PRACTICAL AND TIMELY HORIZONTAL MULTISTAGE INFILL WELL PRODUCTION AND EUR EVALUATION METHODOLOGY

Harmony RTA & RUBIS Numerical Simulation Models

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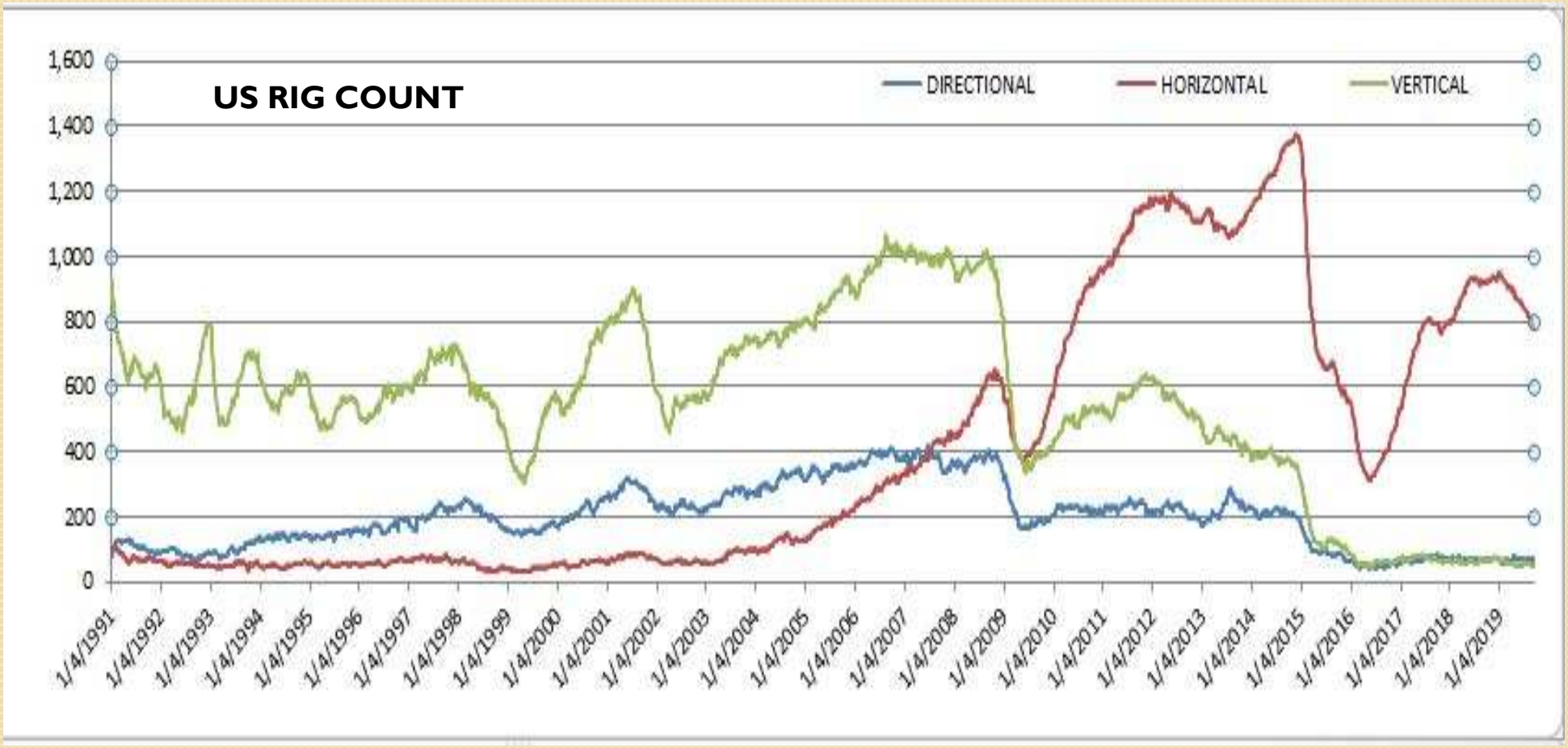
INTRODUCTION

- **A methodology is presented to determine production profiles, EUR and NPV10 values for new infill well optimization.**
- **The methodology takes into account variances in well completion types, offset well parent well history, and reservoir complexity including pressure depletion and well spacing.**
- **Examples are presented for the Williston Basin but the basic analysis procedure can be applied to any horizontal well development area by small and large companies.**

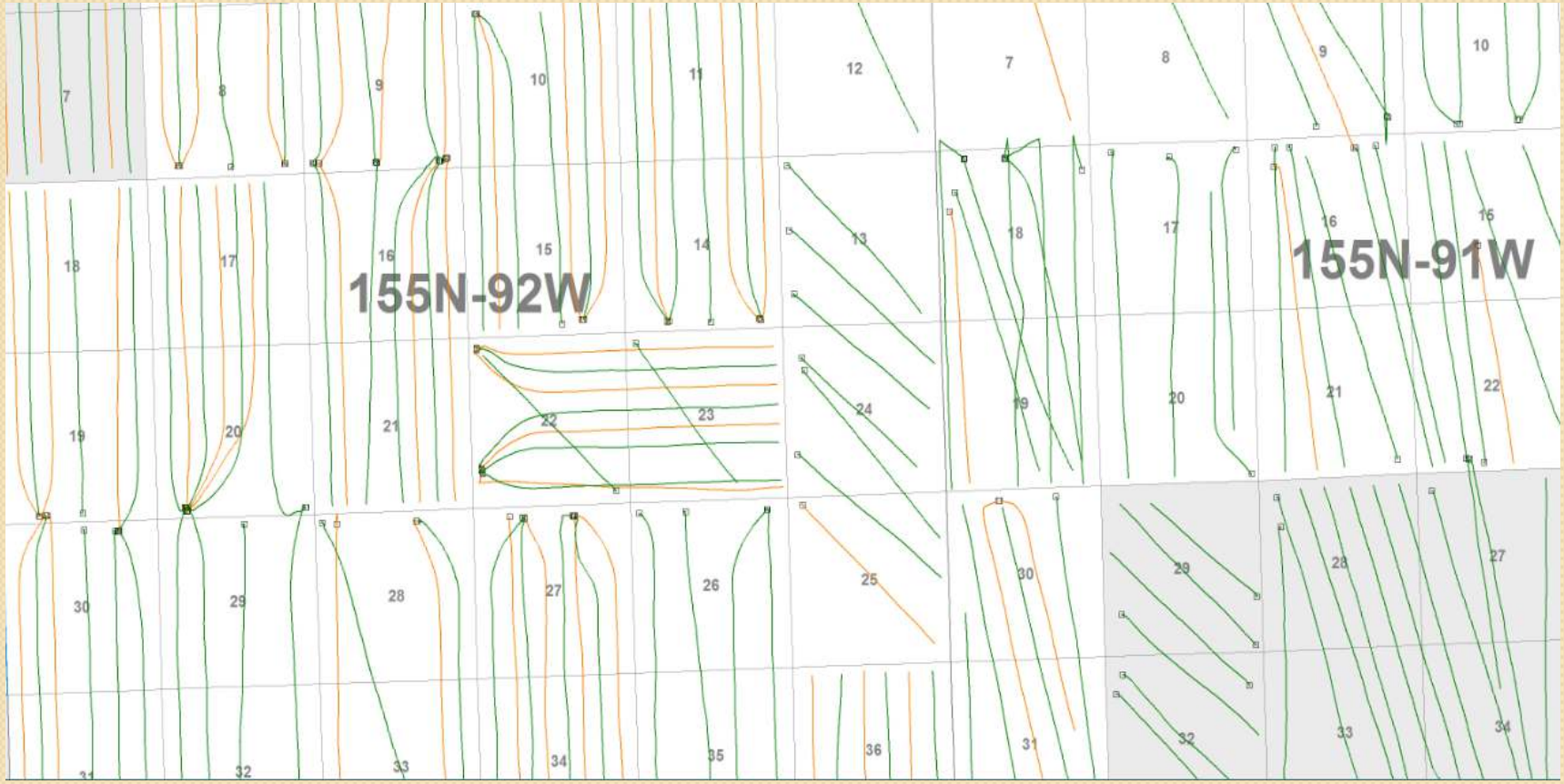
BAKER HUGHES RIG COUNT BY WELL TYPE 1991-2019

1991 9% HORIZONTAL WELLS 2019 87% HORIZONTAL WELLS



VISUALIZATION OF THE PROBLEM

OVER 14,000 HORIZONTAL WELLS IN NORTH DAKOTA DRILLED FROM 1987 TO 2019 IN BAKKEN AND THREE FORKS (Bakken Pool)



NDIC Well Index.xlsx 6 Different Well Orientations | 6 Different Completion Types | Pressure Depletion |

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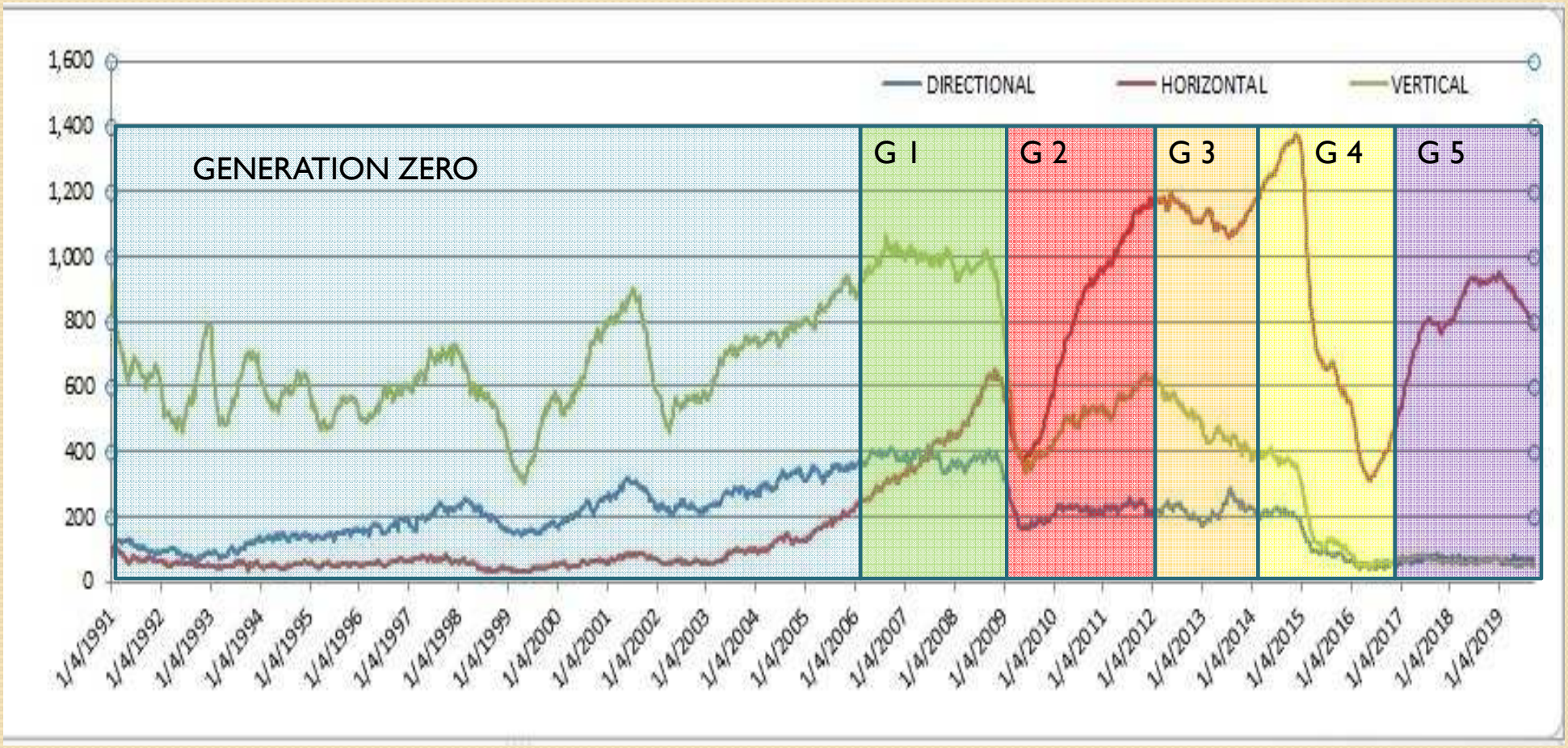
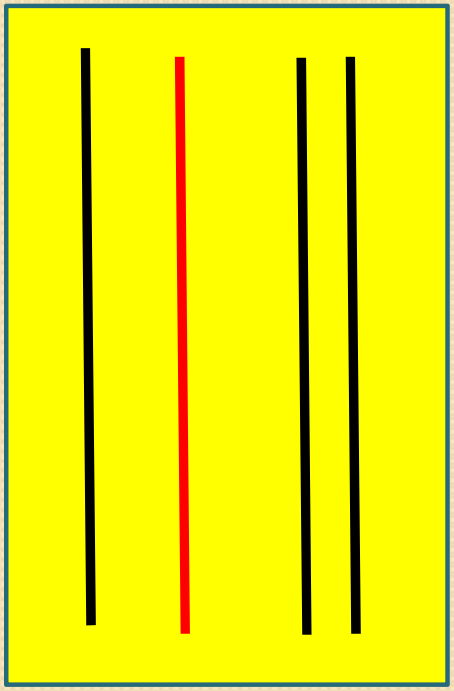


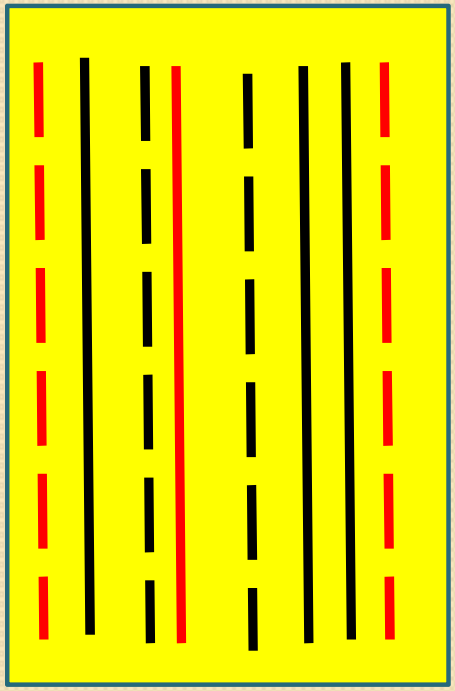
WHAT IS THE RIGHT SOLUTION TO MAXIMIZE NPV10 ?

BAKKEN —— THREE FORKS ——

PARENT WELLS
3 BK + 1 TFK

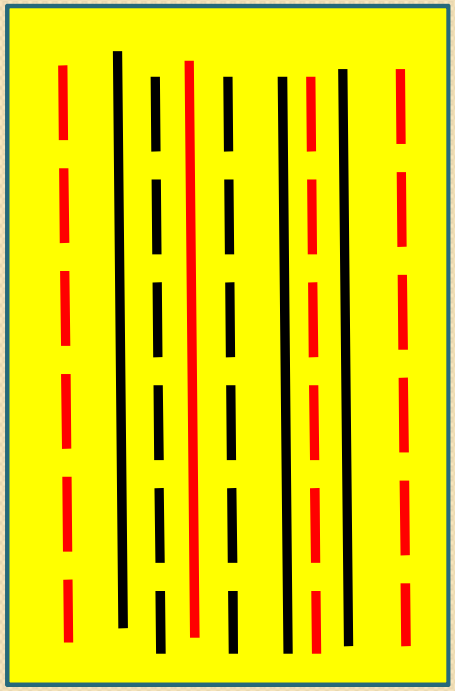


INFILL OPTION I
5 BK + 3 TFK



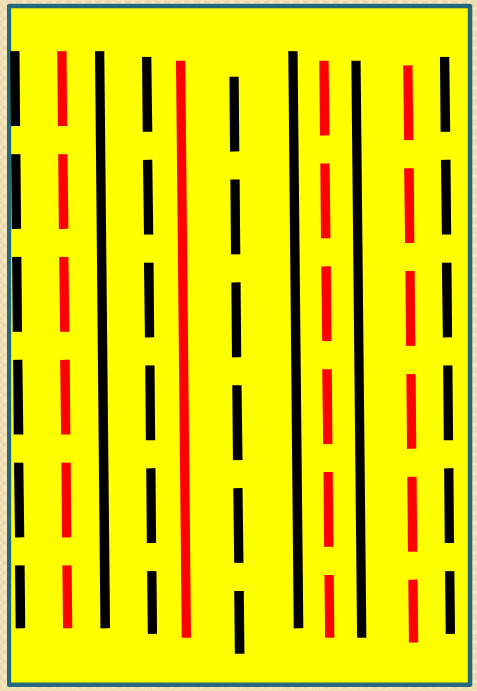
NEW ADD RESERVES

INFILL OPTION II
5 BK + 4 TFK



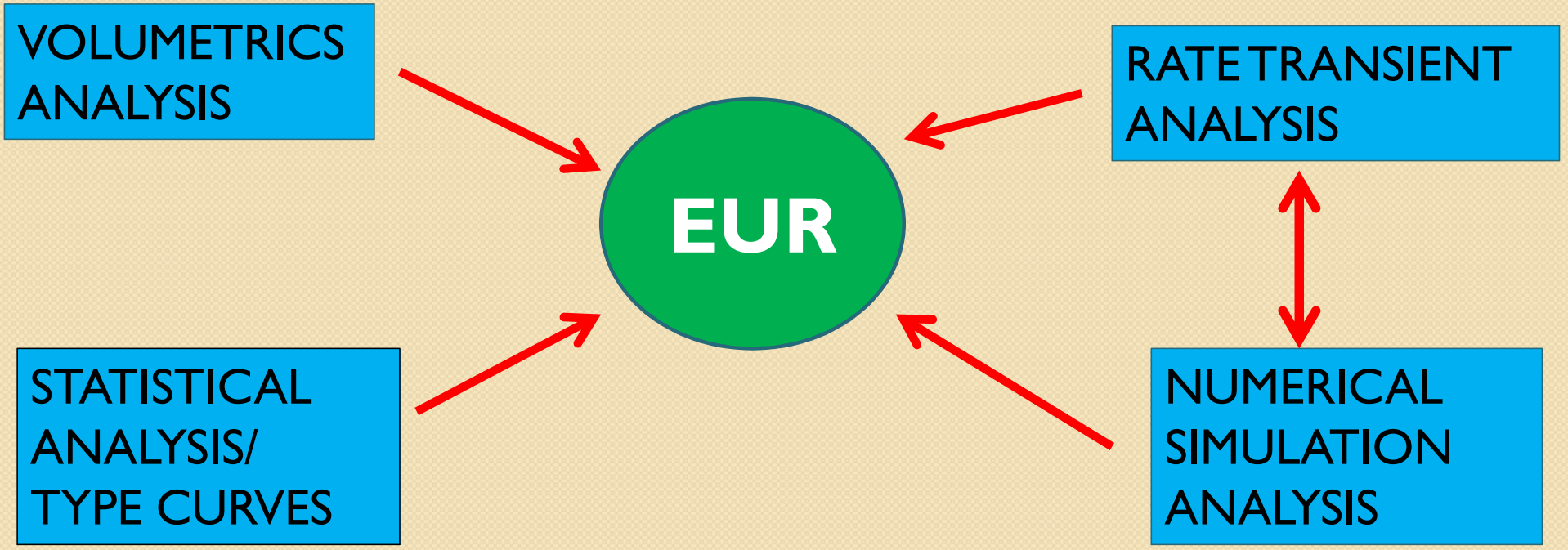
NEW ADD RESERVES

INFILL OPTION III
7 BK + 4 TFK



ACCELERATION ?

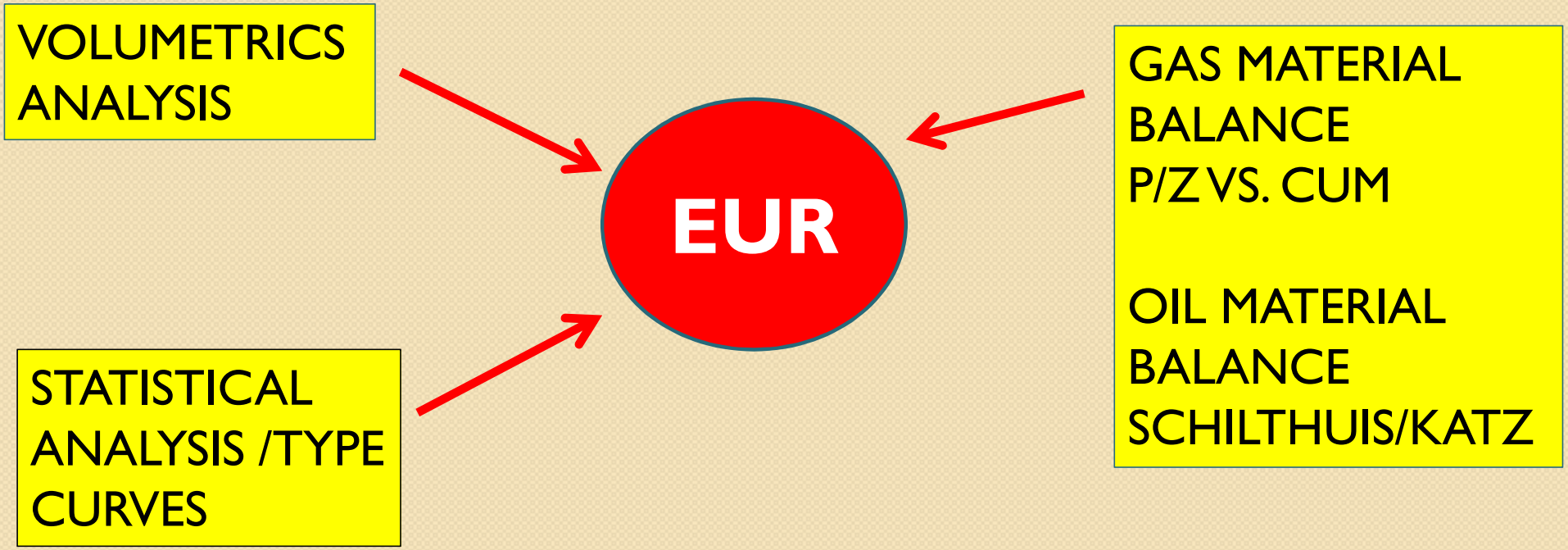
Methodology Used for Analysis Horizontal Multistage Infill Wells EUR and NPV10 Analysis



Tool Kit Used for Analysis Horizontal Multistage Infill Wells EUR and NPV10 Analysis

VOLUMETRICS ANALYSIS	STATISTICAL ANALYSIS/TYPE CURVES	RATE TRANSIENT ANALYSIS	NUMERICAL SIMULATION ANALYSIS
PETREL	SPOTFIRE	HARMONY RTA	RUBIS
PETRA	DECLINE PLUS	TOPAZ	ECLIPSE/PETREL
LESA	ARIES	HARMONY ENTERPRISE	CMG
JLOG	PEEP		INTERSECT
GEOGRAPHIX	PHDWIN		
	VALUE NAVIGATOR		

Methodology Used for Analysis Infill Vertical Gas/Oil Wells 1950's-1990's



Evolution of Horizontal Well Analysis Methodology Open Hole Completions

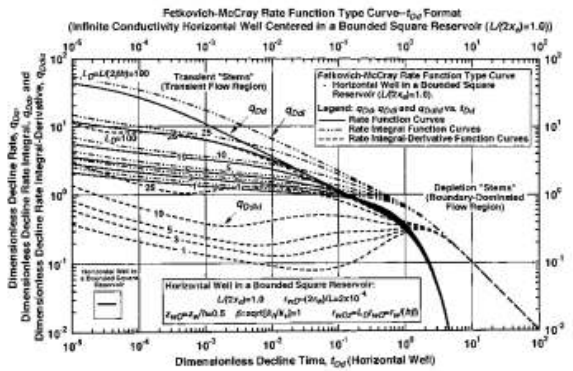
- **Analytical Solutions**
  - Joshi (1990), Goode & Thambynaygam (1989) Babu & Odeh (1989), Aquilera et al. (1991)
- **Dimensionless Type Curves**
  - Blasingame and Shih 1995, University of Texas
- **Numerical Models**
  - Fanchi Boast and Eclipse 1990-1991, Kazemi 1991

CSM MS 1997 1ST HORIZONAL THESIS NELMS

Evolution of Horizontal Well Analysis Methodology Open Hole Completions

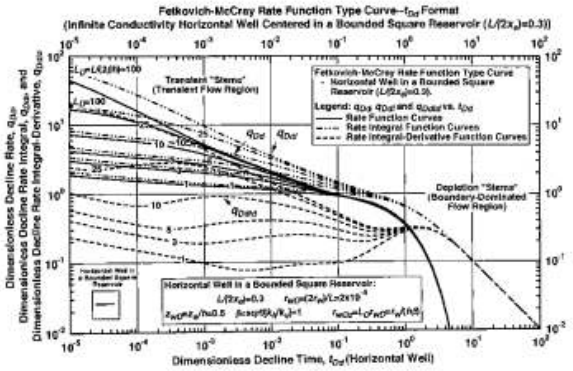
Doublet/Blasingame Type Curve Format — Horizontal Wells

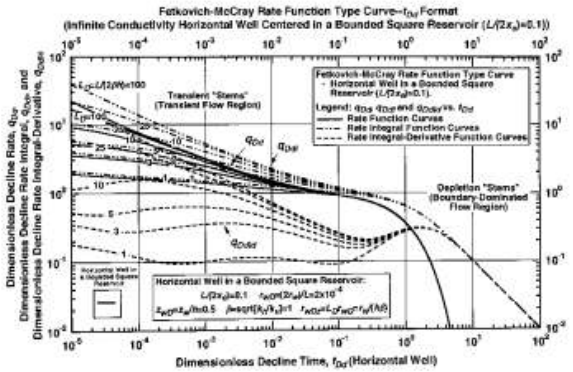
Shih, M.-Y. and Blasingame, T.A.: "Decline Curve Analysis Using Type Curves: Horizontal Wells," paper SPE 29572 presented at the 1995 Joint Rocky Mountain Regional/Low Permeability Reservoirs Symposium, Denver, CO, 20-22 March, 1995.



Horizontal Well Cases:

- "Infinite-conductivity" horizontal well case(s).
- Dimensionless reservoir model requires several parameters.

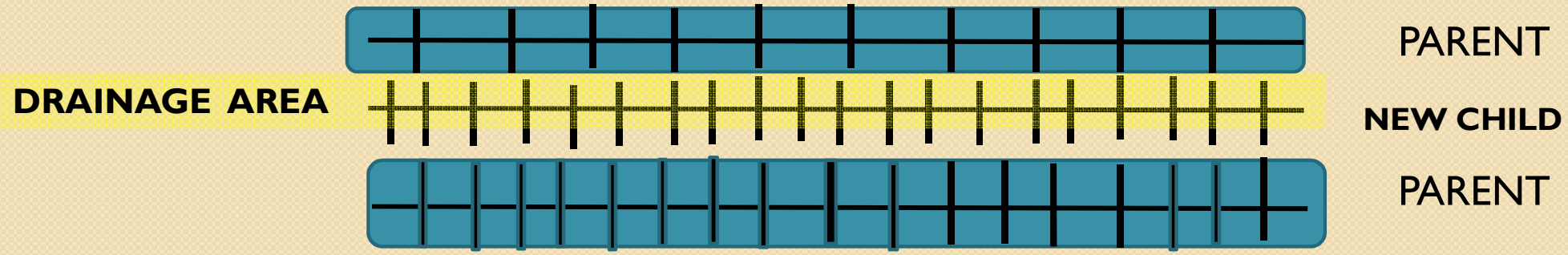




Wells That Started the Shale Revolution

1987	Meridian	Bakken	Billings	ND
1990		Niobrara	Silo Field	WY
1991	UPRC	Austin Chalk		TX
1991	Hess	Madison	McKenzie Co	ND
1994		Green River	Uintah Basin	UT
1996	Burlington	Tocito	San Juan Basin	NM
2000		Edwards	Kayne Co	TX
2003	Continental	Bakken	Elm Coulee	ND
2008	Petro Hawk	Eagleford		TX
2009	EOG	Niobrara	Weld	CO
2009		Shannon	Powder River	WY

Methodology Used for Analysis Infill Wells
Volumetric Analysis:
Parent Well Drainage Areas

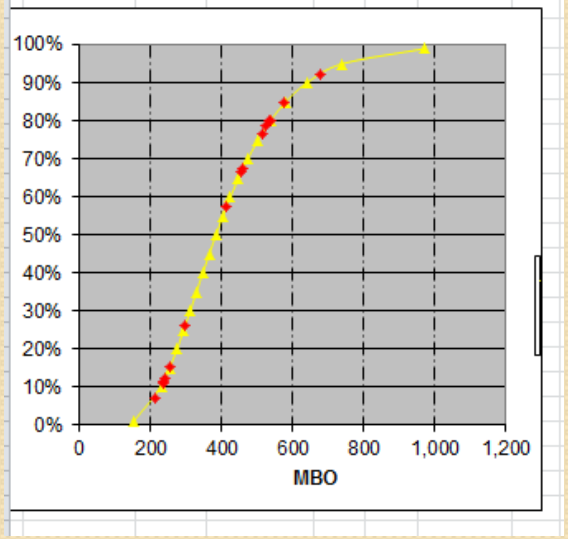


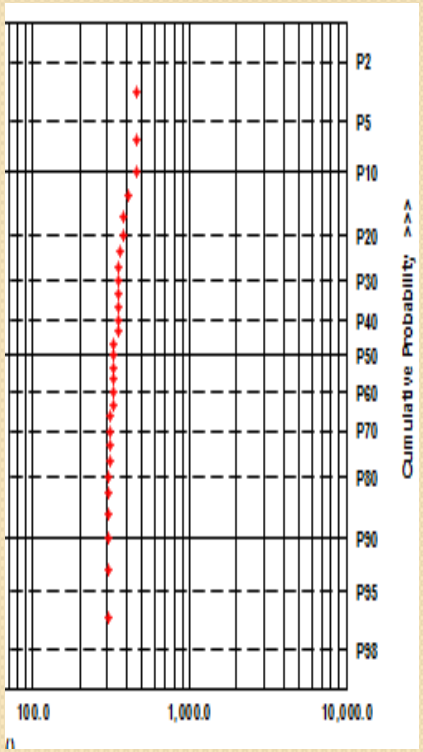
DRAINAGE AREA = f (Sw, H, Porosity, Recovery Factor)

Sources of error: Accuracy Sw, H, Porosity and Heterogeneity
What is the correct Recovery Factor? Statistical ?
RF = f (Keff oil matrix and Kf natural and induced fractures)
Does not take into account pressure depletion.

Methodology Used for Analysis Infill Wells
Statistical Analysis of Offset Parent Wells

Mode (most likely)	327
P_{50} (median)	384
Mean (average)	412
P_{1}	152
P_{10}	230
P_{90}	640
P_{99}	970
Pseudo Mean	371



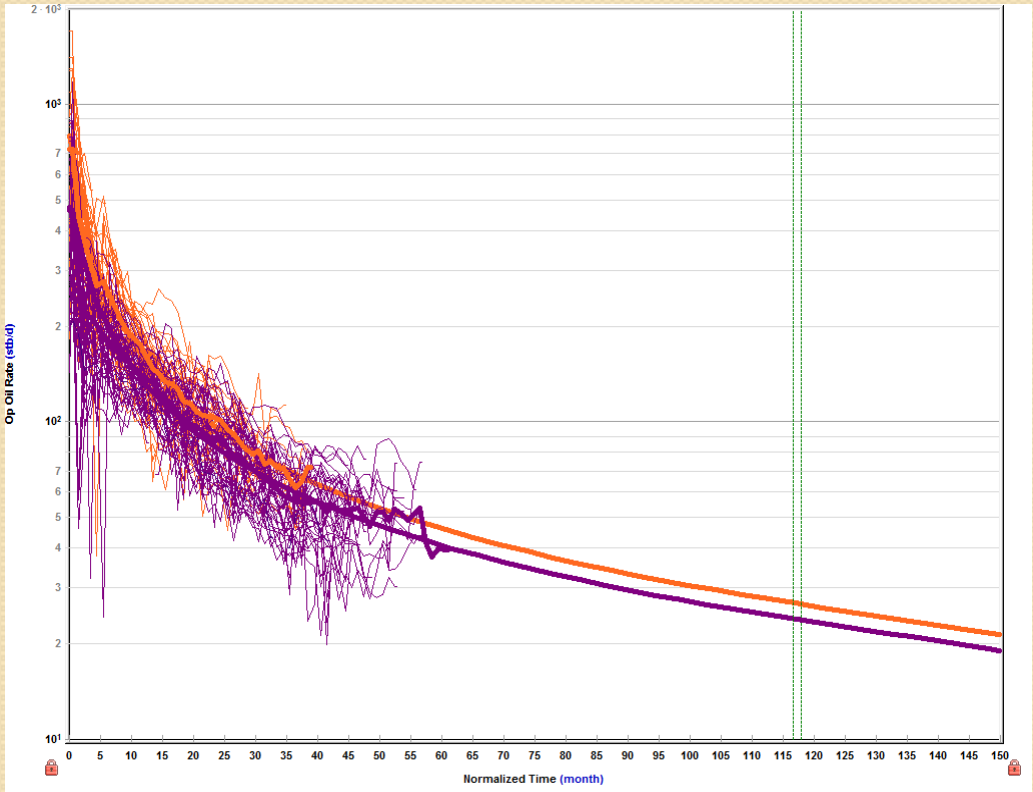


Can get different answers depending on characteristics of input Parent wells selected for P10, P50, P90 plots.

Need to consider completion type and age of offset Parent wells in analysis.

Effects of pressure depletion not quantified for Child wells.

Methodology Used for Analysis Infill Wells
Statistical Analysis of Offset Parent Wells
Offset Well Production Type Curves



Attempt to create type curves for similar wells in similar areas.

Need to consider completion type and age of offset Parent wells in analysis.

If completion type are different attempt to normalize with multiplier

Effects of pressure depletion not quantified for Child wells.

Methodology Used for Analysis Infill Wells Consideration of Completion Types

GENERATION FRAC DESIGN	DATES	COMPLETION TYPE	# STAGES	# CLUSTERS	#MM OF SAND	FLUID MBBLS
0	1985-2006	OPEN HOLE	1	0	<0.5	<10
1	2006-2009	OH- SLEEVES PACKERS	10	0	0.5-1.5	10-20
2	2009-2012	OH- SLEEVES PACKERS	30	0	1.0-2.5	20-30
3	2012-2014	CEMENTED LINERS	40	2	2.5-4.0	30-80
4	2014-2016	CEMENTED LINERS	40	3-4	6.0-8.0	80-150
5	2016-2019	CEMENTED LINERS	75	5-6	8.0-11.0	150-250

Reservoir pressure in 2006-2008 Parent wells was 7,000 psi.

Current reservoir pressures in 2019 for Infill Children wells can be as low as 3,000 to 4000 psi

Must normalize completion types and ages in Statistical and Type Curve analysis to transition form Parent wells to New Child wells.

Multipliers? 0.8X 1.2X 1.4X

Comparing apples to oranges with out pressure depletion considerations?

DARCY LAW $Q = kh/u\ (P^*-P)$

RTA and Numerical Model Infill Well Analysis Steps

1. Perform Harmony RTA model analysis on parent wells.

2. Build Kappa Engineering RUBIS model with parent and child wells.

3. Input geologic parameters (h, Sw, porosity), RTA results, and well construction design into RUBIS

4. Perform history match on parent wells in RUBIS modifying Keff oil on an individual well basis.

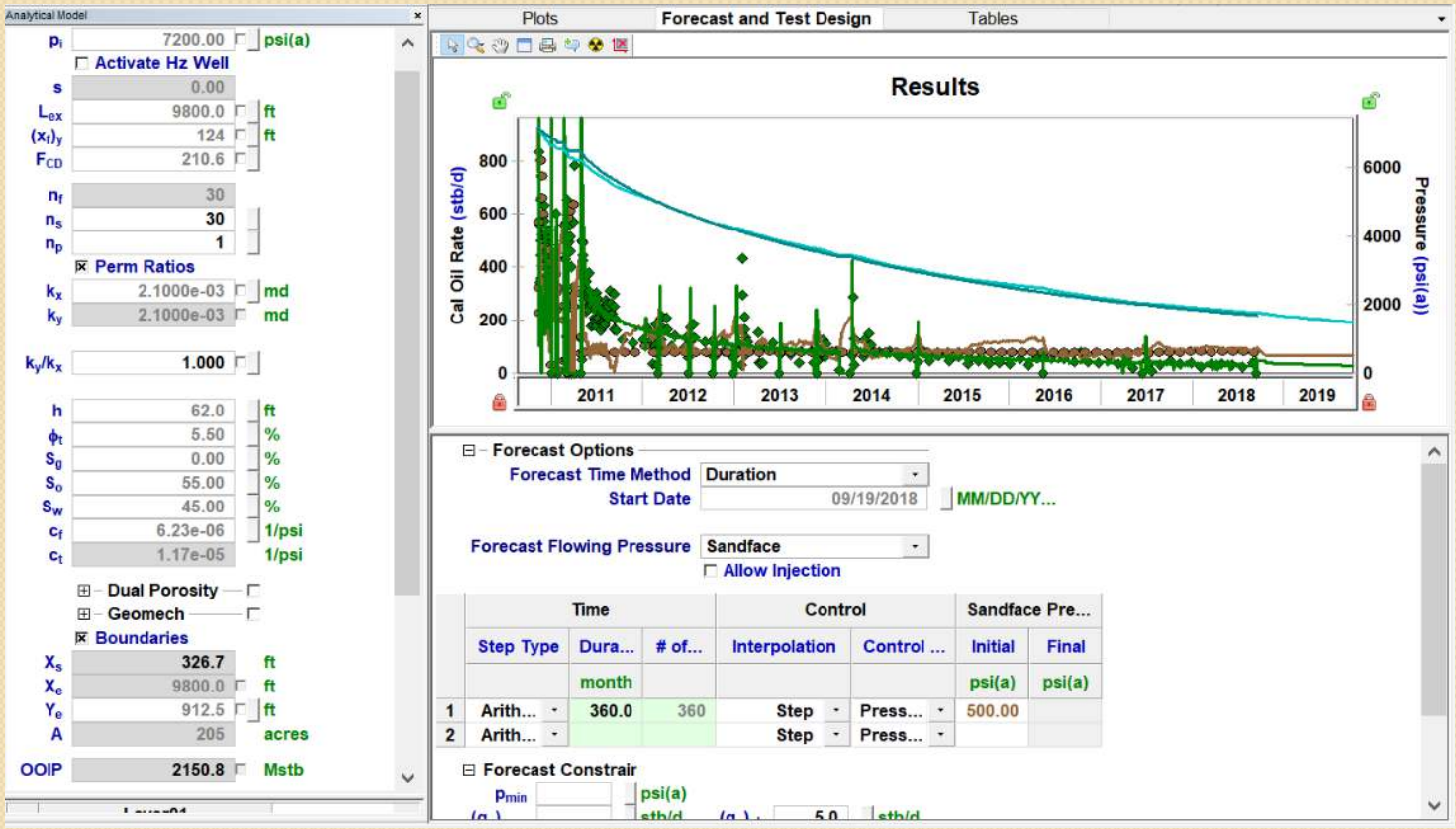
RTA and Numerical Model Infill Well Analysis Steps

5. Compare actual parent well oil production decline curves and **RUBIS** numerical model simulation output to validate history match.

6. Use **RUBIS** model to generate oil production curves. and **EUR** for infill child well(s) taking into account pressure depletion between older parent wells .

7. Load **RUBIS** model simulated oil production curves into economic program to generate **NPV10** based upon **RUBIS** forecasts.

RTA Analysis Parent Well(s) Production History Match

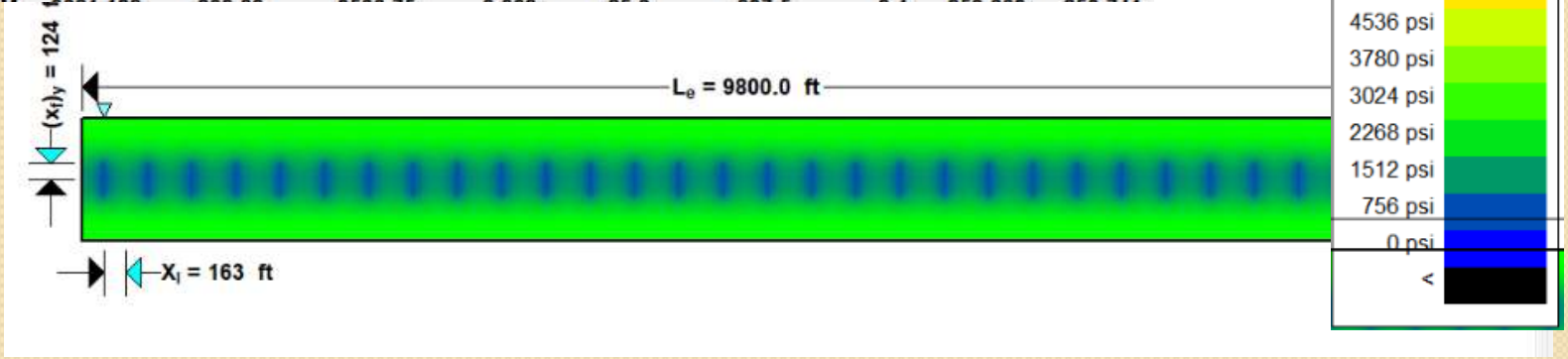


RTA Analysis Pressure Numerical Simluation

Plots | Forecast and Test Design | **Tables** | Status

History Match | **Forecast 1**

	Date	Time	$(p_{wf})_{calc}$	$(p_{avg,q})_{calc}$	$(q_g)_{calc}$	$(q_o)_{calc}$	$(GOR)_{calc}$	$(q_w)_{calc}$	$(G_p)_{calc}$	$(N_p)_{calc}$
	MM/DD/YYYY hh:mm:ss tt	d	psi(a)	psi(a)	MMscfd	stb/d	scf/bbl	stb/d	MMscf	Mstb
1	09/19/2018 12:00:00 AM	2869.000	494.68	3575.74	0.000	0.0		0.0	259.217	249.462
2	10/19/2018 10:30:00 AM	2899.438	677.92	3561.64	0.000	0.0		0.0	259.217	249.462
3	11/18/2018 09:00:00 PM	2929.875	768.94	3547.80	0.001	4.8	296.8	0.6	259.217	249.462
4	12/19/2018 07:30:00 AM	2960.313	800.00	3534.12	0.006	15.5	367.9	1.9	259.260	249.608
5	01/18/2019 06:00:00 PM	2990.750	800.00	3520.39	0.008	21.8	346.5	2.6	259.433	250.078



Pressure at 205 acre boundary is ~ 3600 psi

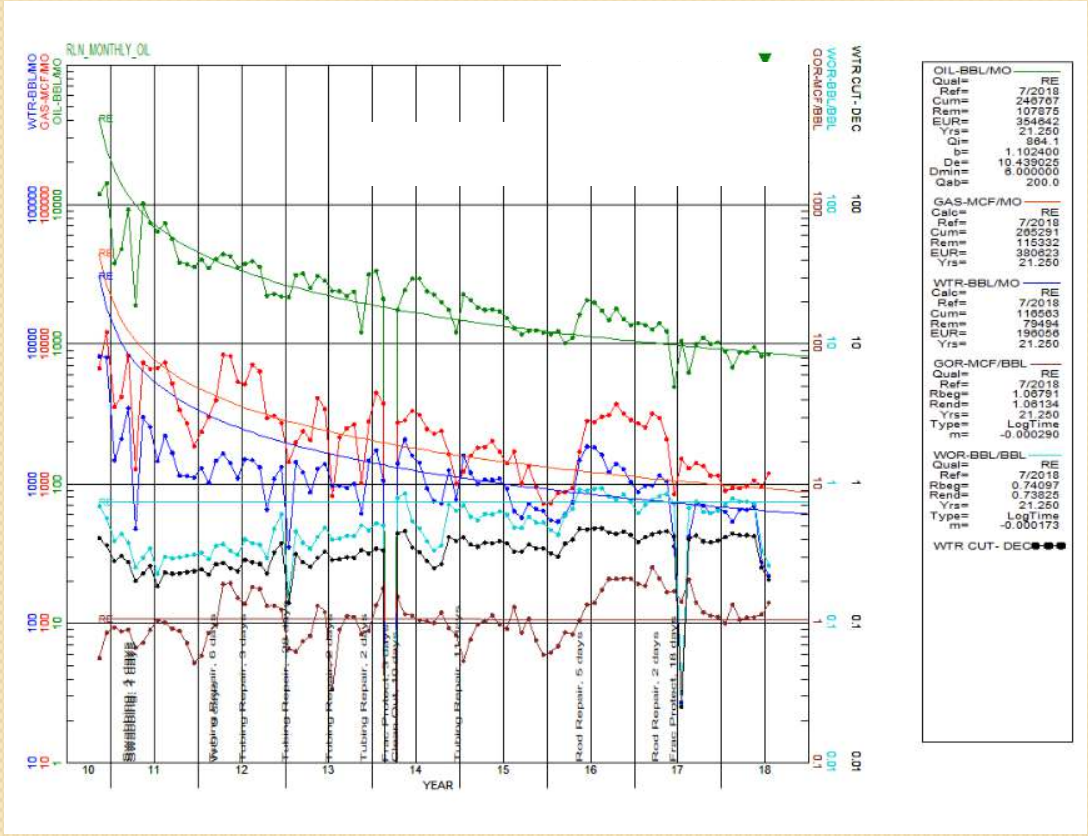
Summary of RTA Parent Well (s) Analysis Model

- P* = 7200 psi, Sw = 45%, h = 62', Por = 5.5%
- nf = 30 , Keff = 0.002 md, Lex = 9800', Xf = 124'
- FCD = 211
- Drainage area = 205 acres (9,800' x 913')
- RTA EUR = 297 Mbo
- RTA OOIP = 2.15MMbo

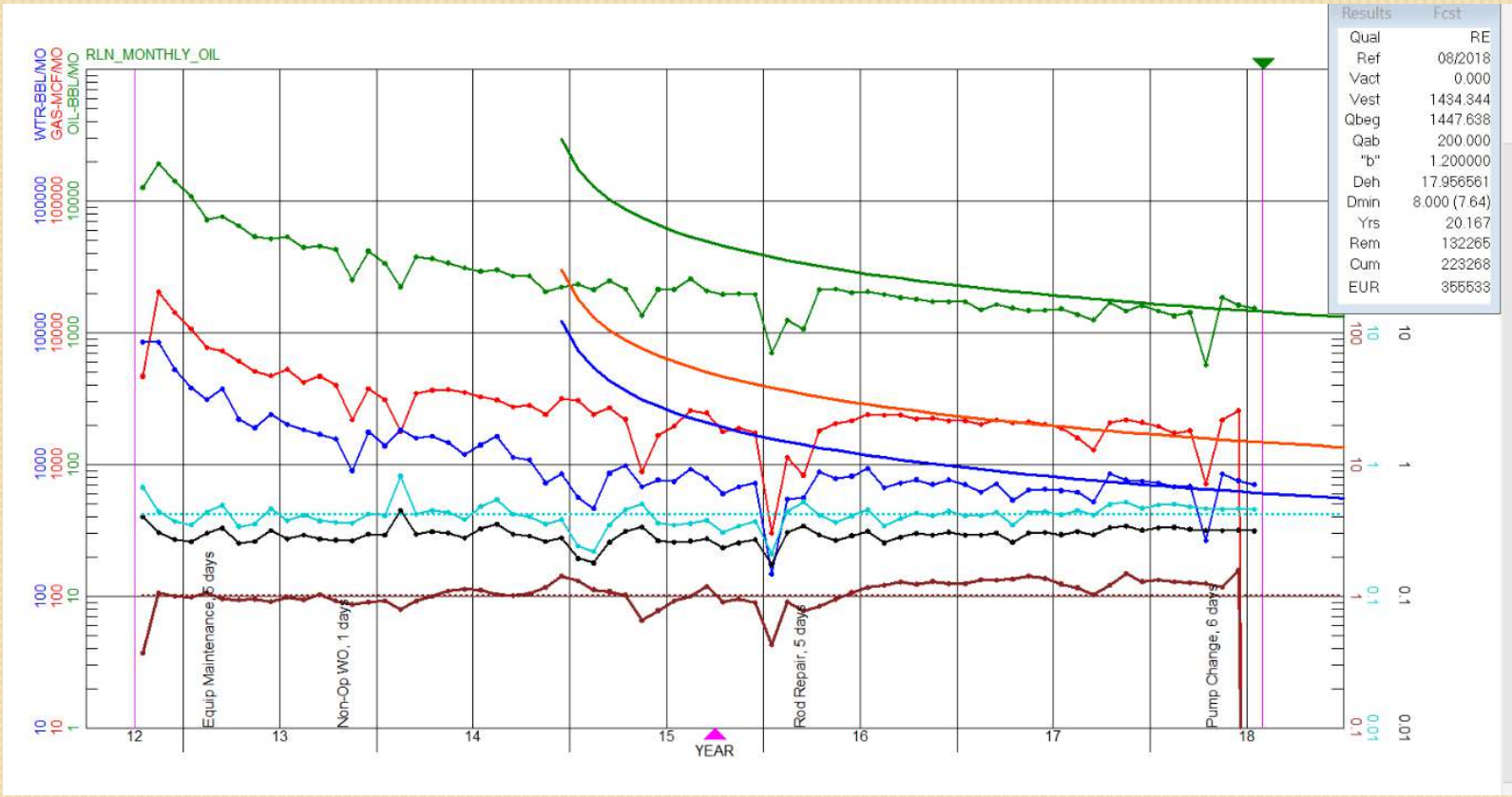
RTA Children Well Simulation Analysis Option

- Use RTA results from offset parent well history match to generate reservoir parameters.
- Create new RTA model with child well drainage area from volumetric analysis and input parent well reservoir parameters
- Set initial pressure to parent well boundary pressure.
- Change RTA child model parameters to reflect newer larger completion types. nf, xf, etc.

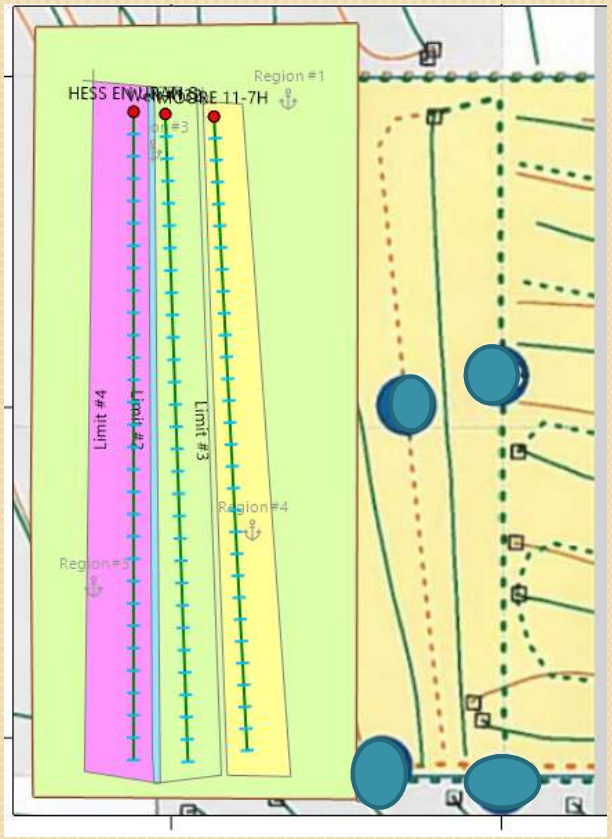
Offset Parent Production Decline Curves. EUR = 354 Mbo, Cum = 246 Mbo, DOFP = 11/30/2010, ARIES life = +21 Yrs, EL at 2039



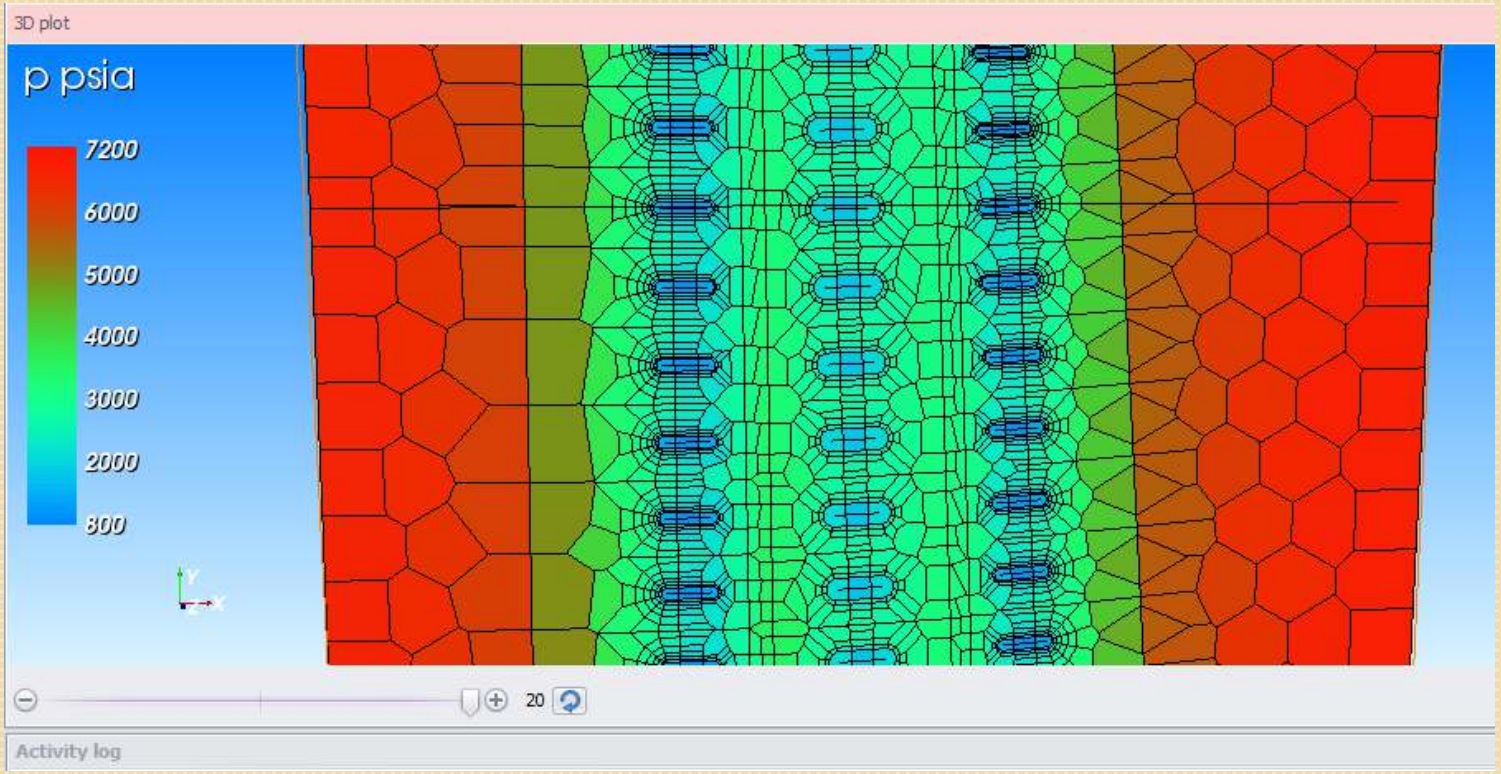
Offset Parent Well EUR = 355 Mbo, Cum = 223 Mbo, Life = 20 yrs, DOFP = 10/31/2012, EL = 2038



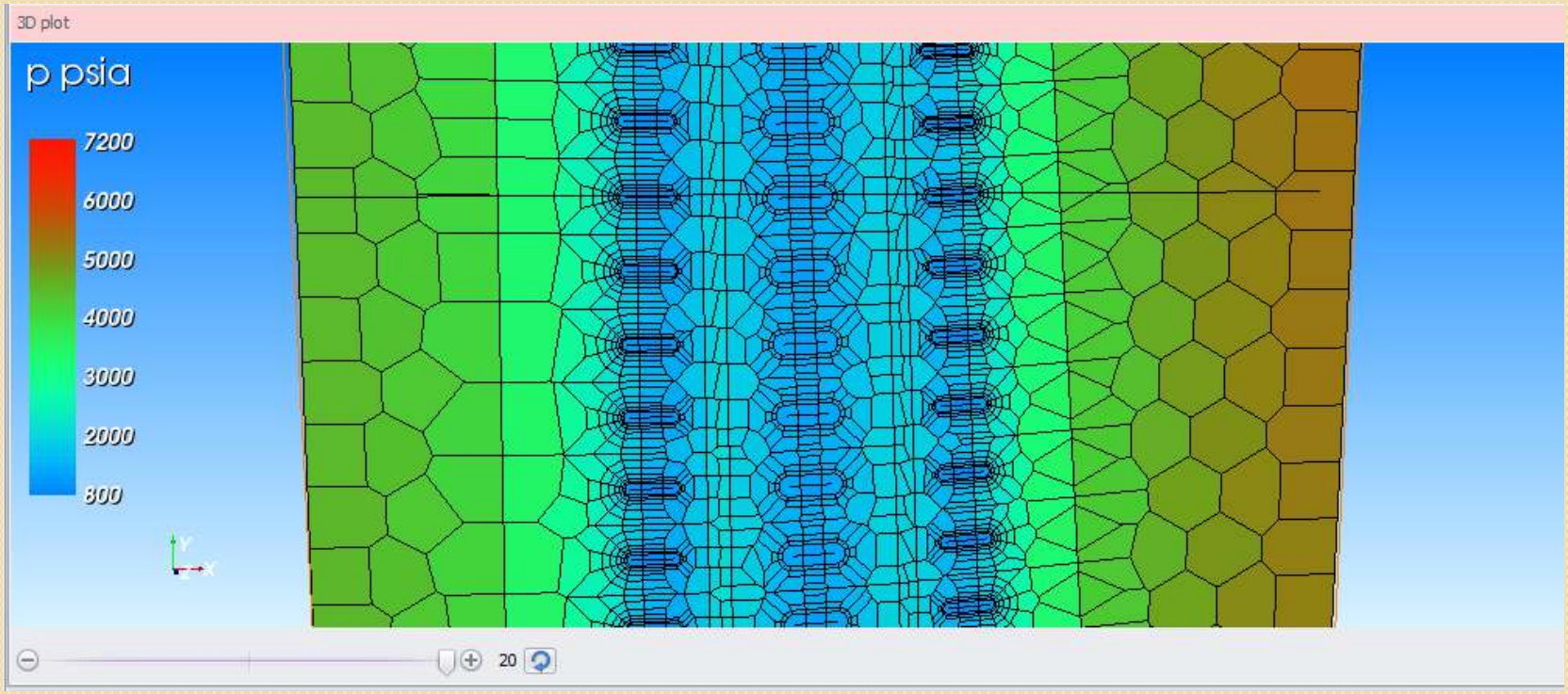
RUBIS Model Input Map Two Parent and One Child Well.



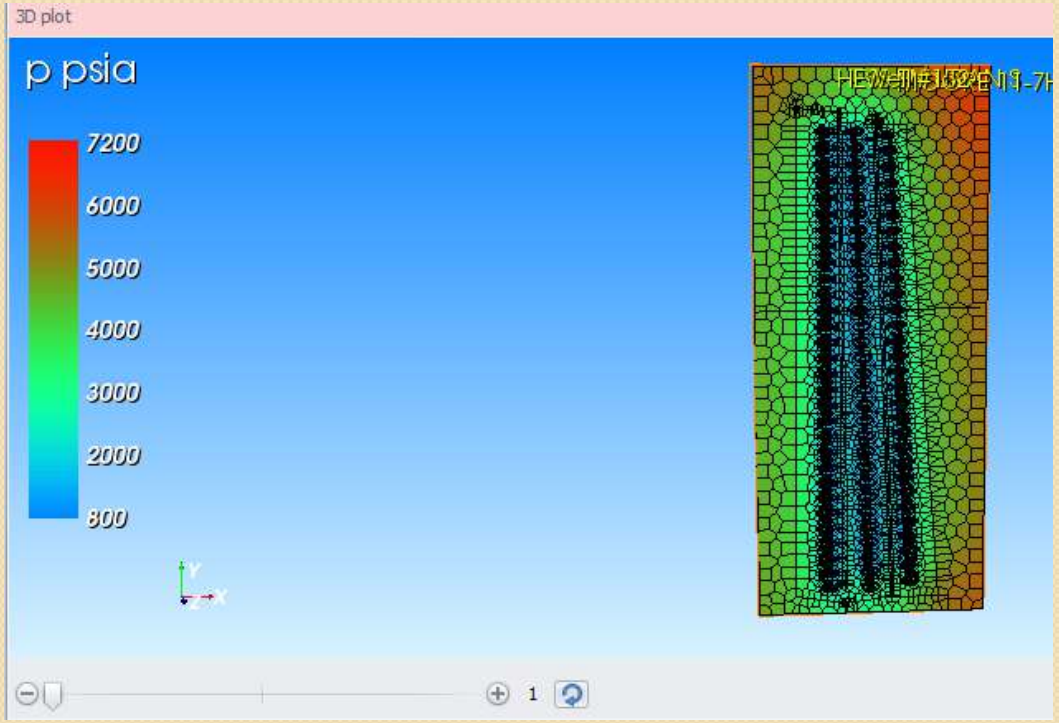
Pressure Depletion at 2018 When Infill Child well is Drilled at 750'



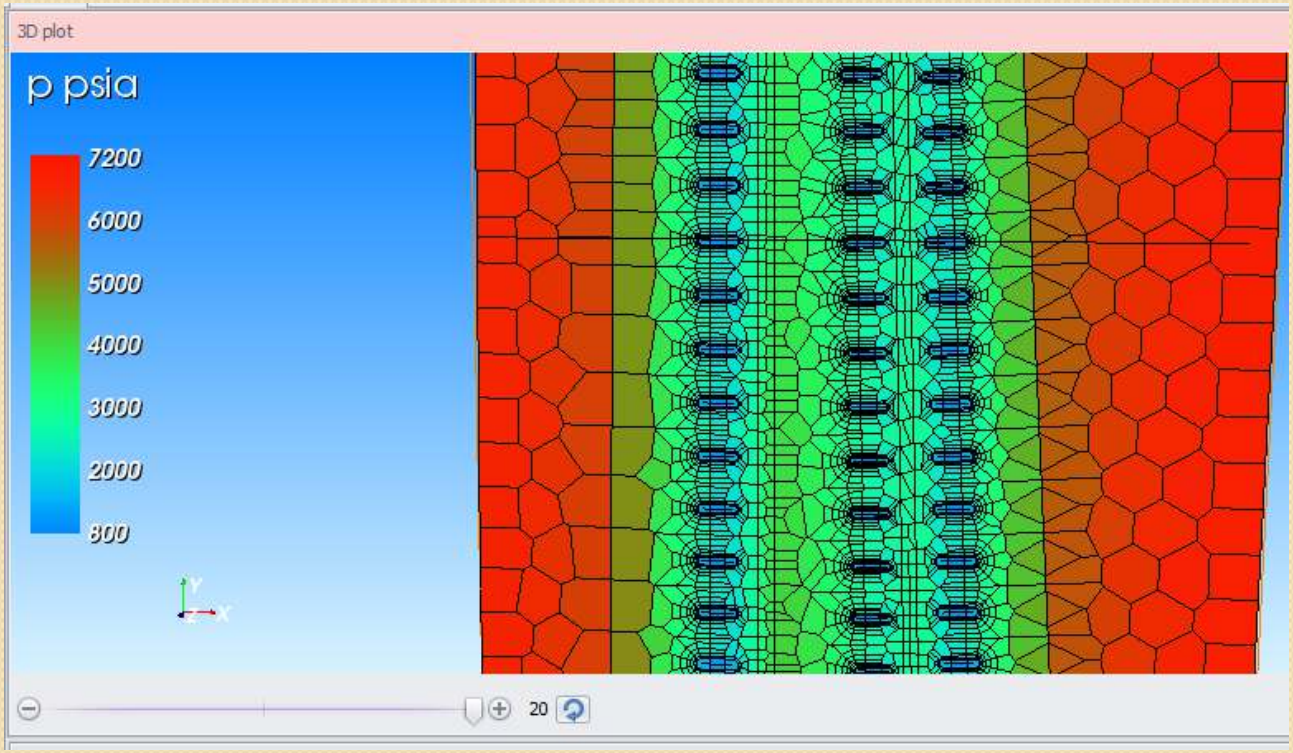
Pressure Depletion at 2038 after Infill Child well has produced for 20 years at 750'



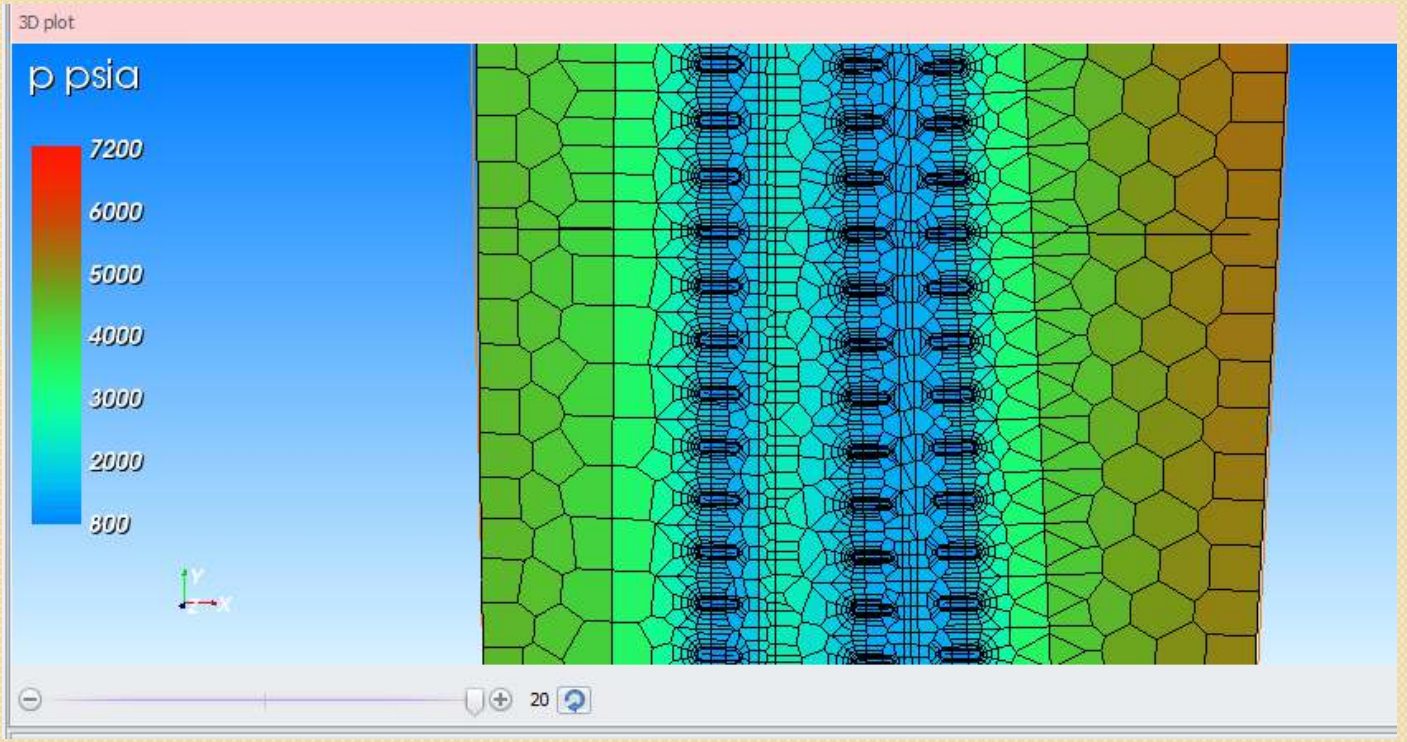
Pressure Depletion at 2038 at 750’



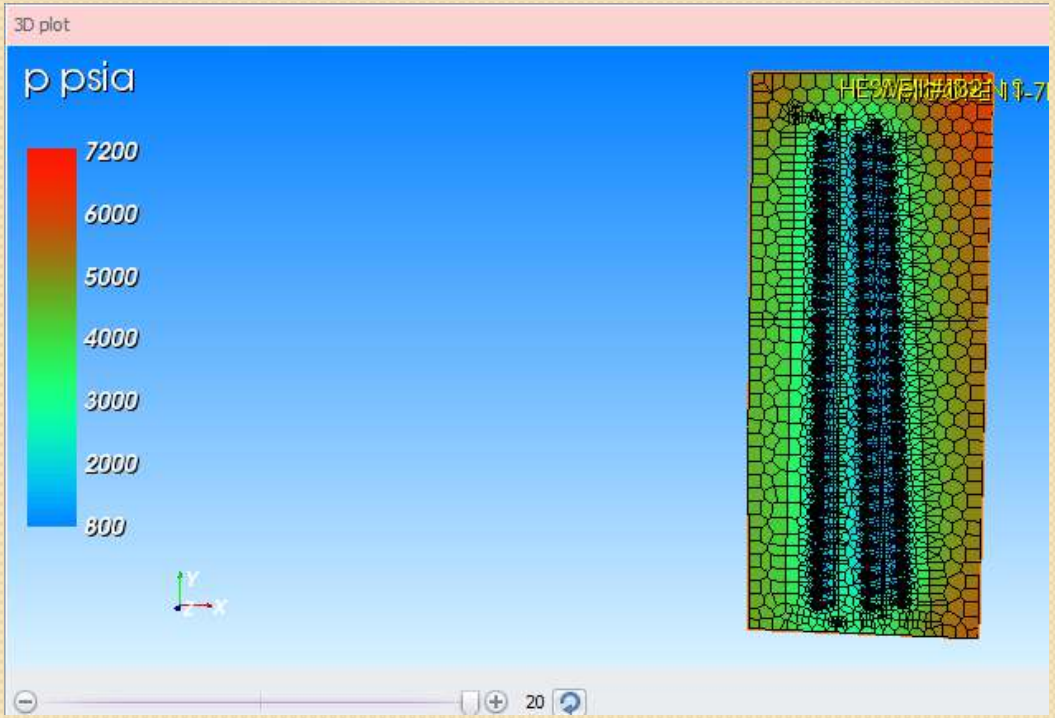
Pressure Depletion at 2018 When Infill child well is Drilled at 500'



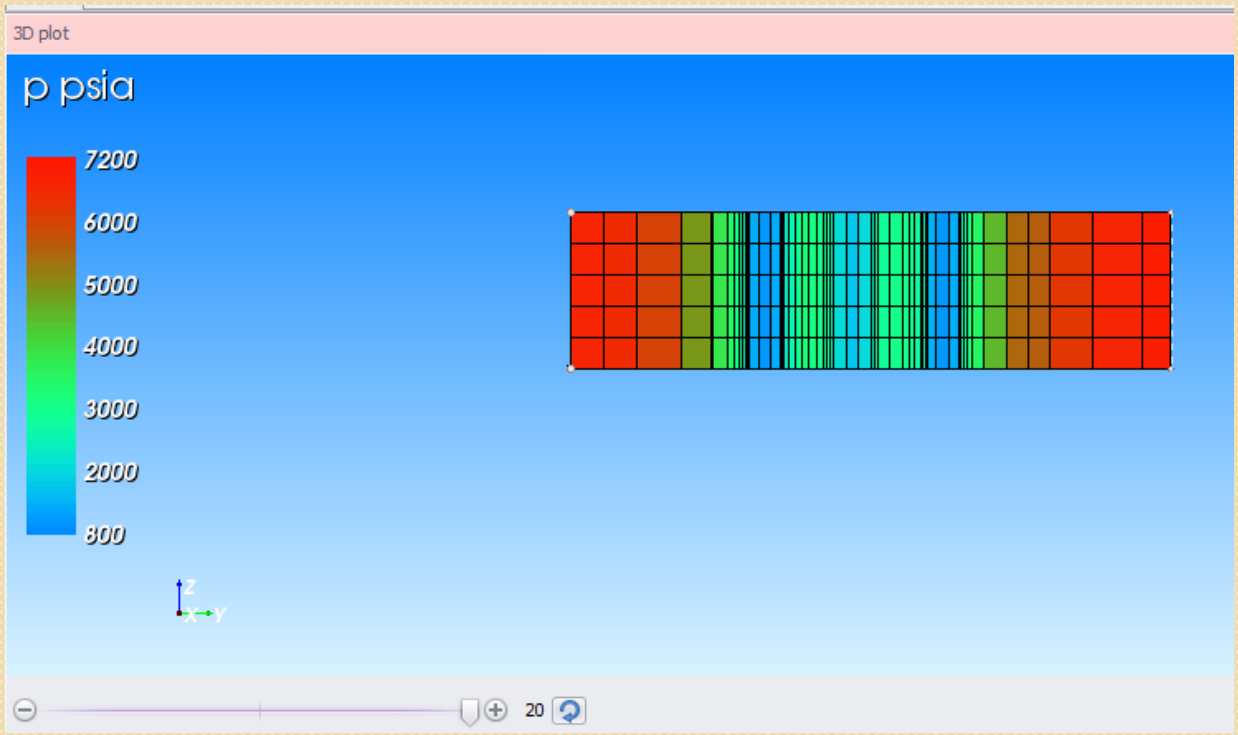
Pressure Depletion at 2038 After Infill Child well has produced for 20 years at 500'



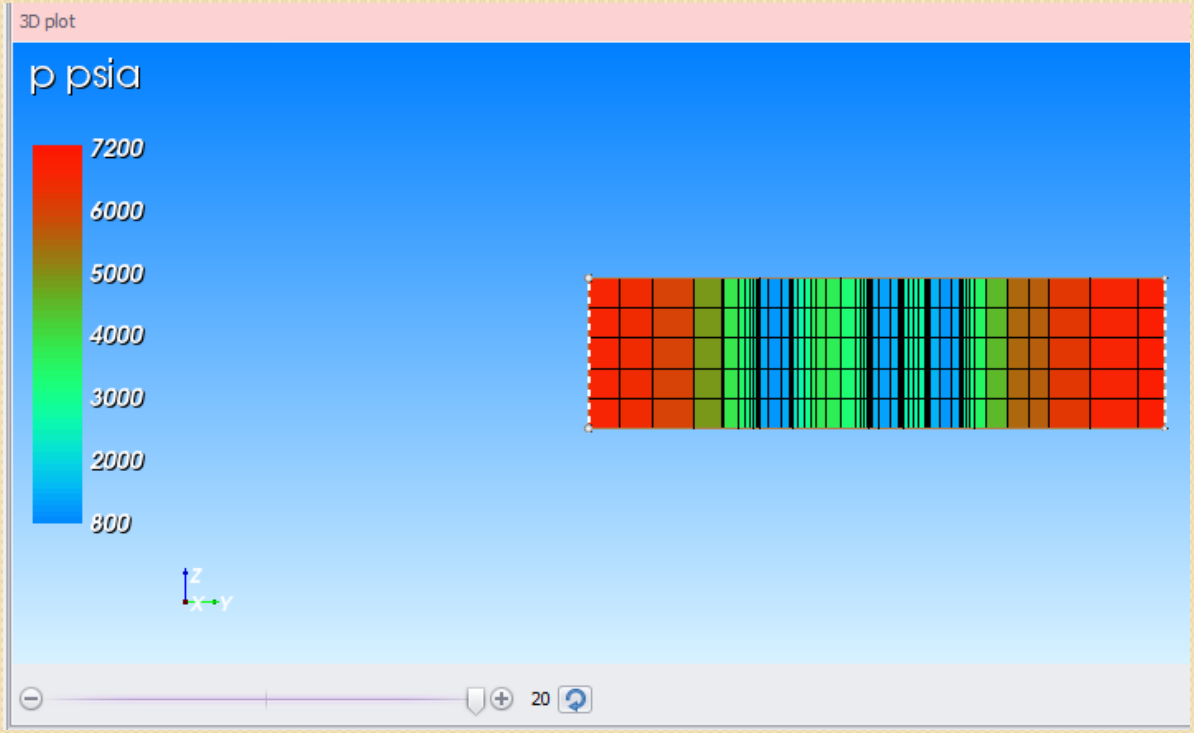
Pressure Depletion at 2038 at 500’



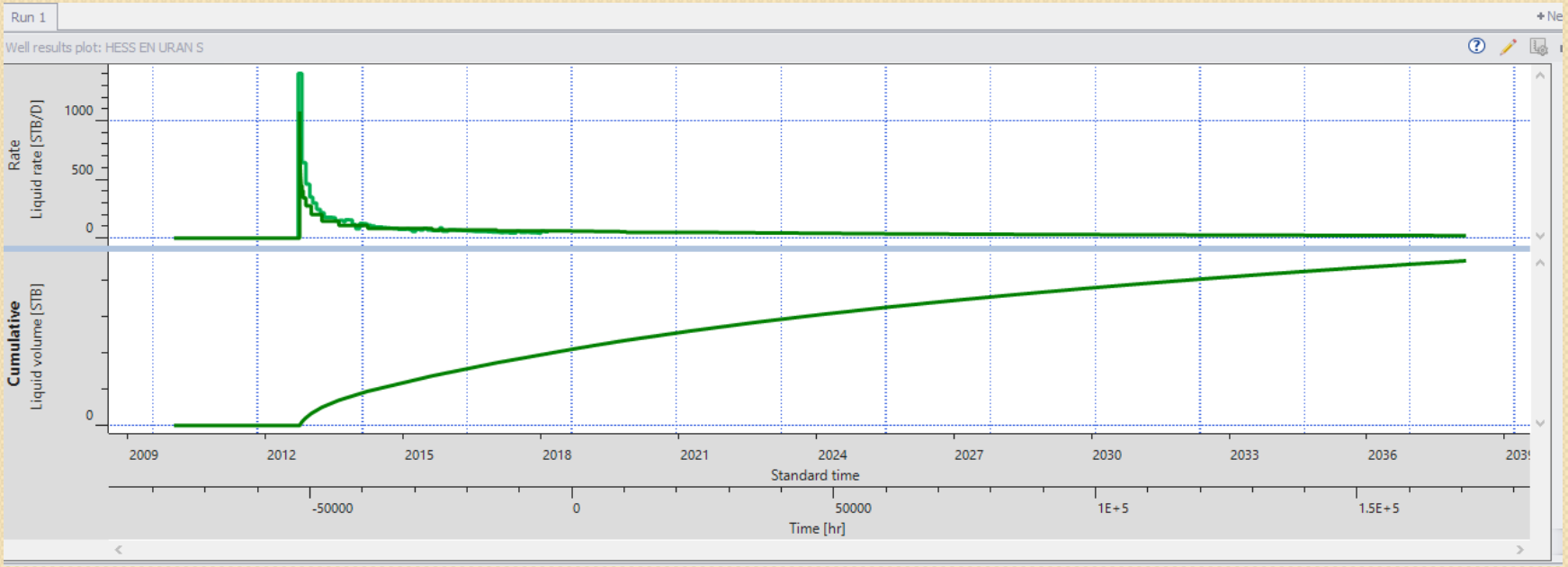
Pressure Depletion at 2038 when Infill Child well is drilled at 750'.



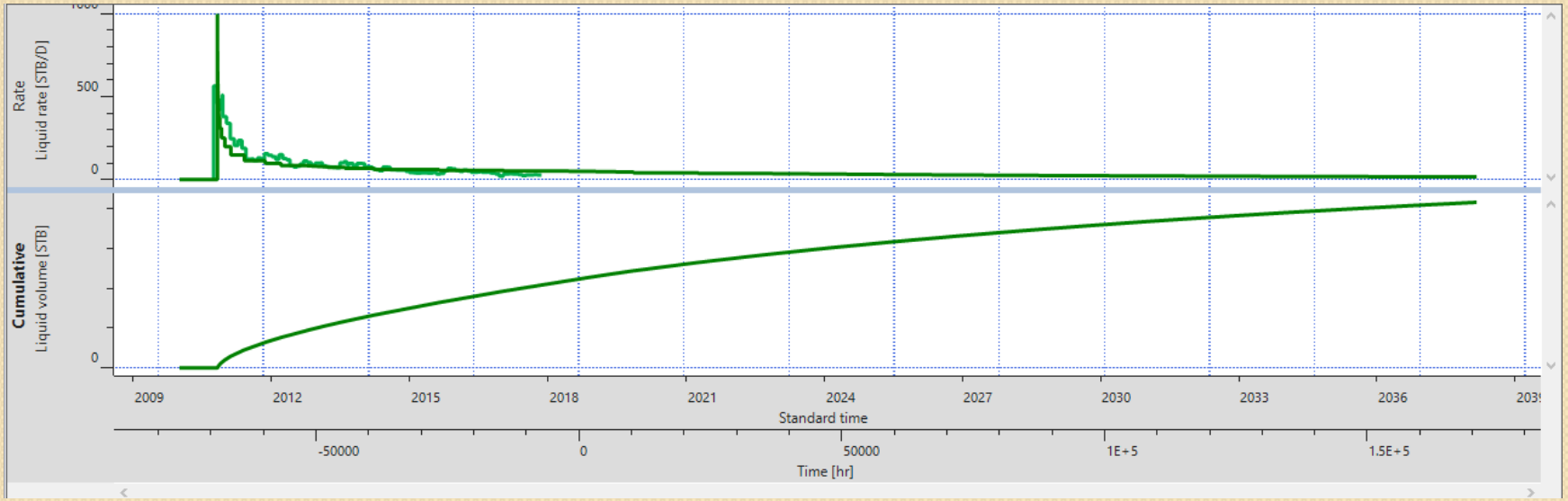
Pressure Depletion at 2038 when Infill Child well is drilled at 500’



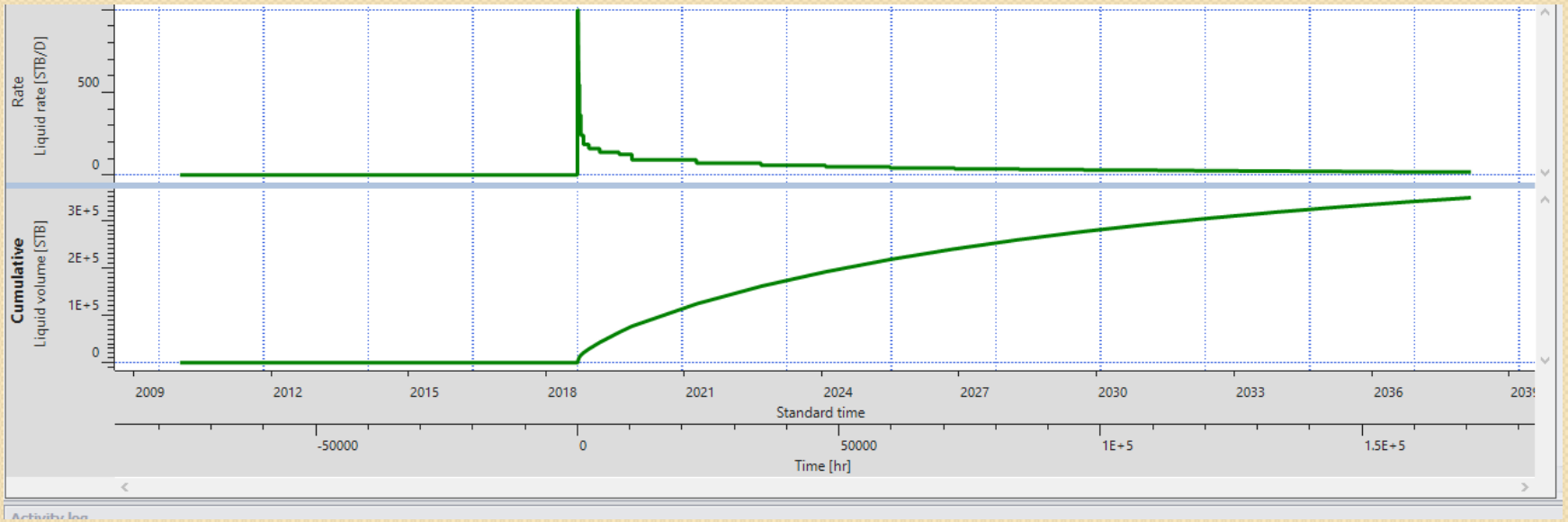
RUBIS Simulation Model Production History Match Parent Well 1



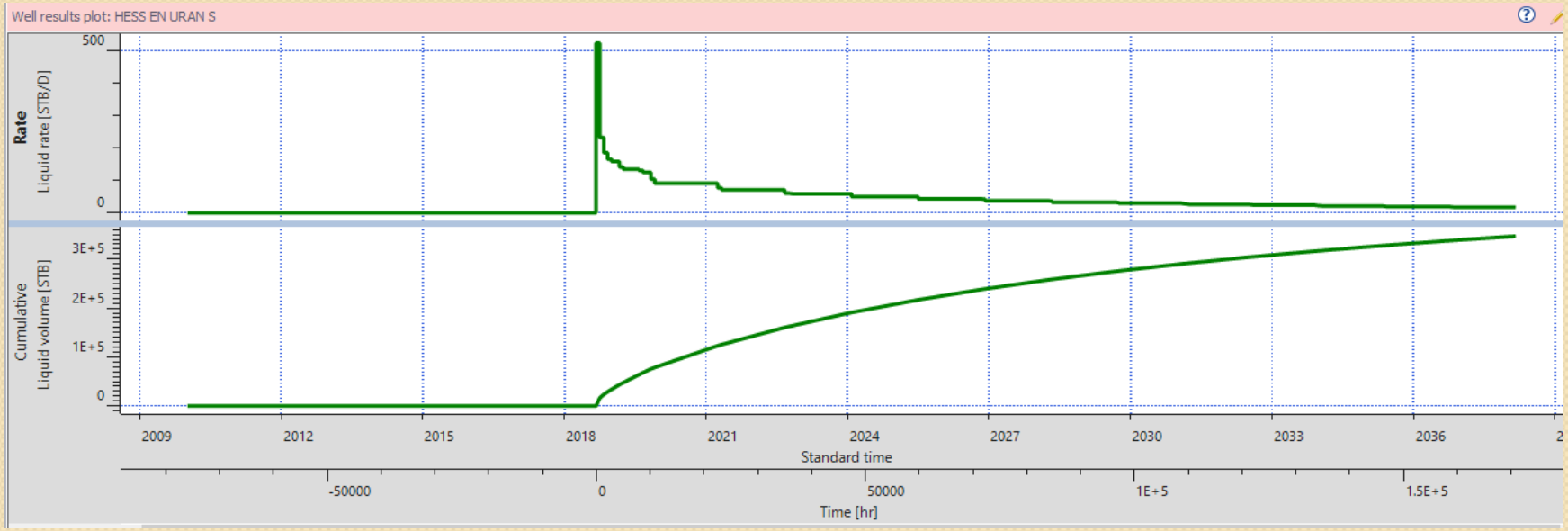
RUBIS Simulation Production History Match Parent Well 2



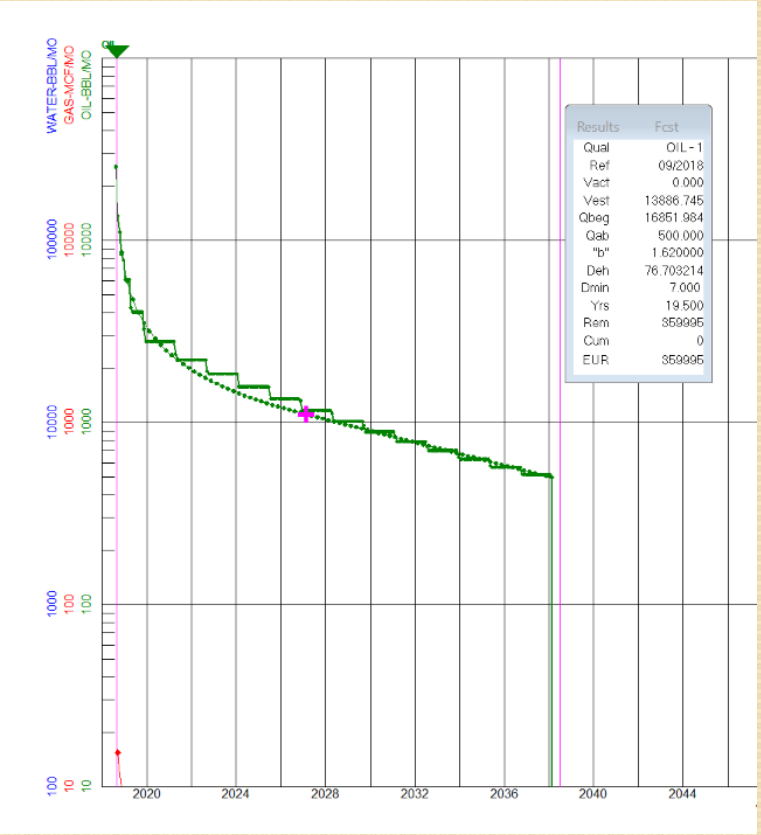
RUBIS Simulation Model Infill Child Production Forecast at 750’ from Parent Wells.



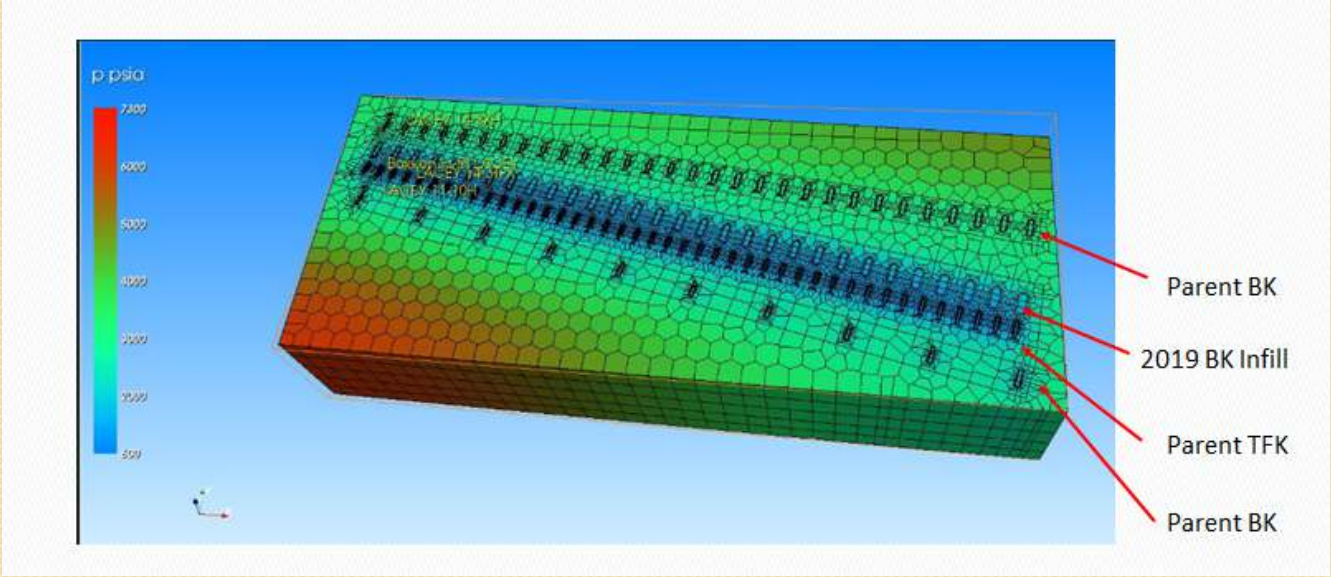
RUBIS Simulation Model Infill Child Production Forecast at 500' from Parent Wells



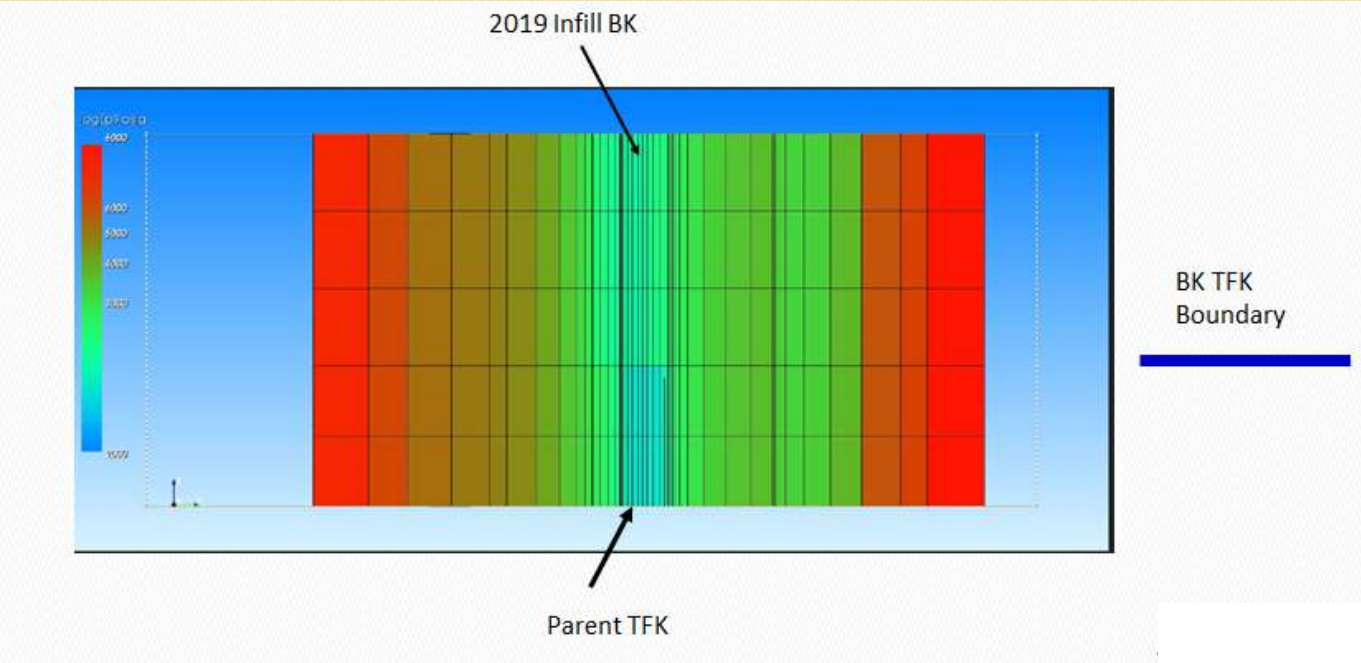
RUBIS Model Child Monthly Output Loaded into ARIES with EUR of 359 Mbo for 750' Offset



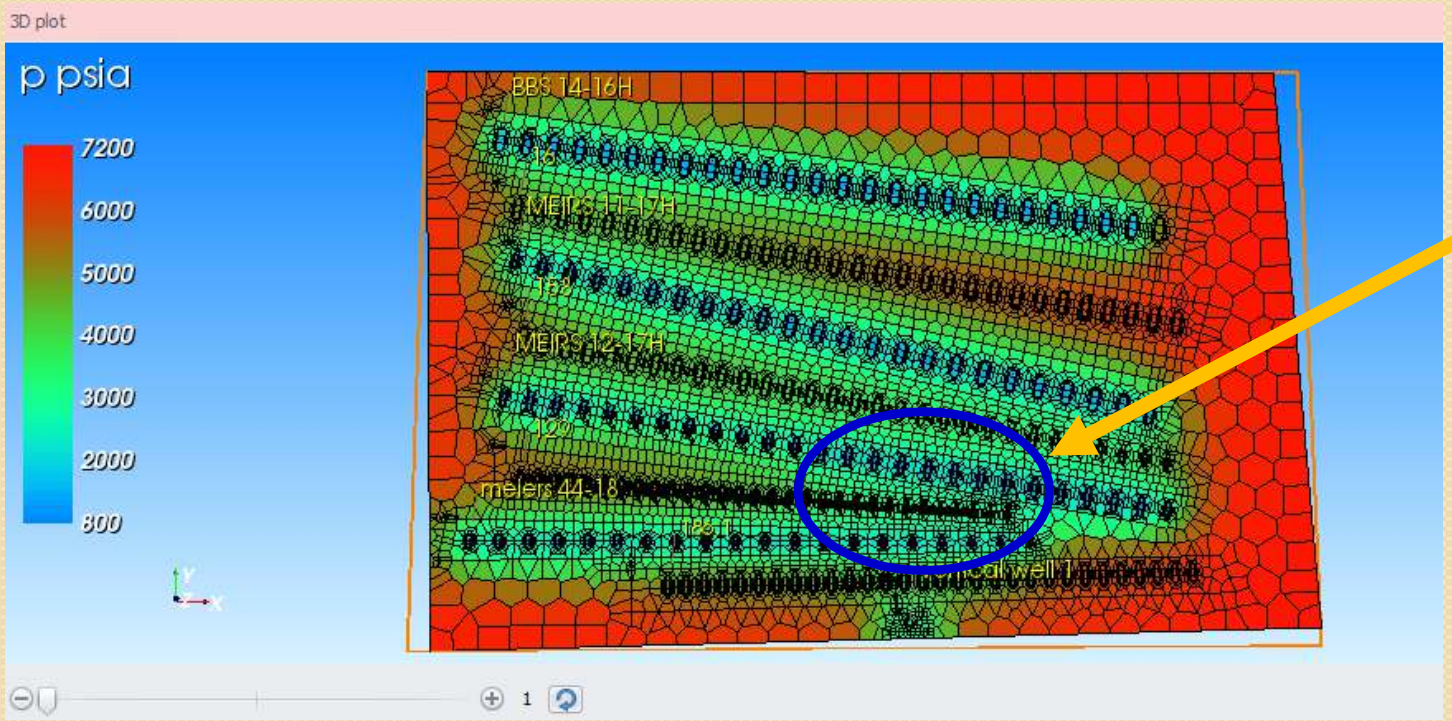
RUBIS Model Multiple Stacked Pay Example



RUBIS Model Multiple Stacked Pay Example

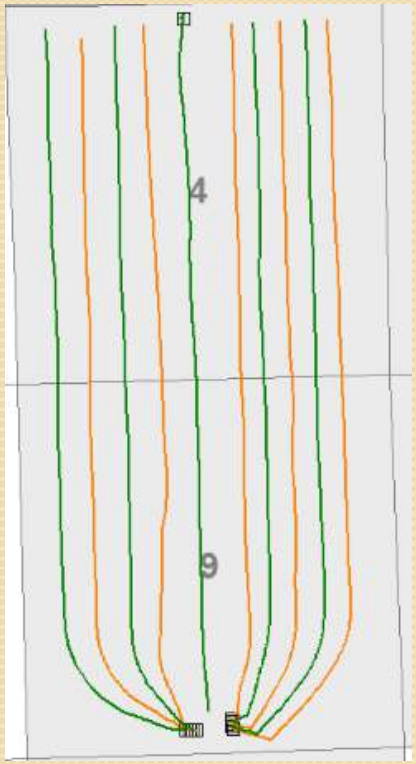


High Density Infill Pressure Depletion Example of Drilling Child Well to Close to Parents.

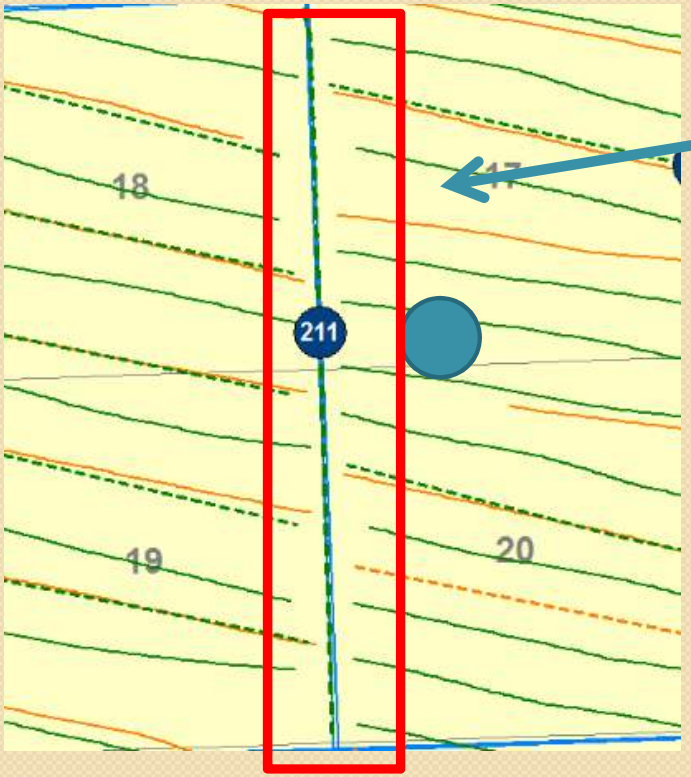


Pressure Depleted Area

RUBIS Model Challenges



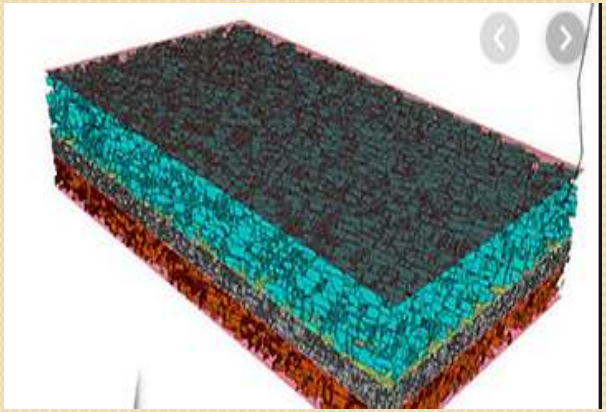
QUICK AND EASY



MUCH MORE DIFFICULT AND CHALLENGING FOR SECTION LINE WELLS WITH MULITPLE TOES OR HEALS.

DISCRETE FRACTURE NETWORKS REQUIRED

RUBIS Model Challenges



NATURAL FRACTURE SYSTEMS

FRAC HITS.

ASSYMETRICAL HYDRAULIC FRACTURE PATTERNS DUE TO SEVERE PRESSURE DEPLETION.

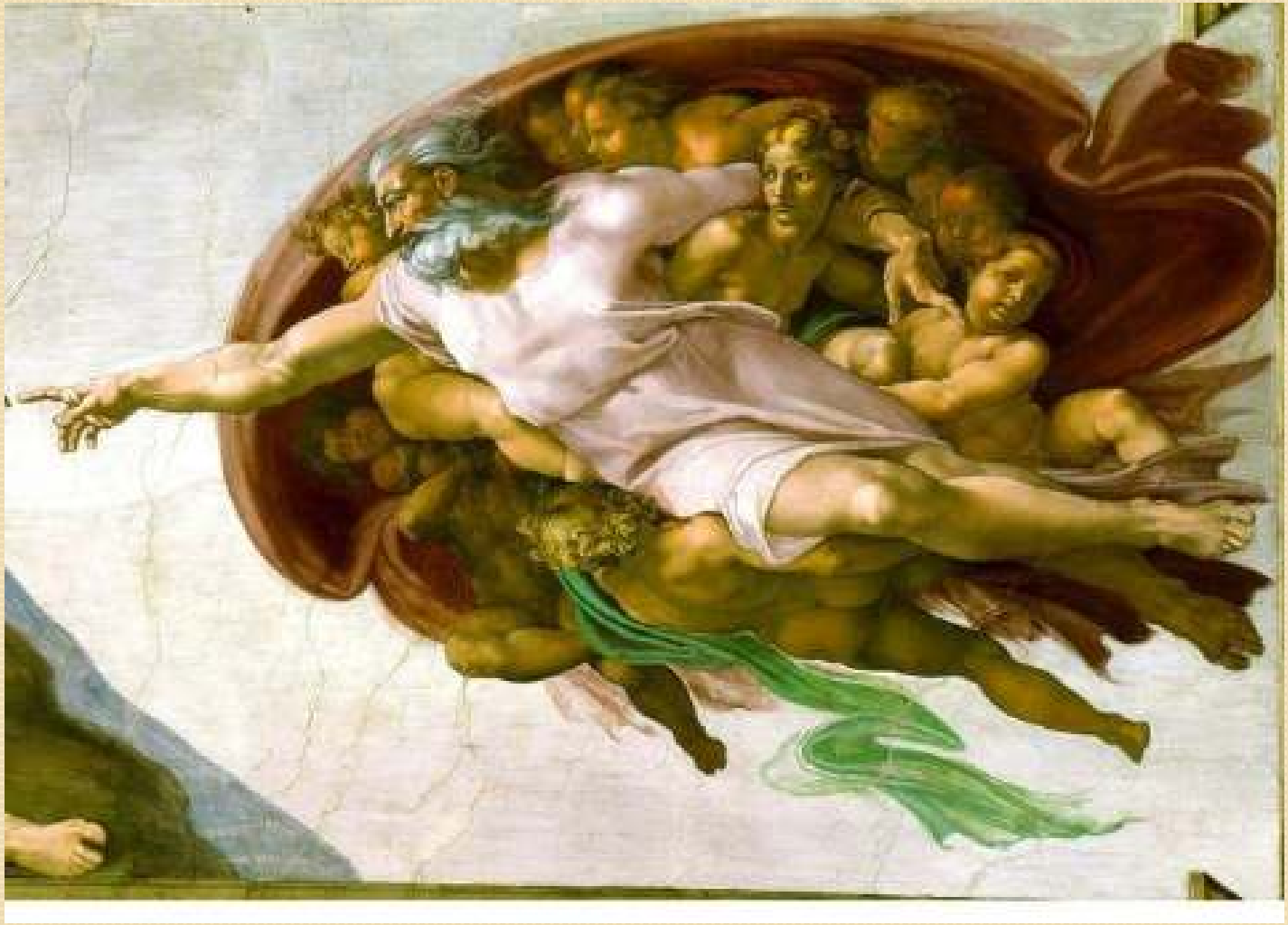
LOCAL RESERVOIR HETEROGENEITY.

NOT APPLICABLE TO LARGE FIELD WIDE SIMULATION PROJECTS.

CONCLUSIONS

- **Practical, timely and cost effective evaluations with high degree of accuracy for new infill wells.**
- **Production forecasts, EUR and NPV10 analysis can be completed in days vs. weeks.**
- **Model can be applied to different reservoirs taking into account multiple unique wellbore configurations and pressure depletion effects.**
- **Simulation model is "ground truthed" to actual parent well production history.**
- **Applicable to smaller and mid-sized companies with limited software.**

QUESTIONS ?



Rubis

Multi Purpose Full Field Numerical Model

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