Modeling and Simplicity:
Occam's Razor in the 21st Century

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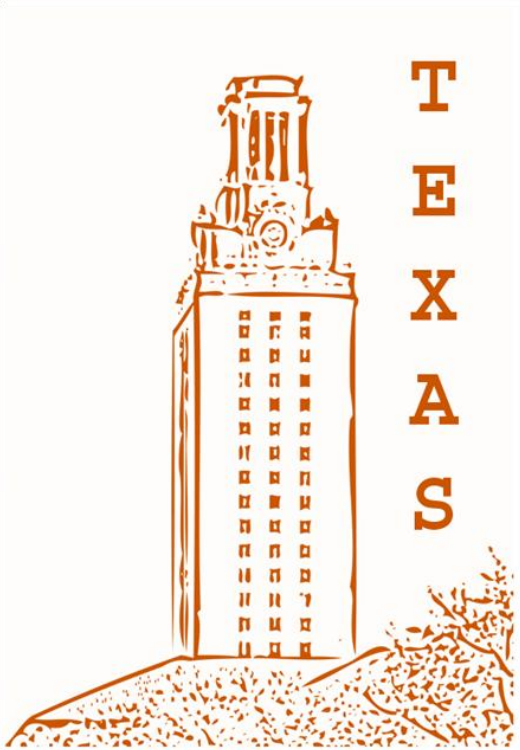
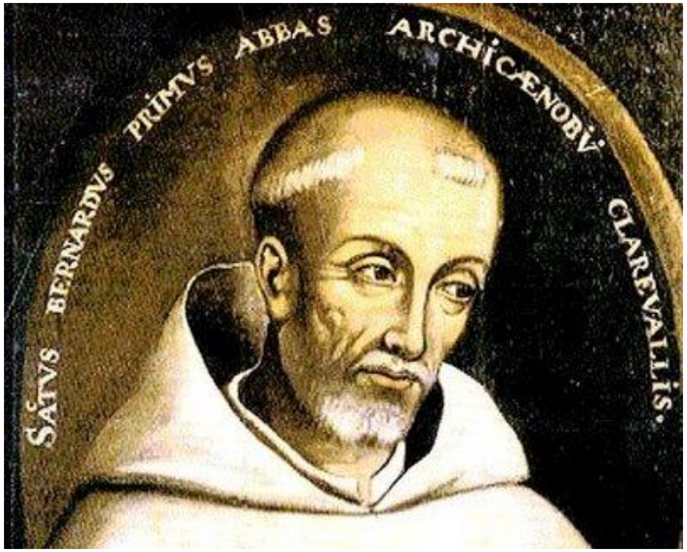


SPE Gulf Coast Section
April 2013

Outline

- A nod to history
- Enter the gorilla
- Simple models
- Summary

A nod to history..



William of Occam
1288-1348 CE

Occam's Razor:
Entities should not be multiplied endlessly
A way to shave away irrelevant explanations

The simplest explanation is the best

Aka…the law of
Parsimony
Succinctness
Economy

But…There is always a well-known solution to every human problem…neat, plausible, and wrong
H.L. Mecklen

And…All principles, rules and methods increasing lack universality and absolute truth the moment they become a positive doctrine
C. von Clausewitz

Early Models-Tanks

Active Oil and Reservoir Energy

By Ralph J. Schilthuis,* Junior Member A.I.M.E.

(Houston Meeting, October, 1935)

The Material Balance as an Equation of a Straight Line

D. HAVLENA | HUDSON'S BAY OIL & GAS CO., LTD. CALGARY, ALTA., CANADA

A. S. ODEH MEMBER AIME | SOCONY MOBIL OIL CO., INC. DALLAS, TEX.

The Material Balance as an Equation of a Straight Line— Part II, Field Cases

D. HAVLENA | HUDSON'S BAY OIL AND GAS CO., LTD. CALGARY, ALTA.

A. S. ODEH MEMBER AIME | SOCONY MOBIL OIL CO. DALLAS, TEX.

1964

Early Models-Displacement

Mechanism of Fluid Displacement in Sands

By S. E. Buckley and M. C. Leverett,* Members A.I.M.E.

(New York Meeting, February 1941)

Chapter 12

THE PREDICTION OF OIL RECOVERY BY WATER FLOOD

Herman Dykstra * and R. L. Parsons * **1950**

A Method for Predicting the Performance of Unstable Miscible Displacement in Heterogeneous Media

E. J. KOVAL* | CALIFORNIA RESEARCH CORP. LA HABRA, CALIF. **1963**

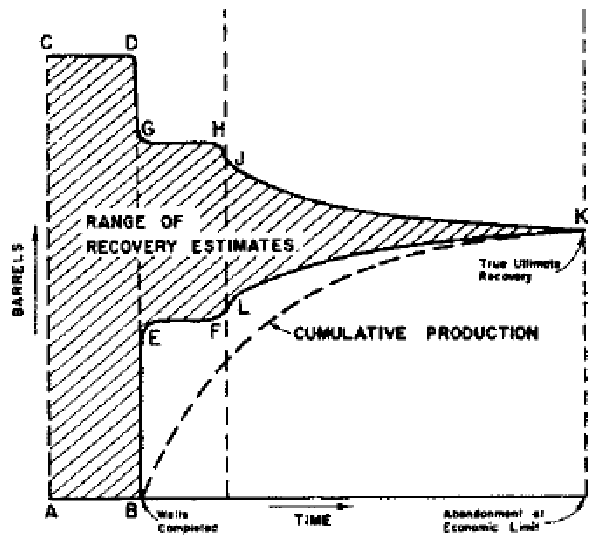
Lest We Forget…

ESTIMATION of PRIMARY OIL RESERVES

1956

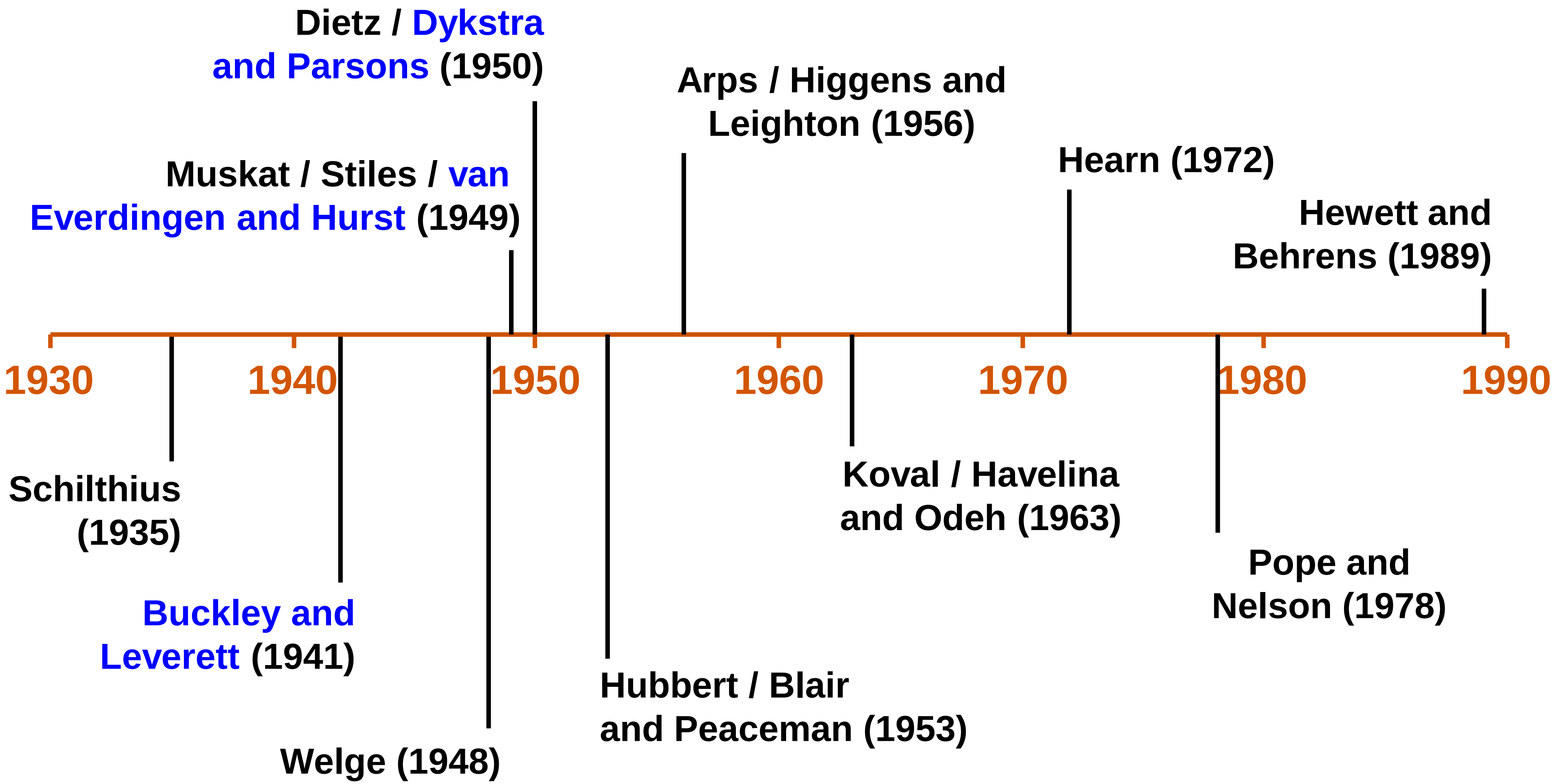
J. J. ARPS
MEMBER AIME

BRITISH-AMERICAN OIL PRODUCING CO.
DALLAS, TEX.



PERIOD	I BARRELS PER ACRE PERIOD	II BARRELS PER ACRE-FOOT PERIOD	III DECLINE CURVE PERIOD
TYPE OF DATA	COMPARATIVE DATA	VOLUMETRIC DATA	PERFORMANCE DATA

Modeling Timeline



Reservoir Engineering Practice

- Develop a model
  - Usually done by someone else
  - An equation or a simulator
- Accumulate and analyze data
- Fit model to data
  - History match
  - Mostly done by hand…still
  - Model is calibrated
- Extrapolate to desired answer
  - Project life
  - Ultimate recovery
  - Net present value
  - Future alternatives

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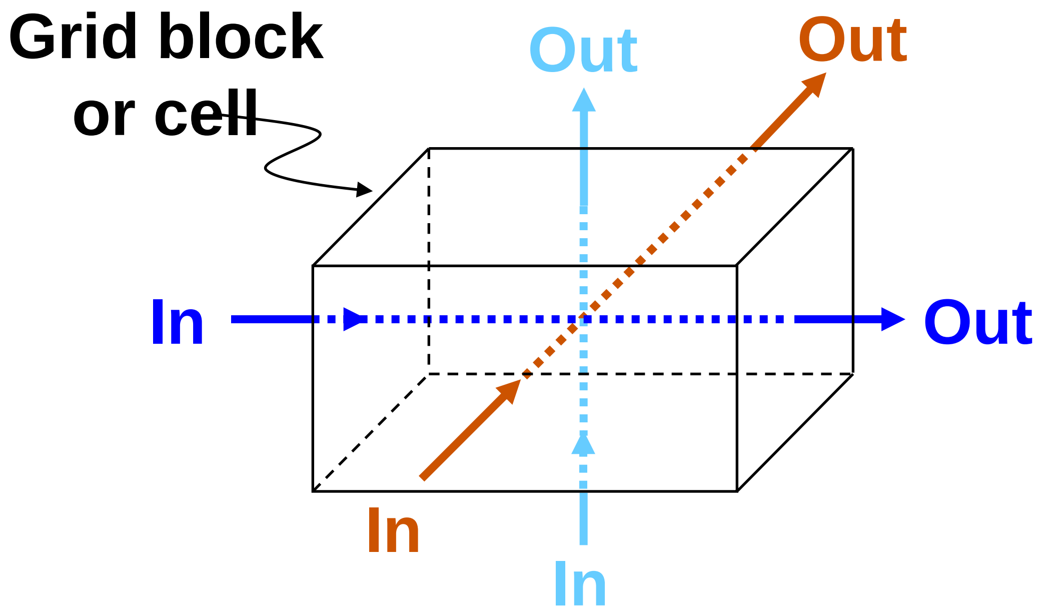
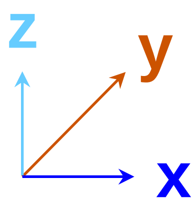
Basic Equations...

- Conservation of
  - Mass
  - Energy
- Empirical laws
  - Darcy
  - Capillary pressure
  - Phase behavior
  - Fick
  - Reaction rates

Simulation Schematic...





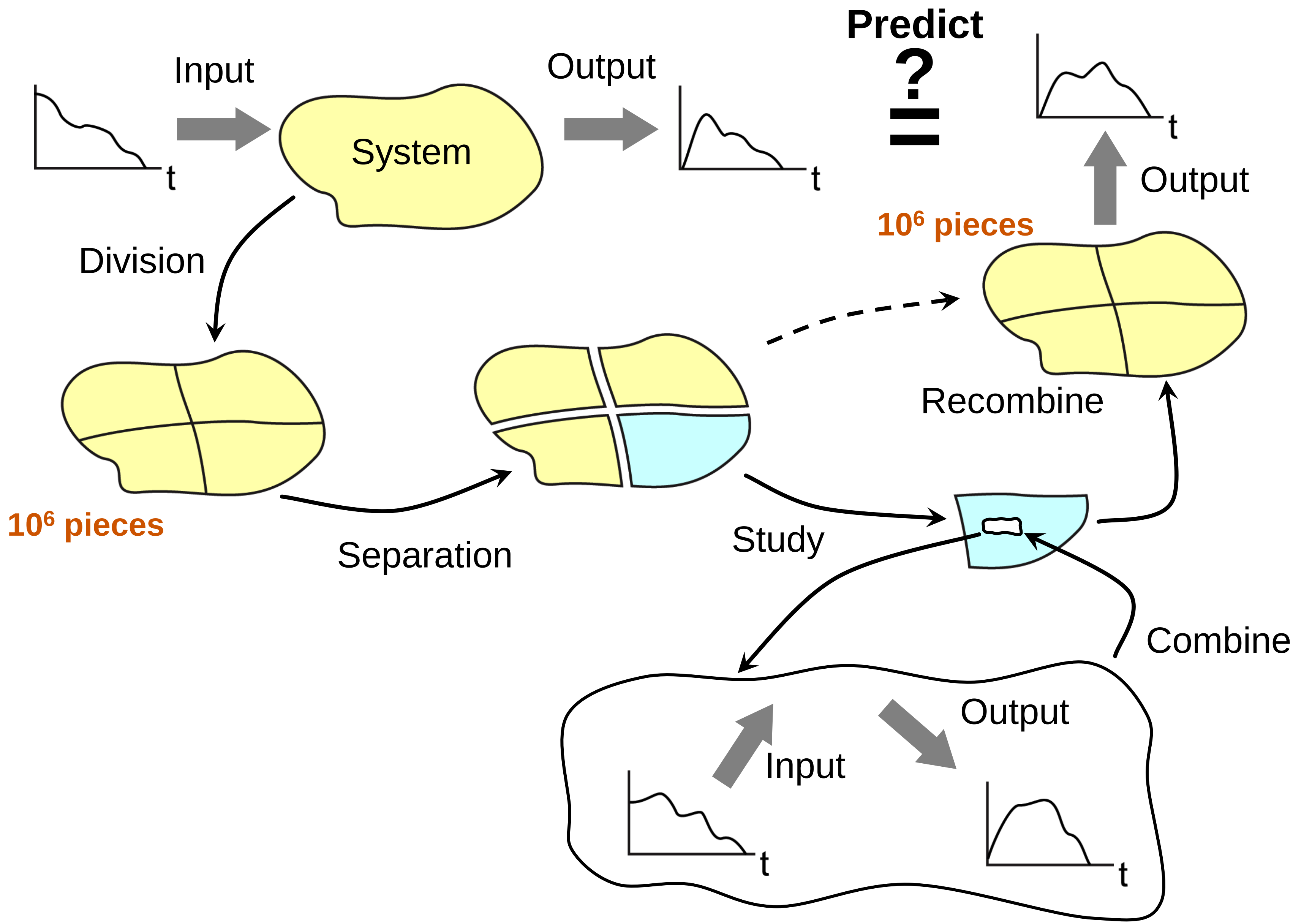
Conservation law...

- **{Rate In} - {Rate Out} = {Accumulation}**
- **For each component (oil, gas, water, energy)**
- **For each cell**

The Current Modeling Paradigm….

- Collect geologic (cores, logs) and geophysical data (ongoing)
- Build geologic (static) model (75%)
- Upscale to simulation model (5%)
- History match (80%)
- Make prediction (1%)
- Response surface/DOE (25%)
- Sensitivity/uncertainty study (10%)

Reductionist View…



Measurement Density for Numerical Simulation

L = Logs (10^3)
C = Core (10^2)
S = Seismic (10^5)
WT = Well Test (10^1)

	Required	Measured	Measured Directly	At Correct Scale	In Situ	All
Porosity	10^6	10^5	10^2	10^5	10^5	0
Horizontal Permeability, k_h	10^6	10^2	10^2	10^1	10^1	0
Vertical Permeability, k_z	10^6	10^1	10^1	0	10^1	0
Pressure	10^6	10^3	10^3	10^3	10^3	0
Saturation	10^6	10^3	10^2	10^3	10^3	0
Relative Permeability	10^6	10^1	10^1	0	0	0
How Measured		L, C, S, WT	C, WT	L, WT	L, S, WT	--

"Requiem for Large-Scale Models"

- By Douglass B. Lee, American Institute of Planning, May 1973, pp. 163-178

- The paper that set urban planning back 25 years

Seven Sins of Large-Scale Models (Lee, 1973)

- Hypercomprehensiveness
- Grossness
- Hungriness
- Wrongheadedness
- Complicatedness
- Mechanicalness
- Expensiveness

Outline

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- **Enter the gorilla**
- **Simple models**
- **Summary**

Tank Models Revisited
(Walsh and Lake, Chap. 9)

Tank Models…

$$q = -V_p c_t \frac{d\bar{p}}{dt}$$

Macroscopic

$$q = J\left(\bar{p} - p_{wf}\right)$$

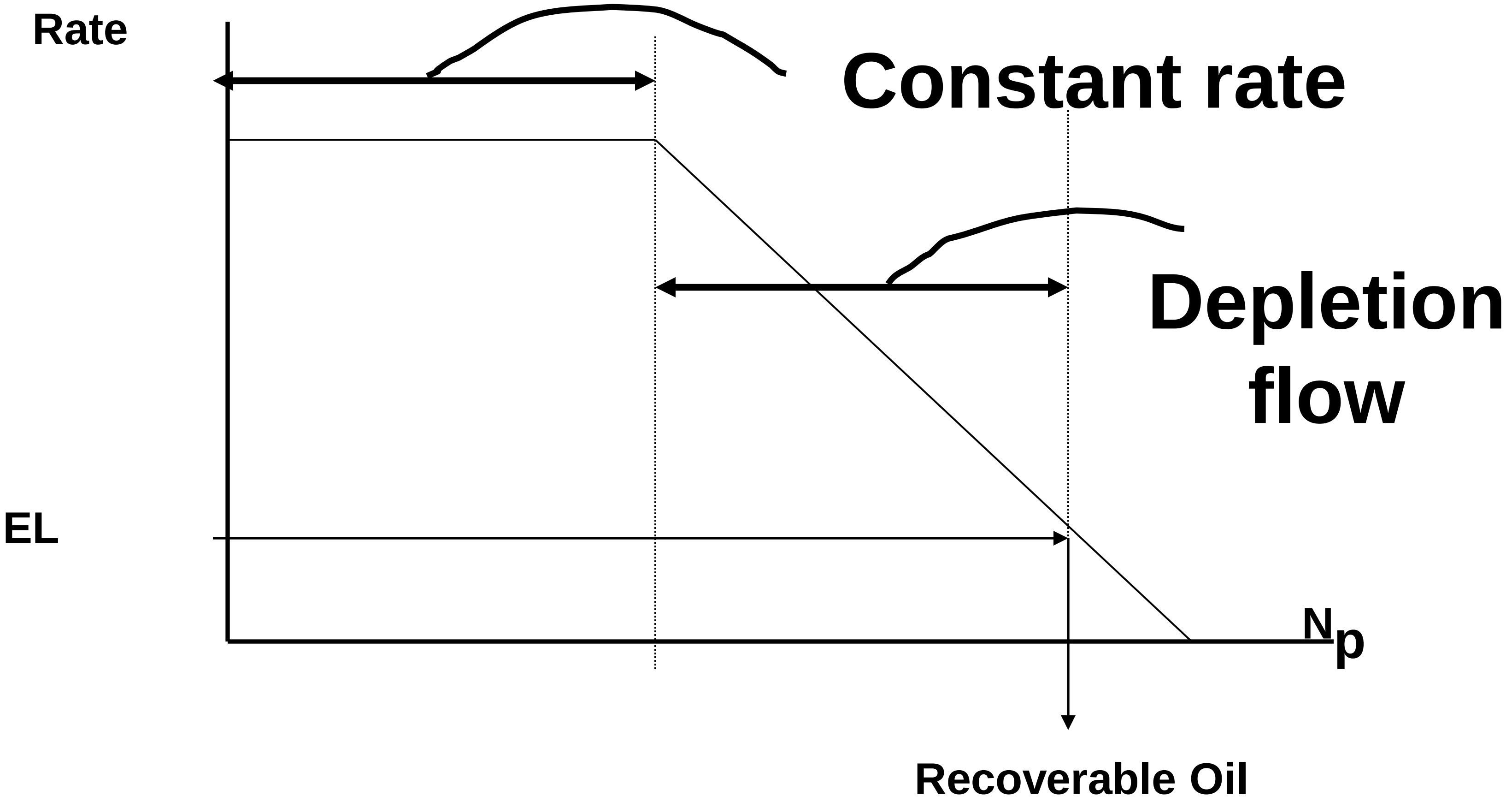
Microscopic

$$N_p = \int_{t=0}^{t} q\,dt$$

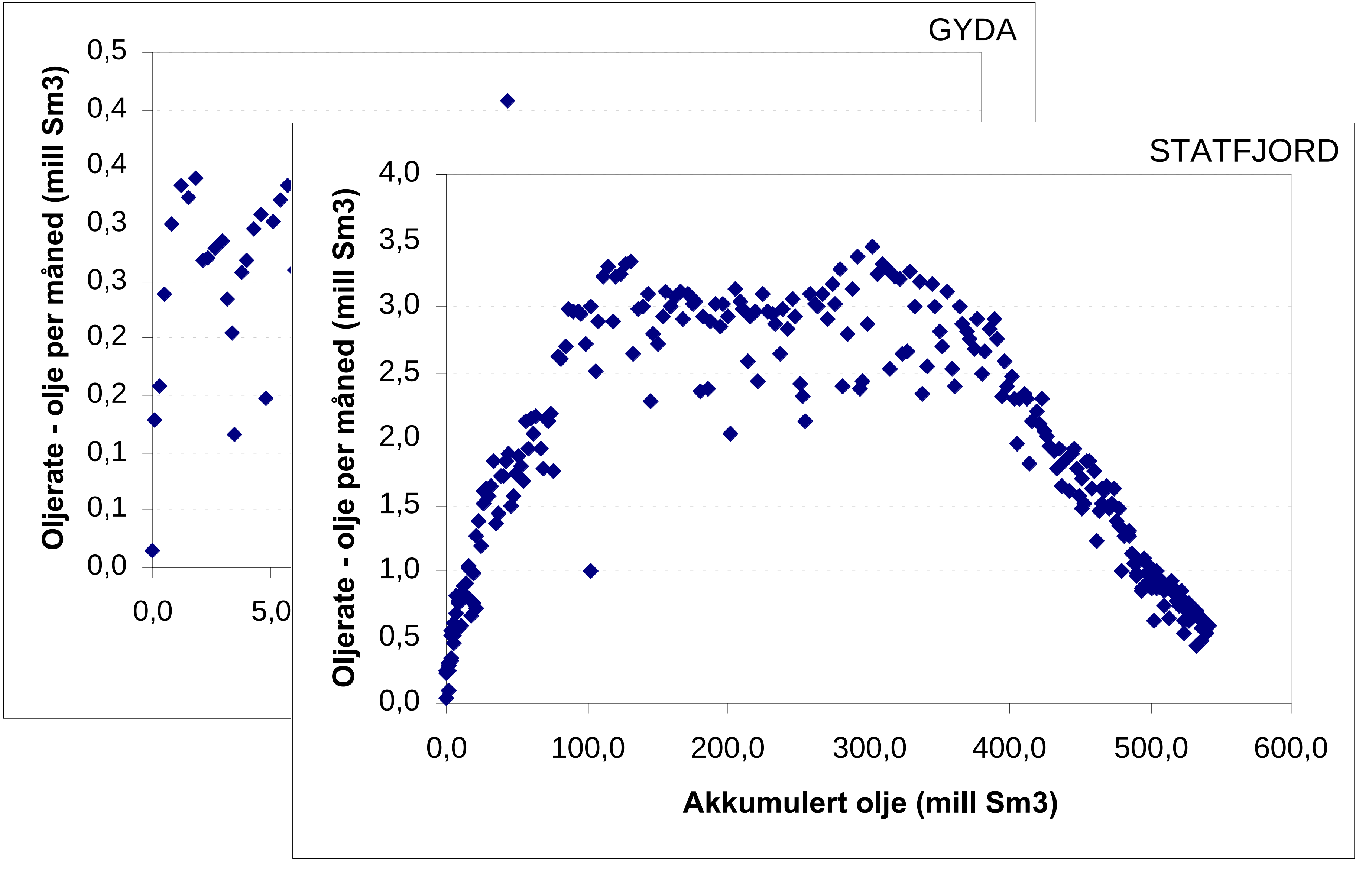
Cumulative production definition

9 parameters

Tank Models…



North Sea Production...



Conclusions from Validation

- Model can easily match data
- Provides a physical basis for ideal behavior
- A standard for deviations from ideal behavior
- Larger fields (more wells) behave ideally
- Precursor for numerical simulation

Capacitance Resistance Models (Jorge Pizarro, Alejandro Albertoni, Pablo Gentil, Ali Yousef Dan Weber, Morteza Sayapour, Anh Nguyen, Jong Kim,Wenli Wang,Gustavo Moreno, Fei Cao, Victor Duribe, Raheephan Louchamroonvorapongse)

An Electrical Device for Analyzing Oil-reservoir Behavior

By W. A. Bruce,* Junior Member A.I.M.E.

(Austin Meeting, October 1942)

Abstract

This paper covers the theory and present state of development of an apparatus for the nonmathematical analysis of complex problems

the block can be used. In analyzing reservoir behavior from this point of view by mathematical means, a set of simultaneous difference equations would be obtained

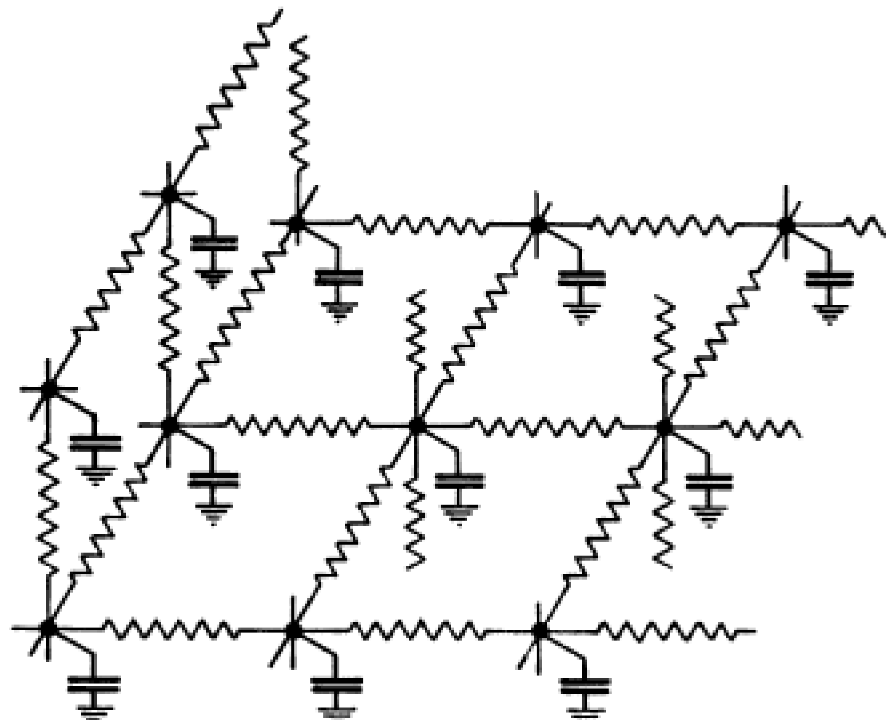
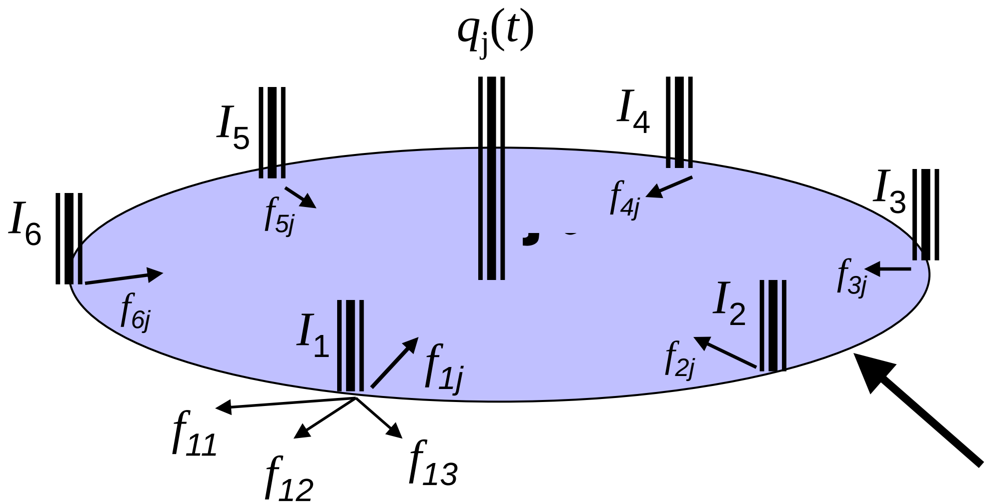


Fig. 3.—Part of three-dimensional electrical representation.

Capacitance-Resistance Model (CRMP)

$$\tau_j = \left(\frac{c_t V_p}{J} \right)_j$$

Time constant



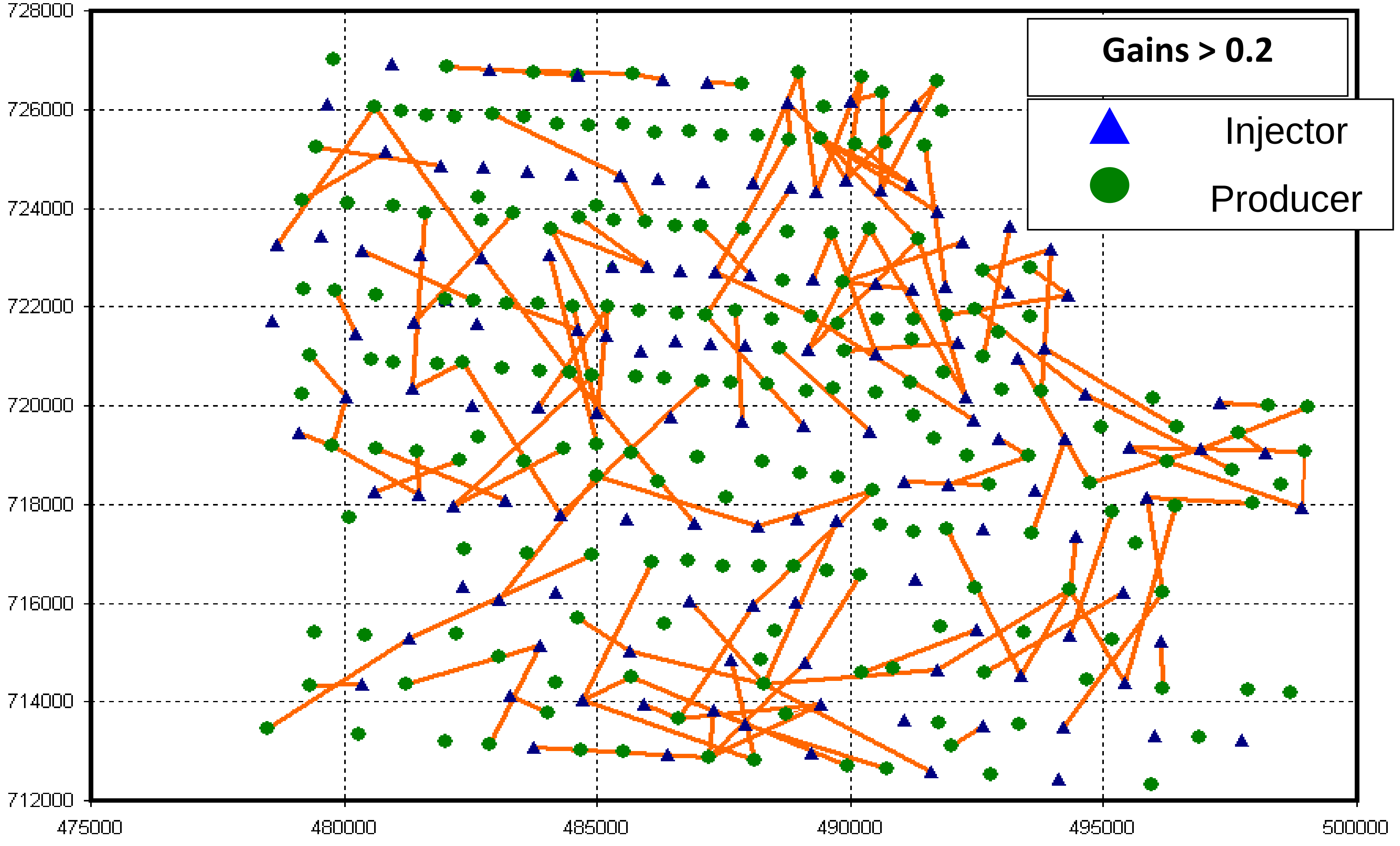
$$\sum_{j=1}^{n_p} f_{ij} \leq 1$$

Inter-well connectivity or gain

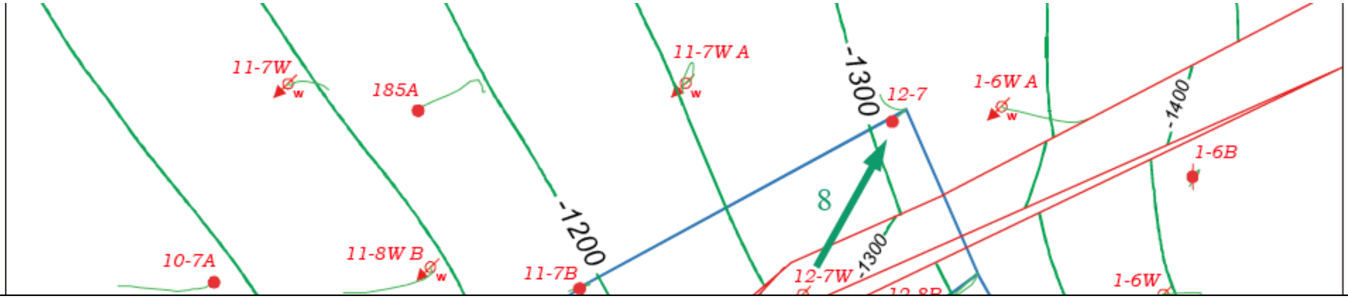
Drainage volume around a producer

$$q_{jk} = q_{j(k-1)} e^{-\Delta t / \tau_j} + \left(1 - e^{-\Delta t / \tau_j} \right) \sum_{i=1}^{n_i} f_{ij} I_{ik}$$

Mature West Texas Waterflood



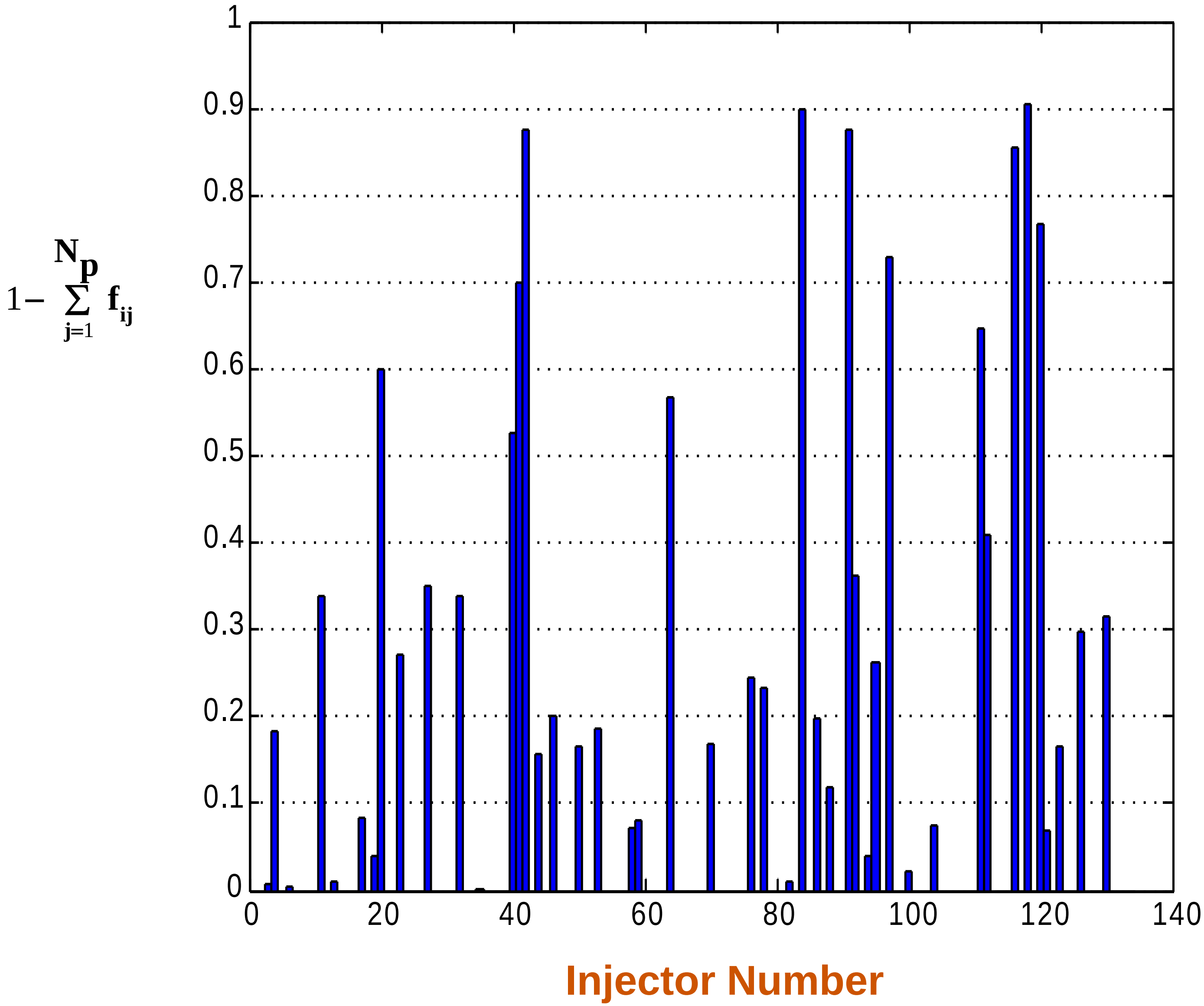
Tracers at Lost Hills



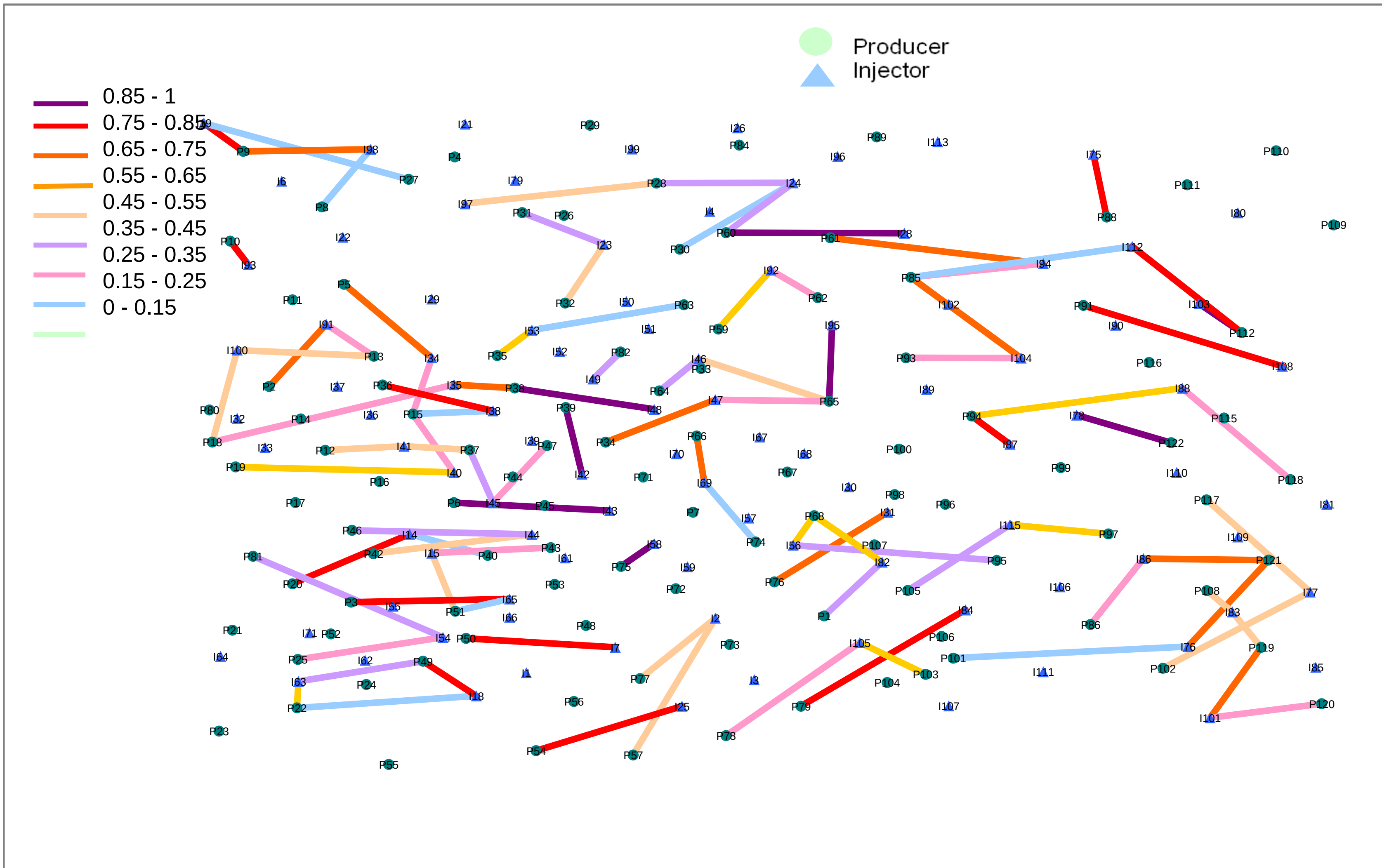
Well Name	Percent Recovery of Injected Tracer Material			
	PMCP	PDMCB	PMCH	PDMCH
11-7B	0.085%	0%	0%	0%
11-8D	0.121%	0.022%	0%	0%
11-8E	0%	2.49%	0%	1.70%
11-9J	0.045%	0.25%	0%	0.031%
12-7	0%	0.912%	0%	0%
Total	0.25%	3.67%	0%	1.73%

DE FC22-95BC14938 (2003)

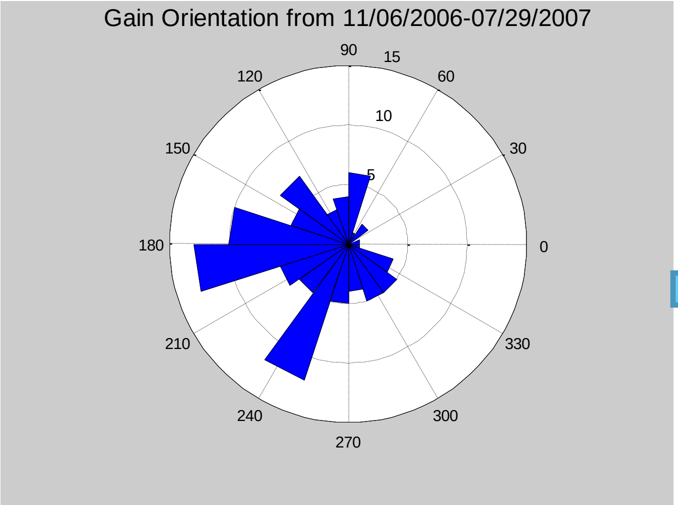
Lost Injection

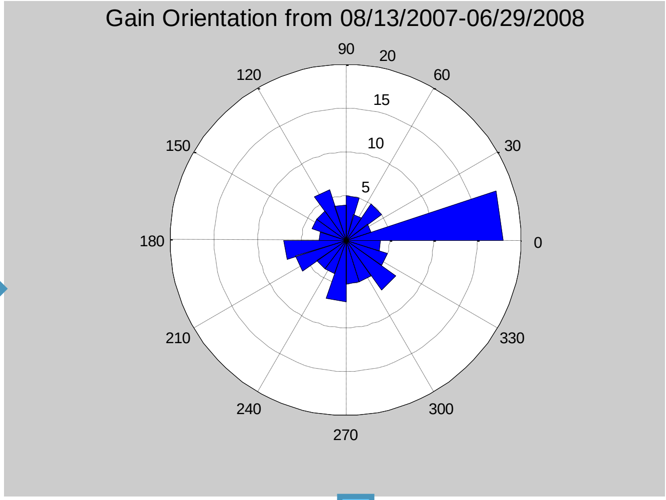


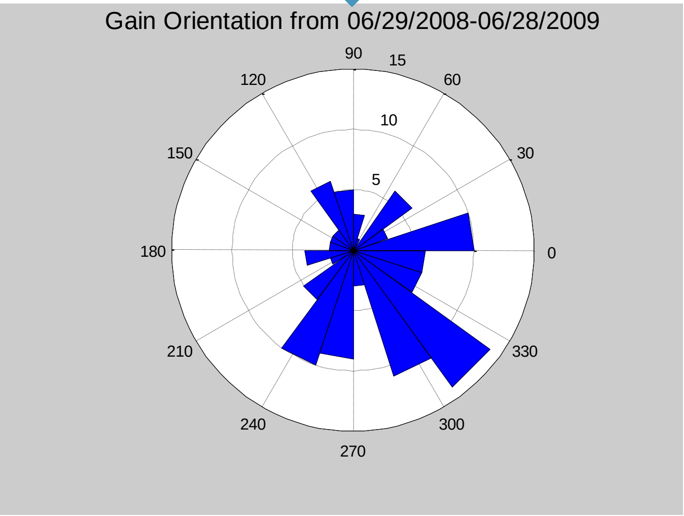
Well Connectivity for Time Interval 11/06/2006-07/29/2007



Gain Orientation Histogram for Different Time Periods

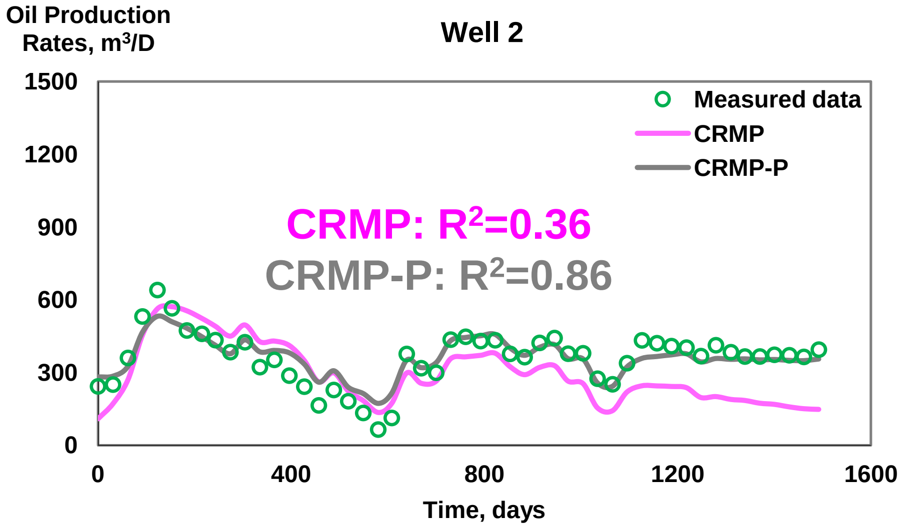


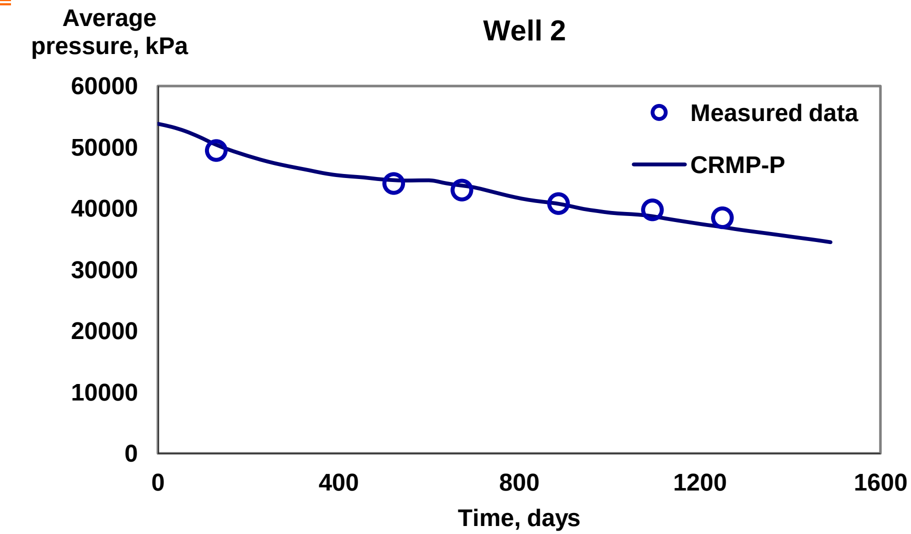


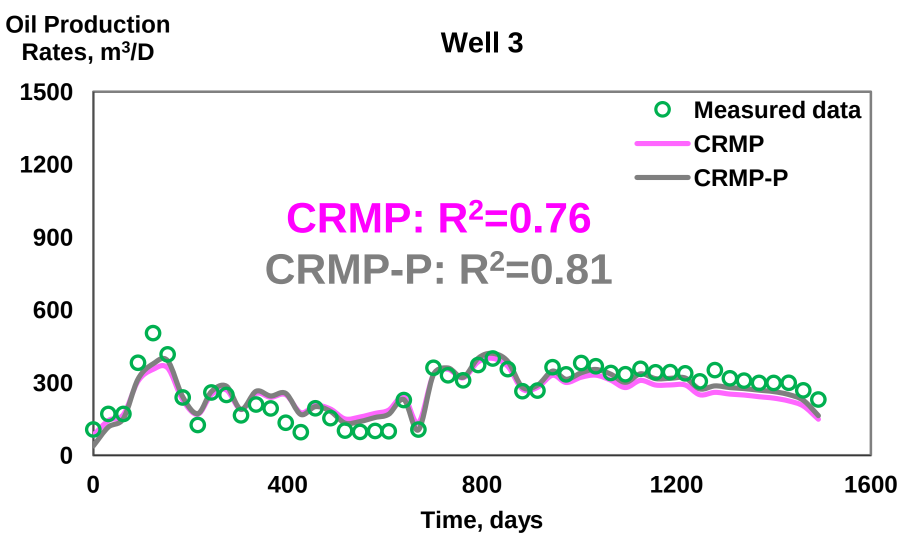


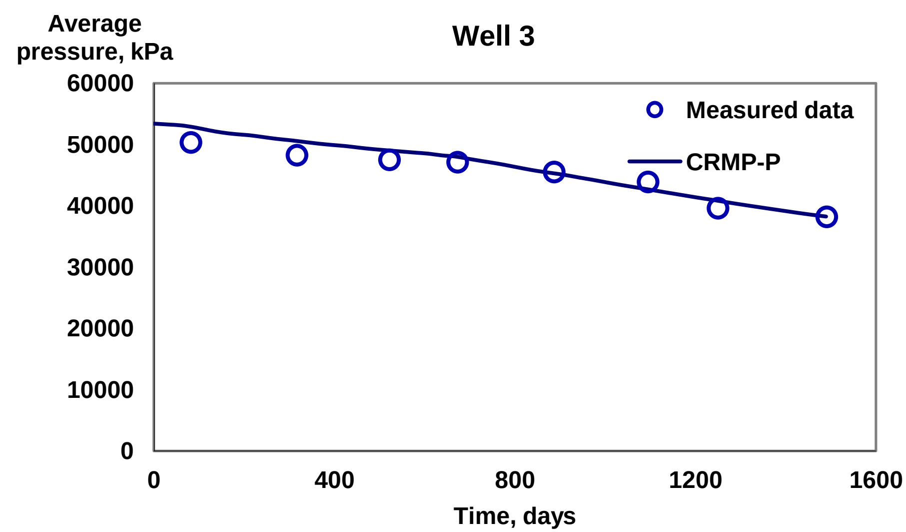
Application of CRMP-P to an Omani field

Simultaneous match of well rates and reservoir pressure









Application of CRMP-P to an Omani field

Simultaneous match of well rates and reservoir pressure

- Estimated reservoir parameters

			Transmissibility, m^3/day-kPa				
CRMP-P	**Time constant, days**	**Productivity index, m^3/day-kPa**	T_{j1}	T_{j2}	T_{j3}	T_{j4}	**Calculated pore volume, million m^3**
Well 1	543	0.07		0.00	0.00	0.01	15.7
Well 2	248	0.09			0.03	0.03	8.8
Well 3	841	0.05				0.00	14.8
Well 4	9	0.09					0.3
						Sum	**40**

Estimated total pore volume:
Field OOIP = 31-59 million m^3
ICR study (Nguyen 12) = 42 million m^3

Conclusions from Validation

- Always good total fluid matches
- Oil production matches ok, but less good
- Several instances of connection at a distance
- Validated against…
  - Numerical simulation
  - Tracers
  - Seismic
  - Structure
- May help produce additional oil

Displacement Models
(Alireza Molleai, Lokendra Jain)

Koval Model

A Method for Predicting the Performance of Unstable Miscible Displacement in Heterogeneous Media

E. J. KOVAL* | CALIFORNIA RESEARCH CORP.
LA HABRA, CALIF.

Koval model:

$$f_{solvent} = \frac{1}{1 + \dfrac{\left(1 - C_{solvent}\right)}{K_v C_{solvent}}}$$

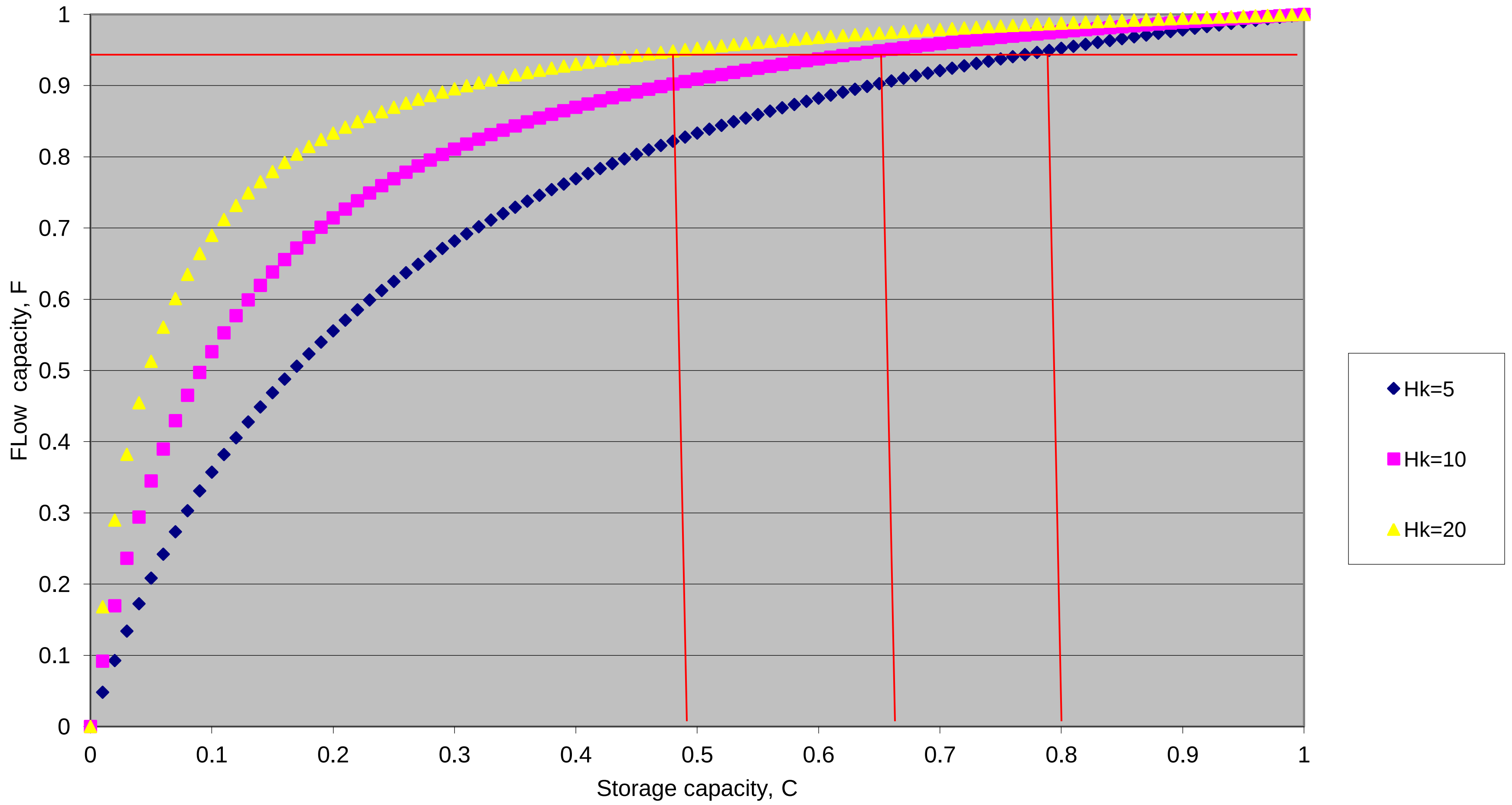
$$K_v = H_k E$$

H_k Heterogeneity factor

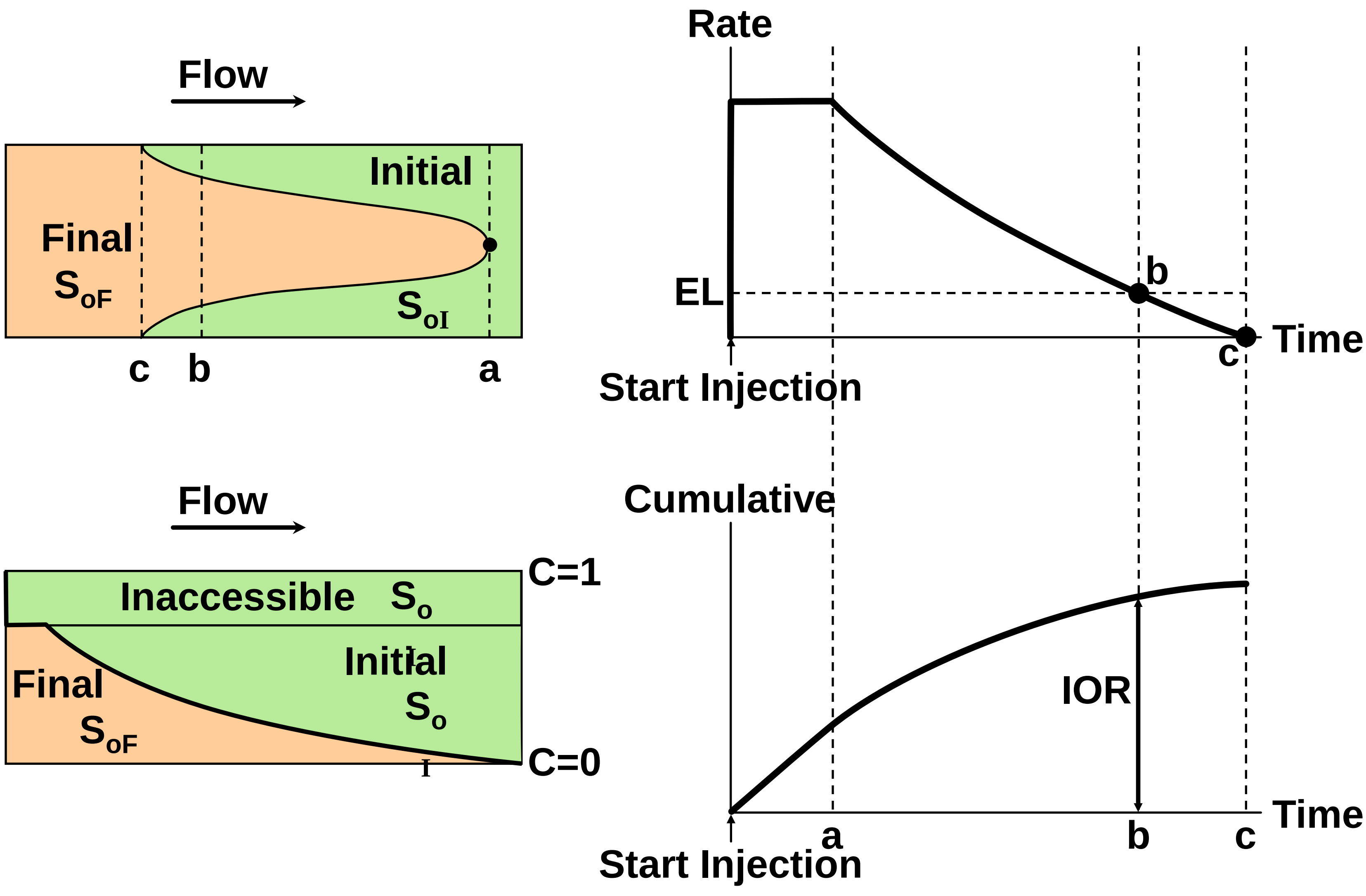
E = effective viscosity ratio

$$H_k = 1 \text{ (homogeneous)} \qquad E = 1 \text{ (tracer)}$$

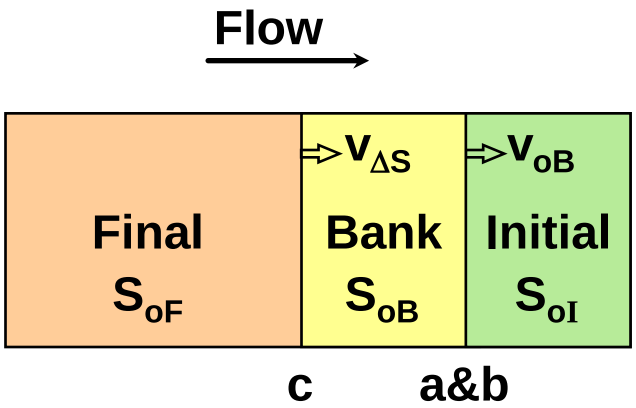
Flow Capacity Curves at Different Heterogeneity Factors

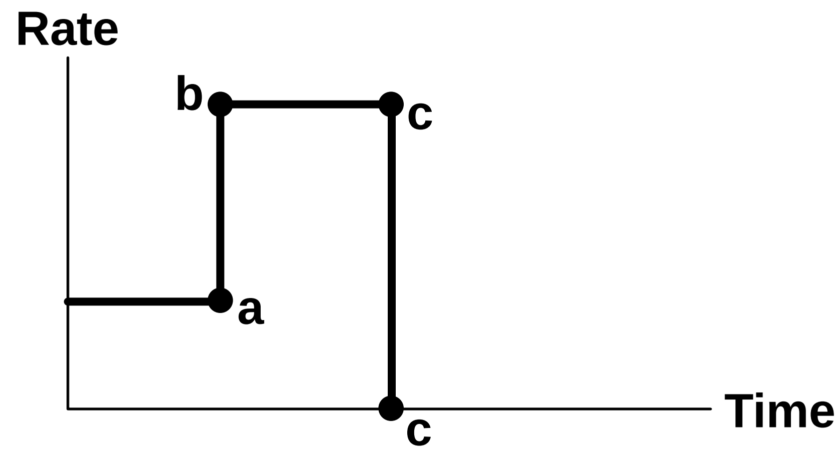


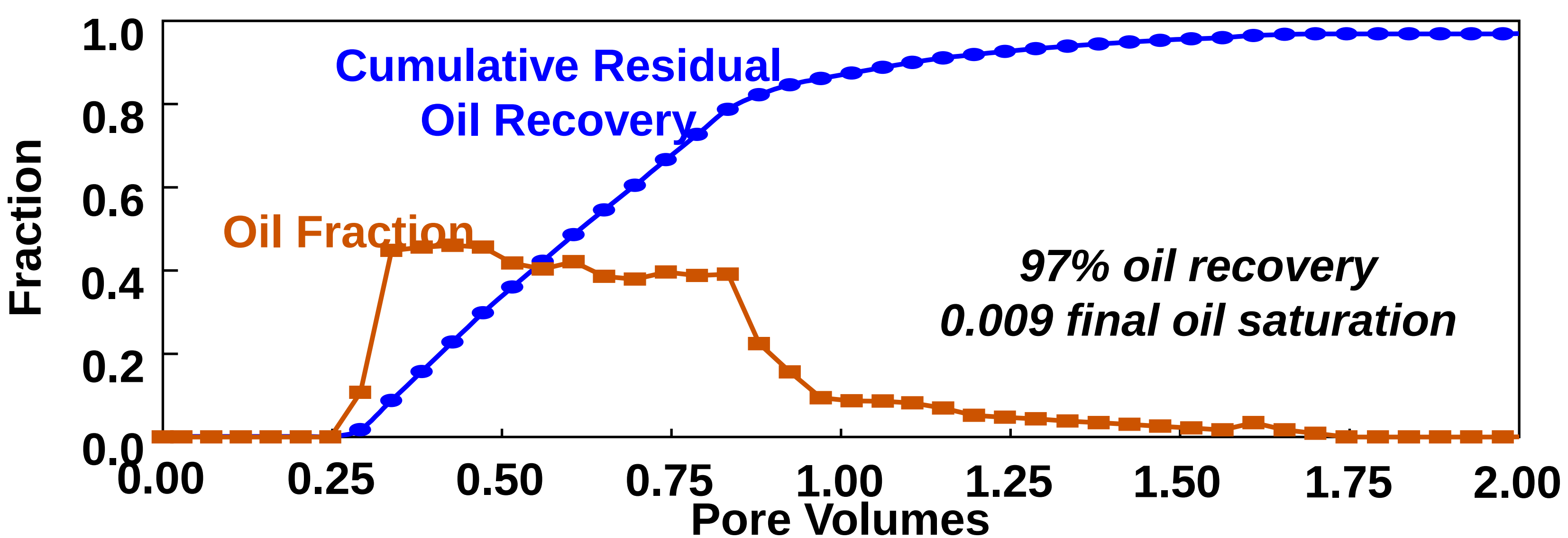
Waterflood (1 front) Displacement



Fractional Flow Solution (Two Fronts)





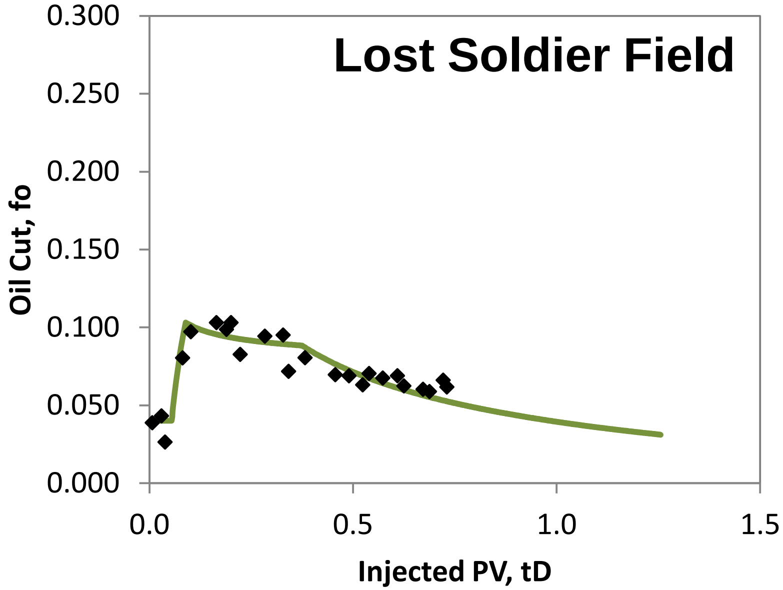


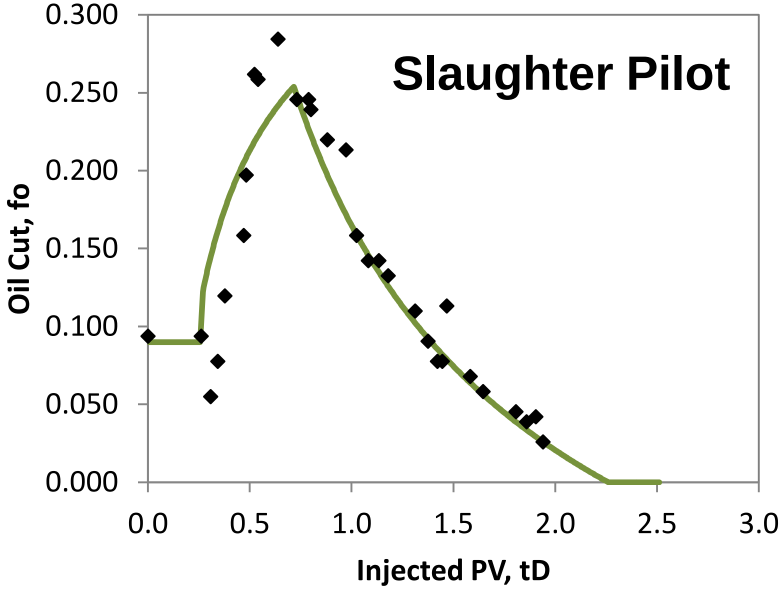
Pope, *et al*., 2007

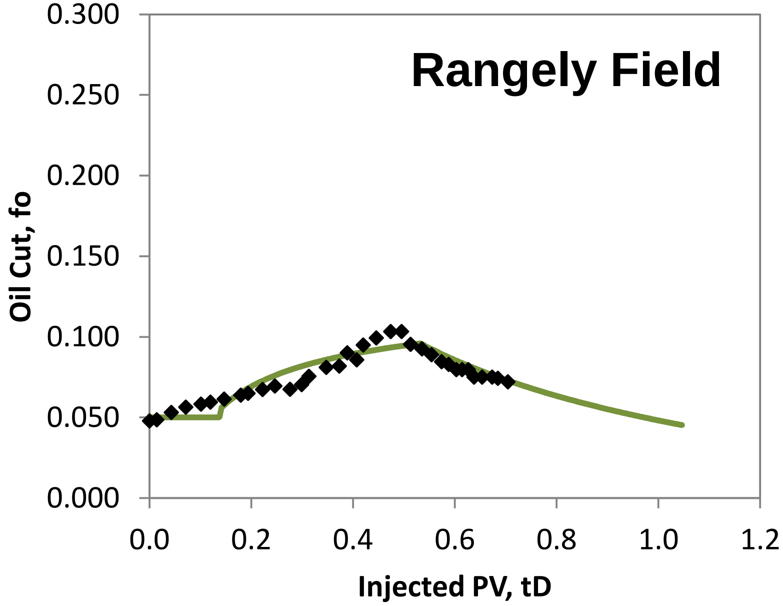
Field Data Summary

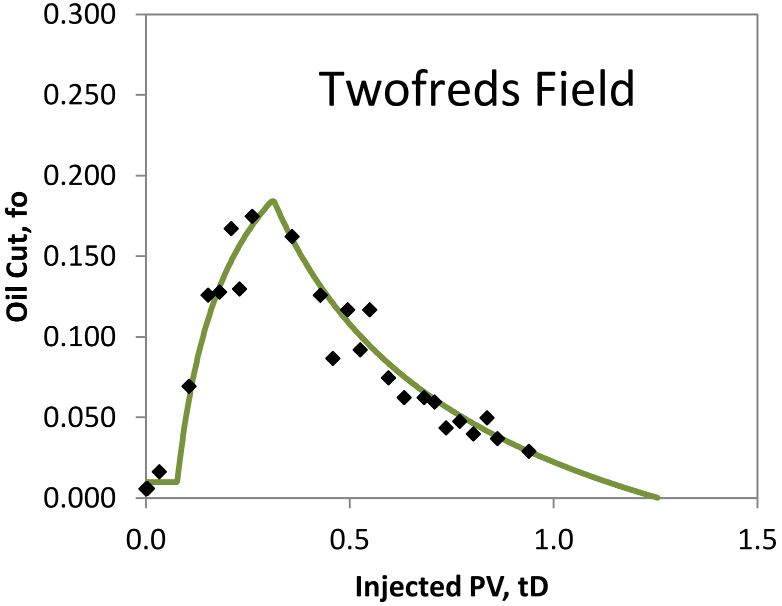
Surfactant polymer (SP)	20
Polymer	4
Alkali-surfactant-polymer (ASP)	4
Solvent (mainly CO_2)	8
Waterfloods	4
Waterflood (wells)	ca. 30

CO_2 Project Results



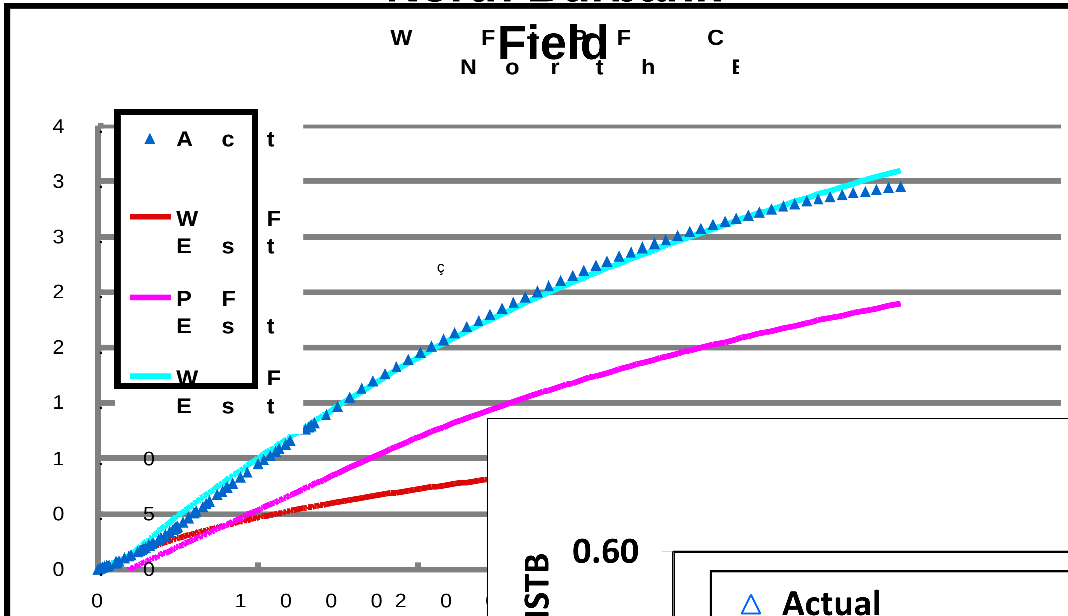


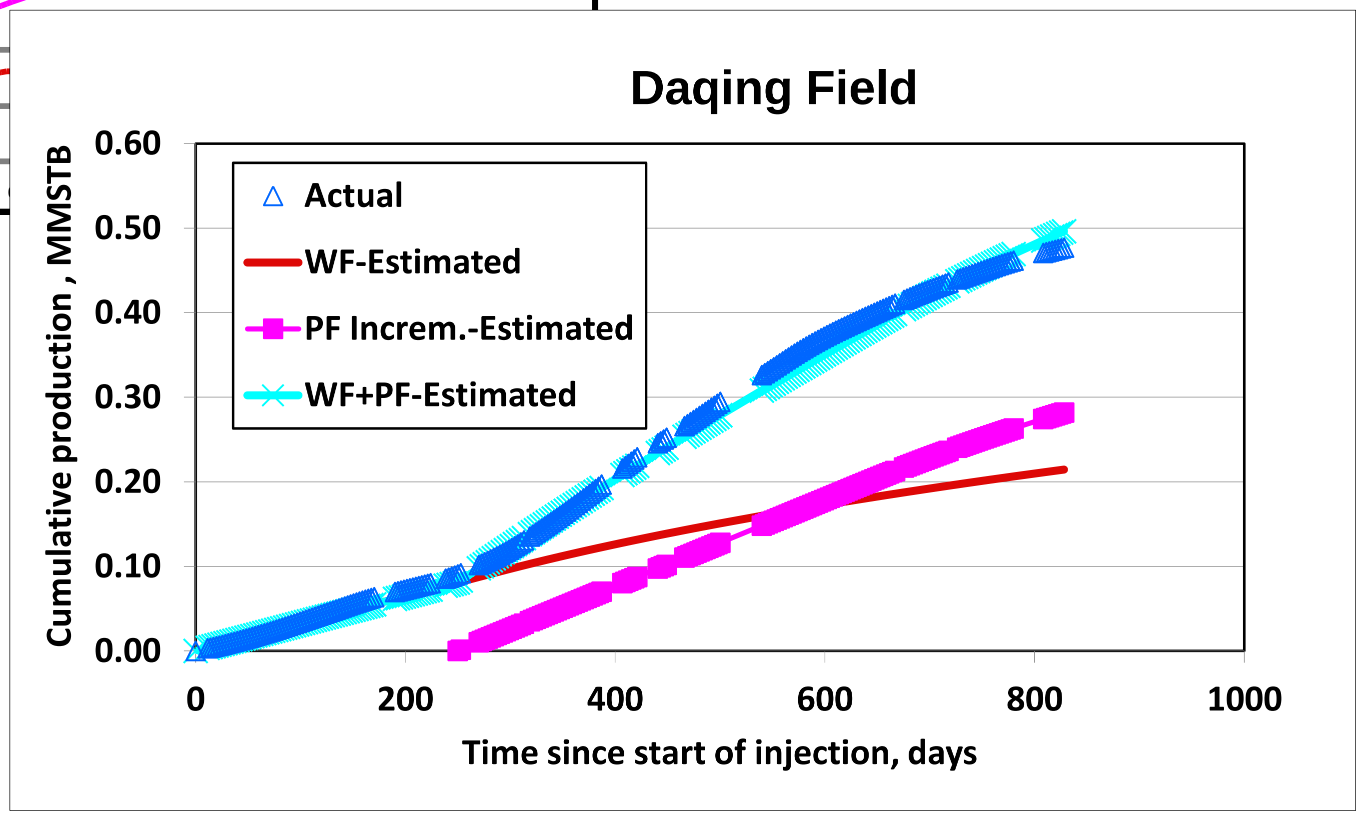




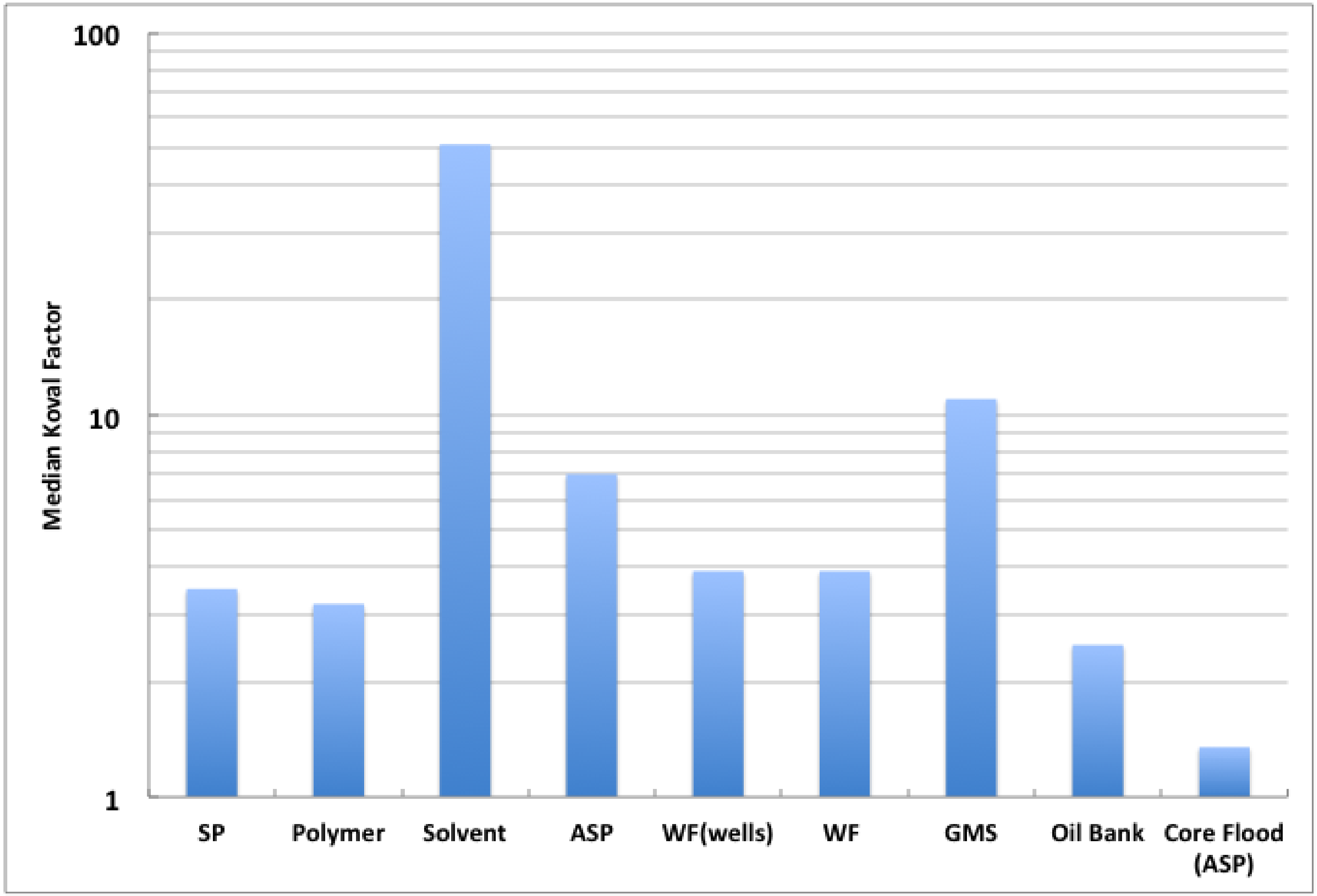
Polymer Flood Results….

North Burbank Field





Koval Factors for EOR Processes….



Conclusions from Validation

- **Model matches field behavior**
- **Generic ranges of values for input variables**
- **No strong correlations among any input variables**
- **...and with field values**
- **Pilots perform slightly better than field scale**
- **Pore volume problem - $(\Delta S_o)_{Field} << (\Delta S_o)_{Lab}$**

Multistage Models
(Cristina Para-Sanchez)

Cash Flow Components: Inflow

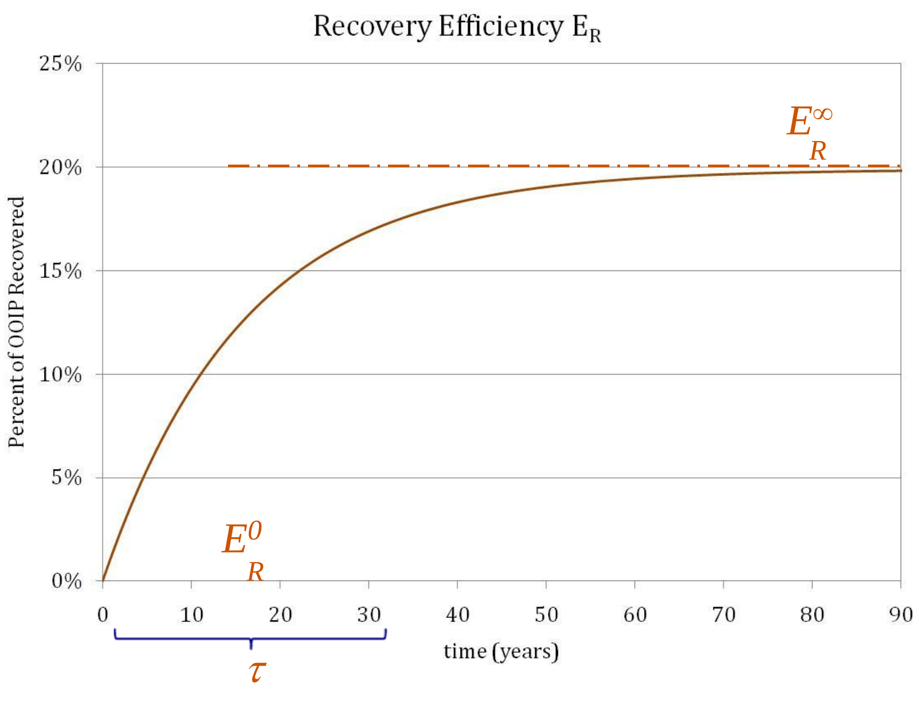
$$Inflow_t = \$_{oil} N\left(E_{R_t} - E_{R_{t-1}}\right)$$

The recovery efficiency is taken to be:

$$E_R(t) = E_R^0 + (E_R^\infty - E_R^0)\left(1 - e^{-t/\tau}\right)$$

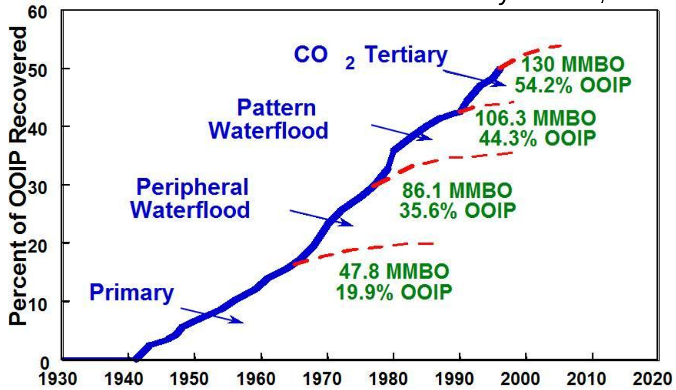
where

E_R^0	**=**	**recovery efficiency at time zero**
E_R^∞	**=**	**theoretical ultimate recovery efficiency**
τ	**=**	**time constant for production**



Data Fit

From Brokmeyer *et al.*, 1996

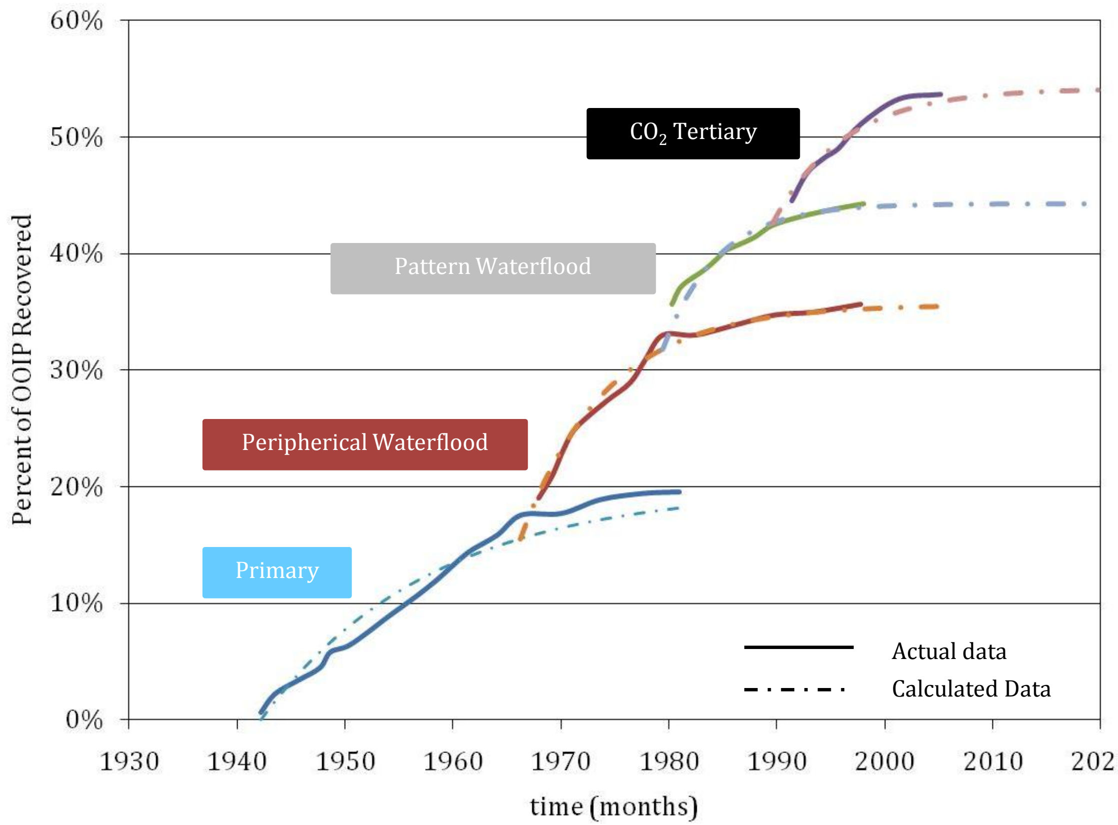


$|_1 = 16$ years

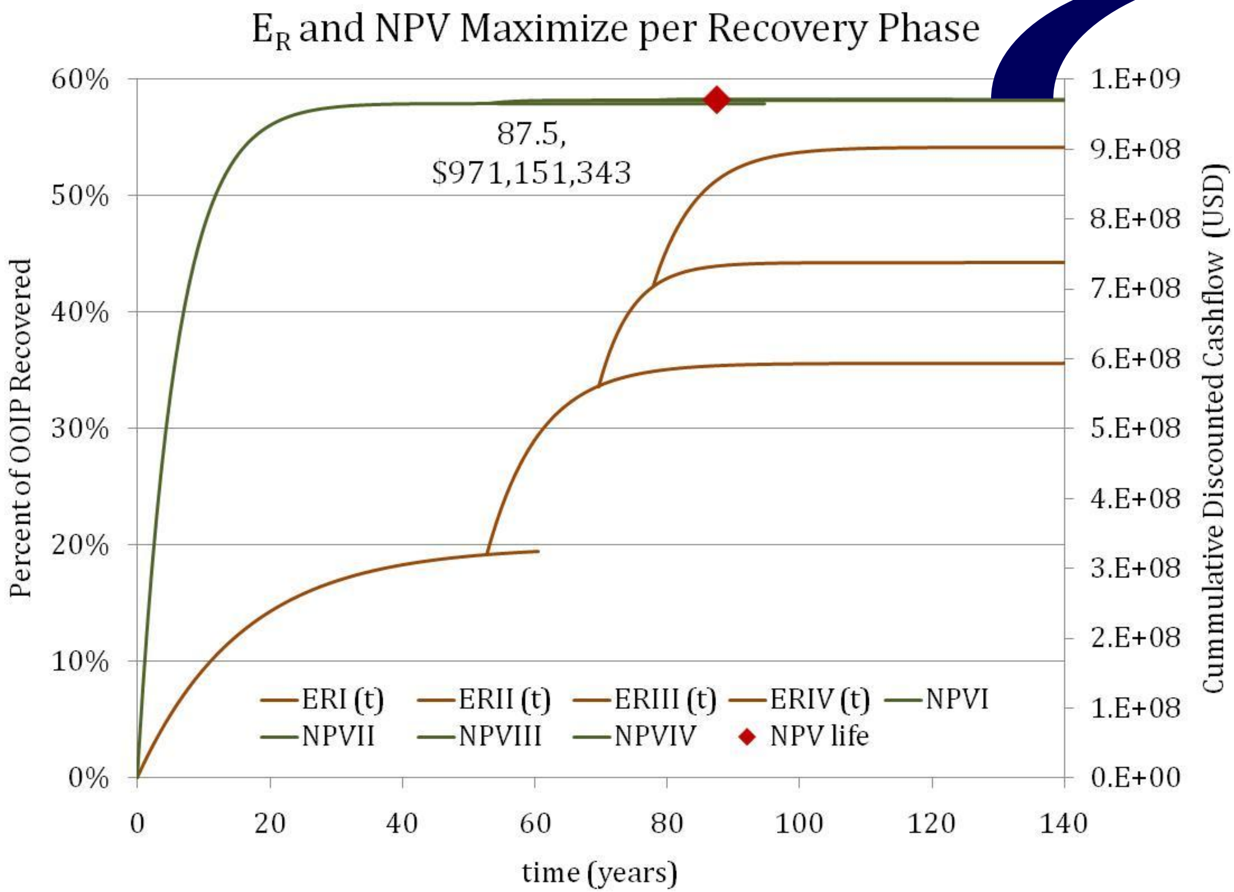
$|_2 = 7.9$ years

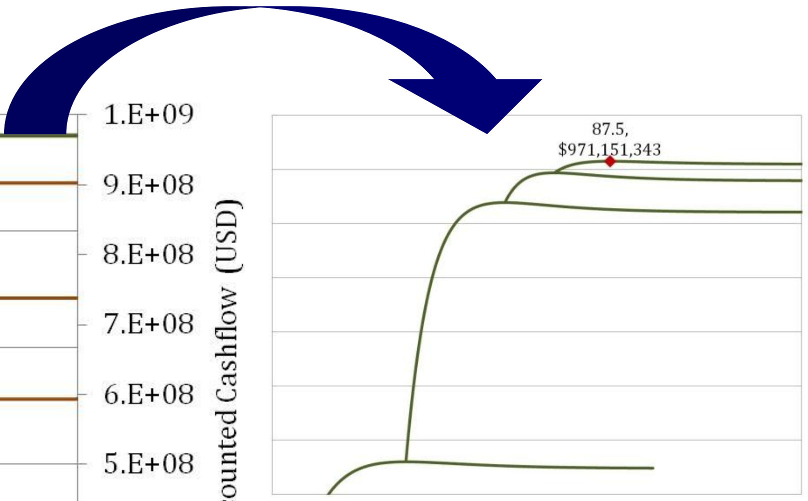
$|_3 = 5$ years

$|_4 = 6.7$ years

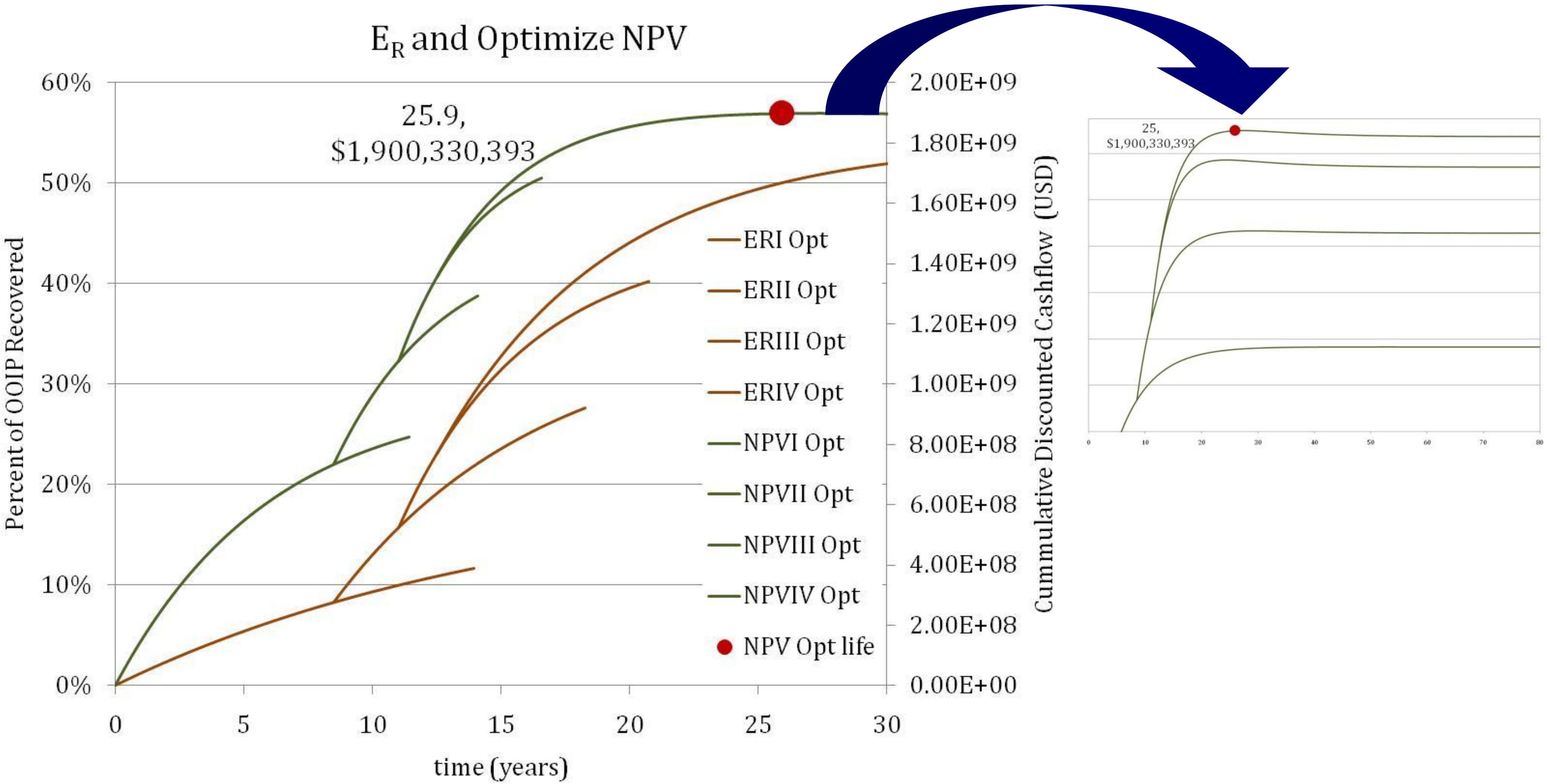


Maximize NPV per Recovery Phase
Myopic Optmization





Optimize Global NPV



Assumptions and Summary

	Case 1: Max NPV per phase	Case 2: NPV Data	Case 3: Optimize NPV
NPV (billion)	$0.97	$1.08	$1.90
tLife (years)	88	61	26
OOIP recovered (%)	51.3	52.7	50.0

- E^{∞}_{R} is constant
- τ is constant
- i = 10%
- $\$_{oil}$ = $55 per bbl
- $\$_{opex\text{-}1ry}$ = $3 per bbl
- $\$_{opex\text{-}1ry}$ = $5 per bbl
- $\$_{opex\text{-}1ry}$ = $6 per bbl

Conclusions from Study

- Matches history very well
- Life cycle optimization always increases NPV
- Often decreases ultimate recovery
- Ratio of contribution to NPV:
  - Primary: 1
  - Secondary: ½
  - Tertiary: 1/10

Outline

- **A nod to history**
- **Enter the gorilla**
- **Simple models**
- **Summary**

Numerical Simulation (Multicell)

- The industry standard
- Requires millions of inputs
  - Hugely over parameterized
  - None are exactly correct (history matching required)
  - Spawned entire technologies
- Can always history match (with an effort)
- No great history of prediction
- Complexity..
  - Discourages application
  - Allows investigation of interacting effects
- Provides a calibration for simple models

Simple Models?

- Any application that requires 1000s of runs
  - Multiple reservoirs (screening)
  - Sensitivity studies
  - Decision/risk analysis
  - Alternative scenarios
  - Concept selection
  - Value of information
- Easy to history match
- Can deal with large quantities of data
- We are not trying to draw an elephant

Other Views on Modeling…

- Bratvold and Bickel…two types
  - Verisimilitude- the appearance of reality
  - Cogent- enables decisions
- Haldorsen….the progress of ideas
  - Youth= simple, naïve
  - Adolescence=complex, naïve
  - Middle age=complex, sophisticated
  - Maturity= simple, sophisticated
- "All models are wrong. Some are useful." G.E.P. Box

What We've Learned

- Procedure can be done in a spreadsheet
- Geologic model is output, not input
- Always get great global matches
- Often get nonintuitive, controversial results
- Matches other sources (reasonably)
- Can be used for….
  - Characterizing reservoir
  - Optimizing injection rates
  - Identifying problem wells
  - Identifying wells for polymer treatment

Looking Forward (from 50,000 ft)

Four phases of modeling…

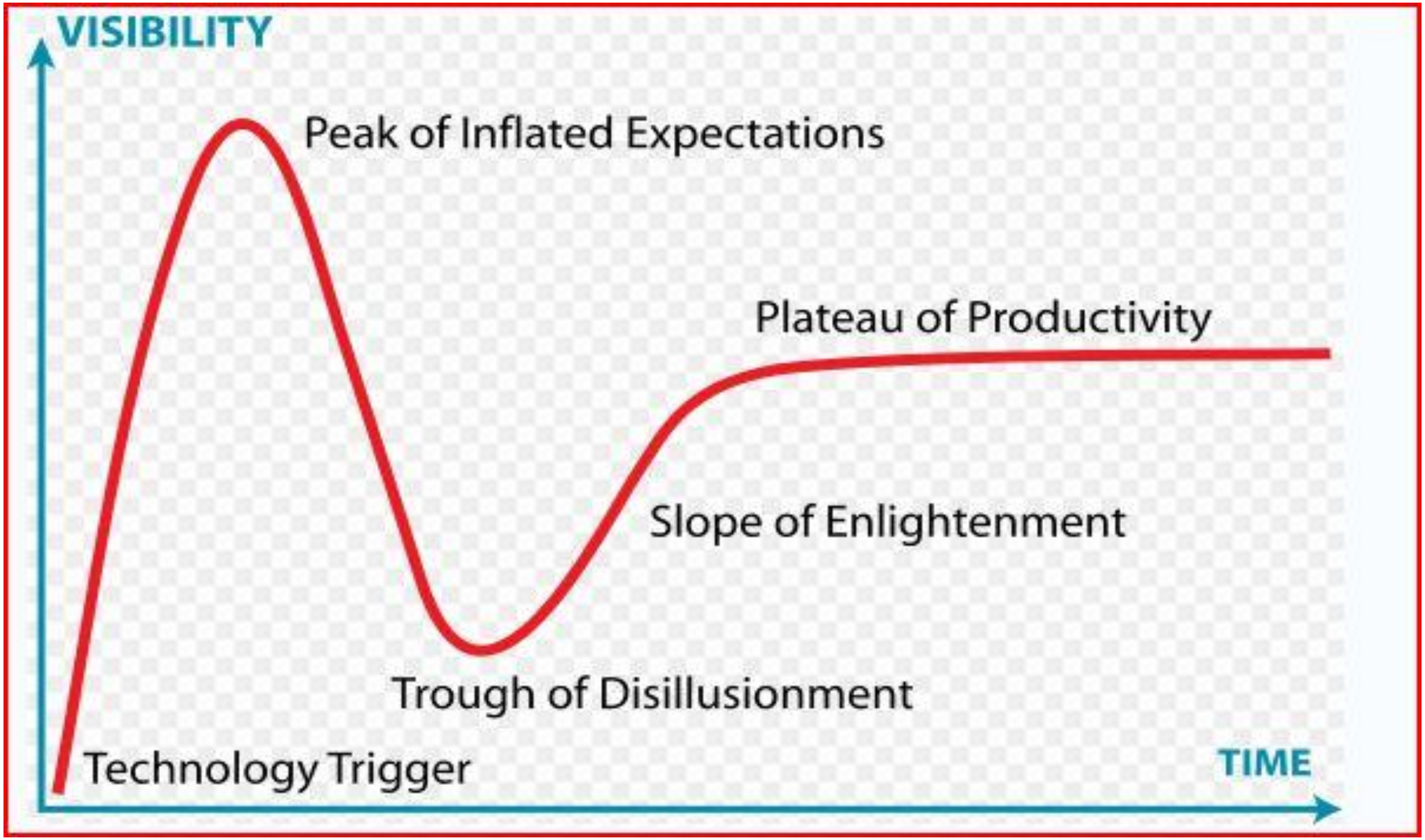
Empirical

Analytical

Numerical

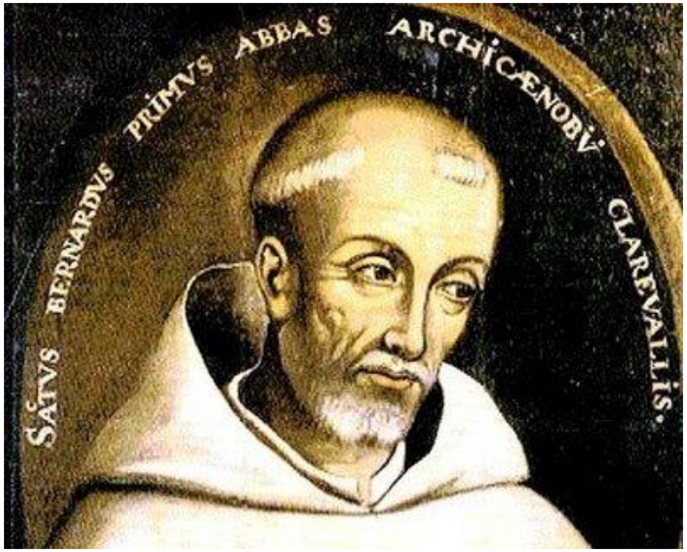
Data intensive

Gardner Hype Curve



Jim Honefenger

A nod to history..



William of Occam
1288-1348 CE

Occam's Razor:
Entities should not be multiplied endlessly
A way to shave away irrelevant explanations

The simplest explanation is the best

Aka…the law of
Parsimony
Succinctness
Economy

But…There is always a well-known solution to every human problem…neat, plausible, and wrong
H.L. Mecklen

And…All principles, rules and methods increasing lack universality and absolute truth the moment they become a positive doctrine
C. von Clausewitz