Enhanced Oil Recovery in a Multilayer Complex Reservoir Casabe Project Case Study

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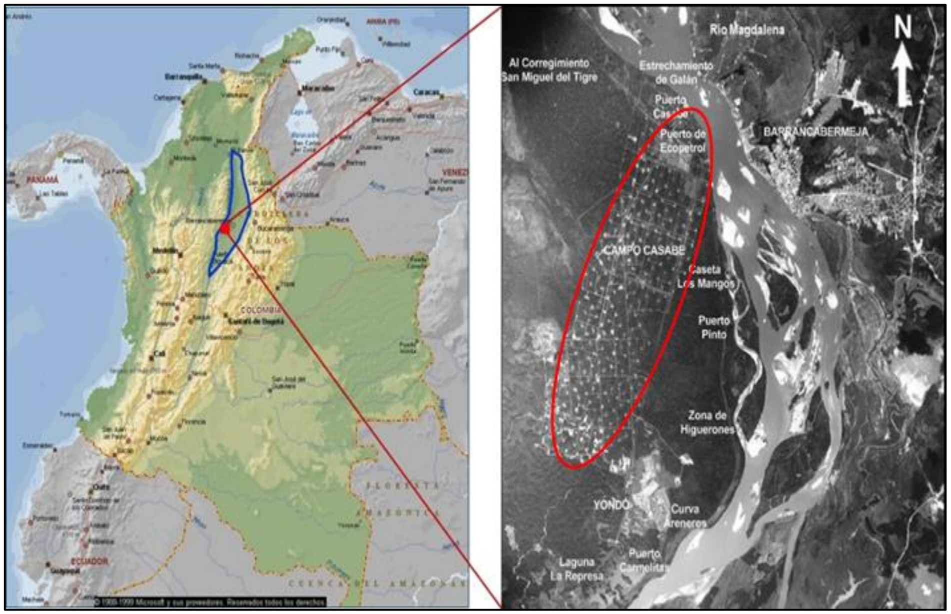
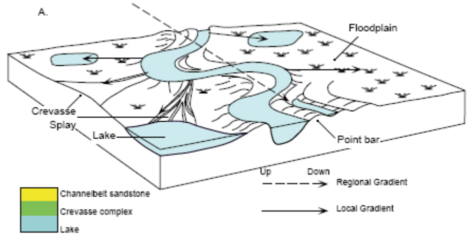
Project Background

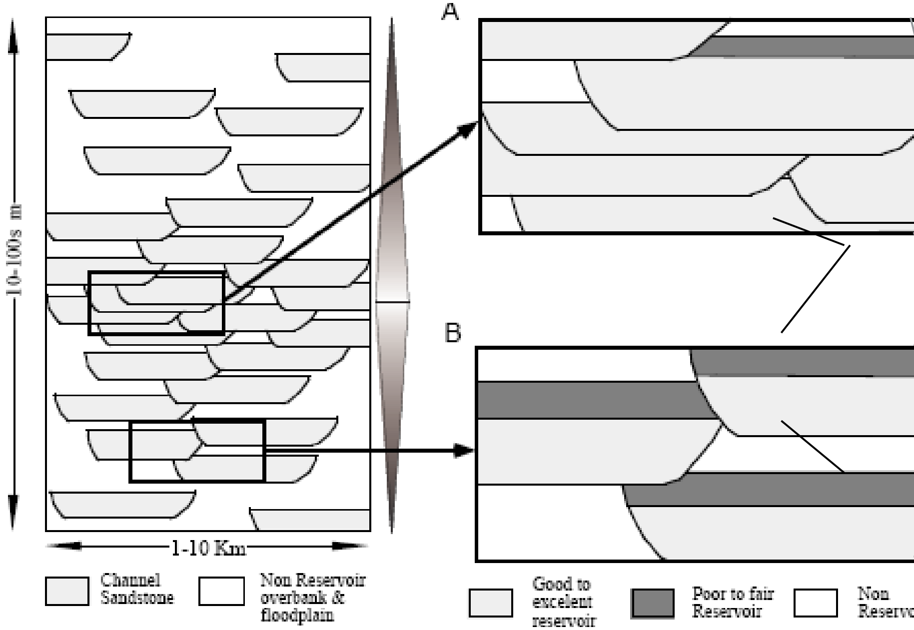


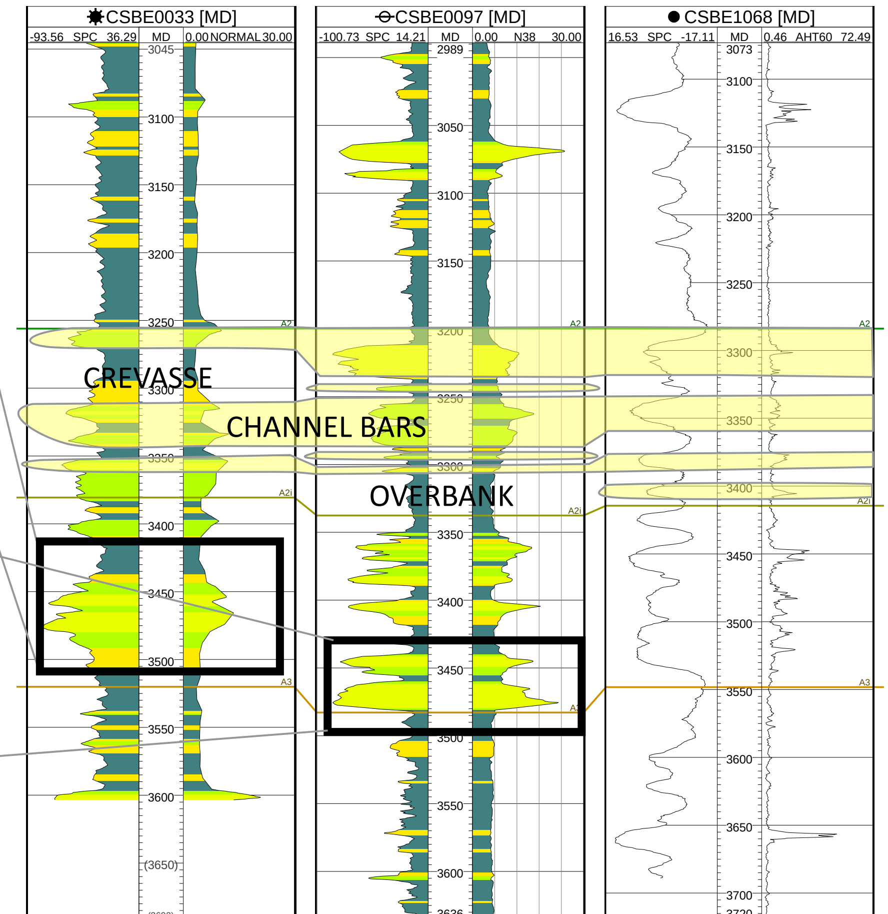
Discovered in 1941
~1,450 wells drilled by 2015
Active waterflooding
Five Spot patterns
~15 acre spacing
Producing formations: Colorado, Mugrosa, La Paz
Fluvial environment
Layered sand/shale sequence
~ as many as 25 zones/producers
18-25 API oil with ~ 30-80 cp viscosity
Original pressure ~ 1,500 psia,
Current range from 400-1,200 psia

- k = 50-300 mD
- RF ~ 20% pattern WF

Vertical and Horizontal Heterogeneity



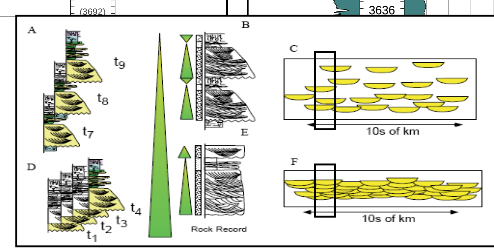




VERTICAL HETEROGENEITY DUE TO CHANNEL STACKING

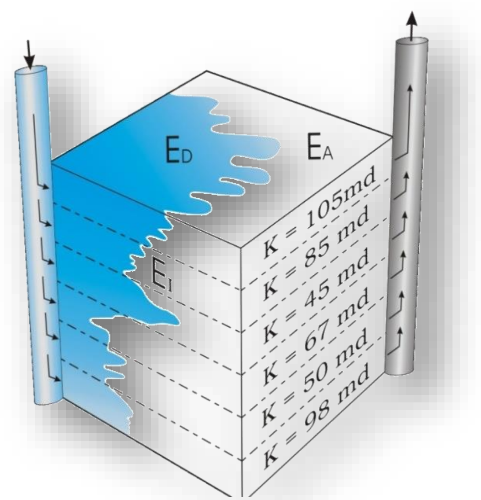
MODIFIED FROM RAMON Y CROSS, 1997

Relative Preservation Of The Channels Sandstones Under Low And High A/S Conditions



Project Background

- Large difference in mobility between oil and water in Casabe (Mw,o ~ 25)
- Maturity of secondary recovery create several operational problems in the field
  - Increase of the water cut
  - water influxes
  - Increased volume of produced sand, etc.
- Heterogeneities create irregular water fronts, causing early water breakthrough



Source: Integrated Waterflood Asset Management. THAKUR Ganesh y SATTER Abdus. 1998.

$$E_V = E_A \times E_I$$

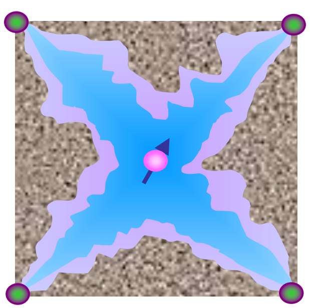
Where:

E_V = Volumetric Efficiency

E_A = Areal Efficiency

E_I = Vertical Efficiency

IMPROVE SWEPT EFFICIENCY

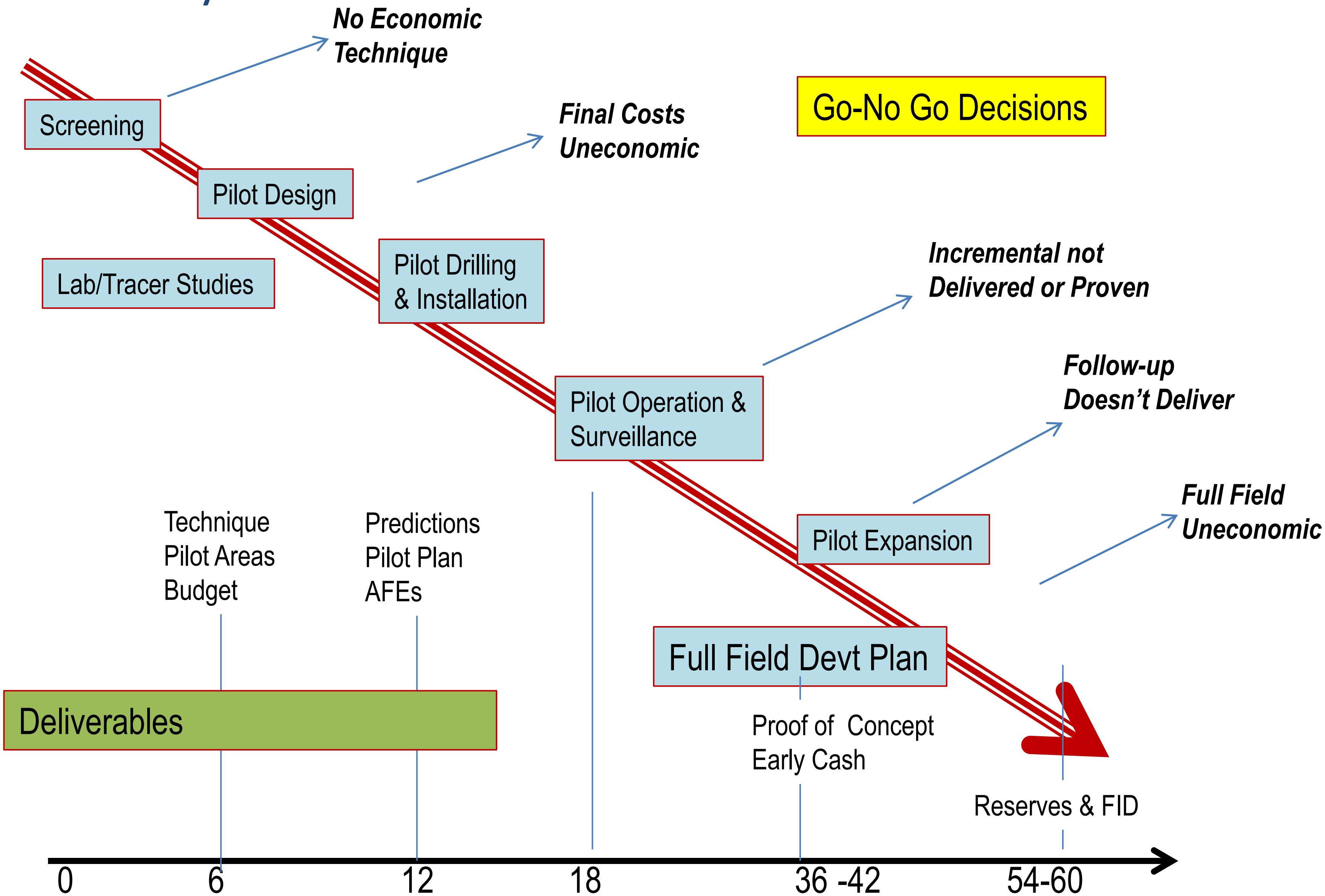


Mobility Ratio Modification

$$\downarrow M = \frac{k_{rD} / \mu_D \uparrow}{k_{rd} / \mu_d}$$

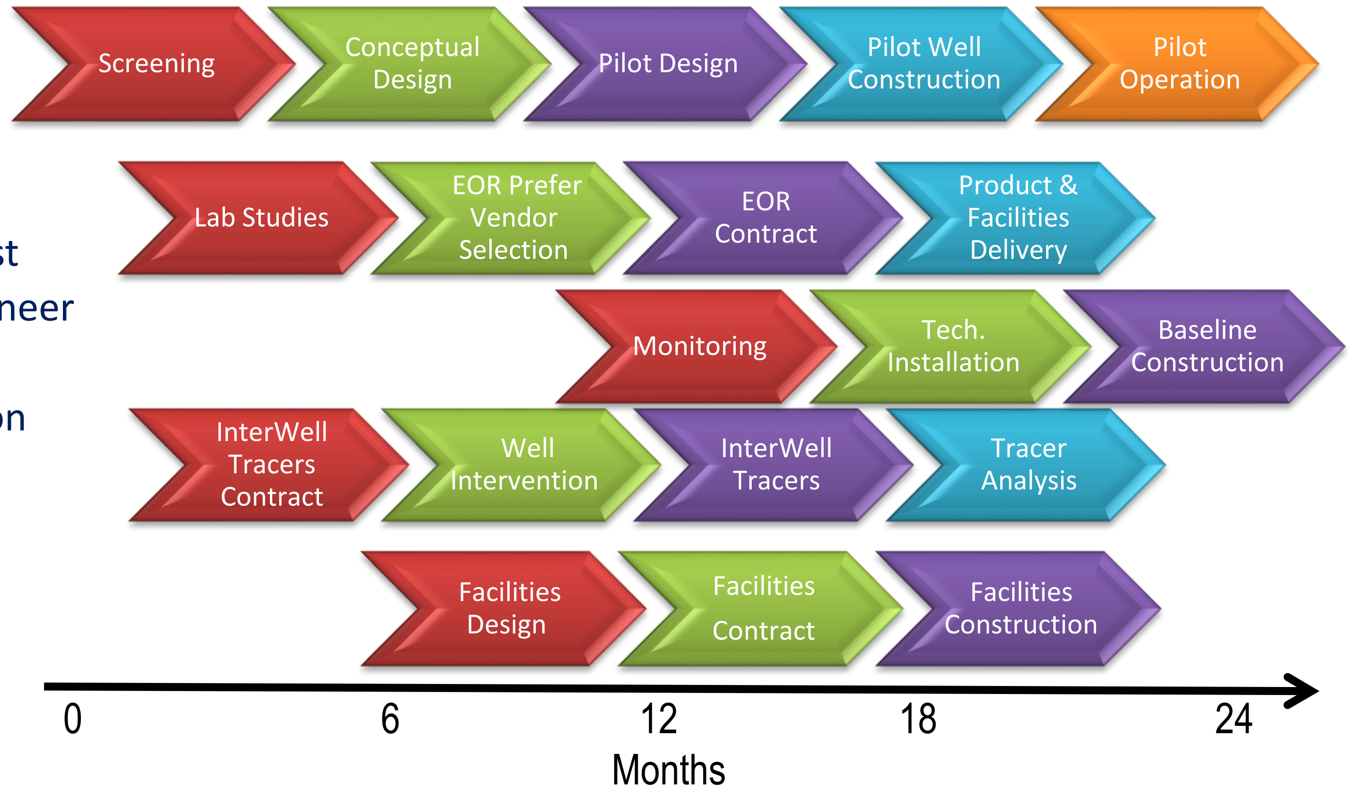
Increase Water Viscosity

5 Year EOR Cycle Time



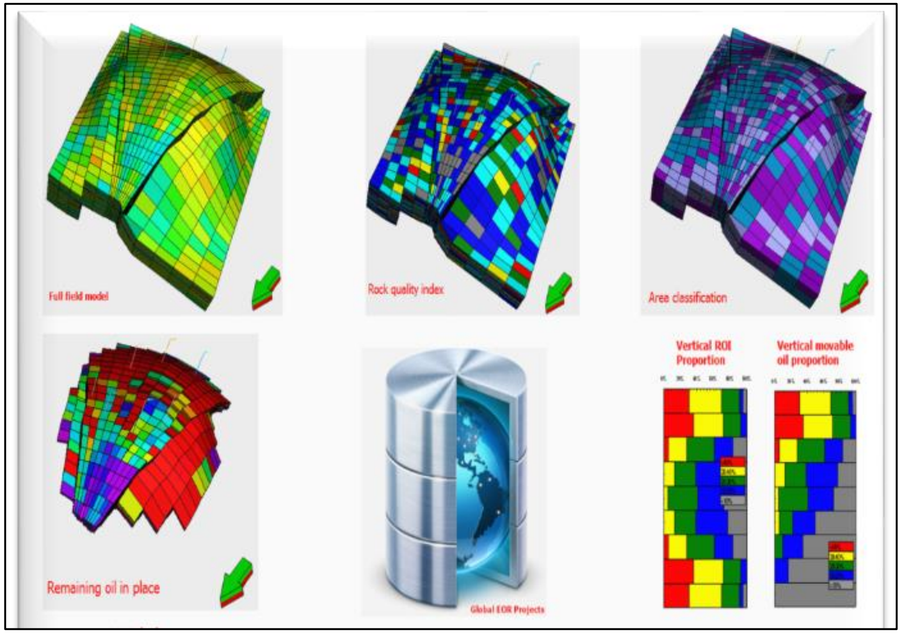
EOR Project Implementation Process + Focus Team

- Project Manager
- Reservoir Engineer
- G&G
- Production Technologist
- Well Construction Engineer
- Facilities Engineer
- Production Optimization
- Economic Analyst
- Supply Chain Support



Screening

EORt Workflow

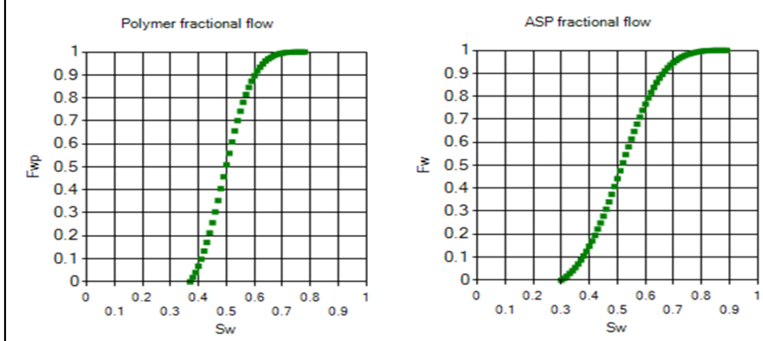


Select EOR potential formation: Colorado

Filter by industry guidance

Not applicable / Applicable / No similar project in database / No method record in database

	EOR agent	Industry guidance	Compatibility	Macro scale filtering	Pore scale ranking
1	ASP				0.565
2	Polymer				0.389
3	Low salt				0.343
4	AS				0.33
5	Surfactant				0.33
6	Water				0.267
7	WAG (immiscible)				0.267
8	N2 (immiscible)				0.167
9	Hydrocarbon gas (immiscible)				0.161
10	CO2 (immiscible)				0.16
11	Foam				0.445



Screening criteria for EOR processes

- Formation type/lithology
- Reservoir geology
- Oil Composition and Oil Viscosity
- Formation Water Salinity and Divalents
- Reservoir Temperature
- Formation Permeability

Operational issues to consider

- Availability of injecting agents (Water, Gas, CO_2, N_2)
- Pattern configuration and well spacing
- Well Completion
- Facilities configuration and constrains
- Energy
- Environmental and Legal Regulations

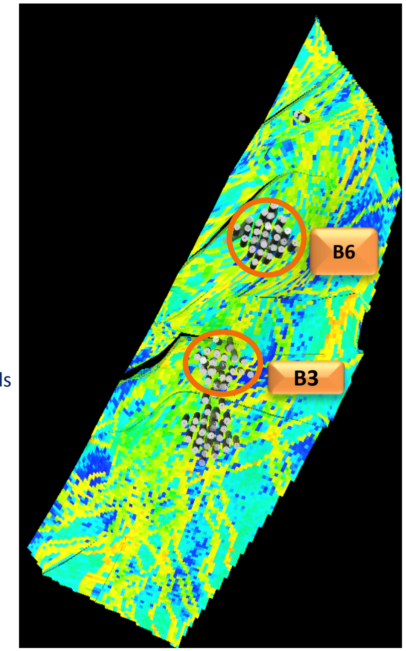
Conceptual Design

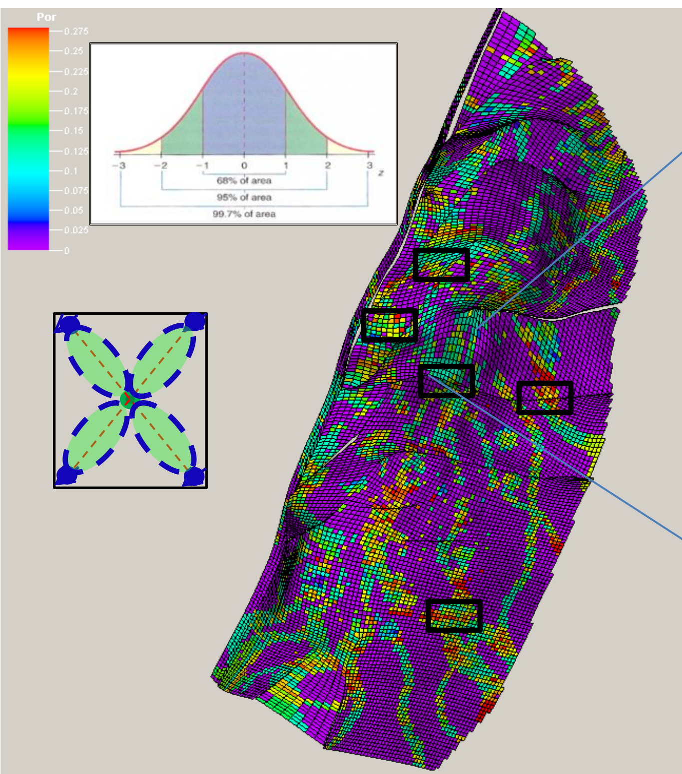
Two ***Polymer Flooding Pilots*** for mobility control and S_{or} Reduction EOR; variation in chemical make up for different K/V shale

- One in Average Rock Quality, swept.
- One in Best Rock Quality, swept

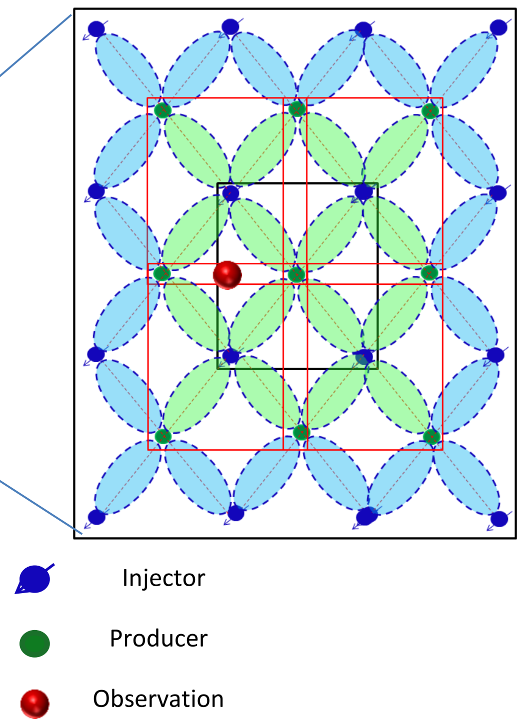
Two layers comprising >30% of OOIP

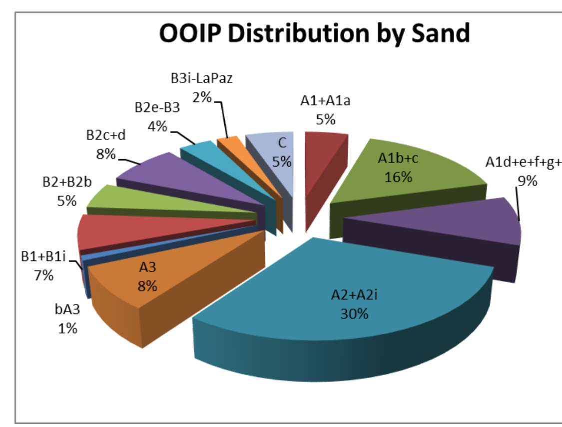
EOR Pilot Areas





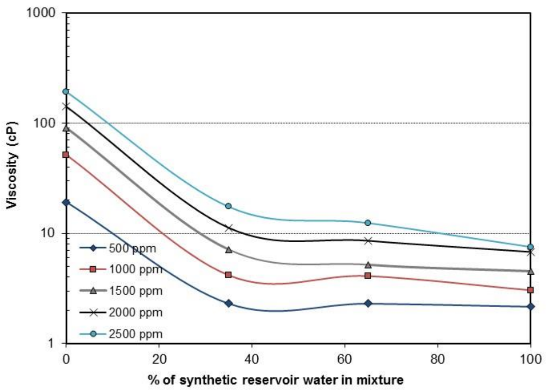
((4 arrangements*3 streamlines)/4)+(1 arrangement*4 streamlines) = 4 Wells



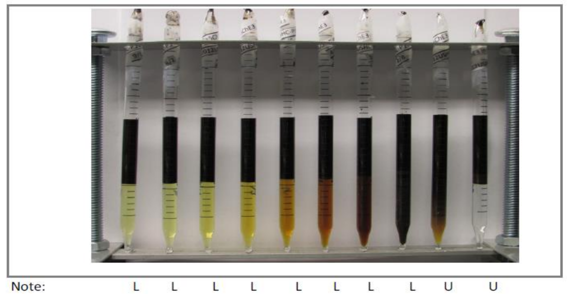


EOR Experimental Tests

Viscosity modification with HMPA Polymer

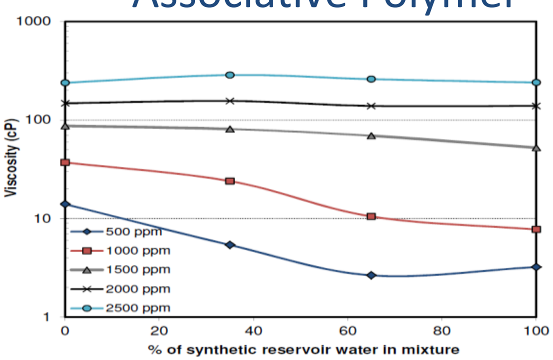


Surfactant Phase Behavior

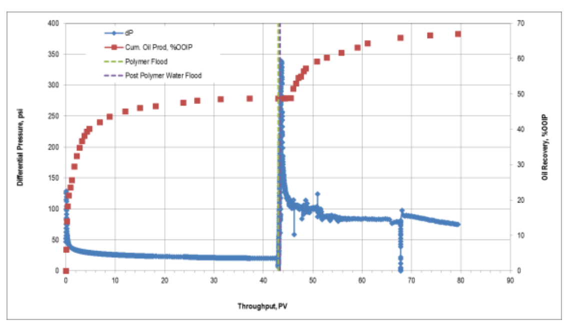


From left to right: Sasol 5 : ChE 3=9:1 to 0:10

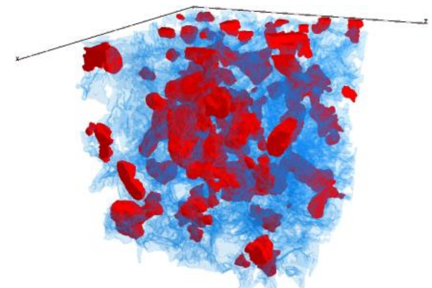
Viscosity modification with Associative Polymer



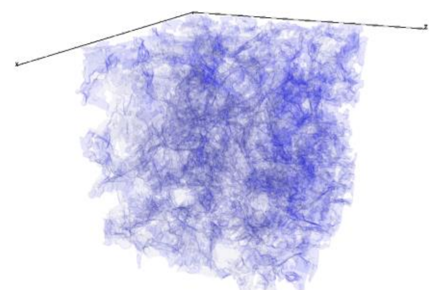
Core Flooding



Digital Rock



Oil and water saturations



Low Polymer concentration High

Tracer Technology

$$M_{traz} = 10 \; V_p \, LDR$$

$$M_{traz} = \frac{5 \; q_{w\,(malla)} \, \Delta t_{pt} \; LDR}{f_{traz\,rec}}$$

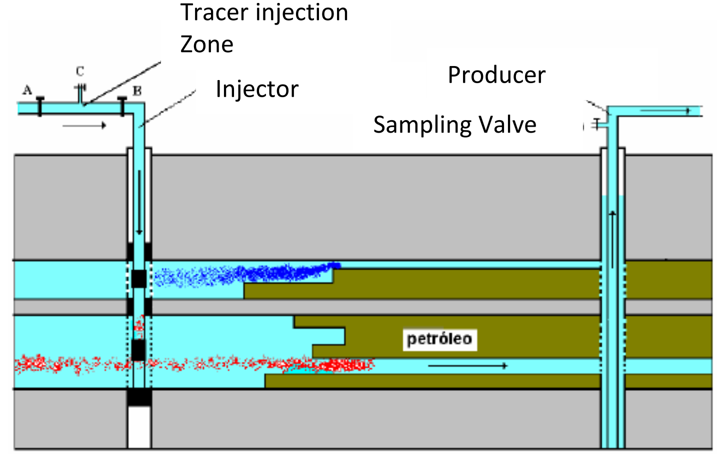
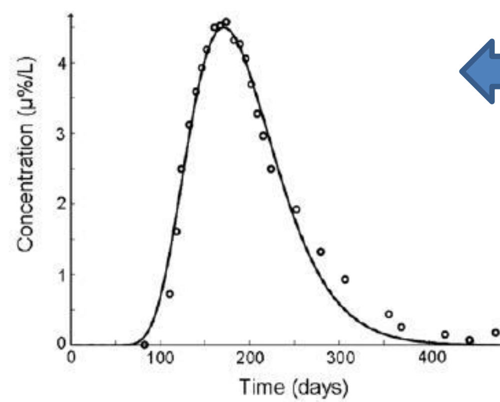
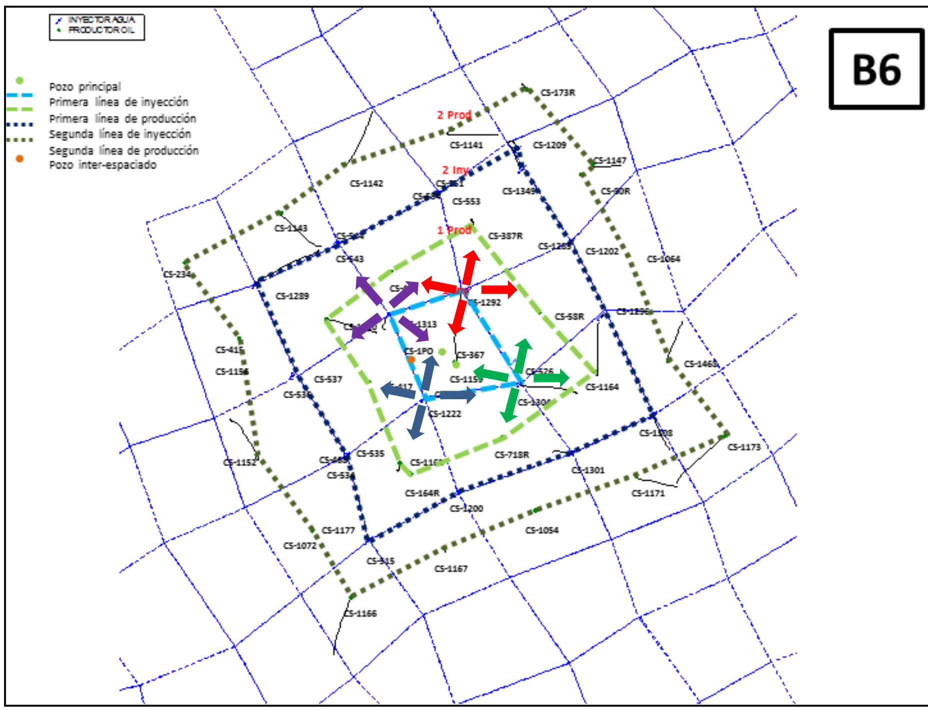
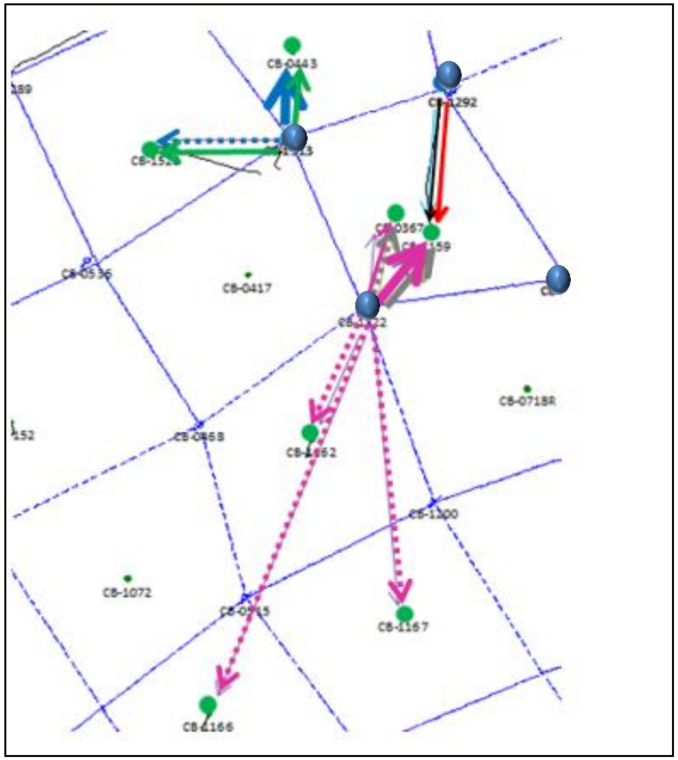


Figura 1: Esquema de un ensayo trazador.



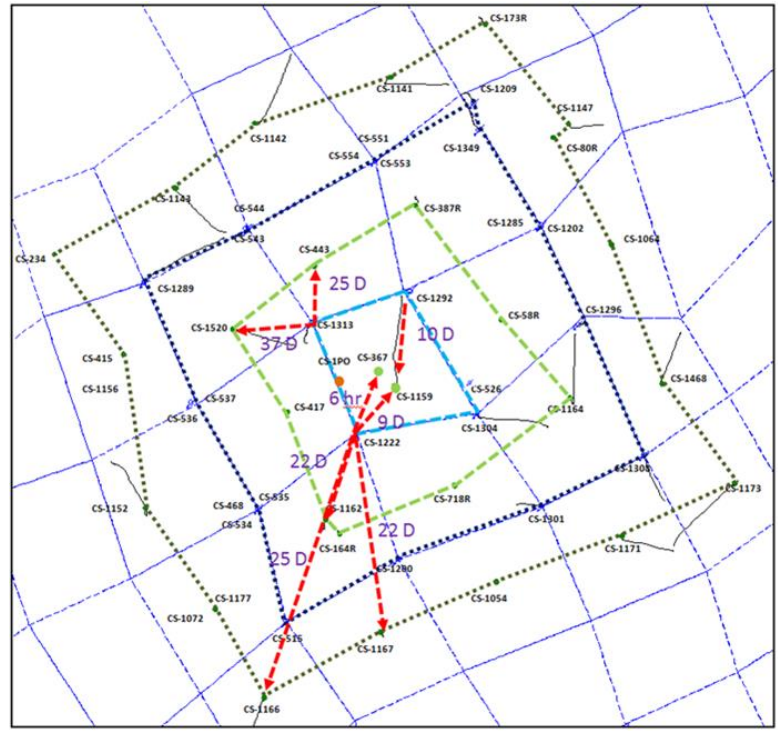


InterWell Tracer Irruptions Map



Black	2 FBA	CSBE-1292 A2i
Red	4 FBA	CSBE-1292 A2
Green	2,3,4,5 FBA	CSBE-1313 A2i
Blue	3,5 FBA	CSBE-1313 A2
Pink	2,6 FBA	CSBE-1222 A2i
Grey	2,3,4 FBA	CSBE-1222 A2
Oranje	3,5 DFBA	CSBE-1304 A2
Yellow	3,4 FBA	CSBE-1304 A2i

A2i Sand Example



- InterWell Tracer Irruption observed on both sands A2 (Upper) and A2i (Lower)
- InterWell Tracers confirm Sand deposition direction.
- Irruption on 2nd line production wells confirm complex channeling system.
- Base on irruption times severe channeling is observed between CSBE 1222 (INY) and CSBE-1159 (Central Well)

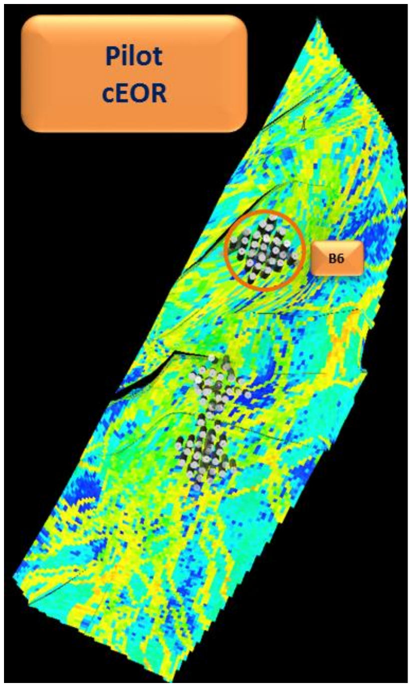
Viscosity reduction test on injection valves

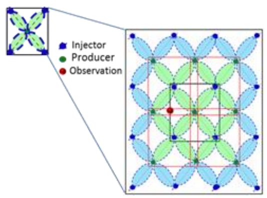
MUESTRA AGUAS ARRIBA DE VÁLVULA	19 Cp			
Válvula Tipo	VC 9 mm	VC 3 mm	VRF 5 mm	VRF 4 mm
Caudal de Prueba	500 bbl/d	260 bbl/d	320 bbl/d	200 bbl/d
Dp de Prueba	900 psi	900 psi	900 psi	900 psi
Muestra 1	18 Cp	7.5 Cp	9 Cp	6 Cp
Muestra 2	19 Cp	8 Cp	5 Cp	3 Cp
Muestra 3	19 Cp	8 Cp	6 Cp	4 Cp

Circulation Valves

No reduction effect on 9 mm circulation valves. Dramatic viscosity reduction on flow regulation valves

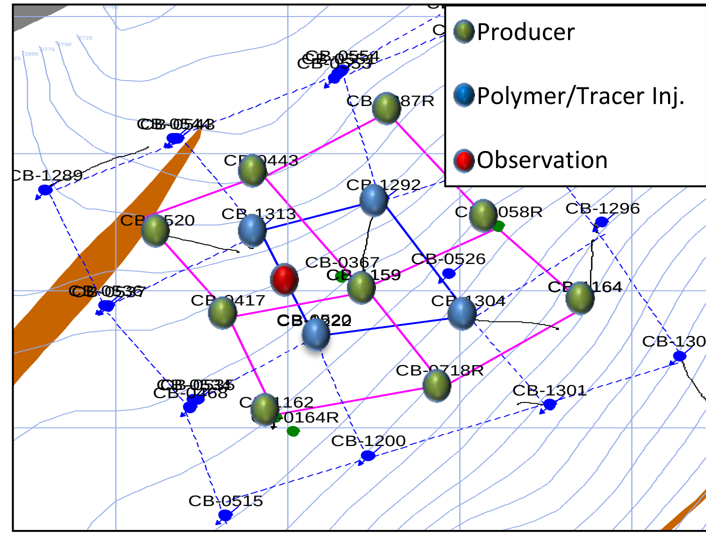
cEOR Project Design



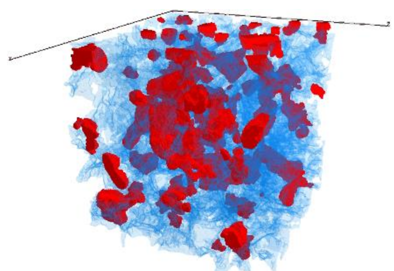


- **Block 6.**
  - ✓ 4 Polymer Injector Wells
  - ✓ 9 Oil Producer Wells
  - ✓ 1 Observation Well
  - ✓ Comingle Production
  - ✓ Selective Polymer Injection

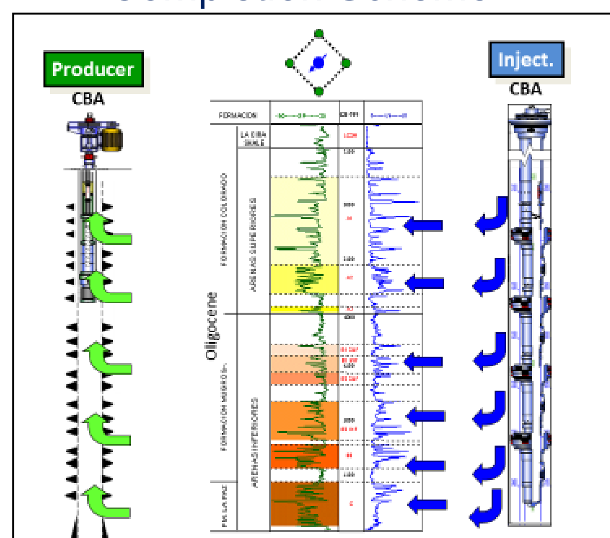
Pattern Distribution



Porous Media

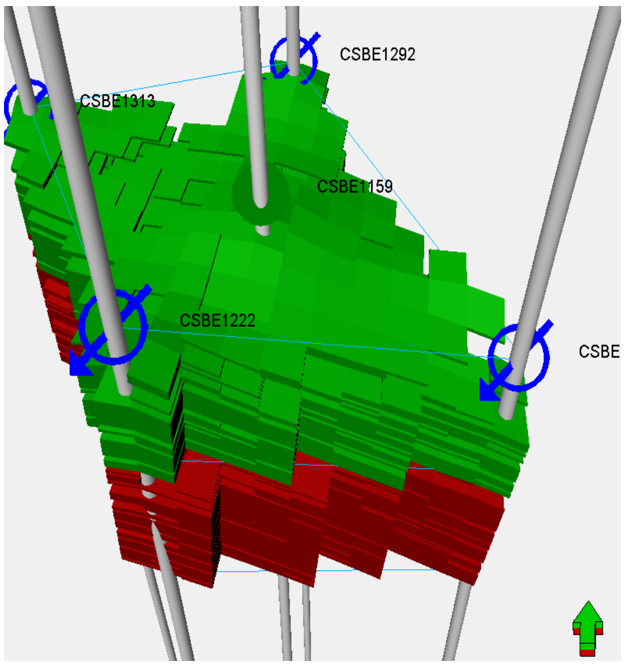


Completion Scheme



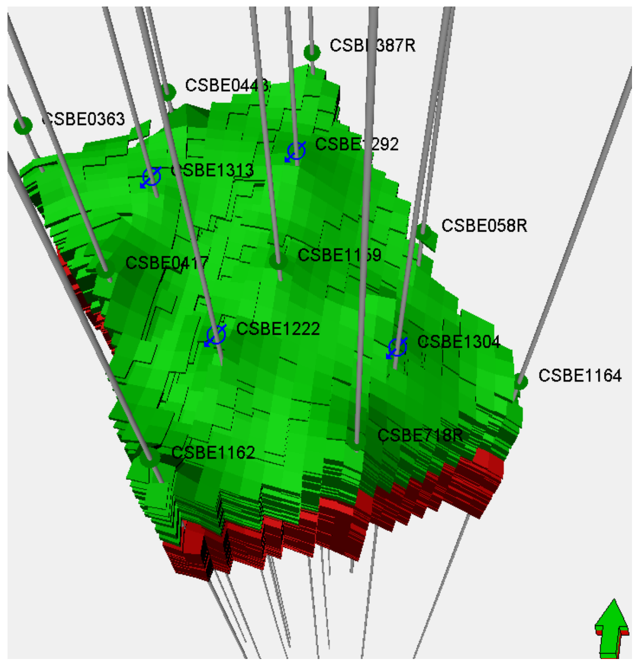
Simulation Cases

- Four (1/4) Injectors



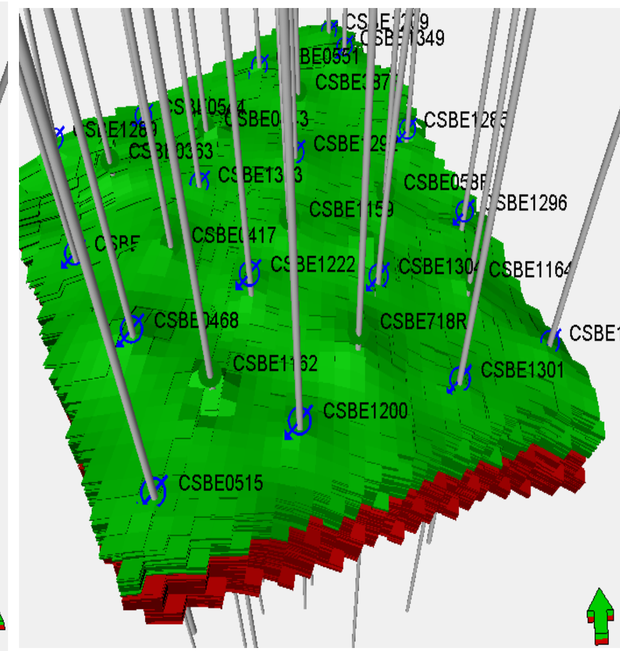
Five Spot Pattern

- Four injectors



Four Inverted Five Spot Patterns

- Sixteen Injectors



Four Inverted Five Spot Pattern

Implementation of the surveillance plan

Preparation & Baseline

- Understand actual well behavior.
- Know actual well mechanical conditions
- Identify prod/inj. enhancement opportunities before the pilot
- Baseline preparation

Monitoring During Pilot

- Monitoring key variables to make decisions related to changes in injection parameters.
- Ensure wells are operating at optimum conditions

Pilot Evaluation

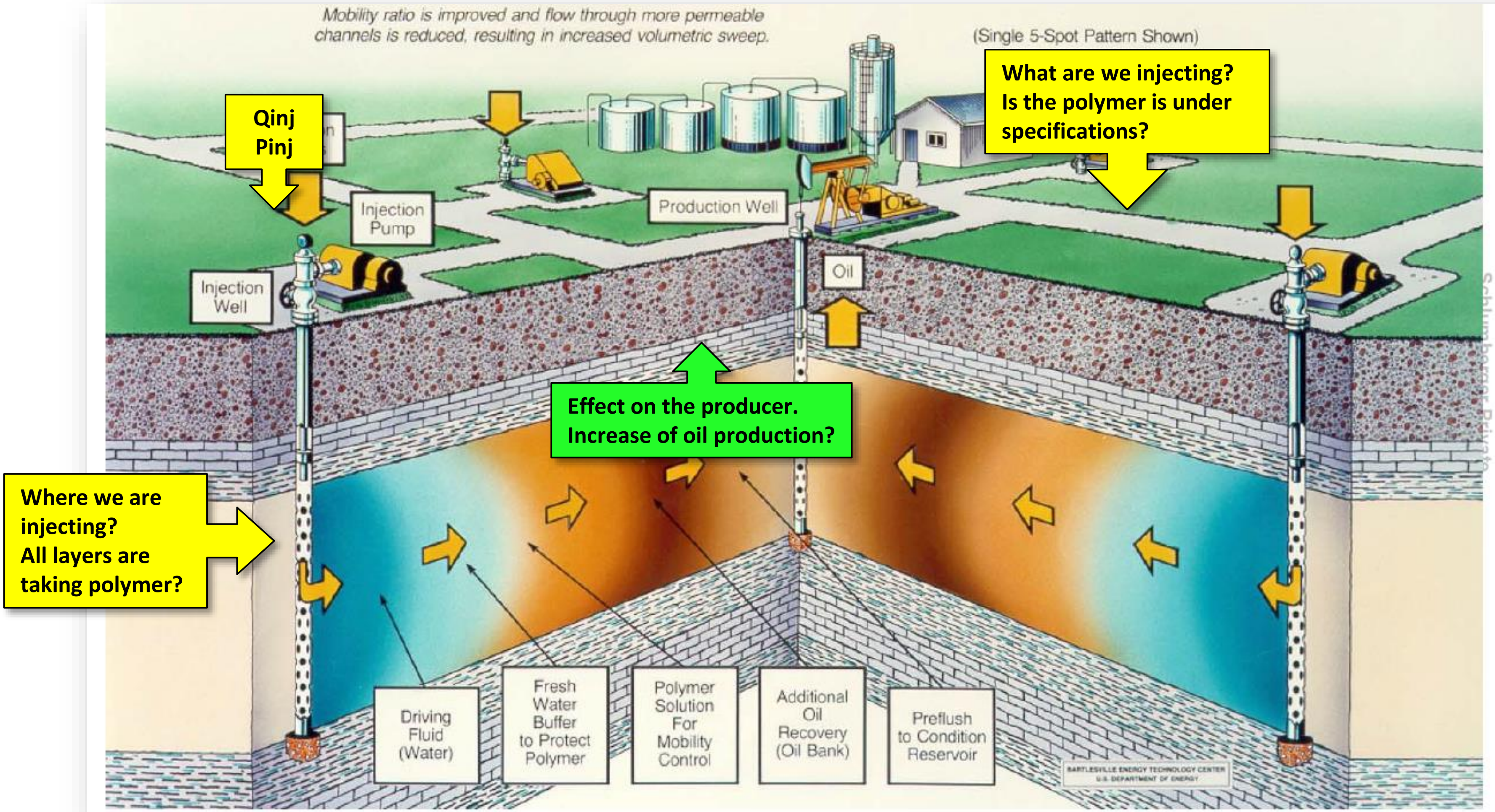
→ No Go

→ Pilot Expansion

Field Challenges

✓ Selective injection	✓ No real time data for production/injection optimization
✓ Water flow regulator valves	✓ Sand production
✓ Commingled production	✓ Different type of ALS with rods
✓ Low Production Rates	✓ High water cut
✓ Poor production monitoring	✓ Casing/tubing damage

Surveillance plan



Preparation & Baseline → Monitoring During Pilot

Initial Evaluation:

Schlumberger
One Stop Shop Concept

Producers:
- Casing integrity evaluation
- Initial production distribution
- Production baseline

→ Corrosion and MultiFinger logs ★
PLT at different flow rates (SIP analysis)
Multiphase flow meters ★

Injectors:
- Initial injection profile
- Injectivity tests
- Sand in annular

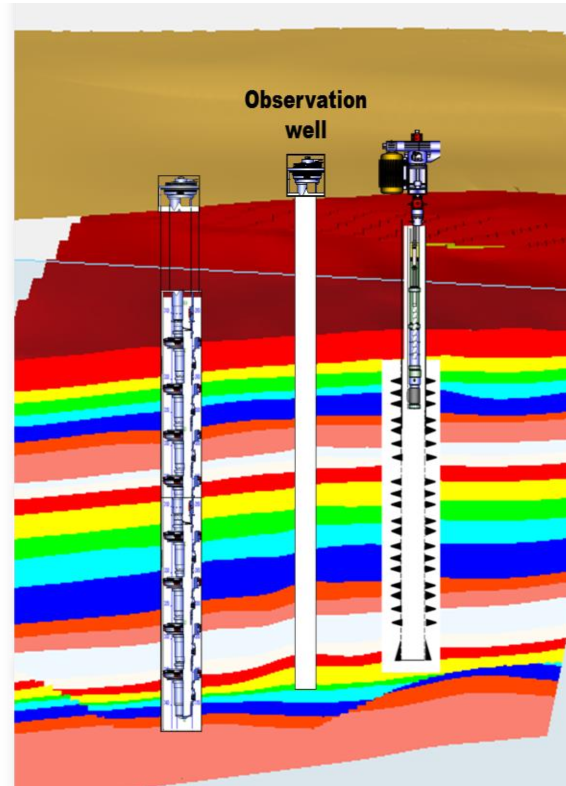
→ DSL ★
WS surface pumps
RST silicon activation log ★

Observation well:
- Initial oil saturation
- Initial formation pressure

→ RST-C/O ★
XPT

Reservoir:
- InterWell tracers

→ Well connectivity
Channel size ★
Breakthrough times



NT in Casabe ★

Preparation & Baseline

Monitoring During Pilot

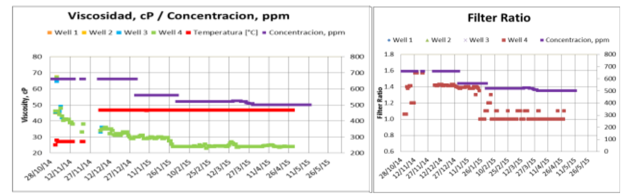
Schlumberger

One Stop Shop Concept

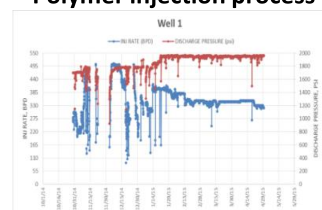
Data Acquisition program:

	Frecuency
Prodution monitoring with multiphase flow meters (# of well tests monthly)	2 well test daily
Wellhead preassure	Real time
ALS parameters	Real time
PLT with wireline	Each 6 months
Downhole pressue gauges	# gauges installed
Polymer injection presure and rate	Daily
Viscosity, concentration, filter ratio	Daily
Polymer stock	Weekly
Injection profiles	Each 2 weeks
Oil saturation	Each 6 months
Formation pressure (PLT and downhole pressure gauges)	As requiered
QA/QC (days per month) QC polymer, polymer breaktrough in producers , water quality, viscosity, filter ratio, concentration	Monthly

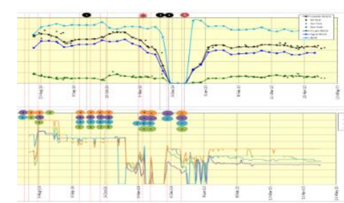
Polymer specifications



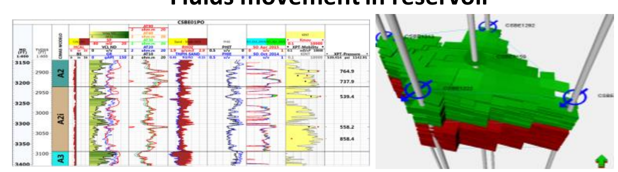
Polymer injection process



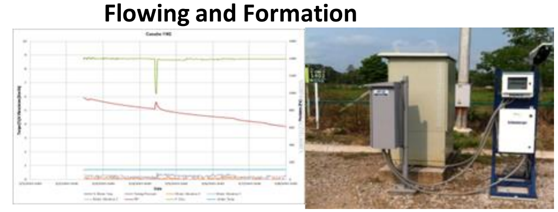
Prod/Inj Analysis



Fluids movement in reservoir



Flowing and Formation

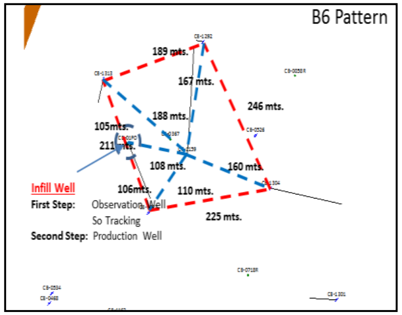


NT in Casabe

EOR Pilot Performance Evaluation

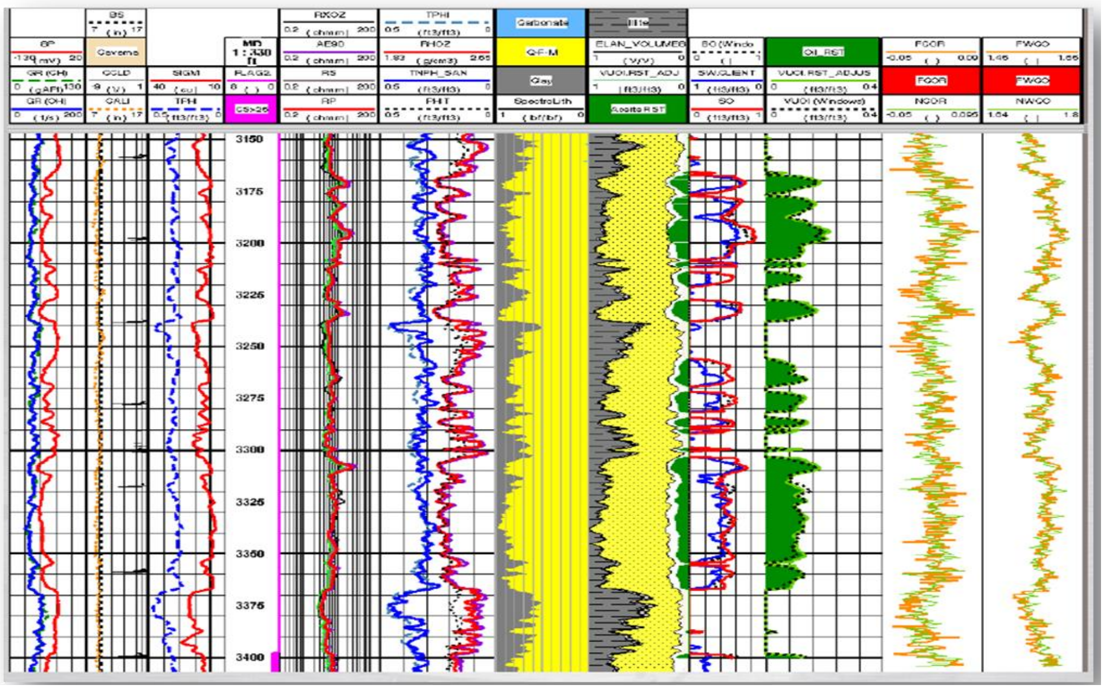
Observation Well

Well Location



Original Oil Saturation

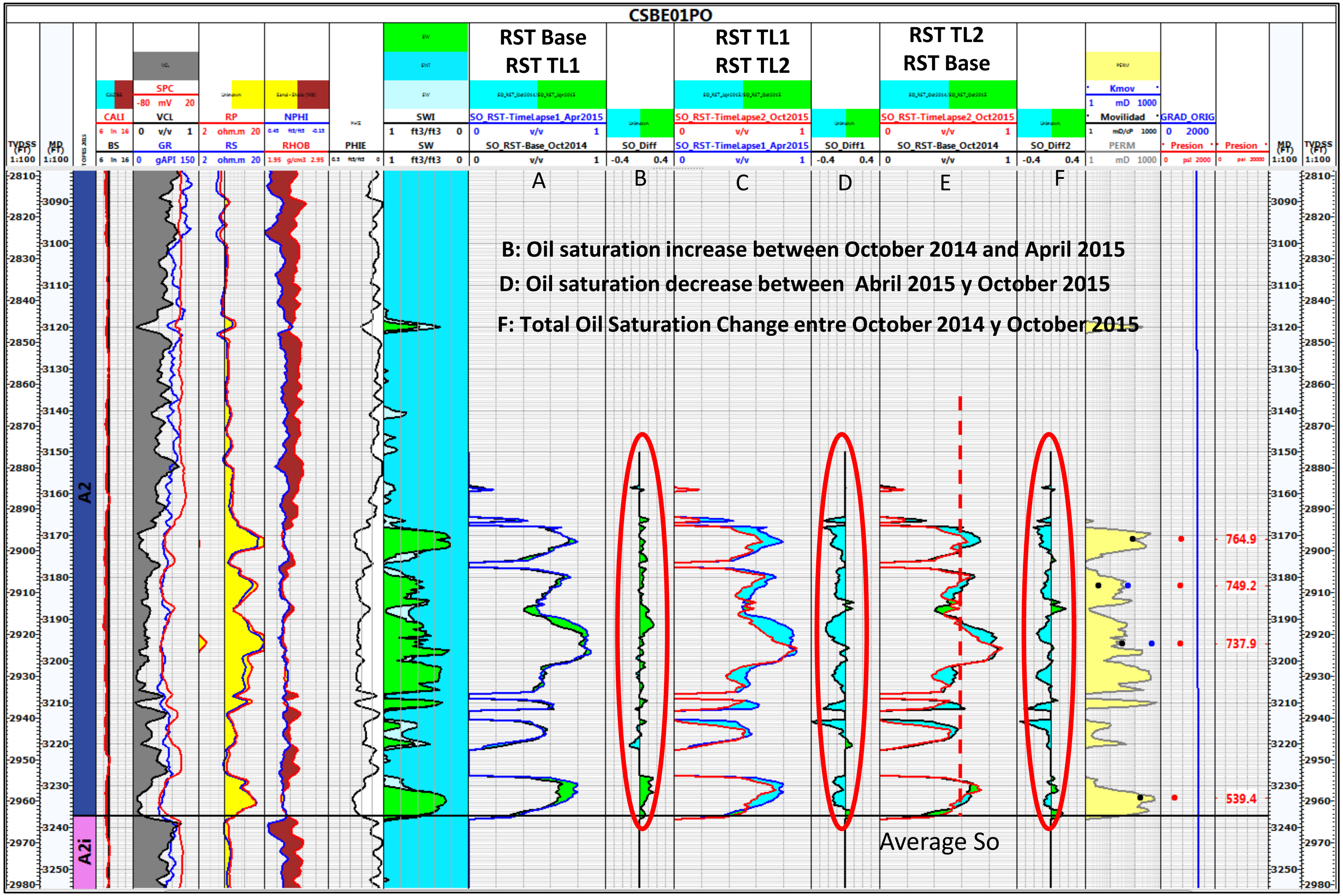
- Shows good Original Oil Saturation
- Not sweep oil



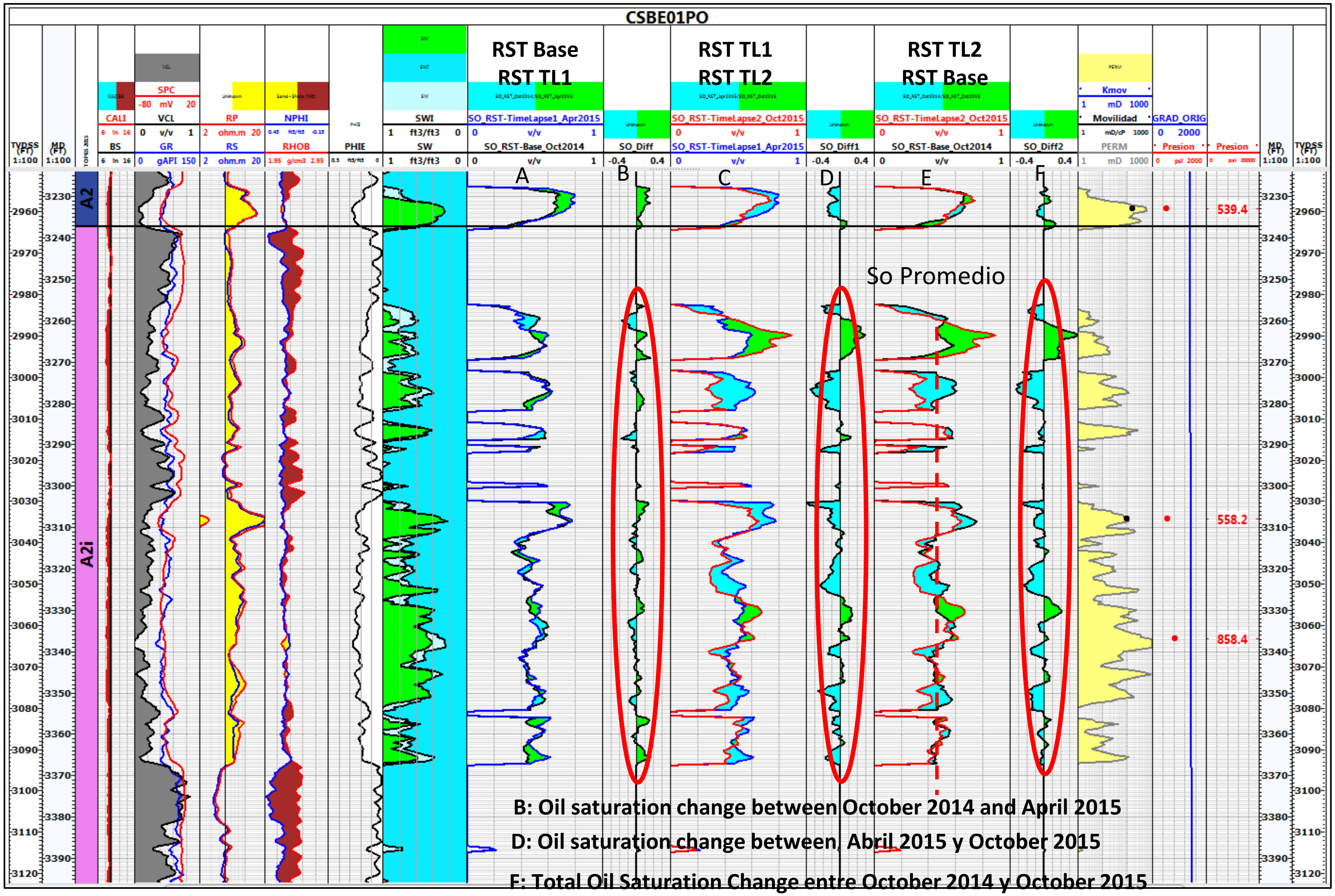
OBSERVATION WELL OBJECTIVES

- Observation well to evaluate increase in sweep efficiency of polymer injection in A2/A2i sands.
- Infill drilling well to evaluate the efficiency of reduction in the injection – production pattern spacing.

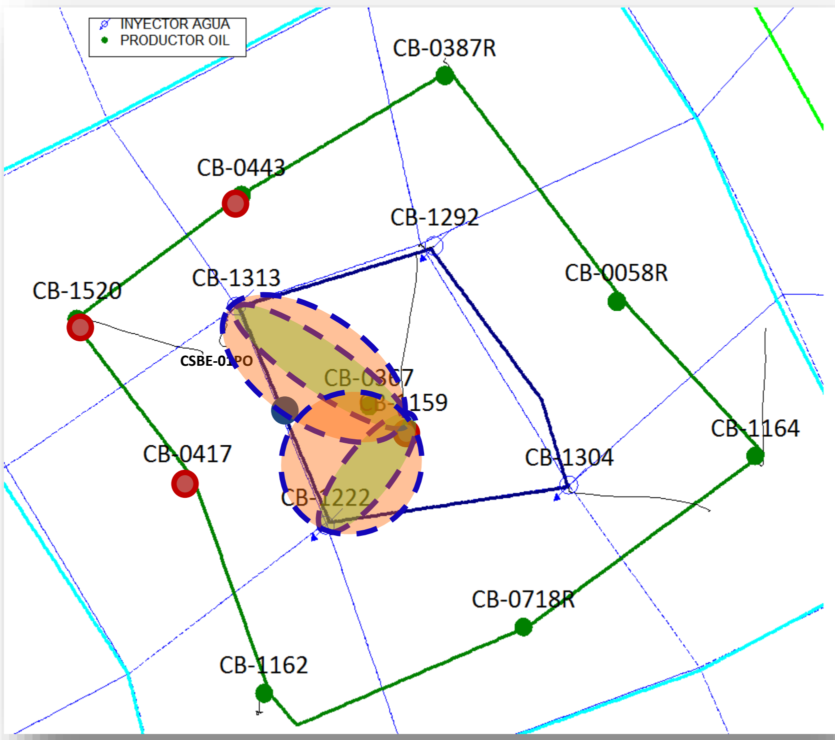
RST Time Lapse. A2 Sand



RST Time Lapse. A2i Sand

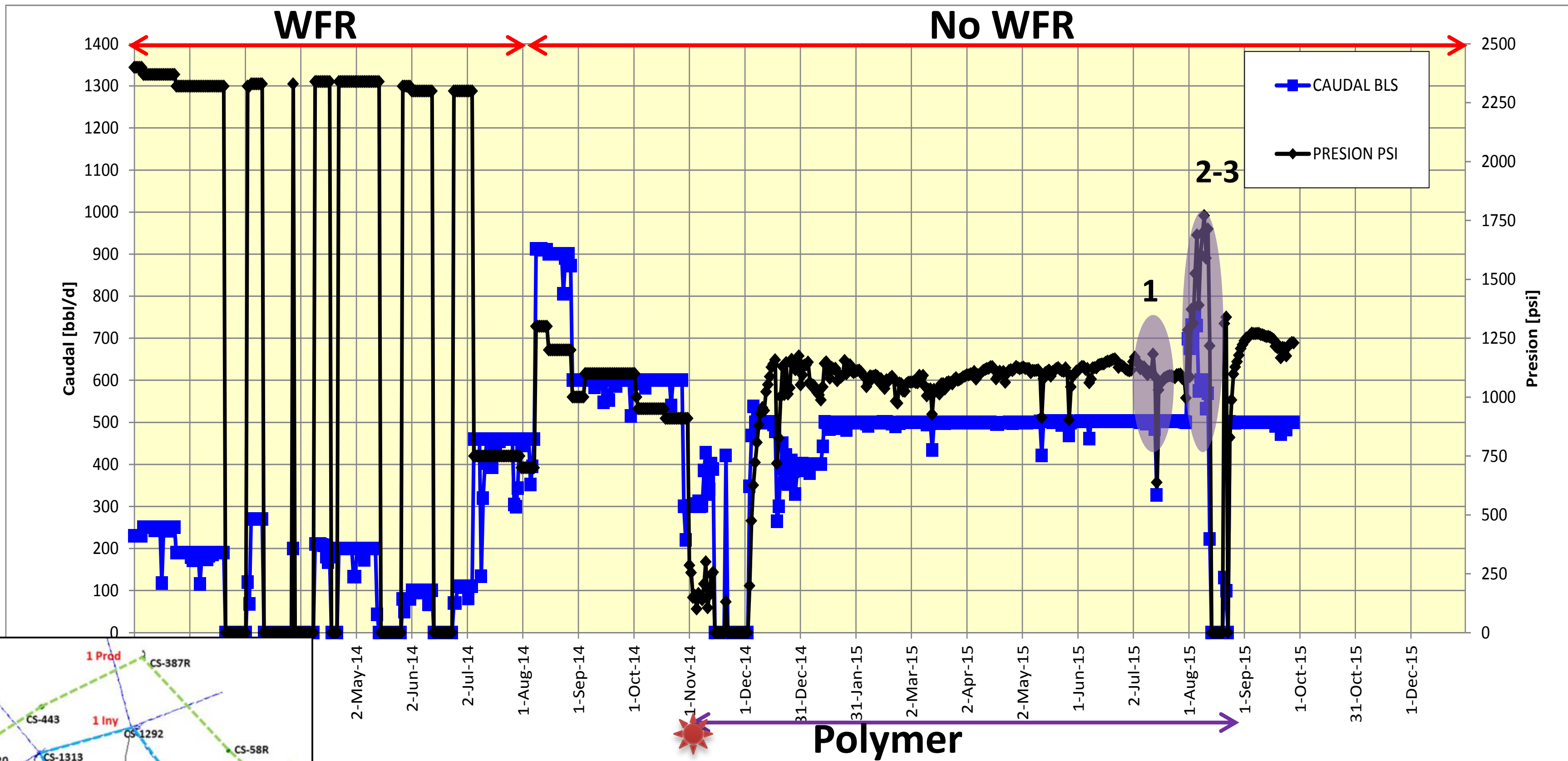


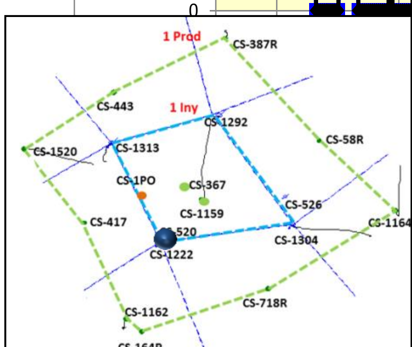
Flow Behavior



1. **Initial Saturation Condition :** Original So
2. **RST @ 6 months:** So increase, oil front reached observation well.
3. **RST @ 1 year:**
   - Preferential drainage.
   - Channels with So reduction due polymer flood effect, oil is pushed to neighbor wells.
   - Channels with So increase due polymer flood effect, entrapment due to lack of drainage points.
4. Proof of concept of areal sweep increase.

Injector Well CSBE-1222

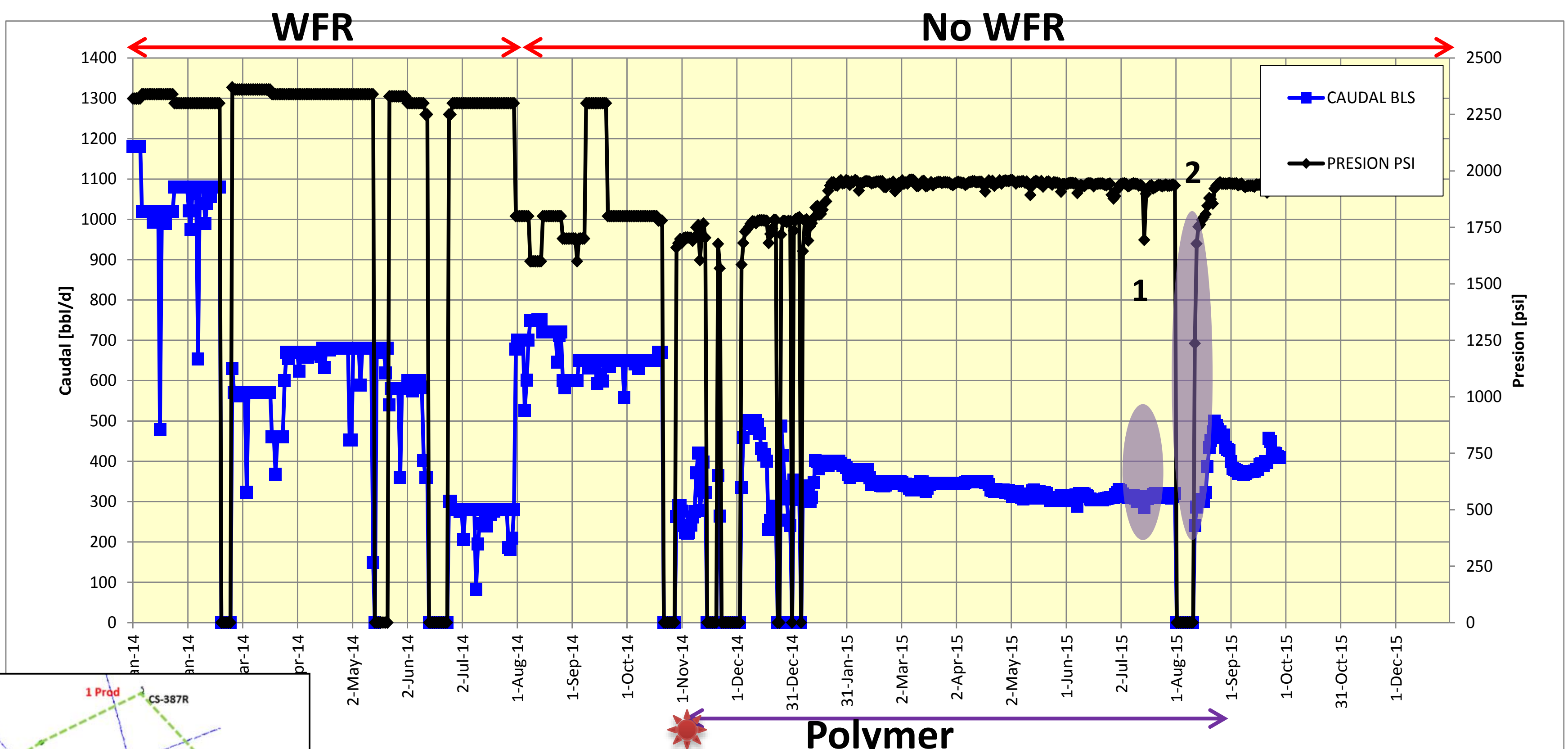


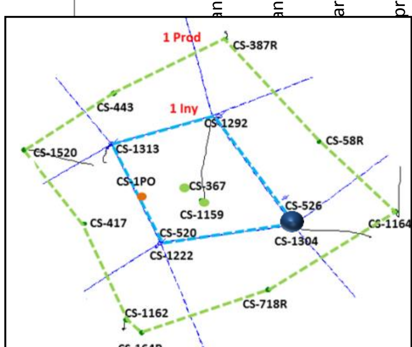


CSBE-1222 shows good injectivity both water and polymer.

1. Concentration reduction to 400 ppm
2. Conformance with mother solution at 3000 ppm - A2i
3. Hypochlorite Clean Up - A2

Injector Well CSBE-1304

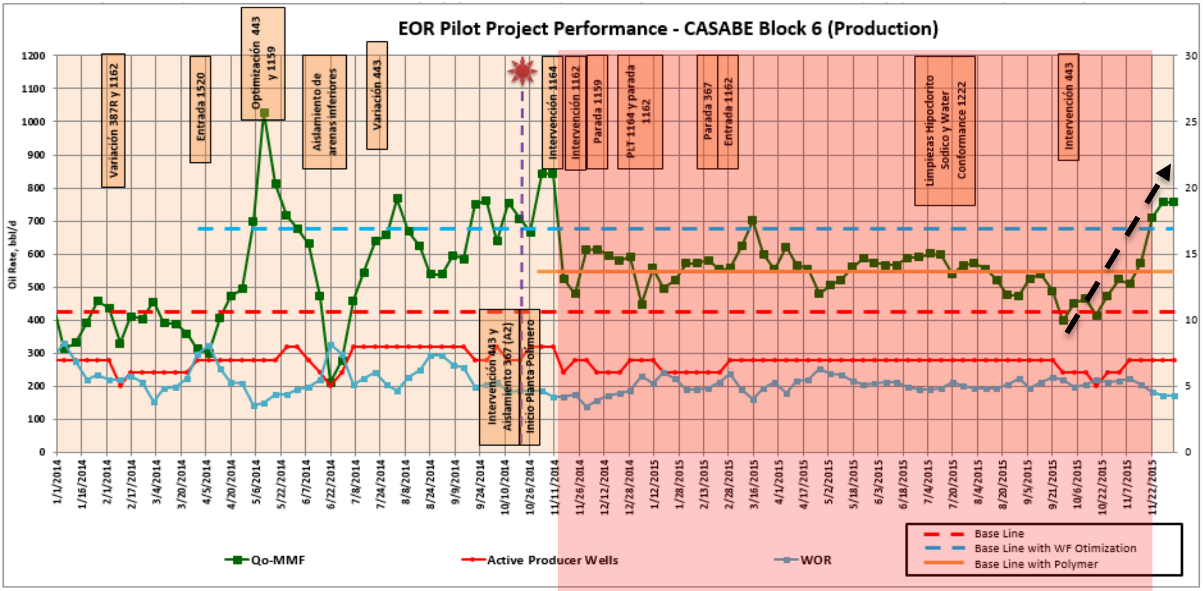


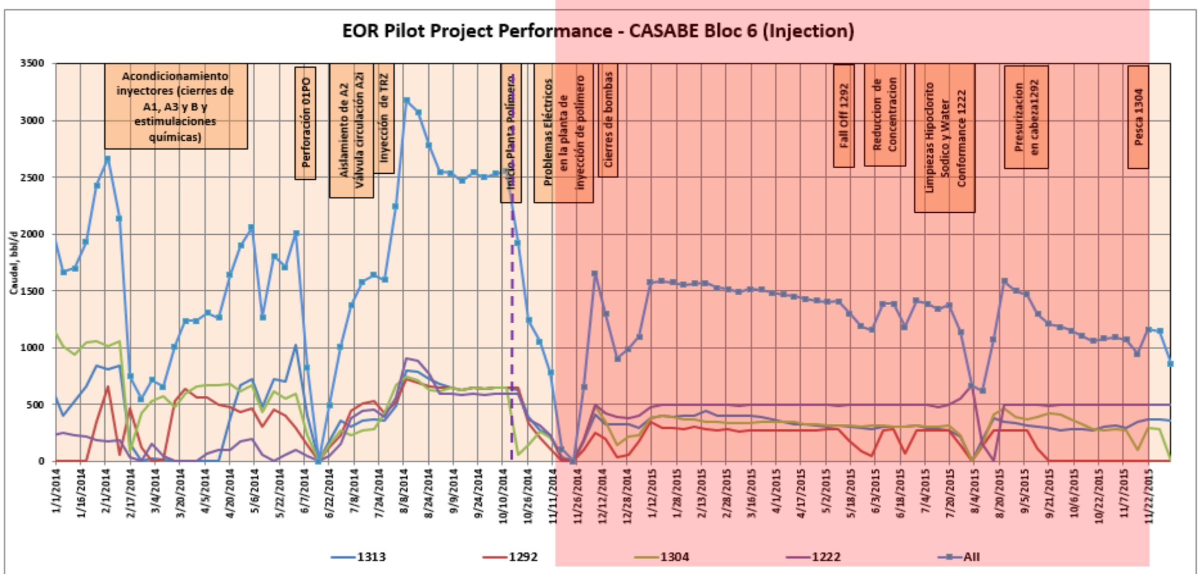


CSBE-1304 shows reduction of injectivity due lack of drainage points.

1. Concentration reduction to 400 ppm
2. Hypochlorite Clean Up - A2. Injection increased.

B6 Pilot Pattern Performance





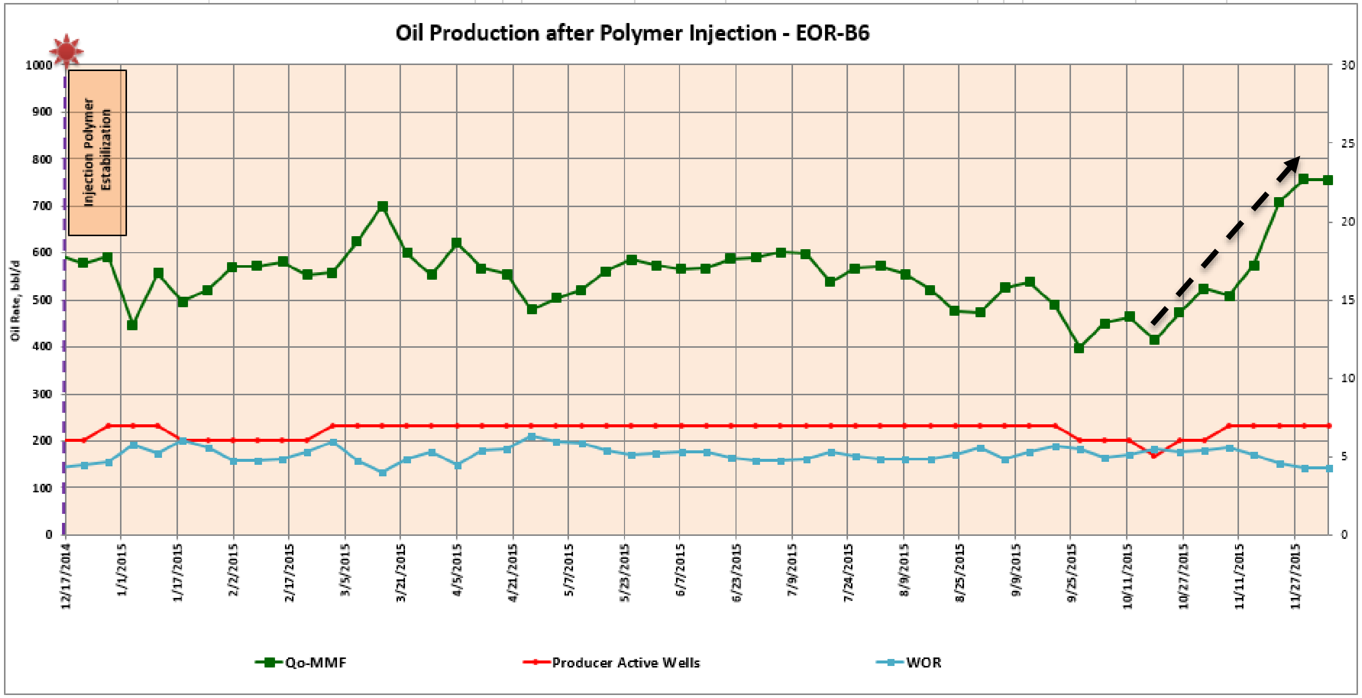
Prior polymer injection, pattern optimization shows a increase in oil production.

Polymer Injection stabilization occurred since January 2015.

Dramatic water production decrease after polymer injection.

Oil Production Increase after 8-9 months of polymer injection.

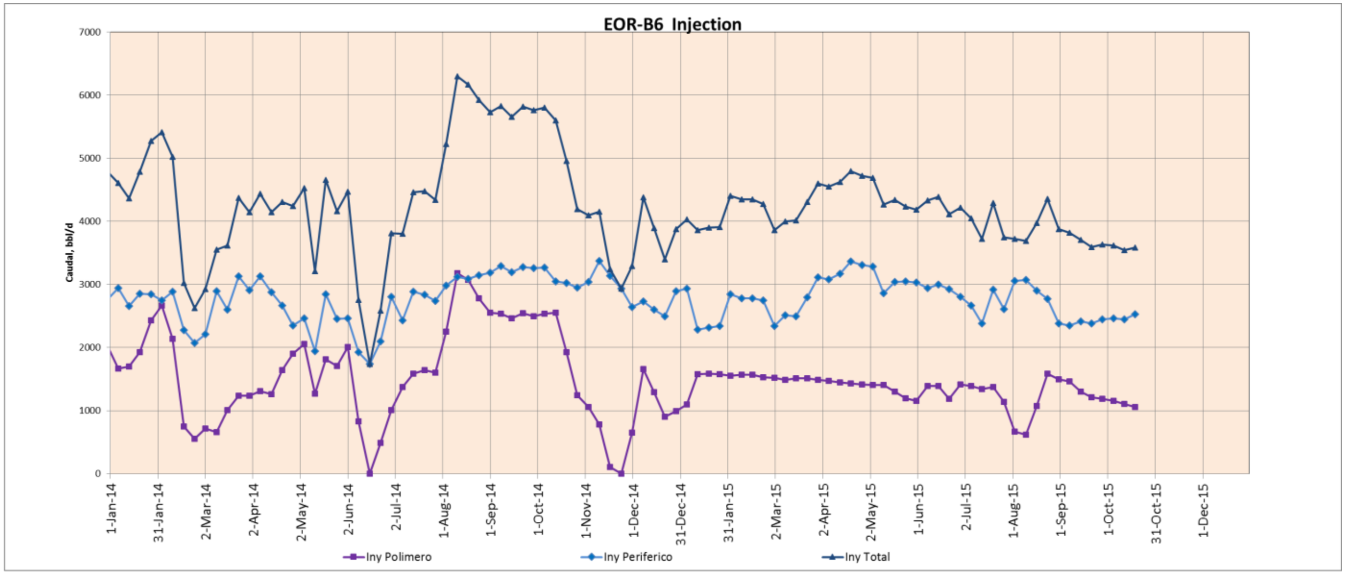
B6 Pilot Pattern Performance

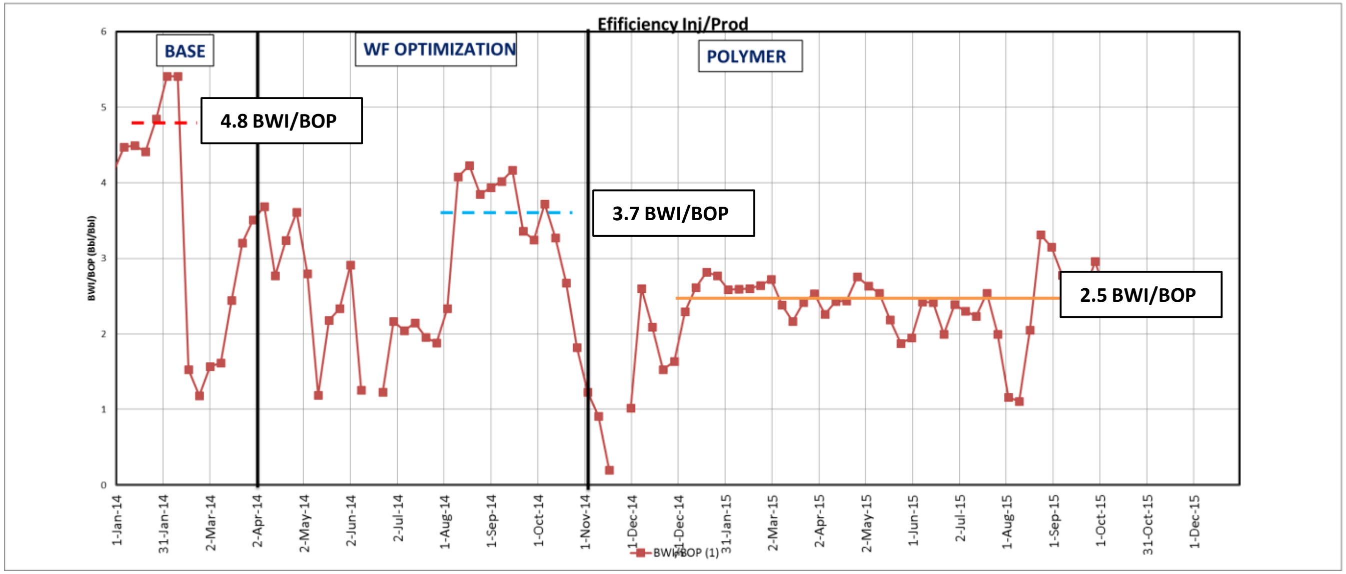


Oil production increased after pattern optimization. After polymer injection oil production decrease slightly but water production decrease drastically.

After 8-9 month oil increase.

B6 Pilot Pattern Performance





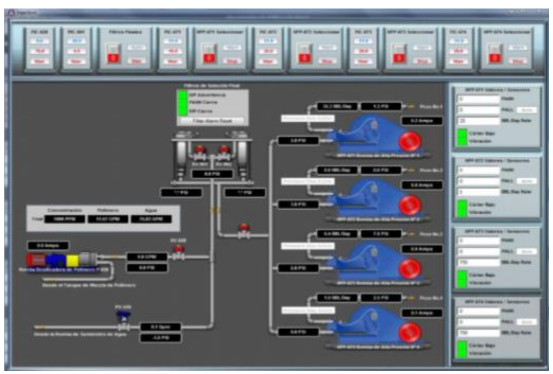
Sweep efficiency increase observed after Water Flooding optimization. Polymer Flood show sweep efficiency over Water flooding. Decrease barrel of water injected by barrel oil produced.

Facilities Installation

Polymer injection started in October 28 2014, in four polymer injector wells.
Total injection capacity is 3.000 B/D of 500 ppm polymer solution at 2,000 psi

Polymer Mixing and Injection Unit

Polymer Mixing and Injection Unit



Polymer Unit Control Panel

Individual pump for each injector is used to allow individual pressure control

Conclusions

- Fast Track EOR is feasible and achievable

  With the right integration of Operator and Service Provider(s):

  18 months to pilot online

  36 months to proof of concept
- One Stop Shop to minimized tender, decision and handovers delays
- Successful Implementation of Casabe Pilot Project
- A surveillance plan for any EOR pilot is key to ensure the collection of critical data that will allow a proper evaluation of the pilot.
- The surveillance plan is determined by the characteristics and challenges of each field.
- The implemented plan is far more robust than conventional surveillance used at the field.
- Design, Operation & Surveillance must still be best in class and focus on earliest proof of concept
- A structured Team dedicated to the project is fundamental for success
- Synergy between different players across the organization are crucial to implement a fast track project