Chapter 6

DOE HORIZONTAL PROJECT

Why a Horizontal Waterflood?

Problems with Conventional Waterflooding

- Low injection rates
- High injection pressures
- Producing wells frac' d into water

Why a Horizontal Waterflood?

Benefits of Horizontal Waterflooding

- Inject large volumes of water
- High producing rates without fracture stimulation
- Bypassed oil in undrained compartments

Introduction

This project has been supported through a grant by the DOE NETL.

The opinions stated are those of the presenter.

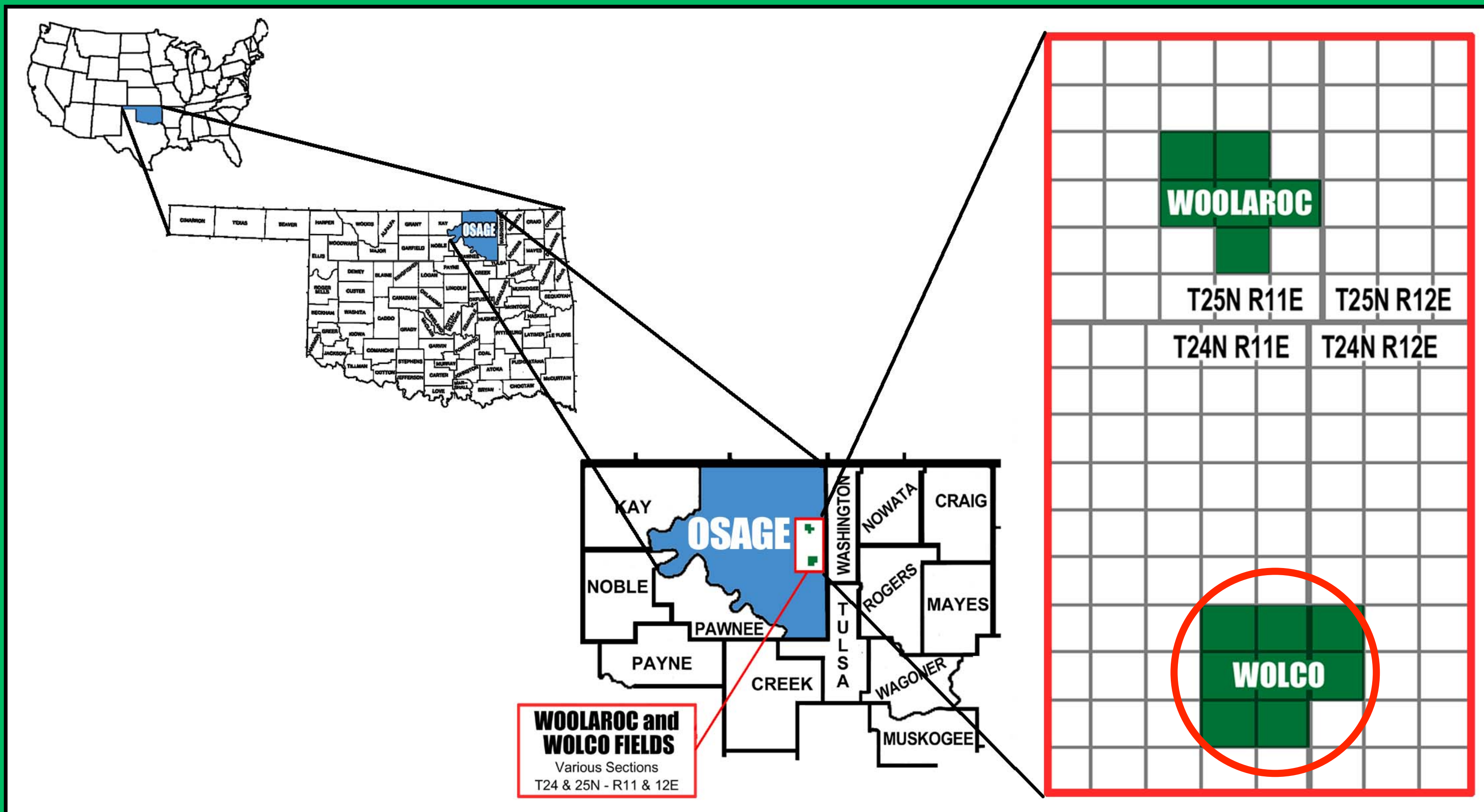
Introduction

- Background
- Reservoir Modeling
- Geologic Interpretation
- Planning the Project
- Drilling the Wells

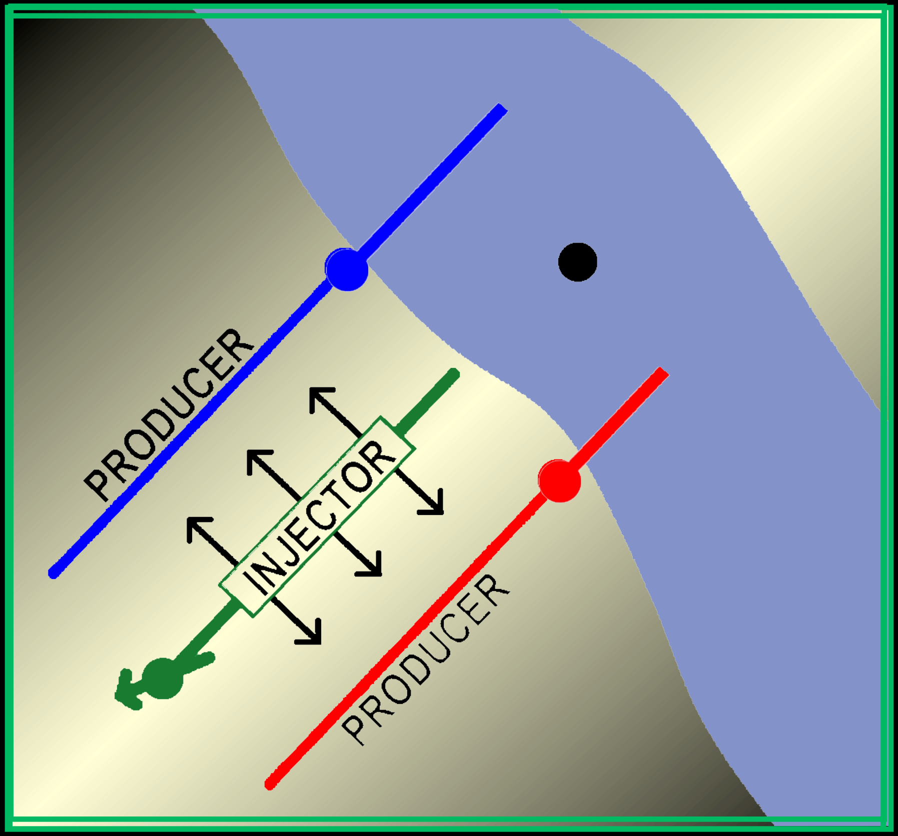
Introduction

- Evaluating the Initial Project Results
- Re-Drilling Operations
- Pilot Production Summary
- Conclusions
- Lessons Learned

Wolco


OSAGE
KAY
NOBLE
PAWNEE
PAYNE
CREEK
WASHINGTON
NOWATA
CRAIG
ROGERS
MAYES
TULSA
WAGONER
MUSKOGEE
WOOLAROC and WOLCO FIELDS
Various Sections
T24 & 25N - R11 & 12E
WOOLAROC
T25N R11E
T25N R12E
T24N R11E
T24N R12E
WOLCO

Evolving Pilot Test



Project Background

- Reservoir Candidate Screening
- Initial Reservoir Simulations
- Initial Pilot Selected
- Results of Original Pilot
- Second Pilot Selected
- Results of Second Pilot

Preliminary Reservoir Screening

Estimating OOIP

If there was only primary production then

Cum Production / 0.1 = OOIP

If there was primary + secondary production then

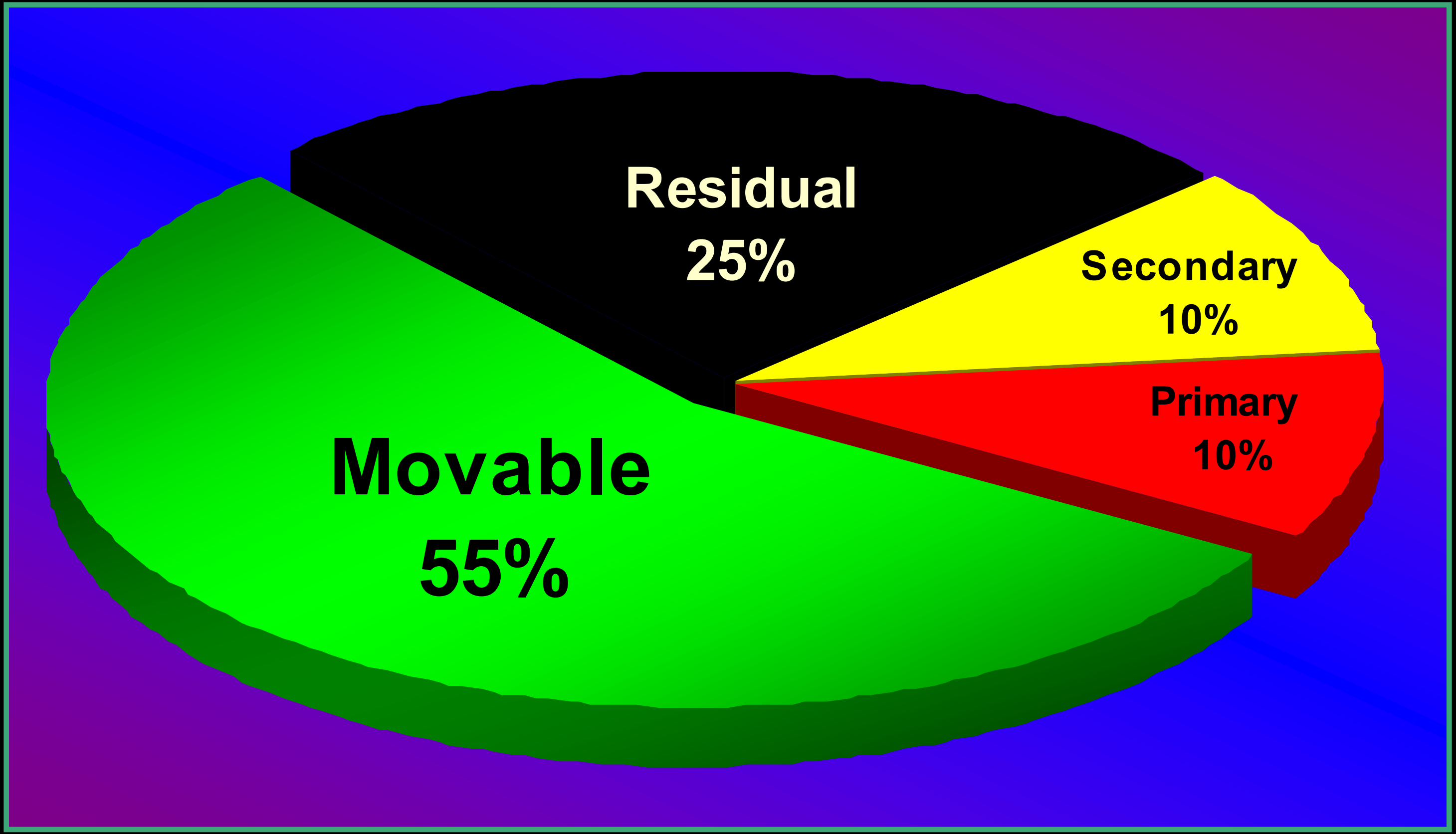
Cum Production / 0.2 = OOIP

Estimating Remaining Oil

= OOIP - Cum Production - 25% S_{RO}

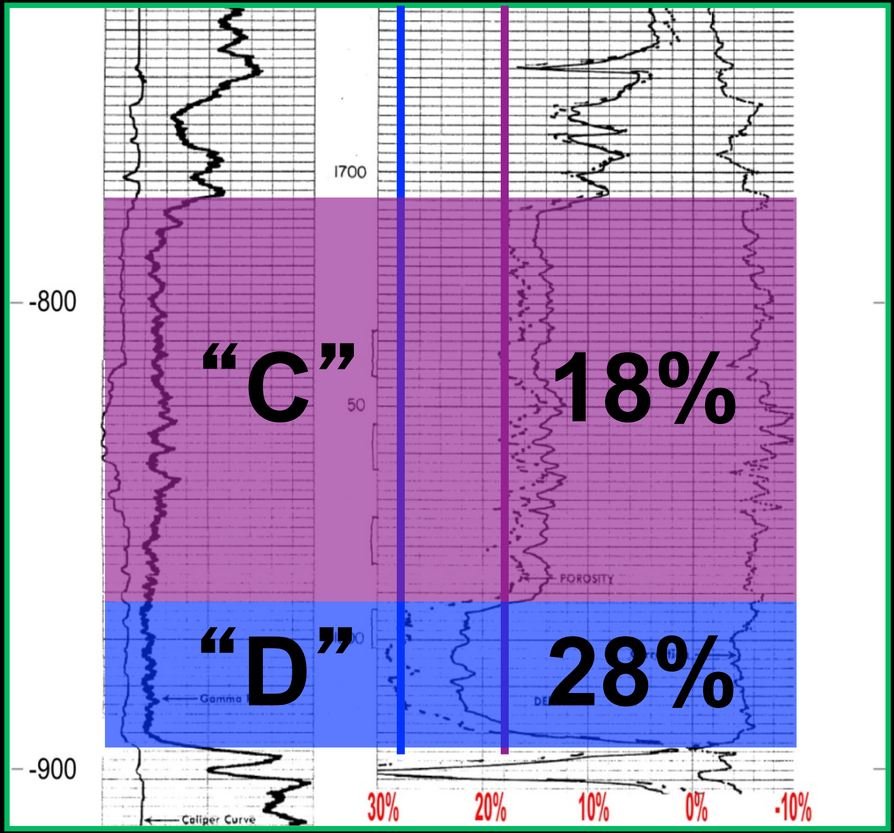
Initial Simulation Results

- Is there sufficient remaining oil?



Preliminary Reservoir Screening

Single layer or stratified reservoir?



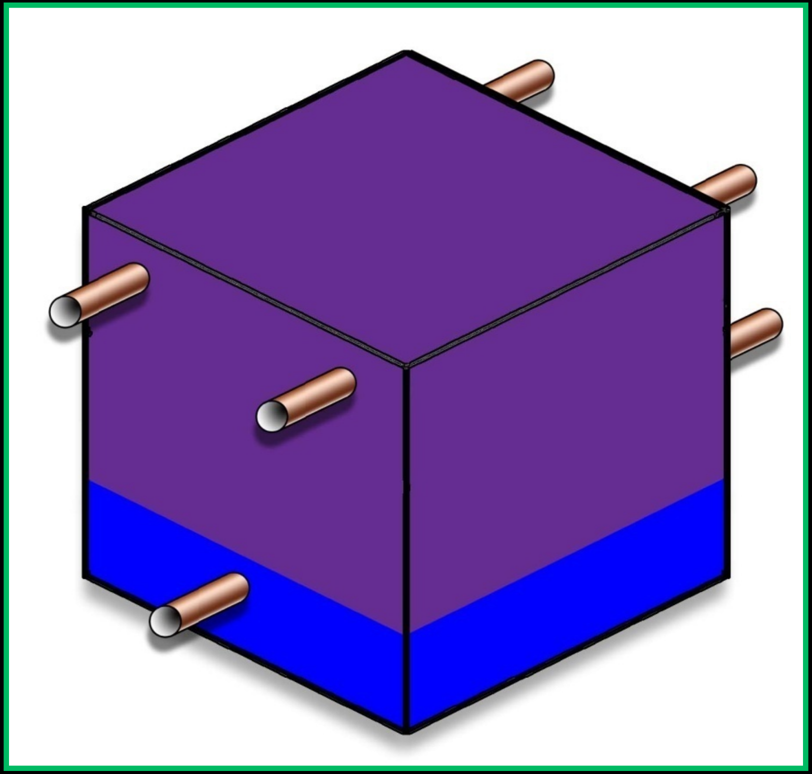
Initial Reservoir Simulation

- Obtain History Including Offset Leases
  - Evaluate Technical Information
  - Open and Cased Hole Logs
  - Core Reports
  - Engineering Reports
  - Osage Agency Reports

- Model Reservoir

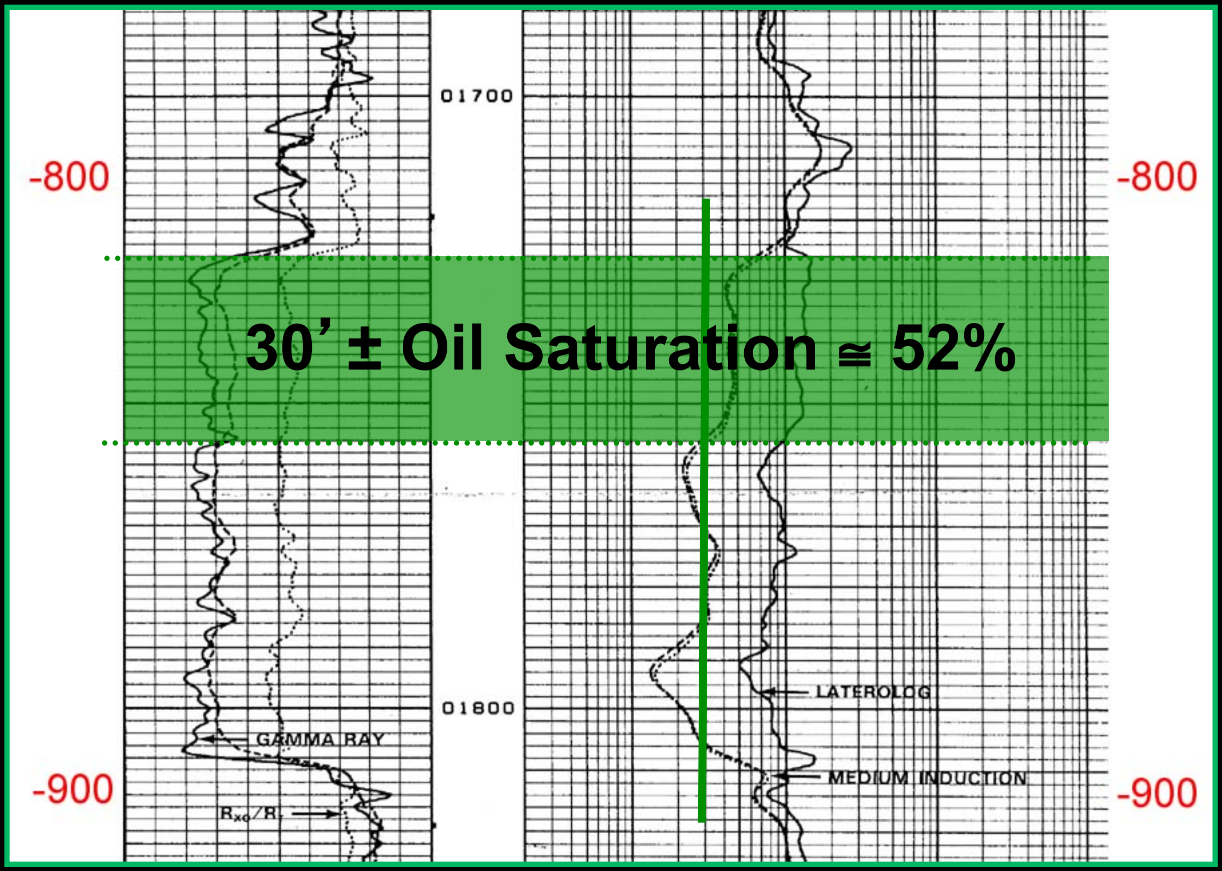
Initial Simulation Results

Vertical Permeability vs. Horizontal Permeability

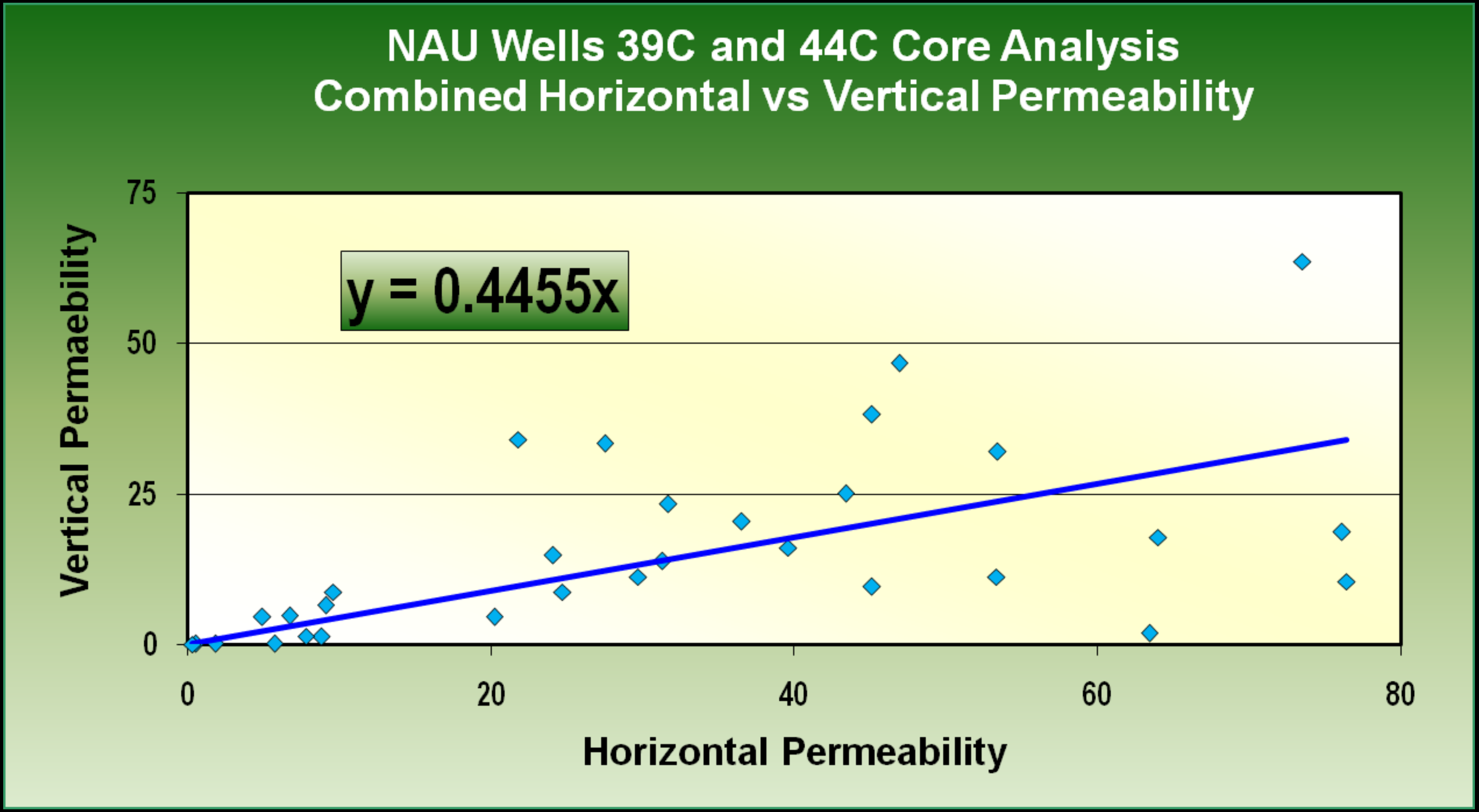


Wolco

Oil saturation determination

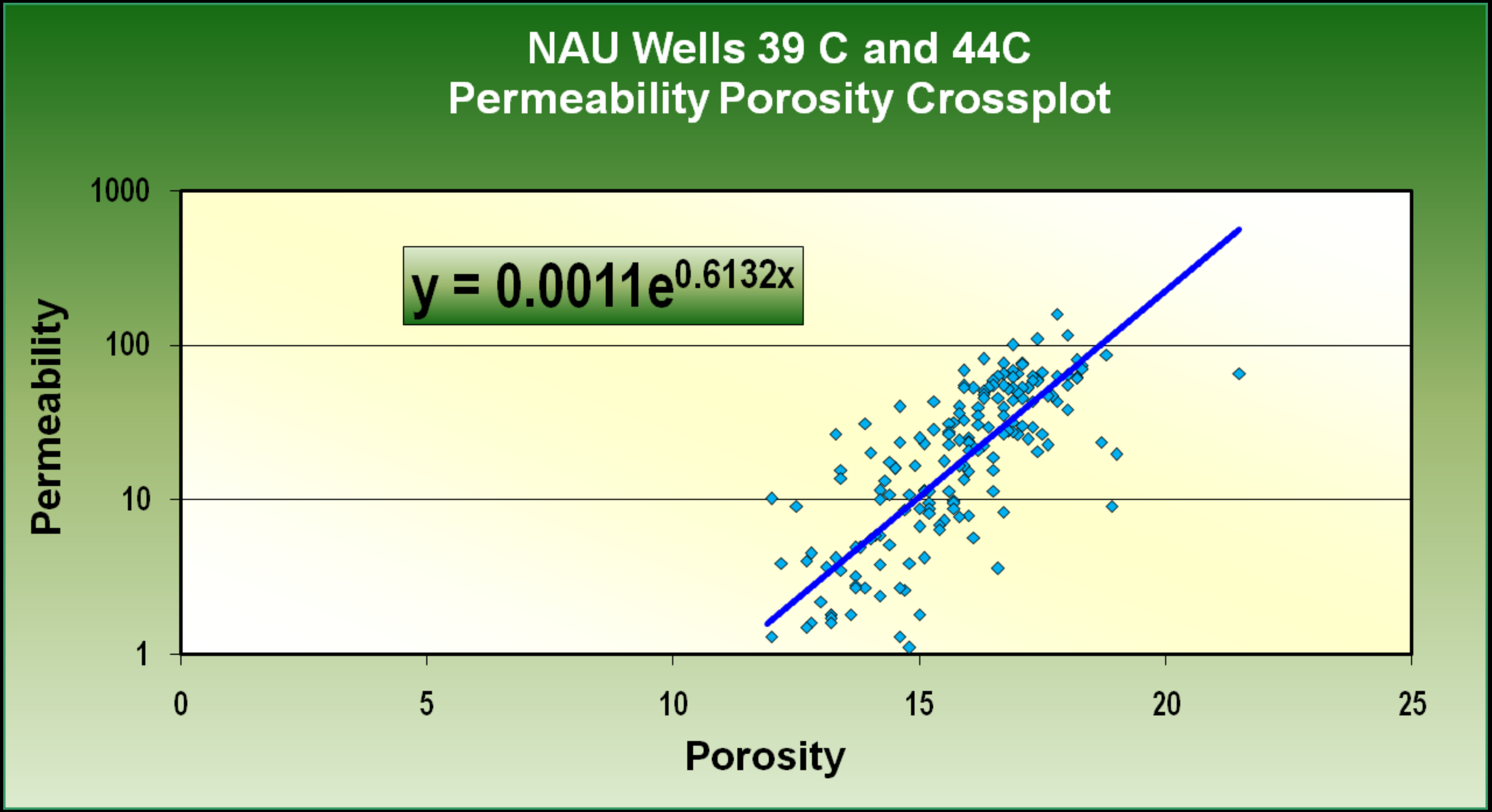


Wolco



NAU Wells 39C and 44C Core Analysis
Combined Horizontal vs Vertical Permeability
y = 0.4455x
Vertical Permaebility
Horizontal Permeability
75
50
25
0
0
20
40
60
80

Wolco



NAU Wells 39 C and 44C
Permeability Porosity Crossplot
y = 0.0011e^0.6132x
Permeability
1000
100
10
1
0
5
10
15
20
25
Porosity

Wolco

Oil Saturation ✓

Vertical v. Horizontal Permeability ✓

Horizontal Permeability ✓

Geologic Interpretations

Geology Depositional Environment

- C Zone: 14-16% Porosity
  D Zone: > 20% Porosity

- Fluvial Dominated Deltaic

- Incised Valley Fill

Geologic Interpretations

Rock Mechanics

- Dr. Leonid Germanovich
  - Rock Mechanics Dept. - Georgia Tech

- Avant Cores – from OGS Core Library

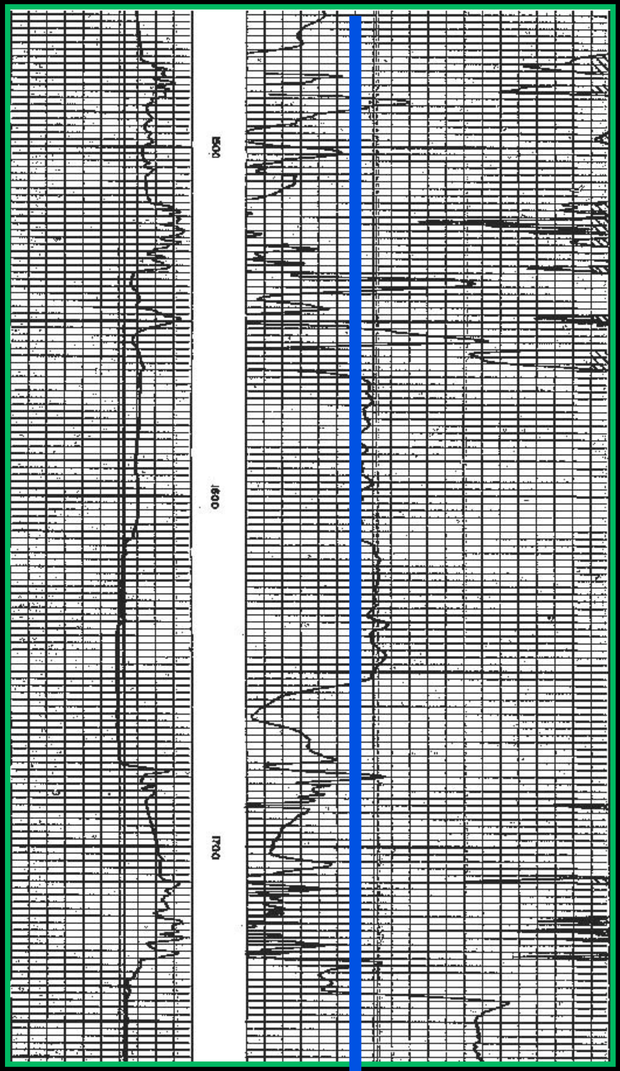
- Sonic Log Evaluation for estimating compressive rock strength

Geologic Interpretations

Rock Mechanics

"Estimating Compressive Strength from Travel Time from Sonic Logs"

by Ken Mason



Geologic Interpretations

Rock Mechanics

- Sonic log determines borehole stability
- Compressive strength estimated from sheer wave values
- Compressive strength based on porosity
- Locally porosity < 25% is stable enough for open hole completion

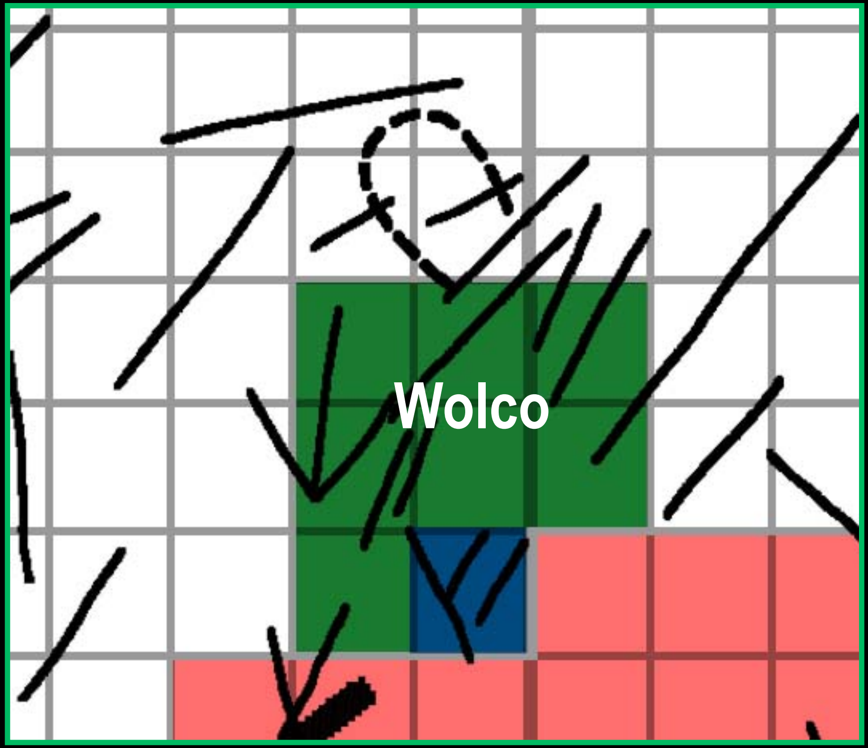
Geologic Interpretations

Natural Fractures

- Osage Surface Fracture Mapping Project

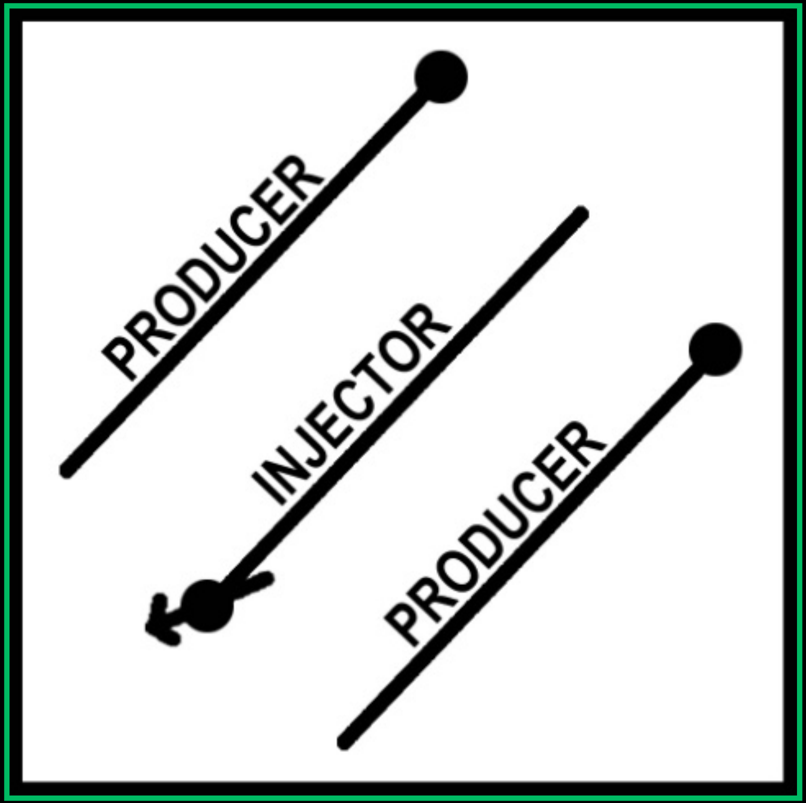
- Primary fracture direction at surface ~ N35E

- <u>Assumed</u> same at Bartlesville zone



Wolco

Heel -to -toe configuration



Geologic Interpretations

Key Project Decision Points

- Horizontal wells should be drilled parallel to the predominate fracture orientation

- In the Bartlesville reservoir, horizontal wells can be drilled with air using and completed open hole

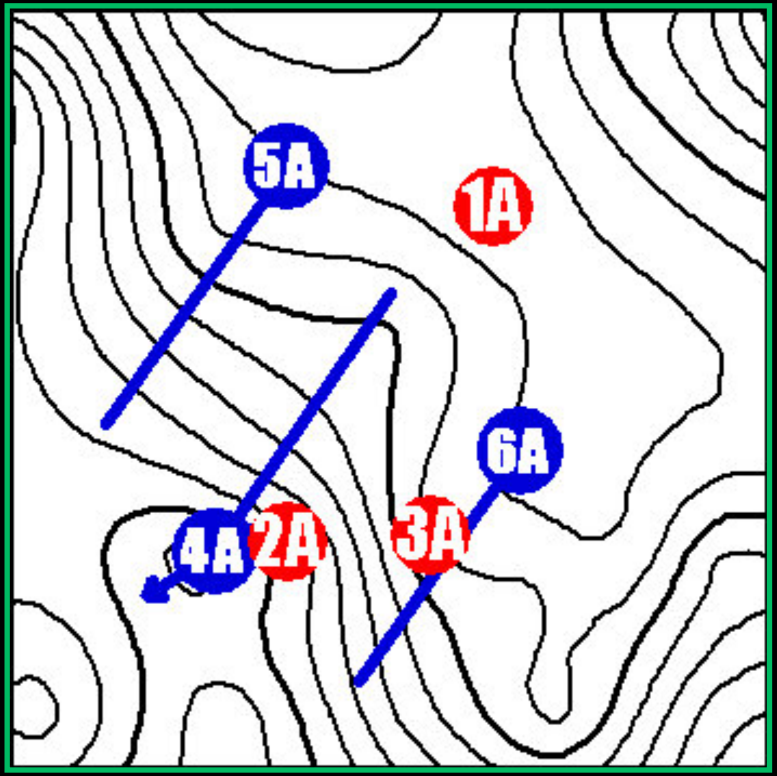
Planning the Project

Log Review

- Blake 3A
- Saturation – 30’
- Assume total reservoir to be 80’ Thick

Planning the Project

Location with pilot horizontal well plans
in relation to existing wells



Drilling the Horizontal Wells

1. Drill the Vertical Well
2. Move Out Drilling Rig
3. Move In Workover Rig
4. Drill the Curve and Horizontal Sections

Drilling the Horizontal Wells

Short Radius Horizontal Drilling Technique
- Amoco (BP) Licensed Rotary Steerable System
- 70 ft. Radius of Curvature
- 1000 ft. Lateral Section

Based on Formation Stability
- Open Hole Completion
- Air/Foam Drilling Fluids

Drilling the Horizontal Wells

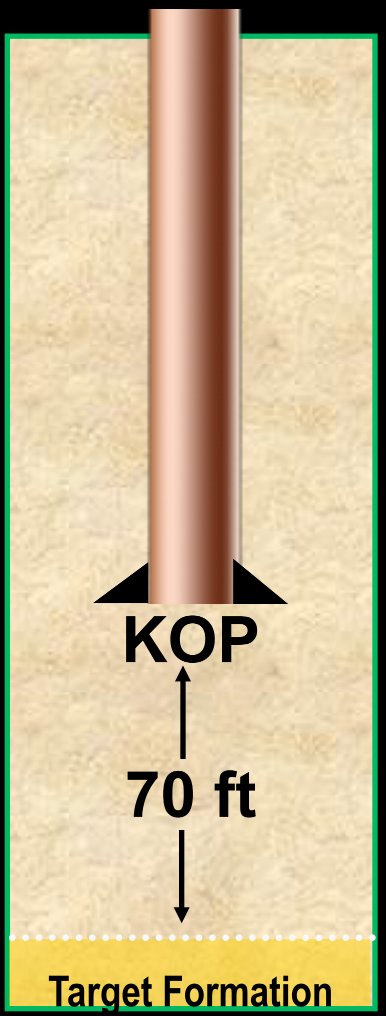
Advantages of These Techniques

- Low cost
- Drilling with air minimizes formation damage in low-pressure, sensitive reservoirs
- Use of air hammer permits rapid penetration rates
- Short-turning radius (70ft) permits wells to be conventionally completed with rod-pump set with low pressure head on the formation

Drilling the Horizontal Wells

Drill the Vertical Well

- Set pipe 70 ft above target formation



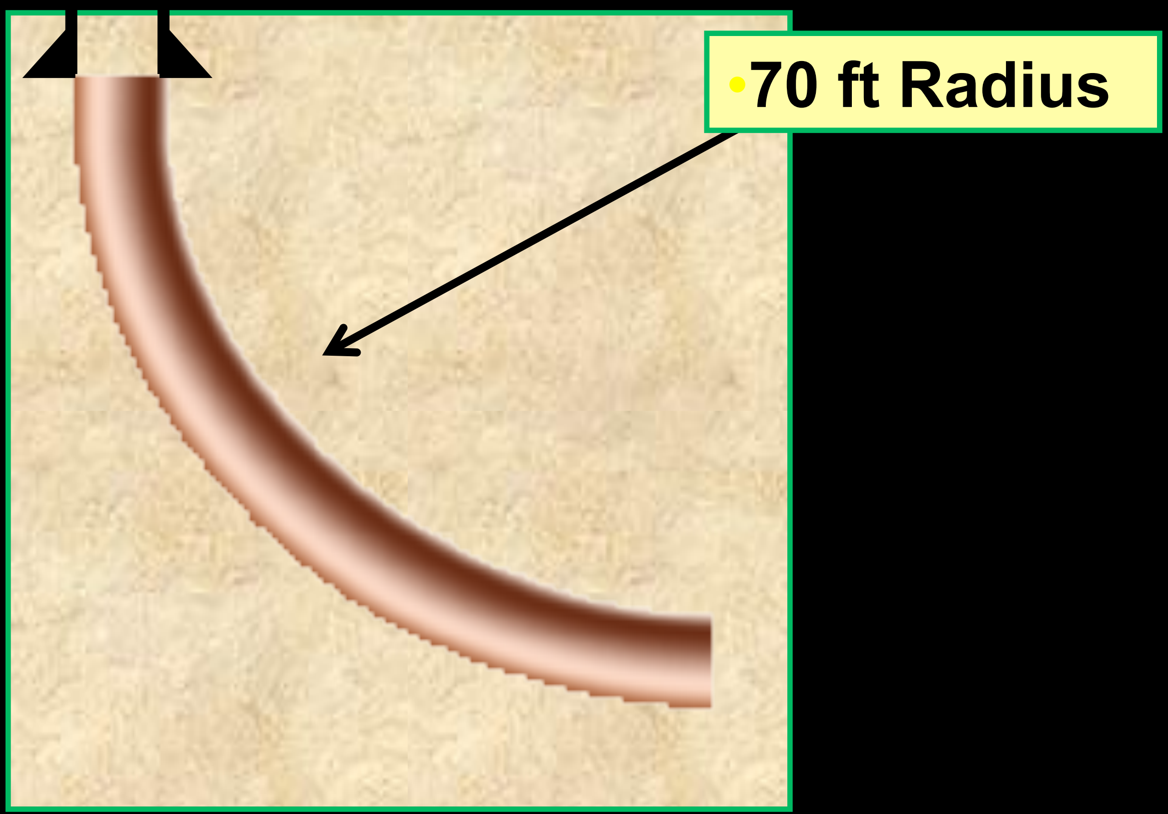
Drilling the Horizontal Wells

Drill the Curve

- Trip in Hole with Curve Drilling Assembly (CDA)
- Run Gyro to Orient CDA Direction
- Drill Curve

Drilling the Horizontal Wells

Drill the Curve



Drilling the Horizontal Wells

Drill the Curve

Drilling the Horizontal Wells

Drill the Curve

Drilling the Horizontal Wells

Drill the Curve

- 4 ½" PDC Bit

Drilling the Horizontal Wells

Drill the Lateral Section

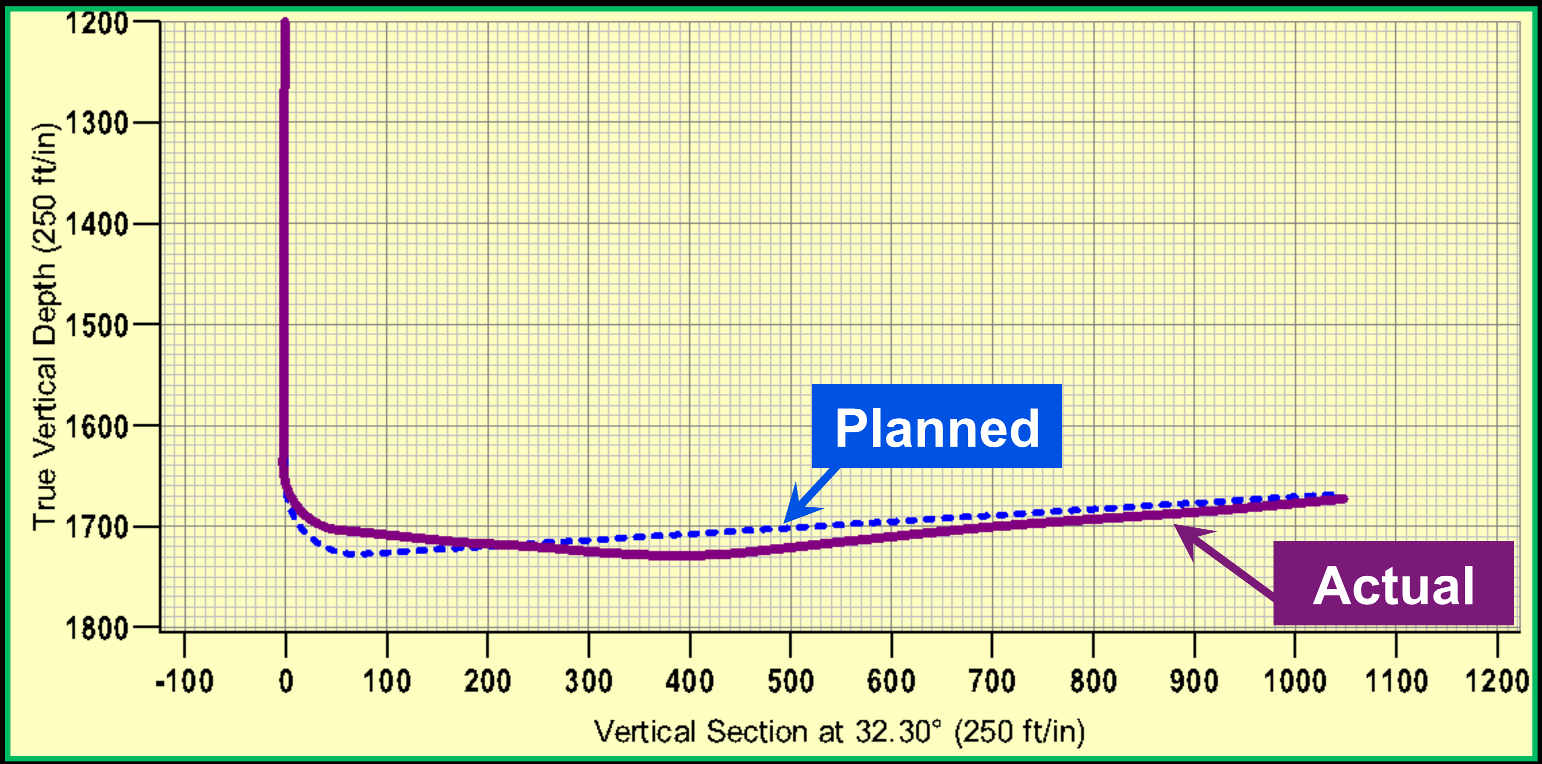
Drilling the Horizontal Wells

Drill the Lateral Section

- 4 $^1/_8$" Air Hammer Bit

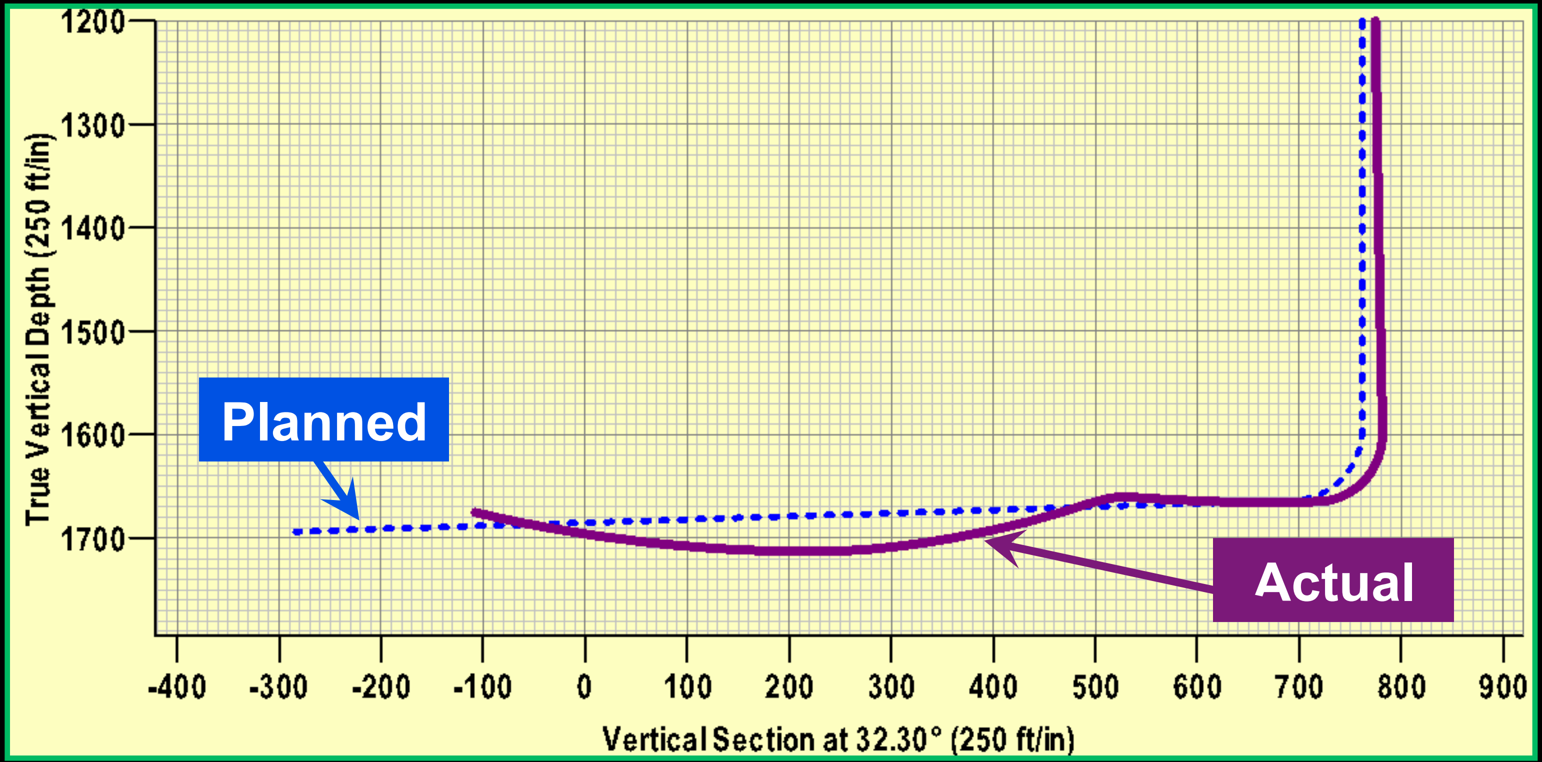
Drilling the Horizontal Wells

Wolco 4A – Section view



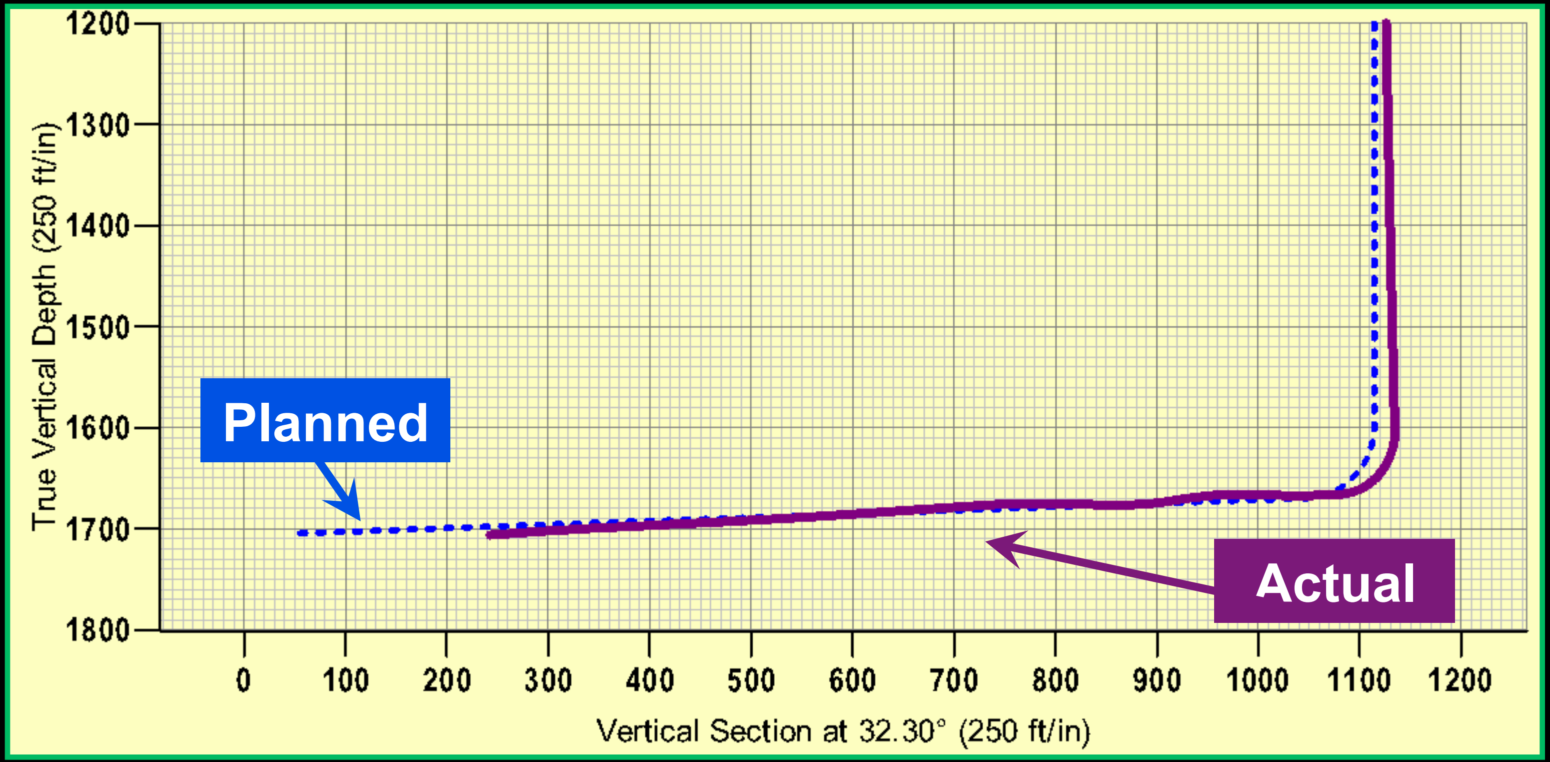
Drilling the Horizontal Wells

Wolco 6A - Section view

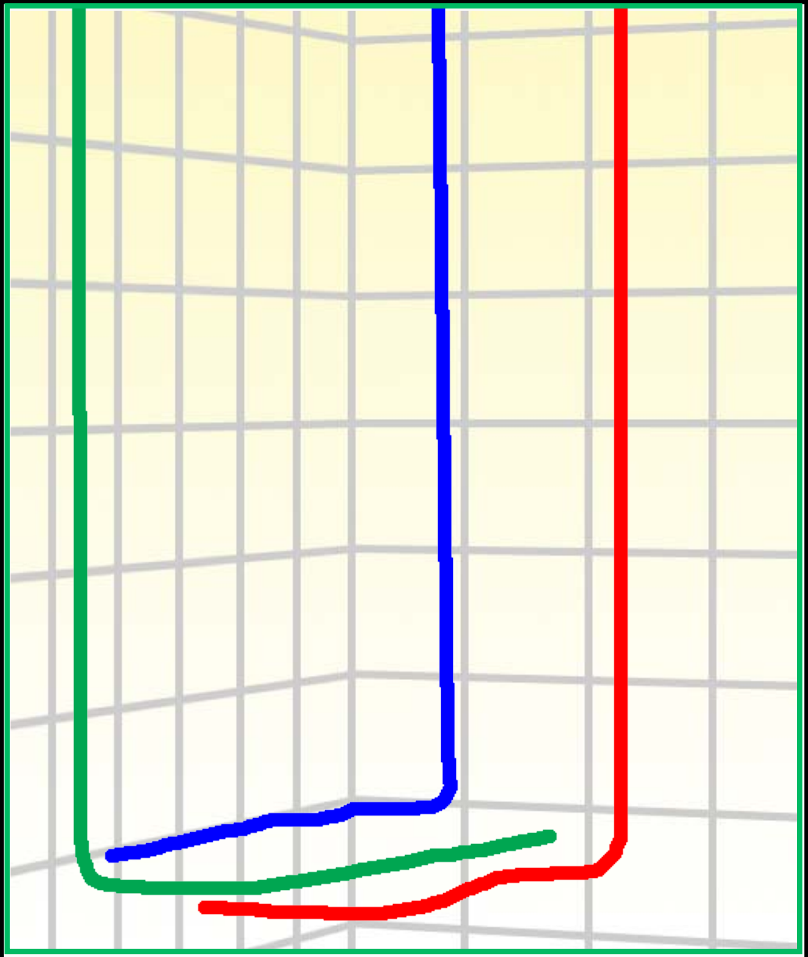


Drilling the Horizontal Wells

Wolco 5A - Section view



Drilling the Horizontal Wells



Drilling the Horizontal Wells

Drilling and Completion Costs - 2001

- Wolco 4A - $257,000
- Wolco 5A - $214,000
- Wolco 6A - $202,000

In 2001 a nearby 1200 ft. horizontal well with a 300 ft. radius curve had an estimated completed cost of $700,000.

The Initial Project Results

Initial Production

- 98% Water Cut

VERY DISAPPOINTING RESULTS

DOE - Wolco Project

Not economic at $30/bbl

The Initial Project Results

Initial Production

High initial water cut was the problem.

The following questions needed
to be answered:

The Initial Project Results

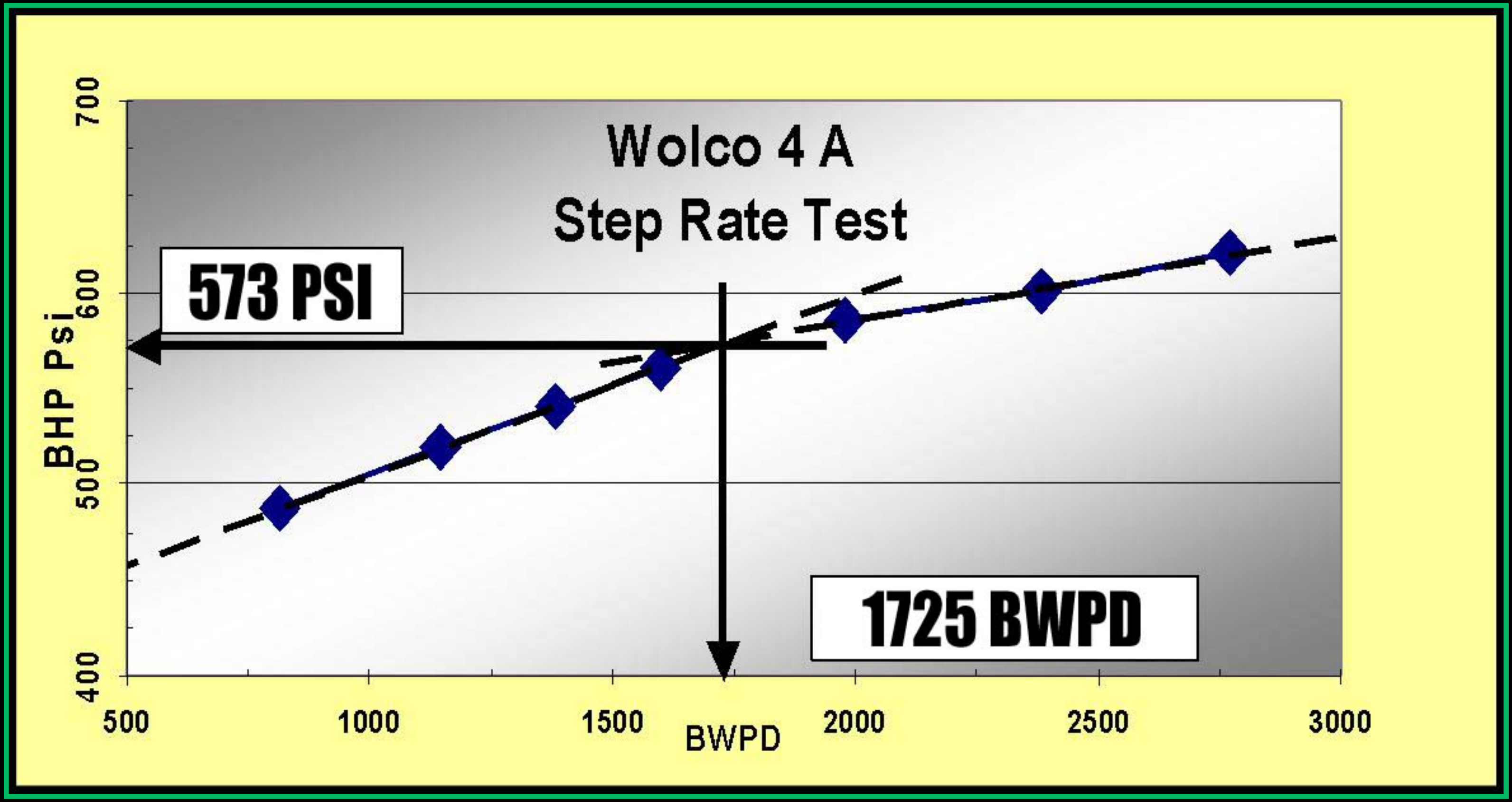
1. Why is the oil production below expectations?

2. Is water injection occurring below the parting pressure?

3. How can we increase oil production to realize economic operations?

The Initial Project Results

Step Rate Test



The Initial Project Results

Step Rate Test Results

- Opened Fractures at 573 psi BHP
- 1725 BWPD
- Fracture gradient of 0.35 pst/ft which is less than a column of water

The Initial Project Results

Significance of Step-Rate Test

- Low fracture gradient of 0.35 psi/ft helps to explain why conventional waterfloods operating in the range of 0.70 psi/ft have often failed.

- Low fracture gradient provides additional support for the concept of using horizontal injection wells.

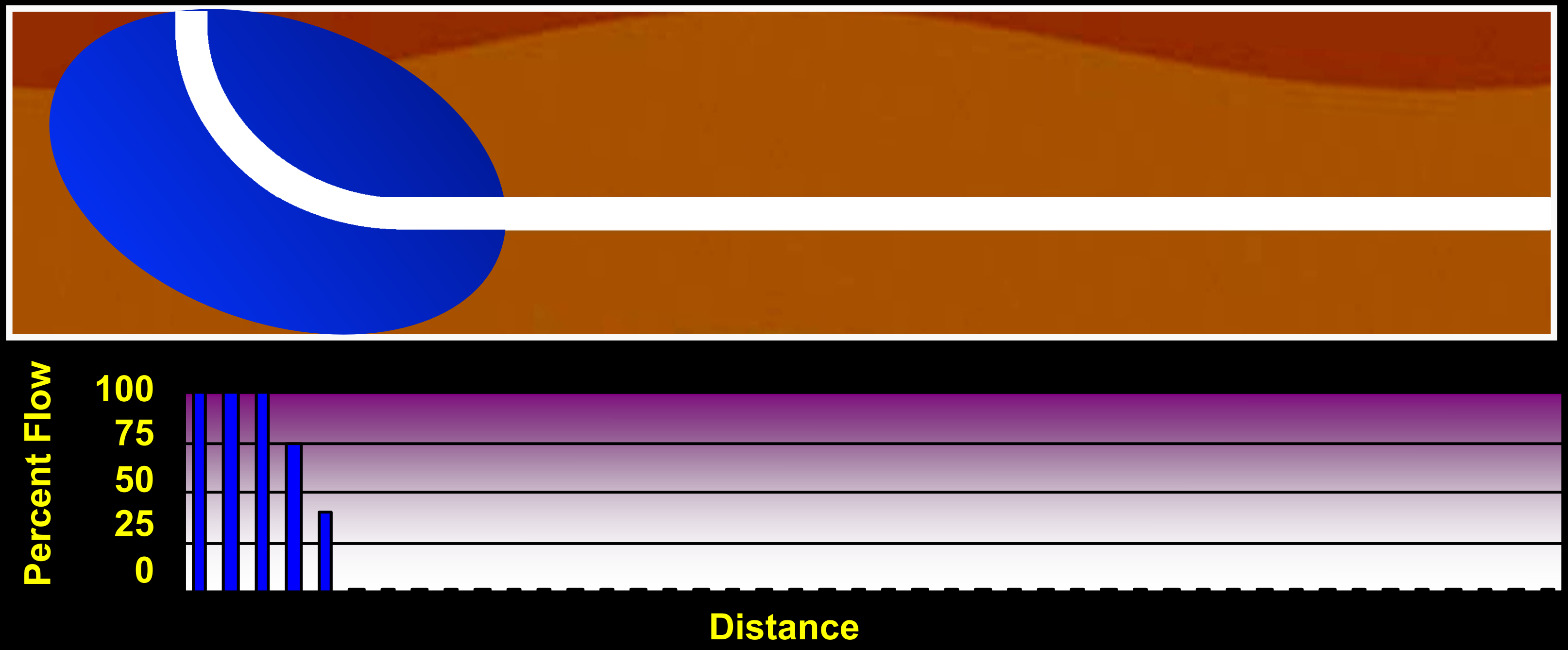
The Initial Project Results

Step Rate Test Operations Changes

- Injecting at approximately 1200 BWPD
- Surface pressure = Vacuum

The Initial Project Results

Spinner Survey



The Initial Project Results

Analyzing the Spinner Survey Results

- Creation or extension of fractures during the drilling of curve with conventional mud

Logging Horizontal Wells

- Induction
- Density
- Fracture Identification & Orientation

Low cost?

Logging Horizontal Wells

- Induction
- Density
- Fracture Identification & Orientation

Low cost?

HOW?

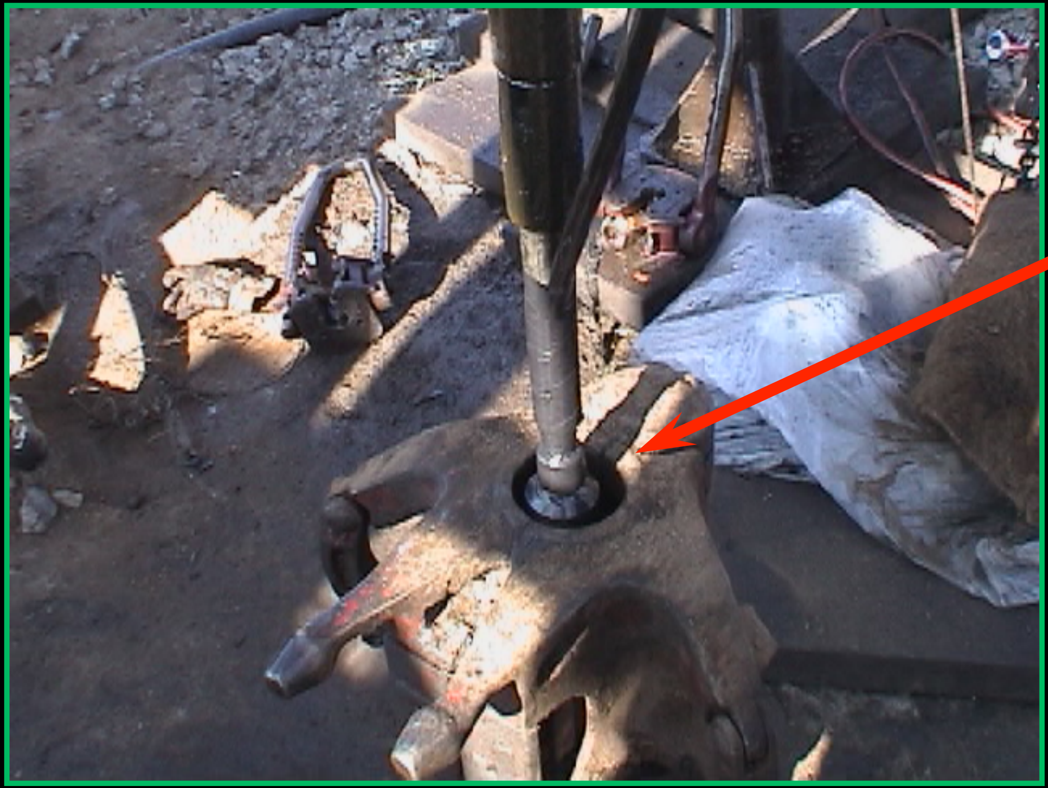
Logging Horizontal Wells

Grand Directions uses the latest and greatest, high tech, state of the art . . .

SRCL!

Logging Horizontal Wells

Sucker Rod Conveyed Logging



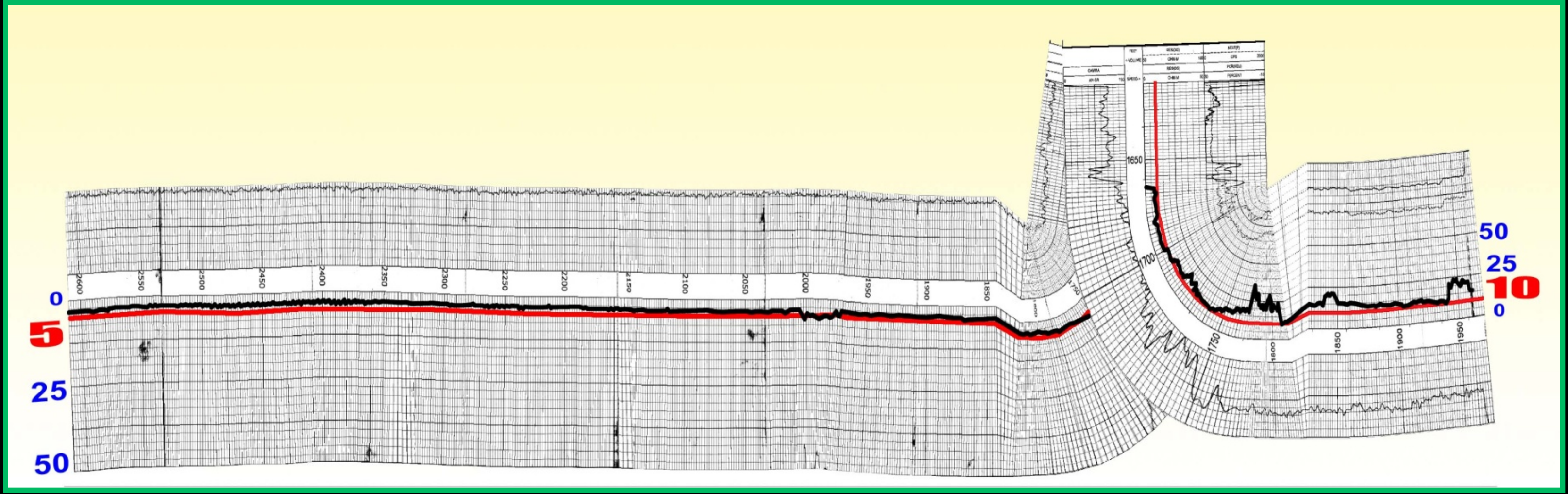
Logging Horizontal Wells

Sucker Rod Conveyed Logging

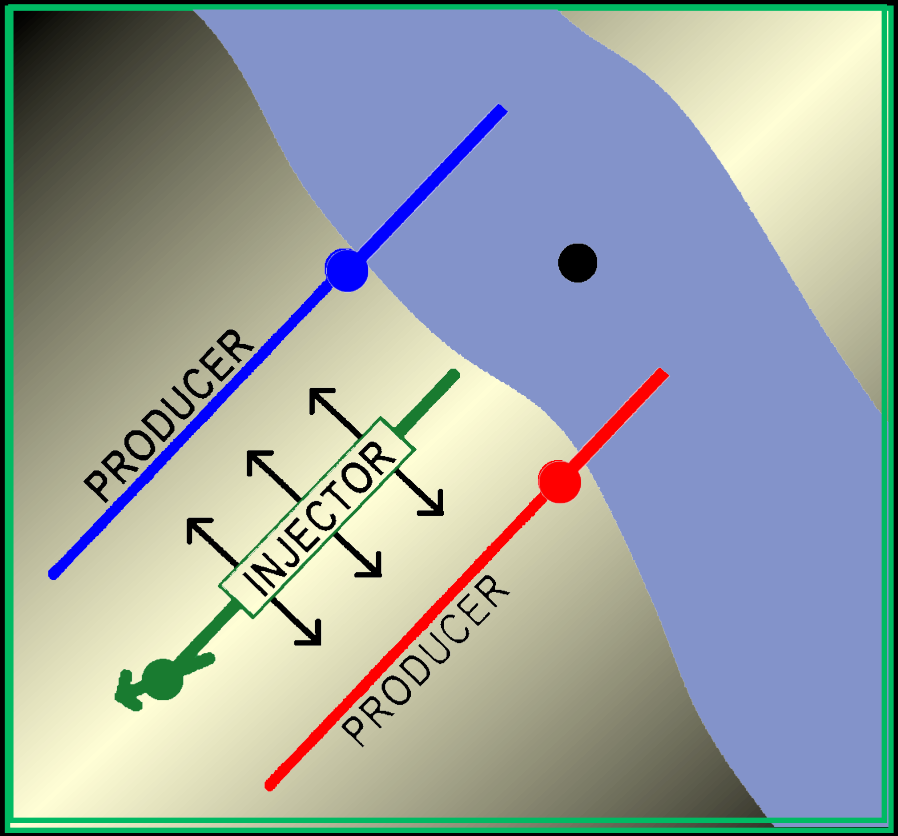
High tech, state of the art *Electrical Tape*

Re-drilling Operations

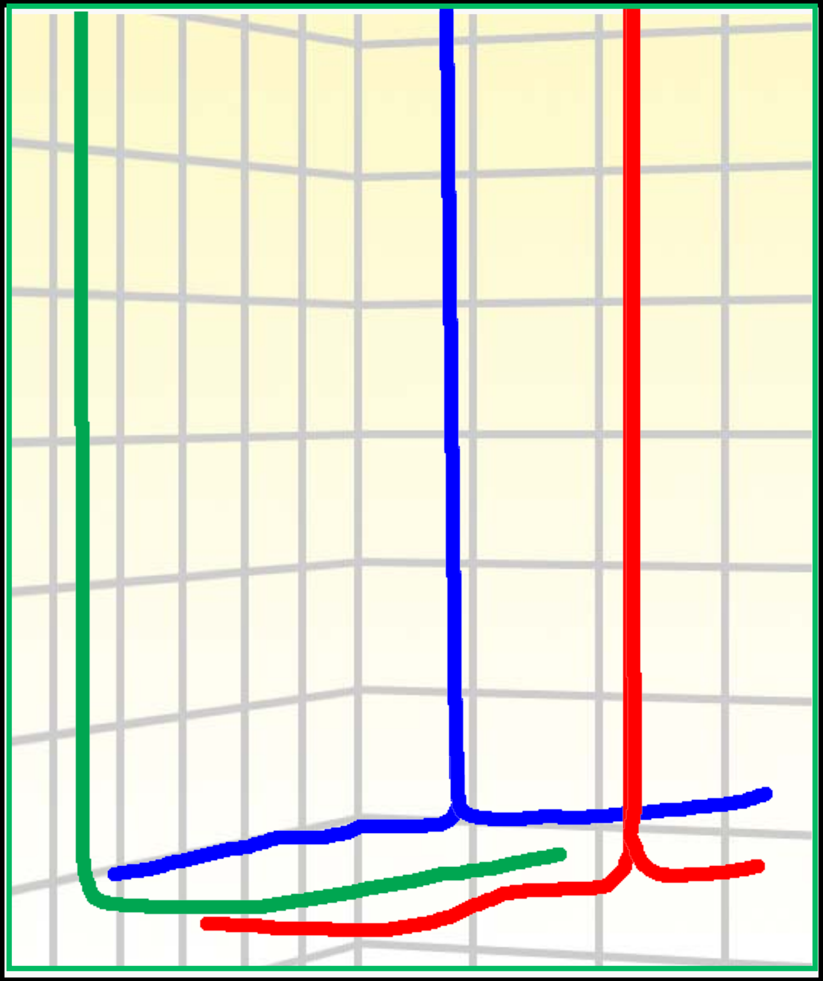
Wolco 6A and 6A-4



Re-drilling Operations



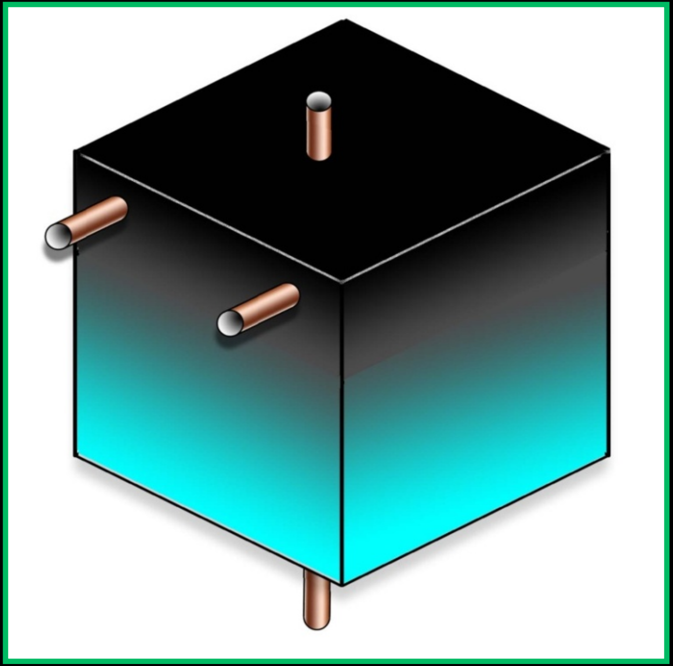
Re-drilling Operations



The Initial Project Results

Reconfigure the Field Pilot Project

- Change from a horizontal waterflood to oil rim recovery

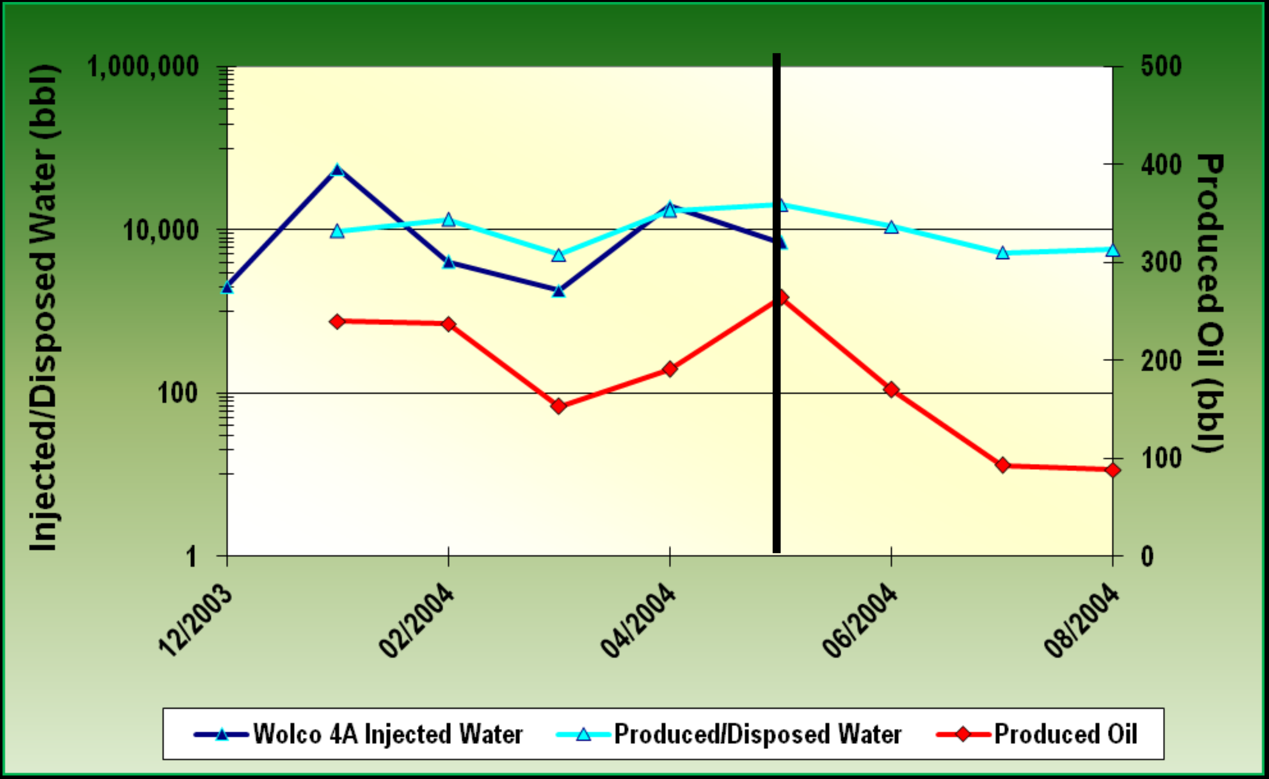


Pilot Production Summary

Monthly

Before Pilot Change

Horizontal Waterflood

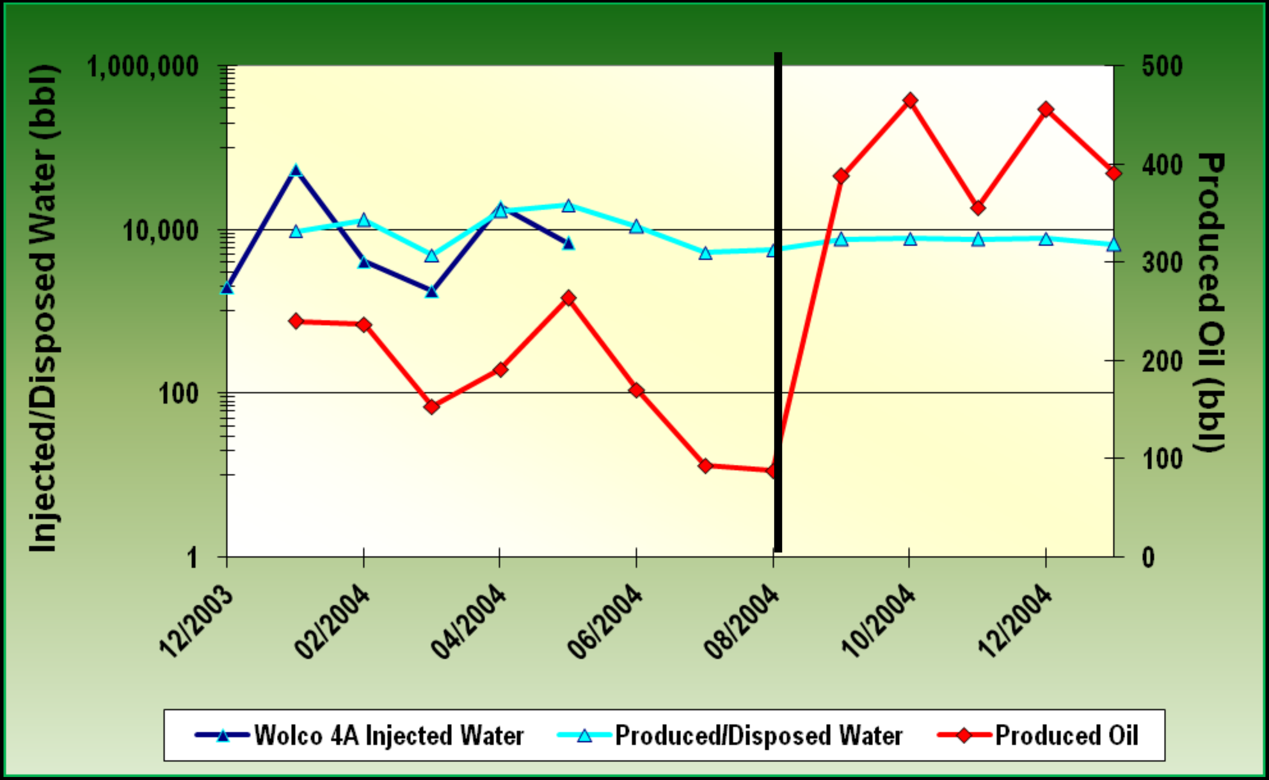


Pilot Production Summary

Monthly

After Pilot Change

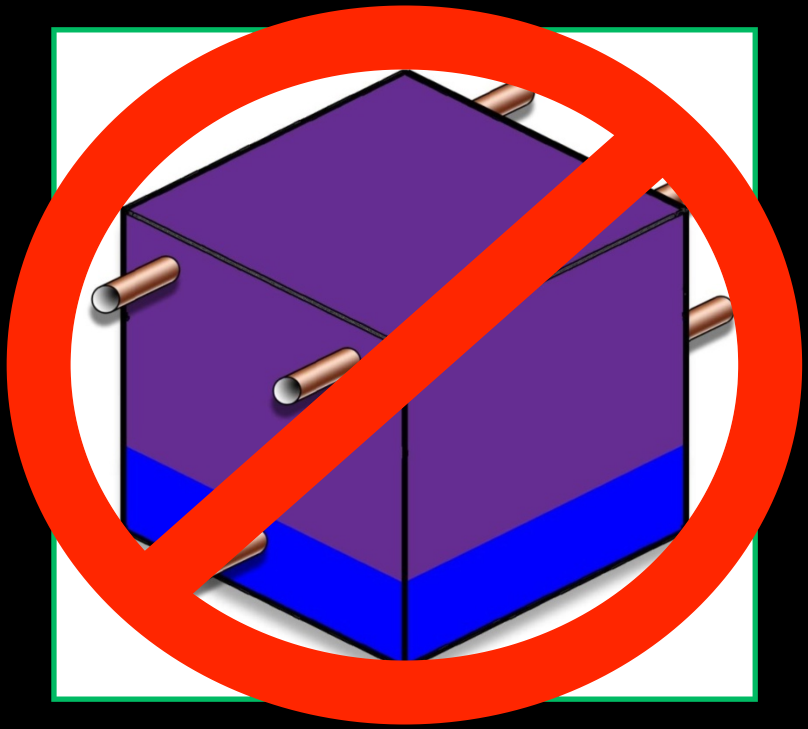
Oil Rim Recovery with Vertical Injection



Conclusions

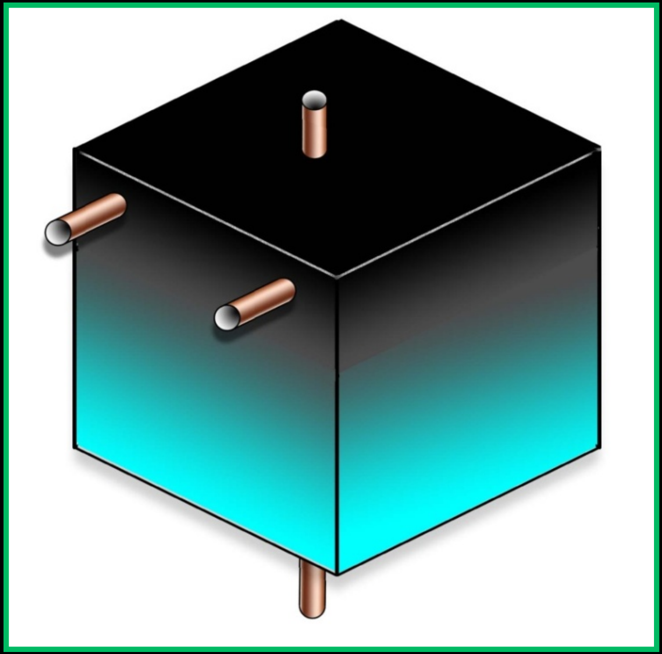
1. The original pilot recovered very little oil making the results uneconomical.

<u>This pilot was discontinued.</u>



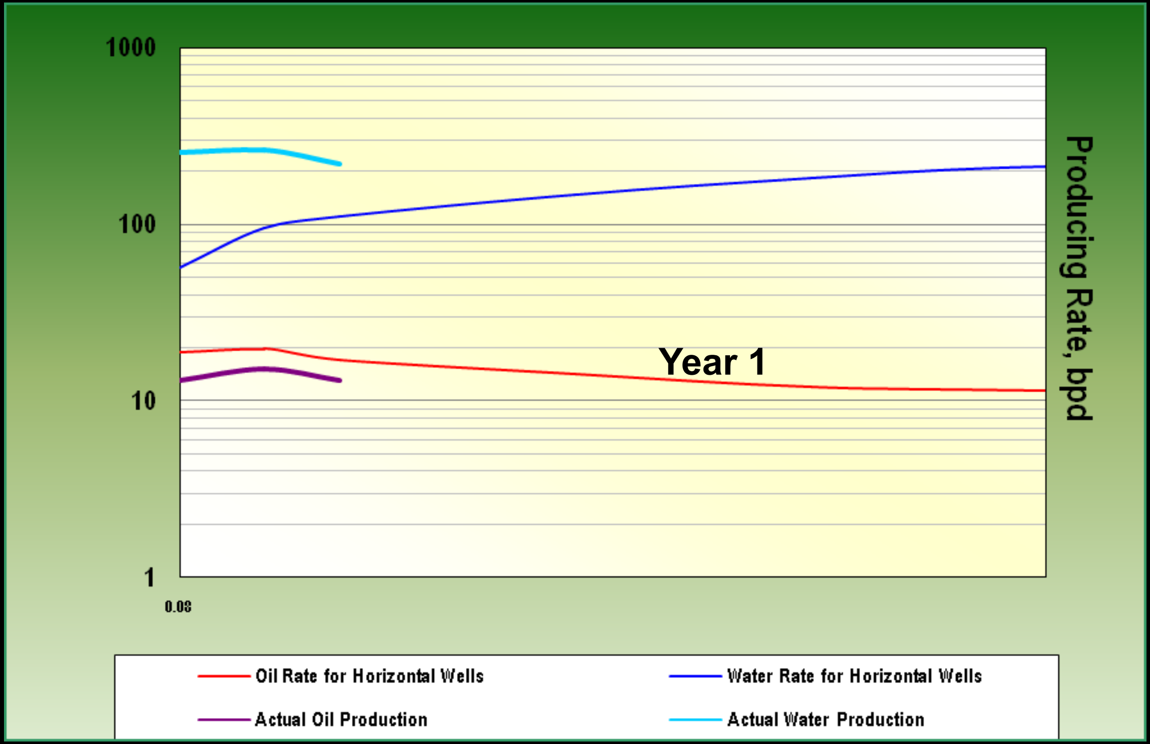
Conclusions

2. The pilot was modified by re-drilling the two horizontal wells into the oil rim and using an existing vertical well injecting into the bottom high permeability zone.



Conclusions

3. Simulations with the current reservoir characteristics match the present performance.

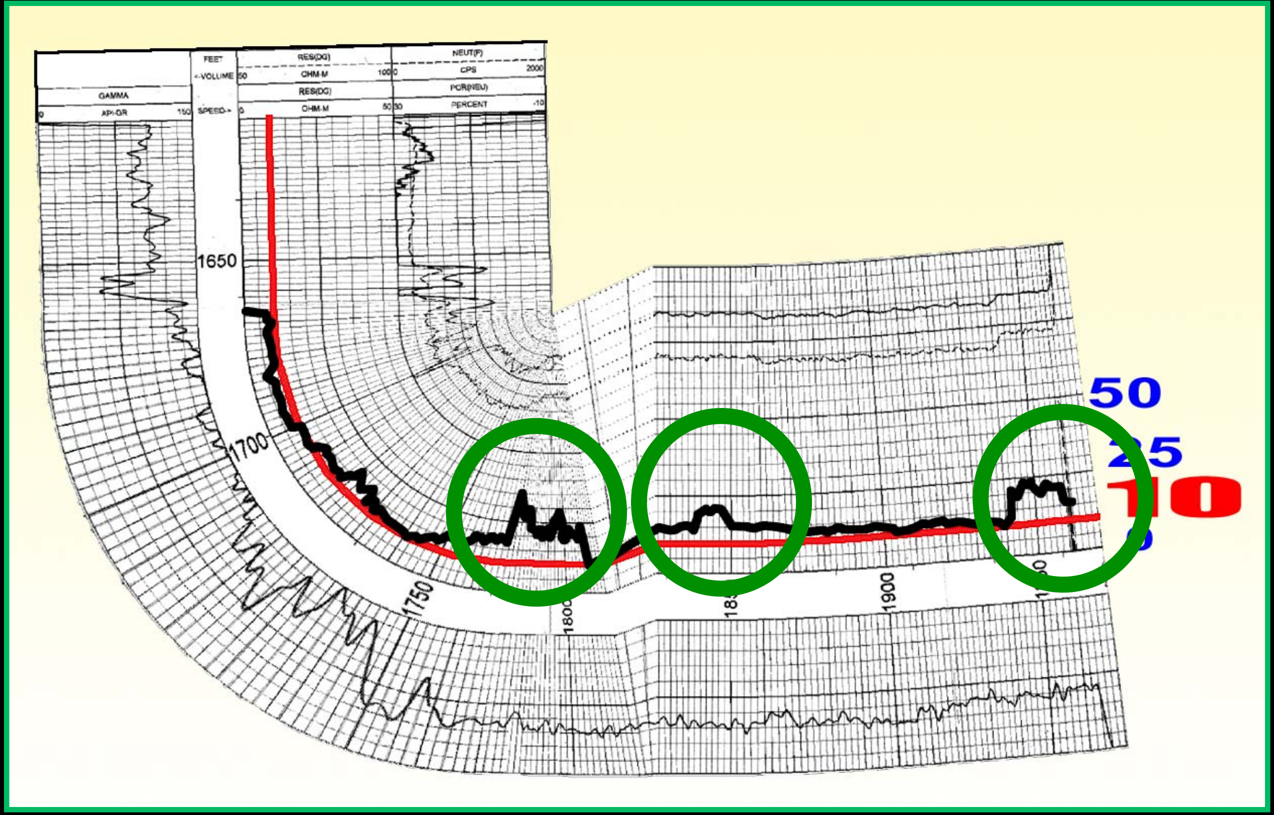


Conclusions

4. In old or abandoned fields where conventional waterfloods were inefficient, production may possibly be re-established with:
   - Horizontal wells placed in the oil rim
   - In areas of adequate oil saturation
   - Reservoirs with sufficient bottom hole pressure

Conclusions

5. Compartmentalization



Horizontal Waterflooding

Specific Lessons Learned

1. Initial production results were disappointing, with an oil cut of 1 to 2%, but total fluid withdrawal and injection rates were as predicted.

Horizontal Waterflooding

Specific Lessons Learned

2. Diagnostic tests on the horizontal injector determined injection parameters, which led operation procedures to keep the injection rates below fracture parting pressure.

Horizontal Waterflooding

Specific Lessons Learned

3. The injection profile survey indicated that all of the injected fluid was exiting at the heel of the horizontal injection well. Negating the value of Wolco 4A pressure support.

Horizontal Waterflooding

Specific Lessons Learned

4. The 0.35 psi/ft fracture gradient was much lower than expected. And confirmed the necessity of using bottomhole pressure gauges when conducting step rate tests.

Horizontal Waterflooding

Specific Lessons Learned

5. Fractures are dynamic and can take large volumes of water; obtaining injection profiles and step rate test information is vital.

Horizontal Waterflooding

Specific Lessons Learned

6. The high permeability providing high injection capacity and location of the disposal well, Blake 1A, supplied pressure support for the re-drilled horizontal producers.

Horizontal Waterflooding

Specific Lessons Learned

7. Re-drilling the producers (Wolco 6A-4 and 5A-4) up structure (heading NE) and away from the original pilot area was successful because by-passed oil was encountered in compartments.

Horizontal Waterflooding

Specific Lessons Learned

8. A bottomhole pressure of 125 psi is enough to have adequate withdrawal rates with horizontal producers at ~ 5% oil cut to generate a satisfactory economic rate of return.

Horizontal Waterflooding

Specific Lessons Learned

9. The character of the layered reservoir with high and low permeabilities was able to be managed by injecting into the high permeability "D" zone in a vertical well and producing the oil rim at top of the lower permeability "C" zone with horizontal wells.

DOE Horizontal Project Conclusion

- Low cost horizontals
- No problem with hole stability
- Low cost logging technique
- Low cost horizontal redrills