The Society of Petroleum Evaluation Engineers

SPEE Denver Chapter announces its January Luncheon Meeting.

(Members and Guests are cordially invited to attend.)

Friday, January 19, 2018

Dr. Bob Barree

President, Barree & Associates, LLP

Will be speaking on:

Interference in Horizontal Well Developments

LUNCHEON STARTS AT 11:30 A.M.

(A plated lunch will be served.)

PRESENTATION BEGINS AT NOON

The Denver Athletic Club

4rd Floor, Ballroom

1325 Glenarm Place (14th and Glenarm) Denver CO 80204

Parking flat rate $7.00 on space available basis

Cost: $25.00 per Person

(Credit Card, Cash or Check made out to 'SPEE Denver Chapter')

Sponsored in part by Entero Corporation, makers of Mosaic, a comprehensive software application for reserves management, petroleum economics, and decline analysis www.entero.com

Please RSVP by Noon Wednesday, January 17, 2018

RSVP and simultaneously pay by credit card online at:

https://secure.spee.org/civicrm/event/info?reset=1&id=173

If the above link does not work, alternatively go to www.spee.org then select 'Local Chapters', then 'Denver', then 'Register Now'.

Abstract: Most unconventional reservoirs are developed with pad drilling of multiple, closely spaced horizontal wells which are then fracture stimulated with closely spaced fracture initiation points. These wells, fractures, and fields are subject to several sources of interference during the drilling, completion, and production phases of development. This talk discusses various forms of interference and their impact on economic development and resource recovery.

Speaker Bio.: **Robert (Bob) D. Baree** (PhD., P.E.) is president and principal investigator of Barree & Associates. Previously Dr. Barree was a Senior Technical Consultant at Marathon's Petroleum Technology Center. He has been involved in the development of hydraulic fracture design simulators and fracture diagnostic procedures for nearly 40 years, and is the author of more than 70 technical publications. He has served as SPE Distinguished Lecturer on the topic of new philosophies in hydraulic fracturing, and has served on many technical committees for SPE annual and regional meetings, Applied Technology Workshops, and Forum Series. He is a registered Professional Engineer in the State of Colorado and holds degrees in Petroleum Engineering (B.S.) from the Pennsylvania State University and Colorado School of Mines (PhD).

SPEE
SOCIETY OF PETROLEUM EVALUATION ENGINEERS

About SPEE: http://www.spee.org SPEE was formed in 1962 as a professional, non-profit organization bringing together specialists in the evaluation of petroleum and natural gas properties. SPEE continues today to be strongly committed to providing educational and other services to its members and to the oil and gas industry, and to promoting the profession of petroleum evaluation engineering.

For additional information, please contact:
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303-573-4886 Ext. 1450

Interference in Horizontal Well Stimulation

R. D. Barree

Barree & Associates LLC

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Interference:
From Merriam-Webster

Definition of INTERFERENCE

- ***1a*** **:** the act or process of interfering ***b*** **:** something that interferes **:** OBSTRUCTION
- ***2*****: the mutual effect on meeting of two wave trains (as of light or sound) that constitutes alternating areas of increased and decreased amplitude (such as light and dark lines or louder and softer sound)**
- ***3a*** **:** the legal blocking of an opponent in football to make way for the ballcarrier
b **:** the illegal hindering of an opponent in sports
- ***4*****:** partial or complete inhibition or sometimes facilitation of other genetic crossovers in the vicinity of a chromosomal locus where a preceding crossover has occurred
- ***5a*** **:** confusion of a received radio signal due to the presence of noise (such as atmospherics) or signals from two or more transmitters on a single frequency
b **:** something that produces such confusion
- ***6*****: the disturbing effect of new learning on the performance of previously learned behavior with which it is inconsistent**

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Interference for Us

- Fracture-to-facture stress interference in a stage
- Stress shadow interference between multiple stages in one well
- Stress interference between multiple wells with multiple stages (zipper fracs, “wine-rack” stacks, parent-child interactions)
- Production transient interference between fractures and frac stages (frac spacing)
- Production transient interference between wells (well spacing, parent-child effects, depletion)

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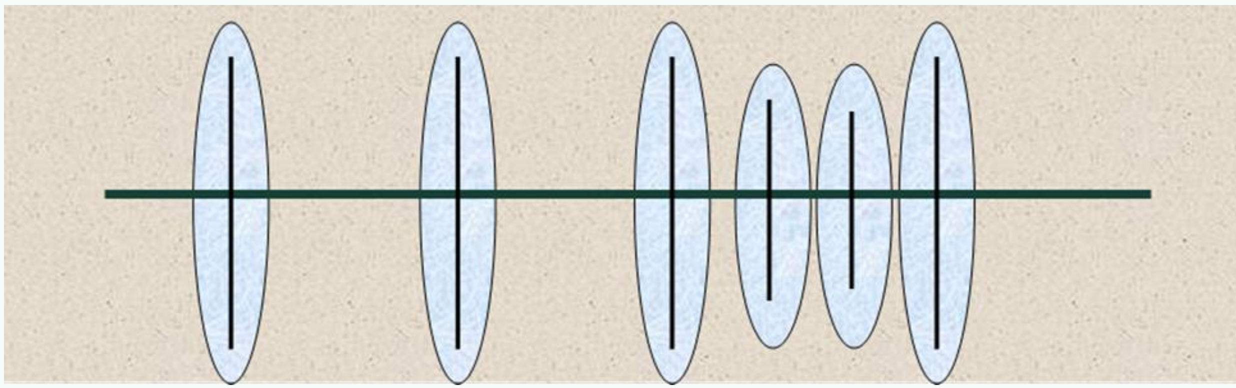
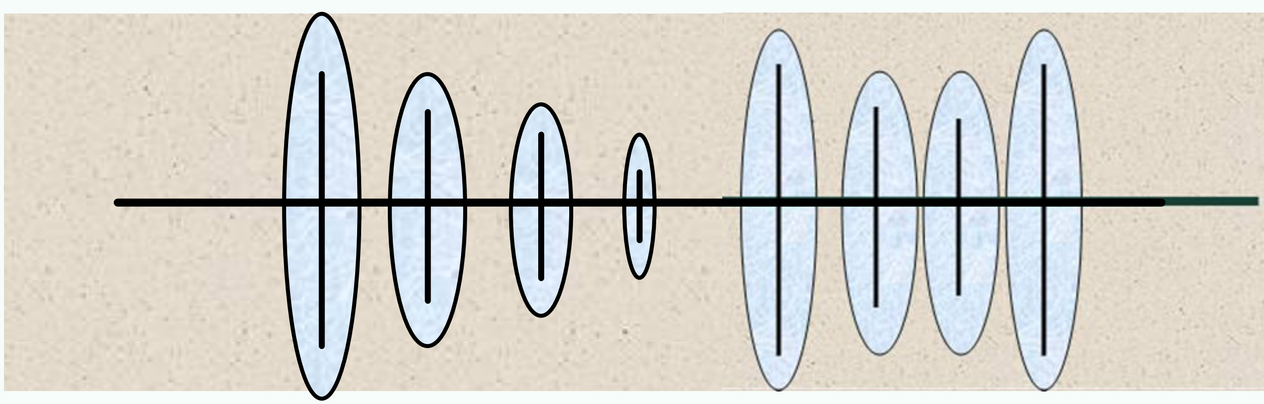
Stress Interference

Fracs spaced far enough apart



Interference between stages



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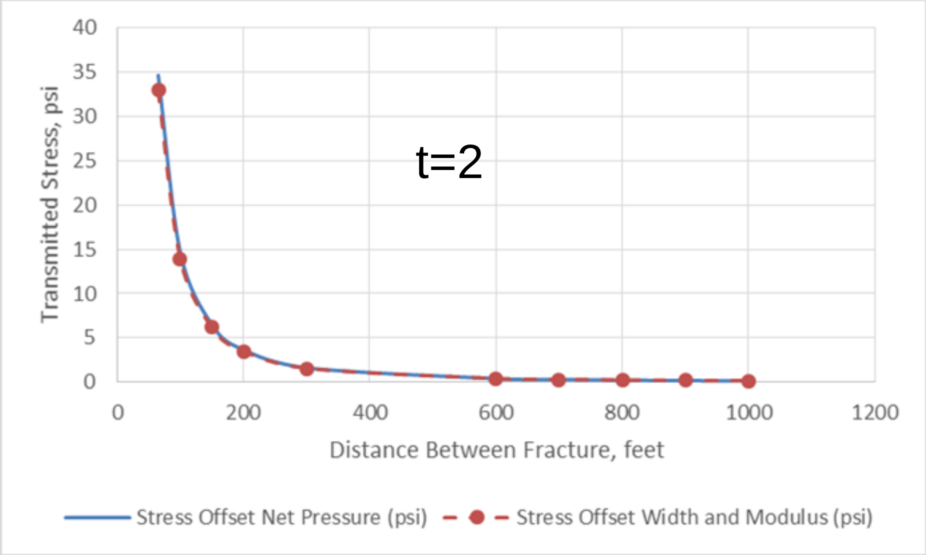
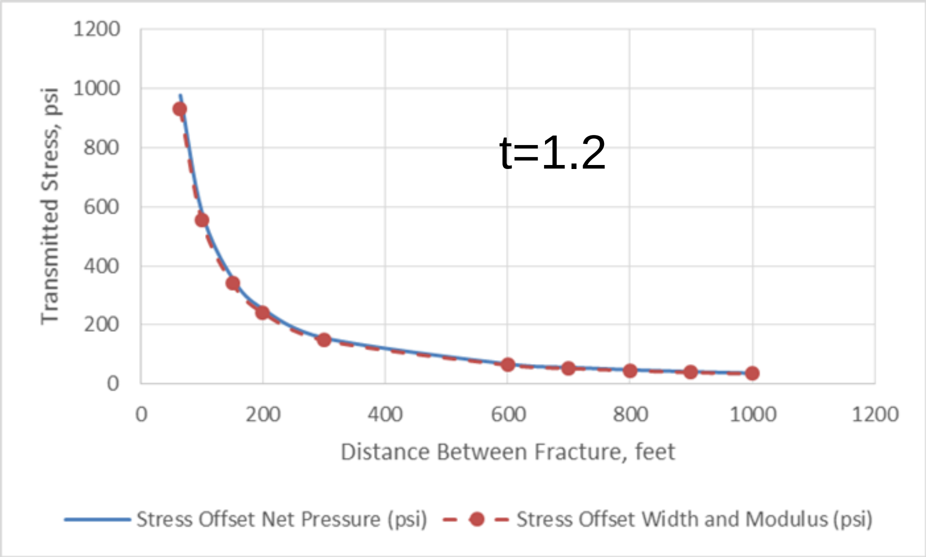
Fracture Stress Shadow



$$\sigma = \frac{3 * 144 * P}{2\pi Z^t}$$



$$\sigma = \frac{wE}{12Z^t}$$

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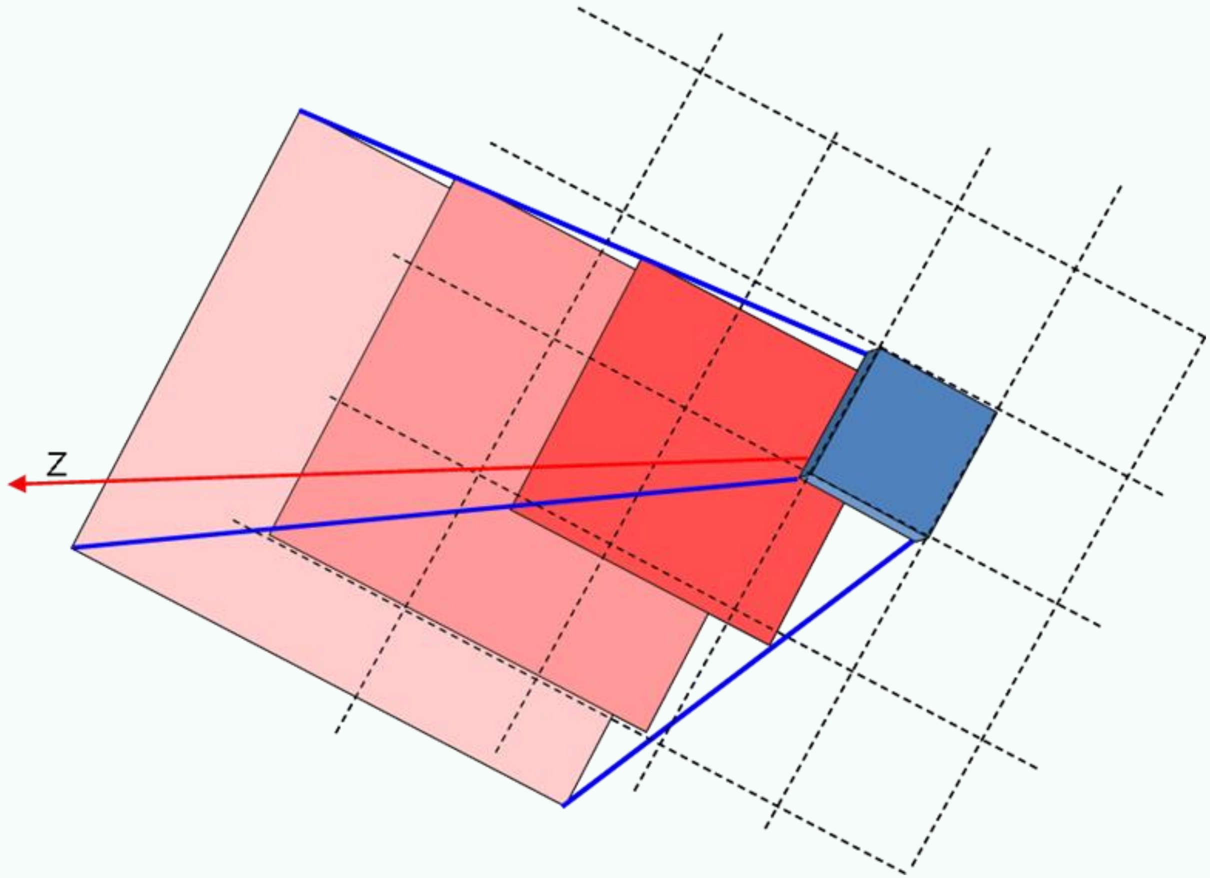
Stress and Strain Projected



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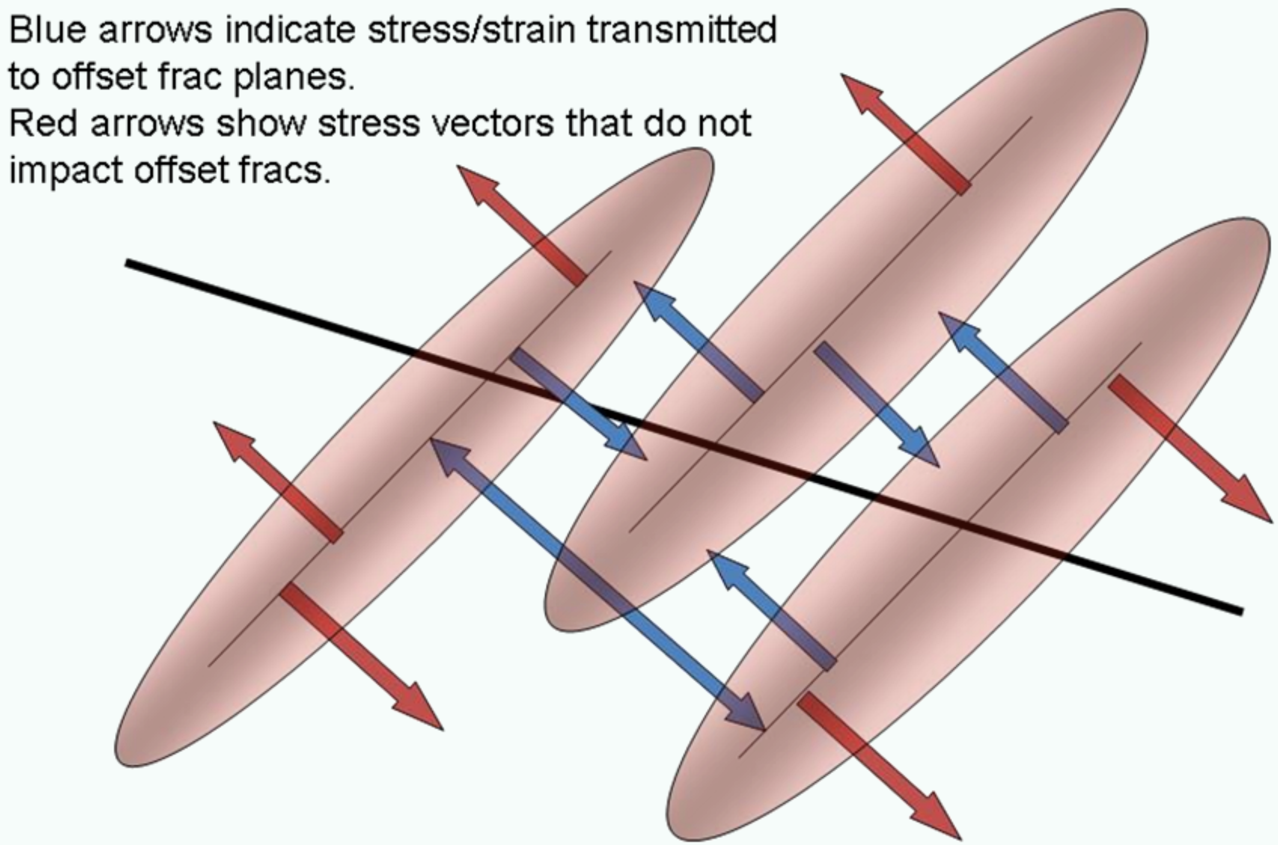
Non-Parellel Fractures



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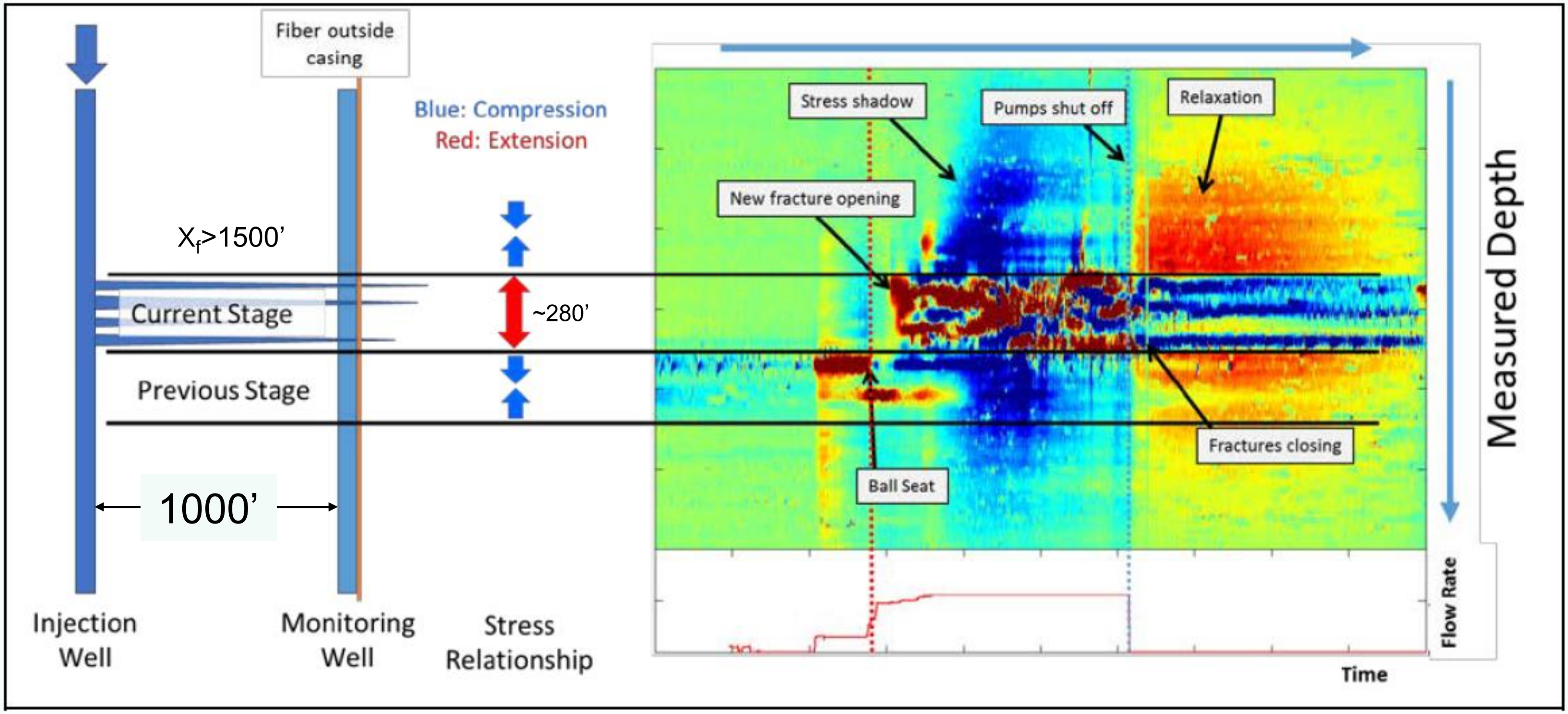
Induced Fiber-Optic Strain



URTeC 2670034, 2017
ConocoPhillips

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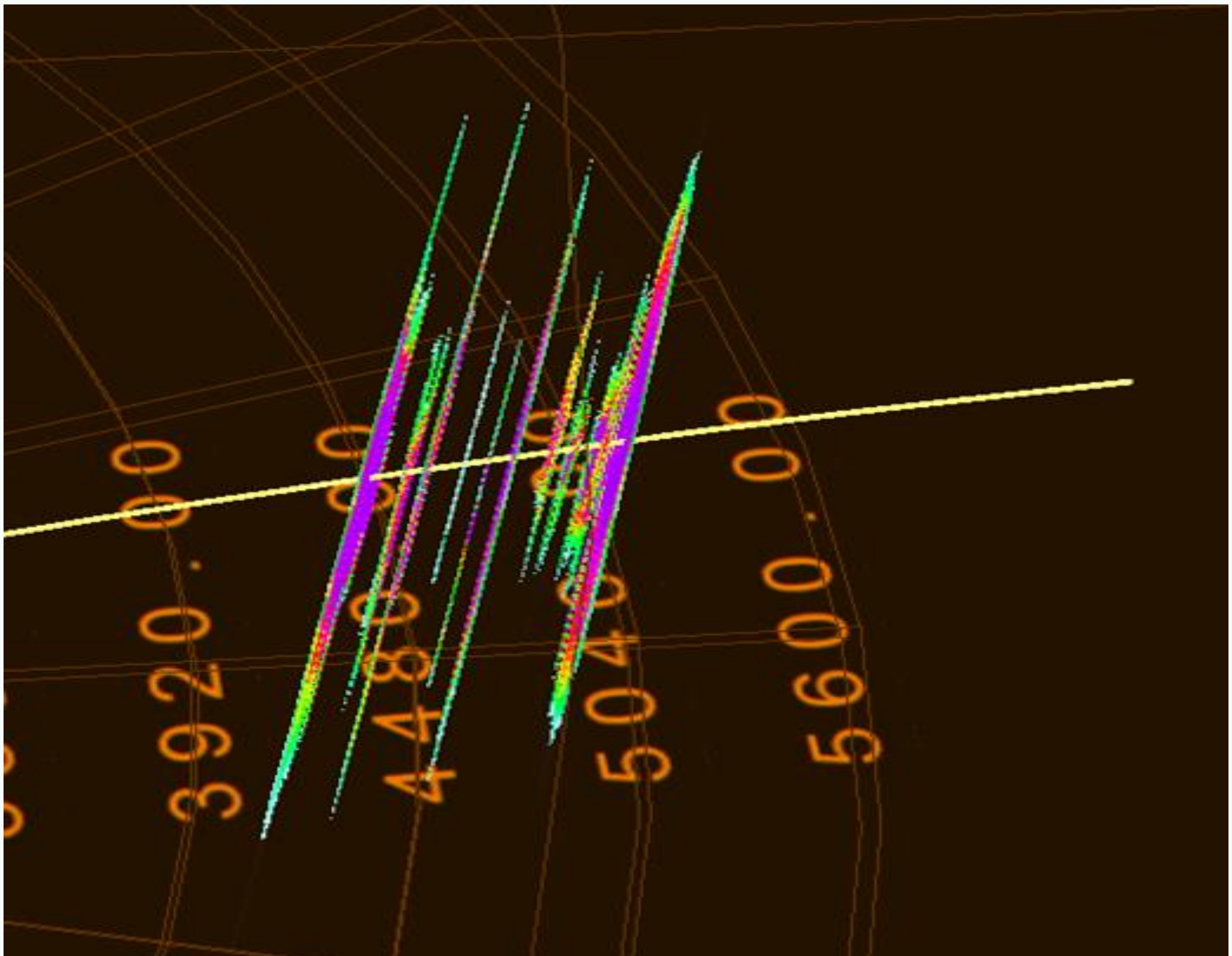
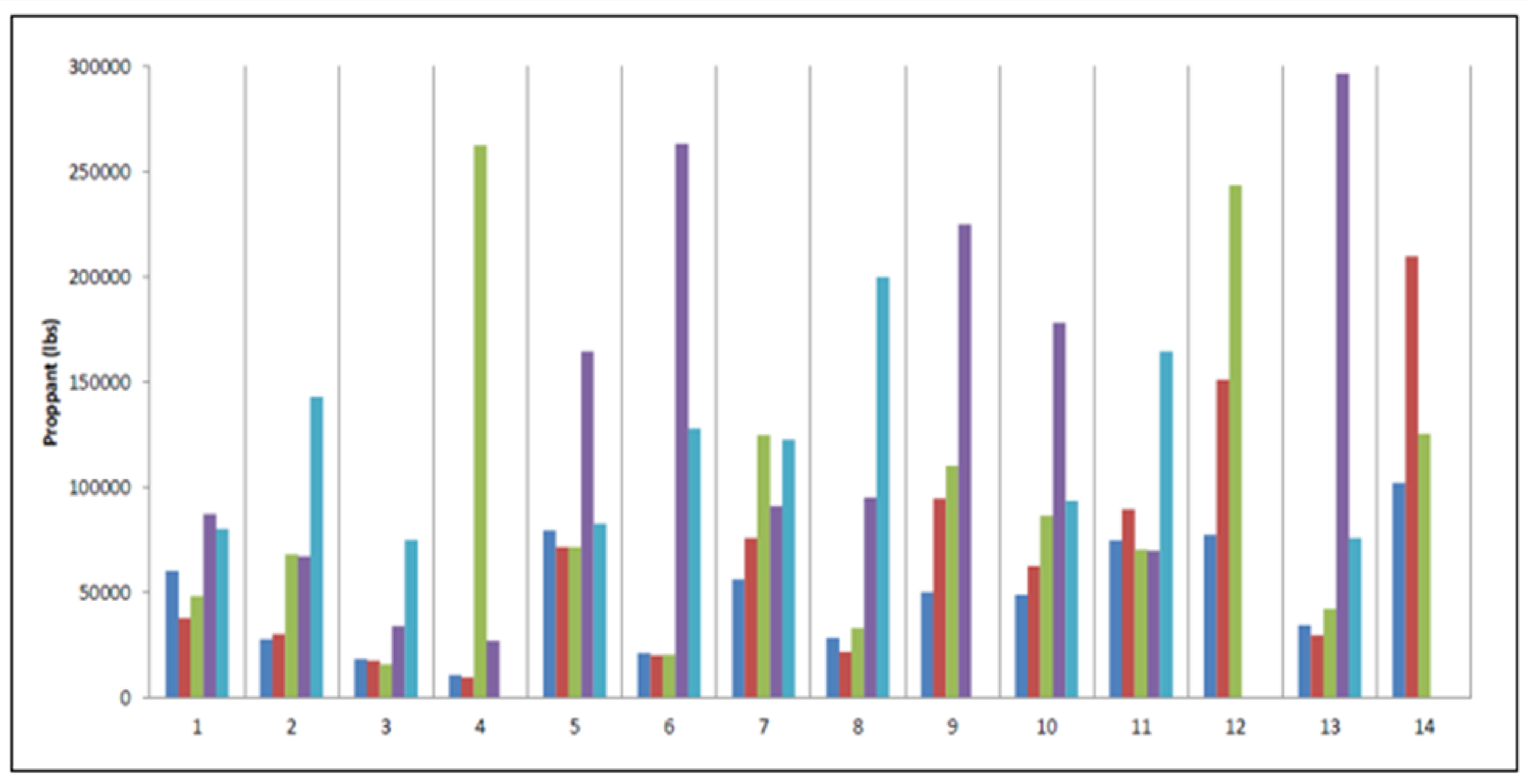
Interference of Oblique Fractures



Proppant Distribution Based on DAS/DTS for 14 Stages



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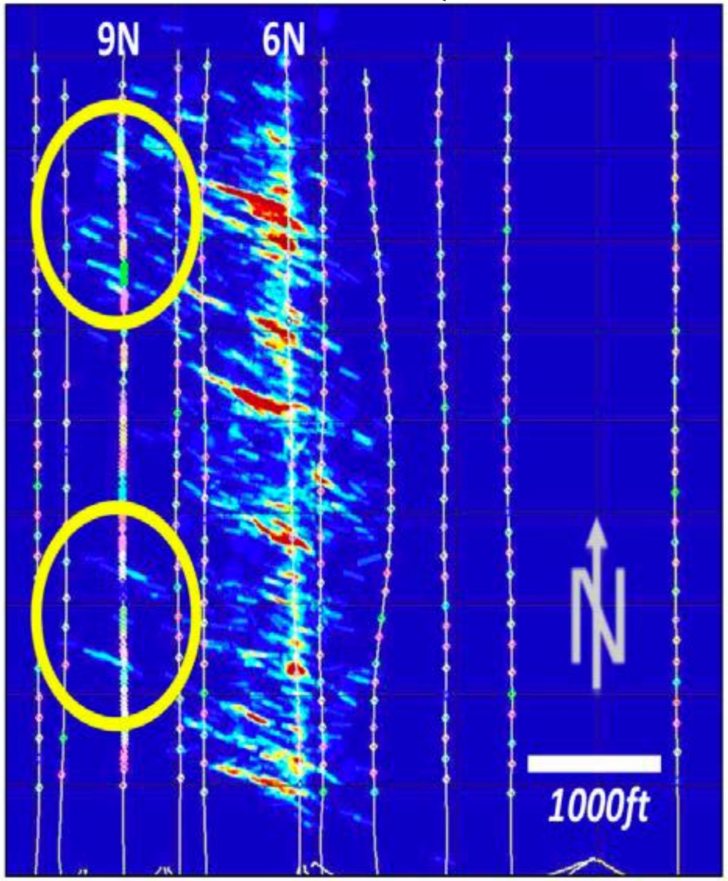
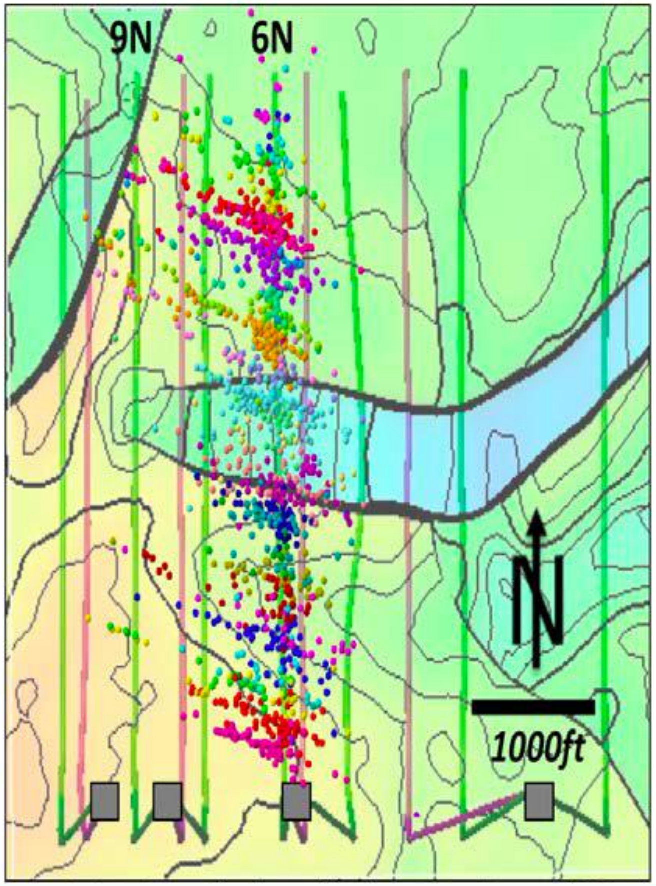
Well-to-Well Stress Interference

Wells frac'd sequentially from east to west





MS Thesis, Ahmed Alfataierge
CSM, 2017

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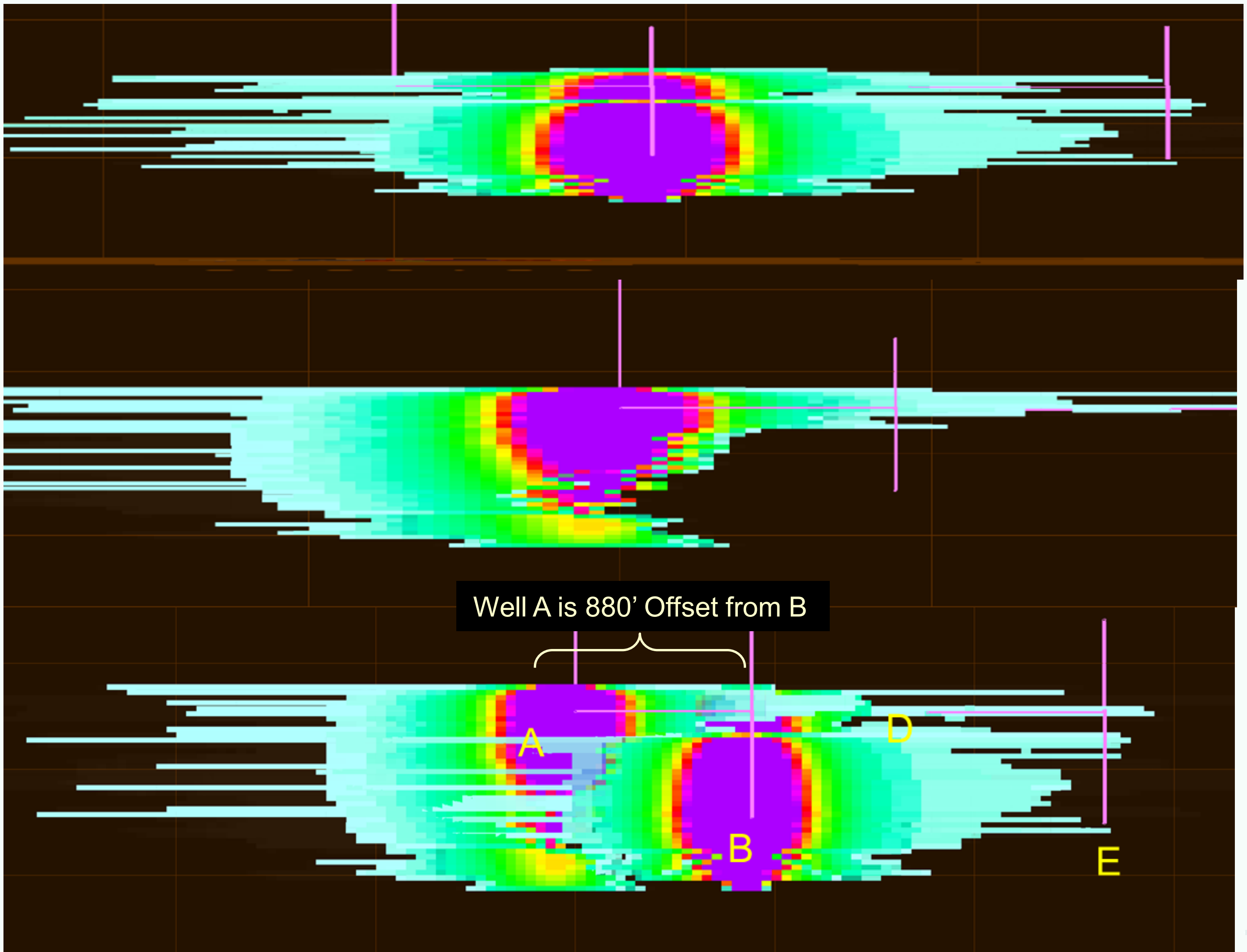
Sequential Fractue Interference

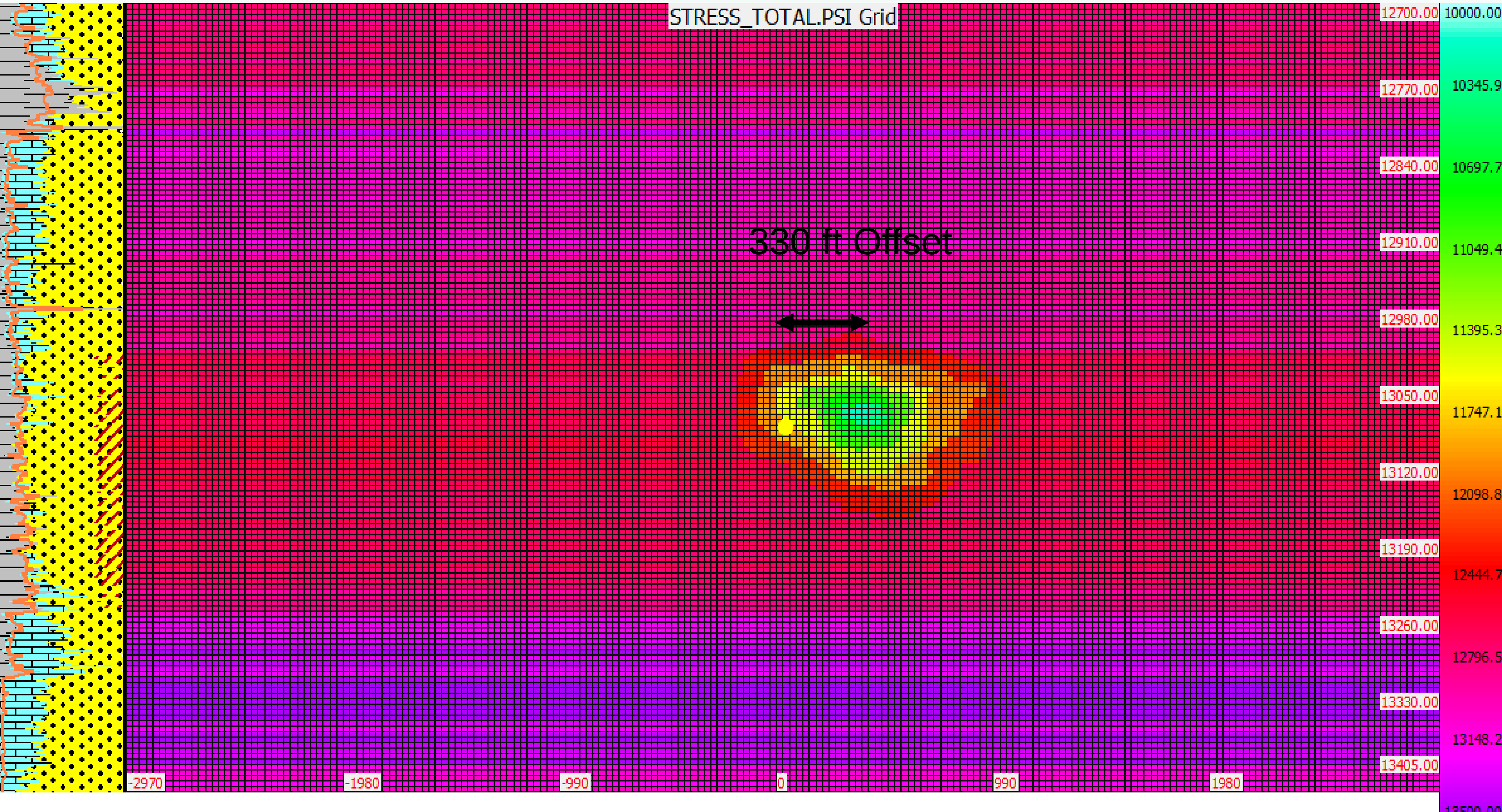
Well B
Frac'd First

Well A Frac'd
Second with
Interference
from Well B

Well A is
100' Above
Well B



Parent-Child Effects: Frac a New Well Offsetting an Older Producing Well



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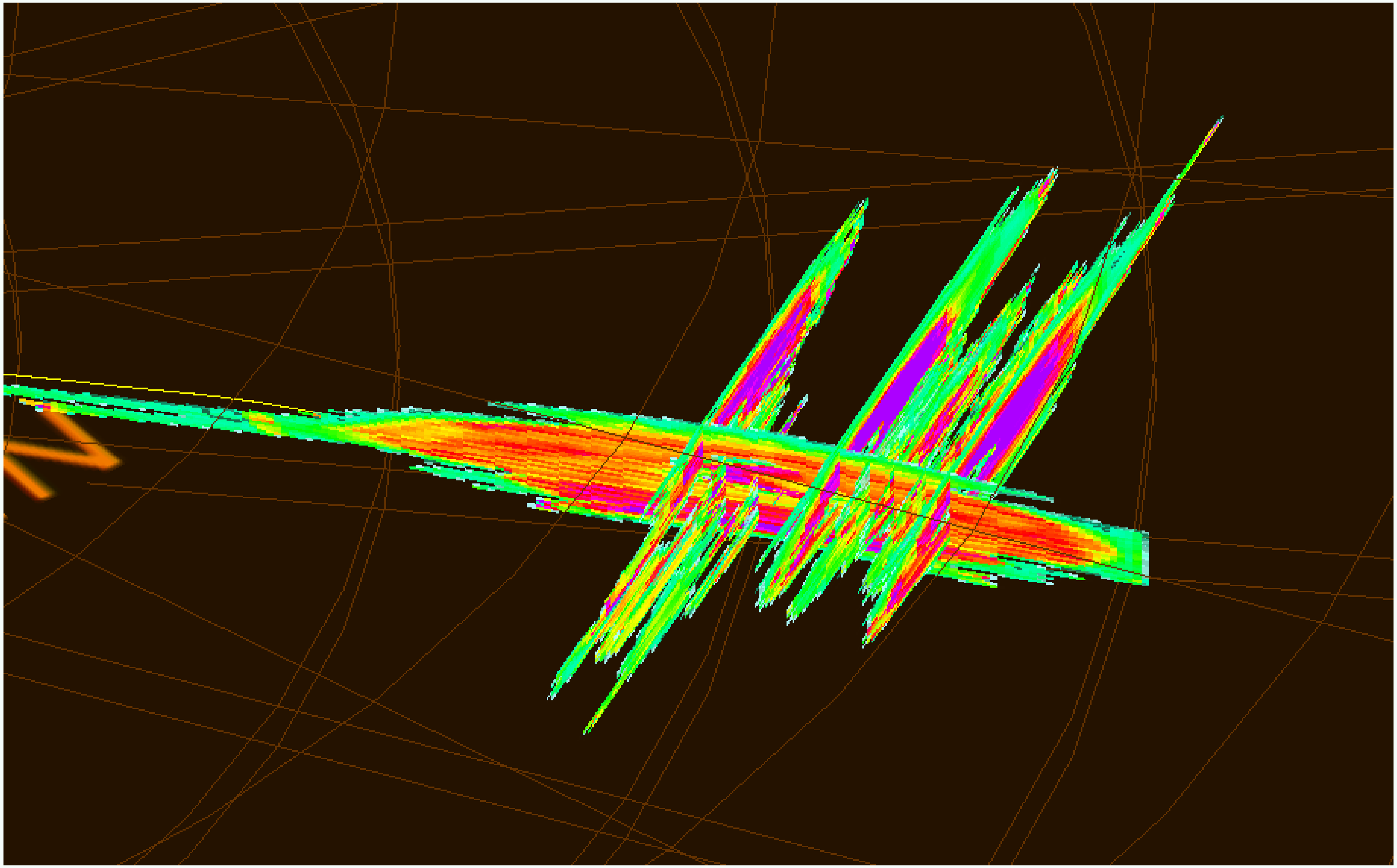
Fracs Offsetting Depleted Well



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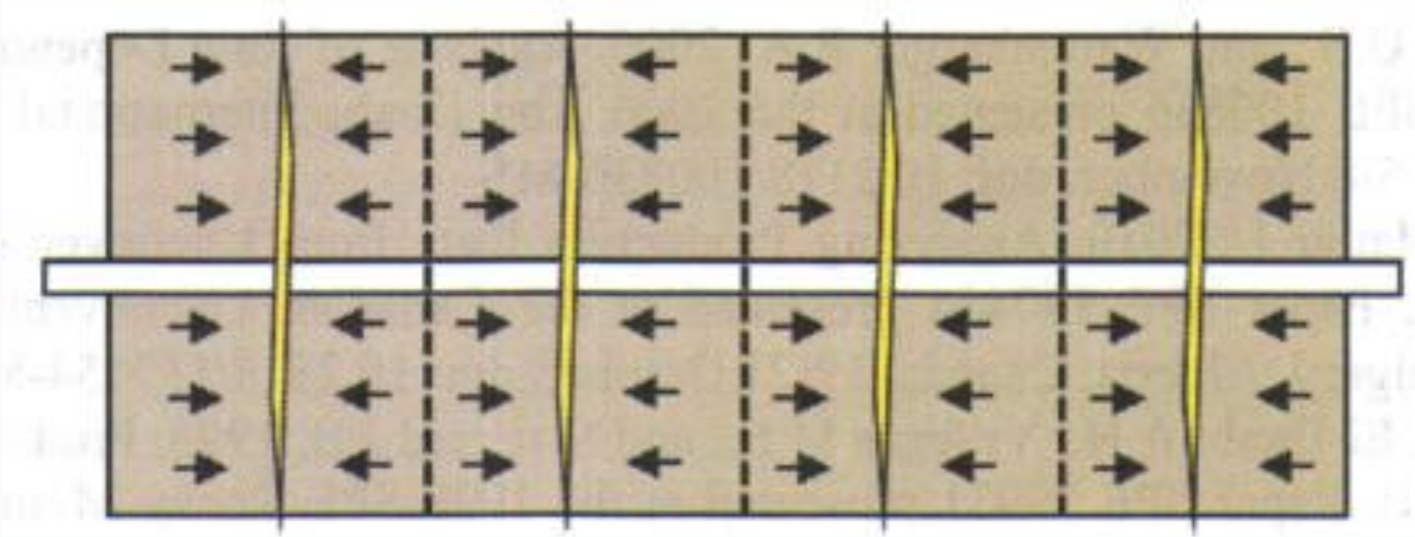
Assumed Fracture Linear Flow Model (Wattenberger, et al)



No flow beyond ends of “effective” fractures.
Linear flow is normal to all fracture faces.
Fractures are very long and perm is very low, so interference time is long.

CSUG/SPE 149472

Analyzing Variable Rate/Pressure Data in Transient Linear Flow in Unconventional Gas Reservoirs
P. Liang, SPE, L. Mattar, SPE, and S. Moghadam, SPE, Fekete Associates Inc.

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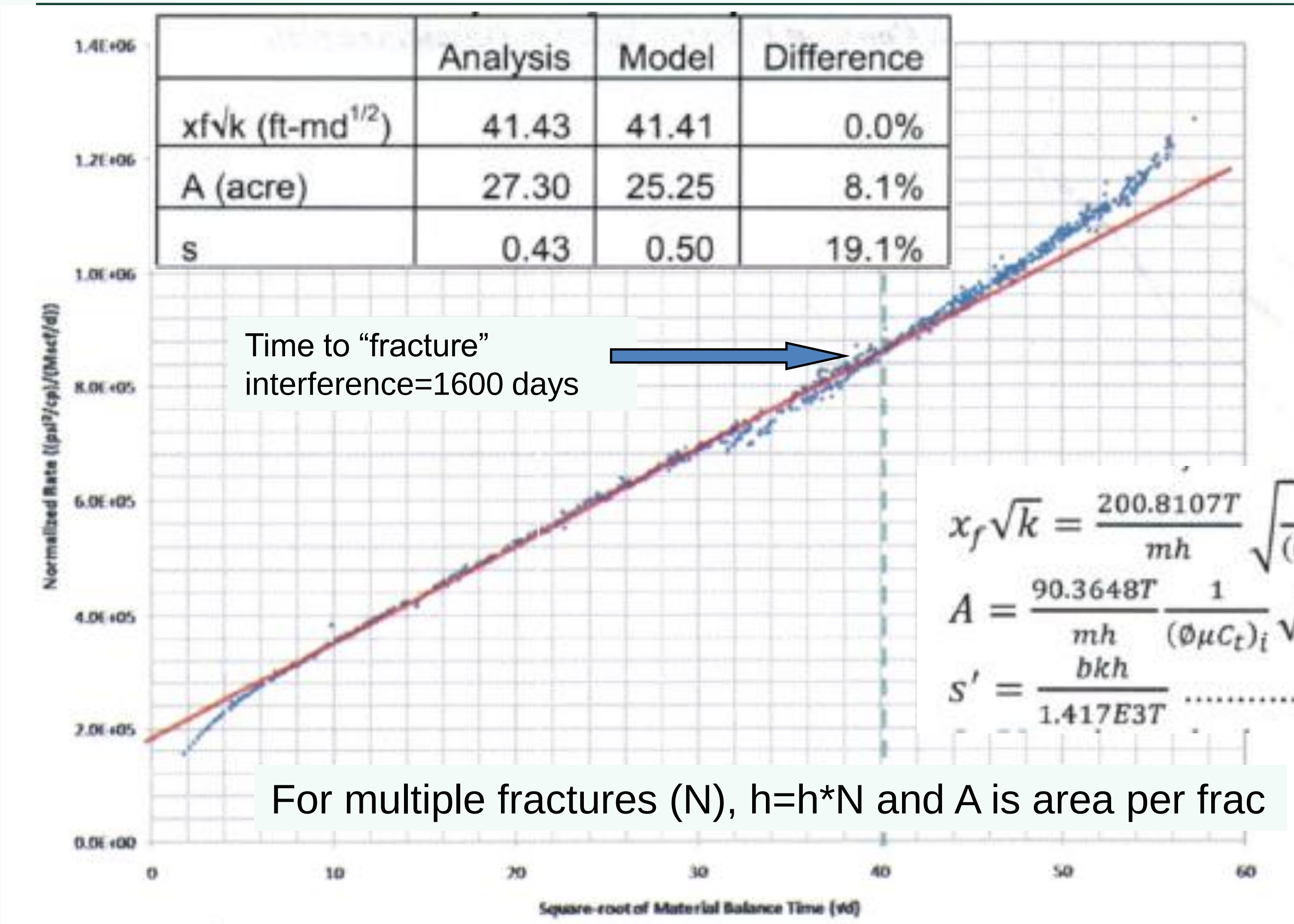
Analysis Using Linear Flow Model



	Analysis	Model	Difference
xf√k (ft-md$^{1/2}$)	41.43	41.41	0.0%
A (acre)	27.30	25.25	8.1%
s	0.43	0.50	19.1%

$$x_f\sqrt{k} = \frac{200.8107T}{mh}\sqrt{\frac{1}{(\phi\mu C_t)_i}} \ldots$$

$$A = \frac{90.3648T}{mh}\frac{1}{(\phi\mu C_t)_i}\sqrt{t_{elf}} \ldots$$

$$s' = \frac{bkh}{1.417E3T} \ldots$$

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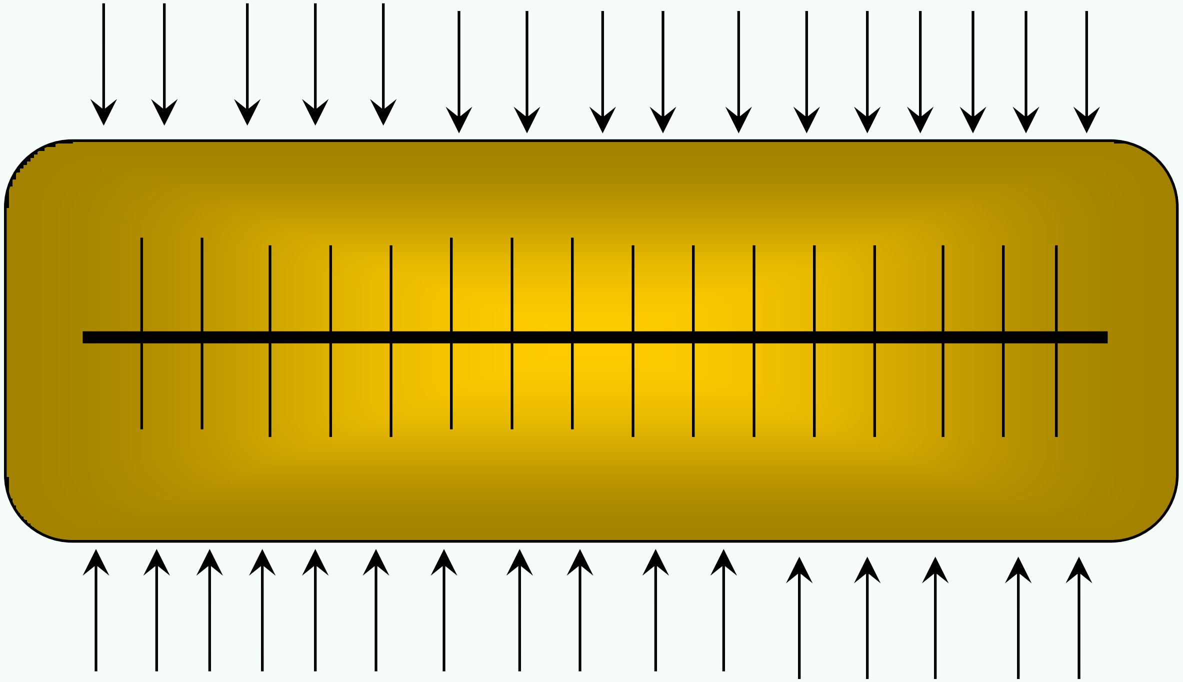
Linear Flow to Composite Drainage Area Model



Fractures appear to interfere quickly to form a continuous pressure sink that leads to linear flow from into the composite well-fracture system.

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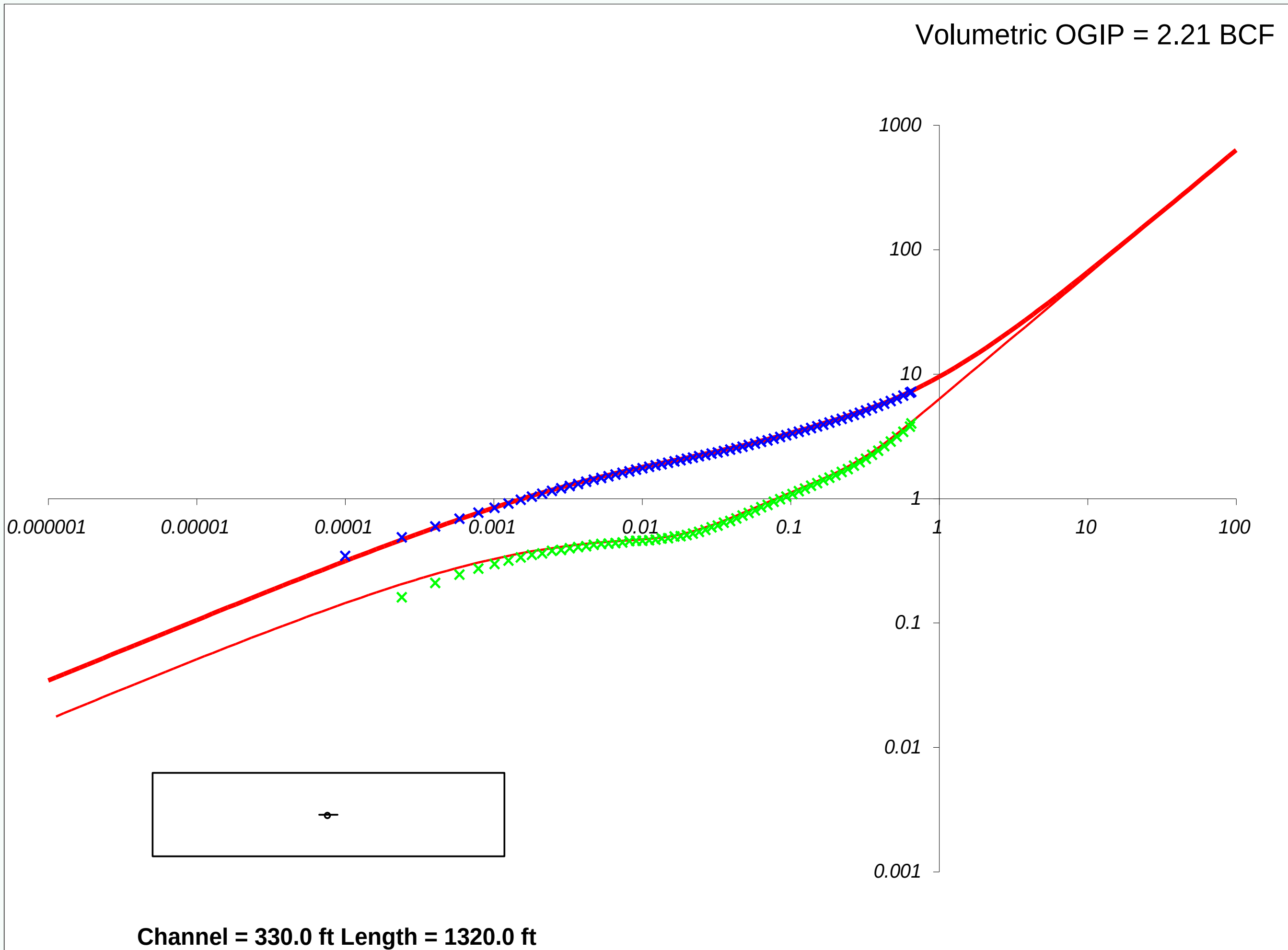
Evaluation of “Linear Flow” Models: 5000’ Lateral, 10 Fracs

10 Transverse 35 ft (inf) fracs

☐ Wellbore Cleanup ☐ Time Superposition ☐ Convert to BHP ☐ Channel Width

History Match

Inner Boundary		Infinite Conductivity Fracture
Outer Boundary		Rectangular
Reservoir Pressure	Pi	5000
Reservoir Temperature	T	212
Thickness	h	500
Permeability	k	0.001
Porosity	ϕ	0.06
Area	A	10
Half length	Xf	35
Skin	Skin	0
Fracture Conductivity	kfwf	1000
Wellbore Storage	C	0
Aspect Ratio	L/W	4
Channel Width	ft	1500
Well X-Offset	Xoff	0.5
Well Y-Offset	Yoff	0.5
Wellbore Radius	Rw	0.354
Vertival/Horizontal Perm	Kv/Kh	0.01
Horizotal Well Length	Lh	5000
Vertical Postion	Zwd	0.5
Specific Gravity	γ_g	0.65
Initial Water Saturation	Swi	0.35
Water Compressibility	cw	3.00E-06
Formation Compressibility	cf	8.11E-06
Carbon Dioxide	CO2	0
Nitrogen	N2	0
Hydrogen Sulphide	H2S	0
Wellhead Temperature	WHT	80
Measured Depth	L	11000
Pipe Roughness	ε	0.0006
Pipe Diameter	d	4.778
Condensate API	API	55
Diameter Perfs	dp	4.892



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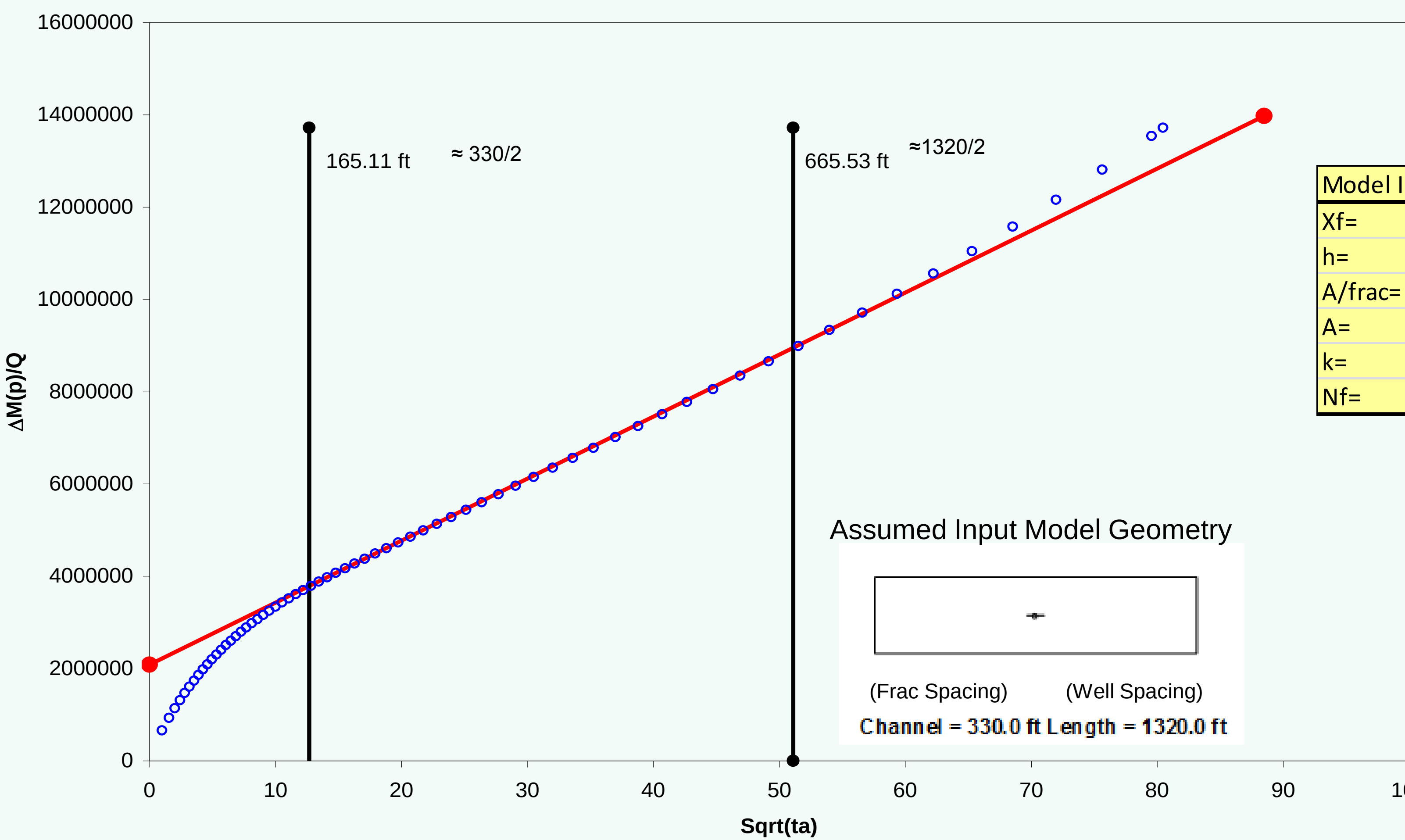
Linear Flow Plot for 10 Frac Case

spacing = 333.56 and Skin' = 1.09 ⟵ Note: skin has no real meaning



Model Inputs	
Xf=	35
h=	50
A/frac=	10
A=	100
k=	0.001
Nf=	10

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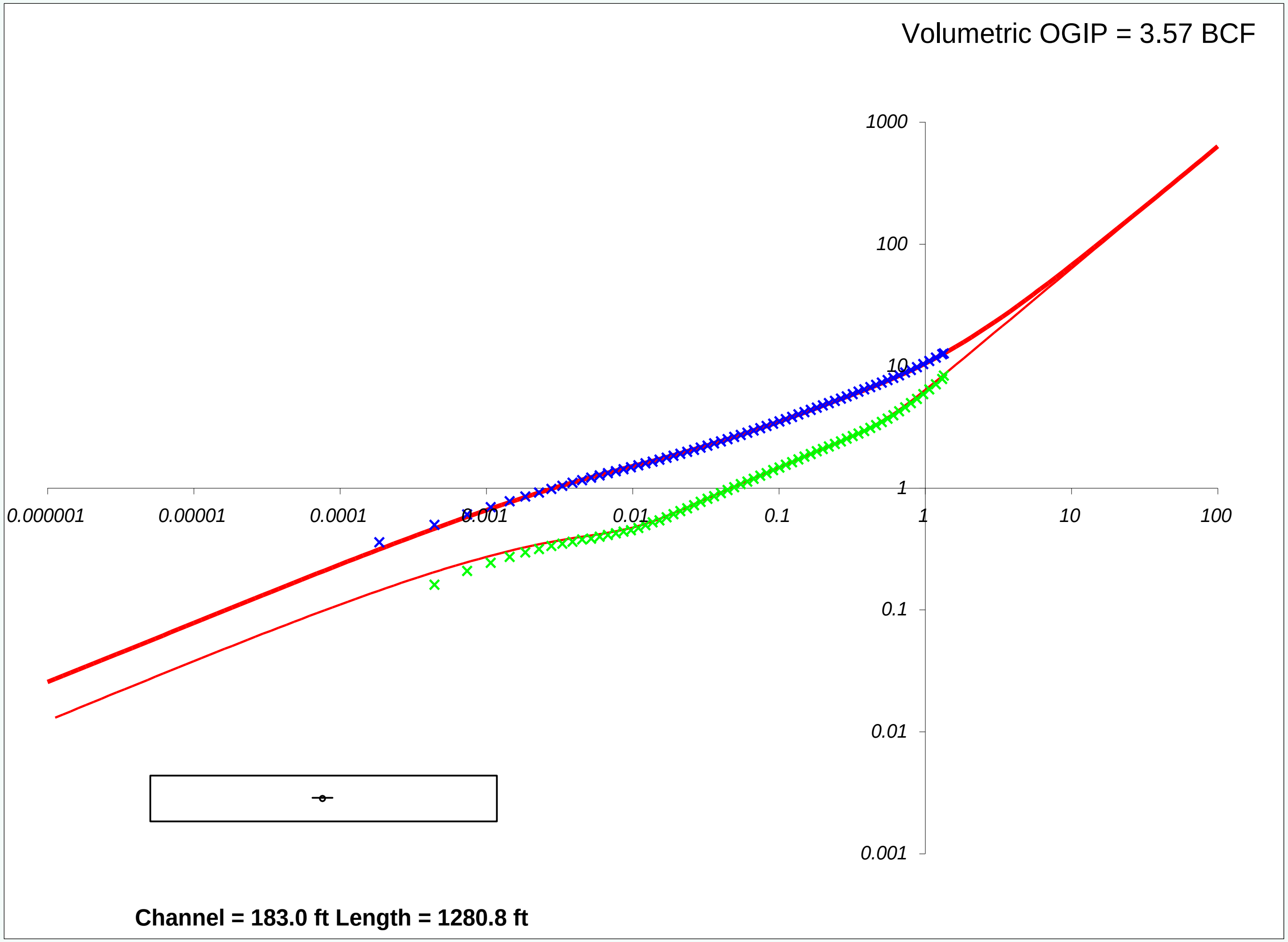
Comparison of Production Analysis with Increased Frac Density: 5000' Lateral, 30 Fracs

30 Transverse 35 ft (inf) fracs

☐ Wellbore Cleanup ☐ Time Superposition ☐ Convert to BHP ☐ Channel Width

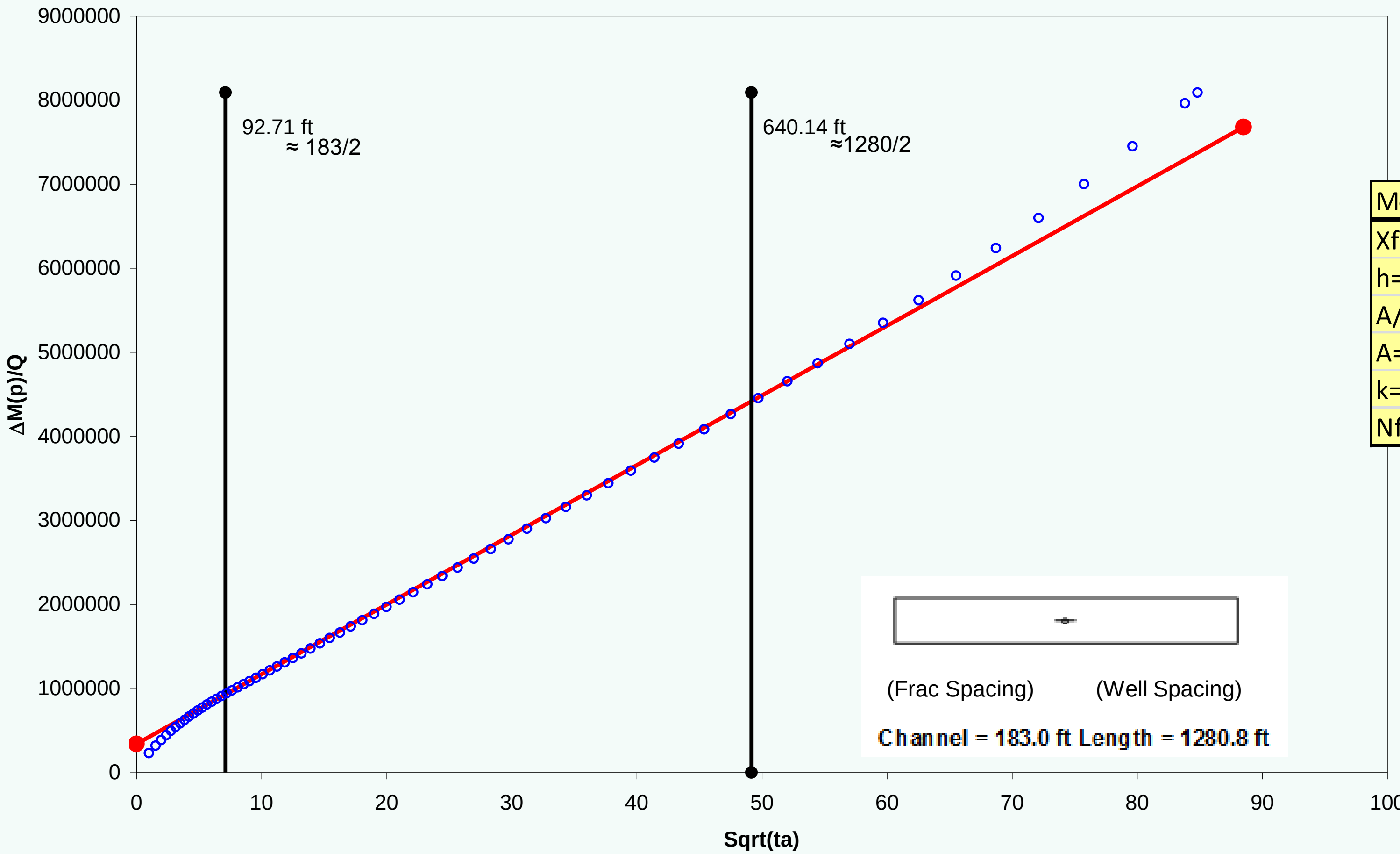
History Match

Inner Boundary		Infinite Conductivity Fracture
Outer Boundary		Rectangular
Reservoir Pressure	Pi	5000
Reservoir Temperature	T	212
Thickness	h	1500
Permeability	k	0.001
Porosity	ϕ	0.06
Area	A	5.38
Half length	Xf	35
Skin	Skin	0
Fracture Conductivity	kfwf	1000
Wellbore Storage	C	0
Aspect Ratio	L/W	7
Channel Width	ft	1500
Well X-Offset	Xoff	0.5
Well Y-Offset	Yoff	0.5
Wellbore Radius	Rw	0.354
Vertival/Horizontal Perm	Kv/Kh	0.01
Horizotal Well Length	Lh	5000
Vertical Postion	Zwd	0.5
Specific Gravity	γ_g	0.65
Initial Water Saturation	Swi	0.35
Water Compressibility	cw	3.00E-06
Formation Compressibility	cf	8.11E-06
Carbon Dioxide	CO2	0
Nitrogen	N2	0
Hydrogen Sulphide	H2S	0
Wellhead Temperature	WHT	80
Measured Depth	L	11000
Pipe Roughness	ε	0.0006
Pipe Diameter	d	4.778
Condensate API	API	55
Diameter Perfs	dp	4.892



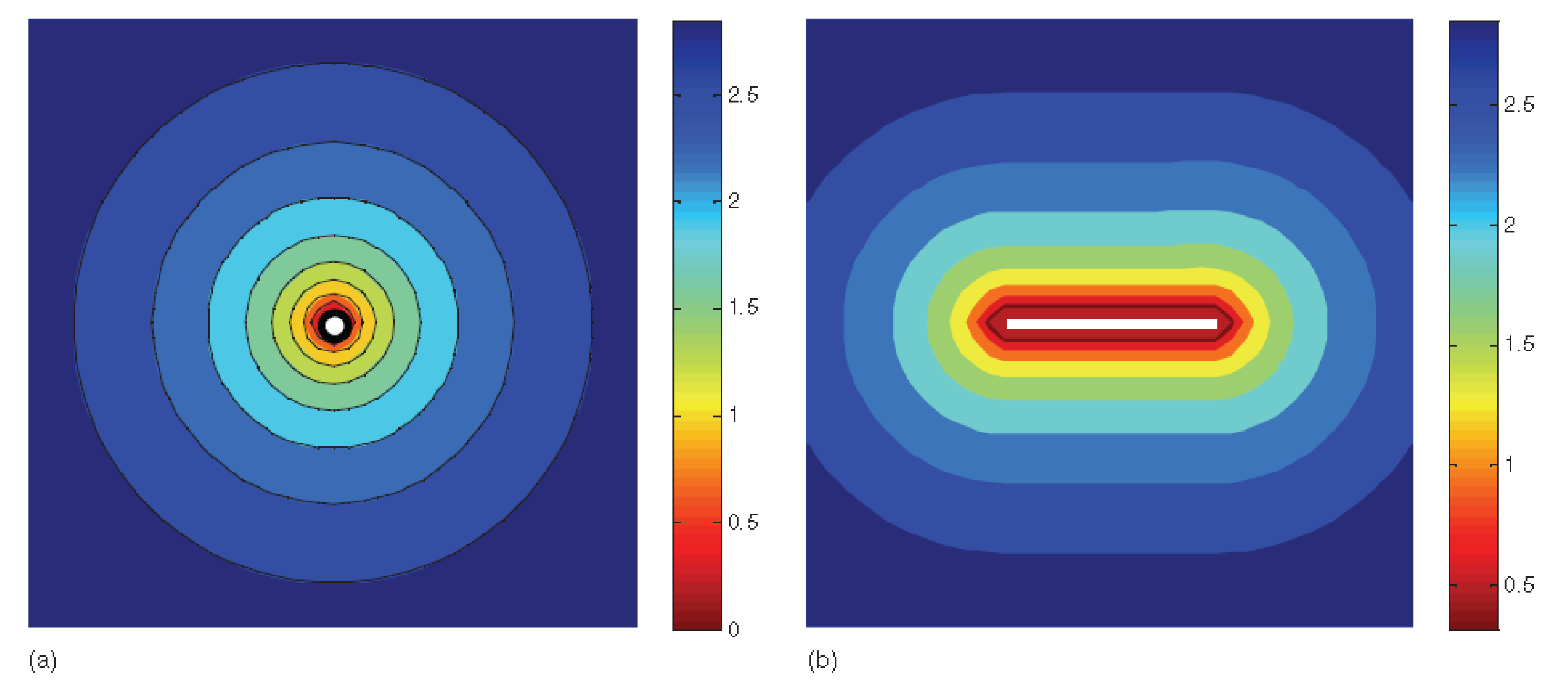
Linear Flow Plot for 30 Frac Case

spacing = 180.11 and Skin' = 0.54 ← Note: skin has no real meaning



Model Inputs	
Xf=	35
h=	50
A/frac=	5.38
A=	161.4
k=	0.001
Nf=	30

Comparison of Radius of investigation for Radial and (Initially) Linear Flow



Depth of investigation at various times in days (log scale):

(a) from FMM with analytic solution for radial flow superimposed (black lines)

(b) from FMM for a vertical well with an infinite conductivity fracture or horizontal well with interfering fractures.

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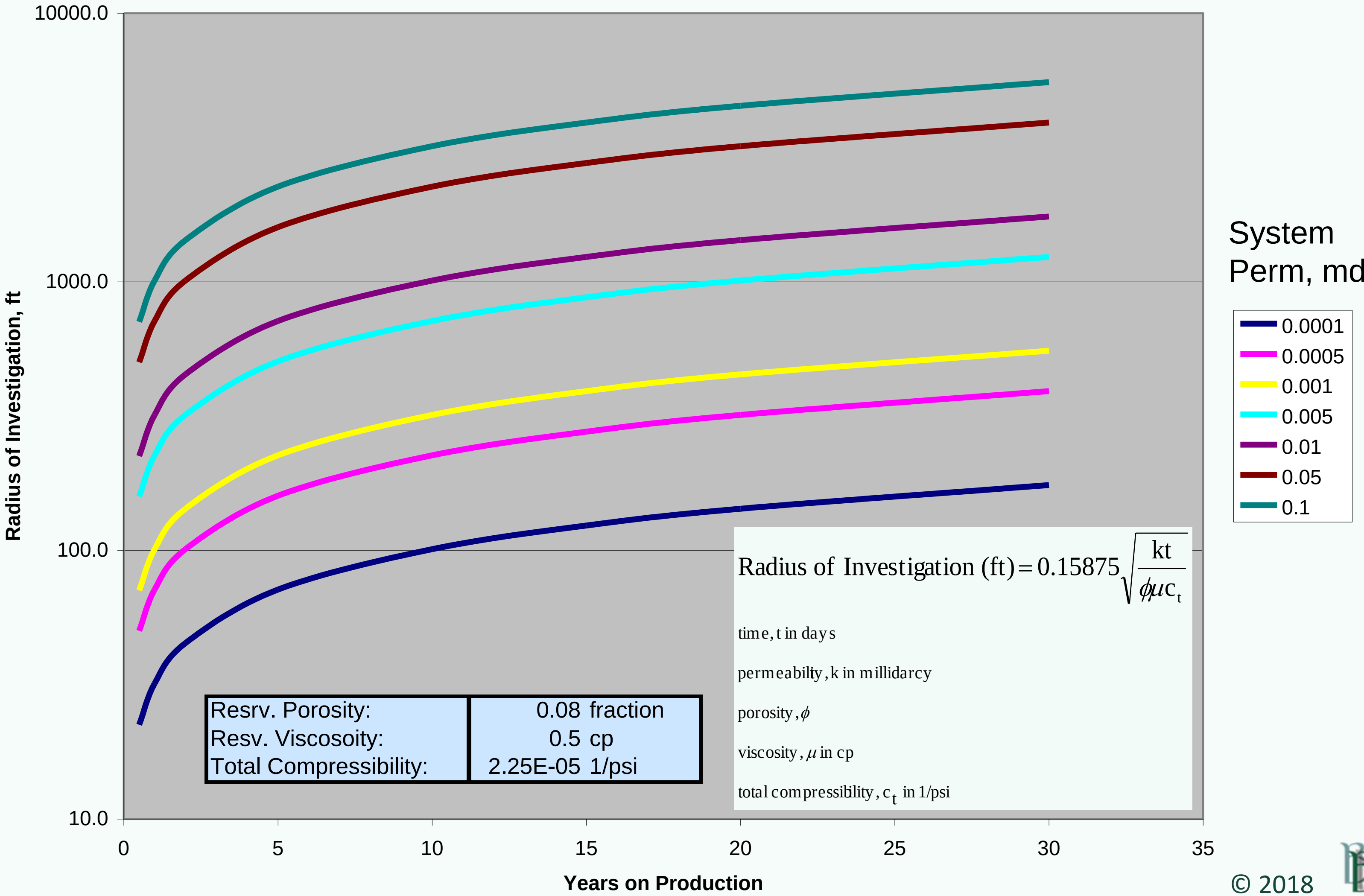
Transient Radius of Investigation
(Oil Reservoir)



$$\text{Radius of Investigation (ft)} = 0.15875\sqrt{\frac{kt}{\phi\mu c_t}}$$

time, t in days

permeability, k in millidarcy

porosity, ϕ

viscosity, μ in cp

total compressibility, c_t in 1/psi

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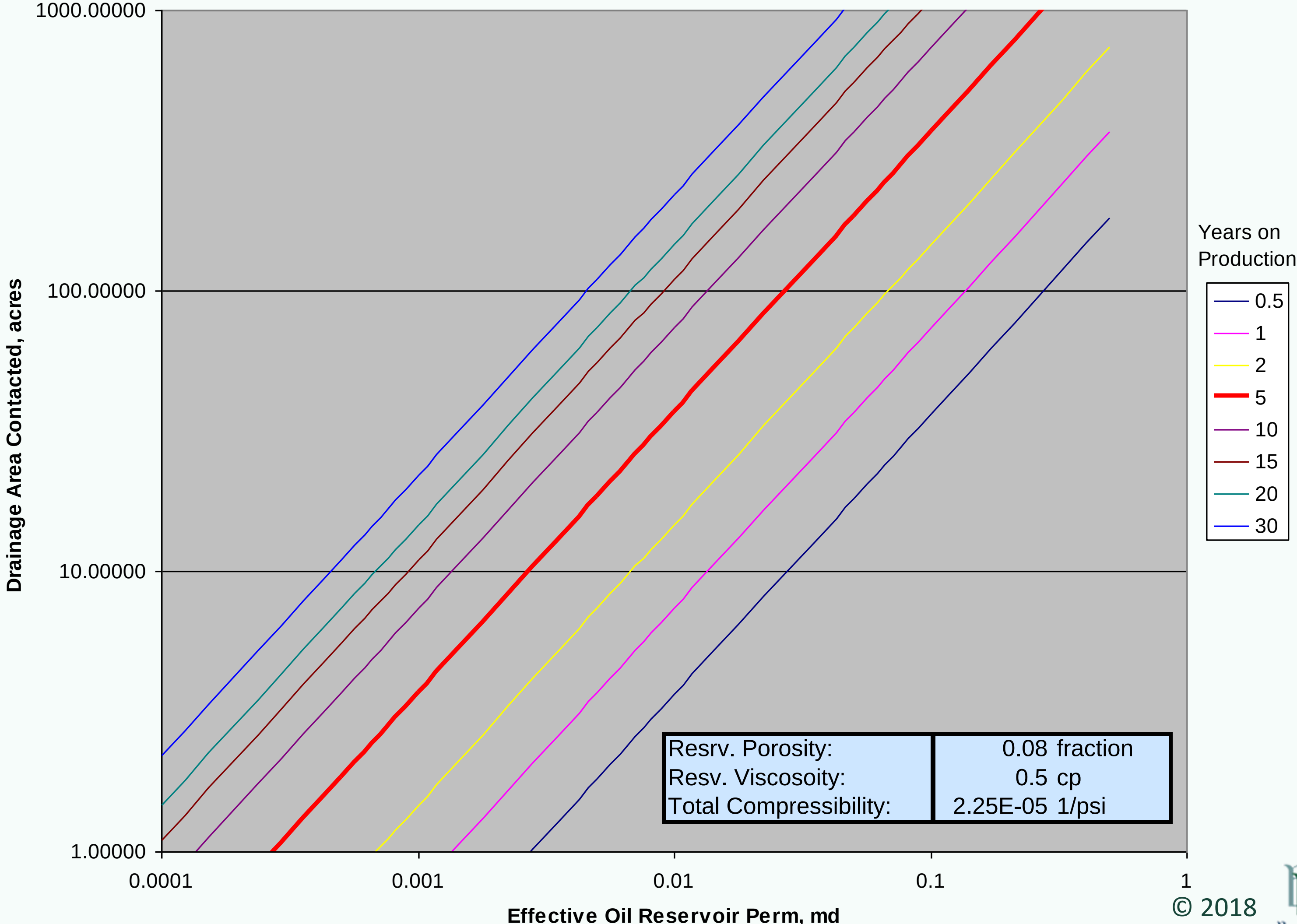
Effective Drainage Area
(Assumes 1:1 Aspect, Oil Reservoir)



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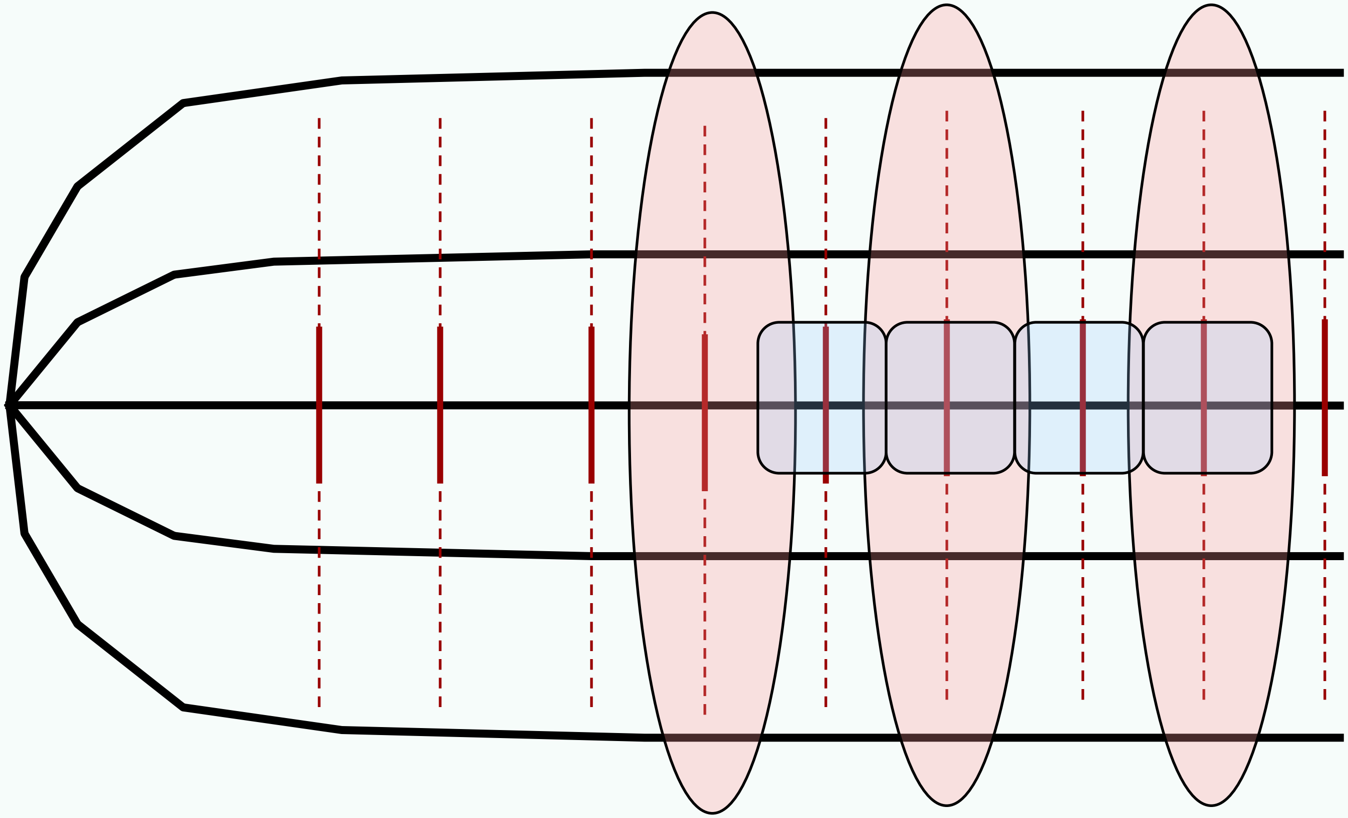
Well Spacing Constraints on Area



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Production Analysis Example

- Depth = 10000 ft
- Pressure = 8000 psi
- Porosity = 0.05
- Sw = 0.35
- Net H = 50 feet
- Perm 1 = 0.01 md (.5 md-ft)
- Perm 2 = 0.0001 md (0.005 md-ft)
- Area 1 = 20 acres
- Area 2 = ? acres
- Xf = 150 feet
- WHFP = 300 psi (3.992” ID Casing)
- BHST = 240F

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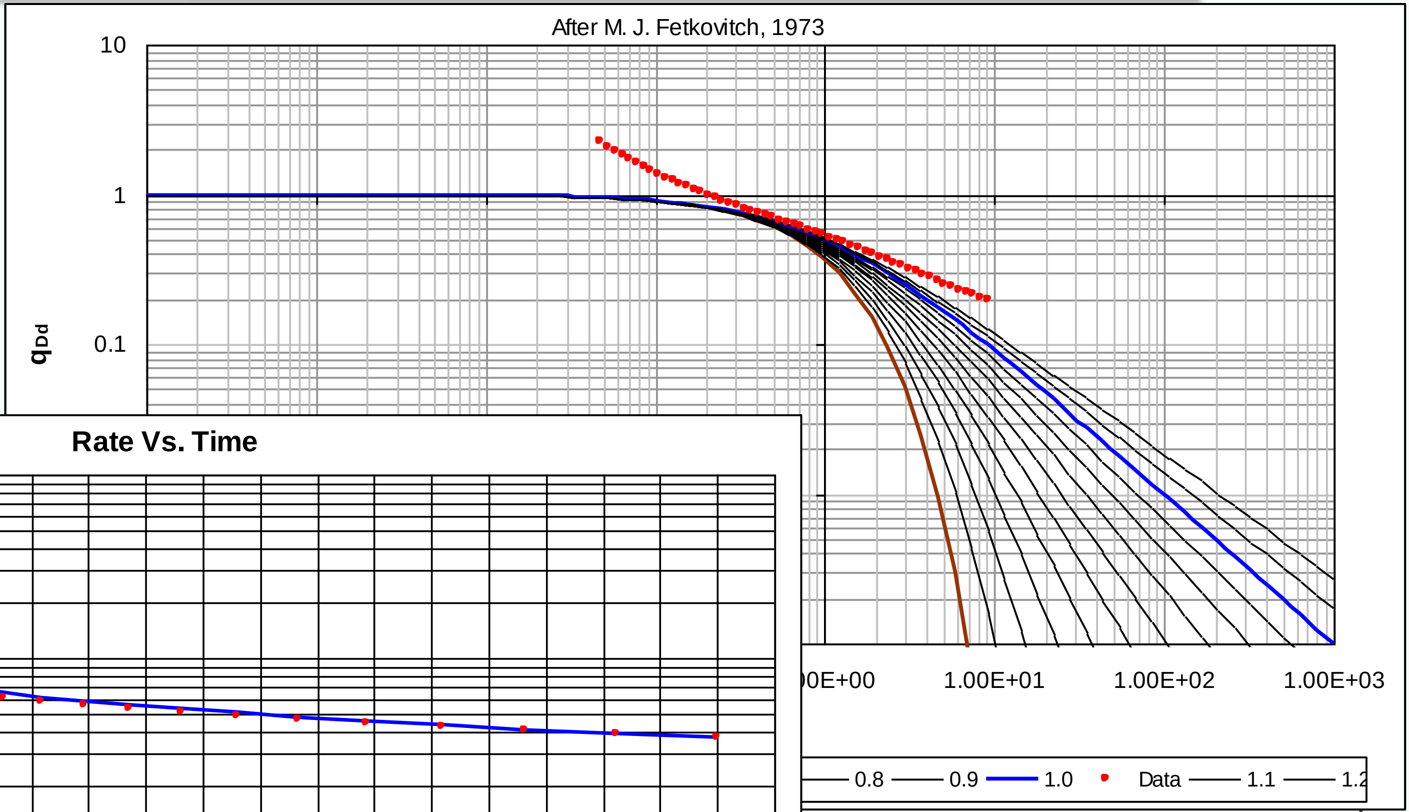
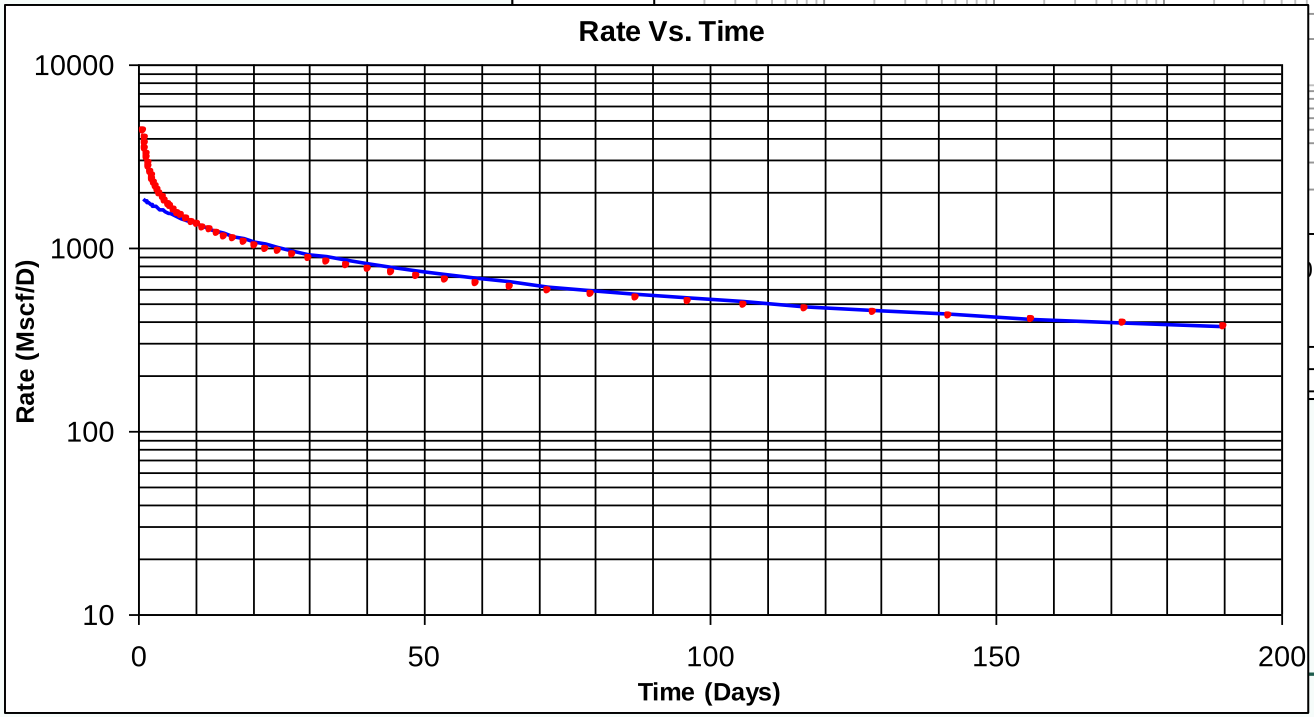
Decline Analysis on 180 Days, b=1.7





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Possible EUR Estimates with Hyperbolic Decline (b>1)

Decline Exponent b	1.7	
EUR	10.998	BCF
Abandonment Rate	1	Mscf/day
Terminal Decline	0	%

- No terminal exponential decline or abandonment rate

Decline Exponent b	1.7	
EUR	0.933	BCF
Abandonment Rate	1	Mscf/day
Terminal Decline	6	%

- Using 6% terminal exponential decline

Decline Exponent b	1.7	
EUR	0.662	BCF
Abandonment Rate	50	Mscf/day
Terminal Decline	0	%

- Using reasonable minimum economic rate

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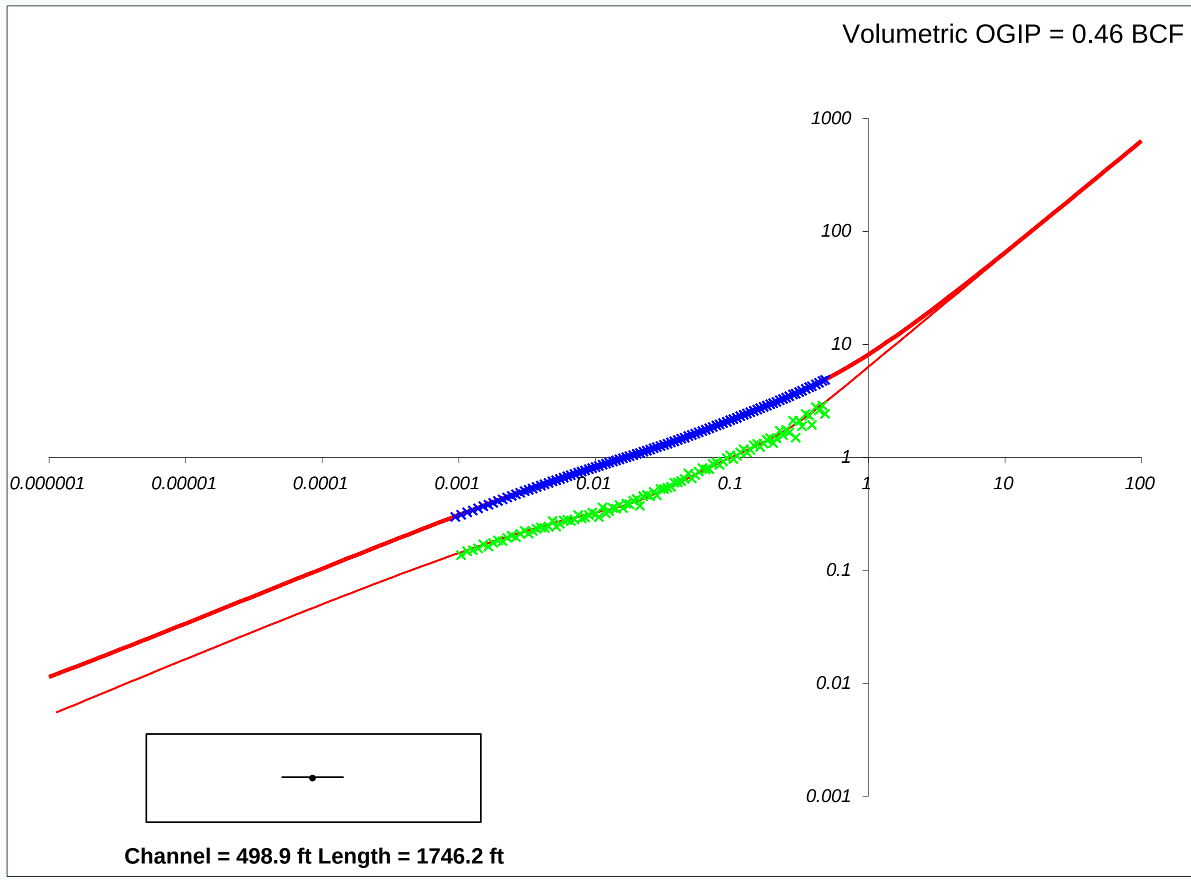
Example Type-Curve (1 year)

Case 2		
Inner Boundary		Infinite Conductivity Fracture
Outer Boundary		Rectangular
Reservoir Pressure	Pi	8000
Reservoir Temperature	T	240
Thickness	h	50
Permeability	k	0.01
Porosity	ϕ	0.05
Area	A	20
Half length	Xf	160
Skin	Skin	0
Fracture Conductivity	kfwf	50
Wellbore Storage	C	0
Aspect Ratio	L/W	3.5
Channel Width	ft	480
Well X-Offset	Xoff	0.5
Well Y-Offset	Yoff	0.5
Wellbore Radius	Rw	0.354
Vertival/Horizontal Perm	Kv/Kh	0.01
Horizotal Well Length	Lh	5000
Vertical Postion	Zwd	0.5
Specific Gravity	γ_g	0.65
Initial Water Saturation	Swi	0.35
Water Compressibility	cw	3.00E-06
Formation Compressibility	cf	6.78E-06
Carbon Dioxide	CO2	0
Nitrogen	N2	0
Hydrogen Sulphide	H2S	0
Wellhead Temperature	WHT	80
Measured Depth	L	10000
Pipe Roughness	ε	0.0023
Pipe Diameter	d	3.992
Condensate API	API	55
Diameter Perfs	dp	3.992

☐ Wellbore Cleanup ☐ Time Superposition ☑ Convert to BHP ☐ Channel Width ☐ Pressure Smooth [History Match]



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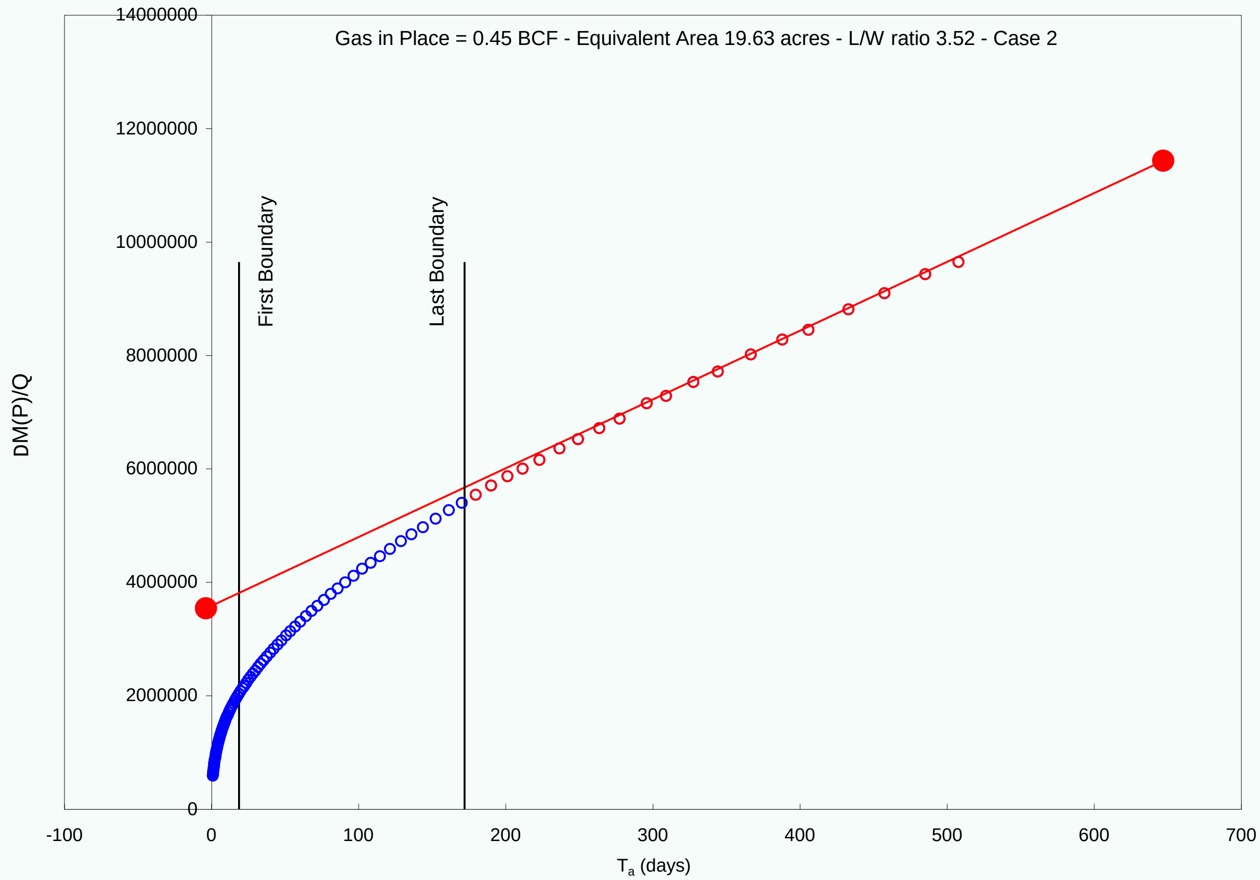
Example Flowing Material Balance Plot (1 year)



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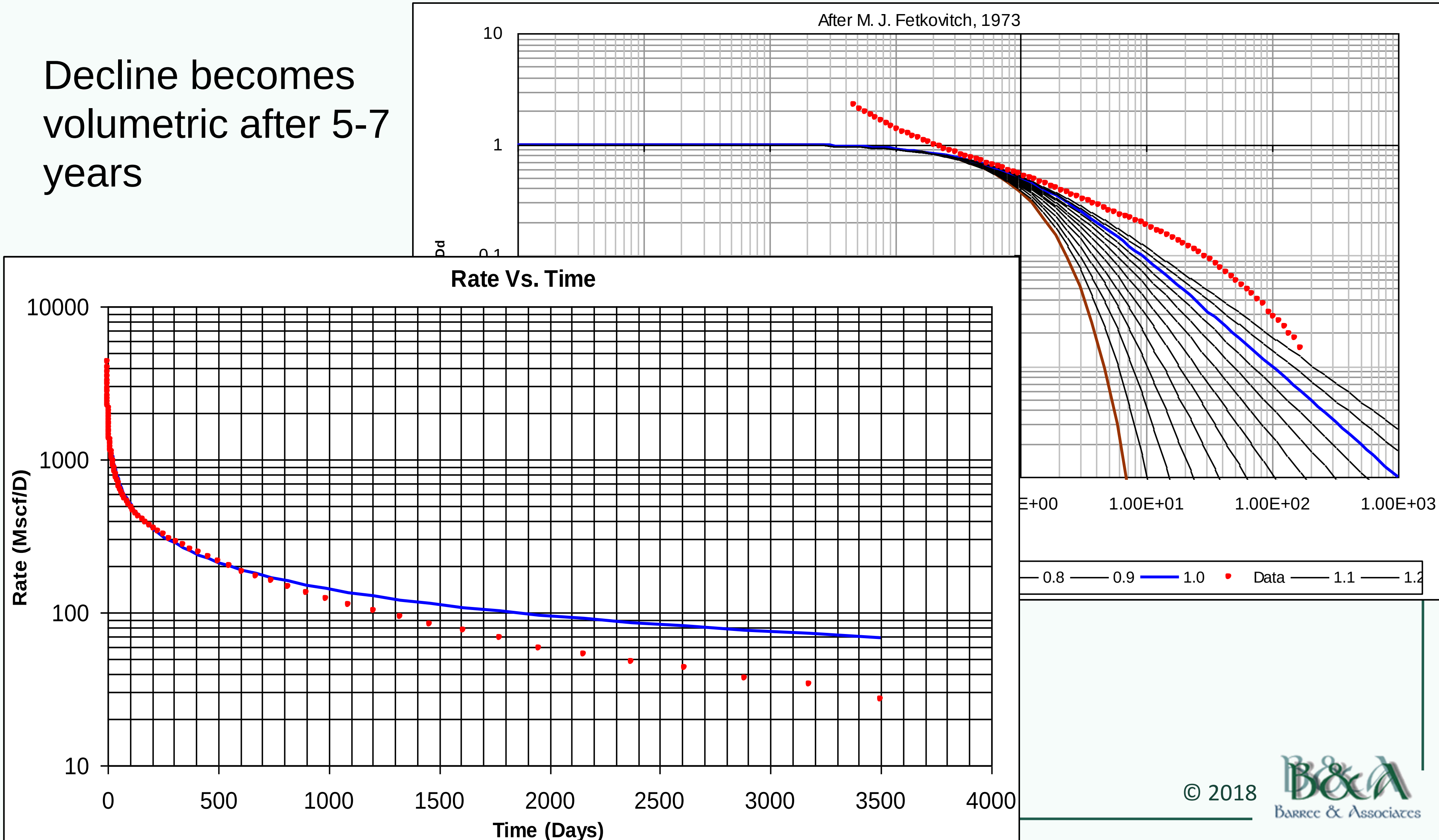
Decline Curve on 10 years Production

Decline becomes volumetric after 5-7 years



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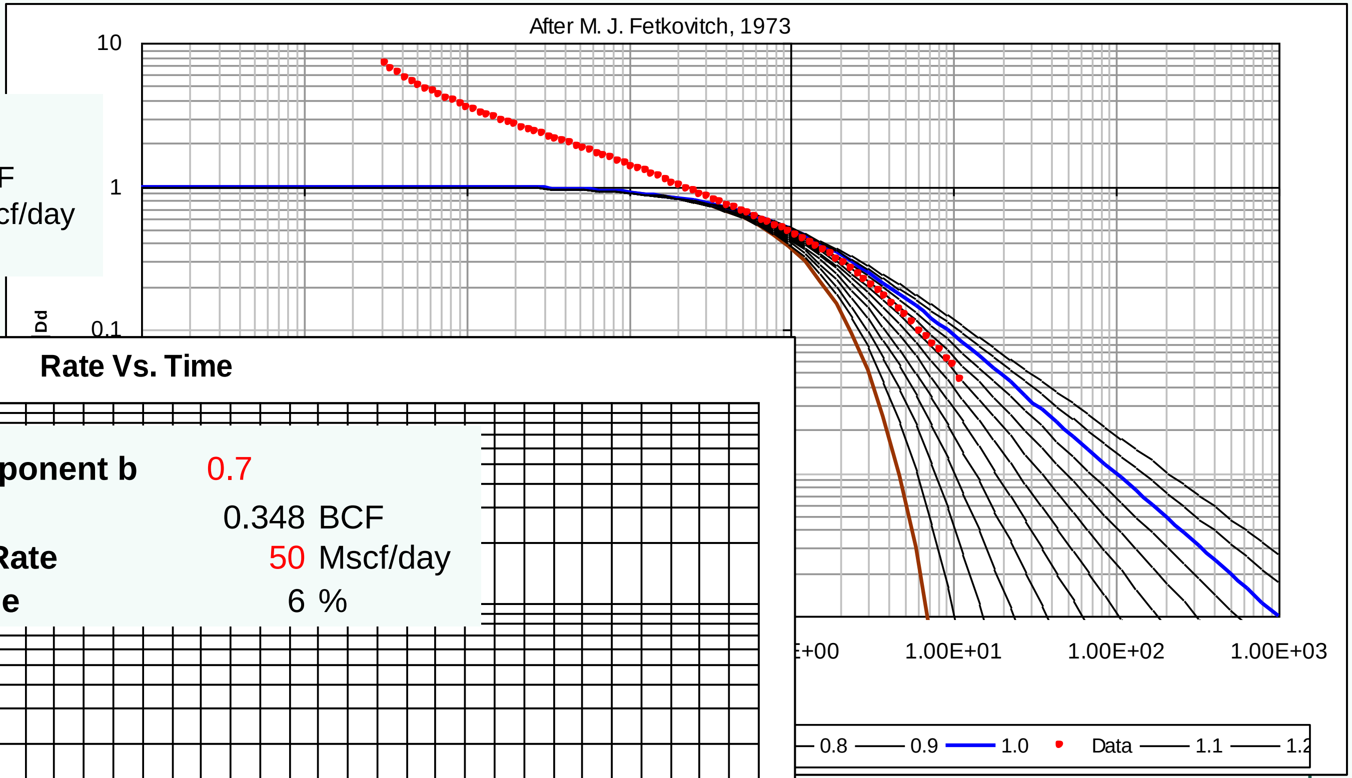
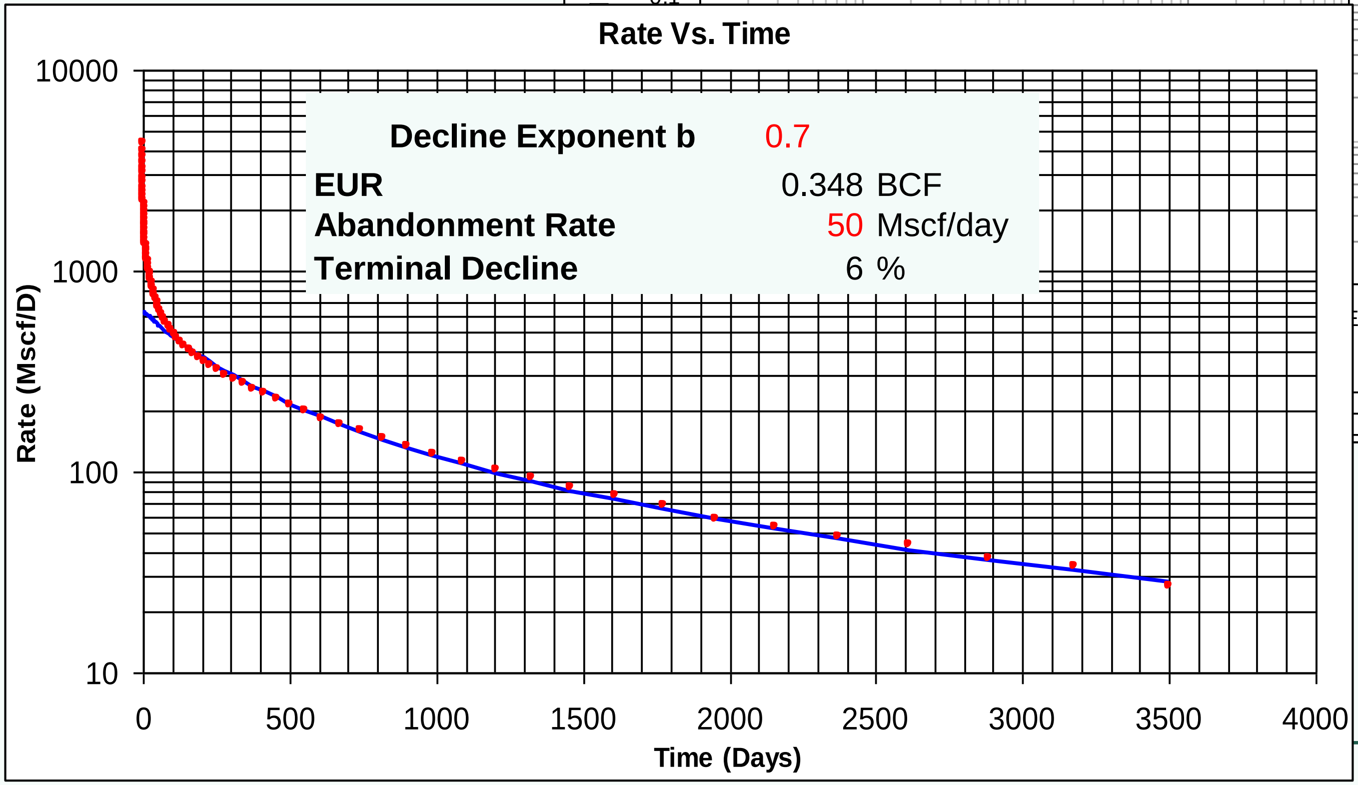
10 year Decline Adjusted to b=0.7

Decline Exponent b	0.7	
EUR	0.561	BCF
Abandonment Rate	1	Mscf/day
Terminal Decline	0	%





Decline Exponent b	0.7	
EUR	0.348	BCF
Abandonment Rate	50	Mscf/day
Terminal Decline	6	%

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Production Analysis Example: What was really there? (2.8 BCF)

- Depth = 10000 ft
- Pressure = 8000 psi
- Porosity = 0.05
- Sw = 0.35
- Net H = 50 feet
- Perm 1 = 0.01 md (.5 md-ft)
- Perm 2 = 0.0001 md (0.005 md-ft)
- Area 1 = 20 acres (0.46 BCF OGIP)
- Area 2 = 100 acres (2.3 BCF OGIP)
- Xf = 150 feet
- WHFP = 300 psi (3.992" ID Casing)
- BHST = 240F

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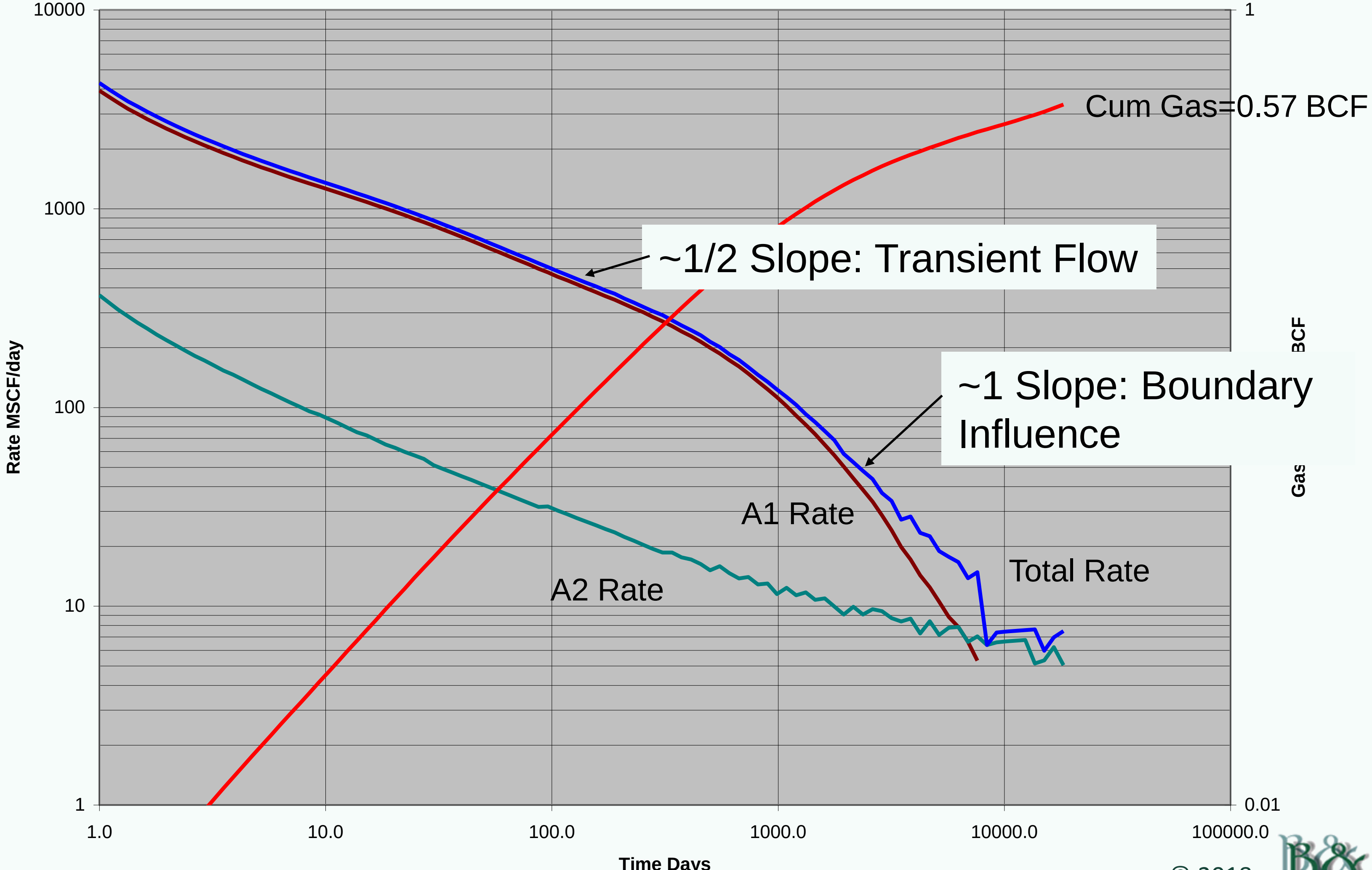
Example Production Decline (50 years)



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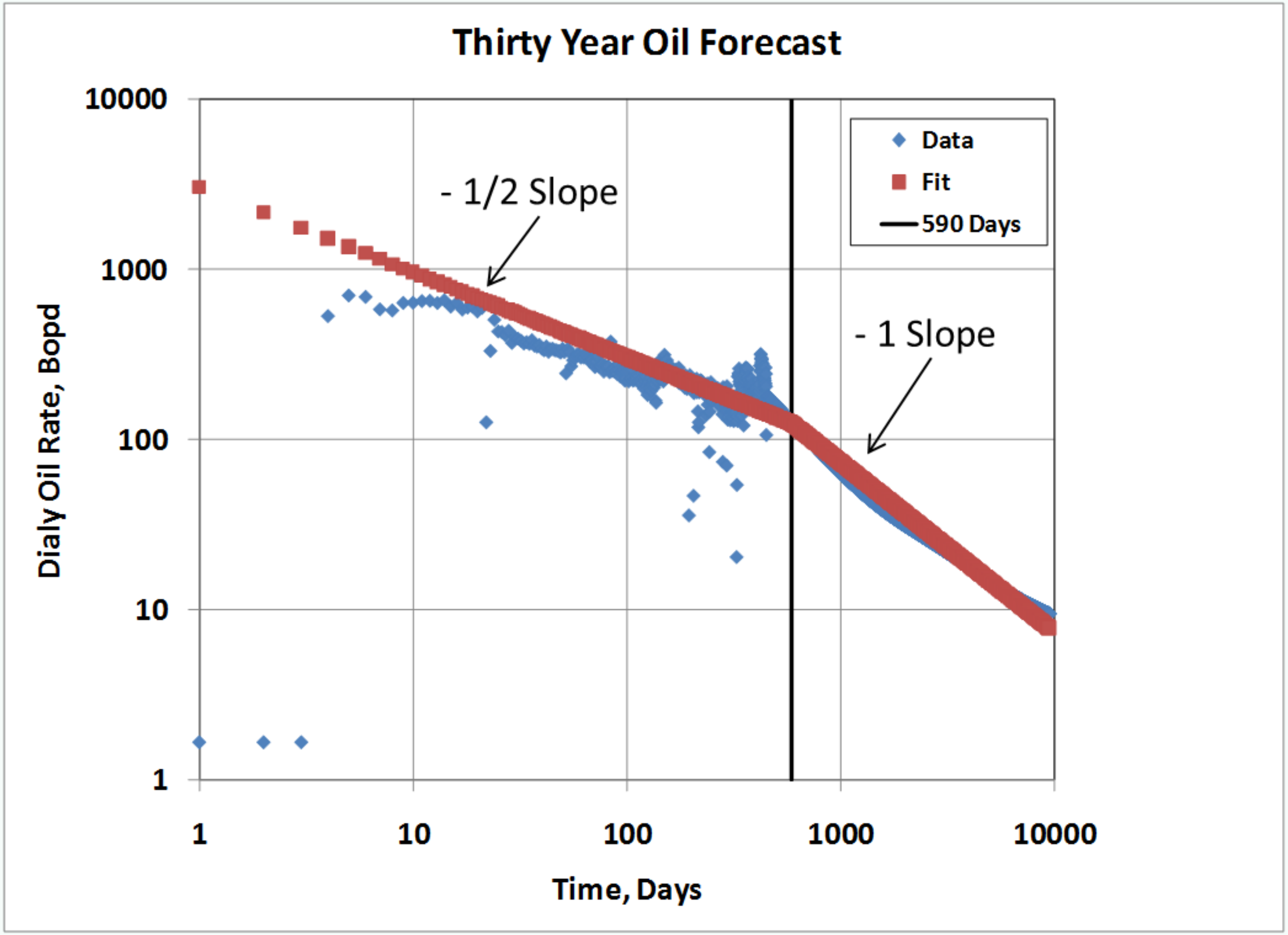
Example of Log-Log Diagnostic Plot for Bakken Oil Well



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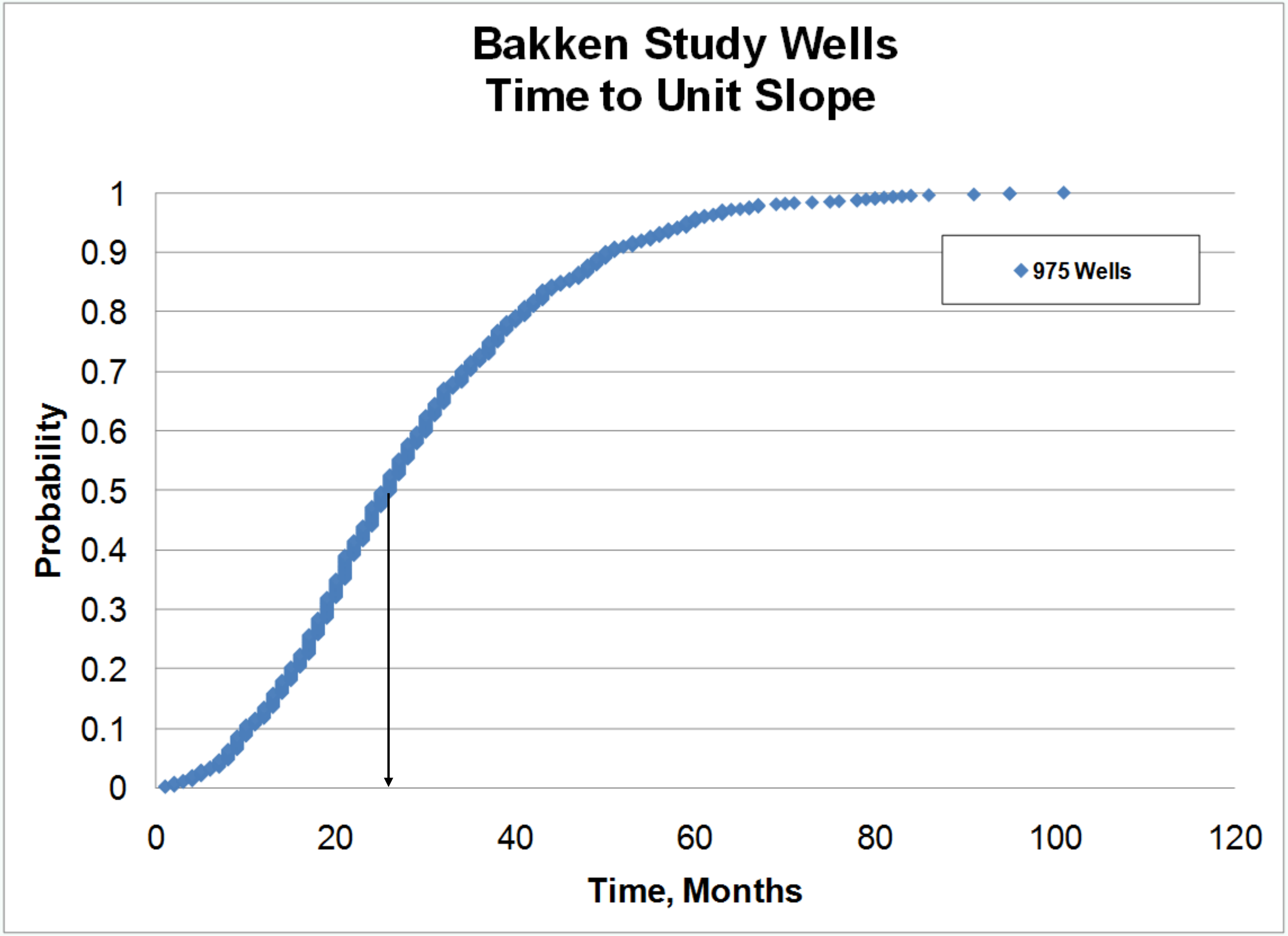
Overall Analysis of Time to Boundary Influenced Flow in Bakken



In Conclusion…

- Closely spaced perf clusters may accelerate early production, but there is a physical limit past which fractures will tend to annihilate one another
- Stress interference affects fracture geometry, asymmetry, and growth direction allowing fracs to be steered constructively or destructively
- Fracturing offsets to partially depleted wells leads to frac hits, well bashing, and loss of reserves
- Stimulated reservoir volumes larger than well spacing [probably] have minimal impact on actual reserves
- Estimating EUR from early production (even a year) can be fruitless and deceiving
- Is the industry "spending money like a drunken sailor"?

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Not to disparage drunken sailors…

"Most of [my pay] goes for likker and wimmen. The rest I spend foolishly"

-A U.S. sailor in China, 1920's
The Quarterly Journal of Military History
Summer 2013, Volume 25, Number 4

Even drunken sailors can weigh and set priorities.

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Thank you!

Questions?

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