Optimizing CO2 Sweep based on Geochemical, and Reservoir Characterization of the Residual Oil Zone of Hess's Seminole Unit

Project Number: **DE-FE0024375**

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U.S. Department of Energy

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Presentation Outline

Technical Status

Analysis of Production/Injection Data

Developing an Upgraded Static Reservoir Model

Simulation of Development of Soil in ROZ

Accomplishments to Date

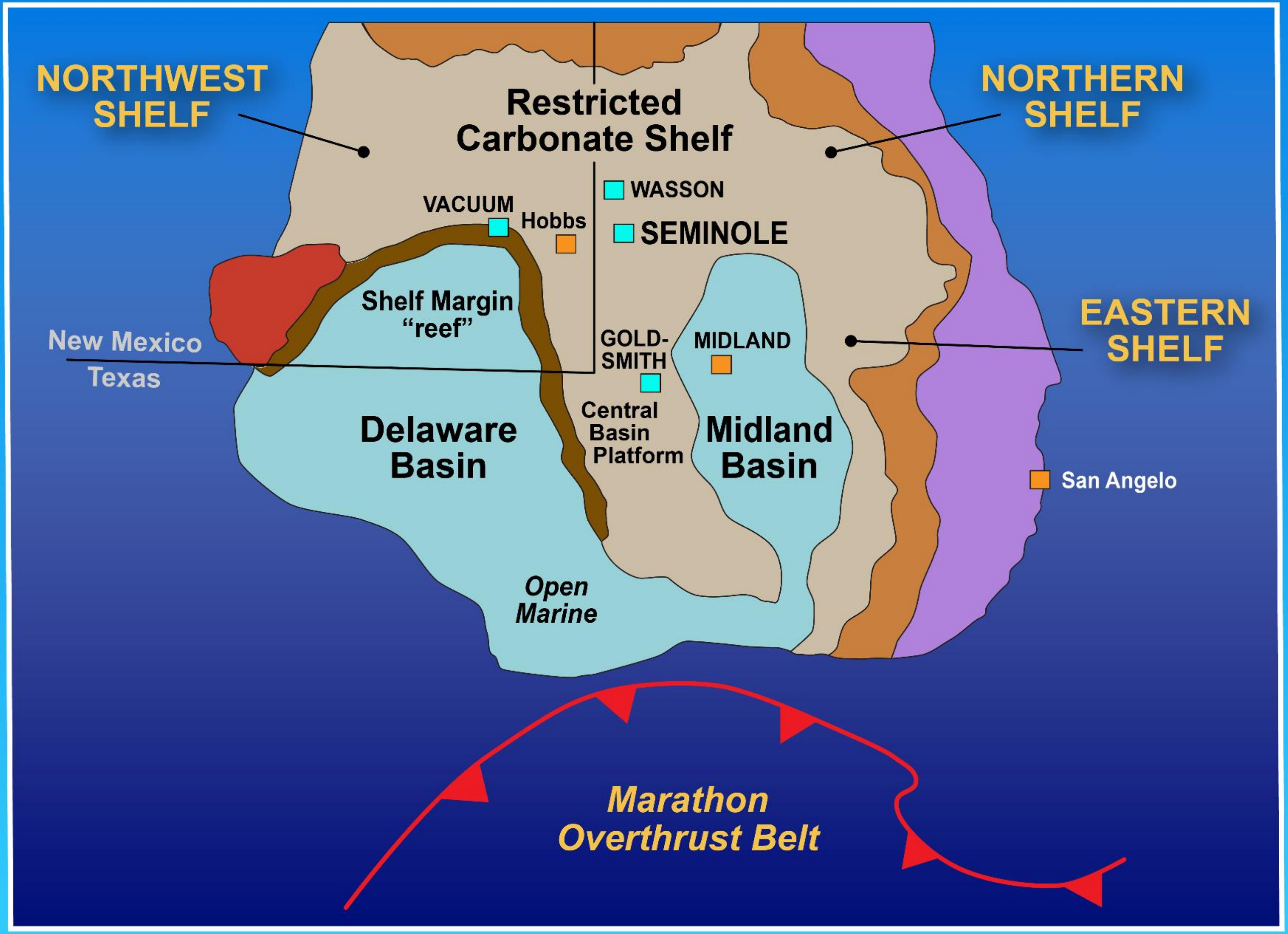
Lessons Learned

Synergy Opportunities

Project Summary

Technical Status

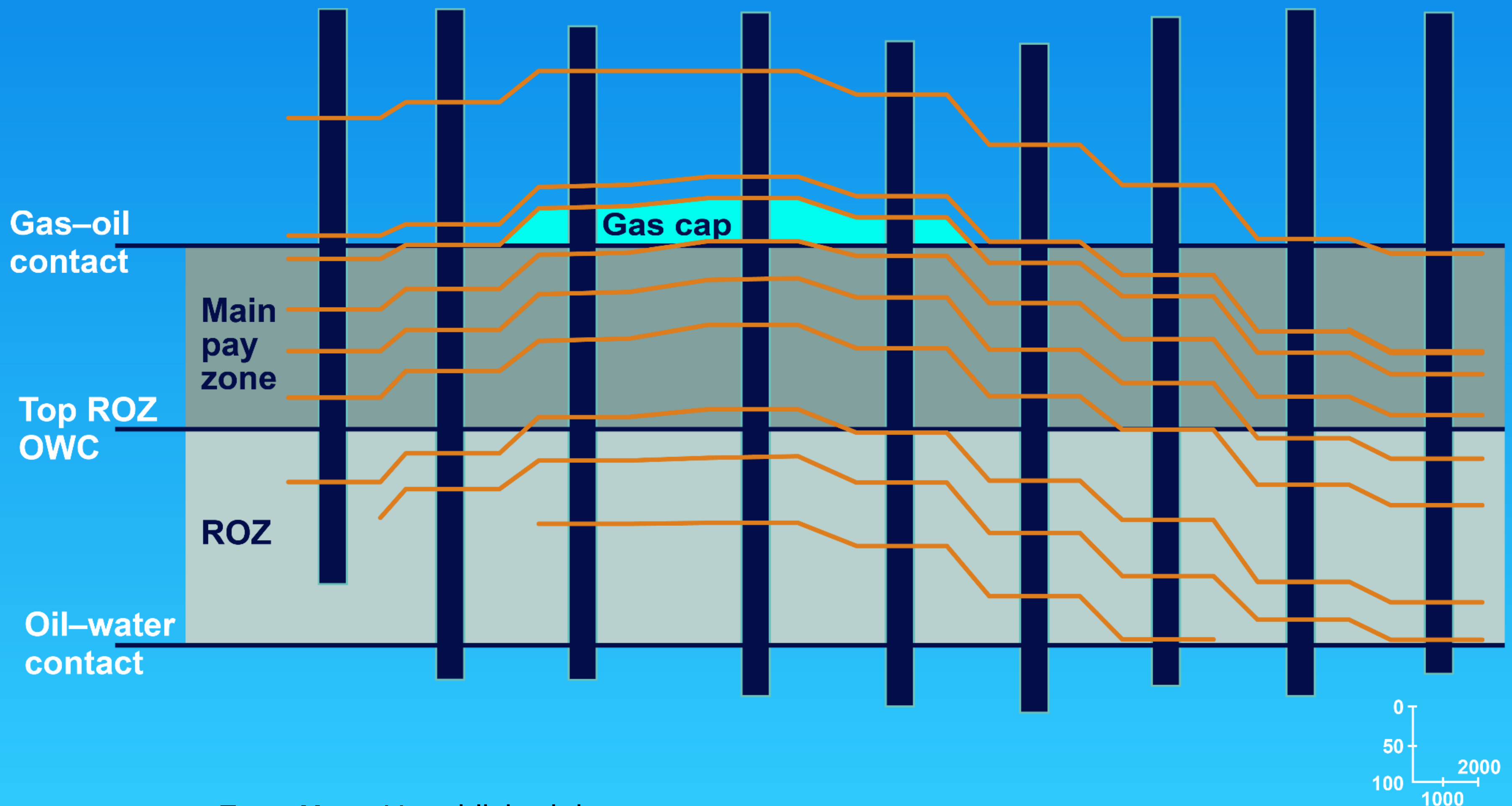
Middle San Andreas Paleogeography with Location of Industry Documented ROZ



Bureau of Economic Geology

QAe3886

Structural Cross-Section
East to West

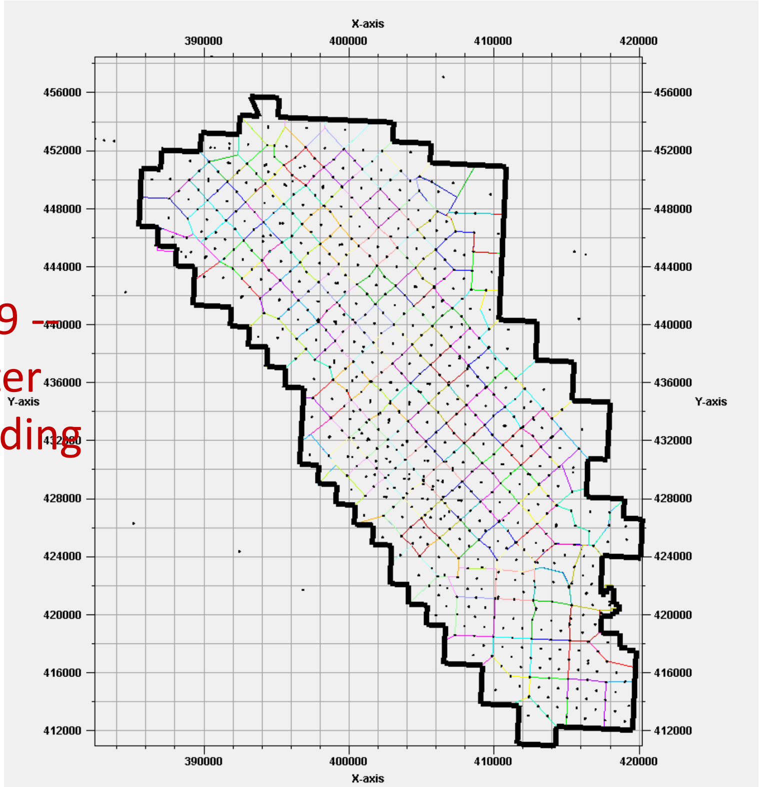


From **Hess** Unpublished data

Analysis of Production/Injection Data

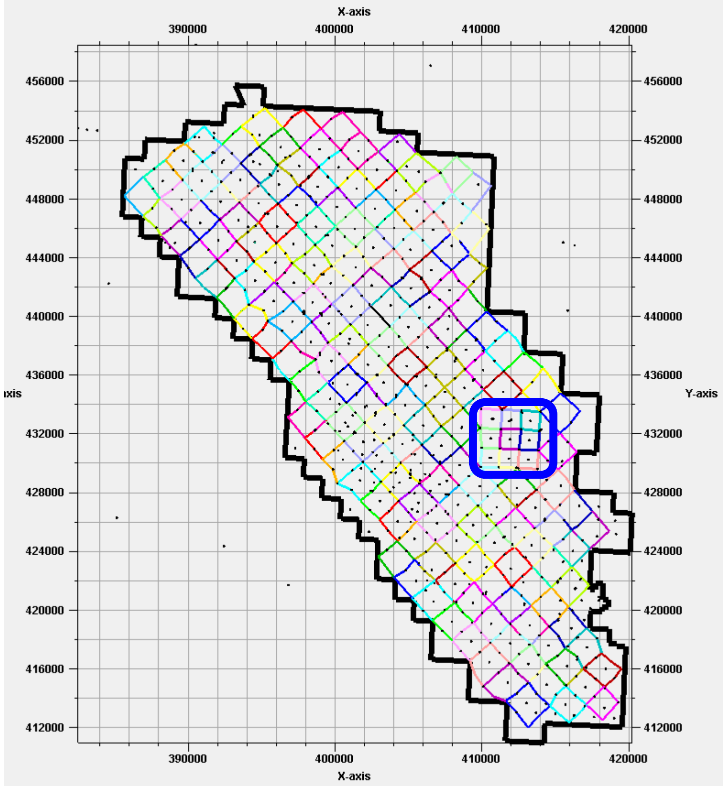
Well pattern

Inverted nine- spot (80 acre), Water flooding, MPZ

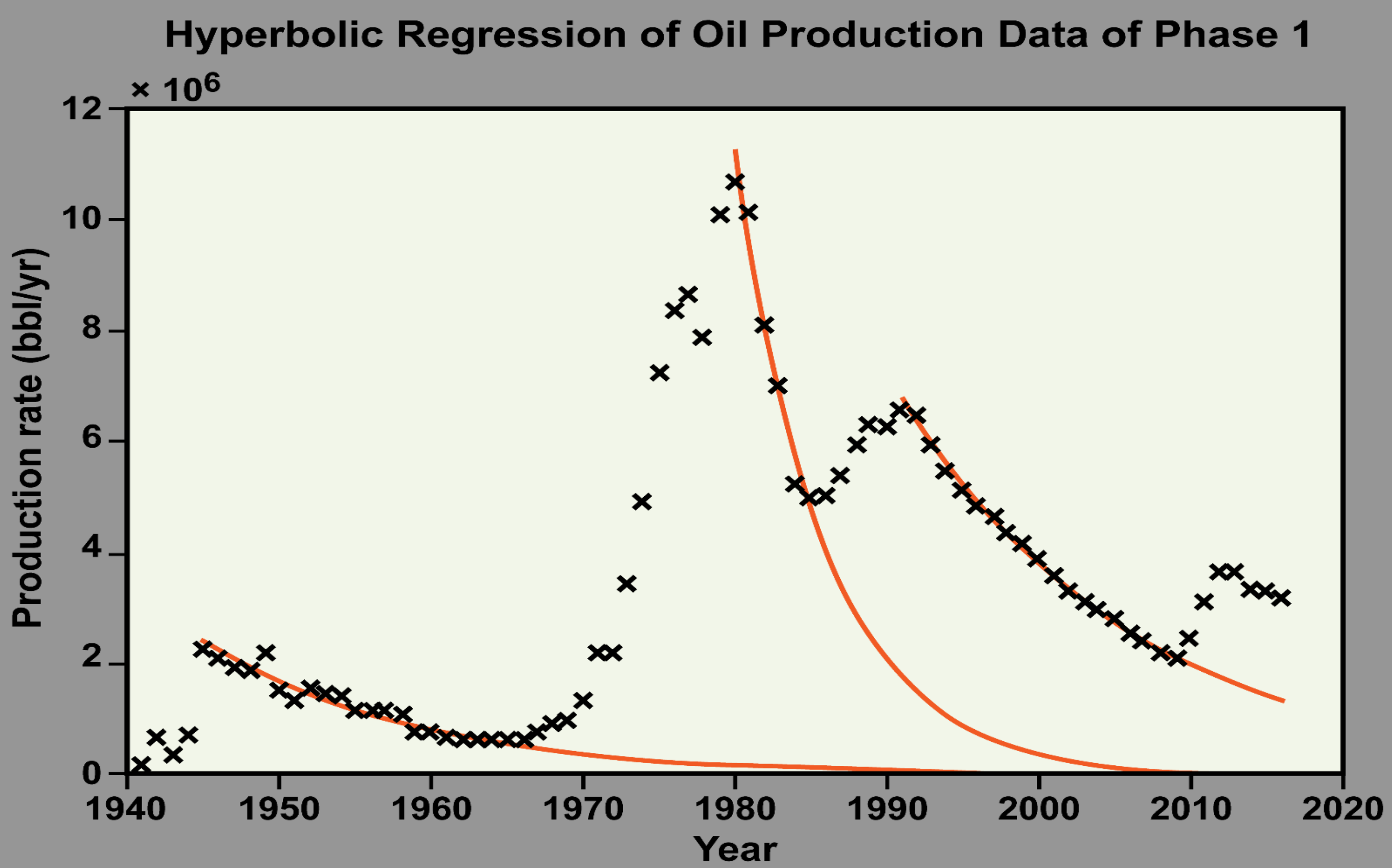


1969 –
Water
flooding

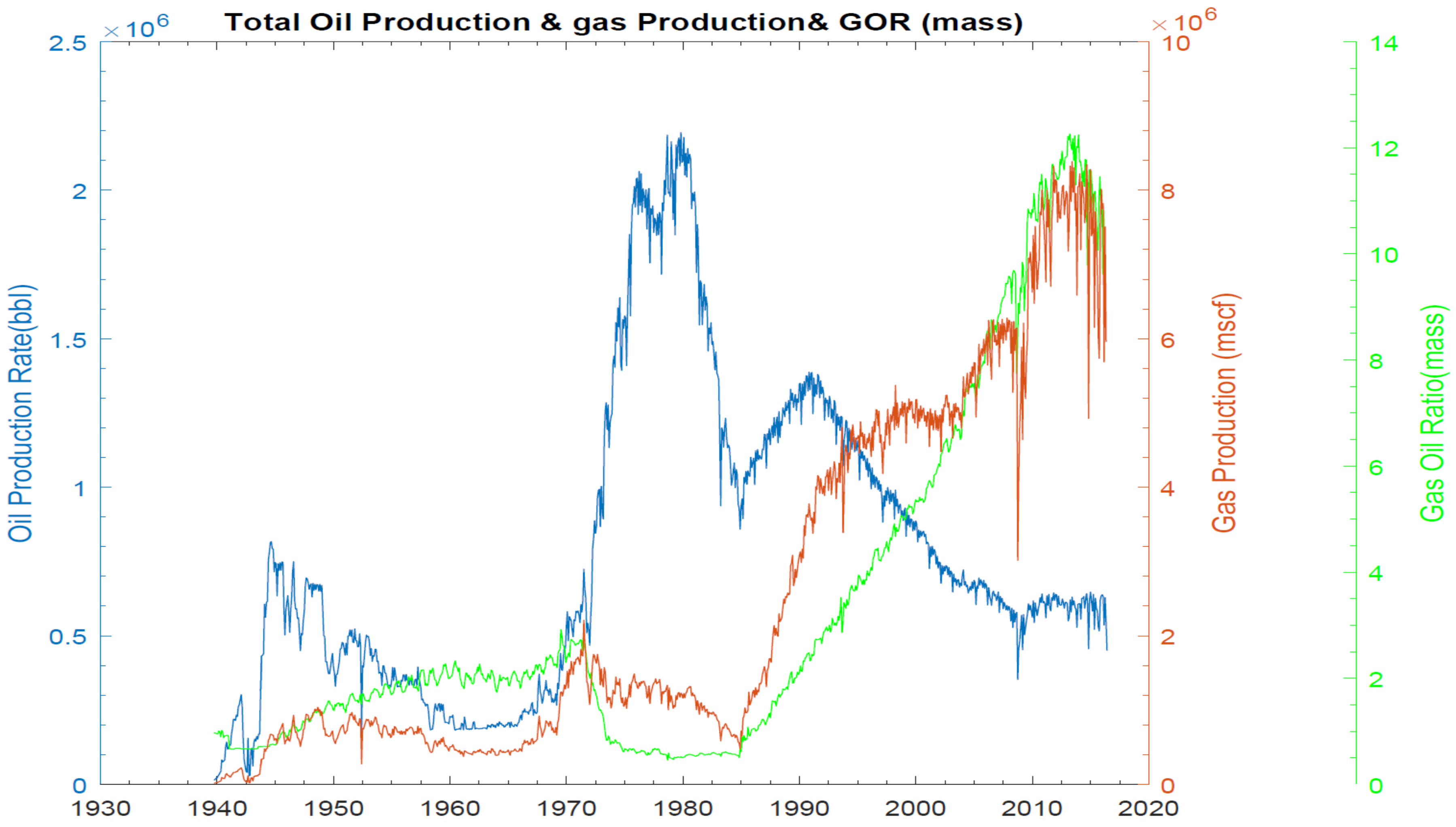
Inverted nine and five-spot, CO2 flooding,



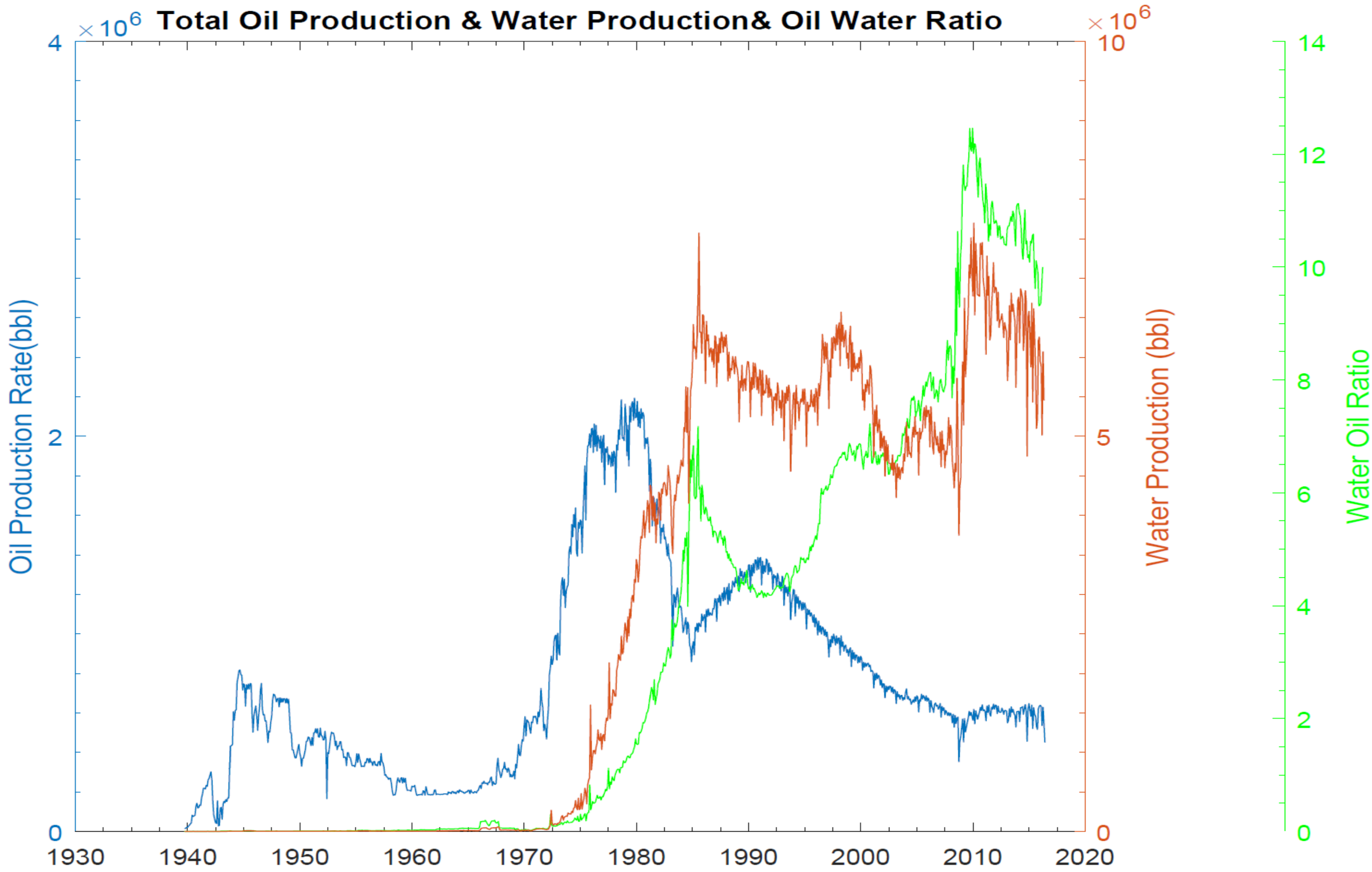
Separating Production Volumes from Primary, Water Flood, CO_2 Flood MPZ, CO_2 Flood ROZ..



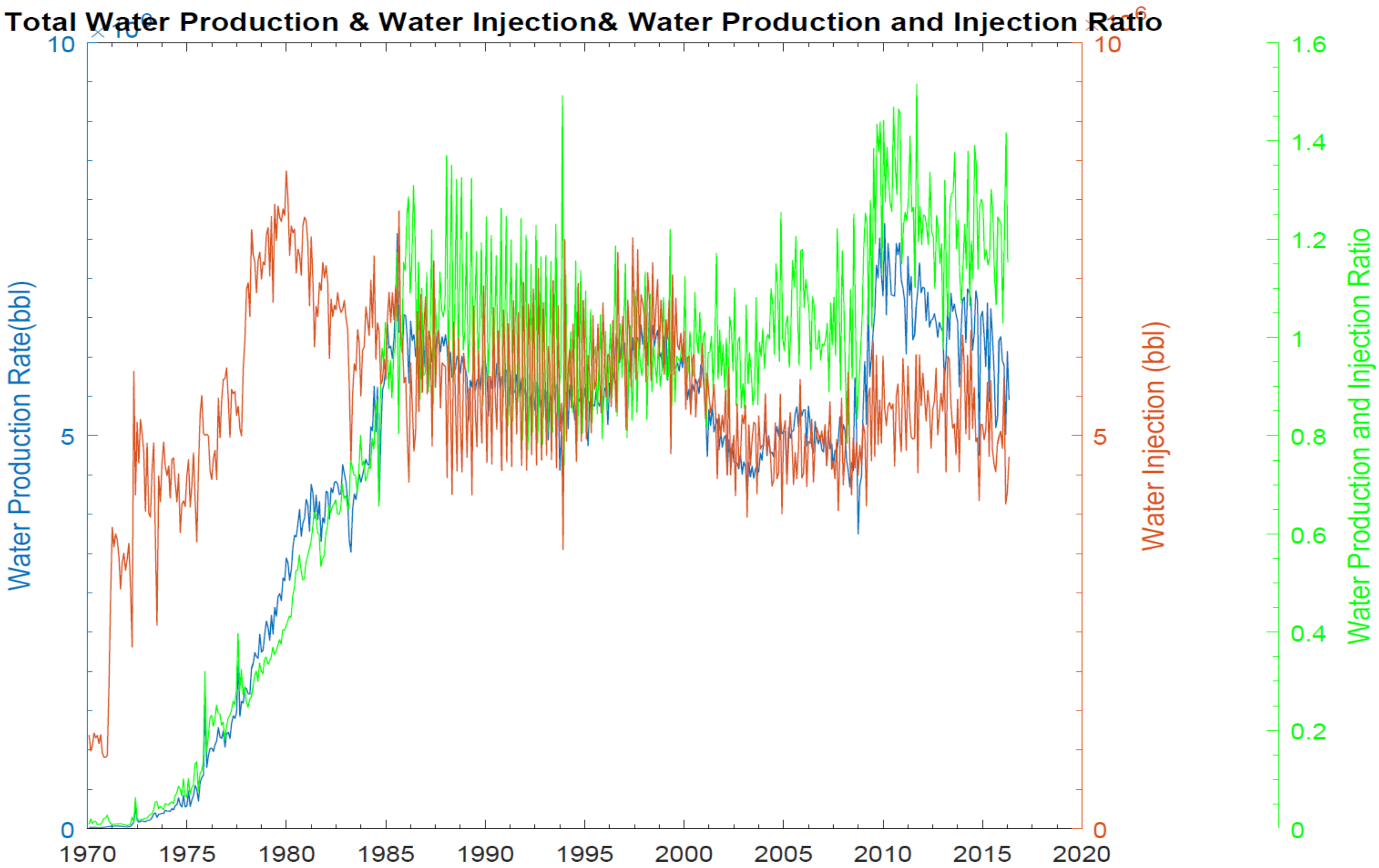
Total Field Production Metrics



Field Wide Water Production



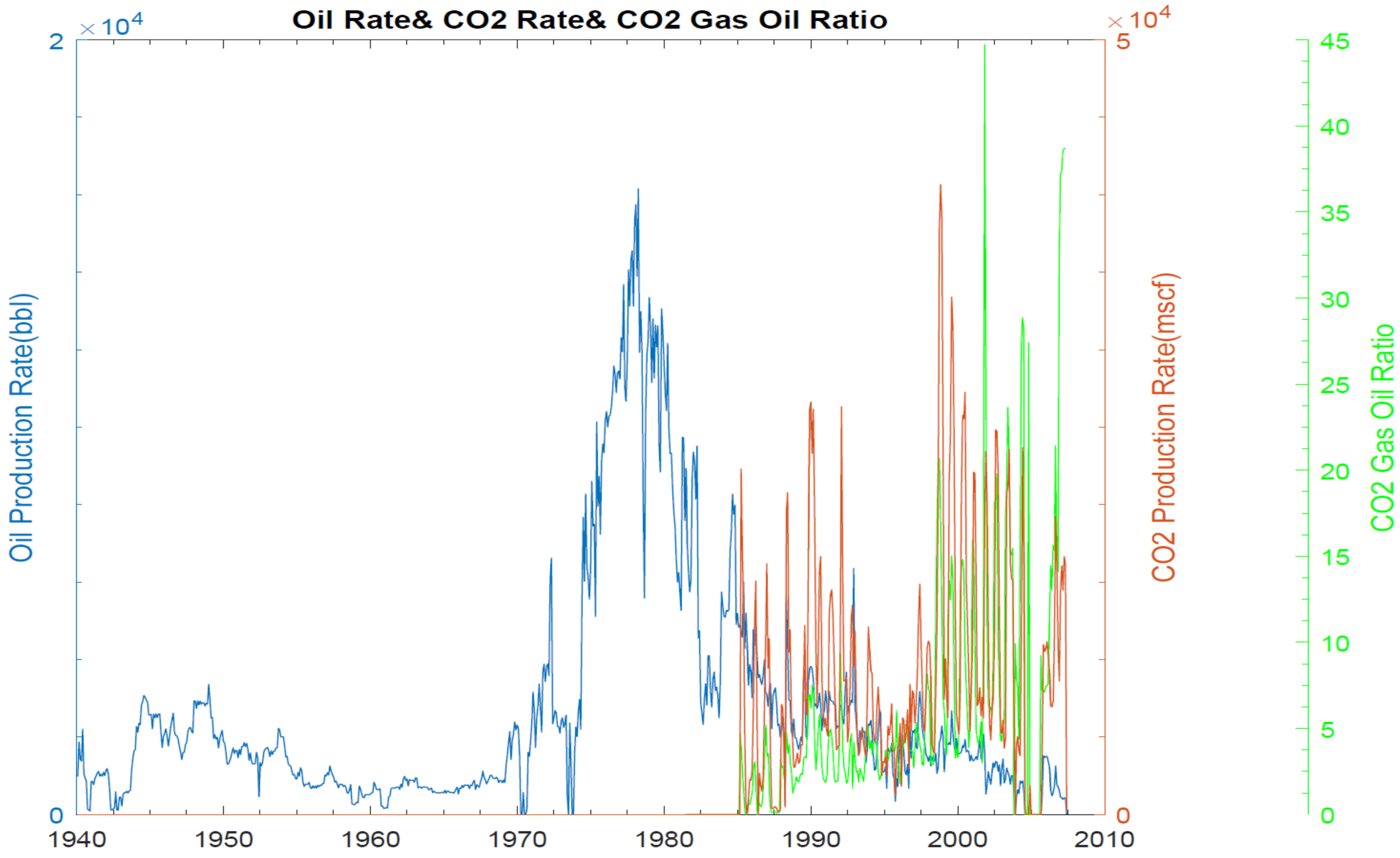
Water Injection/Production since 1970



Individual Production Wells

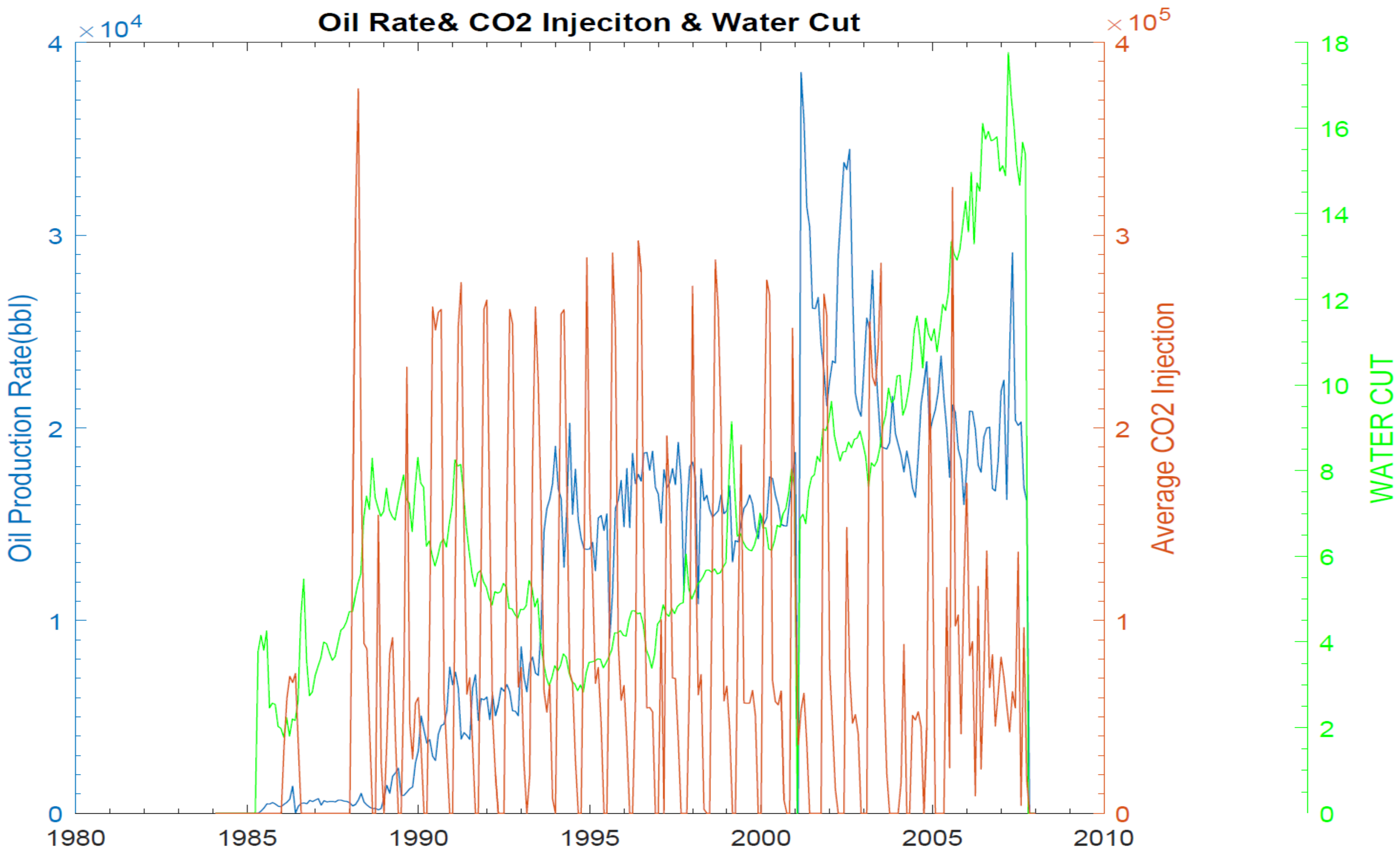
Individual Production Well: Oil, CO2

UWI42165000650000



Individual Production Well with CO2 Injection

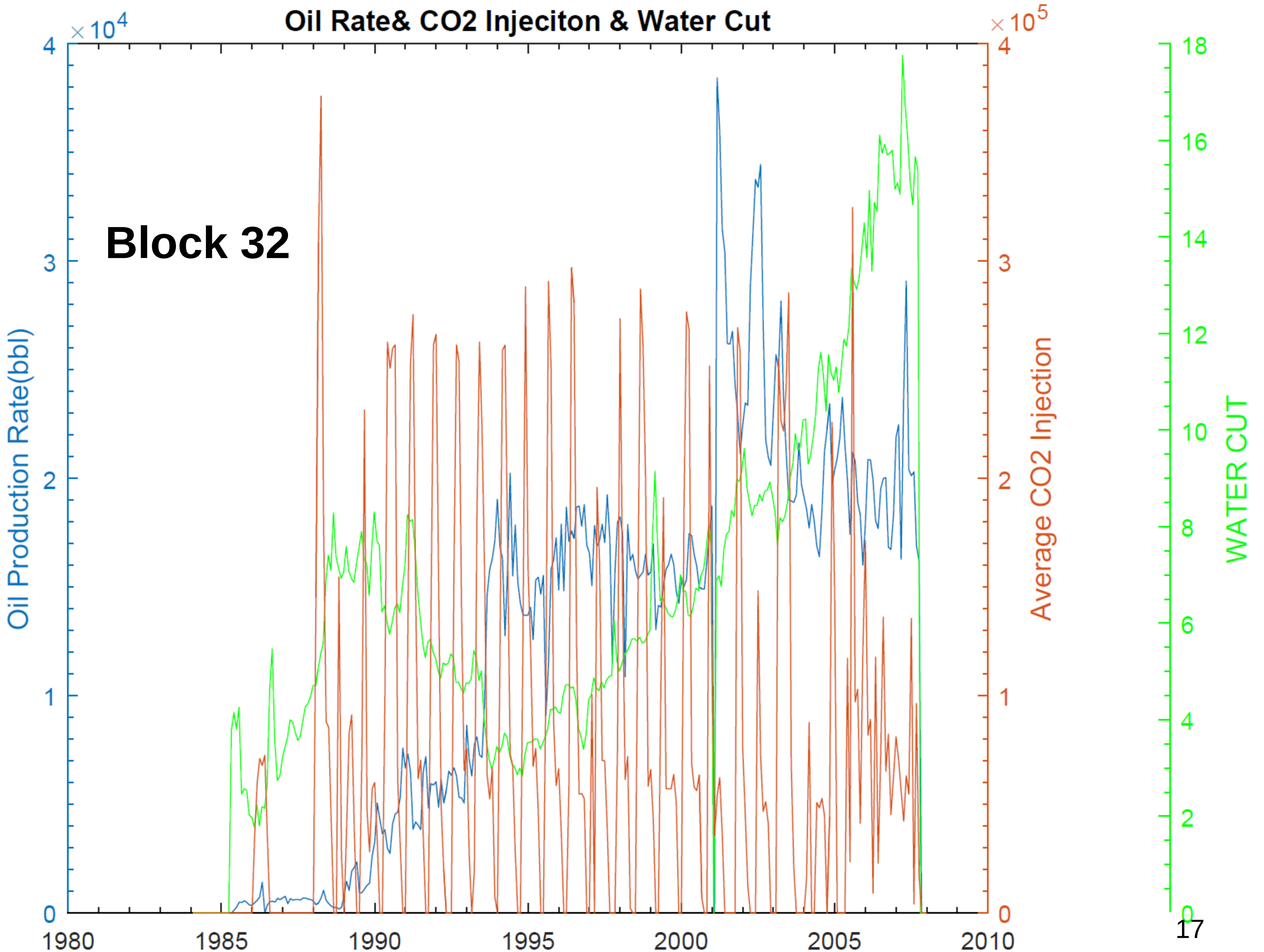
SSAU 2307



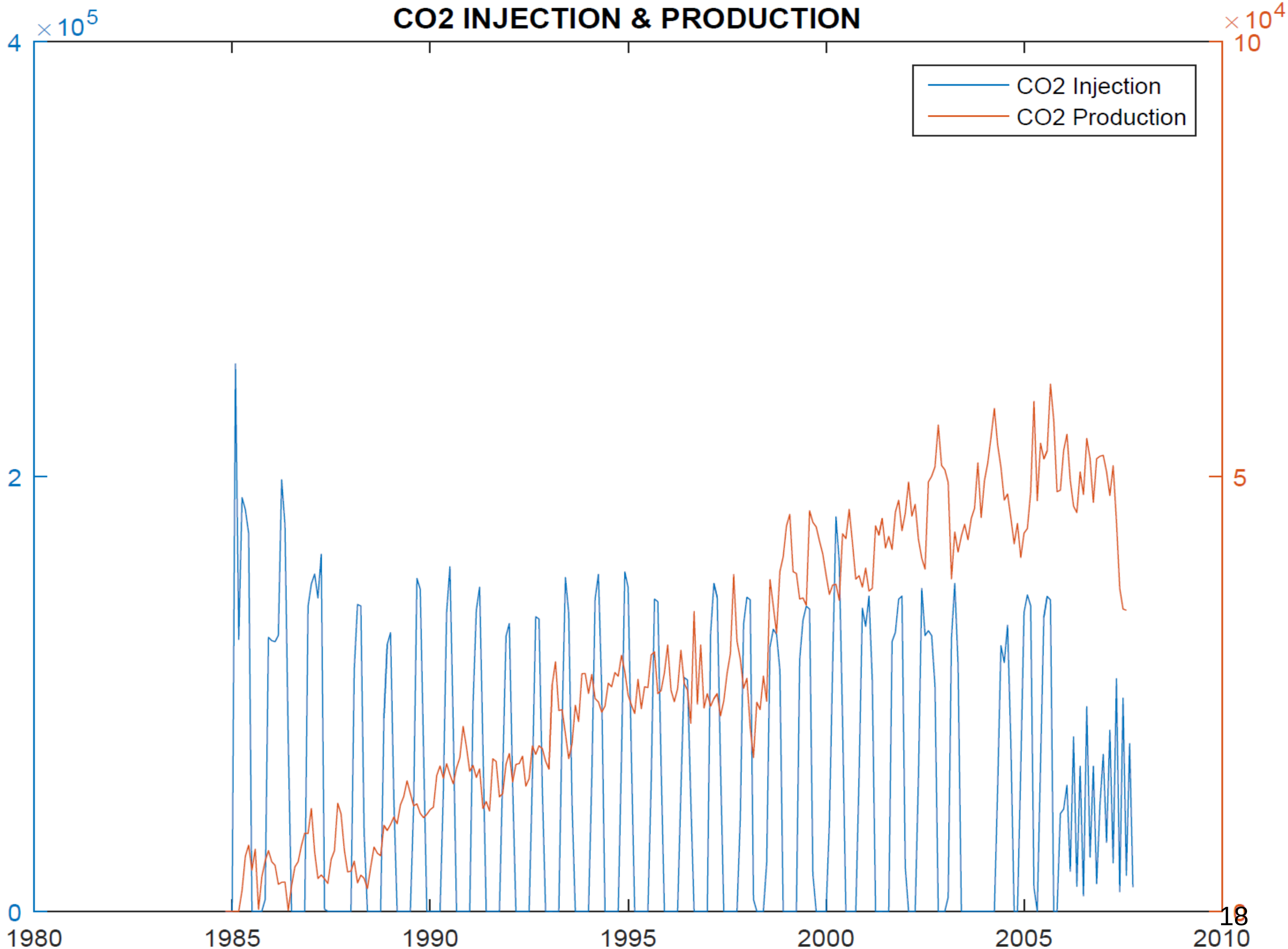
Metrics for 9 spot Blocks

- **Enables analysis of relationships between injection and production rates**
- **Attempt to relate production injection rates to nature of reservoir within 9-spot volume in static reservoir model**

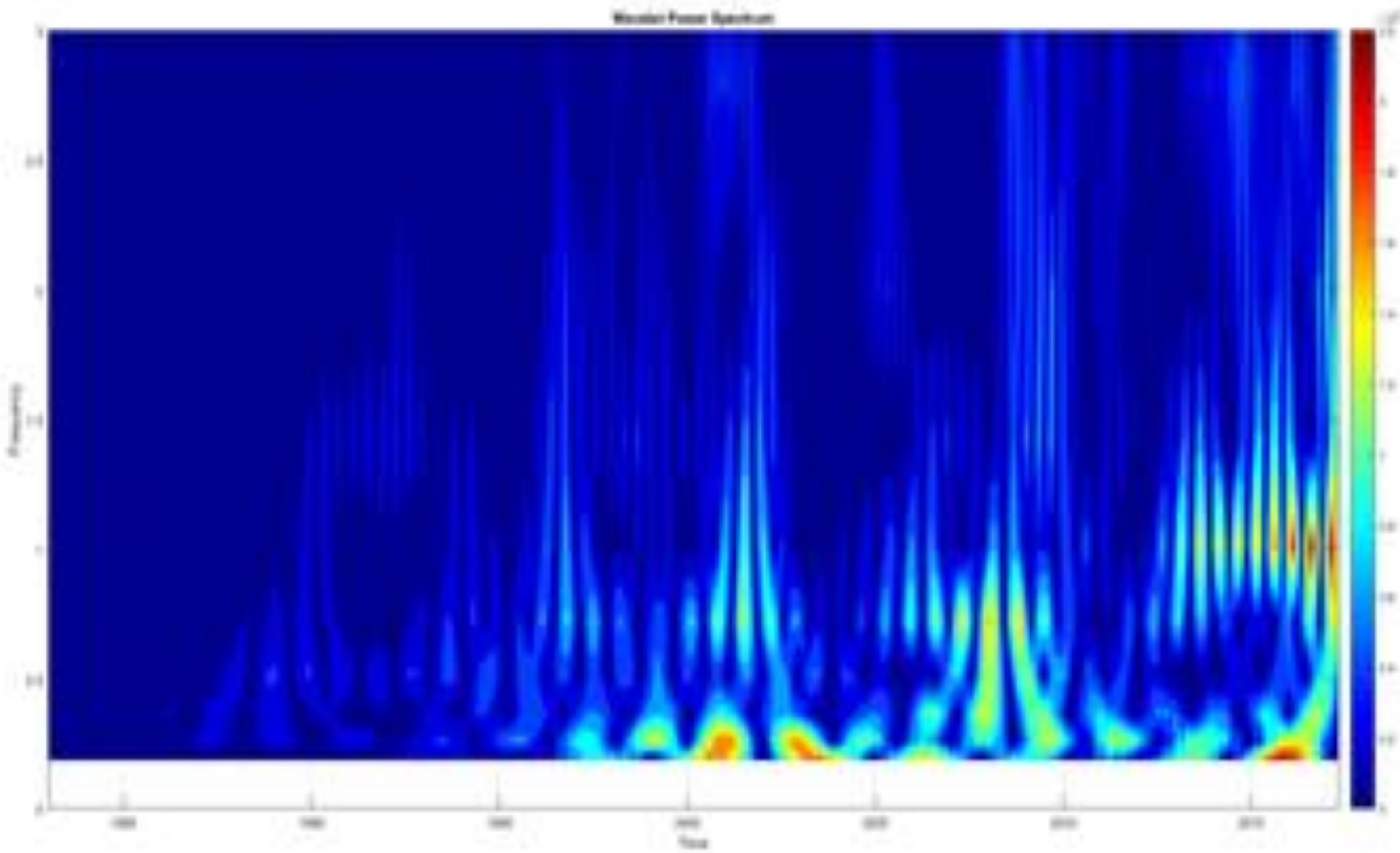
CO_2 WAG inputs Versus Production



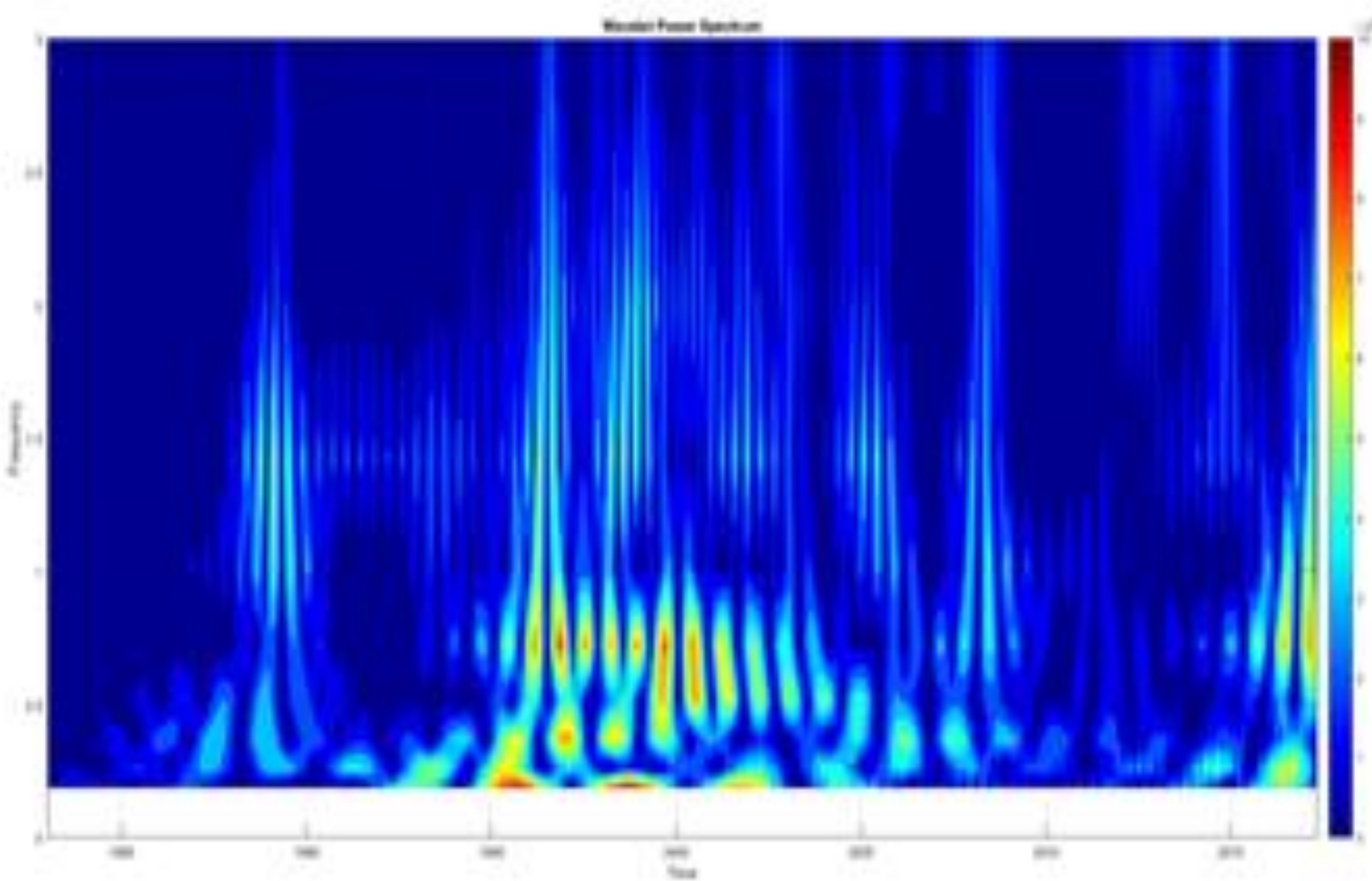
Oil Rate& CO2 Injeciton & Water Cut
Block 32
Oil Production Rate(bbl)
Average CO2 Injection
WATER CUT
×10^4
×10^5


CO2 INJECTION & PRODUCTION
×10^5
4
2
0
×10^4
10
5
0
CO2 Injection
CO2 Production
1980
1985
1990
1995
2000
2005
2010

Power Spectrum CO_2 Injection Stage 1 ROZ



Power Spectrum CO_2 Production Stage 1 ROZ

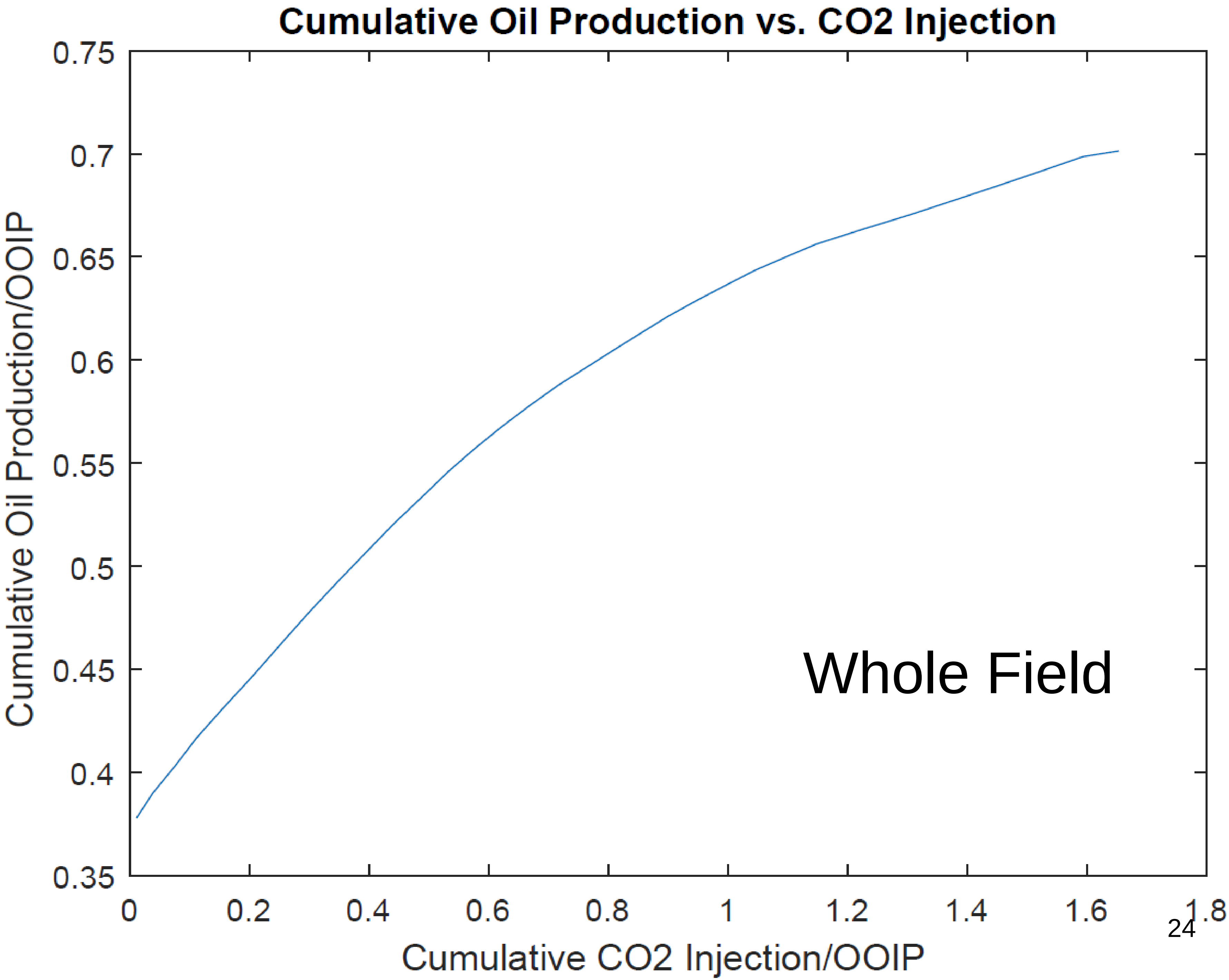


Metrics for CO_2 Storage

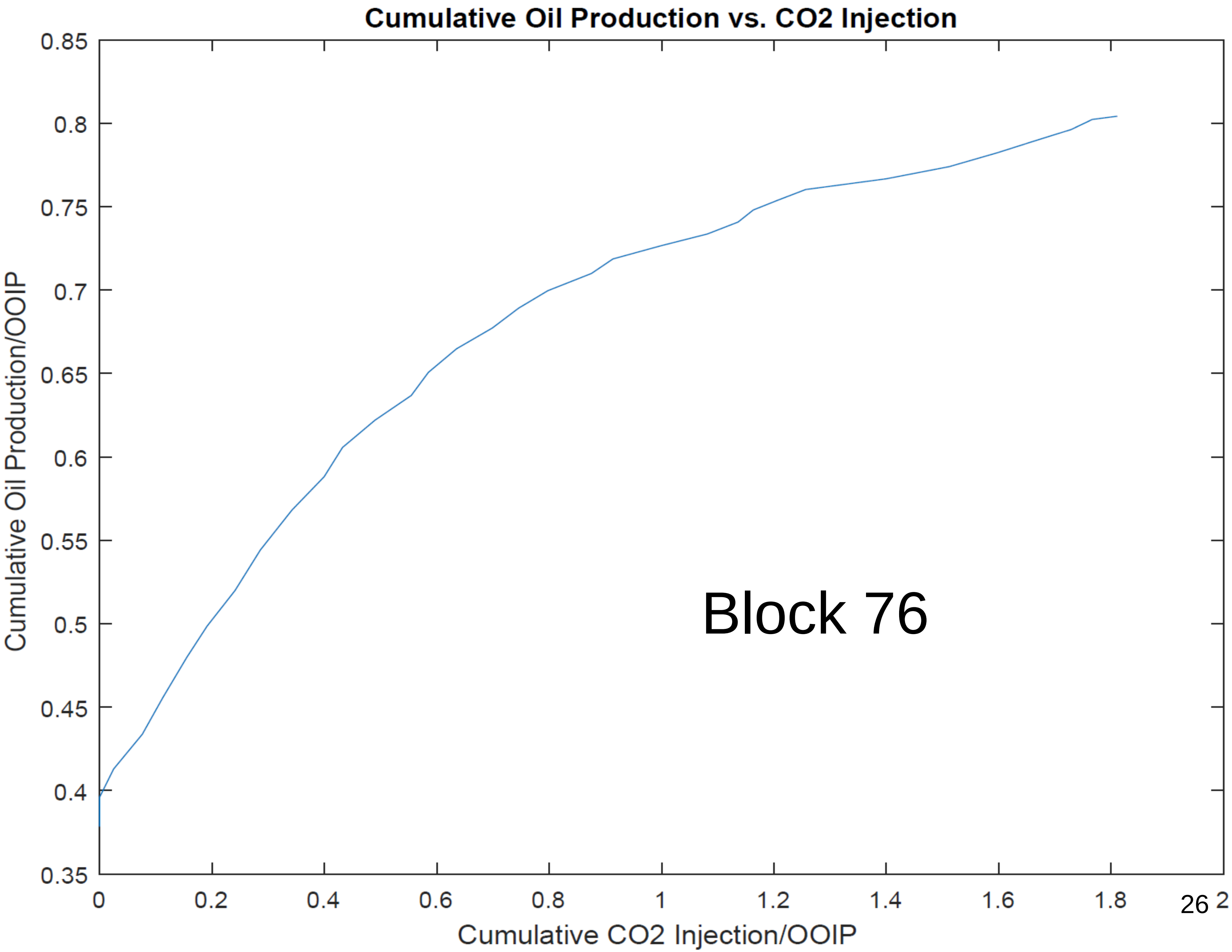
Metrics for CO2 Storage

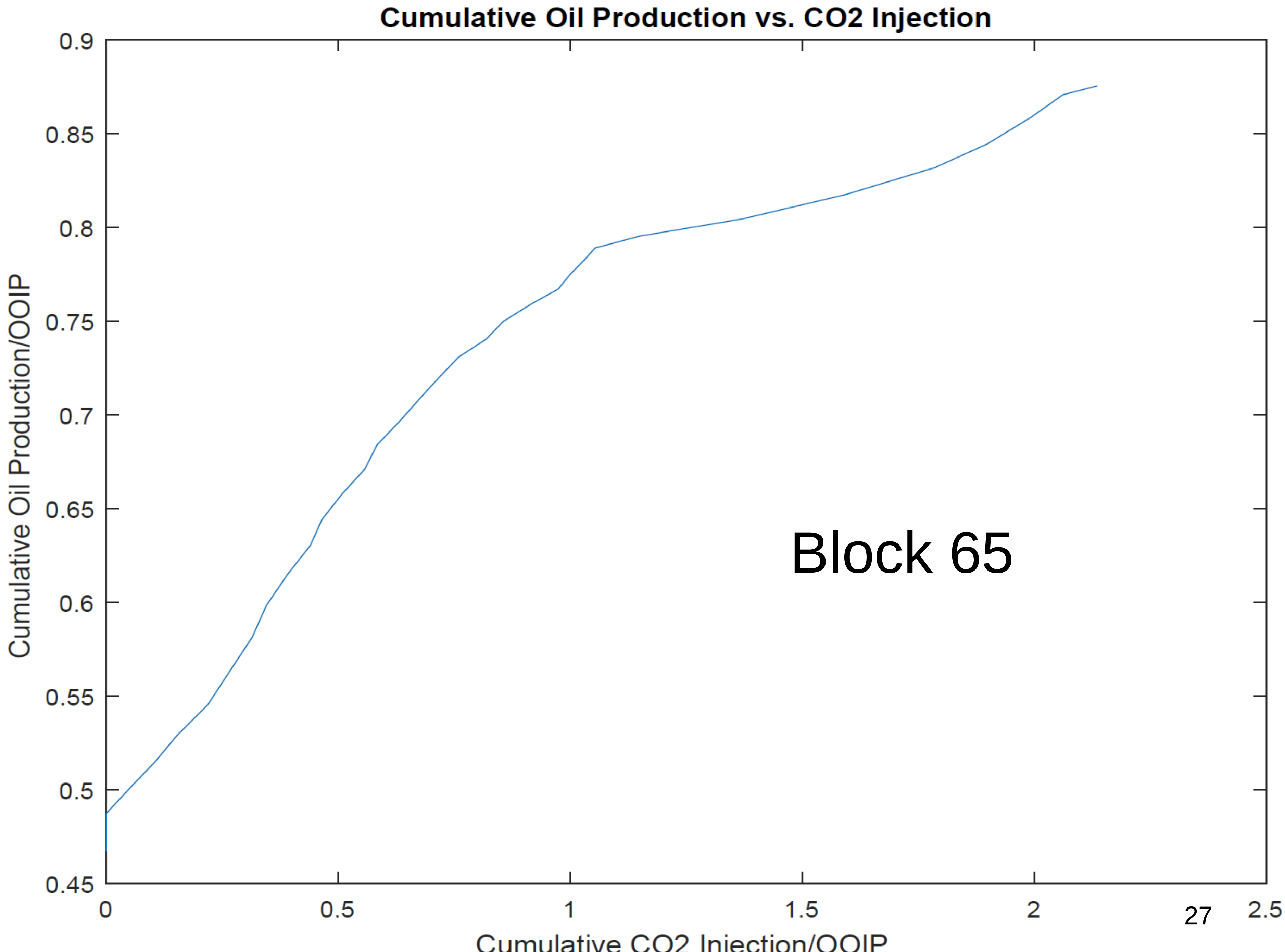
- **CO_2 Storage** = CO_2 Injected – CO_2 Produced
- **Net CO_2 Utilization** = CO_2 injected per Volume Oil Produced
- Metrics can be normed to original hydrocarbon pore volume or pore volume
- **CO_2 Storage Efficiency** = CO_2 injected/CO_2 storage

Cumulative Oil Produced Versus Cumulative CO_2 Injected

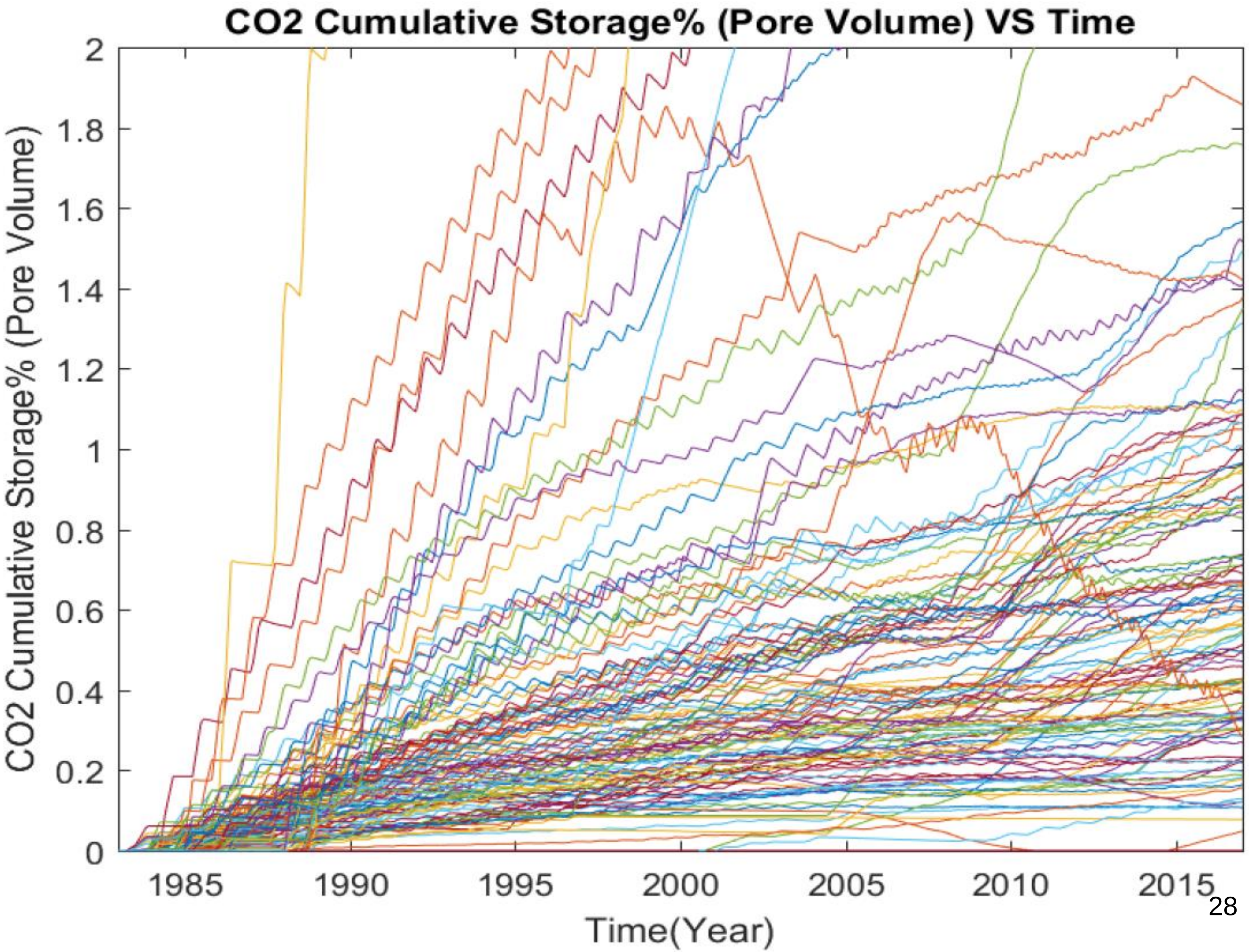

Cumulative Oil Production vs. CO2 Injection
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
Cumulative Oil Production/OOIP
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
Cumulative CO2 Injection/OOIP
Whole Field

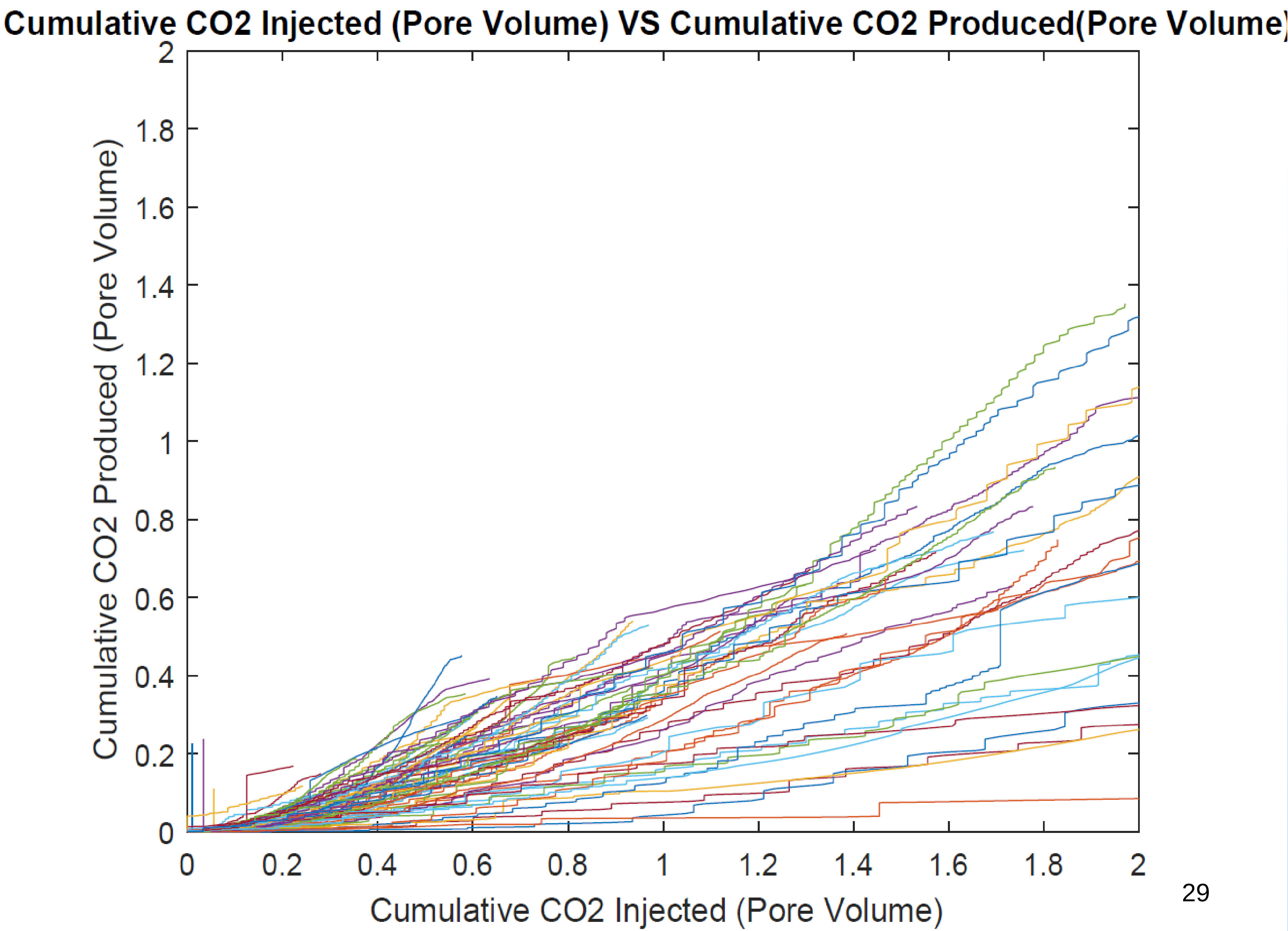
Metrics for 9 Spot Blocks


Cumulative Oil Production vs. CO2 Injection
Cumulative Oil Production/OOIP
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Cumulative CO2 Injection/OOIP
Block 76

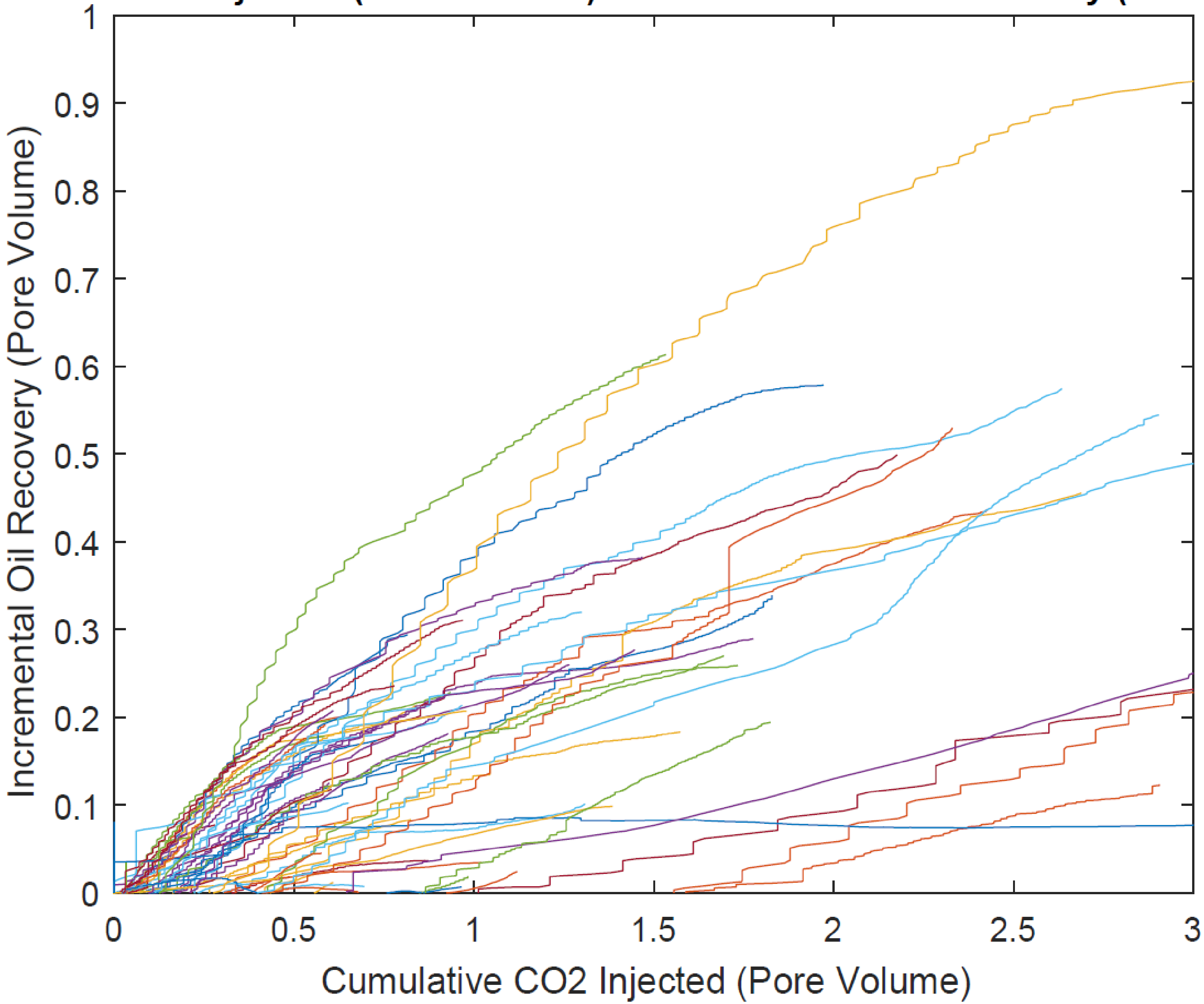


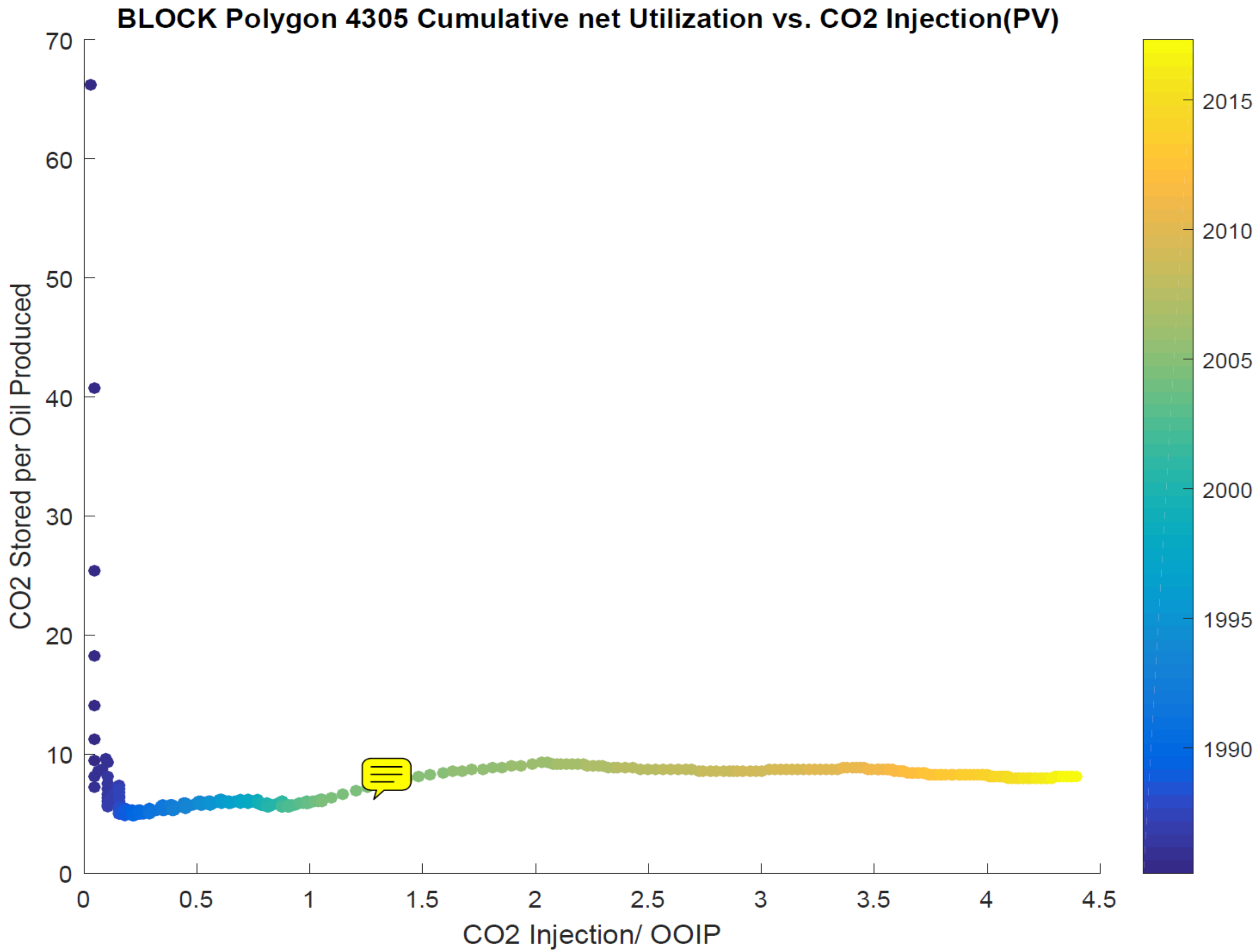
Cumulative Oil Production vs. CO2 Injection
Cumulative Oil Production/OOIP
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0
0.5
1
1.5
2
2.5
Cumulative CO2 Injection/OOIP
Block 65


CO2 Cumulative Storage% (Pore Volume) VS Time
CO2 Cumulative Storage% (Pore Volume)
Time(Year)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1985
1990
1995
2000
2005
2010
2015

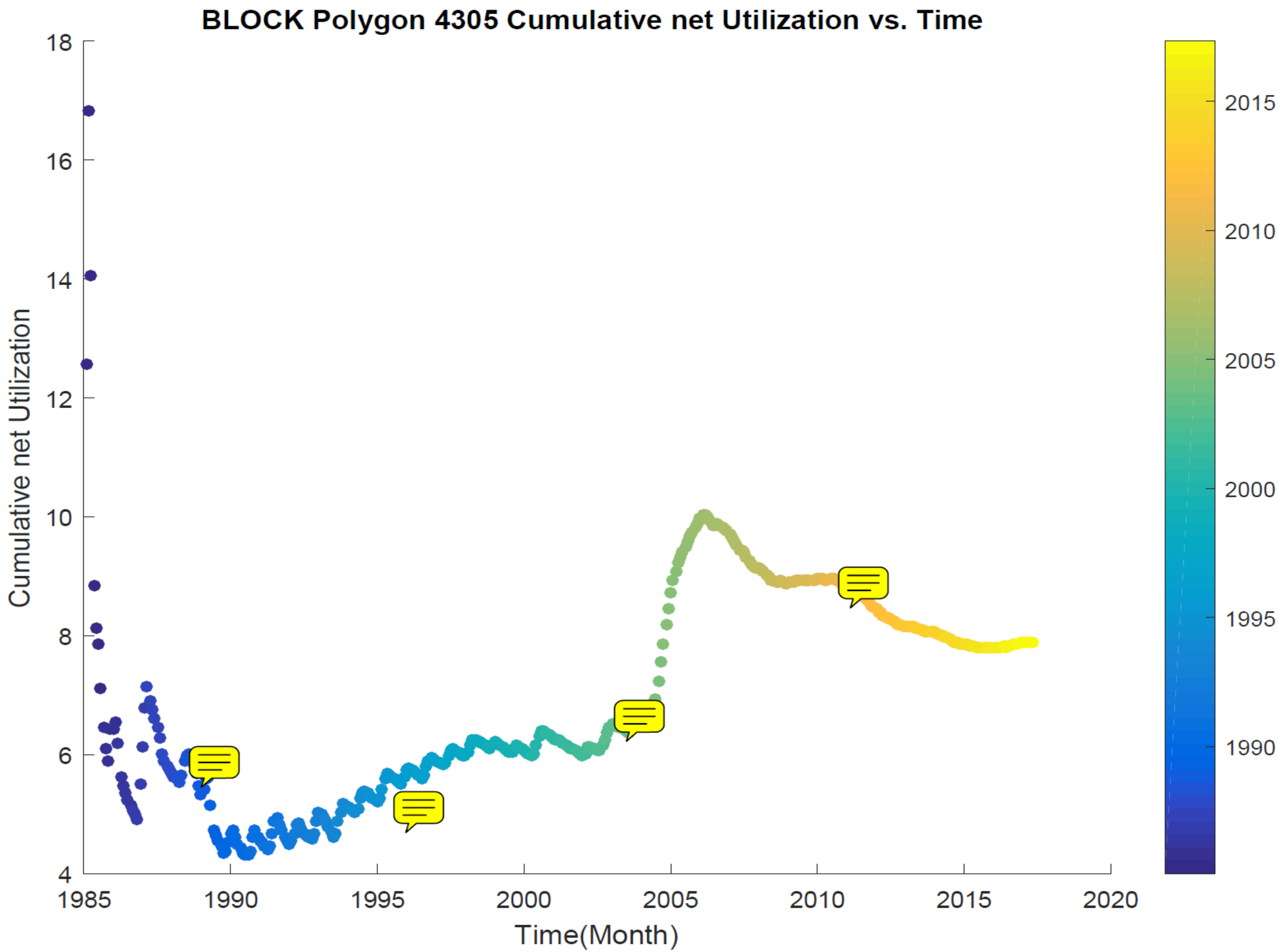

Cumulative CO2 Injected (Pore Volume) VS Cumulative CO2 Produced(Pore Volume)
Cumulative CO2 Produced (Pore Volume)
Cumulative CO2 Injected (Pore Volume)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

Cumulative CO2 Injected (Pore Volume) VS Incremental Oil Recovery (Pore Volume)





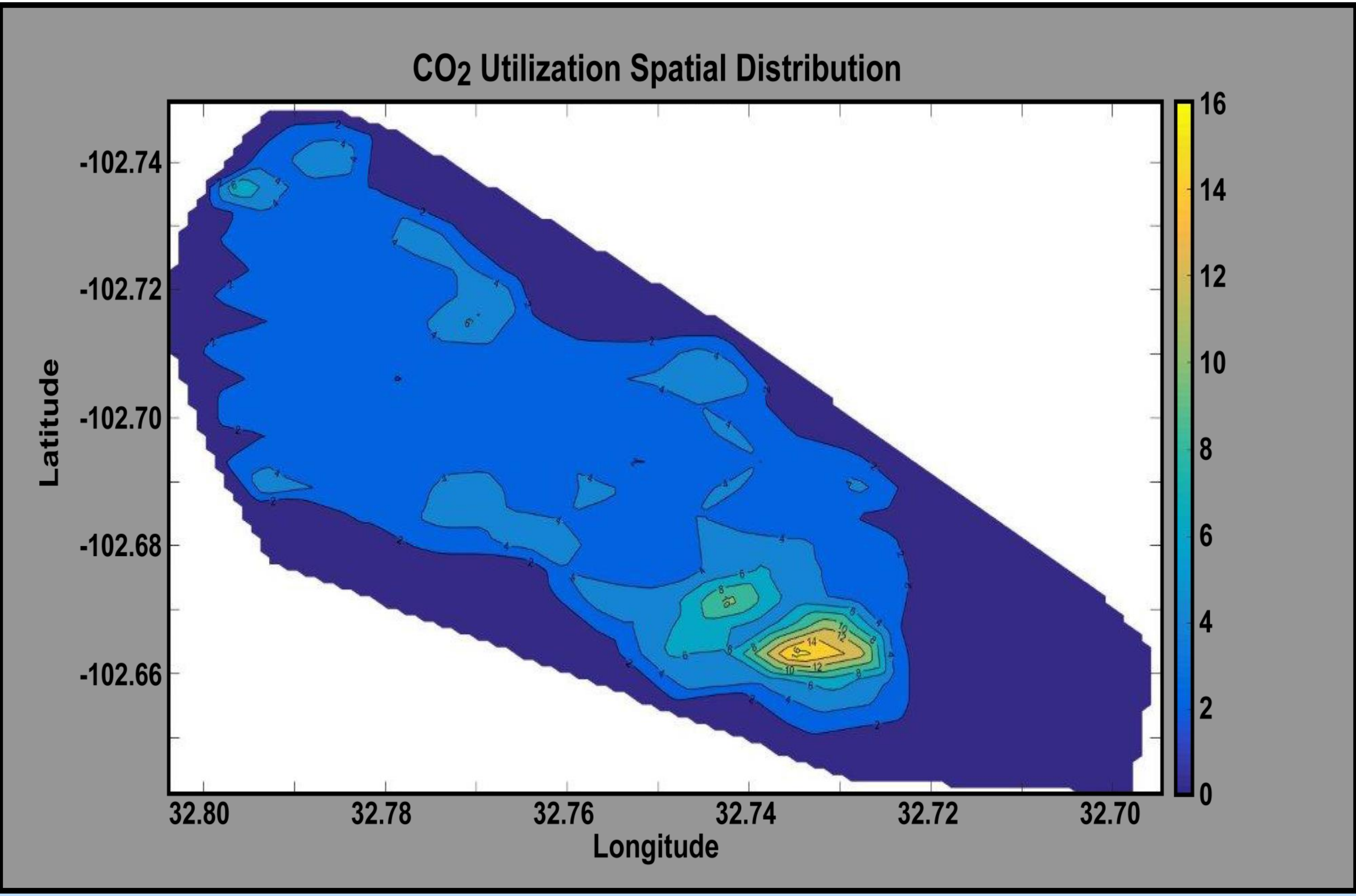
BLOCK Polygon 4305 Cumulative net Utilization vs. CO2 Injection(PV)
CO2 Stored per Oil Produced
CO2 Injection/ OOIP
0
10
20
30
40
50
60
70
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
1990
1995
2000
2005
2010
2015



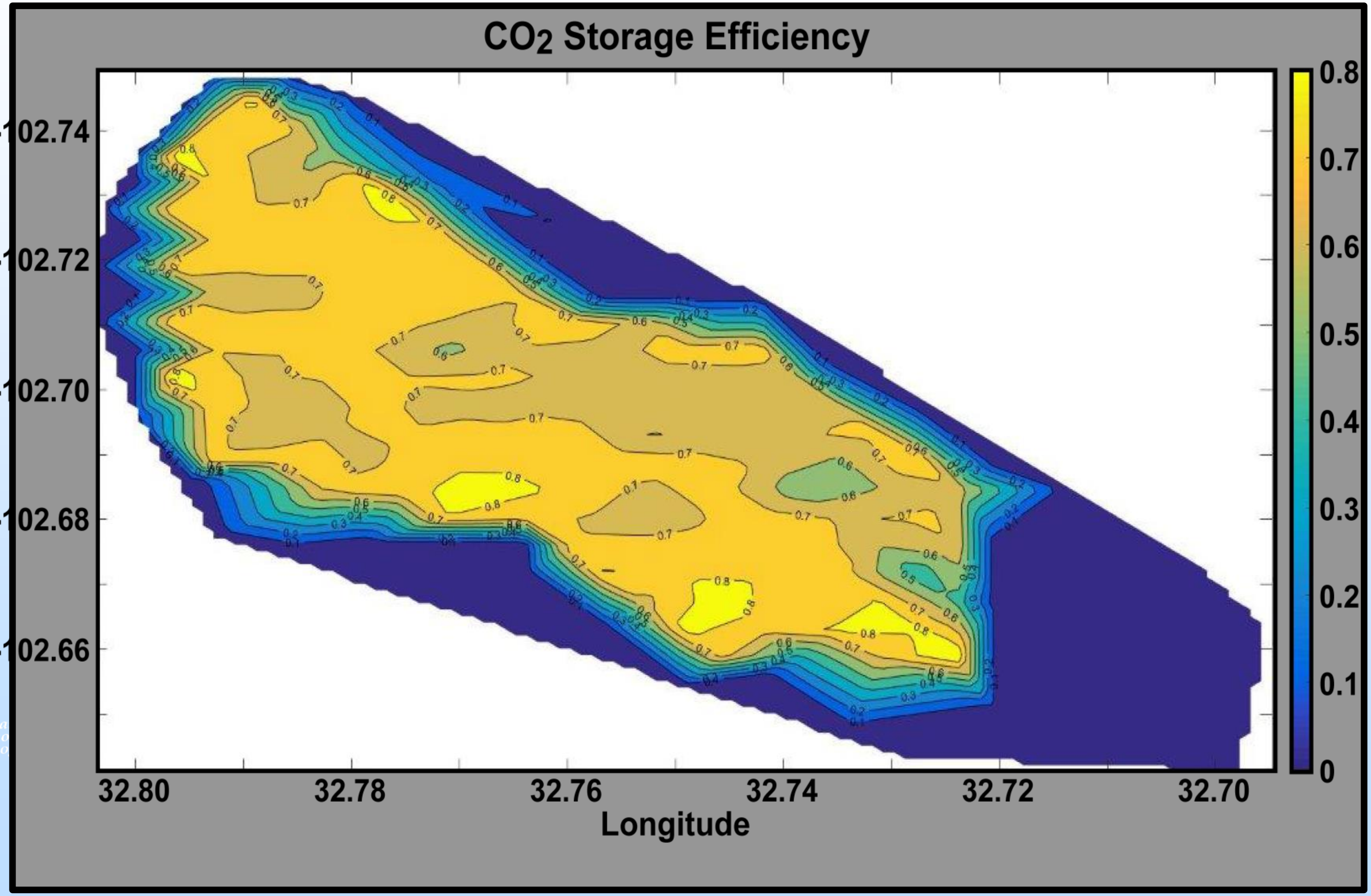
BLOCK Polygon 4305 Cumulative net Utilization vs. Time
Cumulative net Utilization
Time(Month)
18
16
14
12
10
8
6
4
1985
1990
1995
2000
2005
2010
2015
2020
2015
2010
2005
2000
1995
1990

Spatial Variation of CO_2 Flood Metrics

Spatial Distribution of CO_2 Utilization



Spatial Distribution of CO_2 Storage Efficiency



Developing an Upgraded Static Reservoir Model

DEVELOPING A STATIC RESERVOIR MODEL

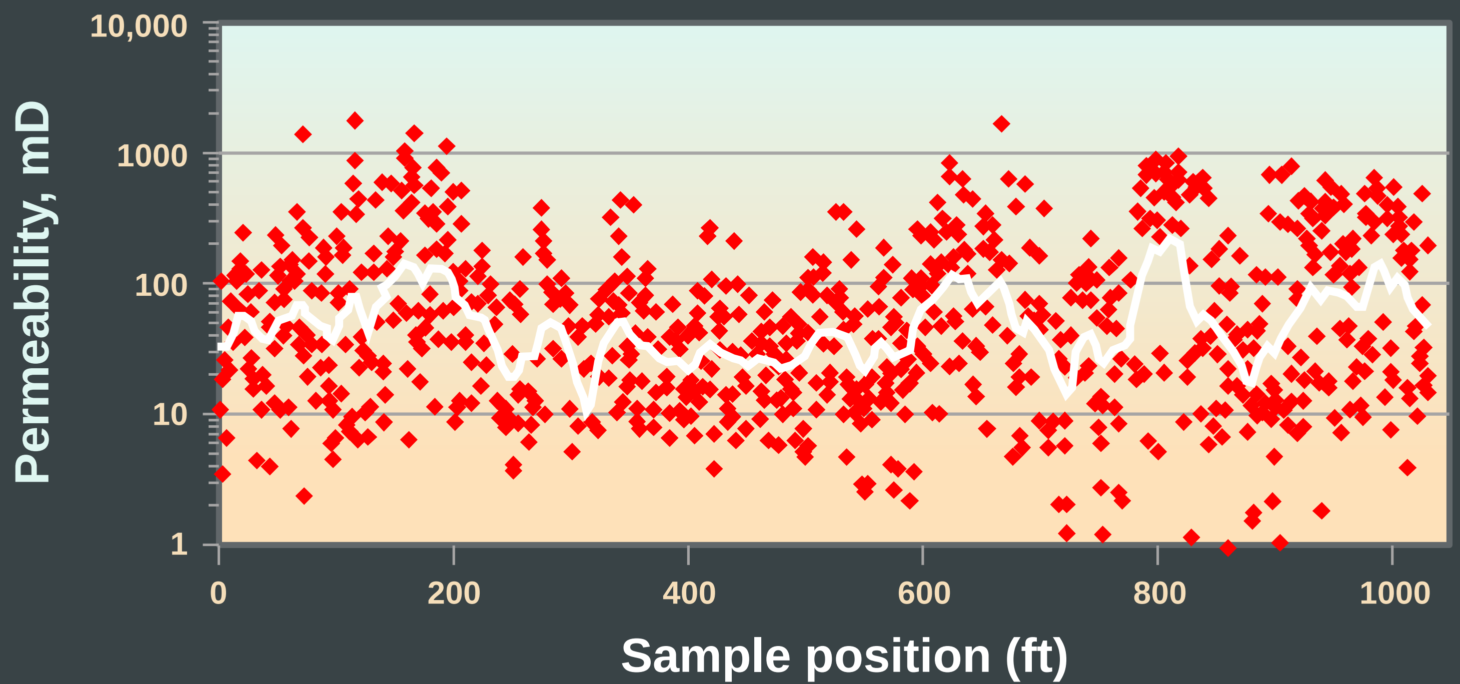
- Geologic logging cores… **new facies interpretations**… new modern analogues
- New approach to **upscaling** porosity and permeability
- New analysis of petrophysical data.
- Inter-well distribution of facies using **Variogram analysis**.

PERMEABILITY DEFICIT DISORDER

- Reservoir simulations of major Permian Basin oil fields cannot match observed data unless much higher permeability magnitudes are used in simulations.

- Our approach... Higher spatial resolution modelling and careful modeling of permeability between wells.

LATERAL PERMEABILITY VARIATION SURFACE OUTCROP

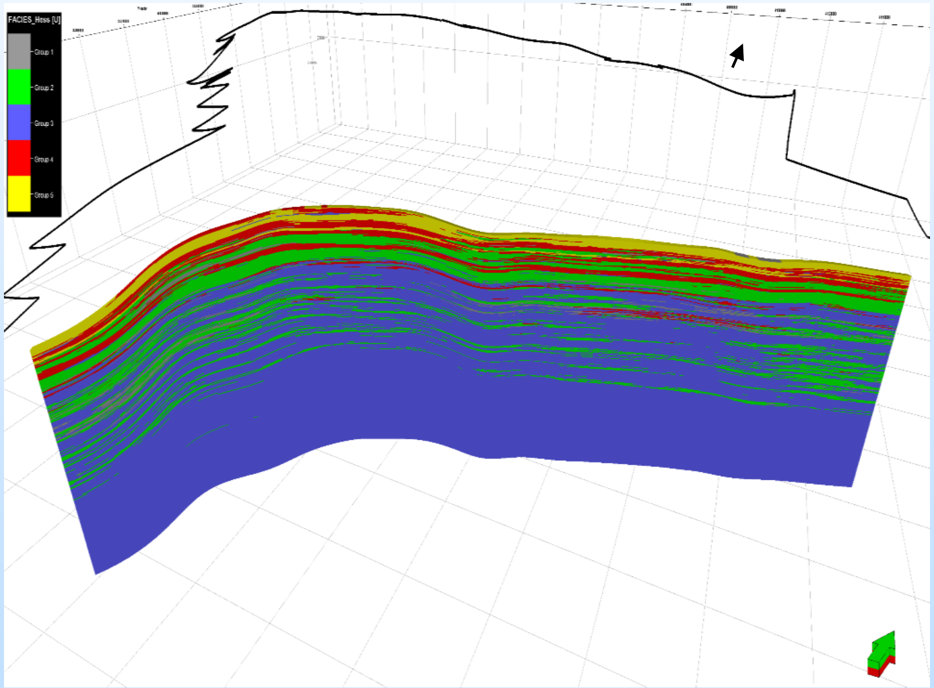


Source: SPE, 2010, Honarpour, M. M., and others
QAe4803

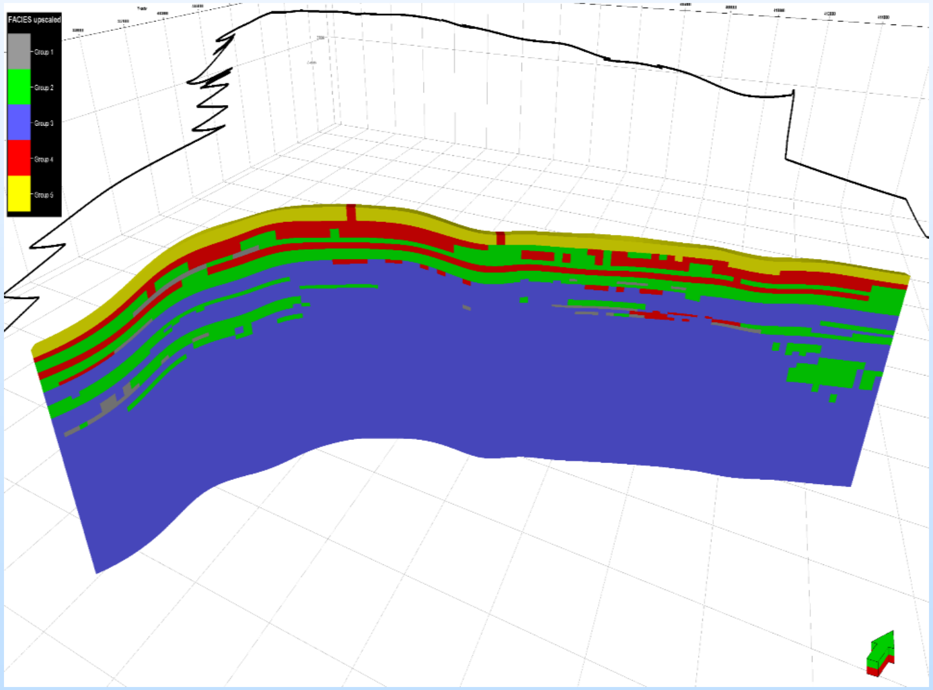
Initial Static Reservoir Model

Facies model slice

Detailed

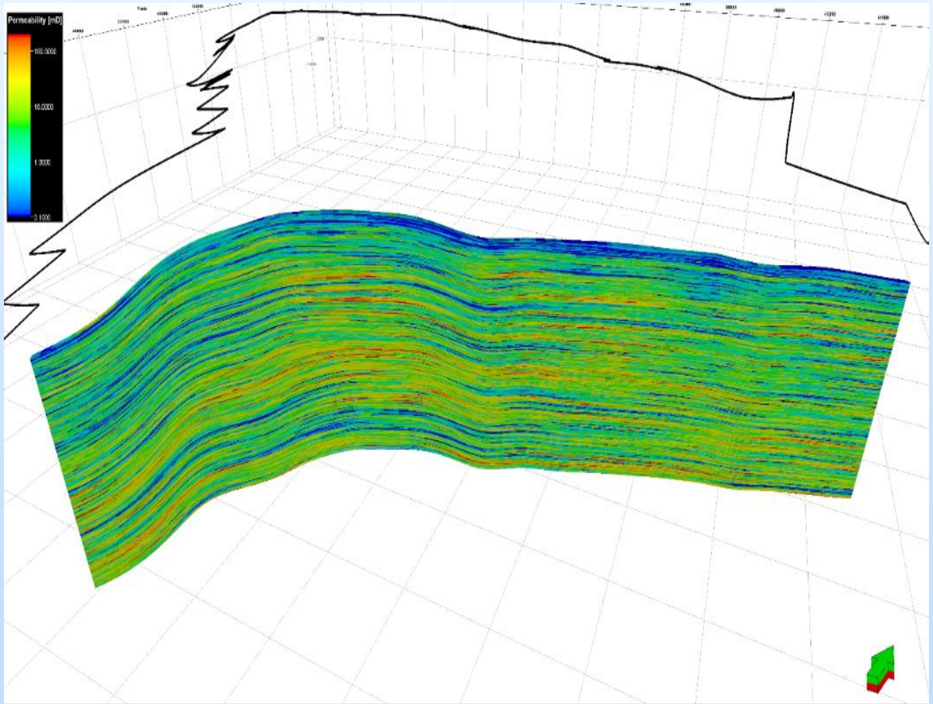


Up-scaled

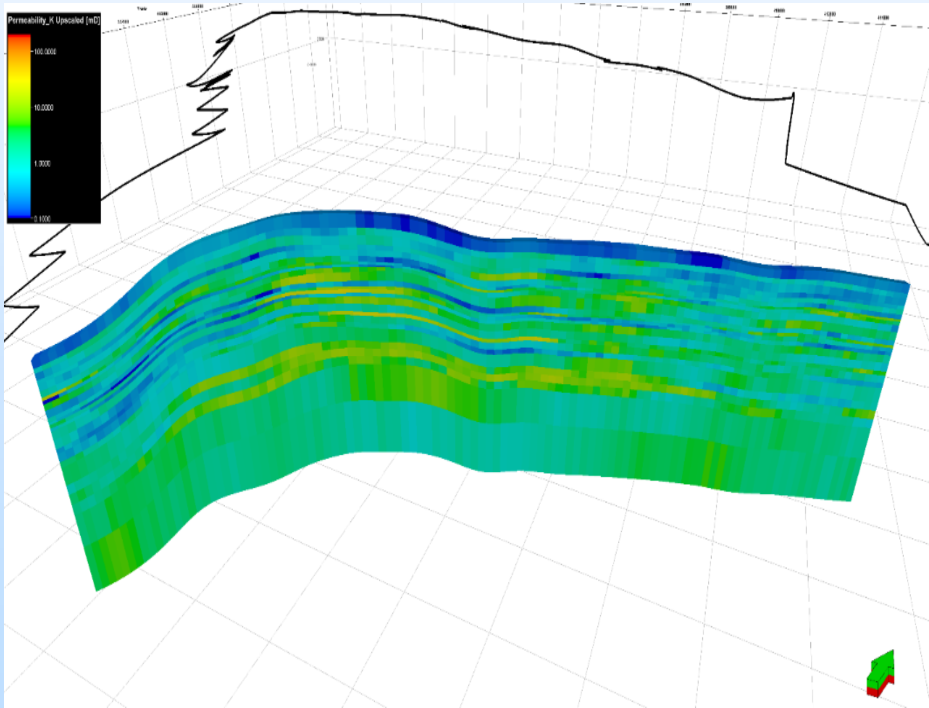


Permeability Model Slice

Detailed

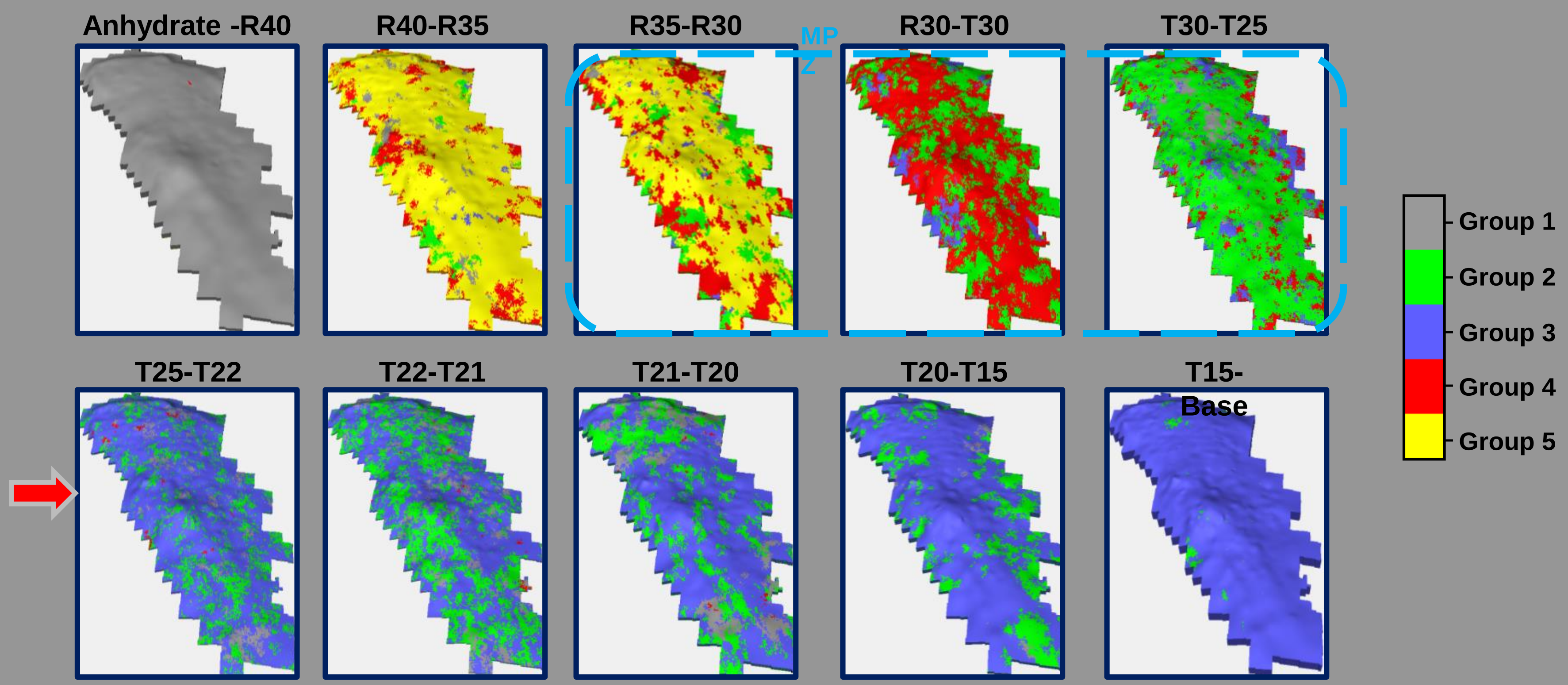


Upscaled



Upgraded Static Reservoir Model

Facies Distribution Through MPZ and ROZ



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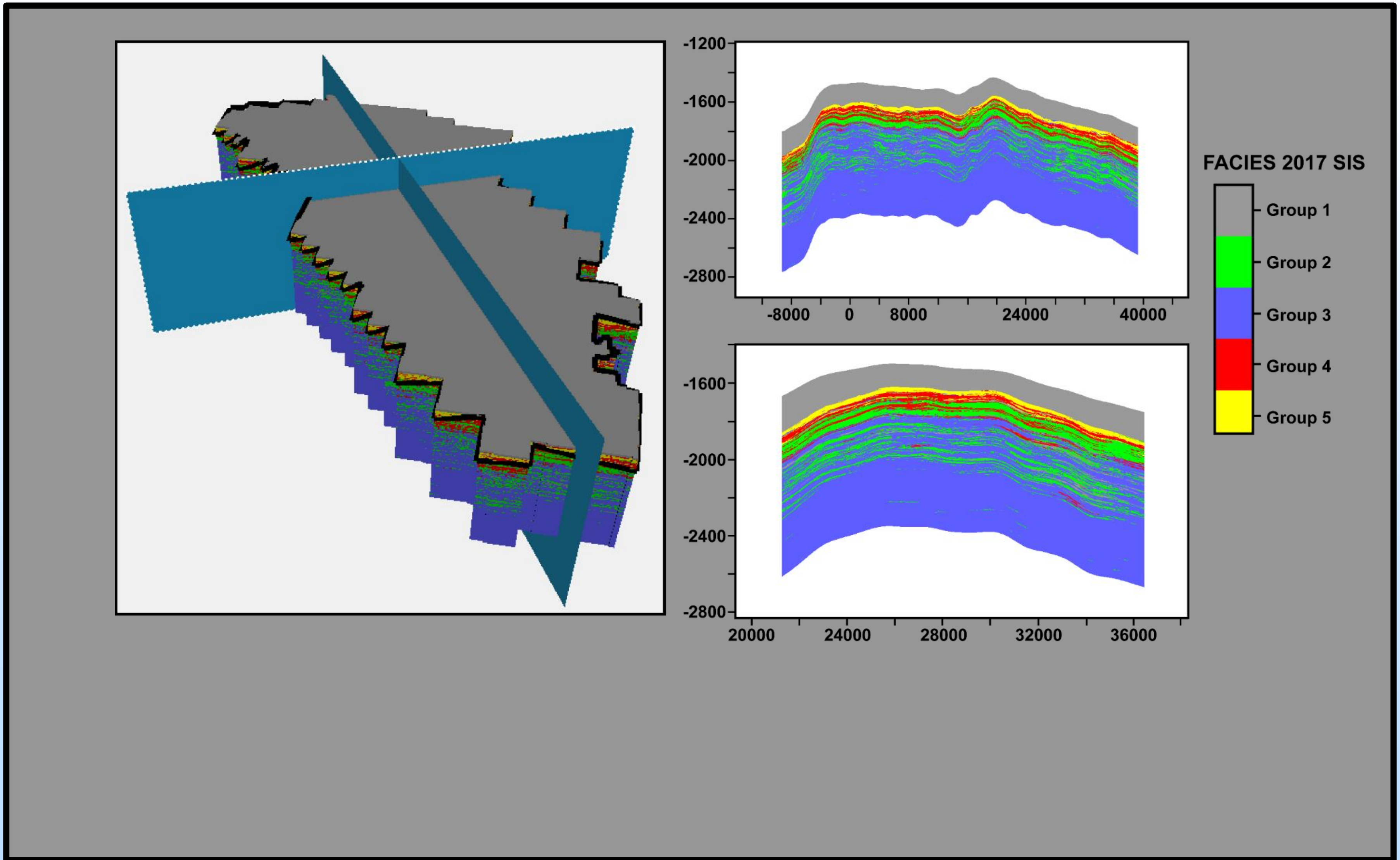
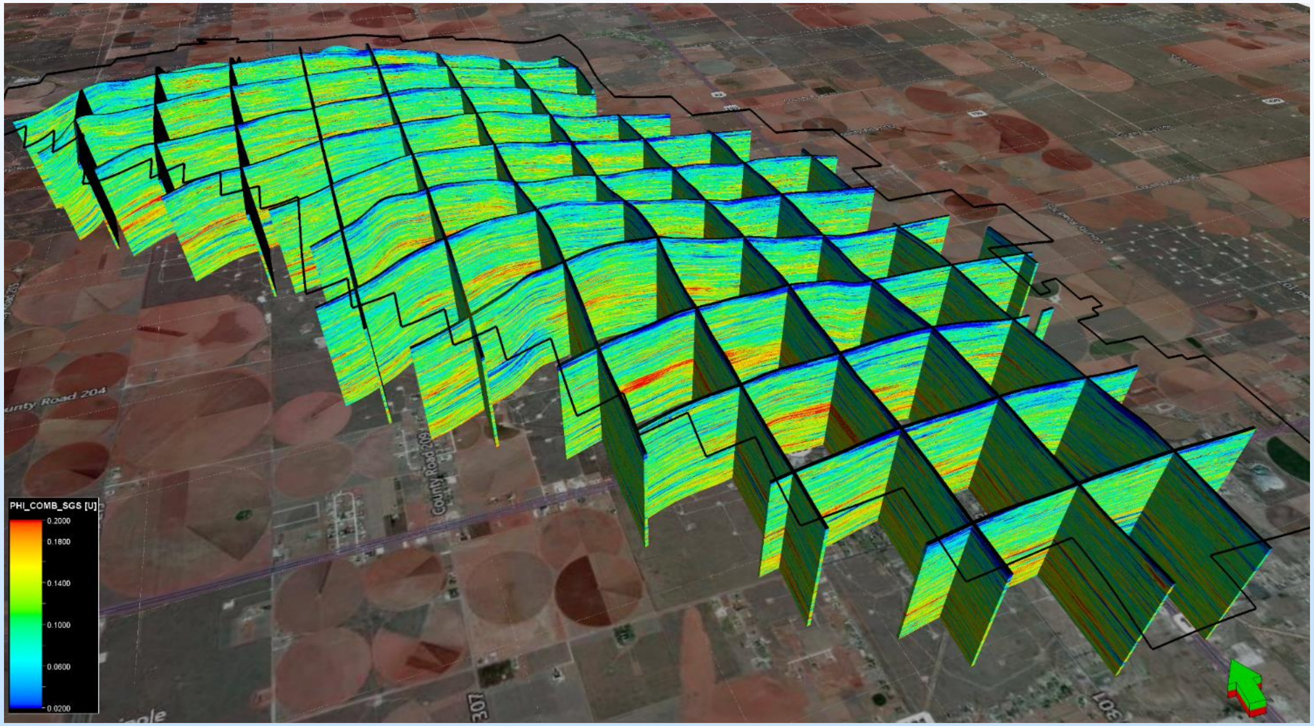
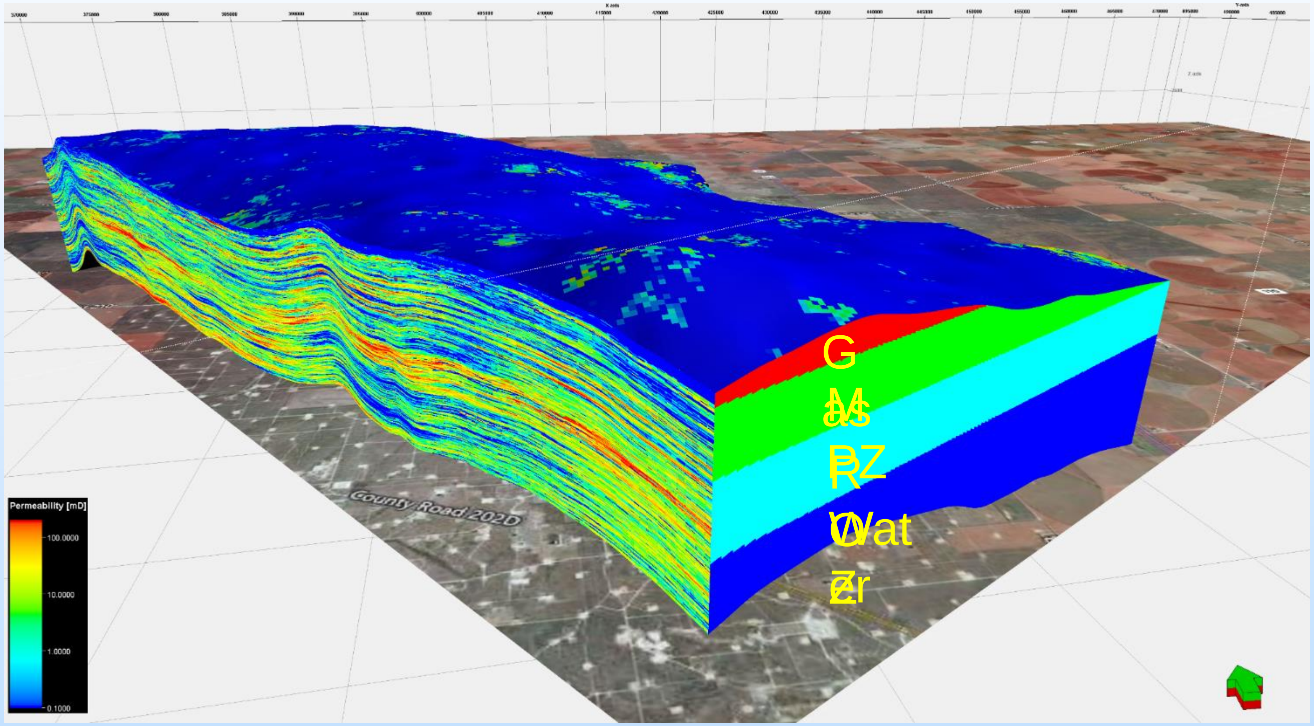
Seminole Oilfield, Facies Model (Sequential Gaussian simulation)



Porosity fence diagram



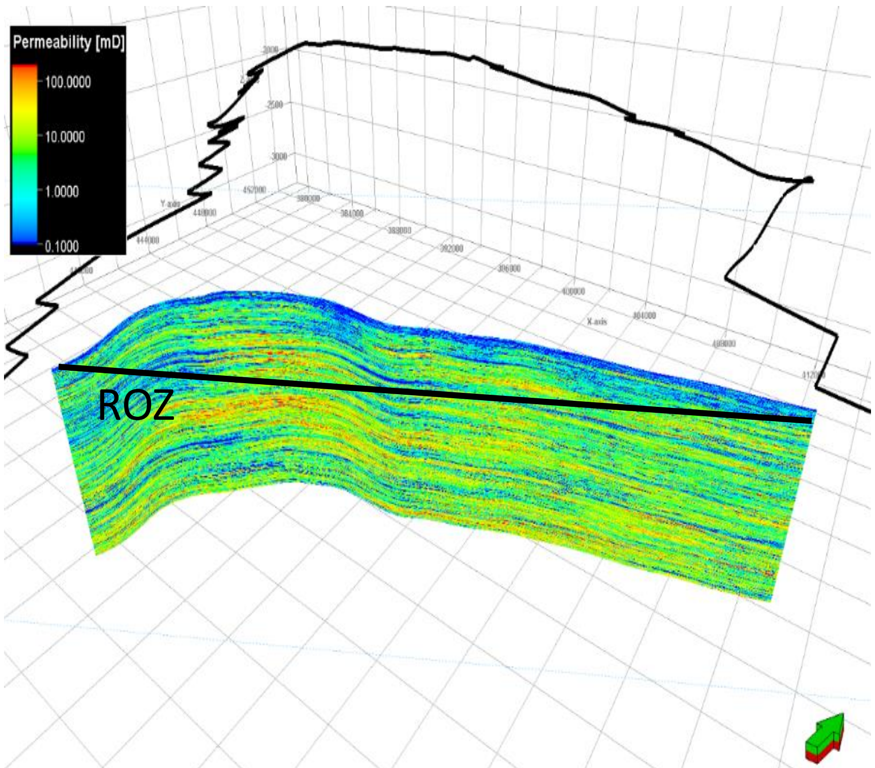
Permeability section view



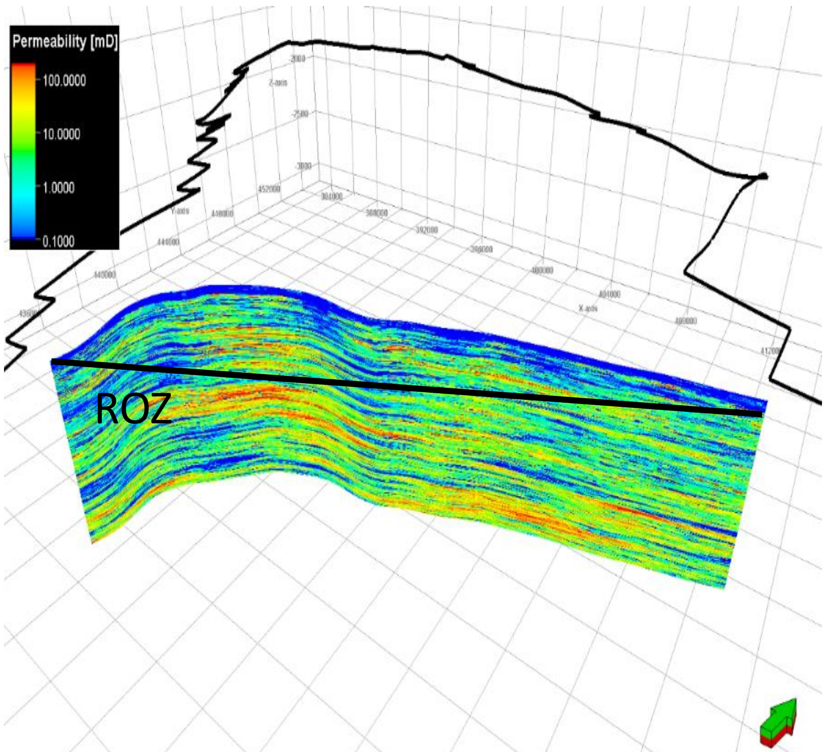
Initial Versus Upgraded Static Reservoir Model

Permeability Model Comparison

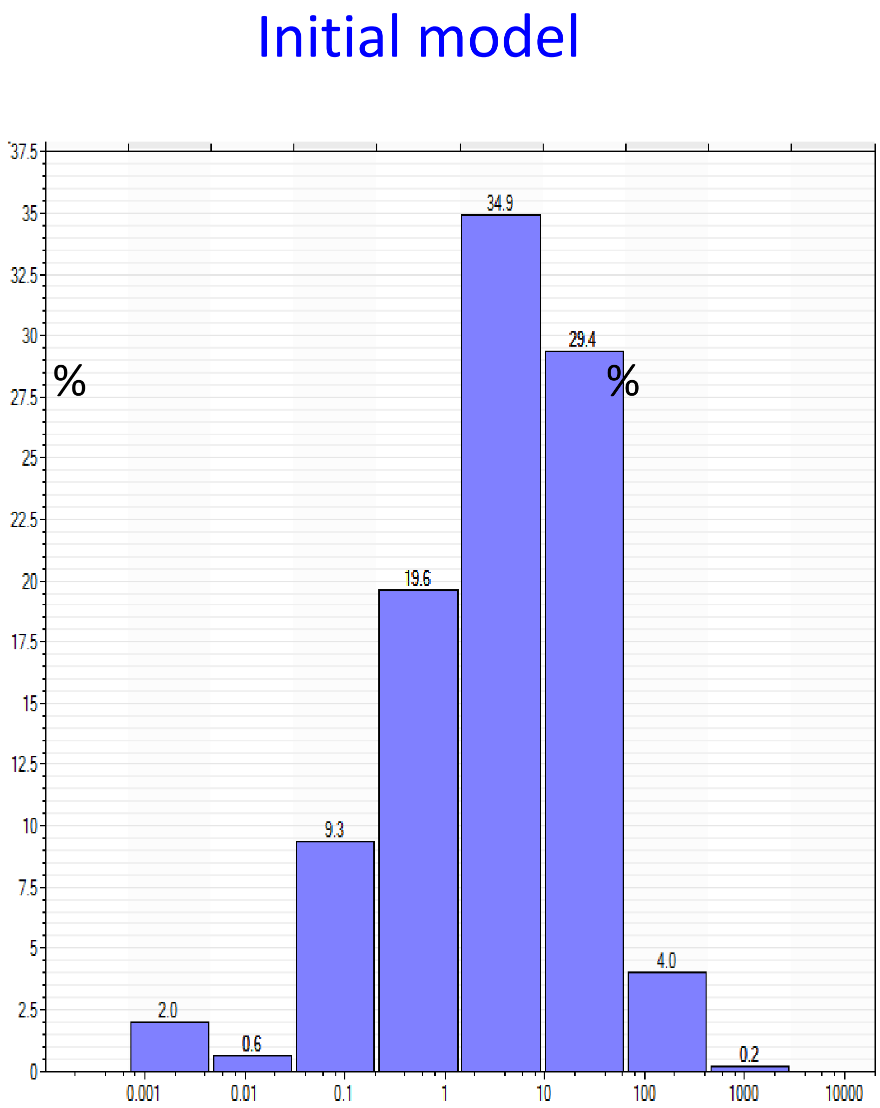
Initial Model – not conditioned by facies

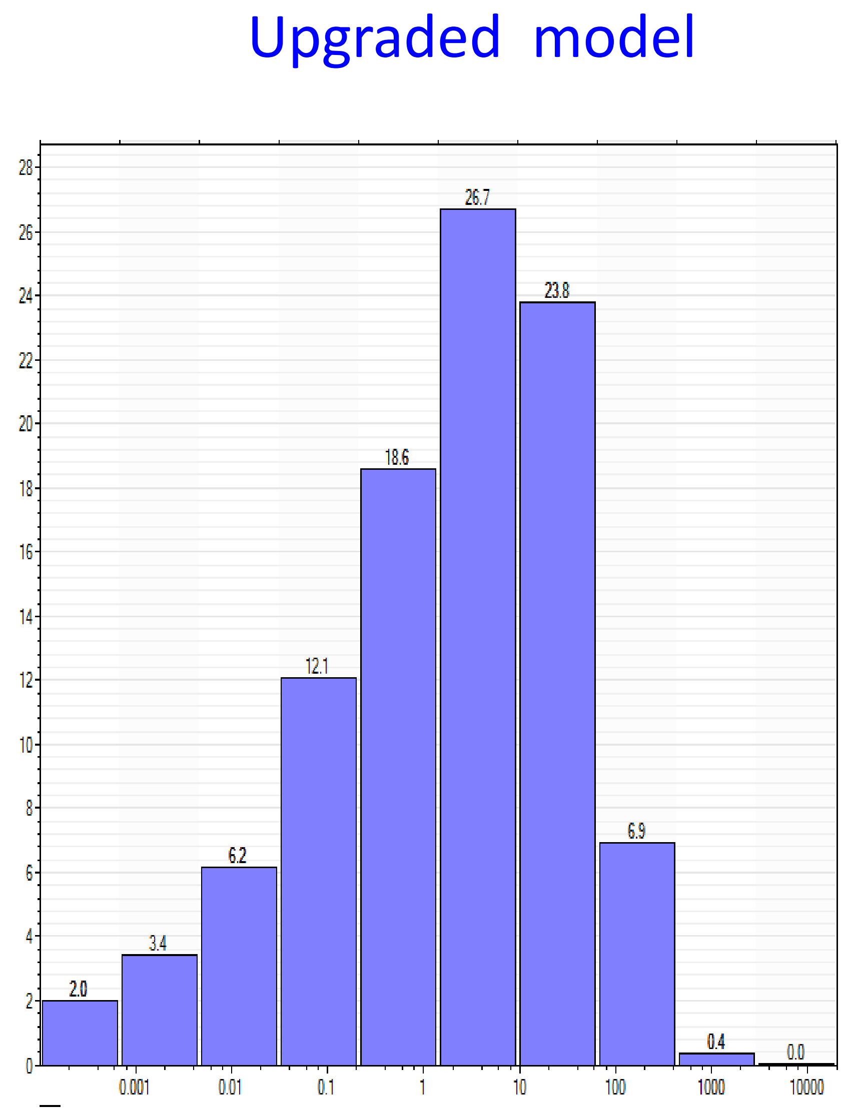


Upgraded – conditioned by facies

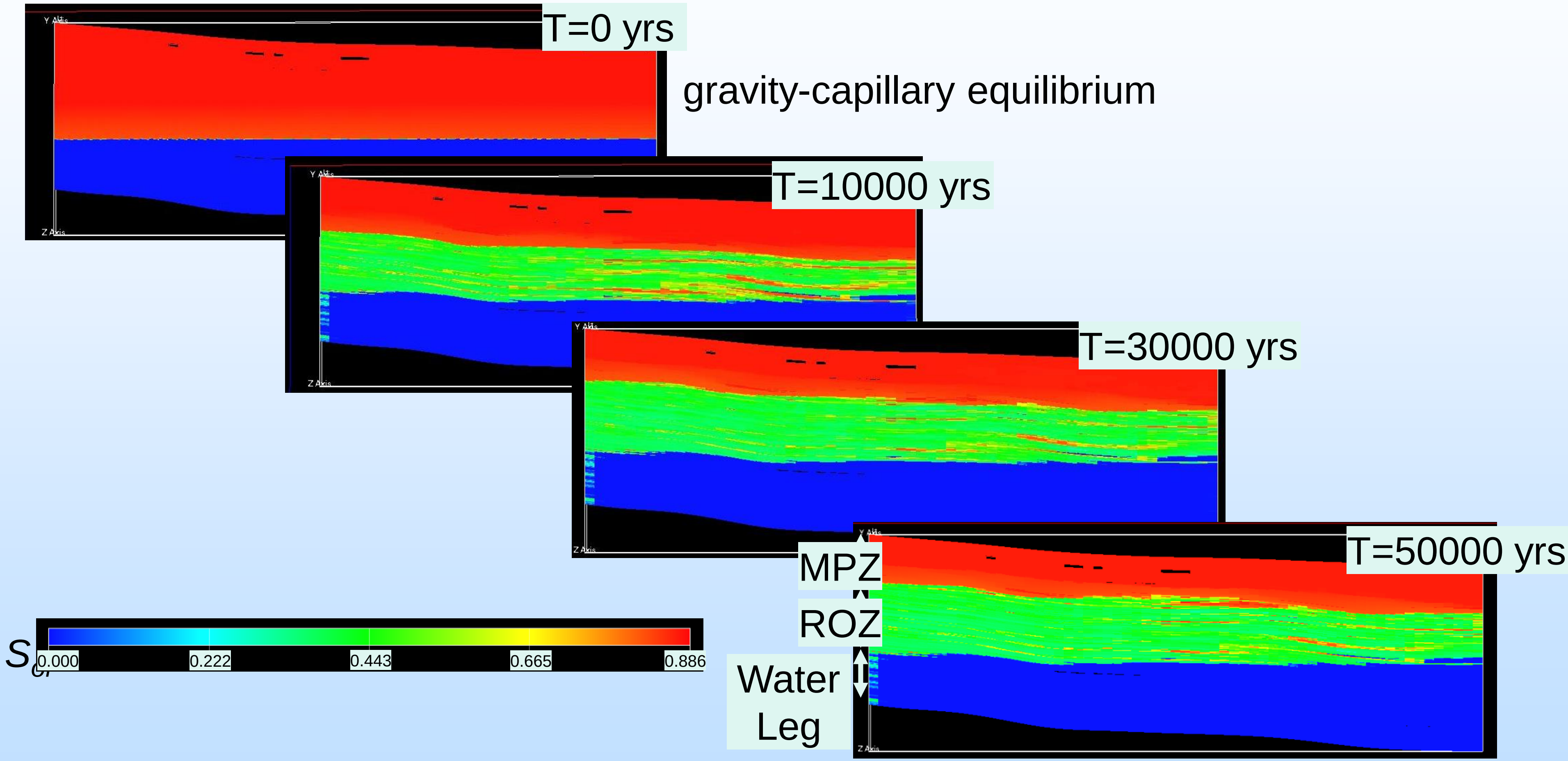


Histogram of permeability model





Oil Saturation Distribution – cross section along well 5512R



Variogram Model

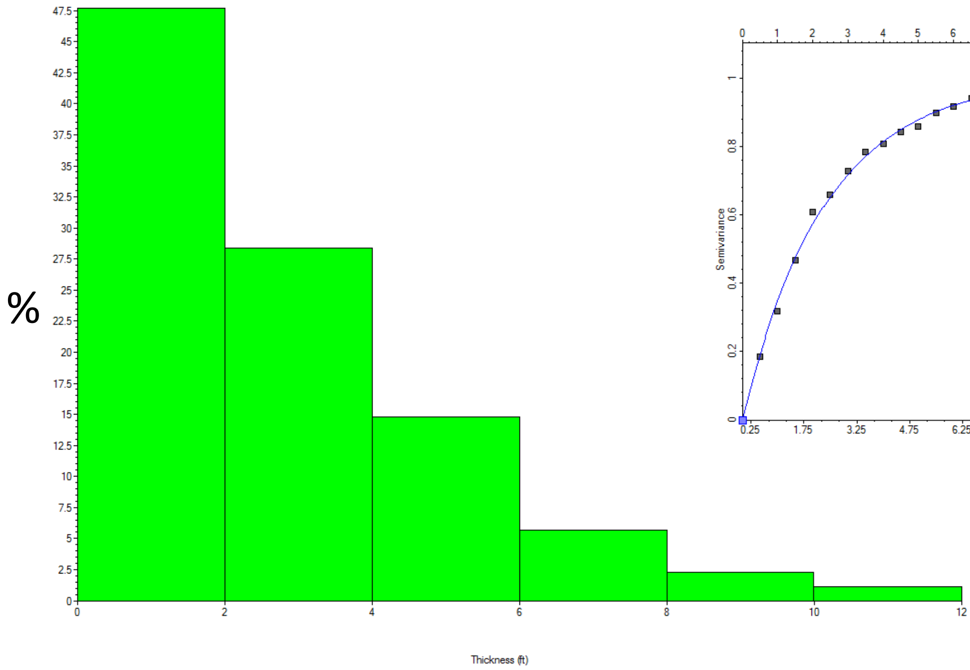
Exponential model

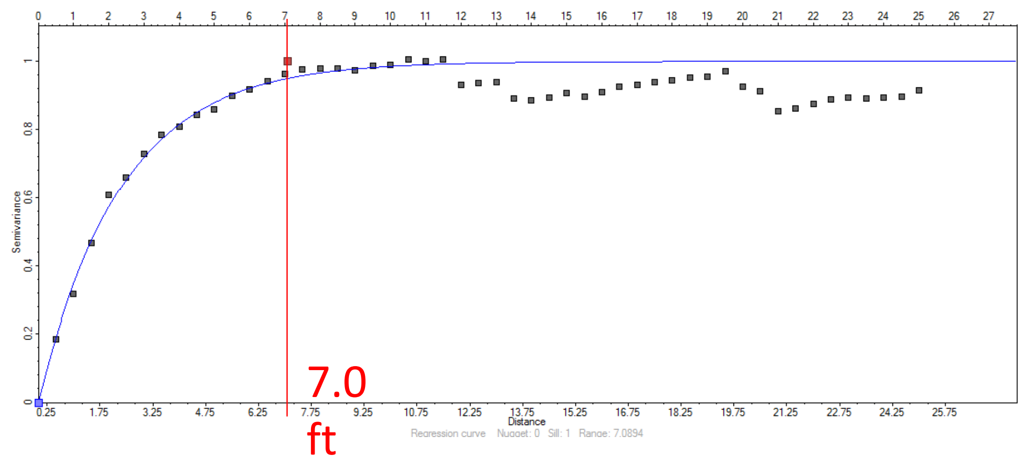
$$\gamma(h) = 1 - e^{-\frac{3|h|}{a}}$$

a, range or auto-correlation length

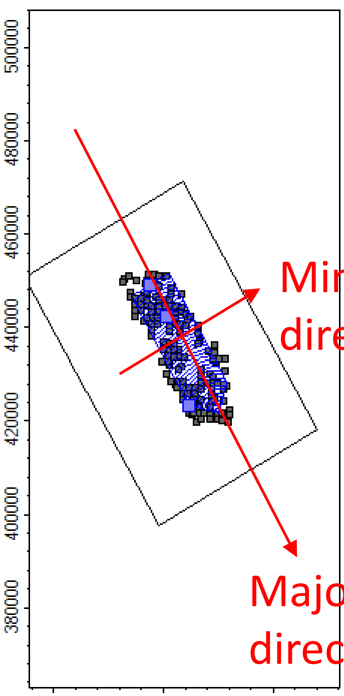
h, lag distance

R40Group2 -- Thickness Frequency, Variogram



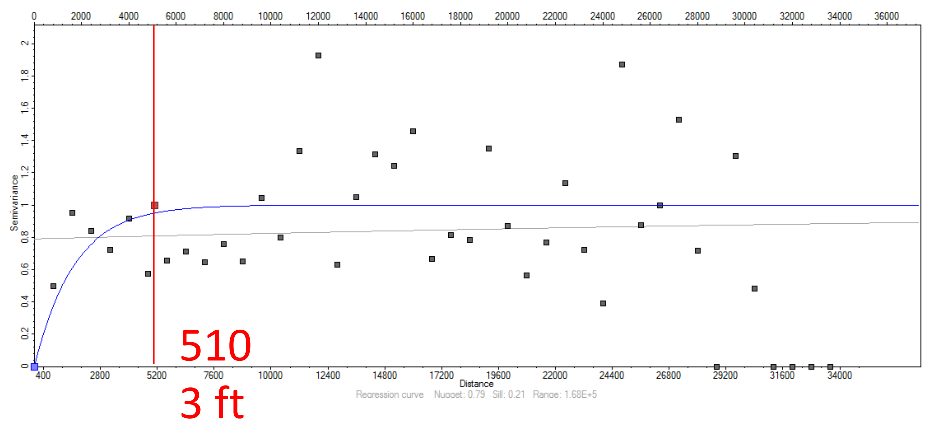


Lateral Variogram modeling

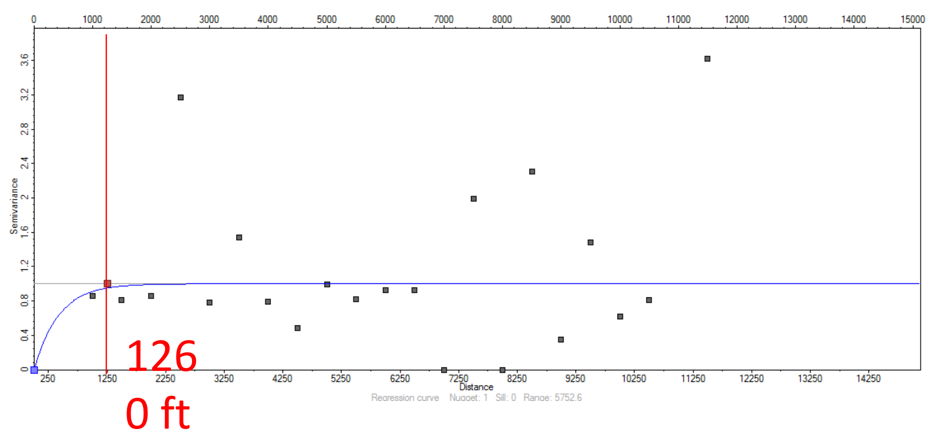


Data spatial distribution

Search ellipsoid



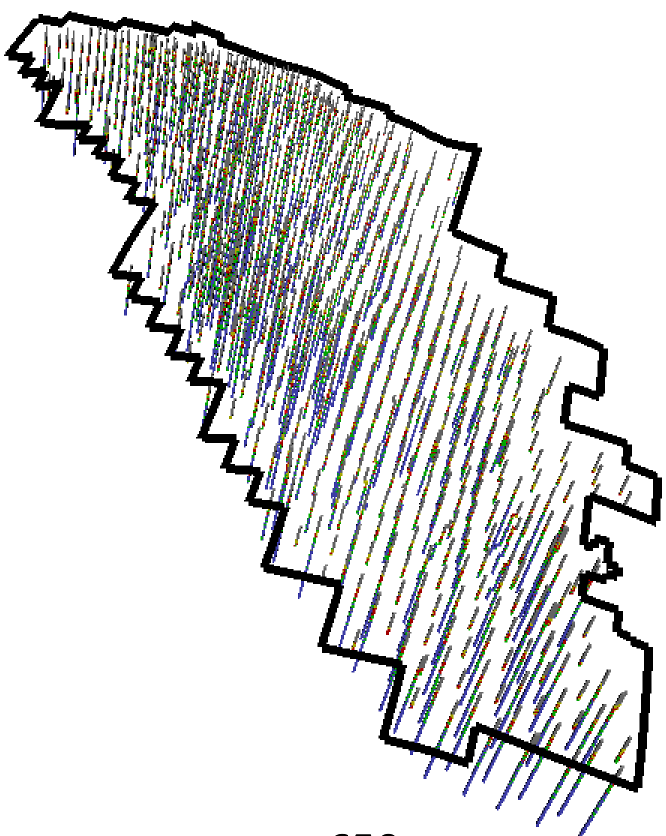
Major direction



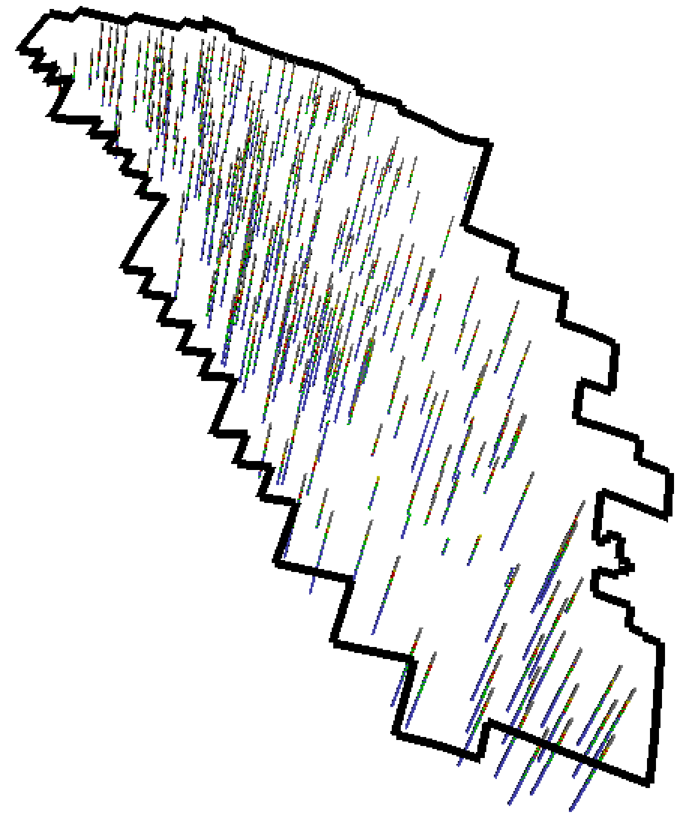
Minor direction

Blind Test of 3-D Static Reservoir Model for Permeability

Random select 300 wells for facies modeling, other wells used for model test.

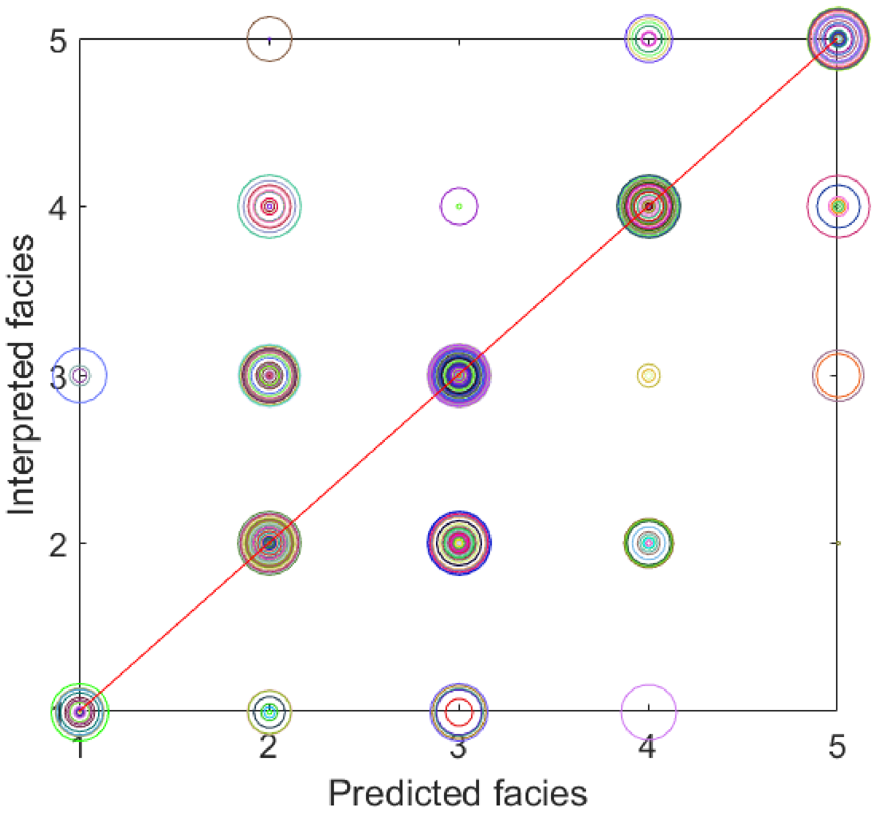


~650
wells



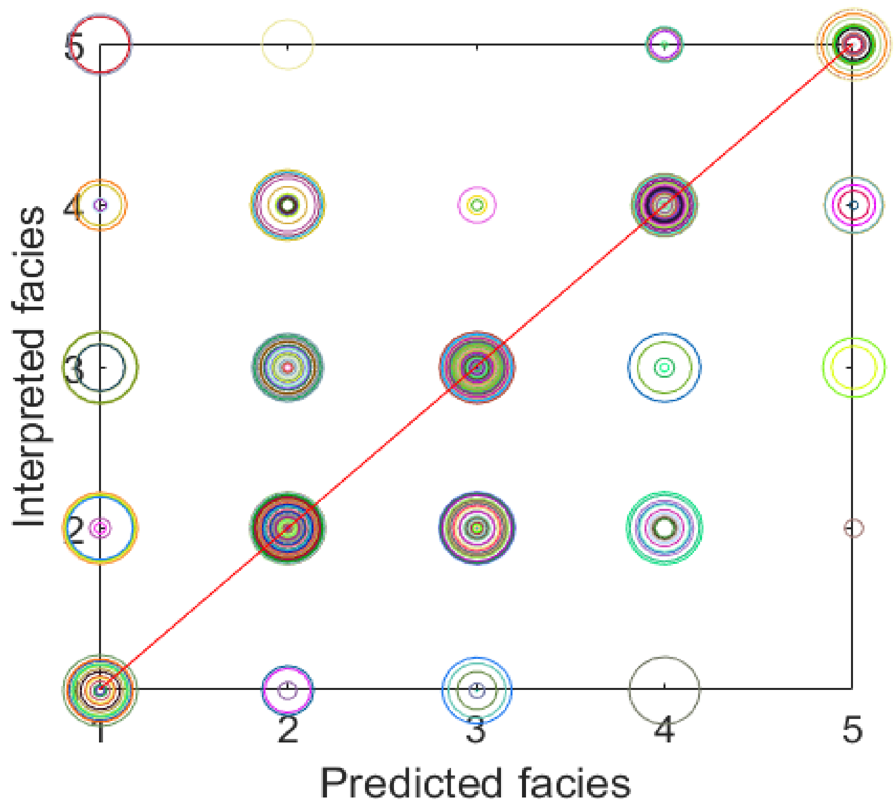
~300
wells

Upgraded Static Model: Predicted vs interpreted Facies



- 73.5% of the points are on the bi-section line
- Points are mostly distributed along the bi-section line.

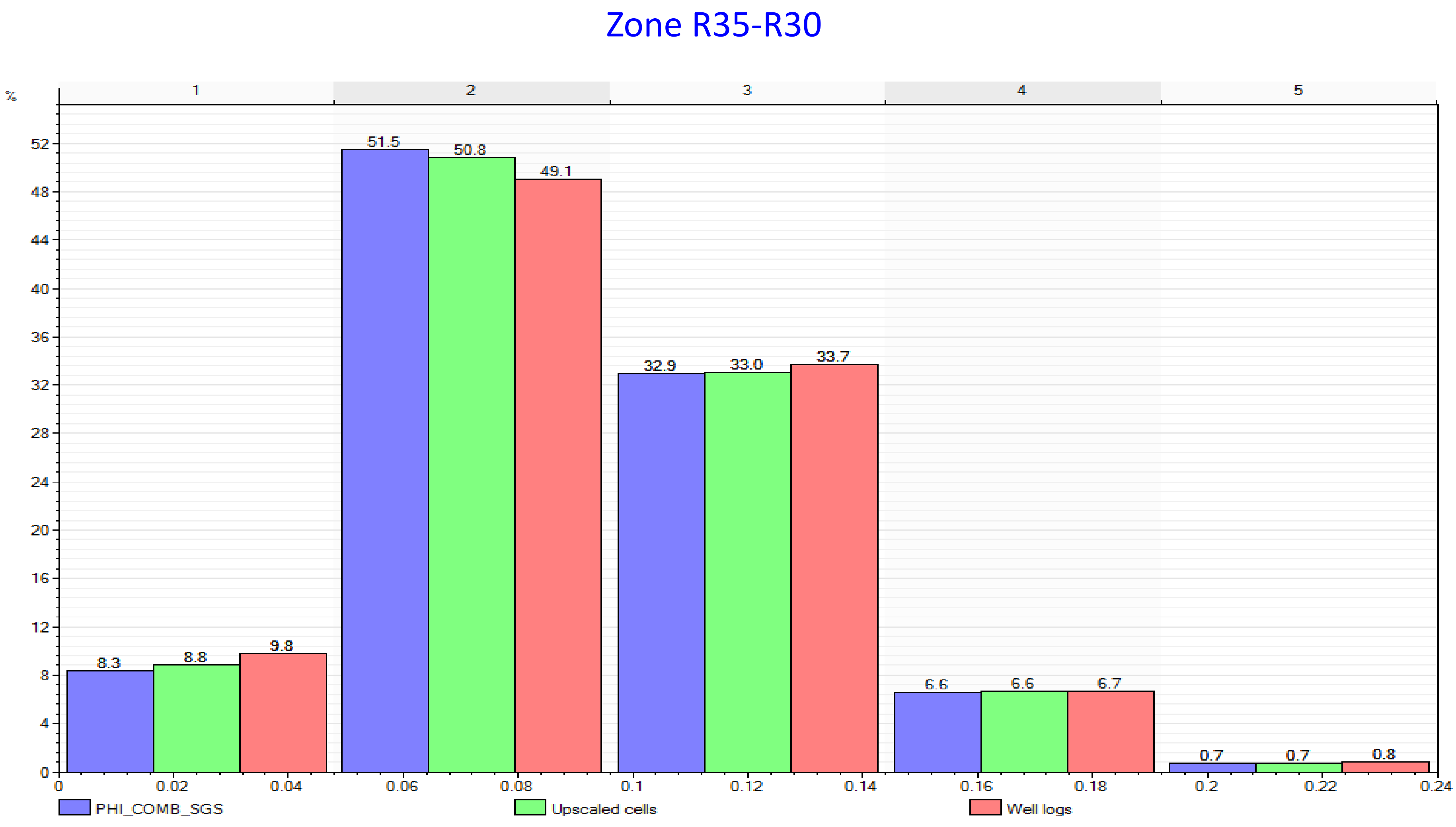
Initial Static Model: Predicted vs Interpreted Facies



- 72.1% of the points are on the bi-section line;
- Points are scattered.

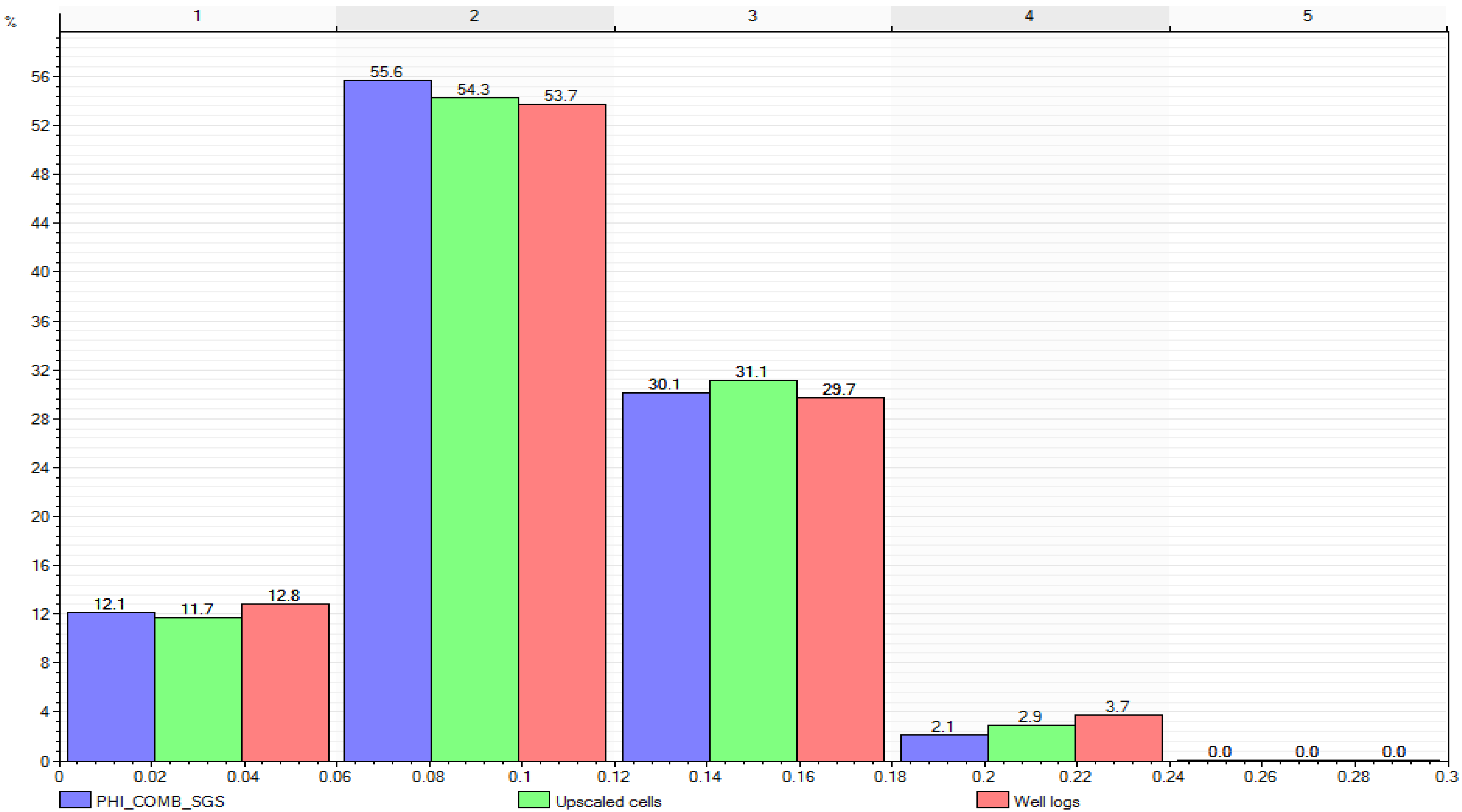
Porosity modeling

Porosity histogram: 3D model, upscaled core data, and well log in example zones



Porosity histogram: 3D model, upscaled core data, and well log in example zones

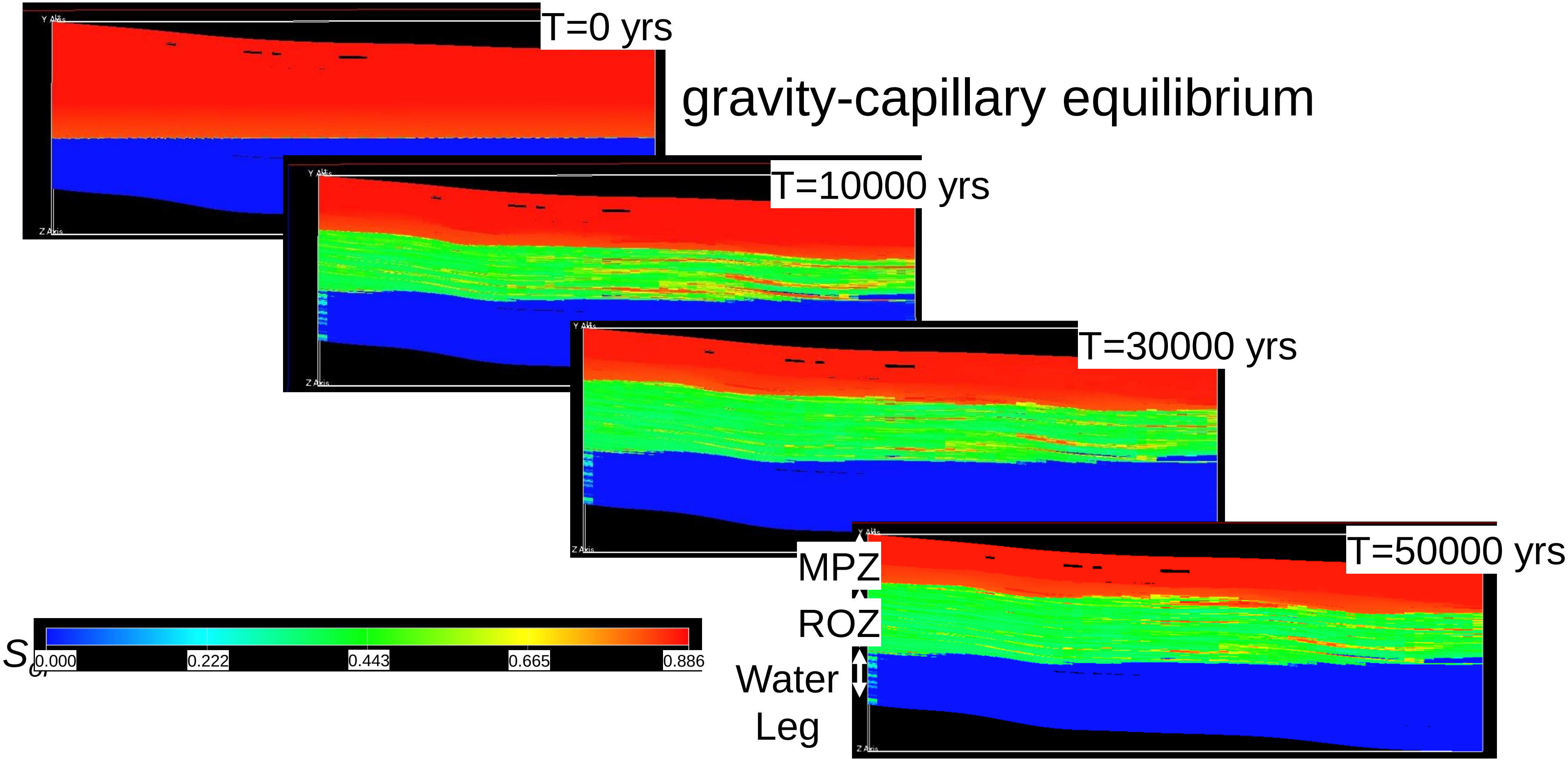
Zone T25-T22



Simulation of Development of Oil Saturation in ROZ

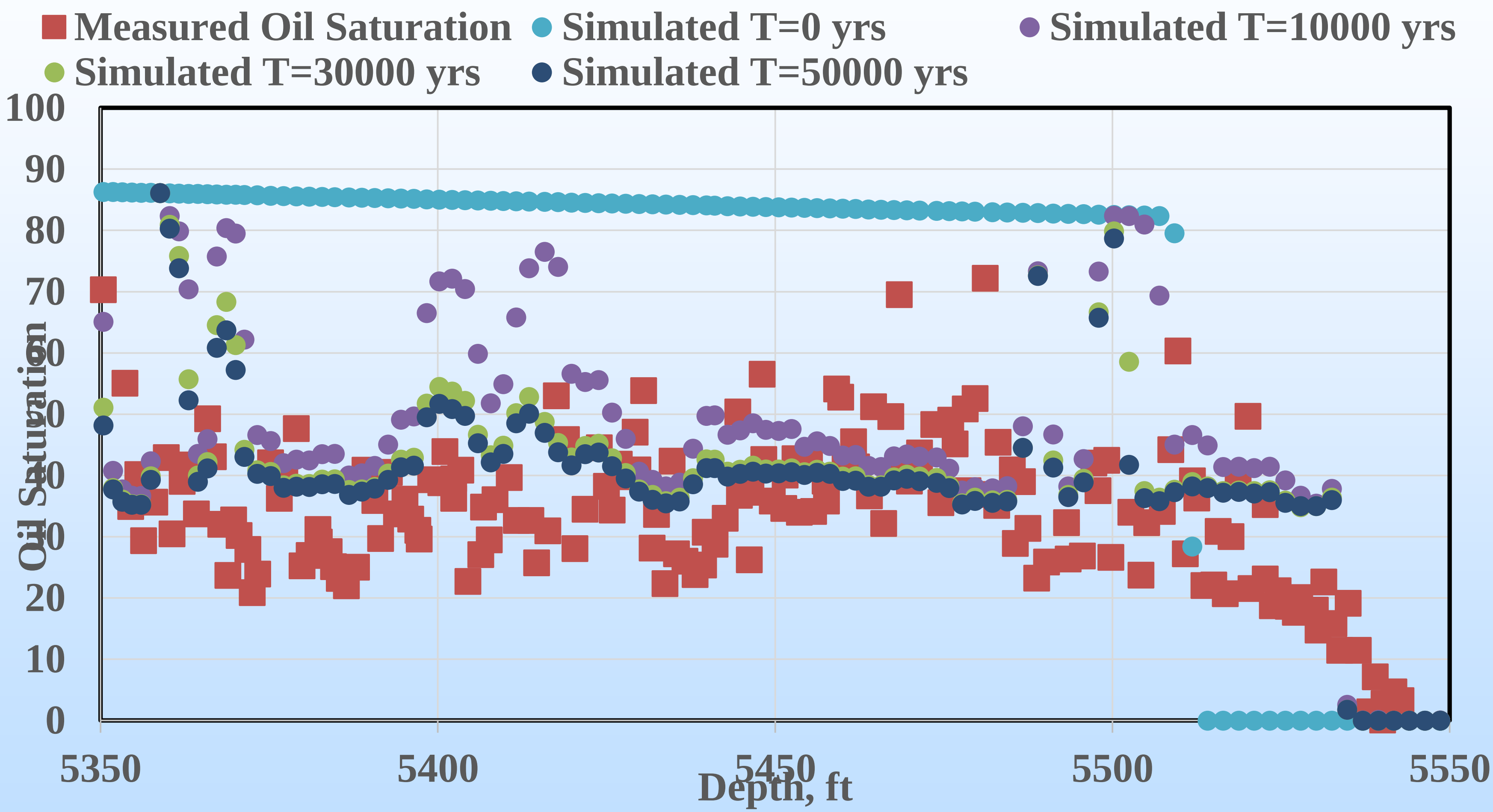
Based on natural aquifer flow.

Oil Saturation Distribution – cross section along well 5512R



Constant flux is imposed equivalent to regional water flow 5ft/yr.

ROZ Oil Saturation profile along well SSAU 5512



Conclusion from ROZ Modeling

1. **Match to residual oil data is reasonable**

2. **Oil/water saturation attained steady-state after around 50000 years**

3. **Oil in low perm/low porosity areas are not efficiently displaced by the regional water**

4. **Water flows over longer time period could change oil chemistry by dissolution of lighter water soluble fractions**

Accomplishments to Date

- Second Generation Static Reservoir Model completed
- Completion NMR studies of brine & oil saturated core plugs
- Completion of water flooding of oil saturated core plugs with NMR analysis
- First pass wireline log calibration/interpretation completed
- All data on well problems and well remediation digitized and in database
- Analysis of all production and injection data completed by well by pattern and by phase
- Partitioning of production and injection data between ROZ and MPZ
- Eclipse simulation of formation of ROZ using full static reservoir model

Lessons Learned

Positive project surprises.

- Usefulness WAG injection in reservoir modeling
- The vast volume of pressure measurements available for our project
- Direct linking of OFM/Petrel/Eclipse to establish dynamic pressure boundary conditions

Unanticipated difficulties

- Software compatibility with sponsor company .. After 2 year effort a $99 million software donation from Schlumberger solved the problems.

Lessons Learned

Technical disappointments.

1. Relative permeability measurements for CO2/oil and CO2/brine require 2 ft core plugs to give valid results
2. Pervasiveness of dolomitization in reservoir make it difficult to identify sequence boundaries in the core.

Synergy Opportunities

– Our study will provide the first detailed publically available study of a ROZ….. We are reaching out to other projects as our data becomes cleared for release by Hess.

Summary

Key Findings

1. Production/injection data a well and 9-spot level contain the most tangible evidence of CO2 storage in response to WAG injections
2. Upgraded static reservoir model using facies conditioned permeability Variograms
3. Higher resolution static reservoir models minimize upscaling lowering flow

Project Summary

Next Steps

1. Using Eclipse simulations to compare to analysis of reservoir metrics such as CO_2 Efficiency and CO_2 Cumulative Storage
2. Calibration of Advanced Wireline Logs with core measurements such as NMR, resistivity…
3. Building upgraded static model based on advanced wireline log interpretation and new petrophysics data
4. Multi-dimensional history matching of Eclipse modeling of specific injection phases and aggregates of 9 spots

Appendix

Benefit to the Program

- Supports DOE’s Programmatic goal No. 2, to “Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness”.

Project Overview:
Goals and Objectives

Project objective: "To improve the understanding of how much CO_2 can be stored in residual oil zones (ROZ) given current practice and how much this could be increased, by using strategies to increase sweep efficiency".

These same strategies will increase the efficiency of oil production.

Organization Chart

Project Director Ian Duncan	
Task 1 Management	**Task 2 through 6**
Task Leader/Back-up Duncan/Ambrose	**Task Leader/Back-up** Duncan/Ambrose

	Yr2 Q3	Yr2 Q4	Yr3 Q1	Yr3 Q2	Yr3 Q3	Yr3 Q4
2	X	X	X	x D7	X	
2.1	x	x				
2.2	x	x				
2.3	x	x	x			
2.4	x	x D8				
2.5	x	x	x	x D9		
3						
4	x D5	X	x D6	X	X	
4.1						
4.2	x					
5	X	X	X	X	X D10	
6	X	X D12	X	X	X	X D13