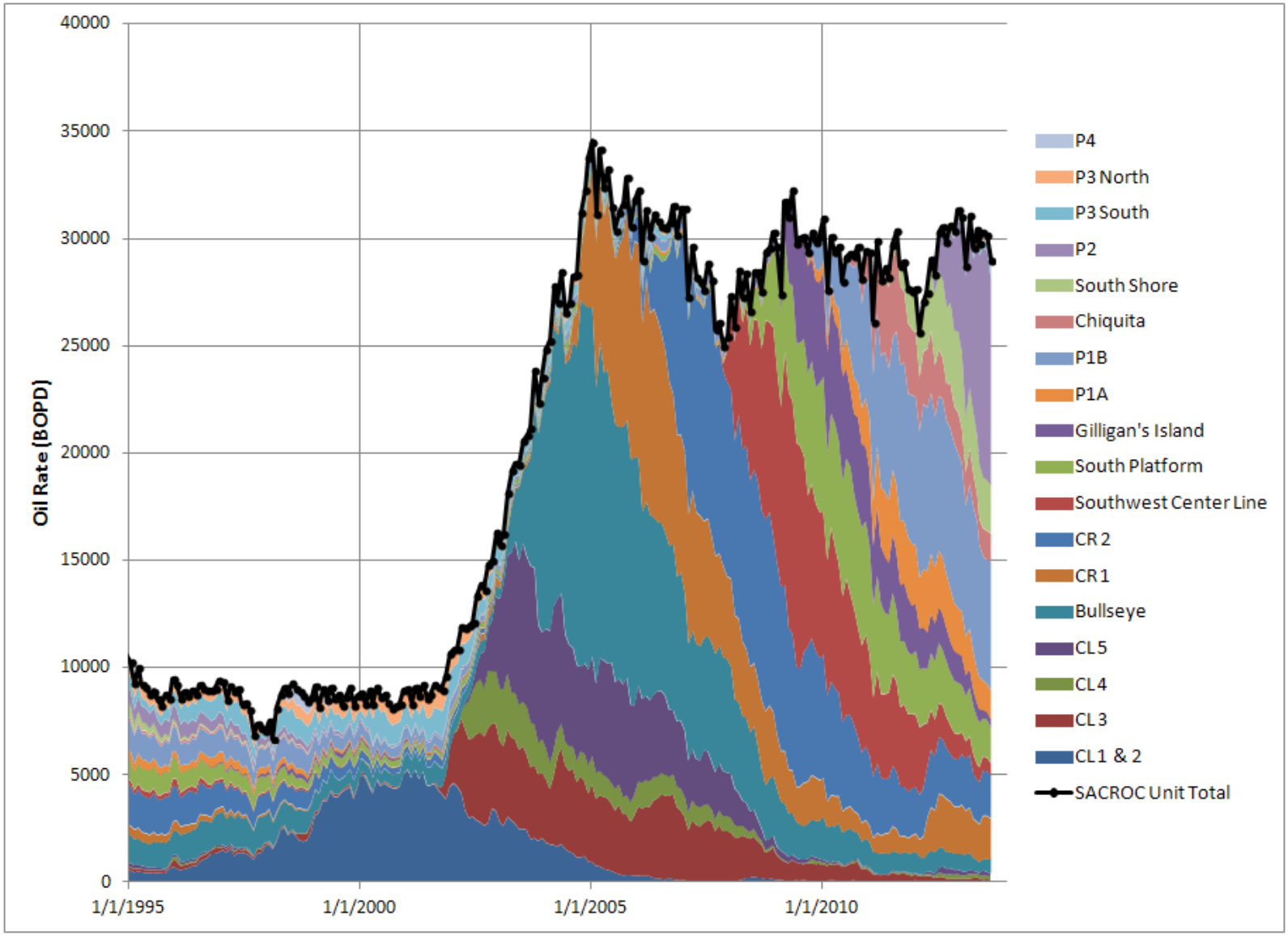
1996-2013 CO2 Flood Project Area Contribution to Total Unit Production



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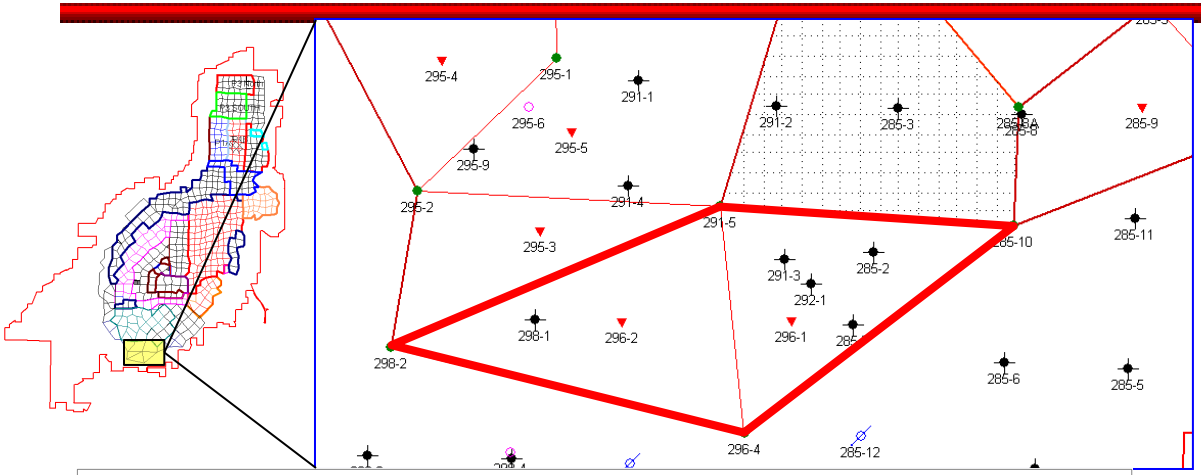
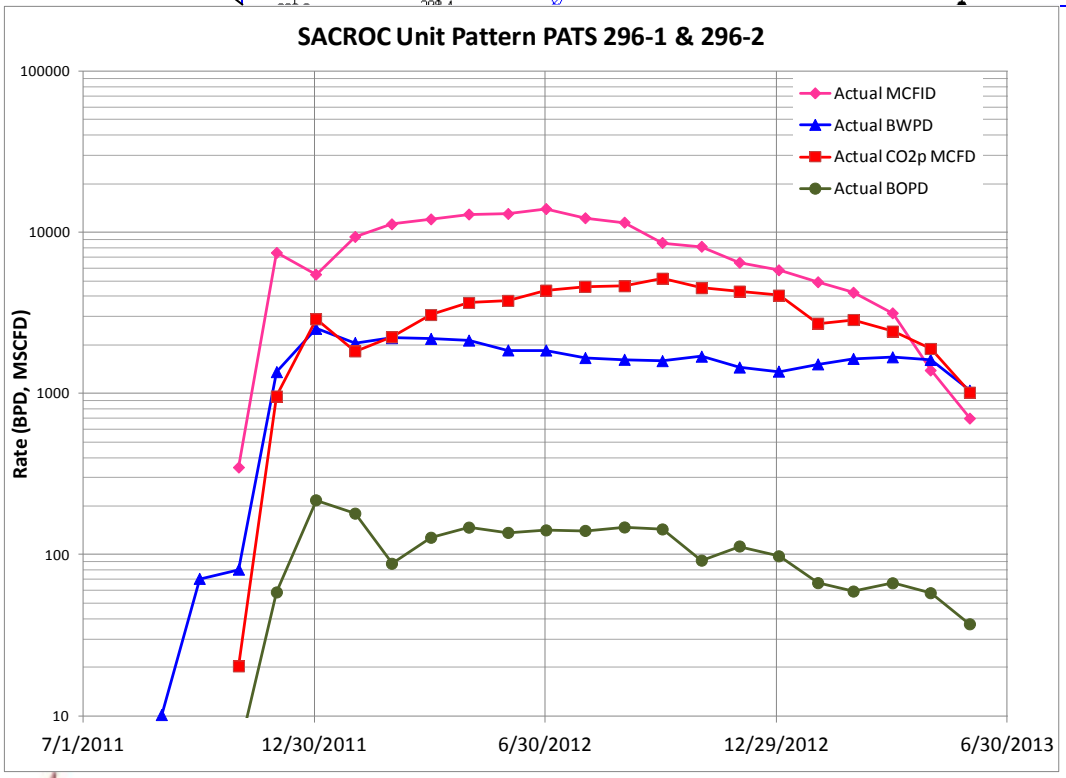
Future SACROC CO2 Flood Development

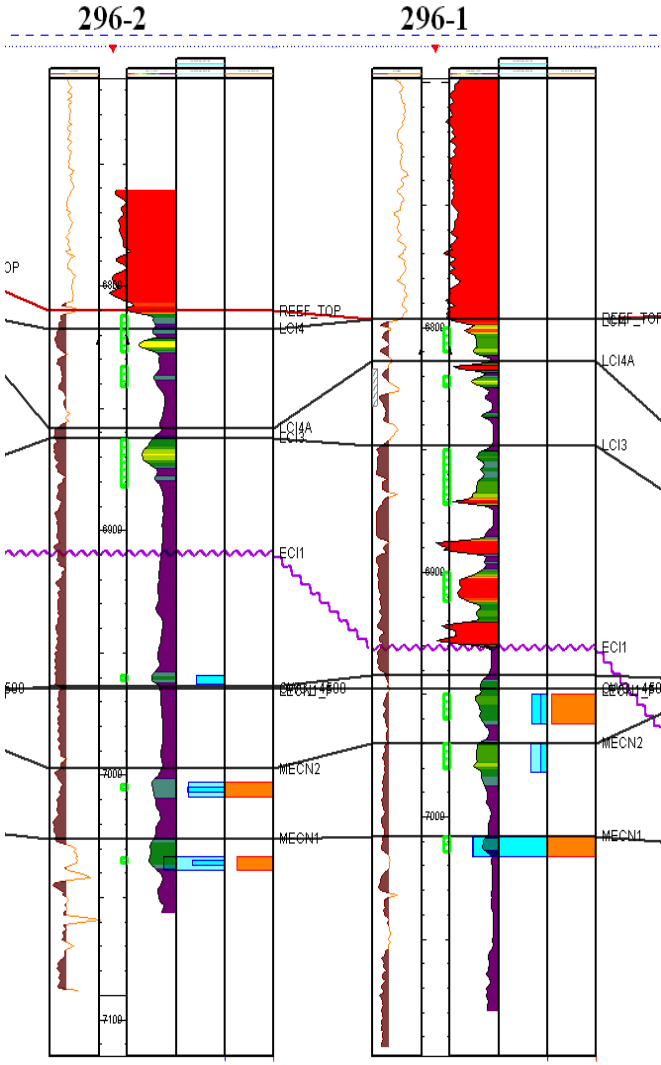
4-Component Strategy:

- Exploit Transition Zone
- By-Passed Redevelopment
- Edge Pattern Development
- Reassessment of Infill Development Potential

SACROC South Shore Transition Zone Test Patterns 296-1 and 296-2







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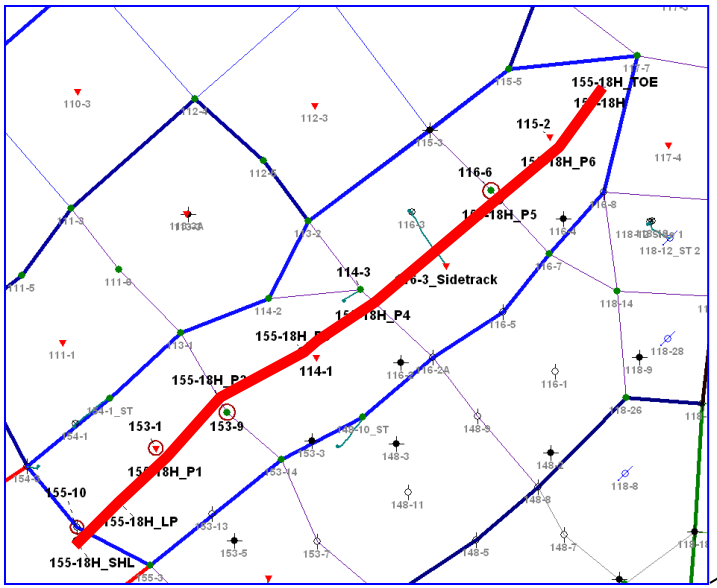
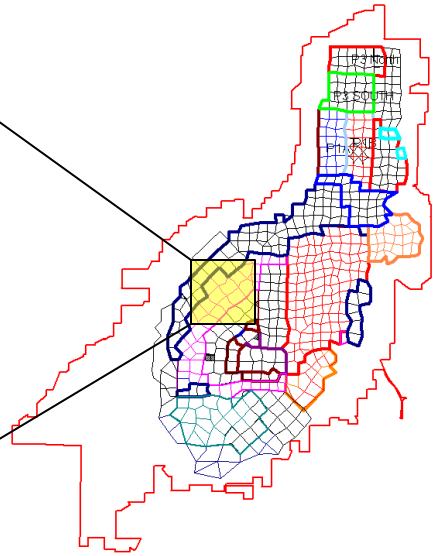
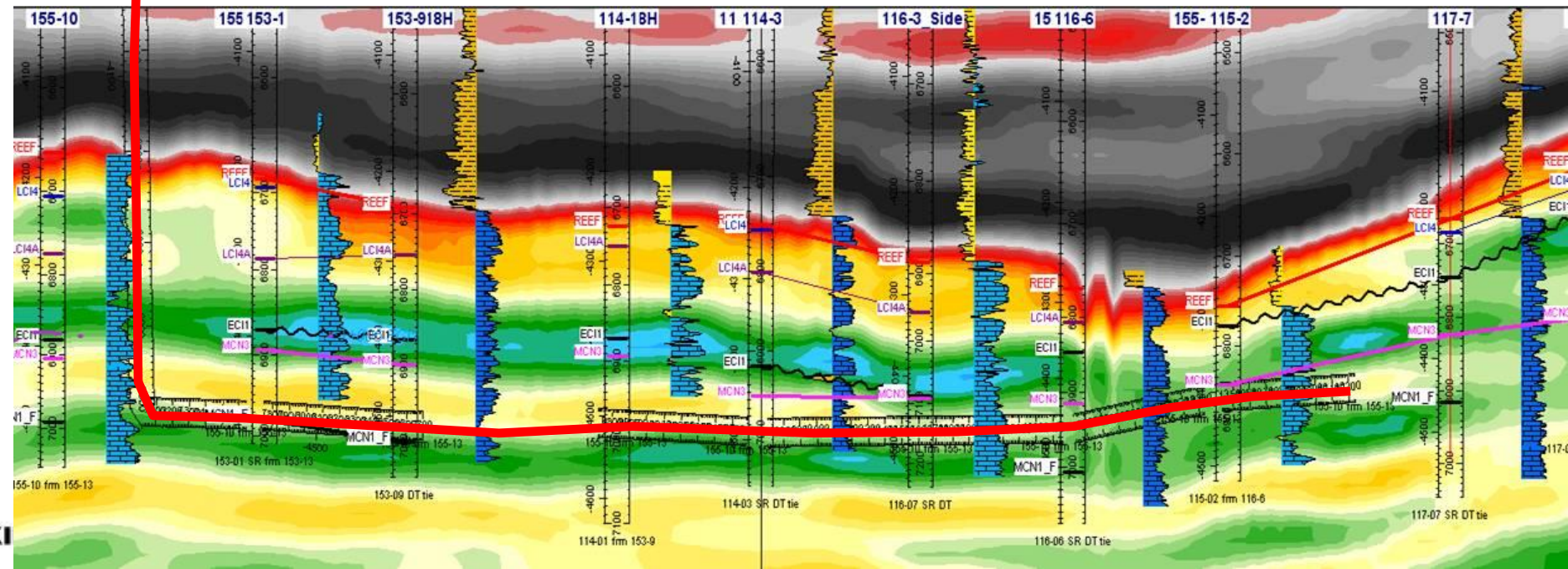
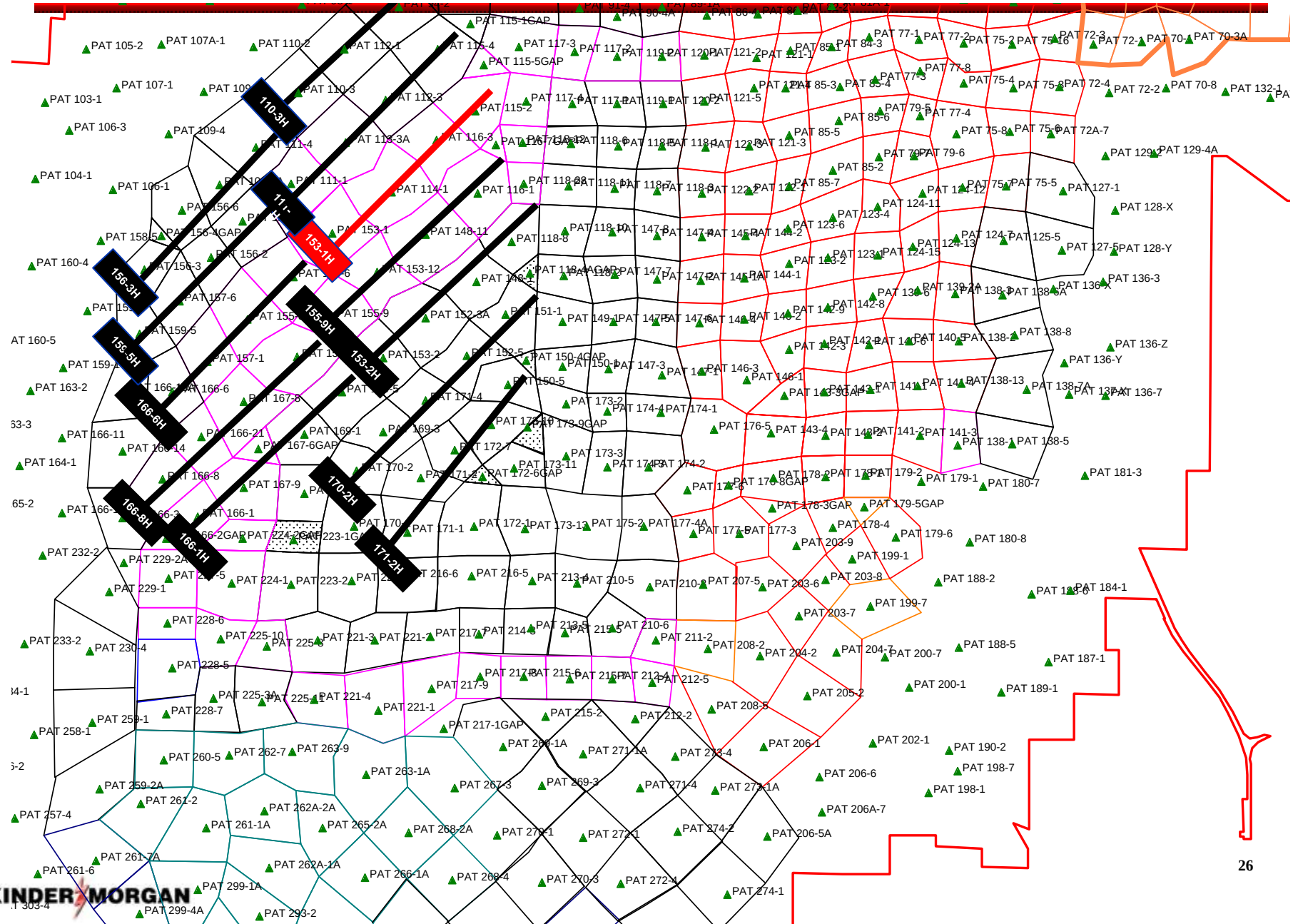
Bypassed MCN Pay Horizontal Injector 155-18H







Center Ring 1 & 2 Bypassed Pay
12-Horizontal Well Redevelopment Area



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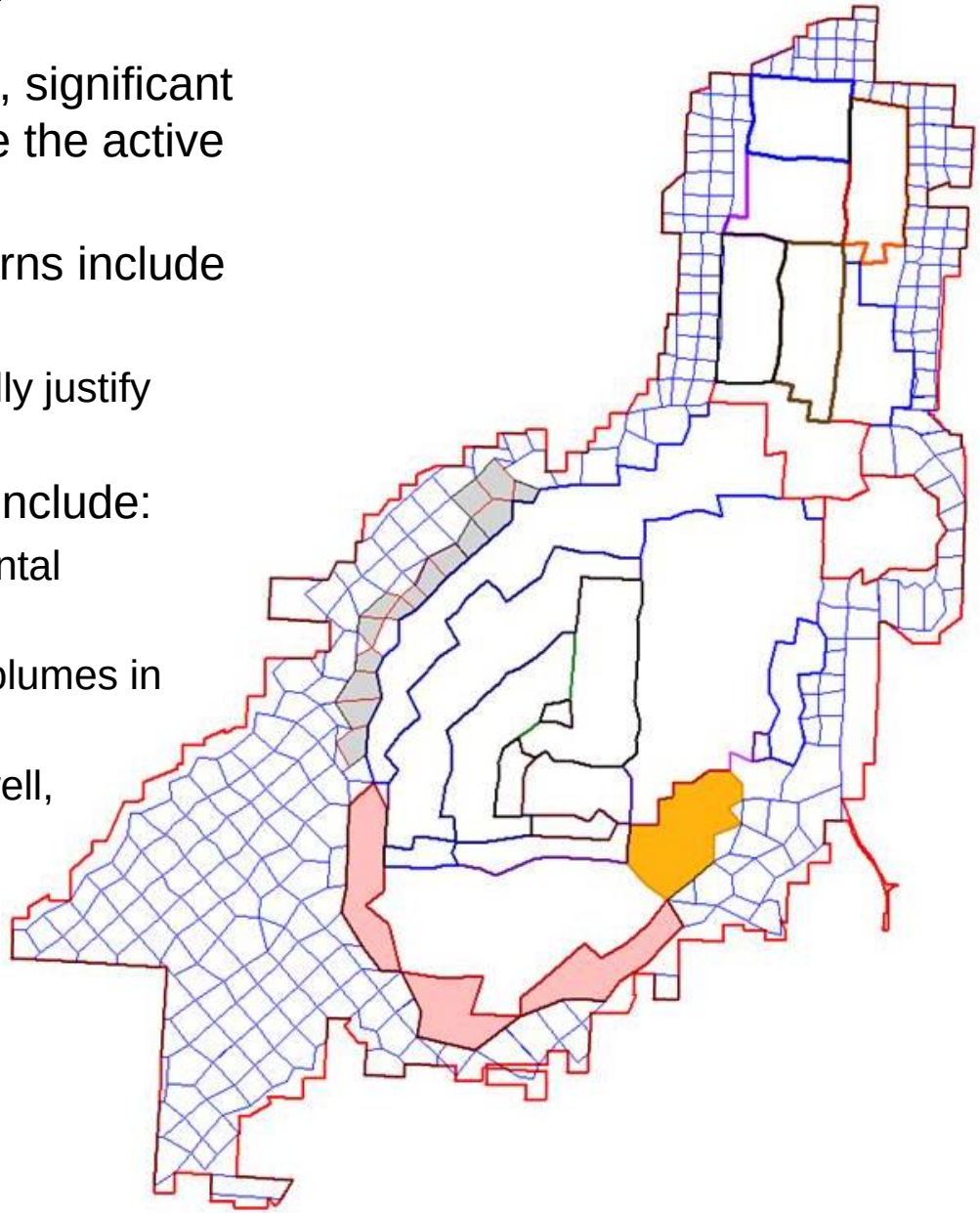
Potential CO2 Flood Expansion Patterns

- Although pay quality is less favorable, significant OOIP (>500 MMSTBO) exists outside the active or currently proposed project areas
- Challenges to developing these patterns include
  - Few if any available well bores
  - Insufficient pay volume to economically justify traditional pattern development
- Potential solutions being evaluated include:
  - Multi-stage fracture stimulated horizontal producers and injectors
  - Including Transition Zone reservoir volumes in recovery forecasts
  - Identifying areas that water flooded well, indicating they will respond well to CO2 injection



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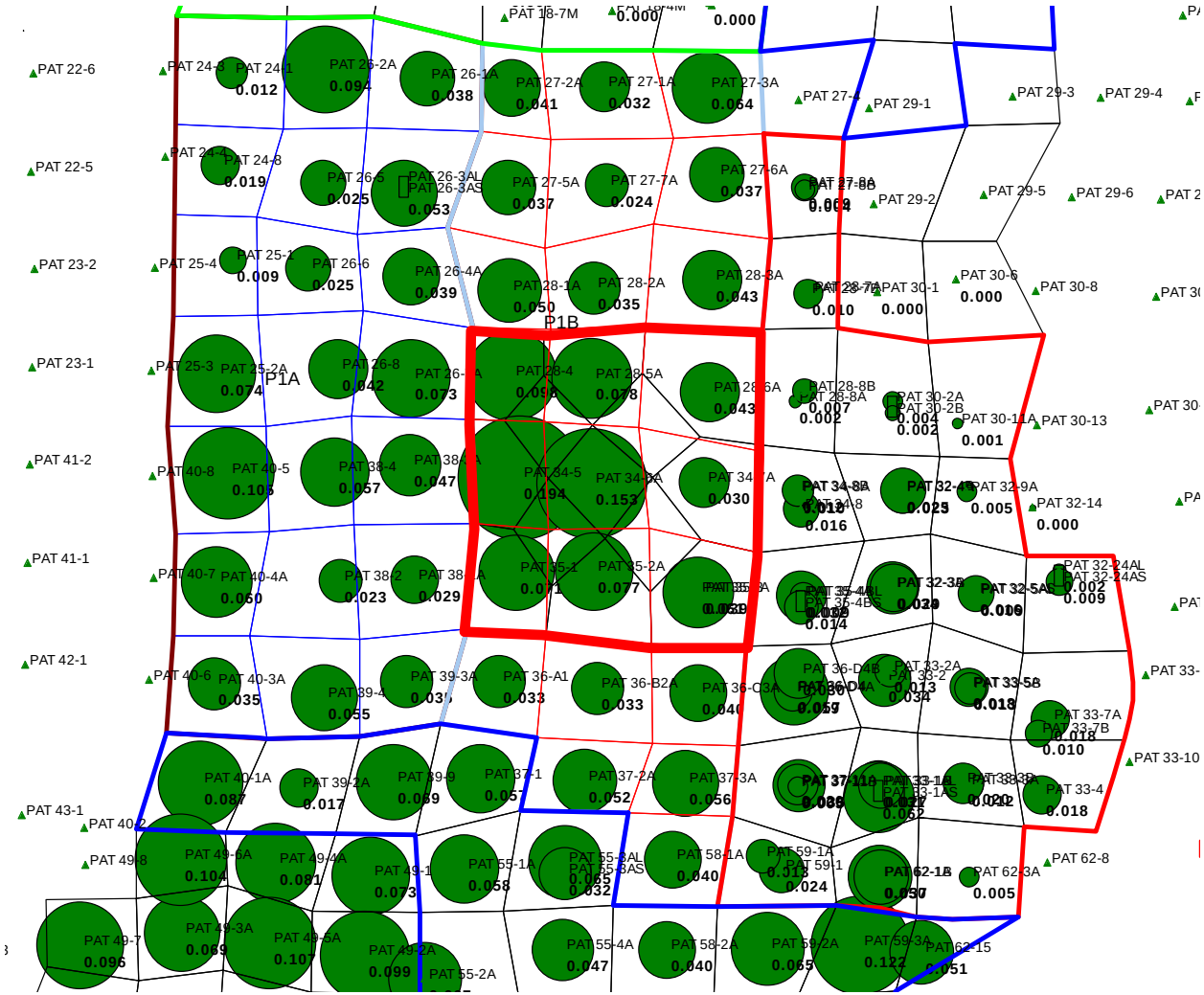
IDEA versus Offset Project Recoveries

IDEA Pattern recoveries to date are around 3% higher than in offset areas

Although initially plagued by CO2 breakthrough problems, <u>the combination of 10-acre infill drilling polymer gel and specialized cement squeeze treatments may have resulted in high efficiency patterns</u>

Some improved recovery due to targeting geologically isolated "Green Zone" Pinchouts

Additional infill wells have been recommended



Summary

- CO_2 flooding has presented SACROC's operators with engineering challenges since 1972
- Focused CO_2 flood development projects, injecting large pore volumes of CO_2 of 80-100% of the HCPV, have resulted in significant incremental EOR
- Mitigating heterogeneity issues through the innovative application of polymer, cementing, and horizontal well technologies has been critical to CO_2 flood performance success
- Continued CO_2 flood development of the lower permeability bypassed pay and reservoir around the edges, along with focused vertical/horizontal infill drilling applications within existing flood areas, will challenge SACROC engineers & geoscientists for many years to come

Big fields keep getting bigger!