Forecasting Production in Shale Gas Reservoirs- A Better Assessment of Reserves

Occidental Petroleum Corporation ■ GCS Reservoir Study Group■ Anadarko Petroleum Convention Center ■
10th May ■ Krunal Joshi, Reservoir Engineer

Disclaimer

This presentation in no way represents or bears upon the Reserves process of Oxy or any of its subsidiaries

Outline

- Problem
- Deterministic forecasting models
- Fixes to the Duong method
- Comparison of deterministic forecasting models for Individual wells
- Comparison of deterministic forecasting models for grouped well sets
- Conclusions

We Have a Problem

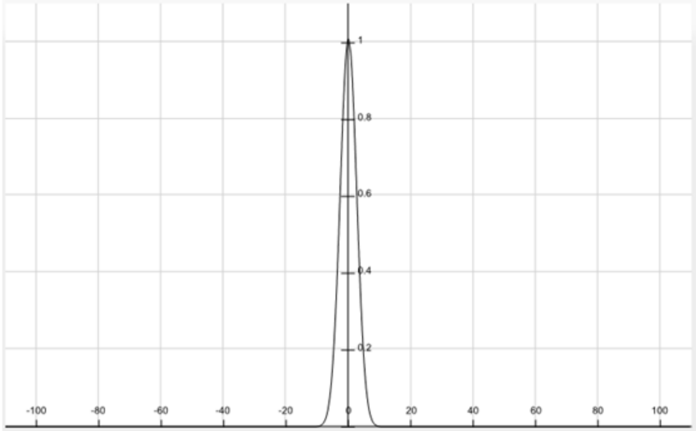
- Forecasting methods we use in conventional reservoirs may not work well in
  - Tight oil, gas
  - Oil, gas shales
  - Unconventional resources generally

- There have been various methods proposed

Criteria for Ideal Decline Model in Ultra-Tight Reservoirs

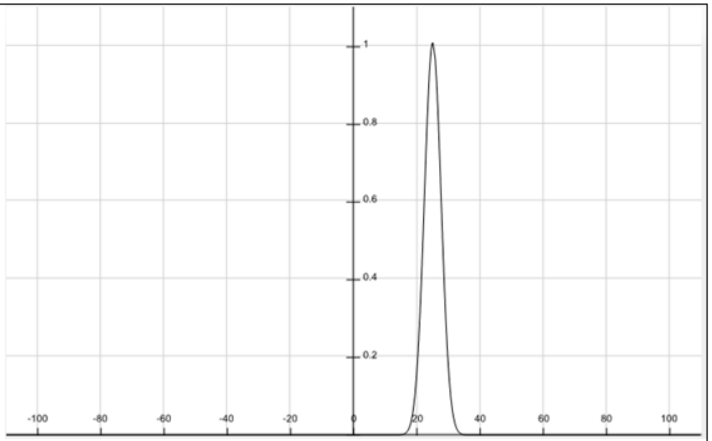
- Forecasts are reasonable and realistic for the well life
- Forecasts reasonable even with <2 years historical production data
- Valid during transient or radial flow
- Valid for boundary-dominated flow
- Easy to use and couple with economics software

A Superior Model Has Higher Accuracy and Precision For a Large Number of Wells



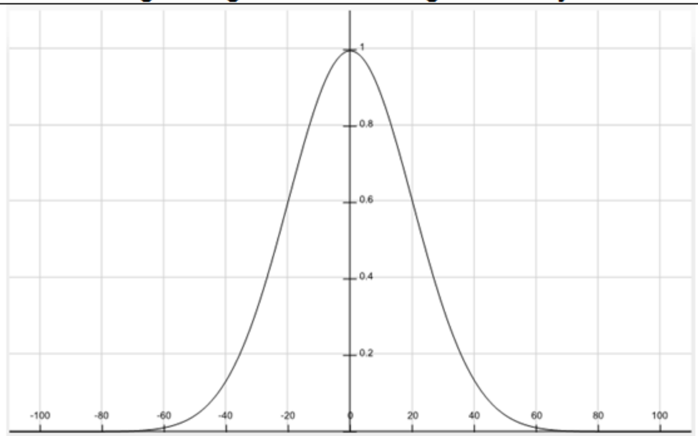
% Error in Reserves

Fig.6a- High Precision & High Accuracy



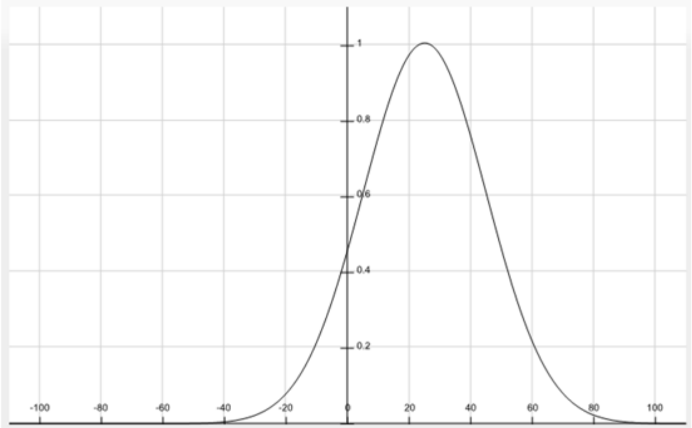
% Error in Reserves

Fig.6b- High Precision but Low Accuracy



% Error in Reserves

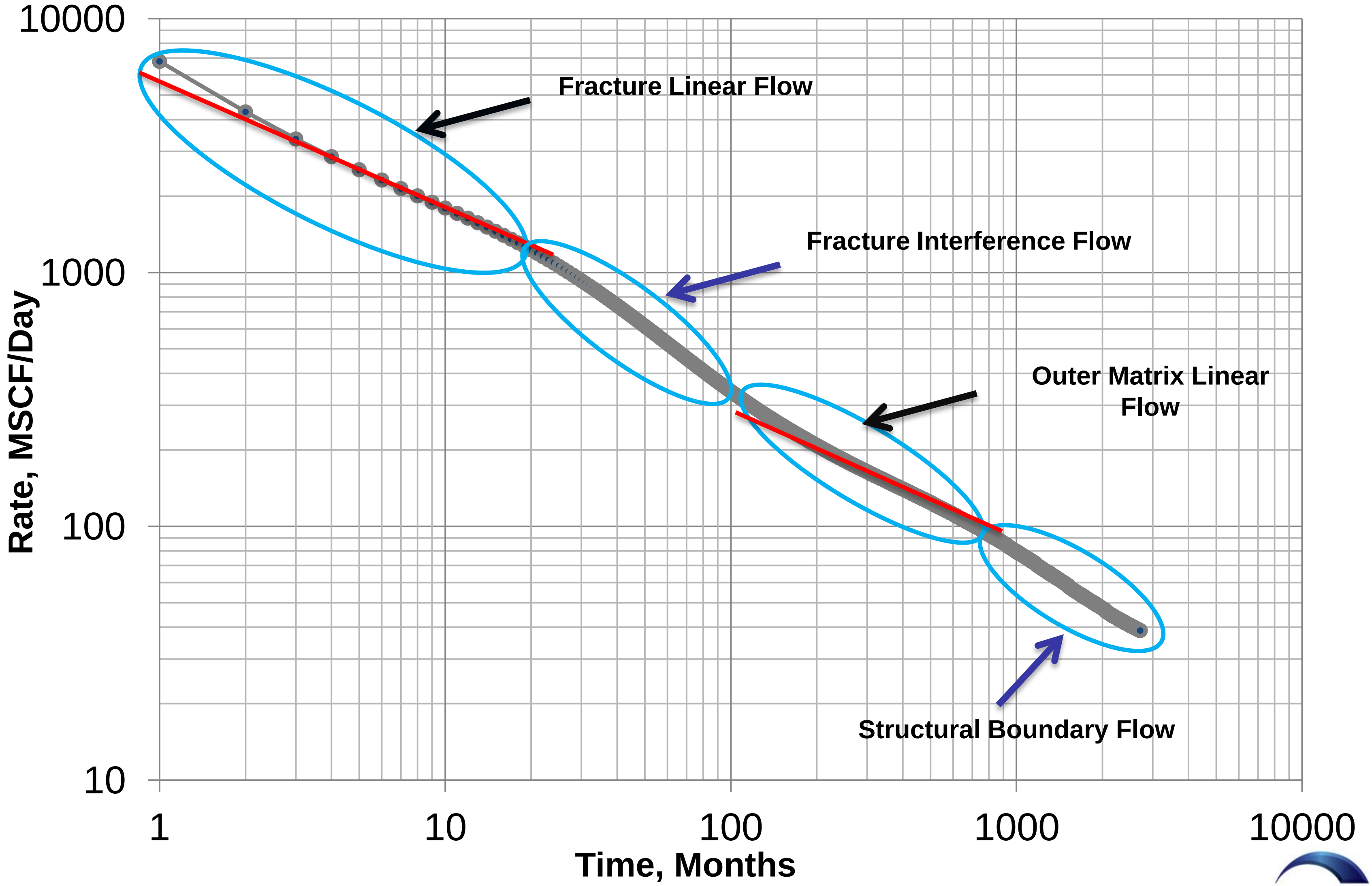
Fig.6c- Low Precision & High Accuracy



% Error in Reserves

Fig.6d- Low Precision & Low Accuracy

Long-Term Horizontal Shale Gas Well Simulation: Linear Flow Plot



Forecasting Models

- Arps(Minimum Decline): Hyperbolic decline followed by exponential decline after a predetermined decline rate. (Arps,1945 & Long,1988)

- Duong Model: A decline model based on long-term flow regime approximating linear flow: $\frac{q}{G_p} = at^{-m}$ (Duong,2010)
  - Modified Duong : With a Dswitch of 5% followed by a Arps curve of b=0.4

- SEDM/SEPD Model: A decline model that is a summation of simultaneous exponential declines in different 'cells' within a reservoir. (Valko et.al,2009)

$$q = q_i \exp\left[-\left(\frac{t}{\tau}\right)^n\right]$$

Arps (Minimum Decline)

- Best-fit "*b*" until predetermined minimum decline rate reached; then impose exponential decline (SPE 16237)

$$q = q_i \frac{1}{(1 + bD_i t)^{(1/b)}}$$

- Problems
  - Apparent "best" *b* decreases continually with time
  - Appropriate minimum decline rate based on observed long-term behavior in appropriate analogy – unavailable in new resource plays

SEPD/SEDM Model

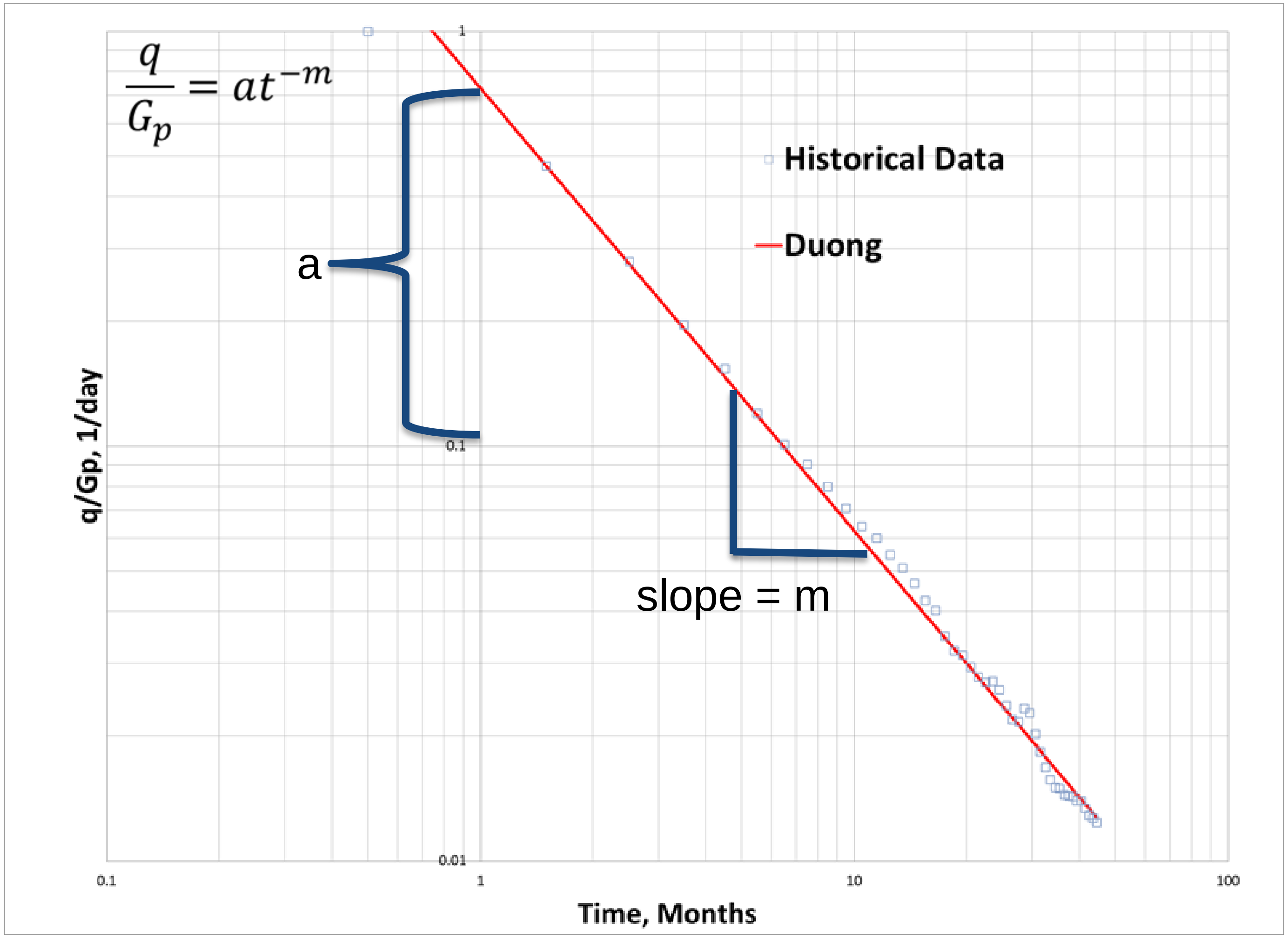
$$q = q_i \exp\left[-\left(\frac{t}{\tau} \right)^n \right]$$

- ‘Validated’ for wells with both transient and stabilized flow in Barnett Shale
- Forecasts unreliable for <18 months of data
- n varies from 0.1 to 1 (exponential decline)
- Practical τ range is 0.01 to 80

Duong Model

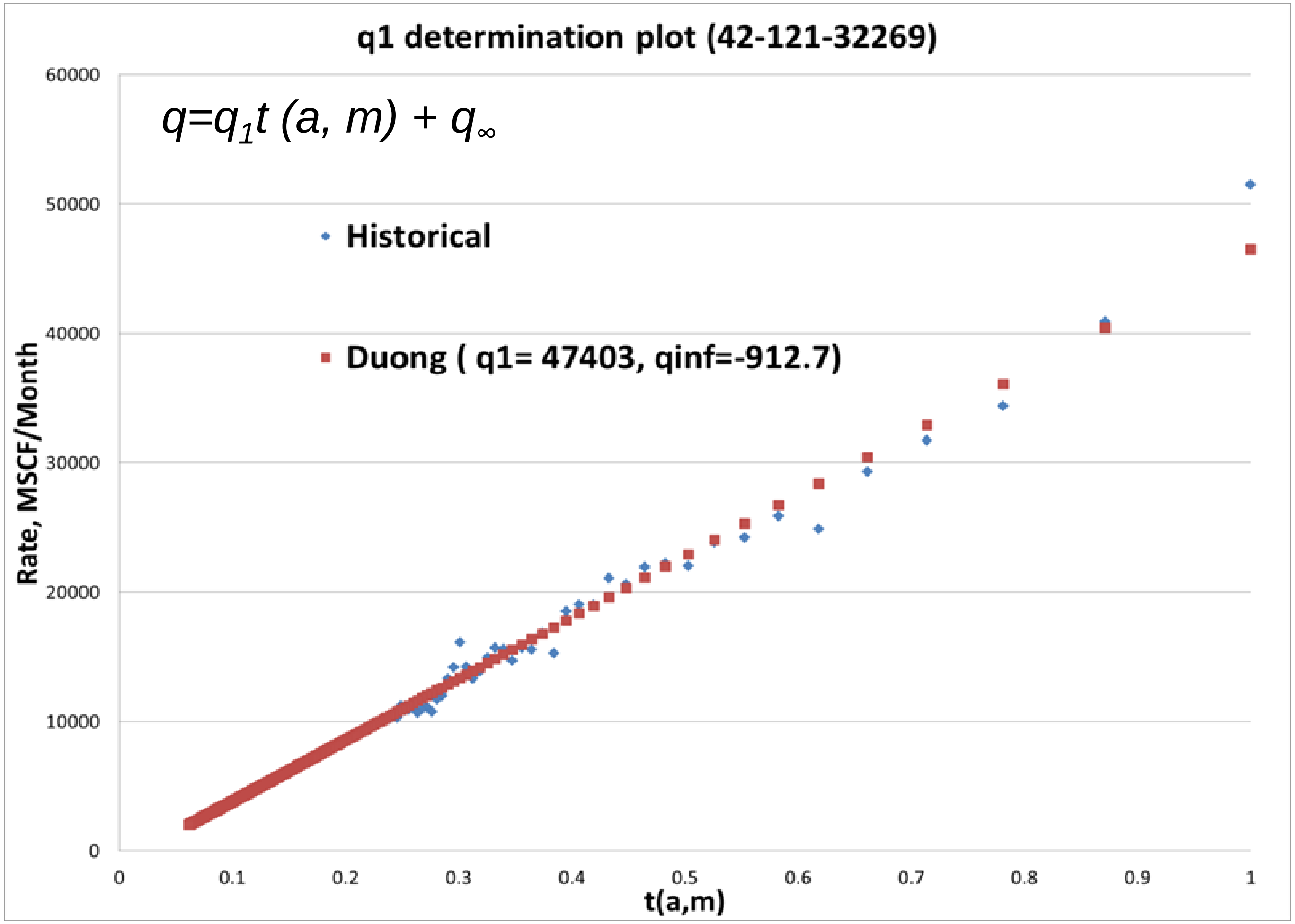
- Based on Long-term linear flow
- $\frac{q}{G_p} = at^{-m}$
- $q = q_1 t(a, m) + q_\infty$
- $t(a, m) = t^{-m} e^{\frac{a}{1-m}(t^{1-m}-1)}$

Determination of a & m (Duong)



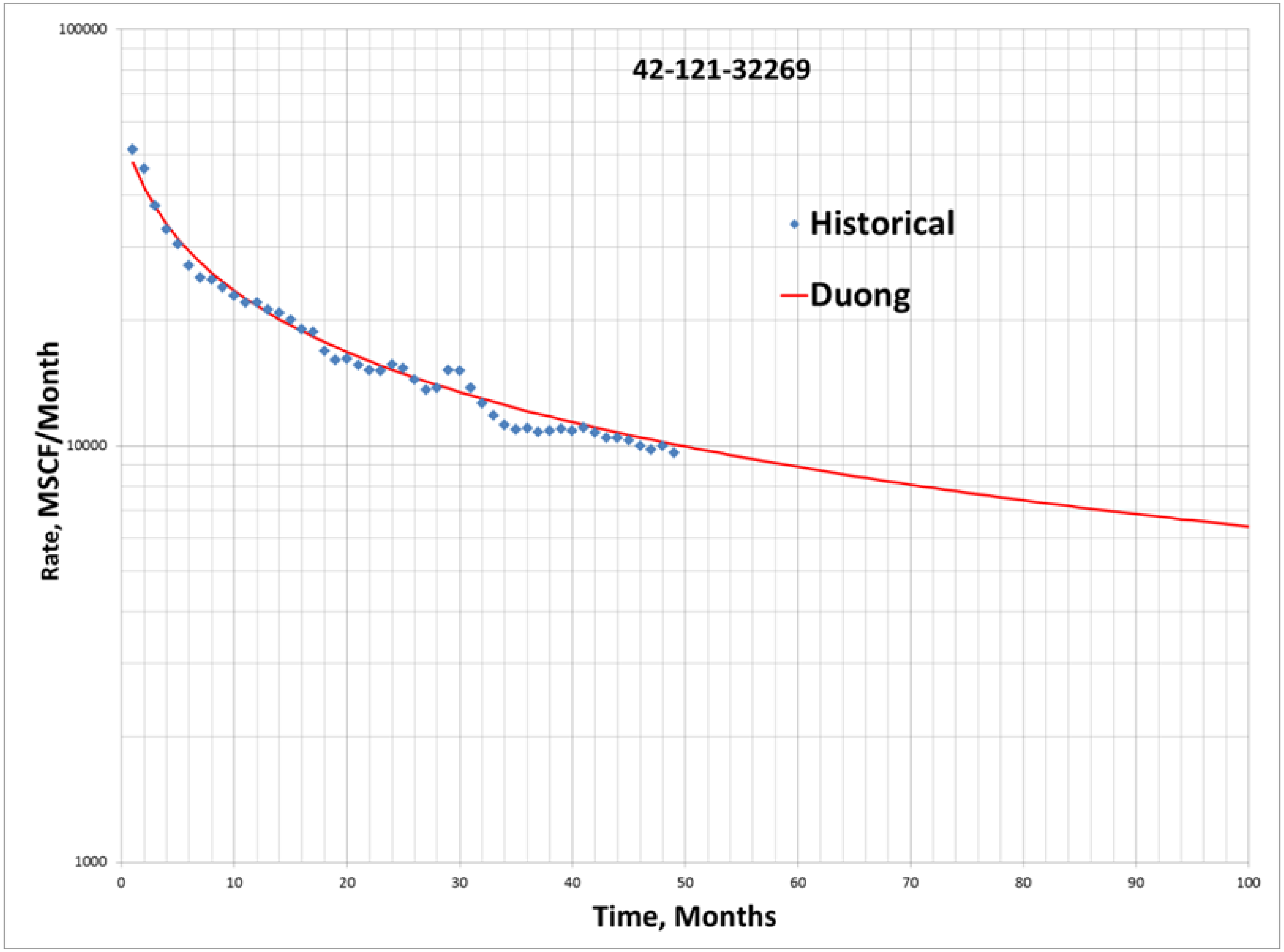
a=0.731 , m=1.067

Determination of q1 & q_∞ (or q_{inf})



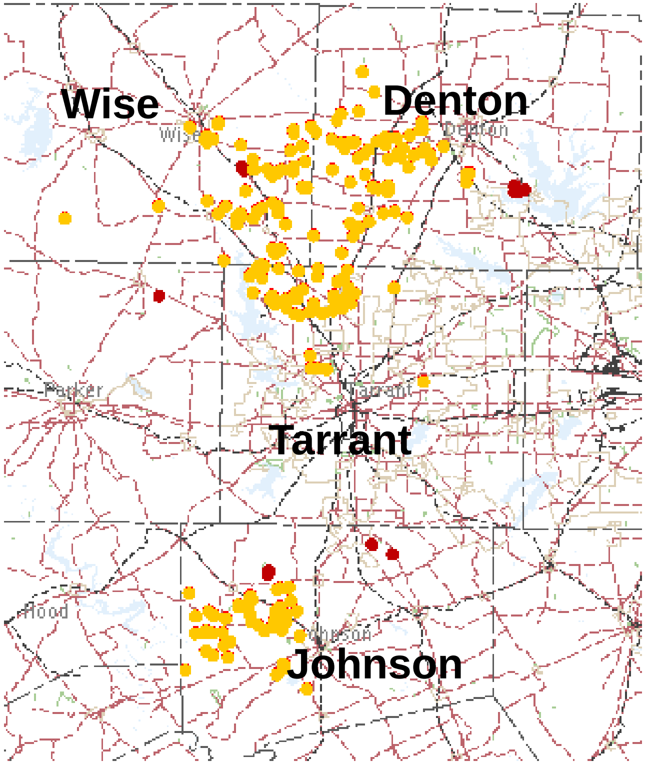
qinf or q_∞ is the x-intercept on the above plot

Duong Forecast



Field Data Set

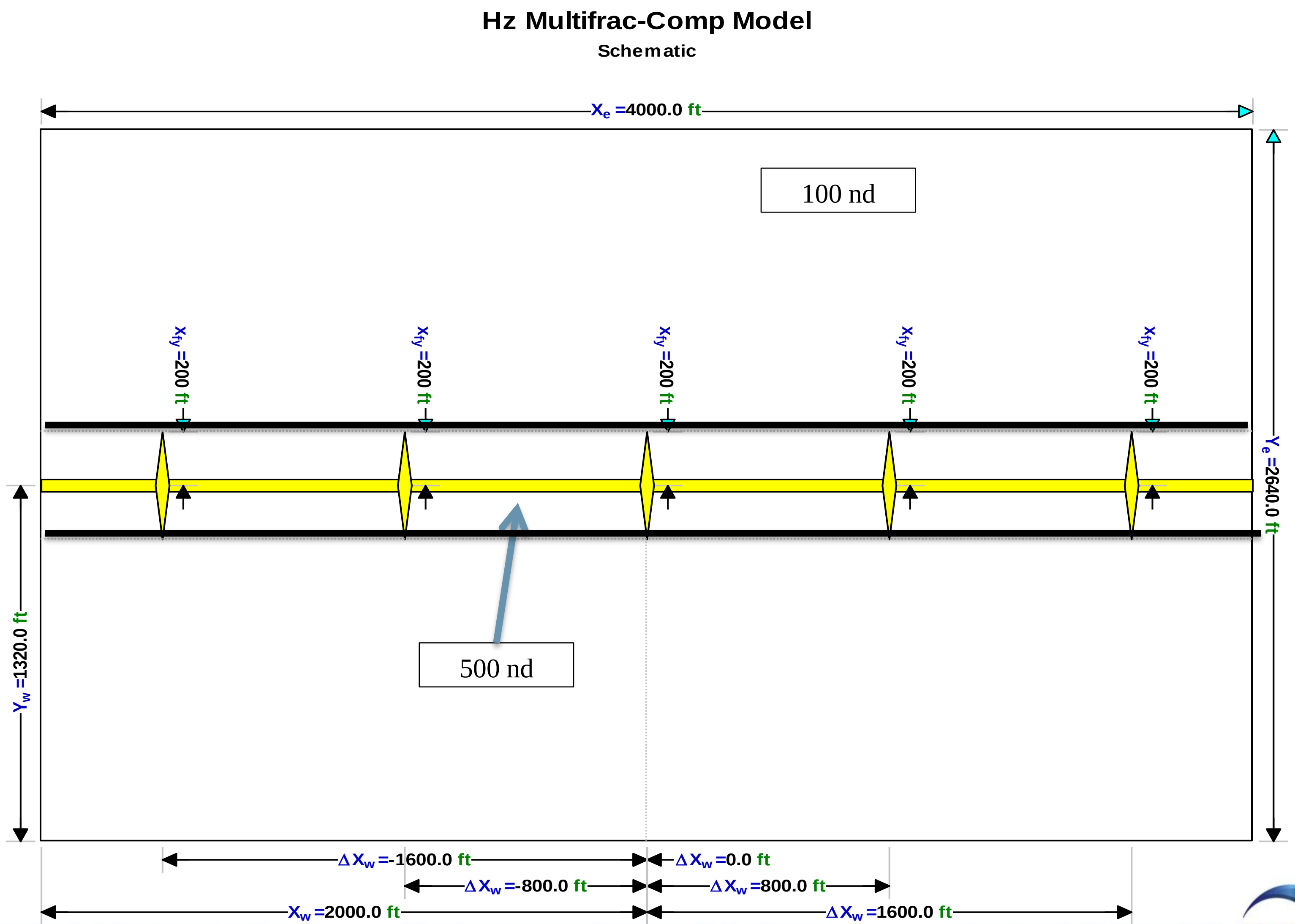
- 250 Well Dataset
  - Barnett Shale (200wells)
    - Denton
    - Tarrant
    - Wise
    - Johnson
  - Fayetteville Shale (50 wells)
    - Van Buuren
  - Drilling Info
  - Horizontal Wells
  - Monthly Rate Data
- 1st production starts 1/1/2004
- Range of total production: 30 to 85 months



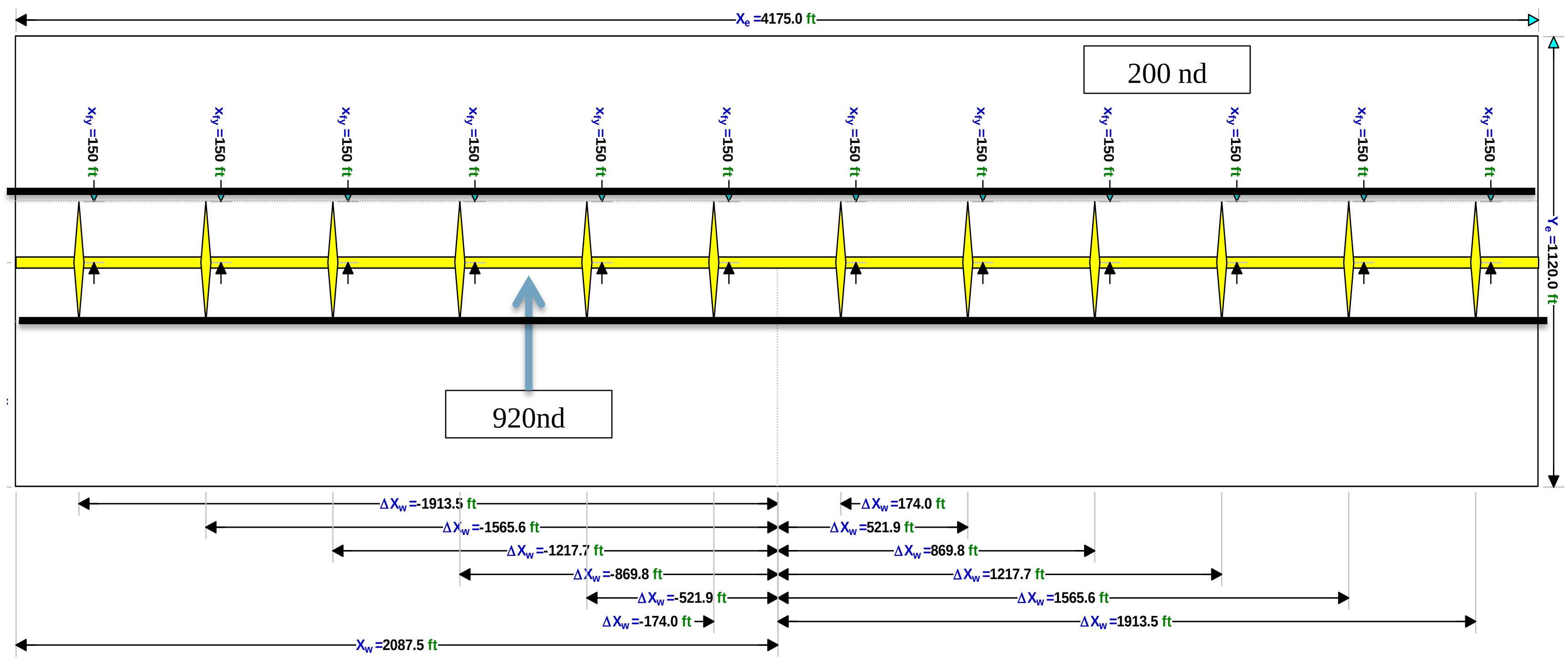
Simulated Data Set

- Composite Model
  - Analytical Simulator (Fekete WellTest)
  - SRV permeability different from Outer Matrix permeability
- Barnett (25 simulations)
  - 133874(Chong et al. 2010), 146876(Cipolla et al. 2011), 144357(Strickland et al. 2011), 96917(Frantz et al. 2005), 125530(Cipolla et al. 2010) and147603(Ehlig-Economides and Economides 2011)
- Marcellus (25 simulations)
  - 133874(Chong et al. 2010), 125530(Cipolla et al. 2010), 144436 (Thompson et al. 2011) and 147603(Ehlig-Economides and Economides 2011).
- Properties Varied:
  - Fracture stages, fracture length and fracture conductivity.
  - Stimulated Reservoir Volume (SRV) permeability
  - In accordance with the ranges in the above papers

Barnett Shale Simulation (Base Case)



Marcellus Shale Simulation (Base Case)

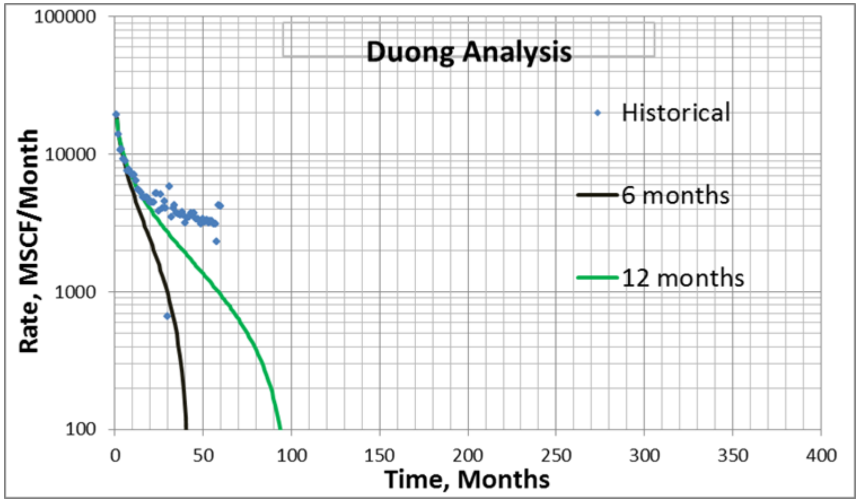


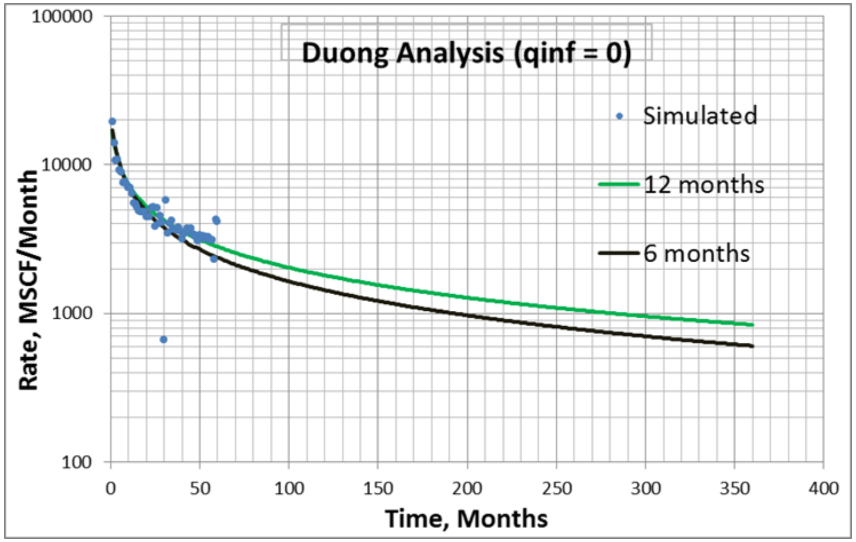
Fixes to the Duong Model

- Use of qinf
  - Not suggested for short term data.
  - Debatable for long-term data
  - Simulated data can solve the conundrum of whether qinf is necessary or not.

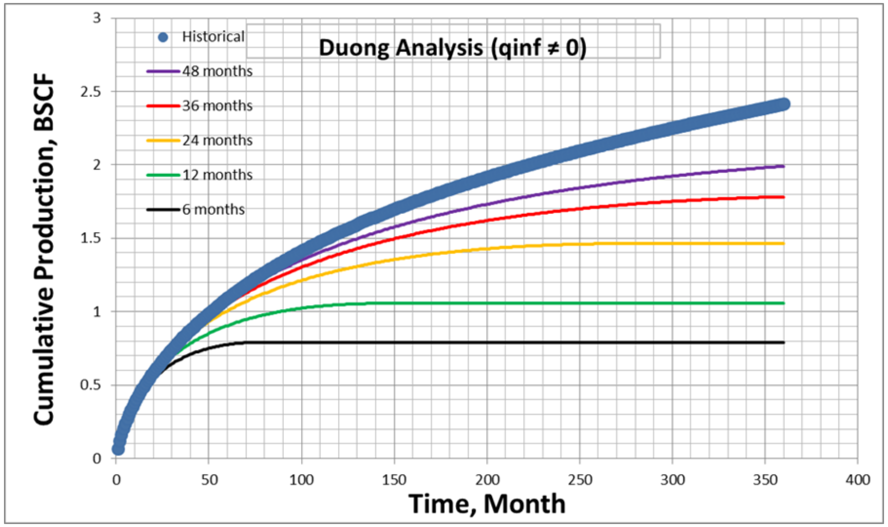
- Modified Duong
  - Accounts for fracture interference
  - Dswitch of 5%, i.e. when decline rate reaches 5%, forecast switches to Arps

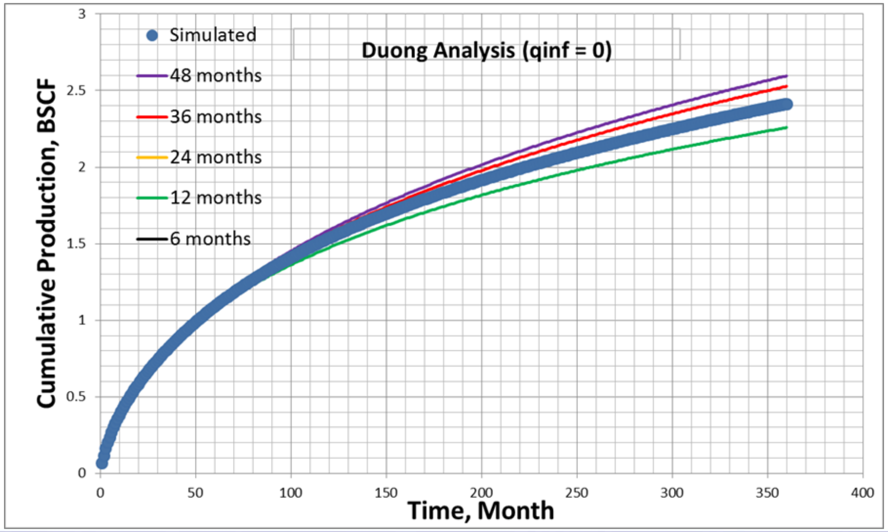
Using qinf Does Not Work For Short Term Field Production Data



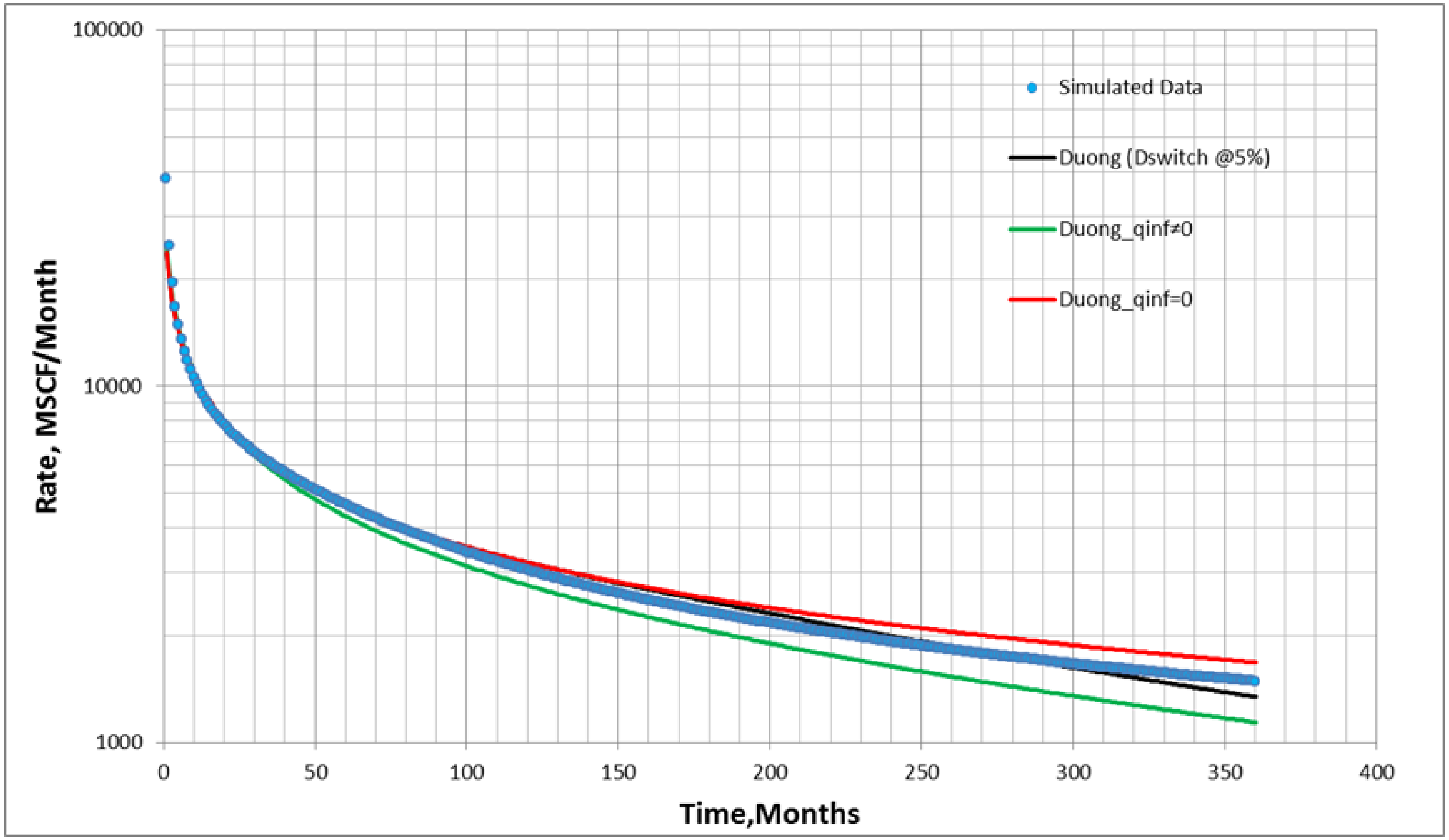


Using q_∞ For Simulated Production Data Does Not Work Well





Modified Duong (Dswitch @5%) Works Better Than the Original Duong

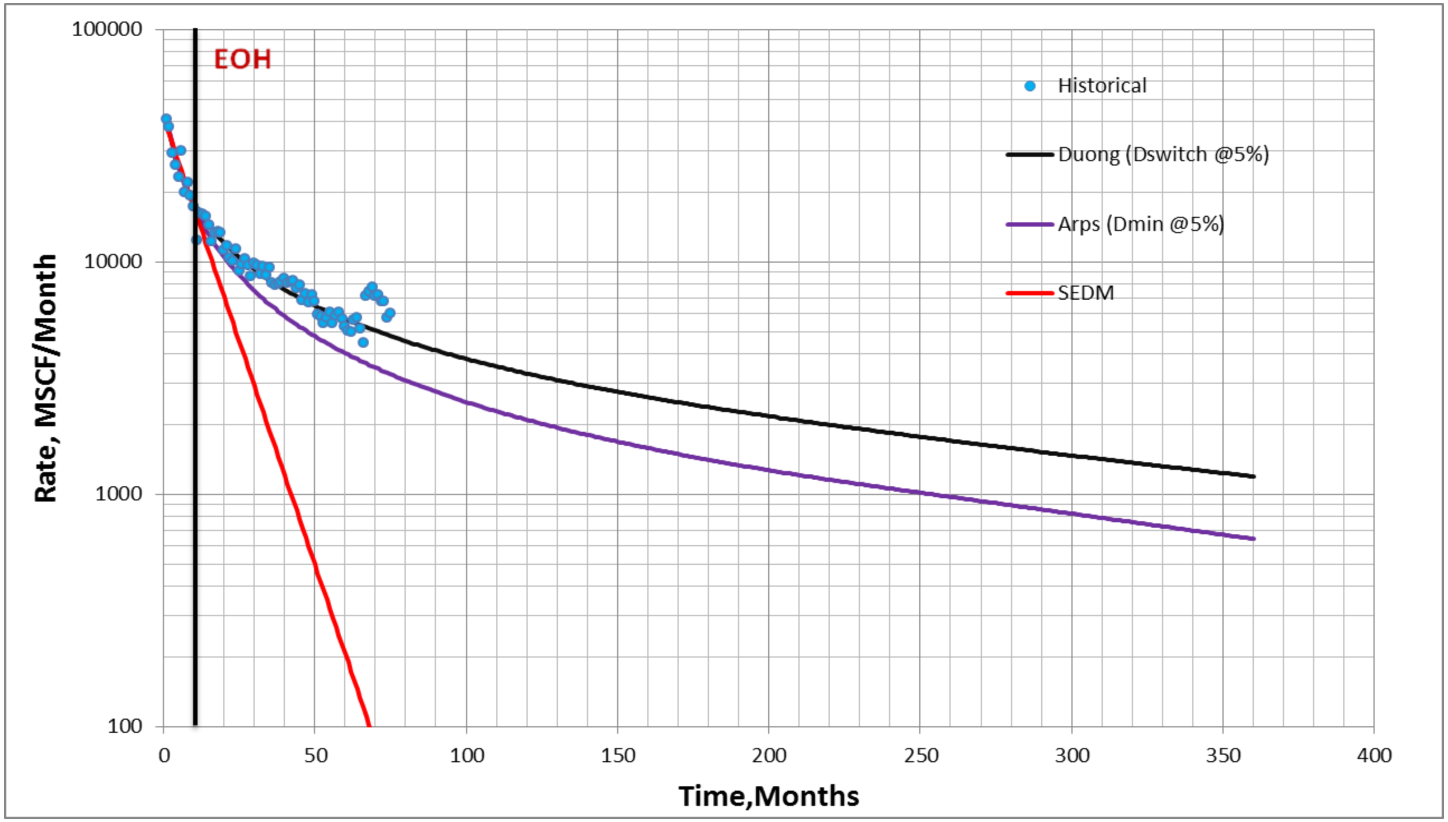


Individual Well Field Production Data

Comparison of The Modified Duong, SEDM and Arps For a Field Data Set

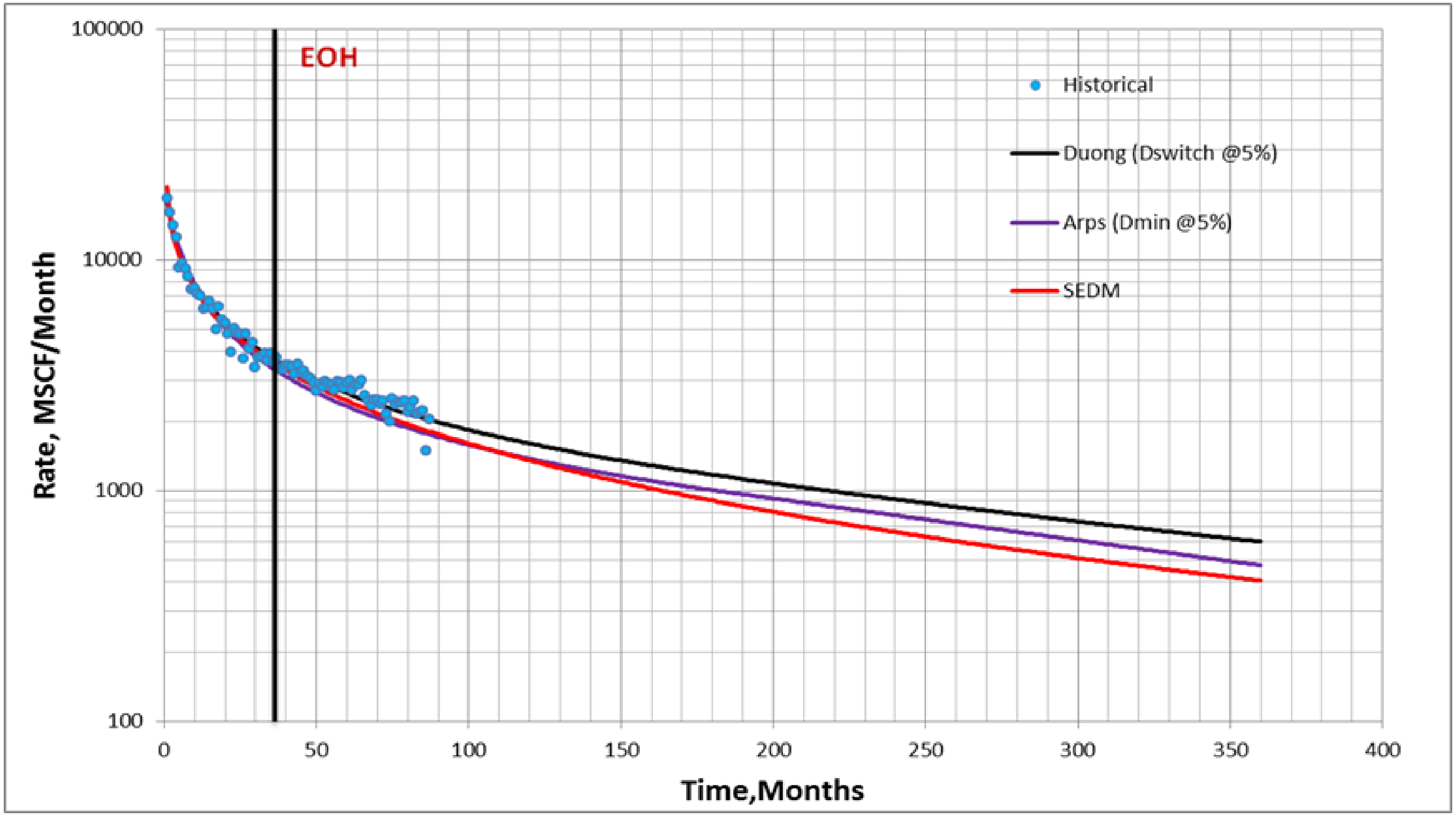
Discrepancy (error%) in remaining production for a field dataset				
History Matched		Duong_Dswitch@5%	SEDM	Arps (Dmin 5%)
6	Mean	-15.98	40.91	10.97
	Std.Dev	29.24	39.06	33.16
	% Wells <15 % error	45.60	22.00	43.20
12	Mean	-7.77	6.44	5.04
	Std.Dev	17.48	27.75	22.57
	% Wells <15% error	66.80	48.40	63.20
18	Mean	-6.90	5.06	3.03
	Std.Dev	14.41	21.90	19.01
	% Wells <15 % error	71.60	59.20	69.20
24	Mean	-2.49	4.49	2.21
	Std.Dev	16.13	20.51	18.92
	% Wells <15 % error	72.80	64.40	71.60
36	Mean	-5.04	4.41	2.77
	Std.Dev	17.88	21.93	22.54
	% Wells <15 % error	71.93	64.91	68.86
48	Mean	-5.45	1.63	-0.05
	Std.Dev	18.08	27.12	26.99
	% Wells <15 % error	77.16	69.04	77.66

How Well Do Different Models Forecast With Short Term Data ?



Comparison of various empirical models for API# 42-121-32245, matching 12 months of historical data.

How Well Do Different Empirical Models Forecast With Long Term Data ?



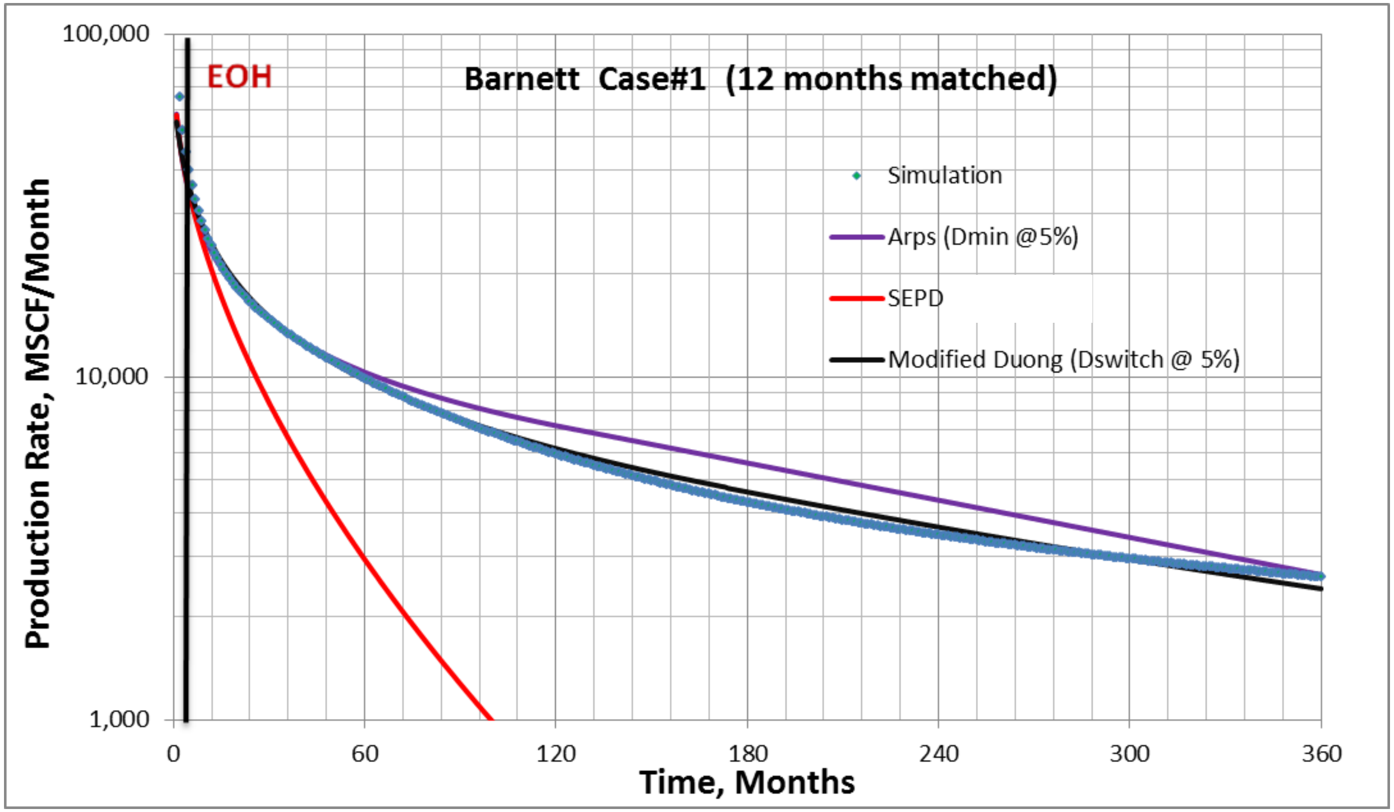
Comparison of various empirical models for API# 42-497-35453, matching 36 months of historical data.

Individual Well Simulated Data

Discrepancy (% error) in Remaining Production For the 3 Empirical Methods on Simulated Wells

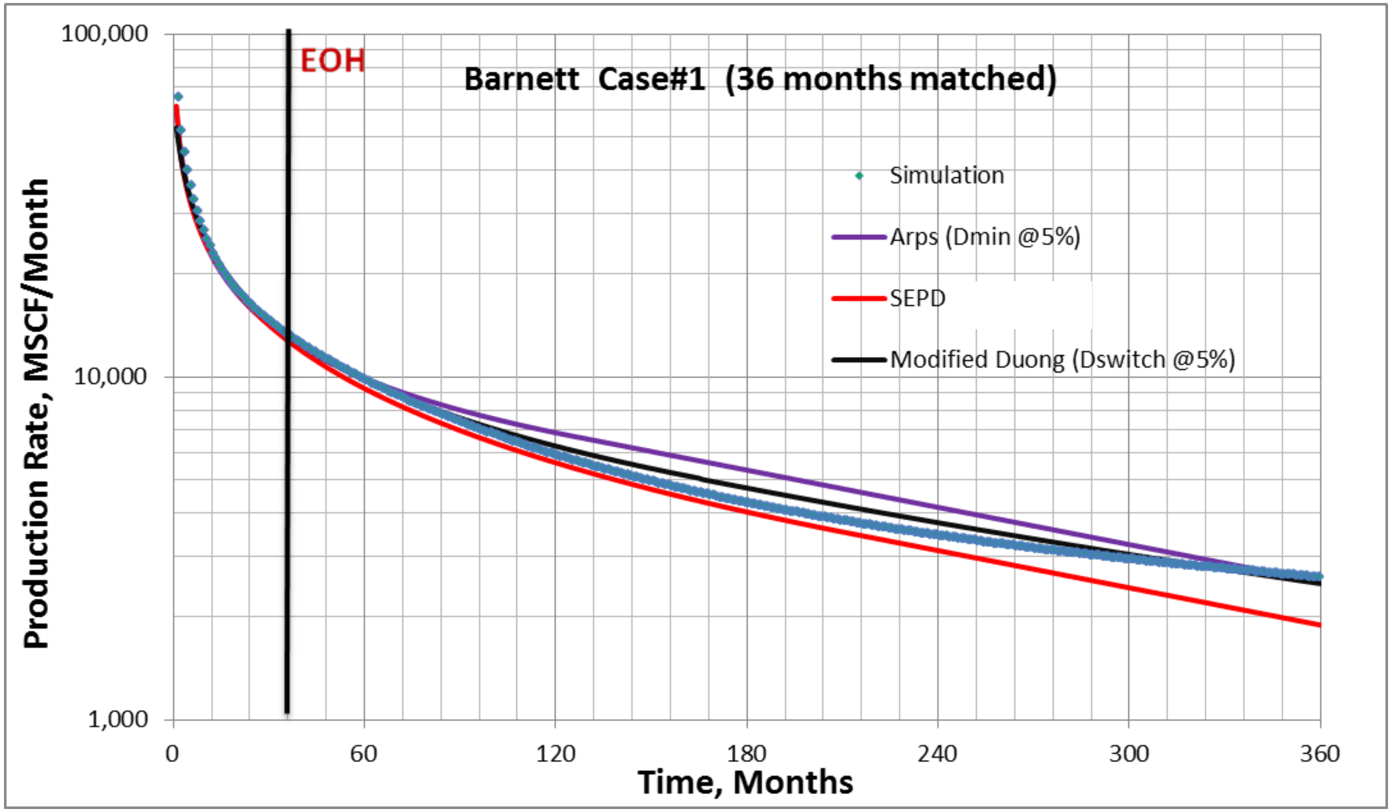
	Discrepancy (Error %) in remaining production			
History Matched		Duong_qinf=0 (Dswitch @5%)	Arps (Dmin @ 5%)	SEPD
6	Mean	22.23	-12.38	38.62
	Std.Dev	19.56	19.80	14.39
12	Mean	5.55	-15.17	22.37
	Std.Dev	17.43	20.98	17.96
18	Mean	-4.33	-18.27	21.40
	Std.Dev	16.09	21.16	19.36
24	Mean	1.00	-18.64	14.96
	Std.Dev	13.10	18.47	18.31
36	Mean	-13.97	-16.79	10.32
	Std.Dev	9.84	13.31	16.24
48	Mean	-13.88	-13.75	10.41
	Std.Dev	7.99	10.81	18.72

How Well Do Different Models Forecast With Short Term Data ?



A Barnett Shale simulation matching 12 months of history

How Well Do Different Empirical Models Forecast With Long Term Data ?

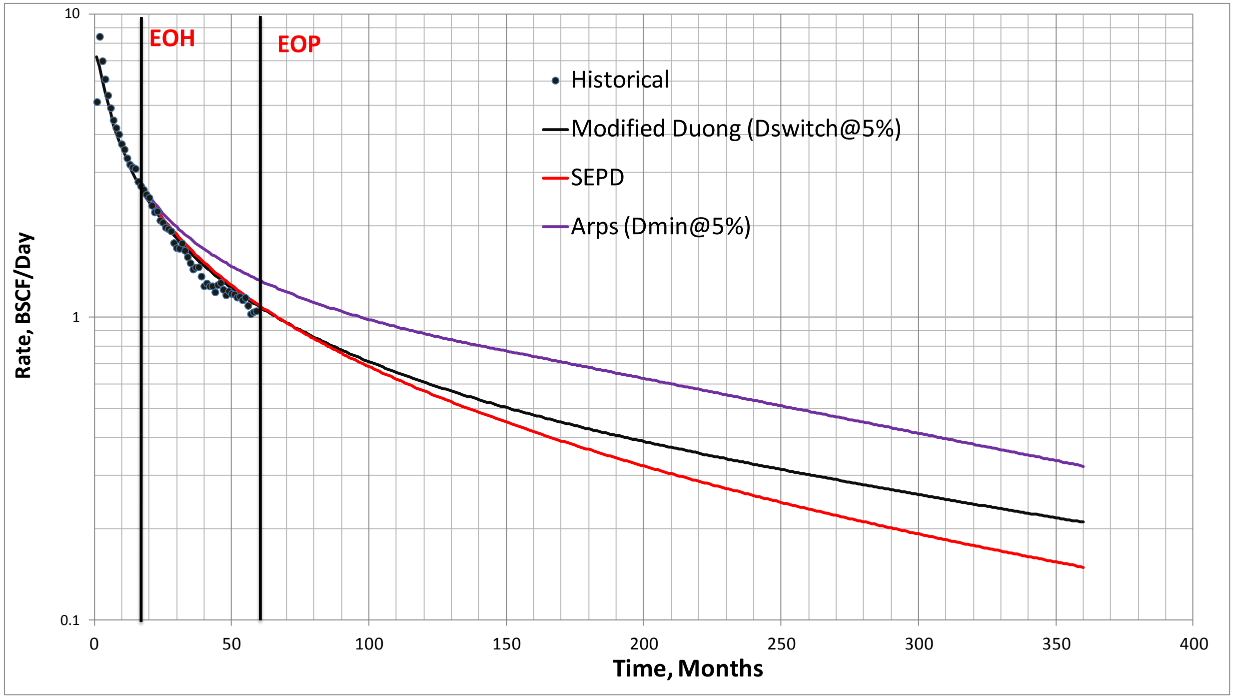


A Barnett Shale simulation matching 36 months of history

Field Grouped Data Sets

How Well Do Different Models Forecast For Short Term Grouped Data ?

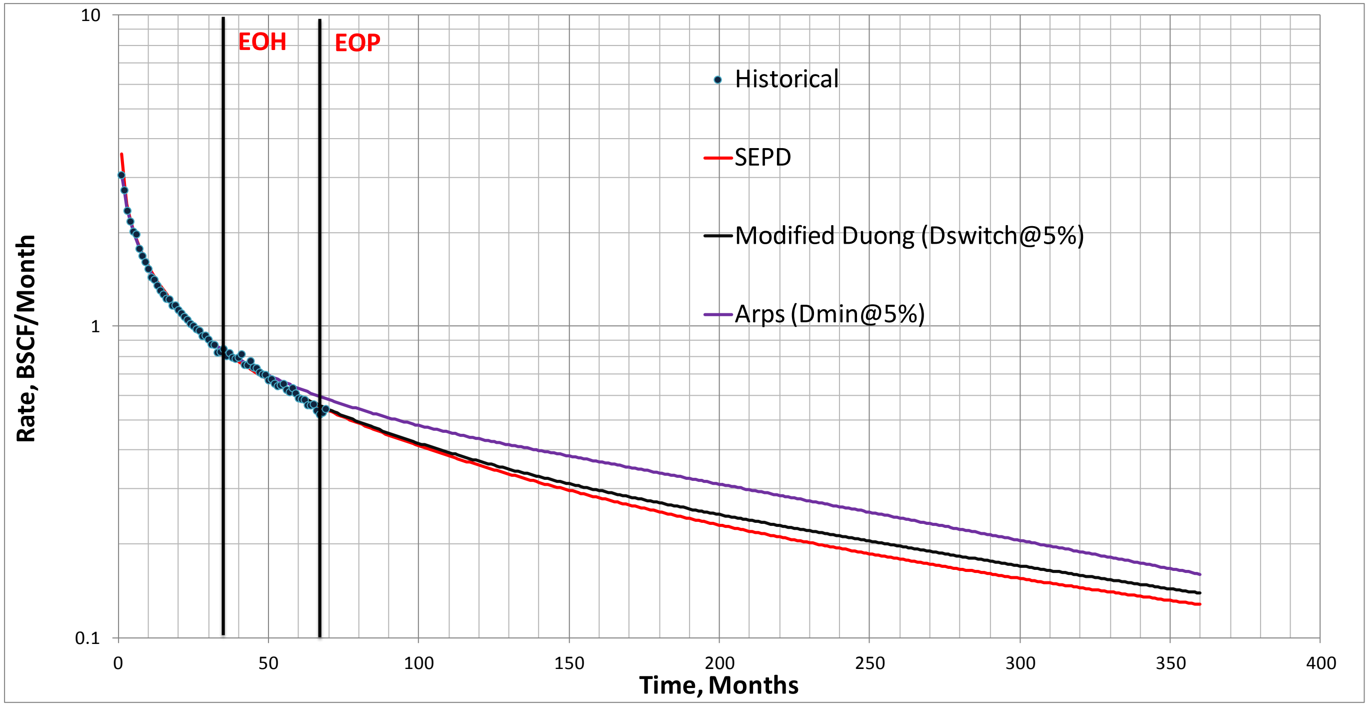
Johnson County (130 wells)- 18 months matched



Method	Reserves (After EOP)(BSCF)	Avg Reserves (After EOP) BSCF/Well	%Discrepancy
Arps (Dmin@5%)	197.168	1.517	-17.7
Modified Duong (Dswitch@5%)	132.856	1.022	-4.8
SEPD	116.648	0.897	-7.2

How Well Do Different Models Forecast For Long Term Grouped Data ?

Denton County (81 wells) – 36 months matched



Method	Reserves (After EOP)(BSCF)	Avg Reserves (After EOP) BSCF/Well	%Discrepancy
Arps (Dmin @5%)	90.007	1.111	-2.0
Modified Duong (Dswitch@5%)	75.244	0.929	1.5
SEPD	71.074	0.877	2.2

What About Oil Wells?

- Same as Gas Wells
  - D_{switch}/D_{min} values vary for different plays
  - Interference
- Account for solution gas
- Operational issues need to be accounted for
  - Pump Issues, Paraffin Issues
  - Higher reserves potential if issues fixed

Conclusions

- Previously mentioned modifications to the Duong makes the Duong model even more robust and accountable for fracture interference
- The Modified Duong (D_{switch}) method provides more accurate results than the SEDM and Modified Arps (D_{min}) Model when more than 12 months of historical production data is available, although some error is still associated with those forecasts
- None of the models studied produces accurate forecasts with 6 months or less of historical production data
- For grouped well sets the SEPD and Modified Duong (D_{switch}) work exceptionally well providing reasonable forecasts

Acknowledgements

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Quiz

- With greater than 12 months of historical production data which of these decline models provided the lowest error in remaining production for an individual well?

a. SEPD/SEDM
b. Modified Duong (Dswitch @ 5%)
c. Arps (Dmin @ 5%)
d. Duong

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