has acquired

Capturing Production Forecasting Uncertainty in Fractured Horizontal Wells

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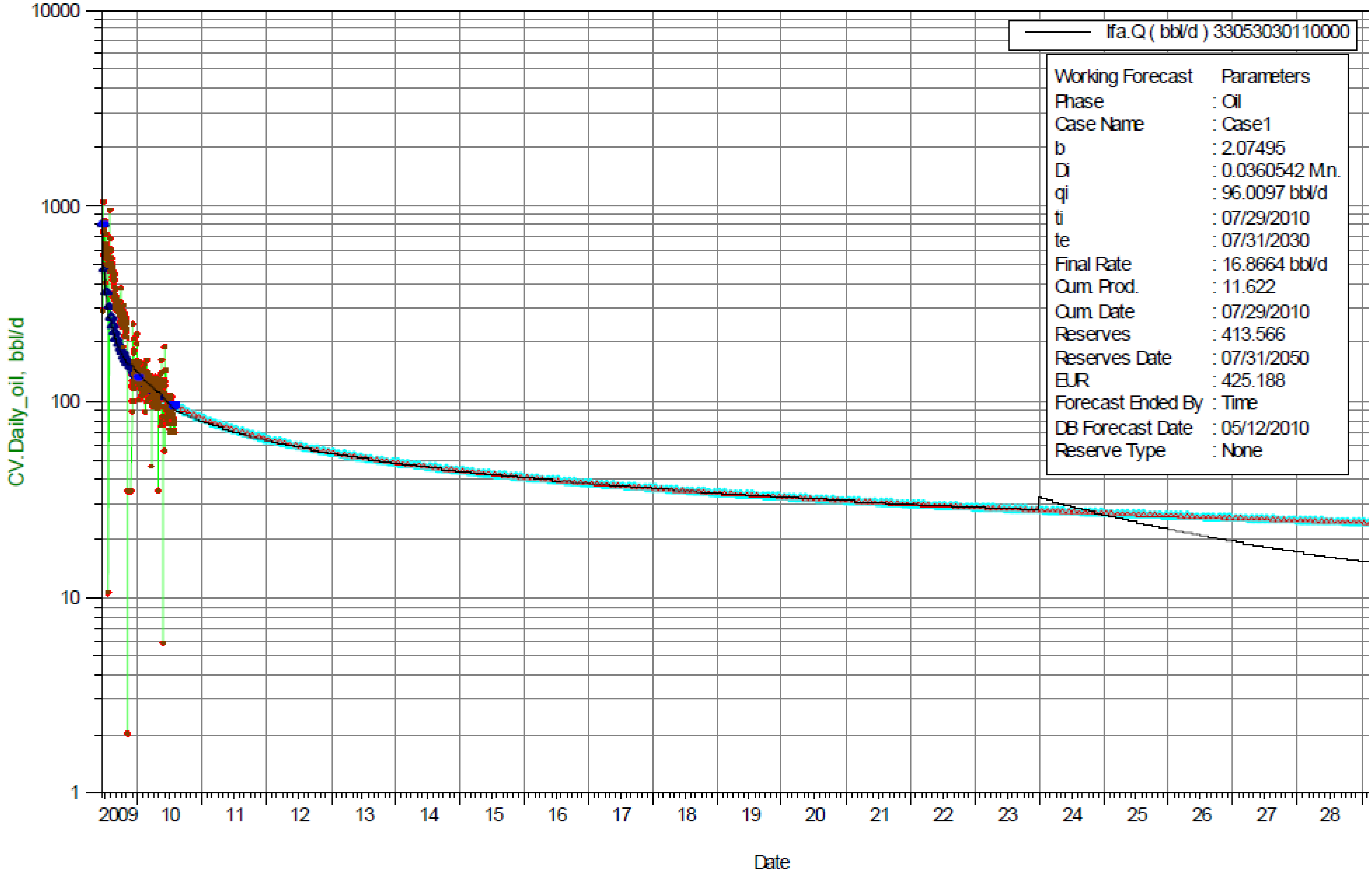
July 10th, 2013

Overview

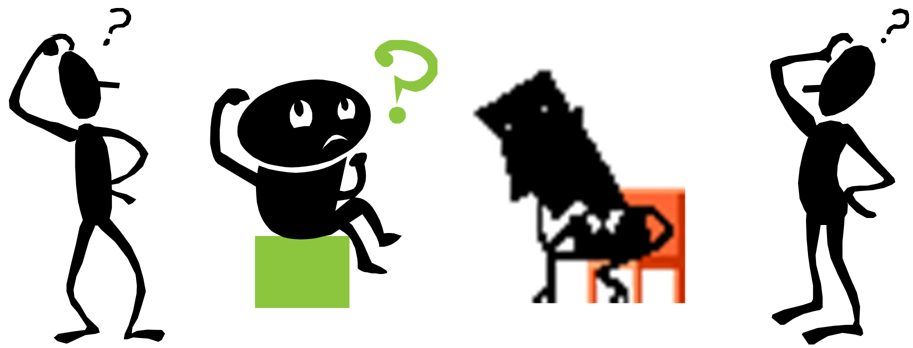
- Reliable, early evaluation of tight, fractured reservoirs is difficult
  - Prolonged transient rate-pressure response
  - Complex completion and reservoir with many unknown parameters
- EUR estimates for these wells are arguably best obtained from model-based production forecasts
- A new RTA probabilistic-model based approach is proposed:
  - Investigates an acceptable "parameter space" and provides probability distributions for forecast and EUR
  - Suitable for wells with limited (or no) production history
  - Demonstrated with field examples

The Problem with Traditional DCA



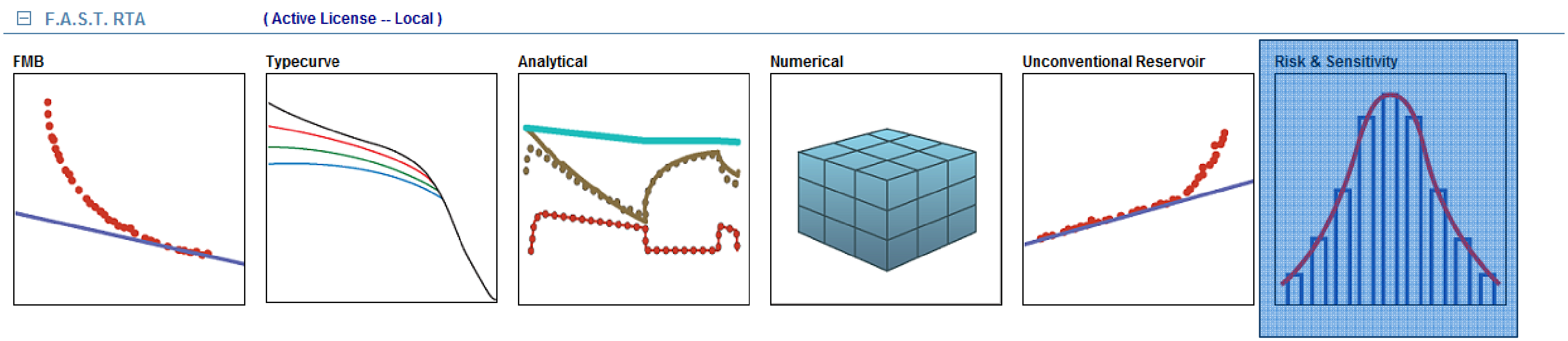
The Problem with Deterministic Modeling

"Hey team, what 's the P50 for that well?"



- The process of seeking an optimum model history match for a multi-stage fractured horizontal well (MFHW) does not result in a single, unique solution
- Deterministic results don't reflect the potential range of uncertainty in reservoir and forecast parameters
- Using expected values of uncertain input does not often produce the expected value of the output!

The Probabilistic Approach



- Uncertainty in production forecasting is quantified using a probabilistic approach (i.e. stochastic process), which generates output through numerous analytical model-based forecasting results
- Using Latin hypercube sampling (an ‘improved’ Monte Carlo sampling), a systematic investigation of an allowable parameter space is adequately and efficiently sampled

The Probabilistic Approach

- Distributions are specified to capture the uncertainty for specific input parameters while others are used in regression analysis to obtain the best history match of the data
- The goodness of fit of each run is tracked and compared against the baseline. Poor history matches do not get included in the EUR results
- Correlation between input parameters may be specified
- This process outputs probabilistic production forecasts, calculated using the raw forecasts from each run

The Assumptions

- Future well performance can be fully described within the context of the chosen model
- Potential future operational issues are not considered
- Results are from analytical model output, therefore equations are based on **constant effective permeability** in the reservoir
- Without multi-phase flow considerations (solution-gas-drive), EURs will be on the conservative-side

Advantage of Analytical Models

- Analytical models
  - provide immediate feedback to the analyst, using regression to quickly optimize the history match
  - are practical as they are much faster and easier to initialize, optimize and run compared to numerical models
  - can be used to generate probabilistic EUR output. Practically speaking, this is not possible with numerical models
  - generate more conservative (and more reasonable-looking) forecasts for tight, fractured horizontal oil wells (in general)
    Operational issues associated with these wells often limit the true reservoir potential from ever being realized at the wellhead

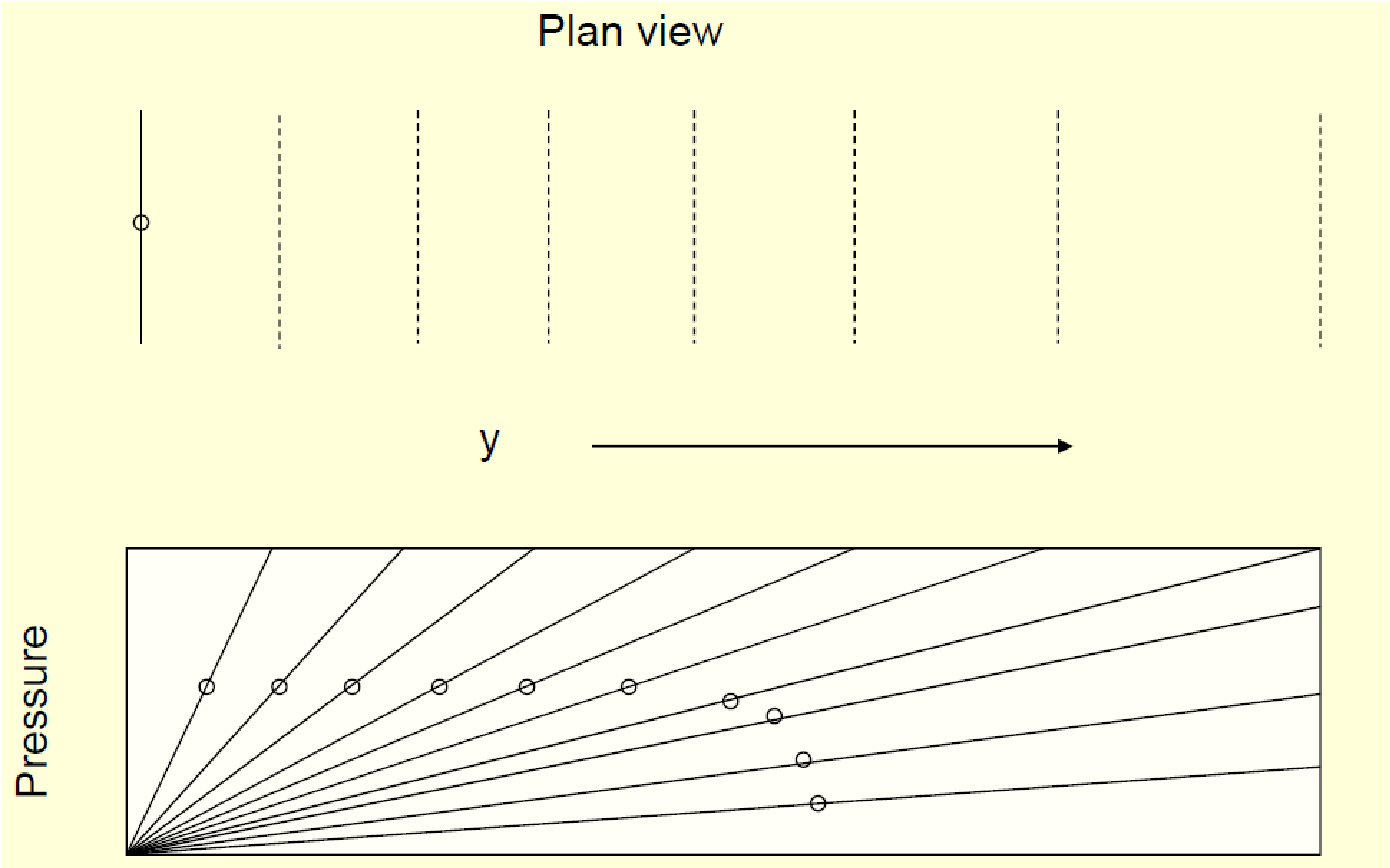
What about Multi-Phase Flow Effects?

While **numerical models** are likely better for forecasting 'long-term' reservoir performance for fractured oil wells, **analytical models** can generate history matches of equal quality while the well is producing at a fairly constant GOR

Constant GOR over 5 years in the Bakken!

Why Transient Flow is Our Friend

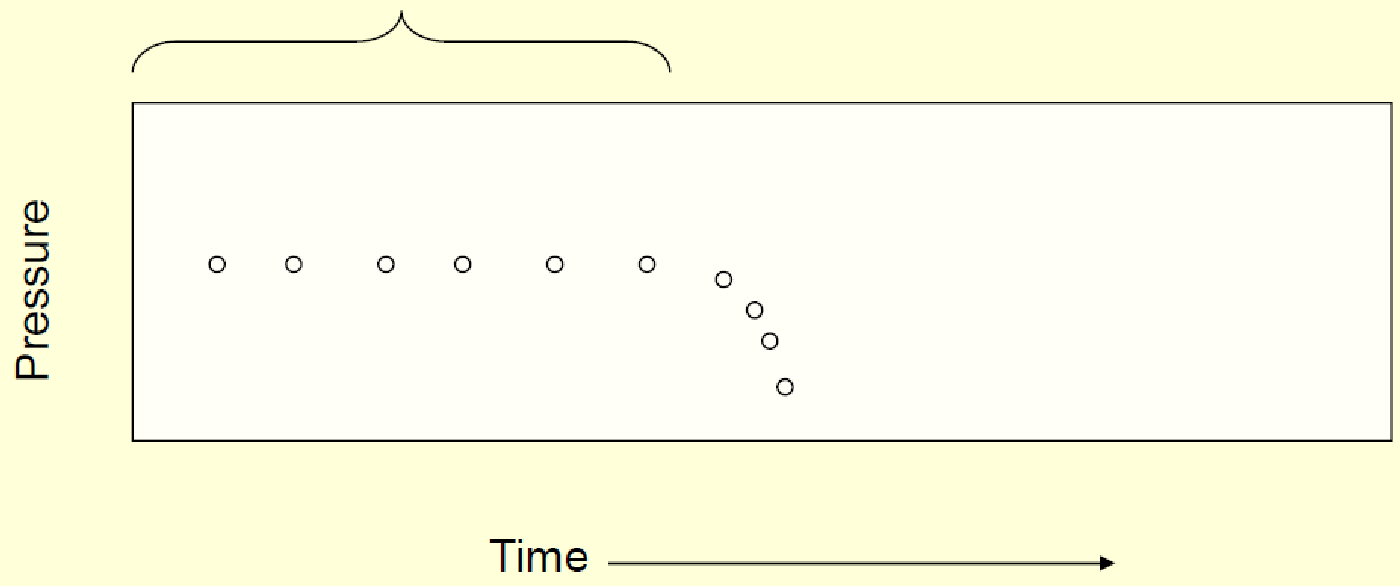
Because Single Phase Flow Equations work!!



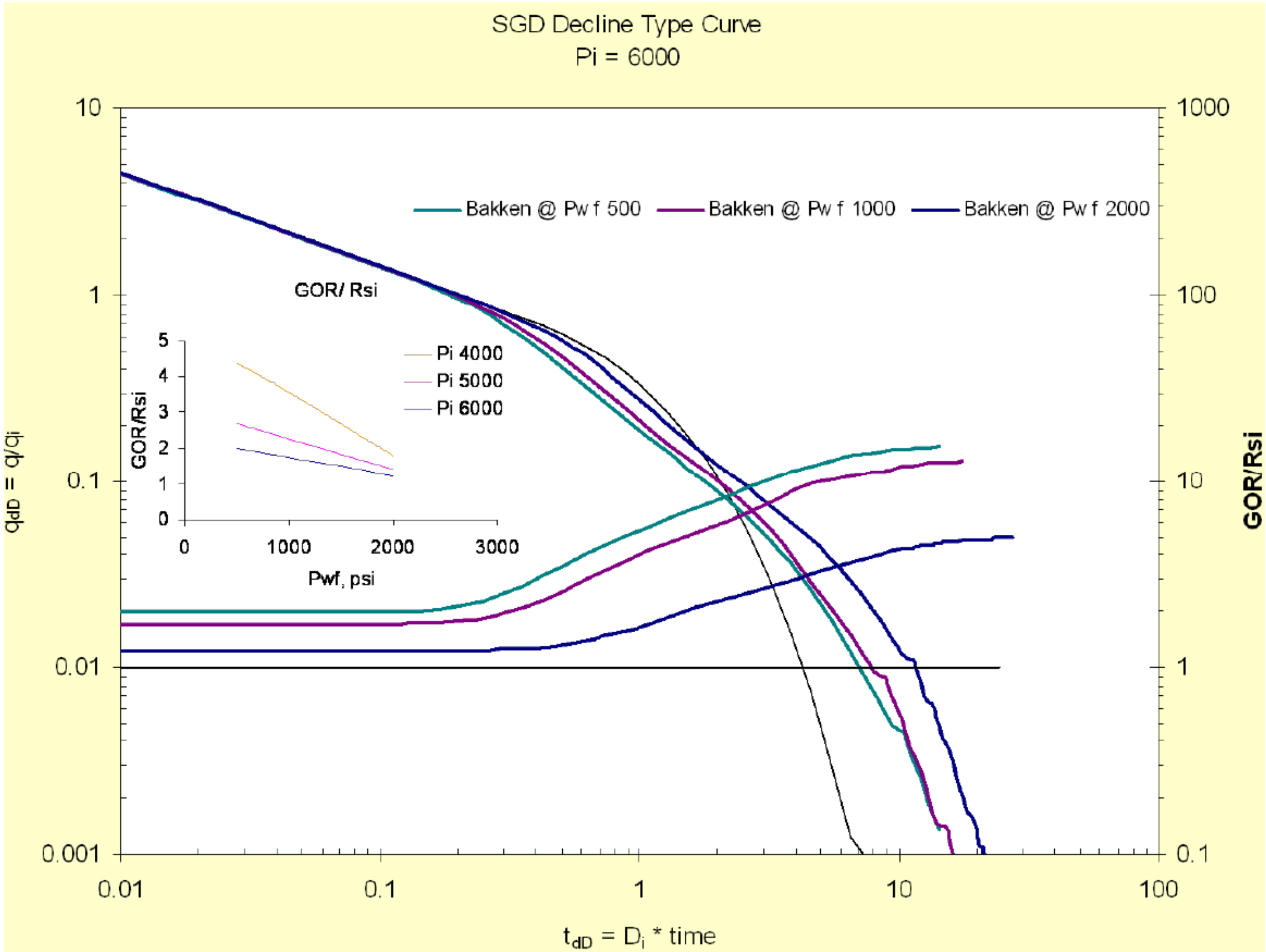
GOR – Diagnostic for BDF!

$$\frac{\partial \overline{P}}{\partial t} = 0 \qquad \frac{\partial S_g}{\partial t} = 0 \quad \Rightarrow$$

Constant GOR during infinite acting linear flow period



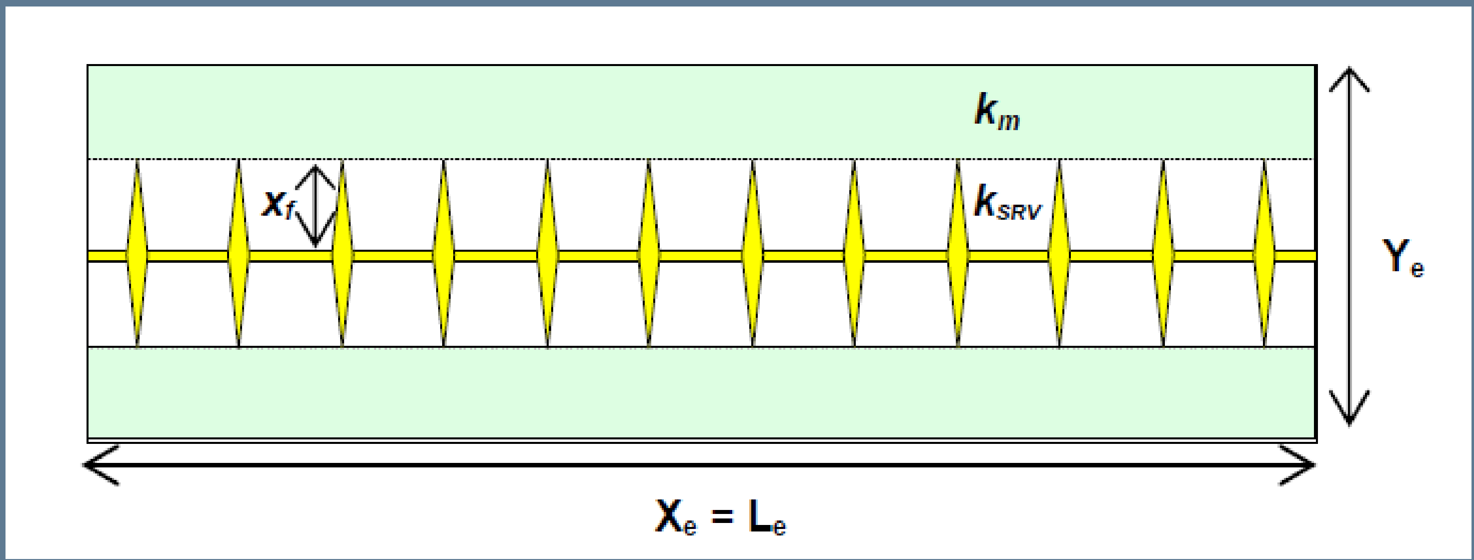
GOR Behavior at Varying p_{wf}



Trilinear-Flow 'Composite' Model

"Despite the complex interplay of flow among matrix, natural fractures, and hydraulic fractures, the key characteristics of flow convergence toward a MFHW may be preserved in a relatively simple, trilinear-flow model." M. Brown, SPE 125043 (2009)

Homogeneous Completion (i.e. uniform fracture distribution)

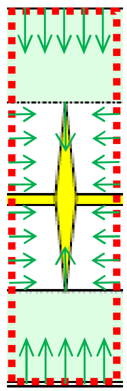


Simplified Trilinear Flow Model used for the Analytical Solution of MFHW Performance
Ozkan et al. SPE 121290 (2009)

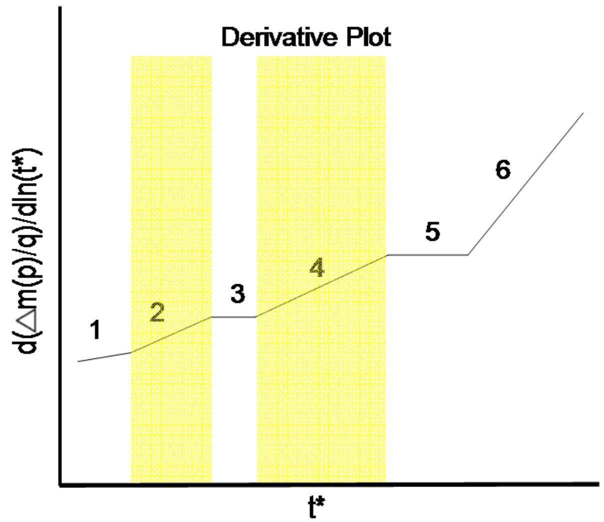
Trilinear-Flow Model

Flow Regime	Radial Derivative on Log-Log Diagnostic Plot
1 – Bilinear	¼ slope
2 – Early Linear	½ slope
3 – Early Radial	zero slope
4 – Late (Compound) Linear	½ slope
5 – Late Radial	zero slope
6 – Boundary Dominated	unit slope

Ref: *JNGSE* **3**: 382–401
Clarkson and Beirele (2011)



Fracture Flow
(1st Linear Flow)



Field Examples

- Bakken (Tight Oil)
- Marcellus (Shale Gas)

Basic Data Requirements for RTA

- ❑ Completions Information
  - Completion type, # stages, # clusters, proppant type/weight, frac fluid type/volume
- ❑ Fluid Analysis
  - Fluid analyses (oil, gas)
  - PVT
- ❑ Petrophysical
  - Interpreted logs (including net pay, porosity and water saturation)
- ❑ Production and Operations
  - Daily production volumes with wellhead/bottomhole pressure data
- ❑ Wellbore
  - Deviation survey with all wellbore configurations during well-life
- ❑ Additional Considerations
  - Dates of fracture stimulations on offset wells (pad drilling)
  - Dates of re-fracs if performed

The Test Conditions

- Forecasting period = 50 years
- Abandonment rate = 5 stb/day (oil), 50 Mscfd (gas)
- Minimum of 500 runs conducted for each well
- Unless otherwise known, all distributions specified (x_f, n_f, k_m, A_d) are either triangular or uniform
- k_{SRV} and FCD are always automatically estimated through regression. k_m is used in regression analysis in the Bakken (*because of higher perm*)

** If many records for parameter data are available (from lab measurements, surveillance info, PTA, etc.), distribution types can be determined*

Wiliston Basin (Bakken/Three-Forks)

Image and information courtesy of Ali Daneshy (Daneshy Consultants Int'l)
2010 SPE Conference "Maximizing Tight Oil in the Bakken"

Bakken Petroleum System

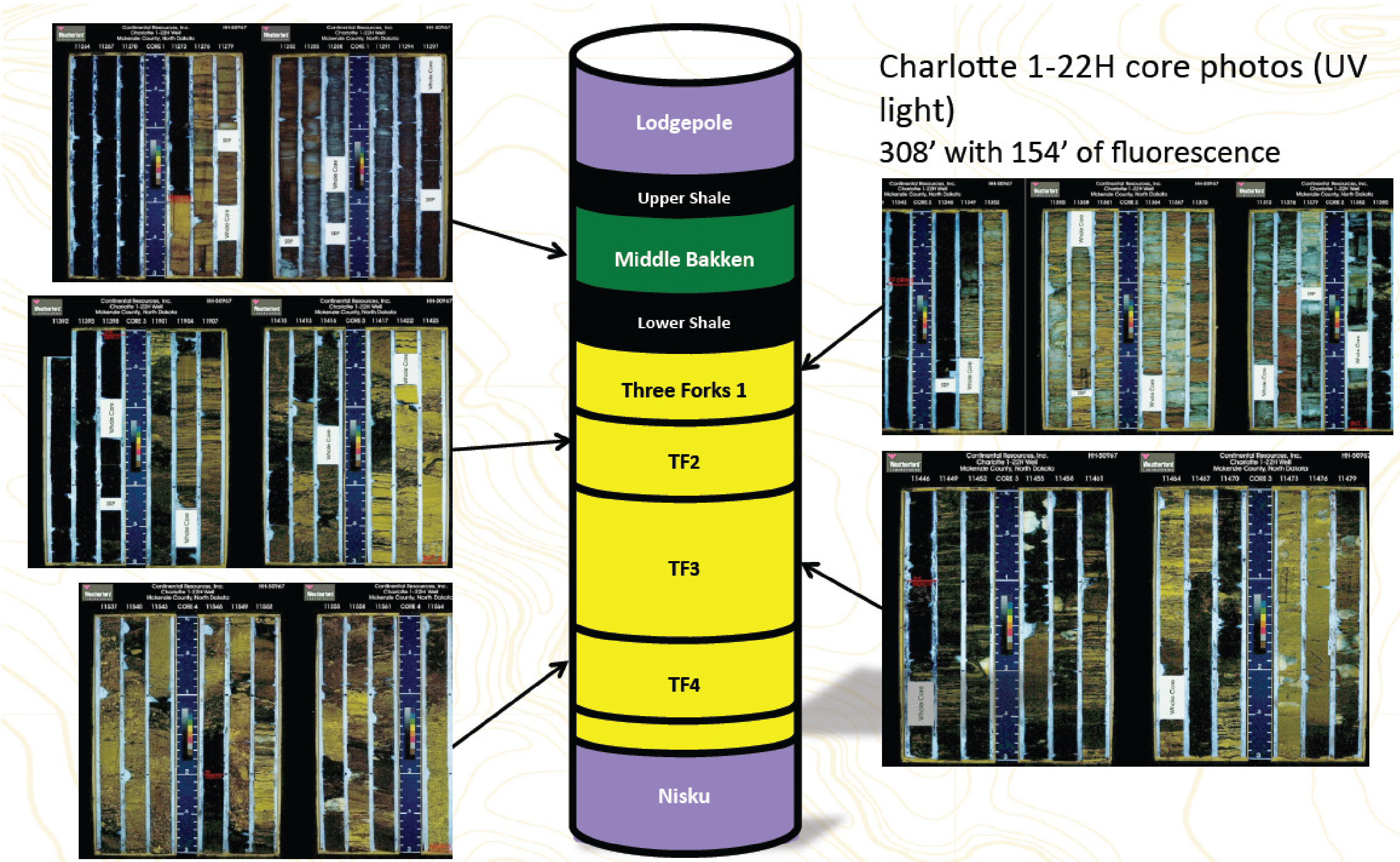
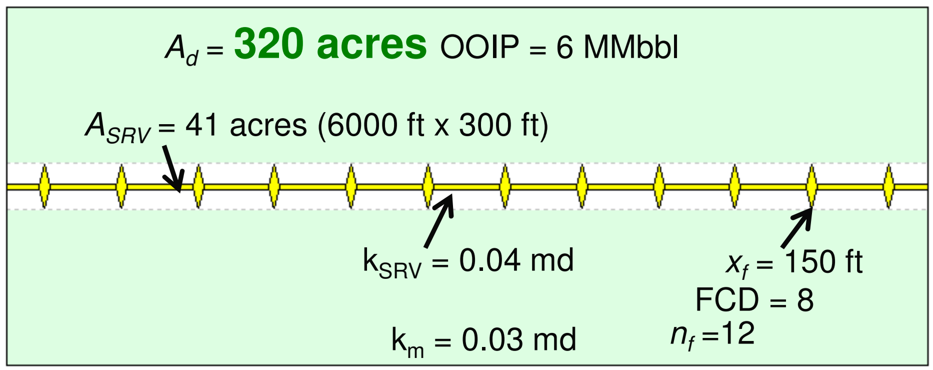


Image courtesy of Archie Taylor (Continental Resources)
2013 Bakken-Three Forks Completions Congress in Denver (American Business Conferences)

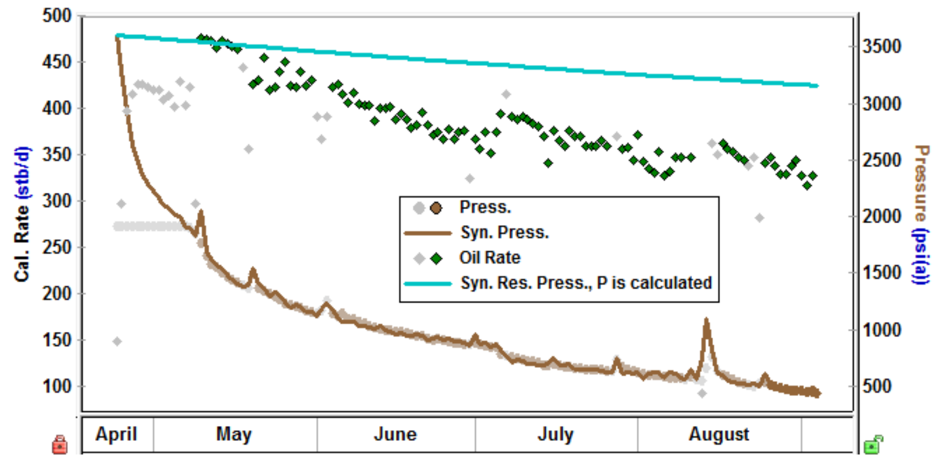
Deterministic Analytical Modeling

12 frac stages (ball-drop)

One possible description…

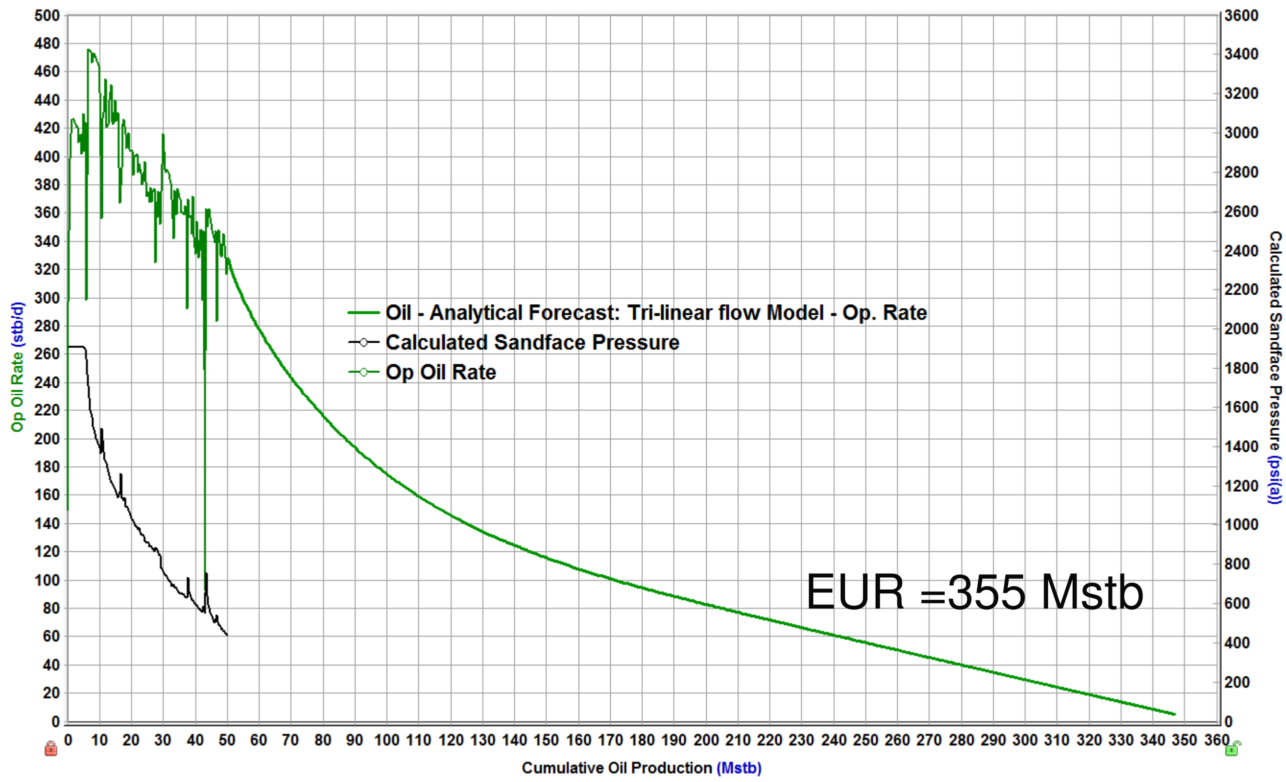


p_i = 3600 psi
h = 65 ft
ϕ = 7%
s_o = 65%
s_w = 35%
c_f = 5.6 psi^{-1}

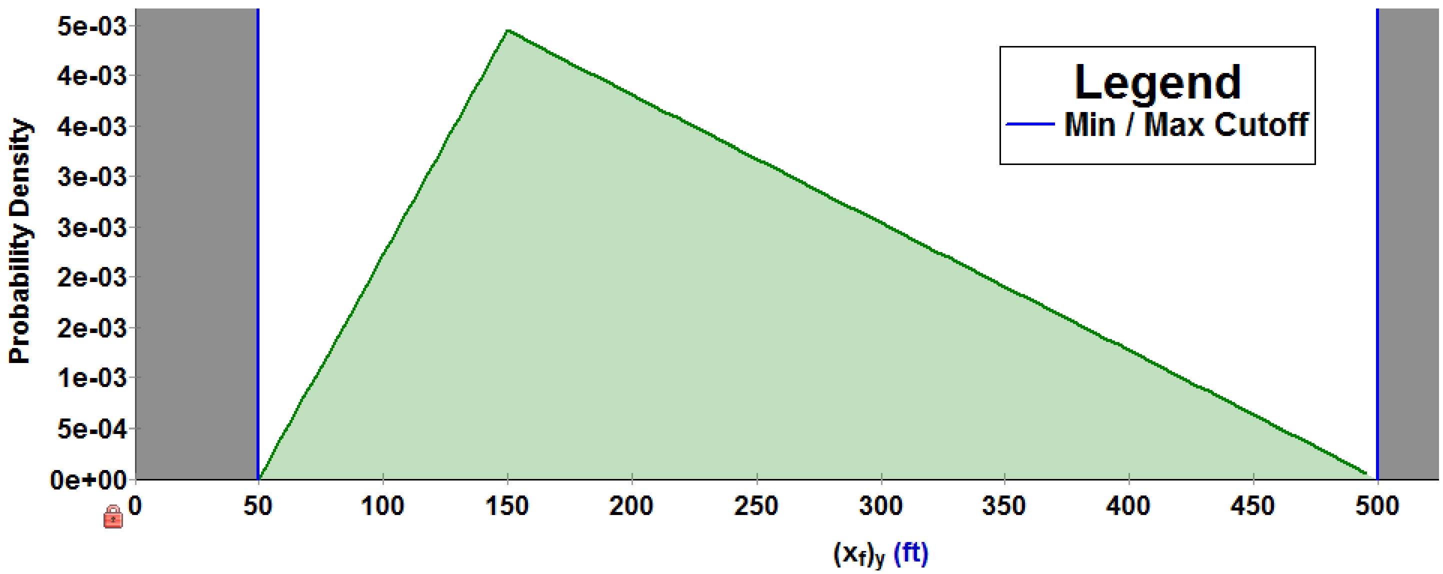


The Forecast (320 acres)

… one possible outcome

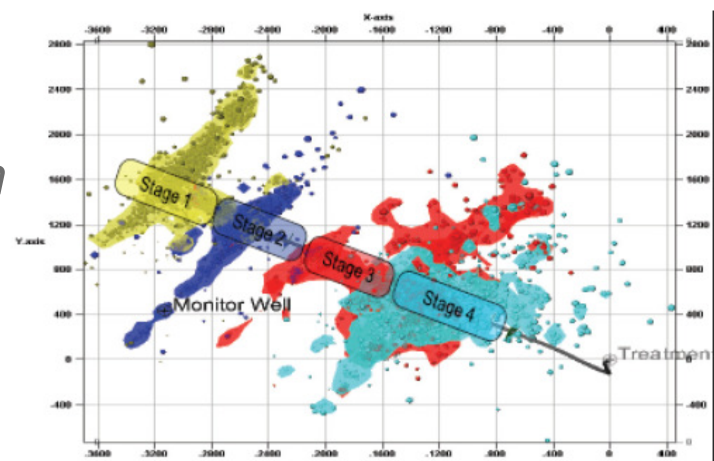


Input – Fracture Half-Length

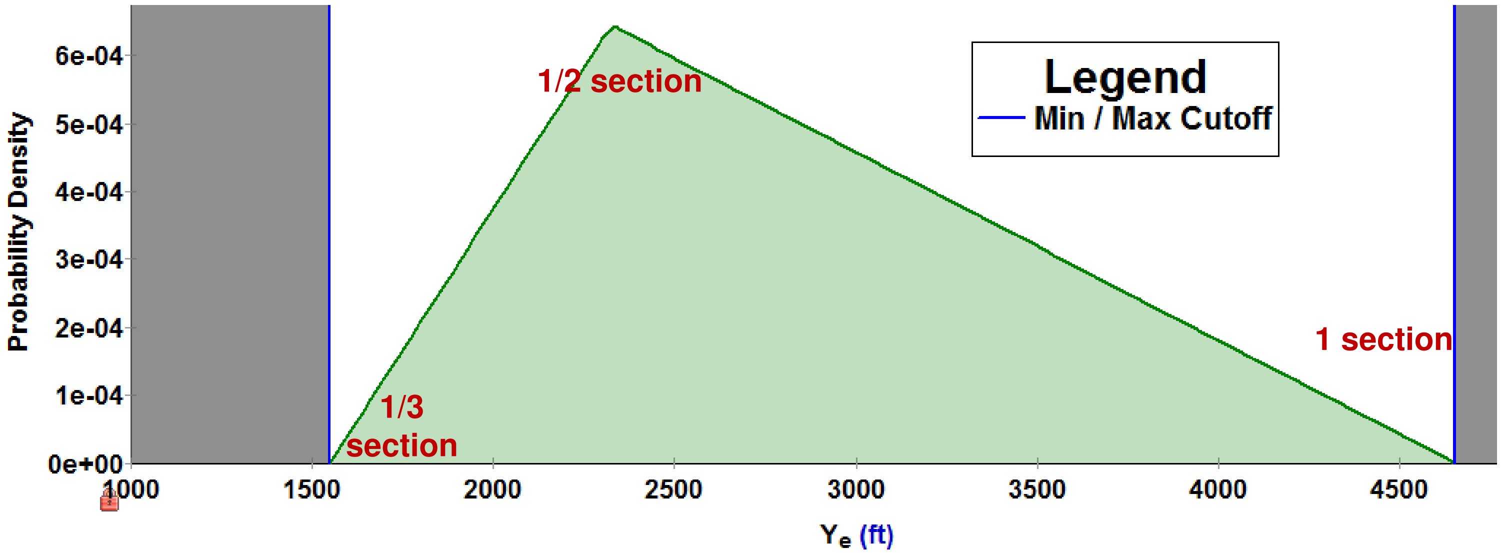


Use of surveillance information (e.g. microseismic)

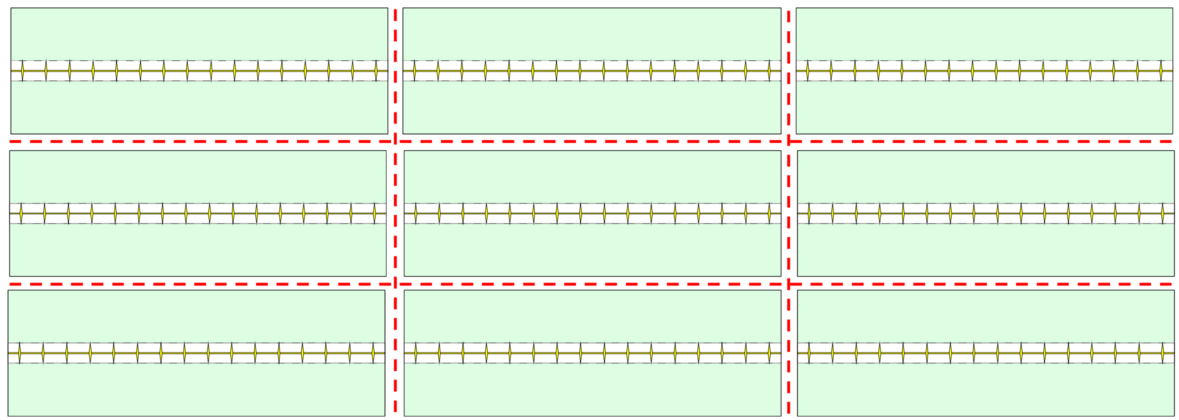
Image courtesy of Chris Tucker (NSAI)



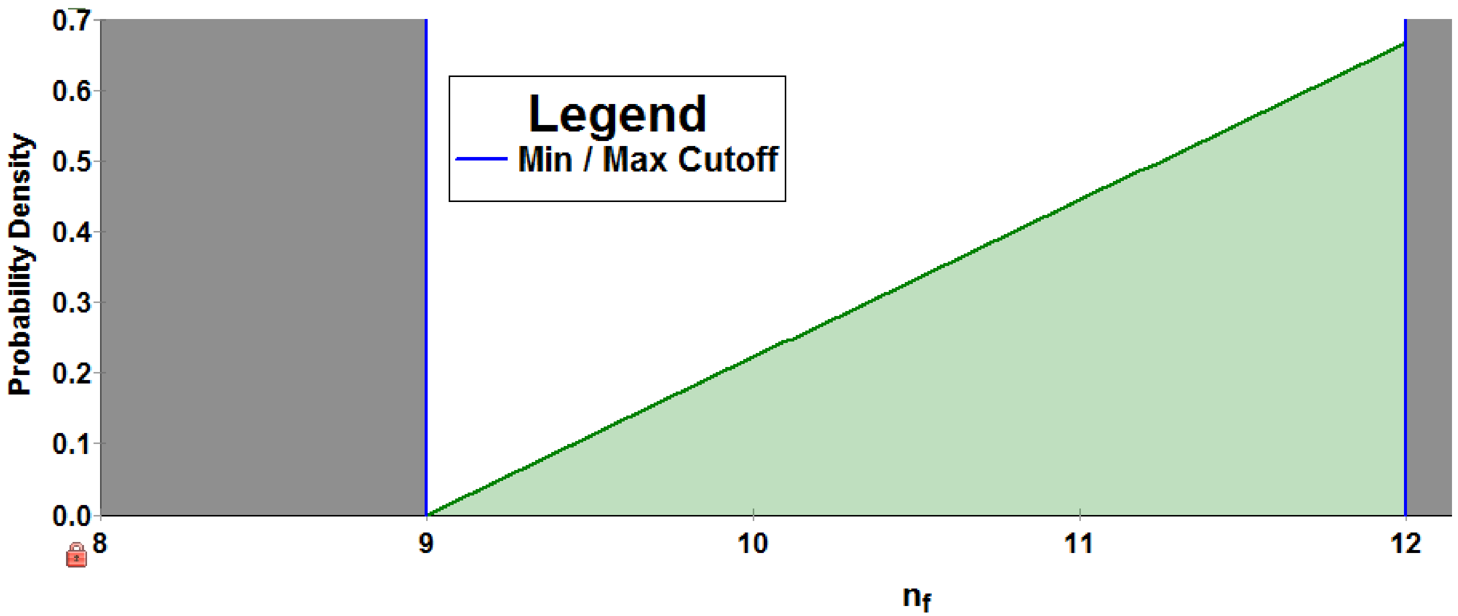
Input – The Drainage Area



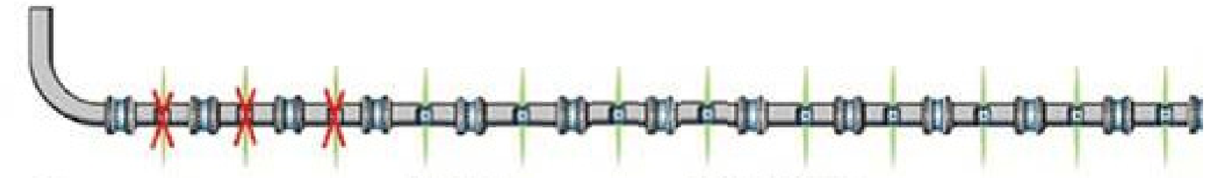
Conceptual model of a developed tight oil field (infill well program)



Input – The Number of Fractures



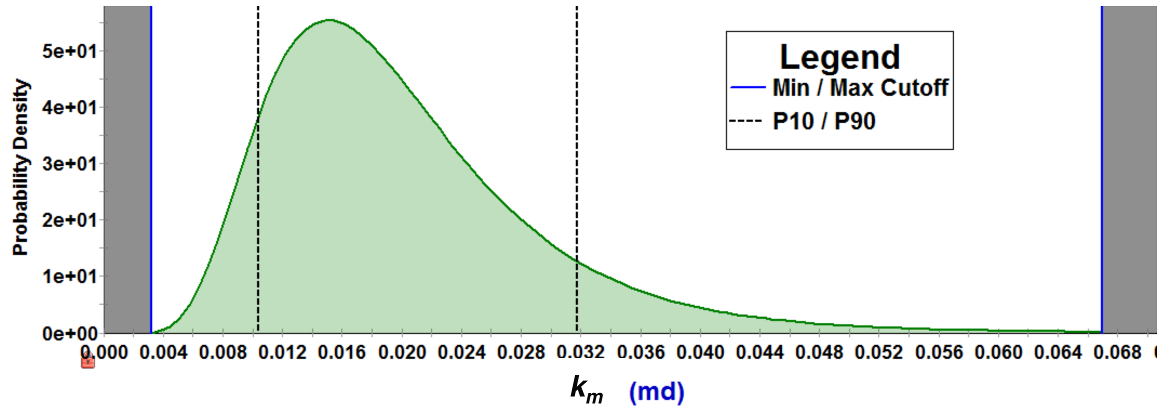
Ball-drop
9 out of 12 stages
successful



Example of Possible Outcome

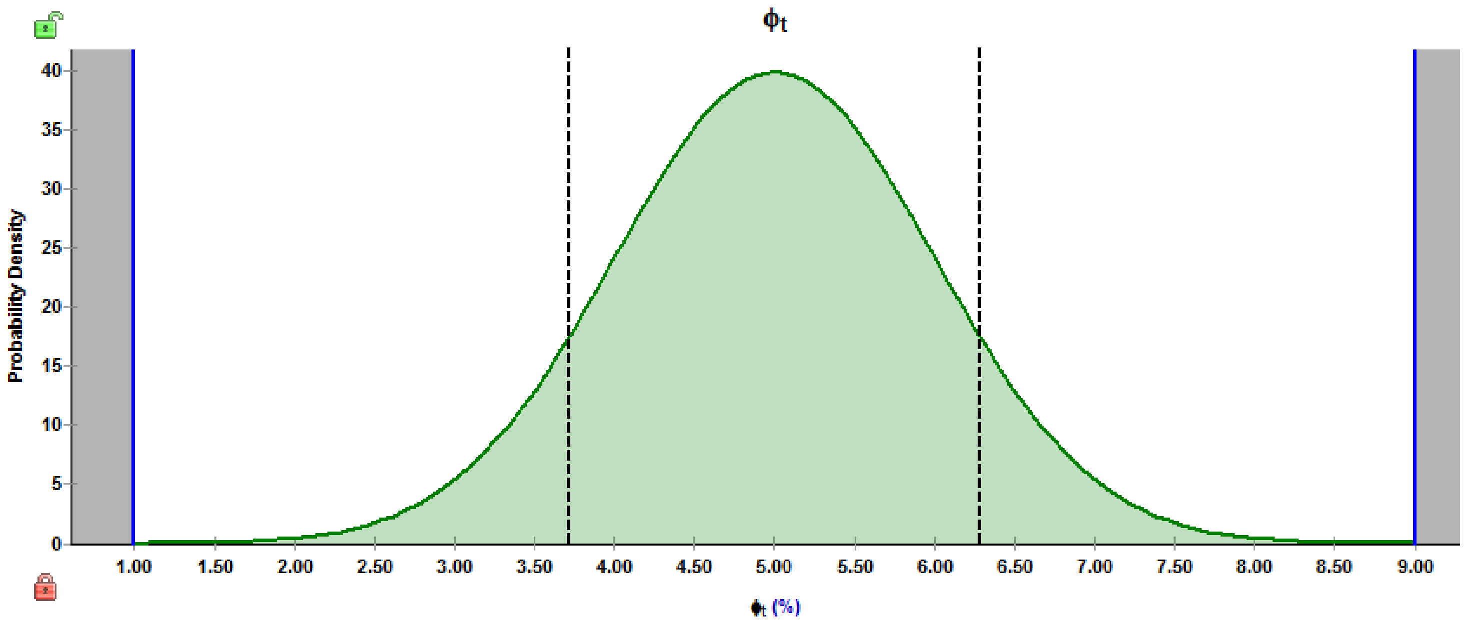
Input – Matrix Permeability

- A distribution for k_m could have been estimated if lots of data were available. Methods for obtaining this data include DFITs, core analysis, and radial flow analysis on older VWs

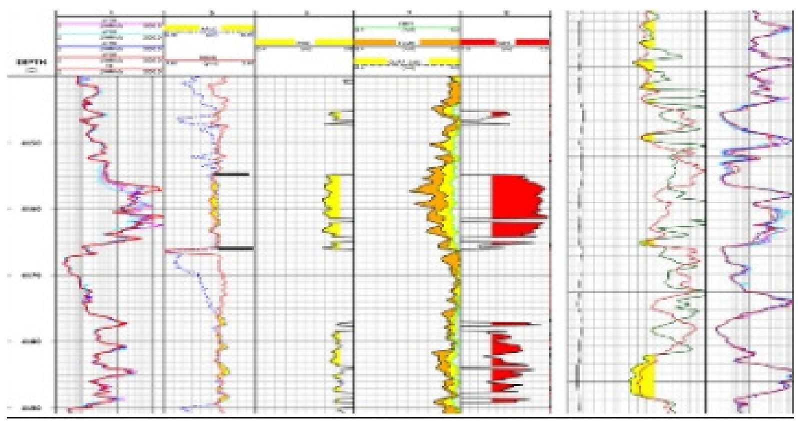


- For this study, k_m was assigned to regression analysis to reduce the number of runs

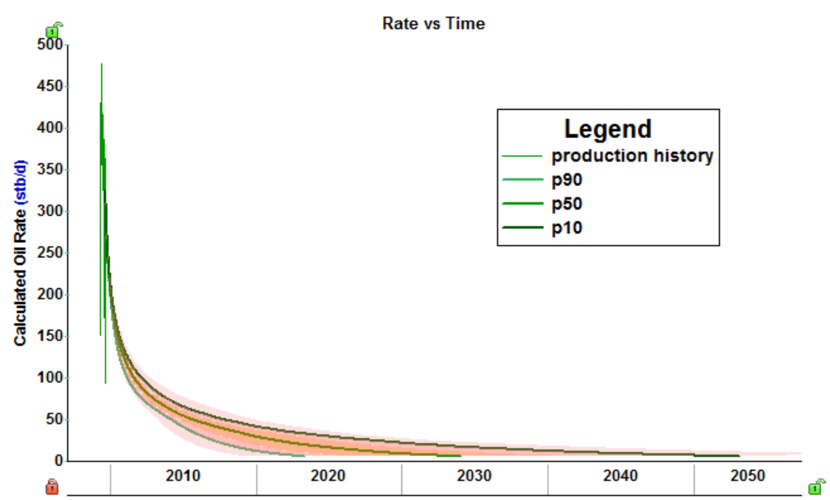
Input – Petrophysical Properties

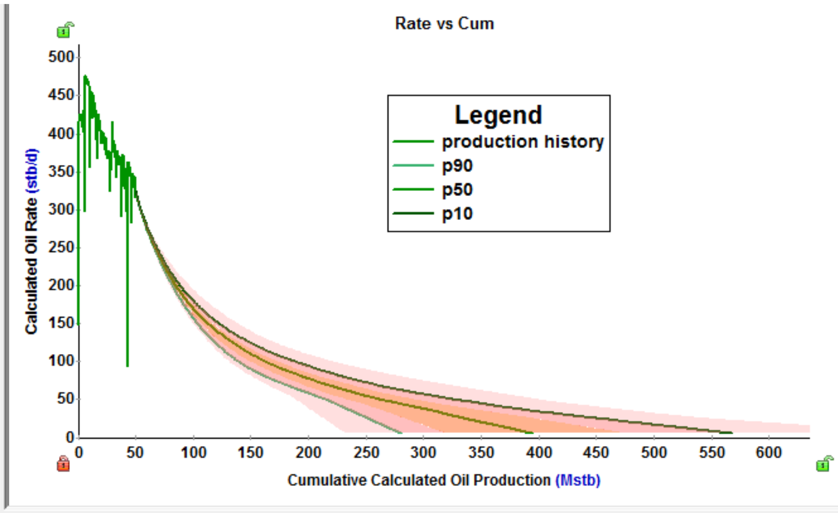


Petrophysical logs to assess
h, ϕ, S_o



Probabilistic Model Results





Summary of statistics

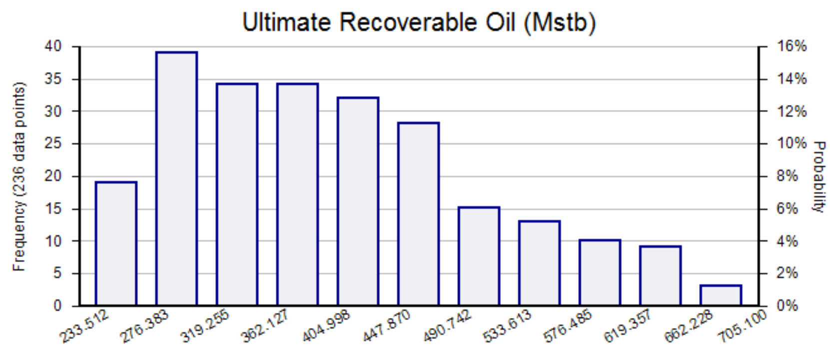
Mean: 408.001 Mstb
Std Dev: 107.835 Mstb

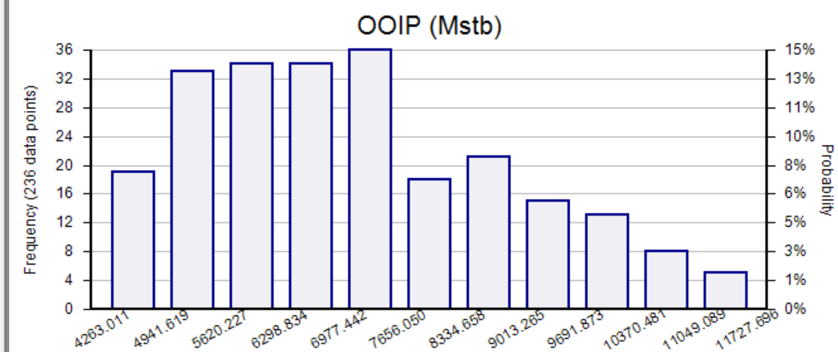
p10: 567.753 Mstb
p50: 394.738 Mstb
p90: 280.978 Mstb

Summary of statistics

Mean: 7178.246 Mstb
Std Dev: 1745.167 Mstb

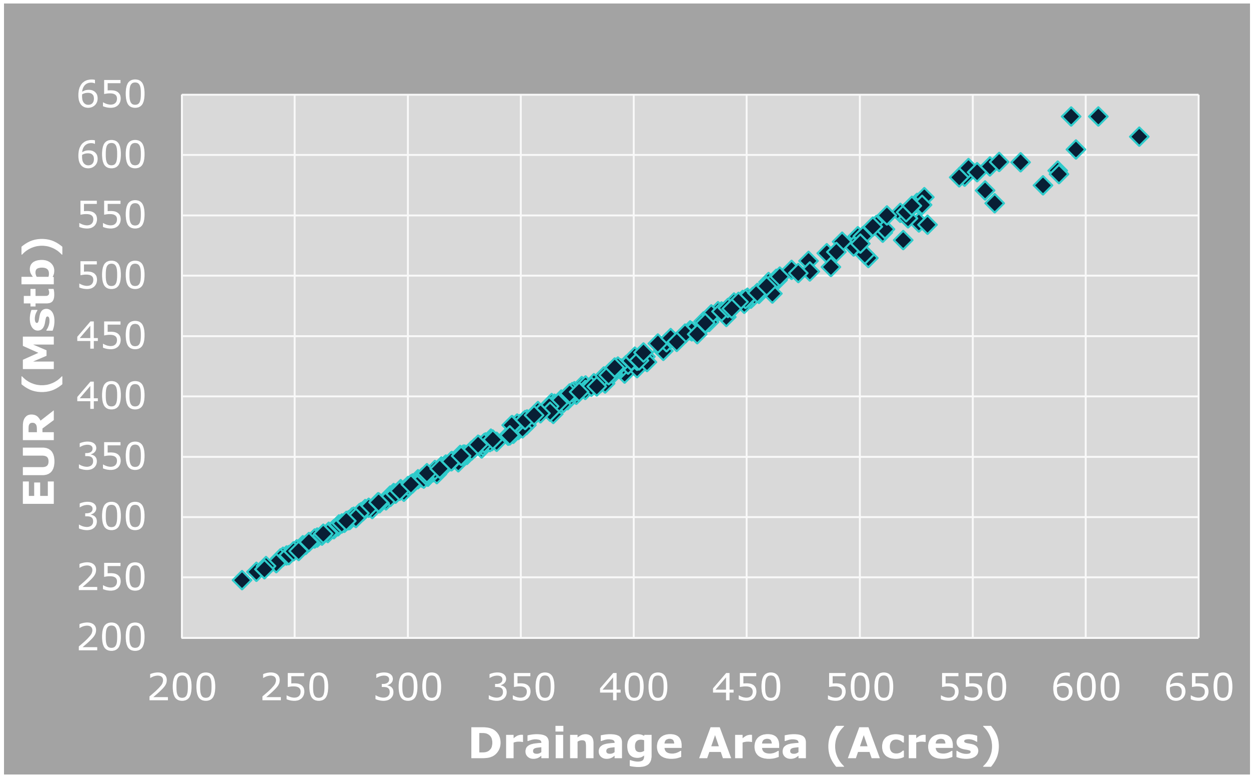
p10: 9775.221 Mstb
p50: 6944.453 Mstb
p90: 5080.289 Mstb



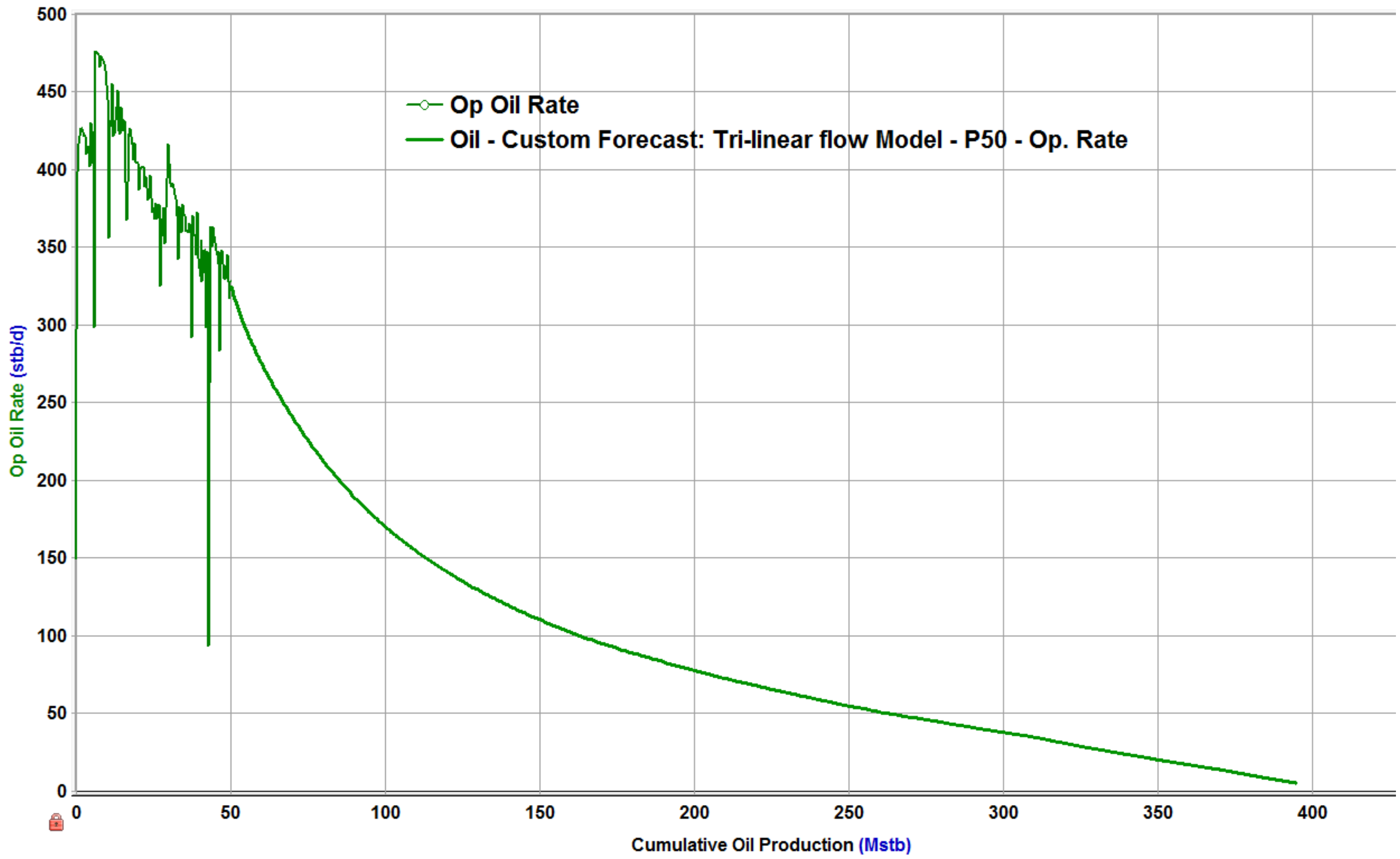


The Sensitivity – A Cross Plot

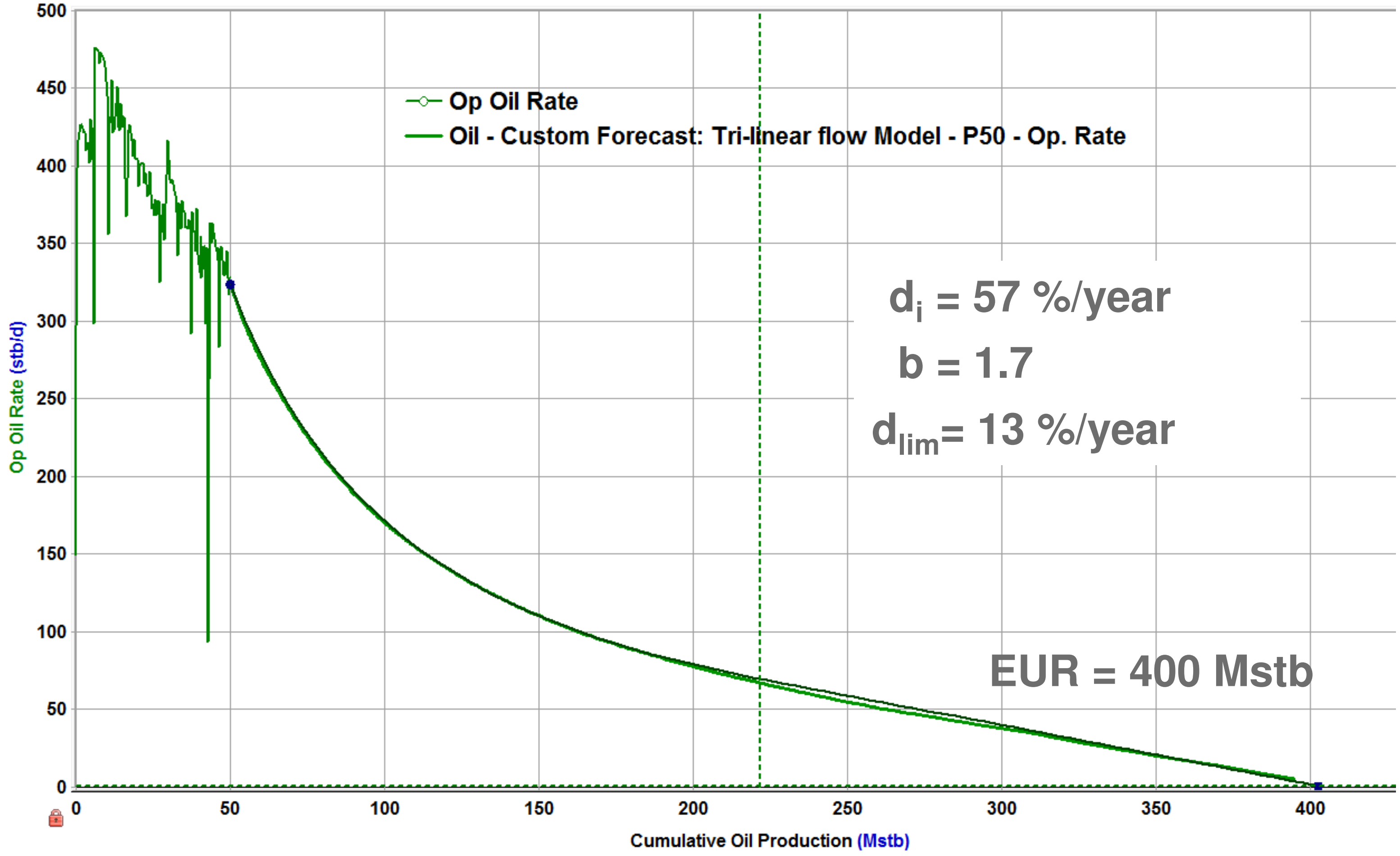
- In general, the most important factor in reducing the uncertainty in EUR (30 – 50 years) in reservoirs of permeability > 0.001 md is the Drainage Area



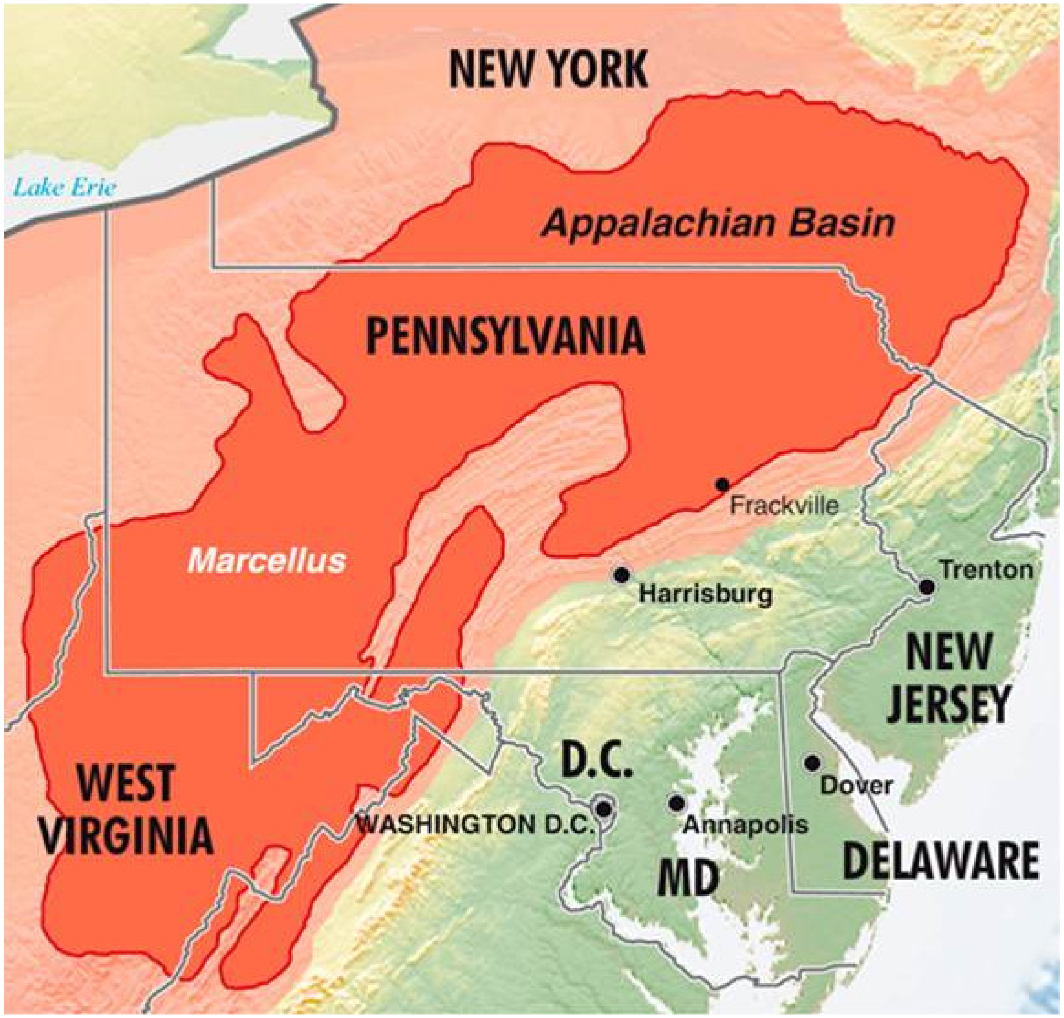
P50 Forecast



DCA parameters for P50



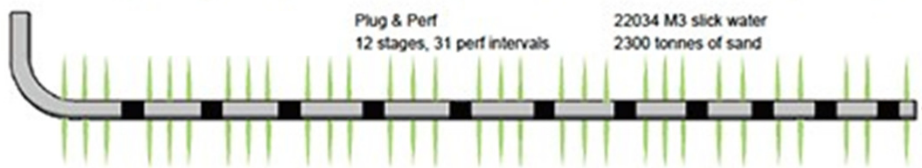
The Marcellus Shale



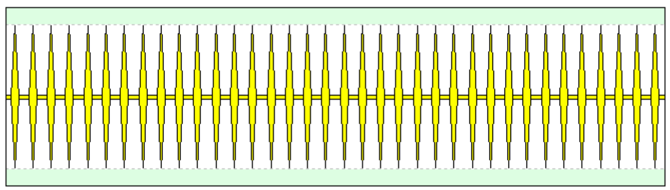
History Matching with Model

p_i	3924.00	psi(a)
$(x_f)_y$	400	ft
L_{ex}	3700.0	ft
F_{CD}	160.841	
n_f	31	
Link Perm		
k_1	24.089	nd
k_2	20.000	nd
h	150.0	ft
ϕ_t	7.10	%
S_g	66.00	%
S_o	0.00	%
S_w	34.00	%
c_f	5.6049e-06	1/psi
Dual Poros		
Adsorption		
Langmuir		
V_{Ls}	50	scf/ton
P_{Ls}	405.00	psi(a)
Shale		
ρ_b	2.60	g/cm³
Ads. Sat.		
ρ_{ads}		g/cm³
S_{ads}	0.00	%
Geomech		
Boundaries		
X_e	3700.0	ft
Y_e	1000.0	ft
A	85	acres
A_{SRV}	68	acres
$OGIP_F$	7018	MMscf
$OGIP_A$	2041	MMscf
OGIP	9059	MMscf
$OGIP_{SRV}$	7247	MMscf
r_w	0.350	ft

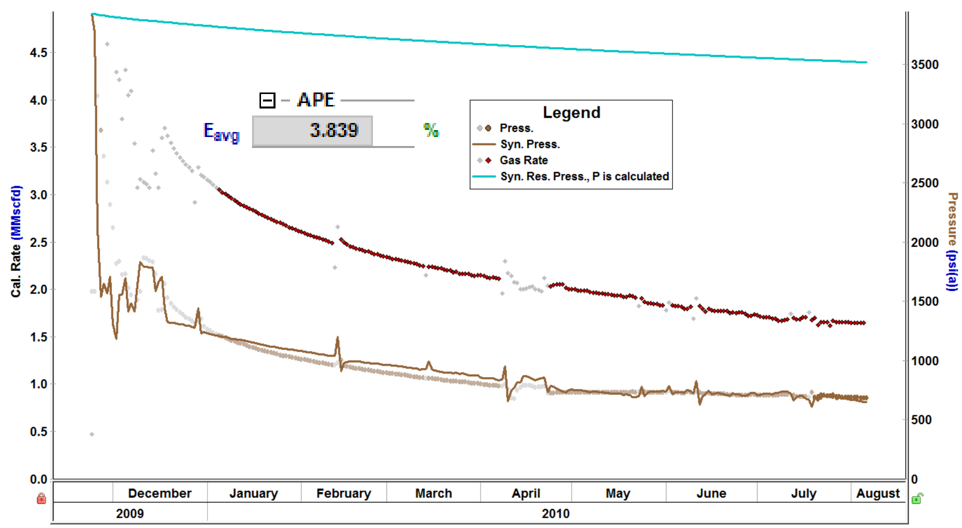
One possible description…



12 Frac Stages,
31 Perf Intervals
(Plug'n'Perf)

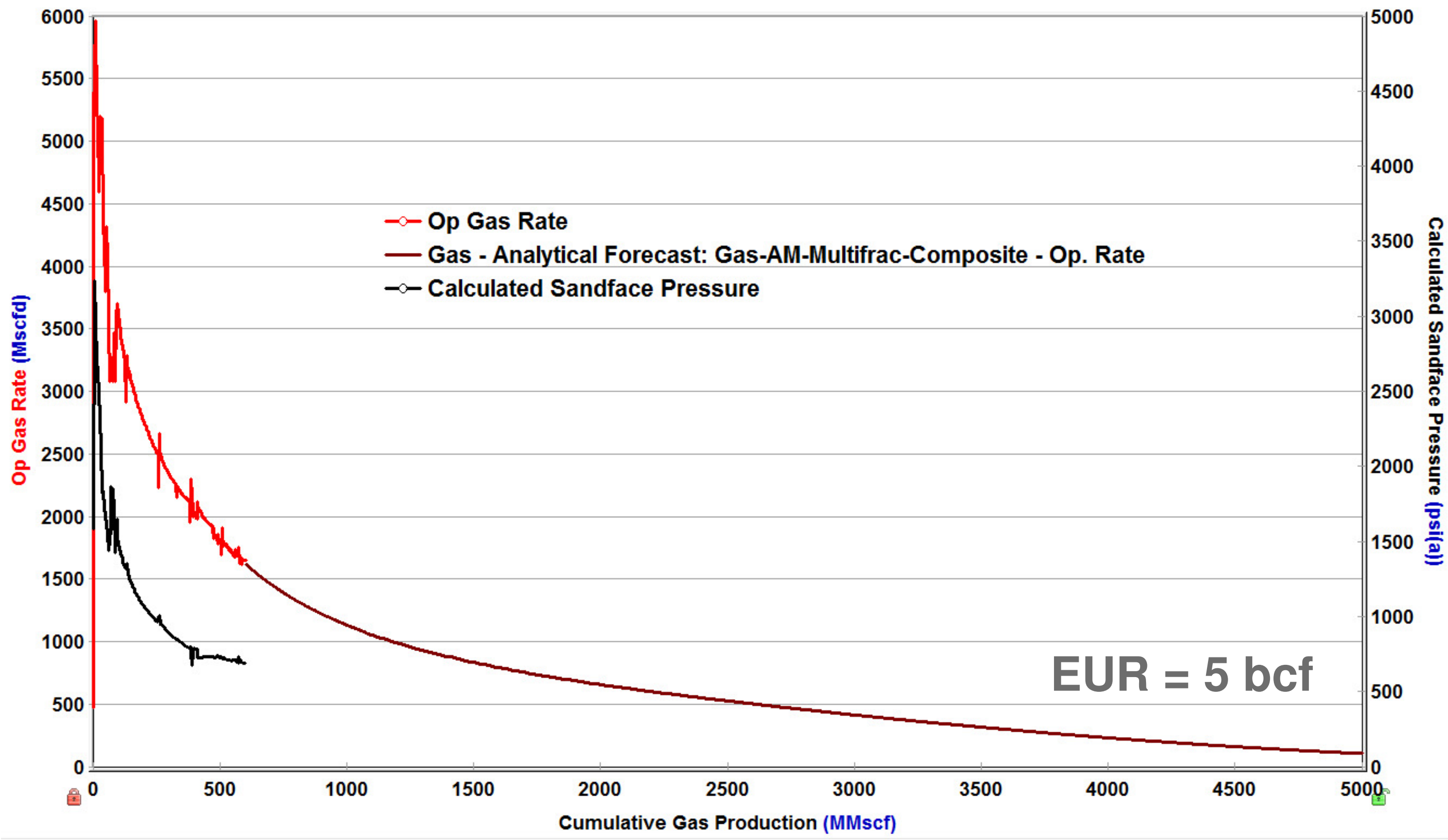


L_e = 3700 ft



The Forecast (85 acres)

One possible outcome



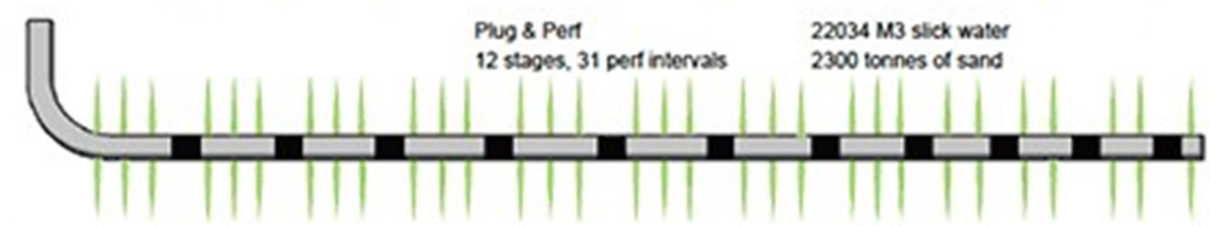
The Probabilistic Approach

Plot Type

- (●) Probability Density Function
- ( ) Cumulative Distribution Function
- ( ) Random Number Distribution

Number of runs: 500

[Run Simulation] [APE Options]



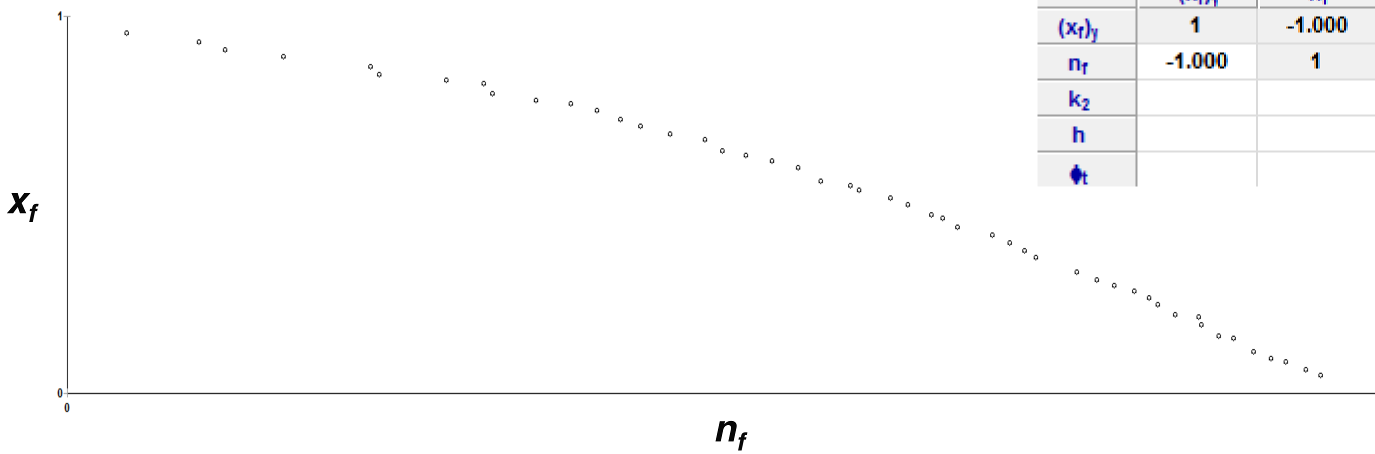
31 perf intervals … but how many fractures (n_f)?

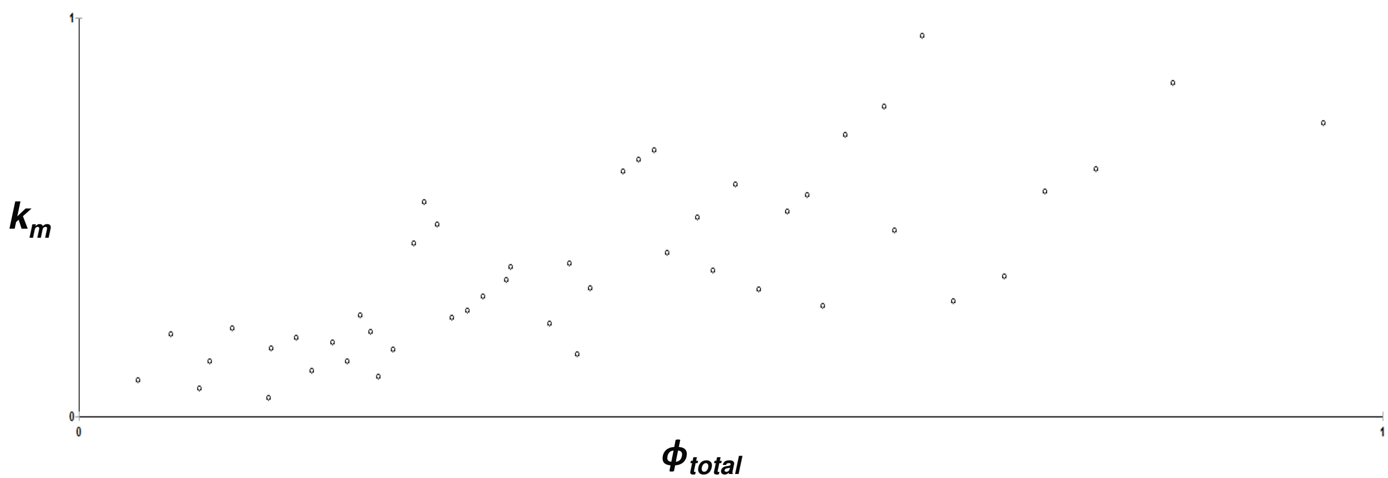
Parameter	Unit	Distribution	Distribution Parameters					
p_i	psi(a)	Constant	Constant	3924.00				
$(x_f)_y$	ft	Uniform	Min	150	Max	500		
F_{CD}		APE	Base	160.841				
n_f		Triangular	Min	24	Mode	31	Max	31
k_1	md	APE	Base	2.4089e-05				
k_2	md	Triangular	Min	1.0000e-05	Mode	2.5000e-05	Max	1.0000e-04
h	ft	Triangular	Min	145.0	Mode	150.0	Max	170.0
ϕ_t	%	Triangular	Min	7.00	Mode	7.10	Max	7.50
S_g	%	Triangular	Min	65.00	Mode	66.00	Max	70.00
S_o	%	Constant	Constant	0.00				
S_w	%	Dependent						
c_f	1/psi	Constant	Constant	5.6049e-06				
L_{ex}	ft	Constant	Constant	3700.0				
Y_e	ft	Triangular	Min	900.0	Mode	1000.0	Max	1200.0
p_{wf}	psi(a)	Constant	Constant	675.00				
V_{LS}	scf/ton	Constant	Constant	50				
P_{LS}	psi(a)	Constant	Constant	405.00				
ρ_b	g/cm^3	Constant	Constant	2.60				

IHS has acquired Fekete

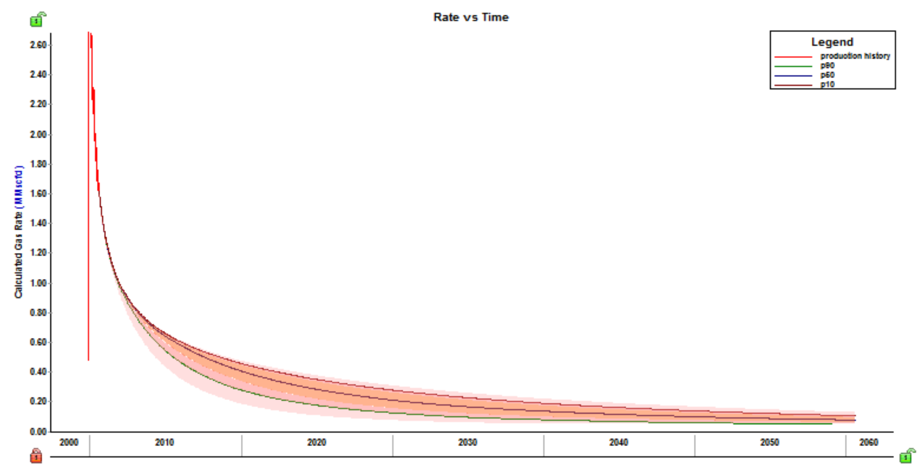
Modeling Dependency

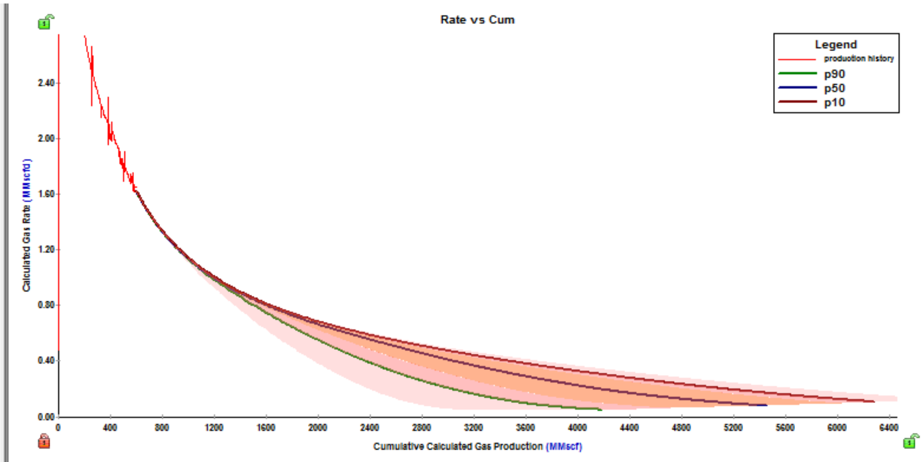
	$(x_f)_y$	n_f	k_2	h	ϕ_t
$(x_f)_y$	1	-1.000			
n_f	-1.000	1			
k_2			1		0.800
h				1	
ϕ_t			0.800		1





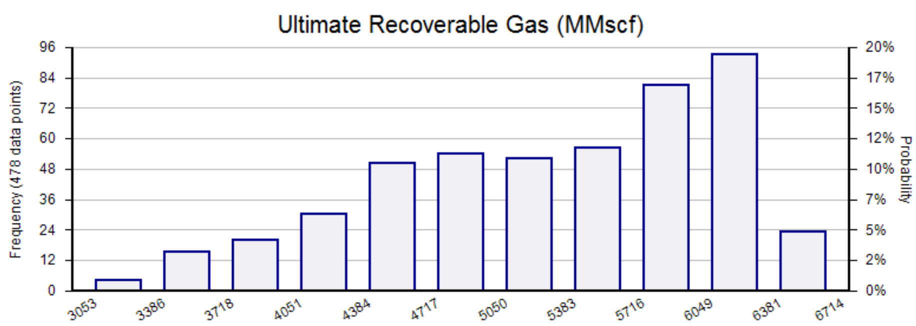
Probabilistic Model Results





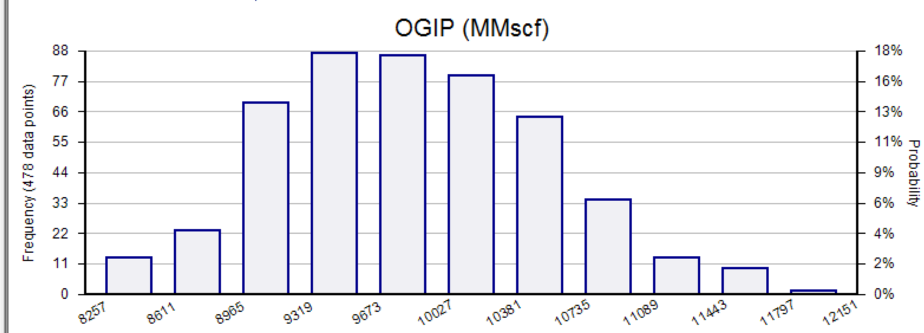
Summary of statistics

Mean: 5329 MMscf
Std Dev: 818 MMscf
p10: 6284 MMscf
p50: 5454 MMscf
p90: 4185 MMscf

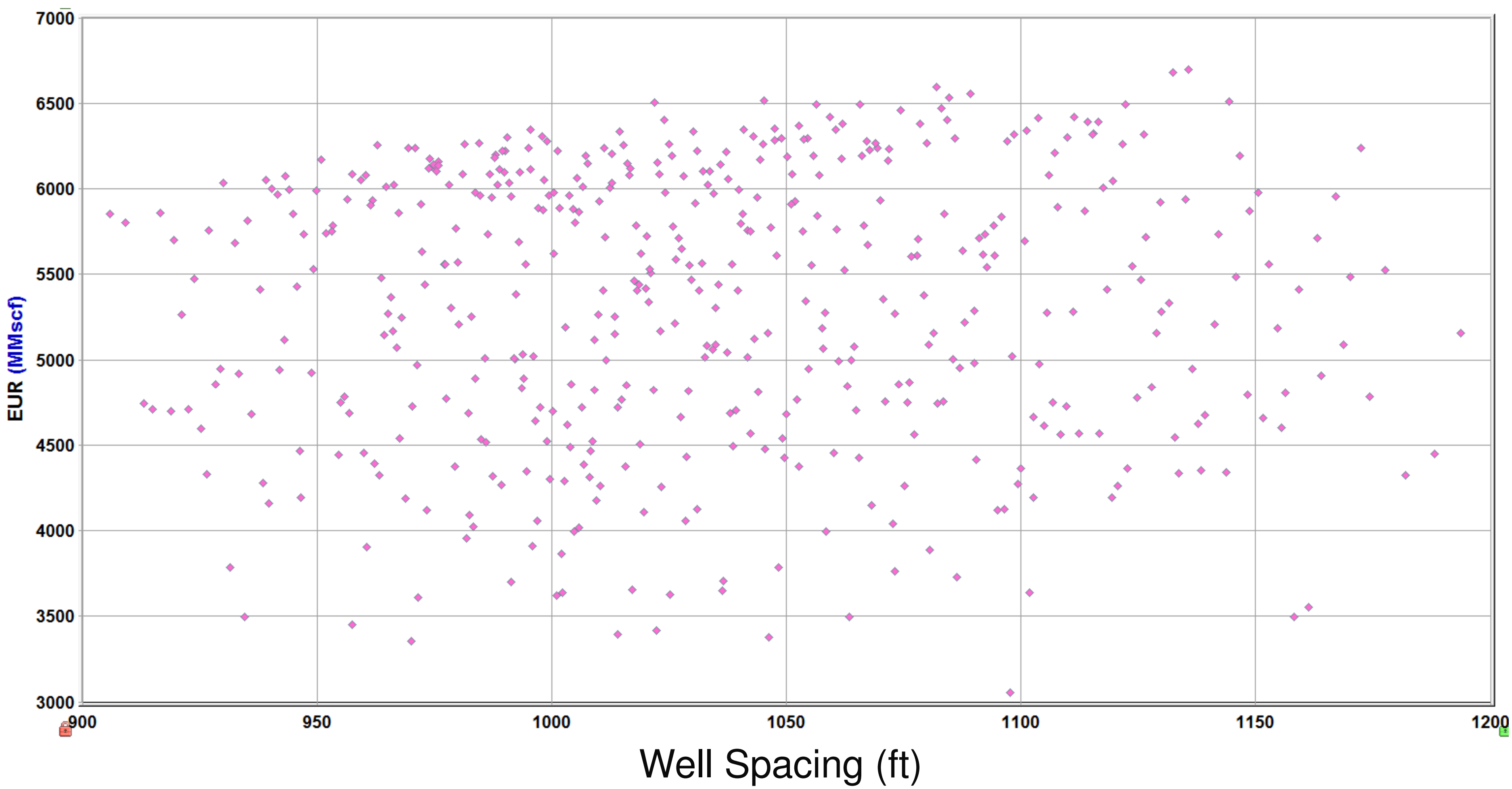


Summary of statistics

Mean: 9898 MMscf
Std Dev: 694 MMscf
p10: 10779 MMscf
p50: 9883 MMscf
p90: 9037 MMscf



The Sensitivity – A Cross Plot



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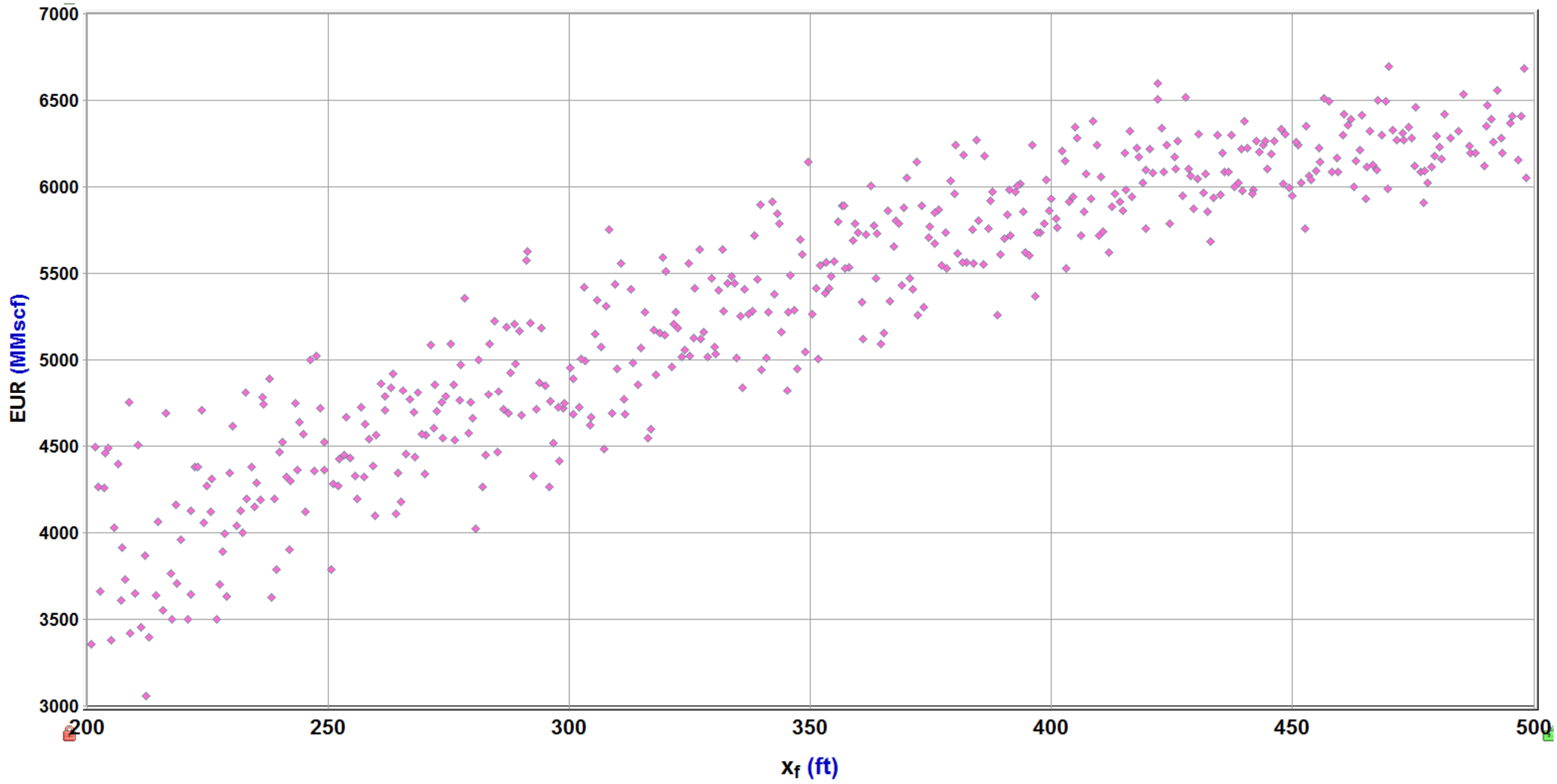
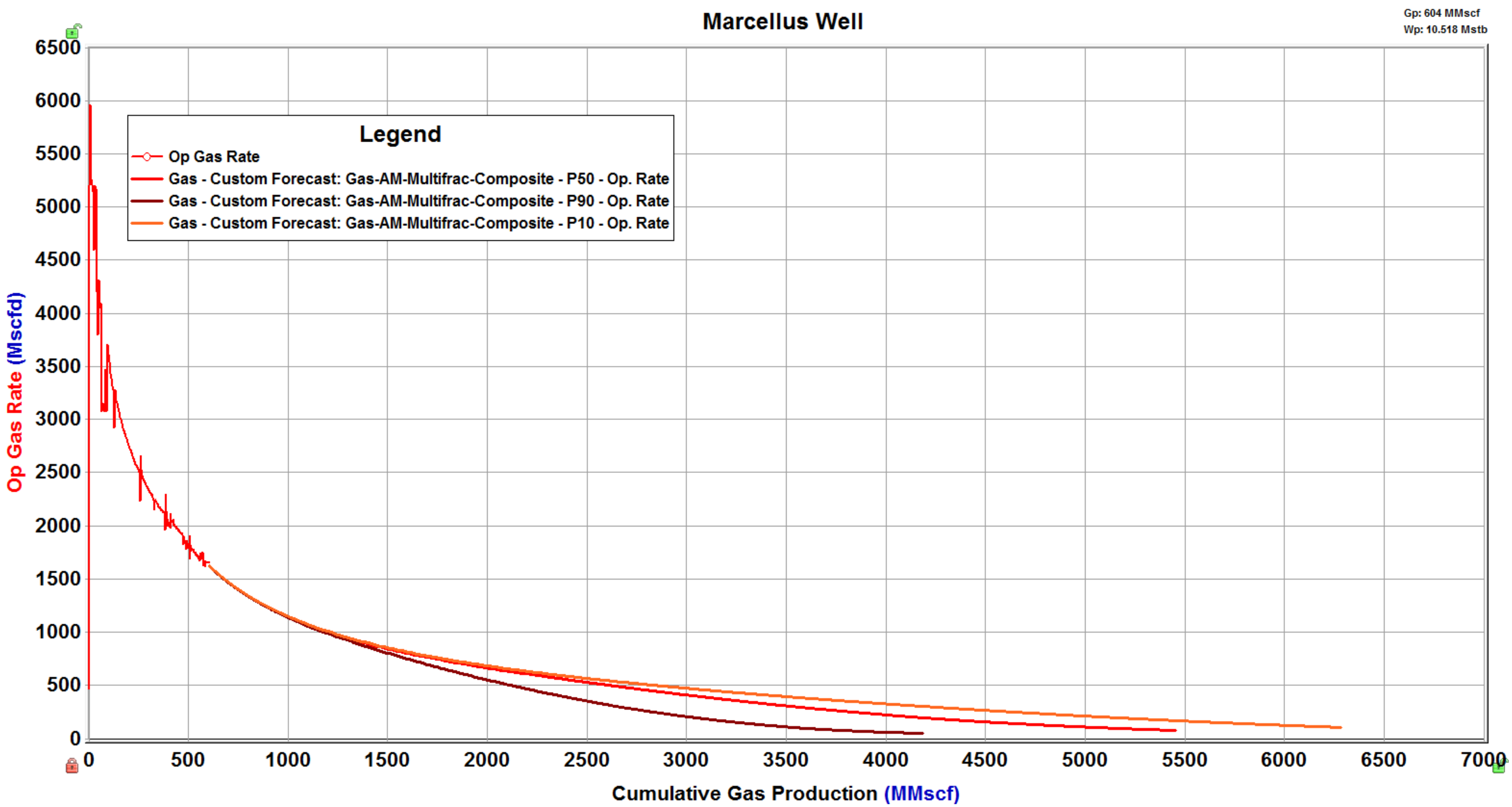
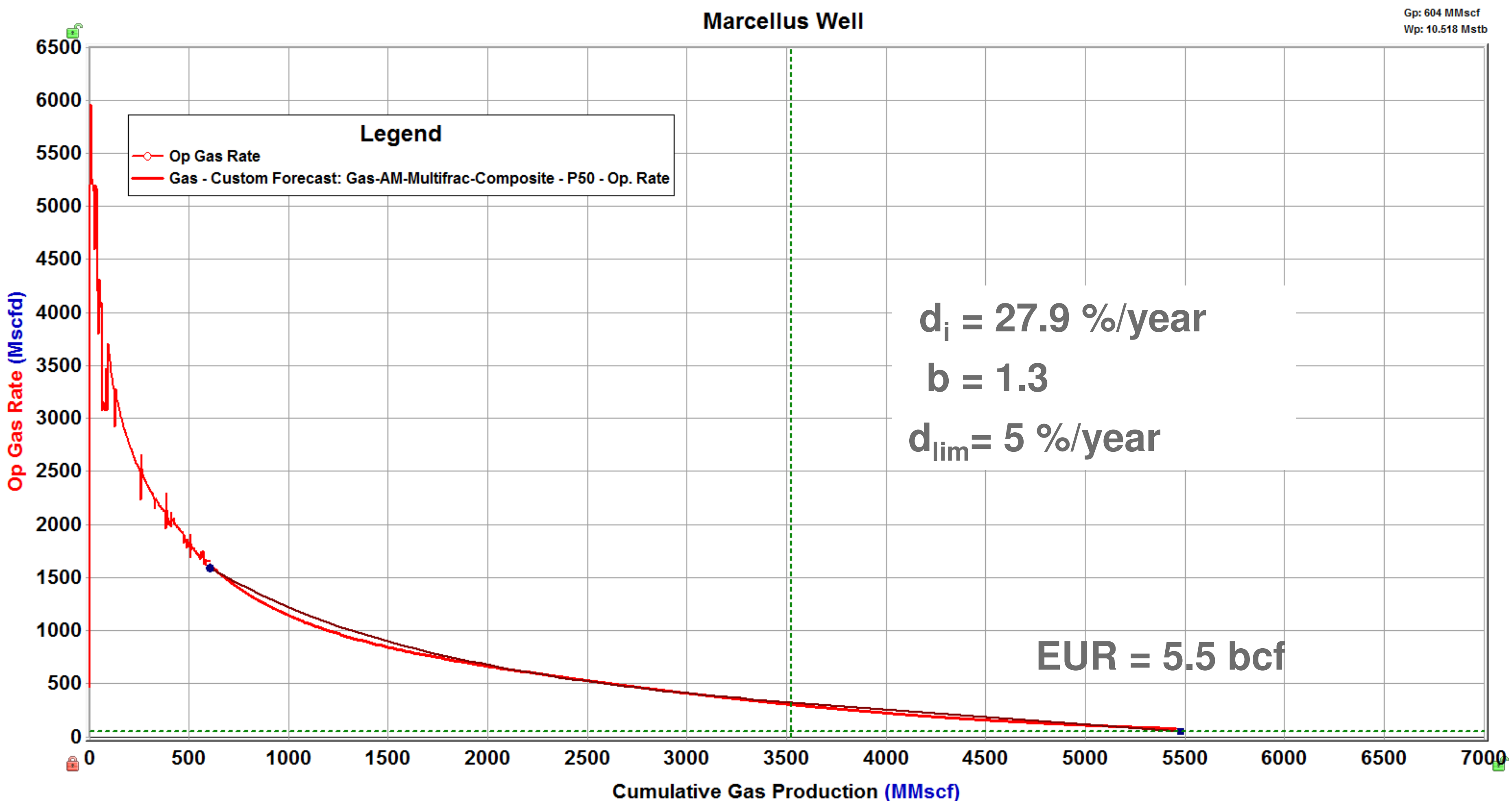


P90-P50-P10 Forecasts



DCA parameters for P50



Summary

- Reliable, early evaluation of tight, fractured reservoirs is difficult
- A new probabilistic approach to RTA is presented
- Provides true P90/P50/P10 defensible forecasts
- Systematic and repeatable
- Requires minimal external knowledge, based on lower and upper bounds for parameter inputs
- Honors established production trend
- Methodology will continue to be validated using field examples


Questions?