UPDATED

whitson

RTA in whitson$^+$

Mathias Carlsen | Mohamad Dahouk | Curtis Whitson

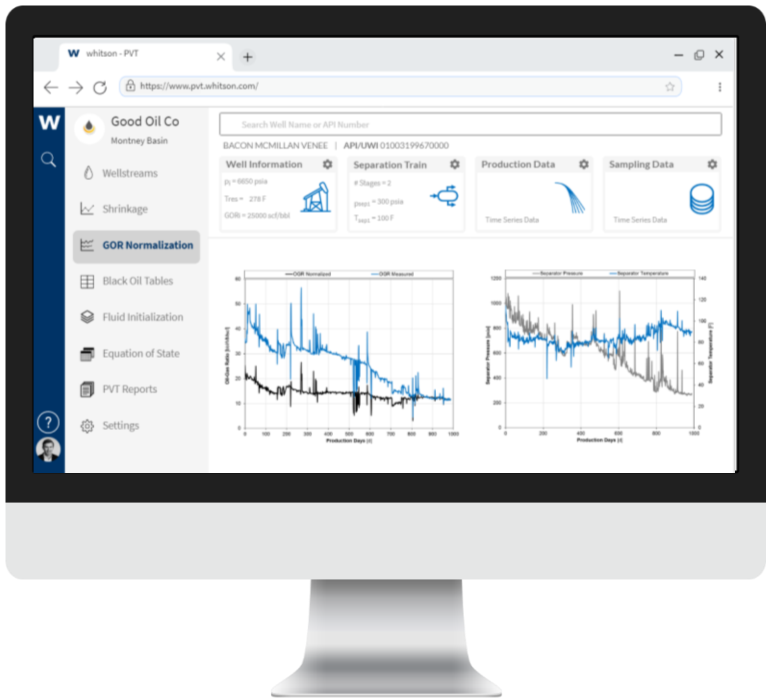
Course held Virtually

26 June 2023

The course
is recorded

Access to whitson+

NOT YOUR COMPANY DOMAIN



www.courses.whitson.com

Username: your e-mail

Password: WhitsonRTA2024*

*Send an e-mail to support@whitson.com if you need help to login.

Introduction

Knowledge Sharing Session Tomorrow!

Small Courses throughout the Year

- Half-day courses (4 hrs)
- Hands-on focus with software and theory
- 7 Different Virtual Courses, 8 am – 12 pm CST
  - ~~PVT & Phase Behavior – 14 Feb 2024~~
    Recording: https://youtu.be/qxqzl8B_I2A
    Slides: https://shorturl.at/gzBNW
  - ~~Bottomhole Pressure Calculations – 24 April 2024~~
    Recording: https://youtu.be/0pvojymb-5U
    Slides: https://shorturl.at/wLWZ9
  - **Analytical & Numerical RTA – 26 June 2024 (TODAY)**
  - Flowing material balance – 21 Aug 2024
  - Nodal Analysis – 2 October 2024
  - Well Tests (CPG & DFIT) – 16 October 2024
  - DCA & Type Wells – 4 December 2024

Send e-mail to carlsen@whitson.com if you haven't received the invite to the courses.

Need Course Certificate?

Contact carlsen@whitson.com

CERTIFICATE OF ATTENDANCE

John Doe

has successfully completed

RTA in whitson+

1/2-day Course held Virtually

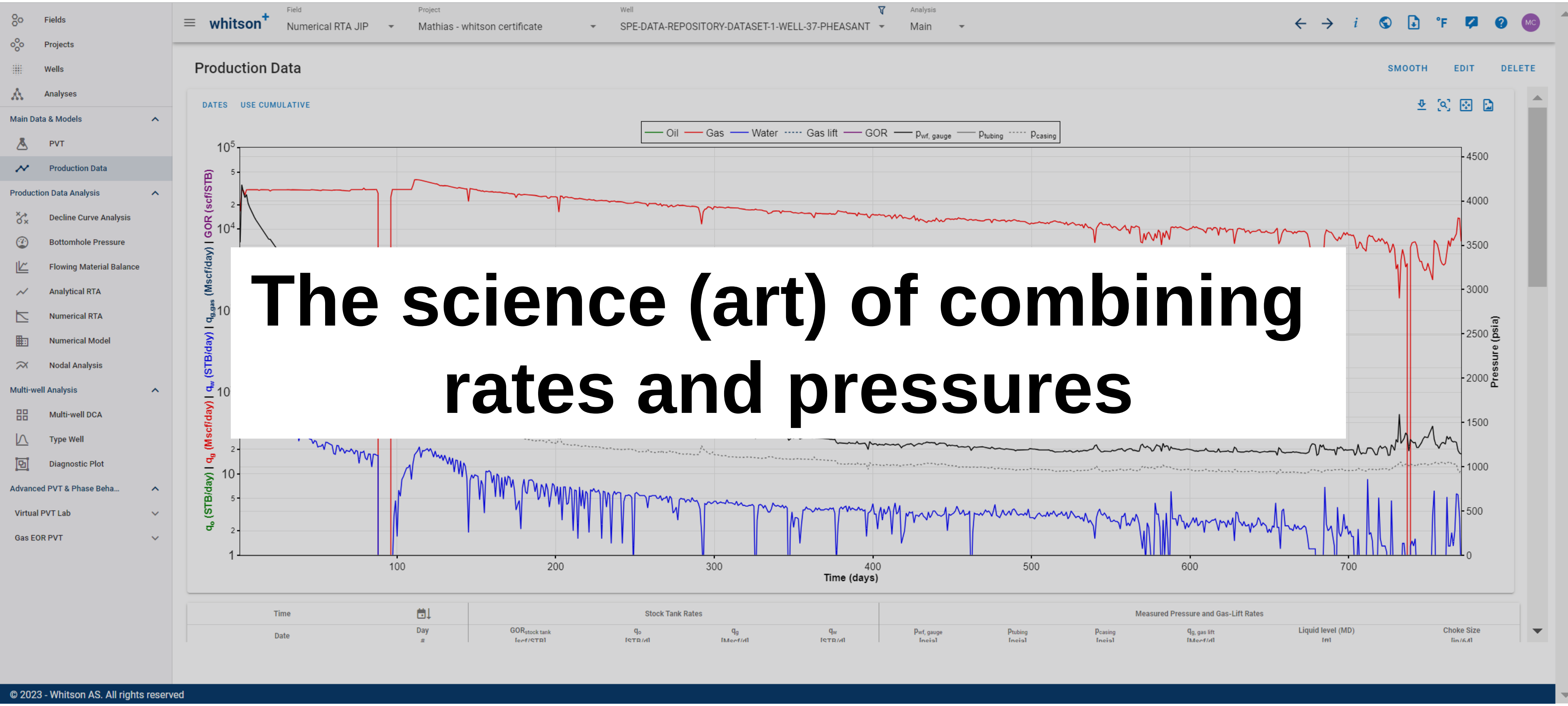
14 July 2022

Mathias Lia Carlsen

GM Americas

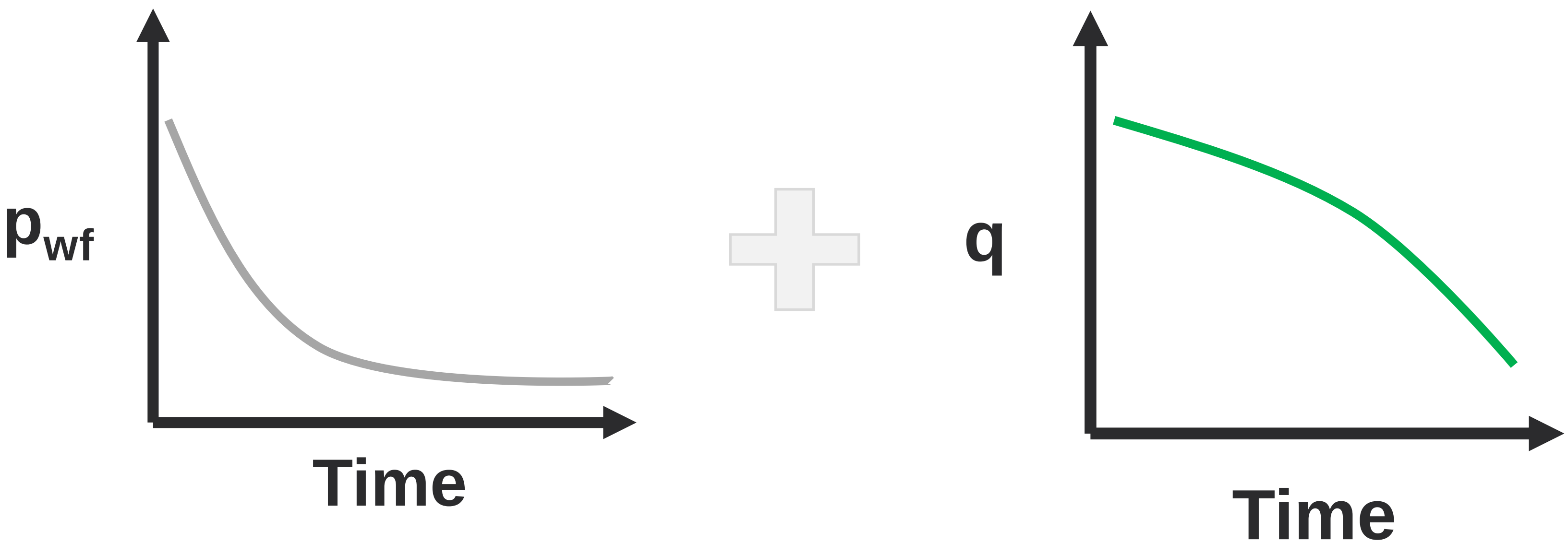
www.whitson.com

Rate Transient Analysis



The science (art) of combining rates and pressures

Rate Transient Analysis



What we will Cover

- **whitson**$^{+}$ and **RTA** basics
  - Login & Access
  - Workflow ("Clicking the buttons")
  - General structure and functionality
- **The course has an RTA Focus <u>primarily</u>**
  - Classical RTA (Square root of Time Plot)
  - Numerical RTA ("Bowie Workflow")
  - Fractional RTA (Acuna Work)

We'll assume the inputs are correct (PVT, BHP, etc.)


I BELIEVE IN
A REPETITION
imgflip.com

RTA 1.01

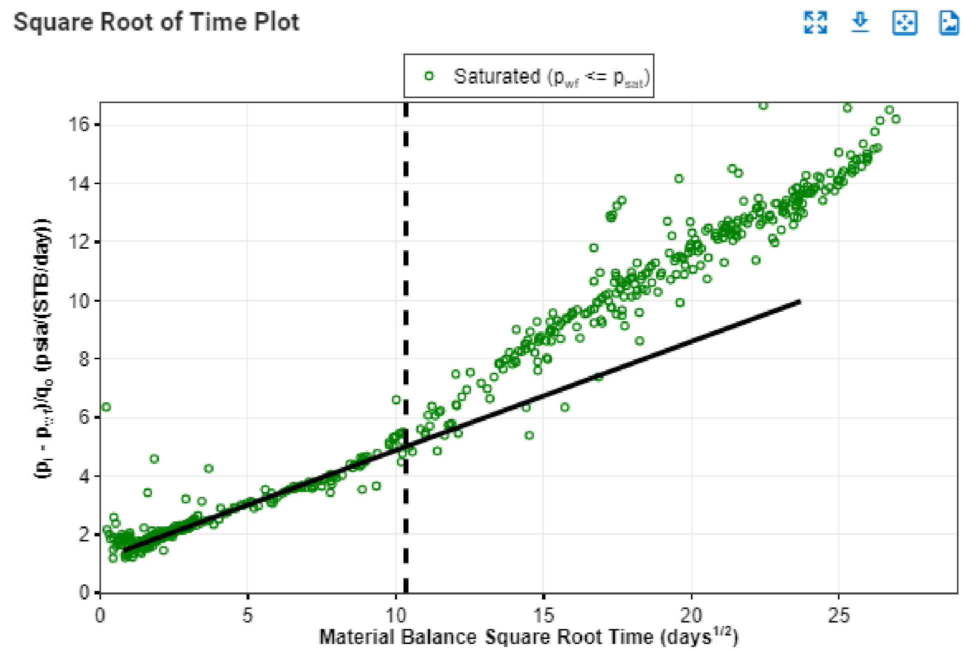
Rate Transient Analysis (RTA) 1.01

Incorporates both fluid rates and flowing pressures

What is it used for?

Quantify productivity (LFP aka A√k) and contacted pore volumes (OGIP and OOIP)

- Well performance comparison
- Forecasting
- Completion effectiveness & frac optimization
- Production optimization / drawdown management
- Calibration / starting point for advanced simulation studies



whitson

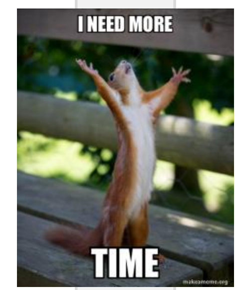
Four “Buckets” of RTA

1. Diagnostics
   - Flow regime identification

2. Relative well performance normalized for difference in pressure drawdown

More advanced

3. Quantifying A√k (aka LFP) and contacted pore volume (OOIP | OGIP)

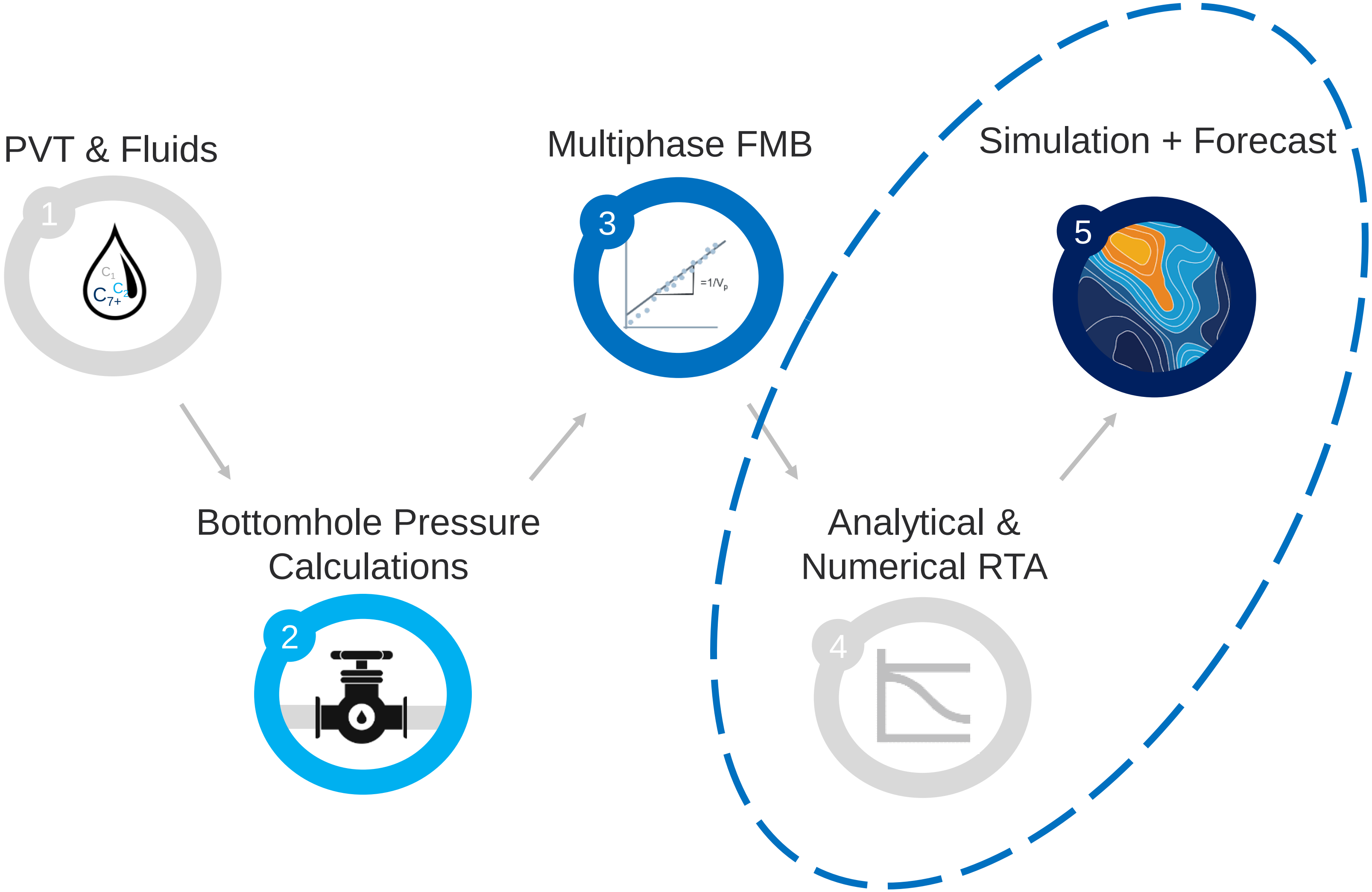


4. Resolving physical parameters like x_f and perm
   - Must be in full boundary
   - Also need to know N_f and h
   - Fracture shape (rectangular vs non-uniform)

“It is better to be roughly right, than precisely wrong”

- John Maynard Keynes

Unconventional Reservoir Workflow



Flow Regimes 1.01

Infinite acting flow ends as pressure transient reaches *one* reservoir boundary

Transitional flow (period in between)

Boundary dominated flow starts when the wellbore pressure response is affected by *all* reservoir boundaries

What can be Derived "Uniquely" from RTA?

LFP

(or A√k)

Observed during
infinite-acting, linear flow

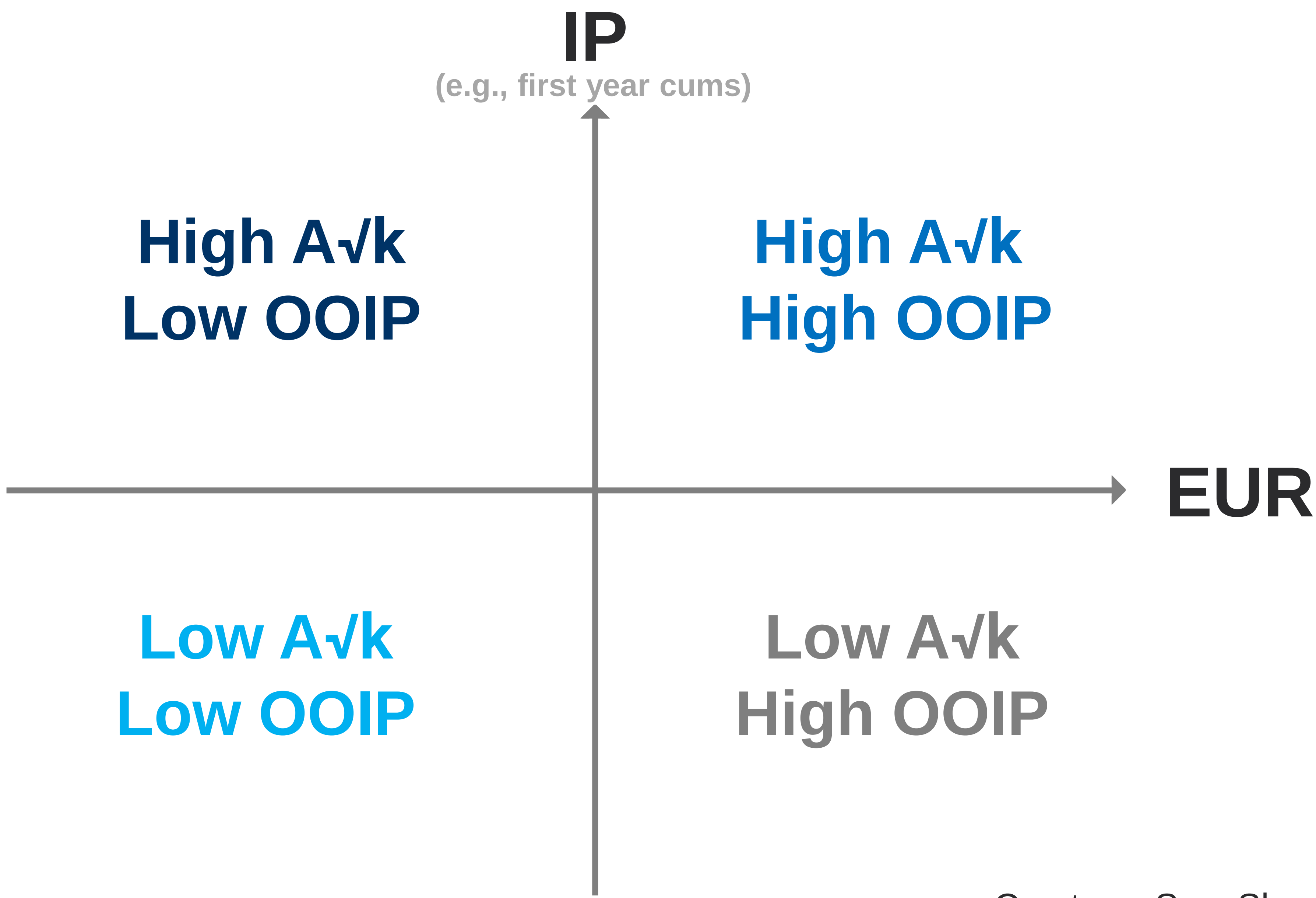
<u>CONTACTED</u>

OOIP

(or OGIP)

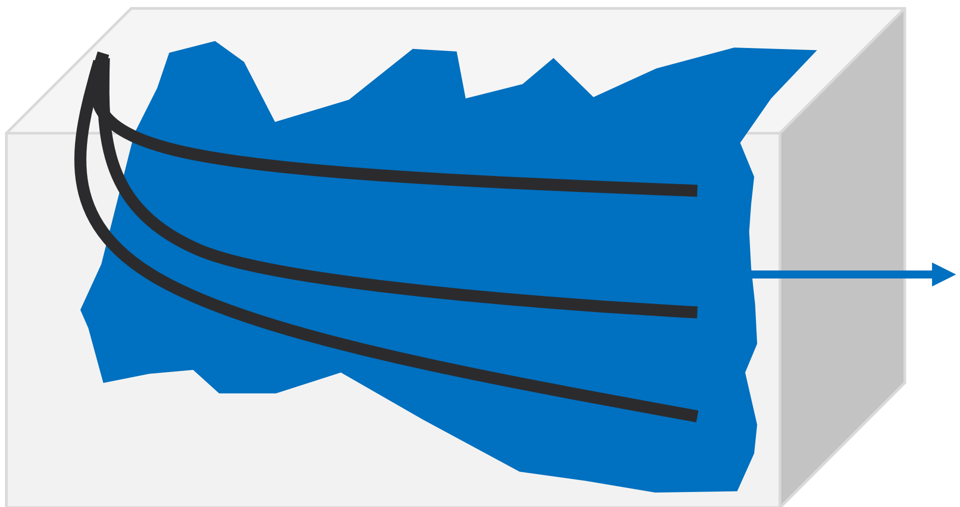
Observed during
boundary dominated flow

whitson



Courtesy: Sam Shoun

Volume Resolved from RTA



<u>IMPORTANT</u>

There is a difference between the petrophysically mapped in-place volume (**grey**) and the volume resolved from RTA, i.e. the **<u>contacted</u>** pore volume* (**blue**).

**Also called stimulated rock volume (SRV) or drained rock volume (DRV)*

whitson

Contacted Pore Volume (V_p)

All the below used interchangeably

$$V_p = HCPV/(1-S_{wi})$$

$$OOIP = HCPV/B_{oi}$$

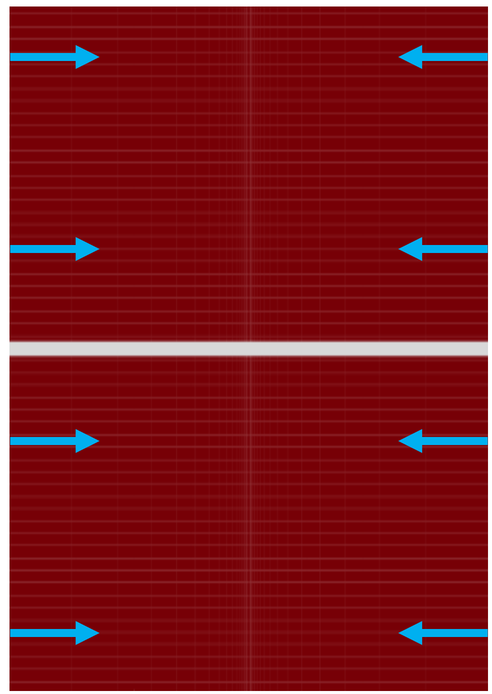
$$OGIP = OOIP x R_{si}$$

$$OWIP = PV x S_{wi}/B_w$$

whitson

How many boundaries?

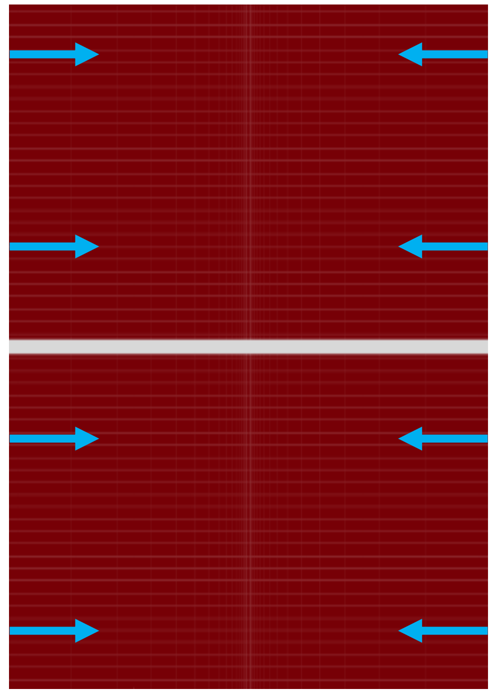
1 boundary



1 dimensional model

How many flow regimes?

2 flow regimes

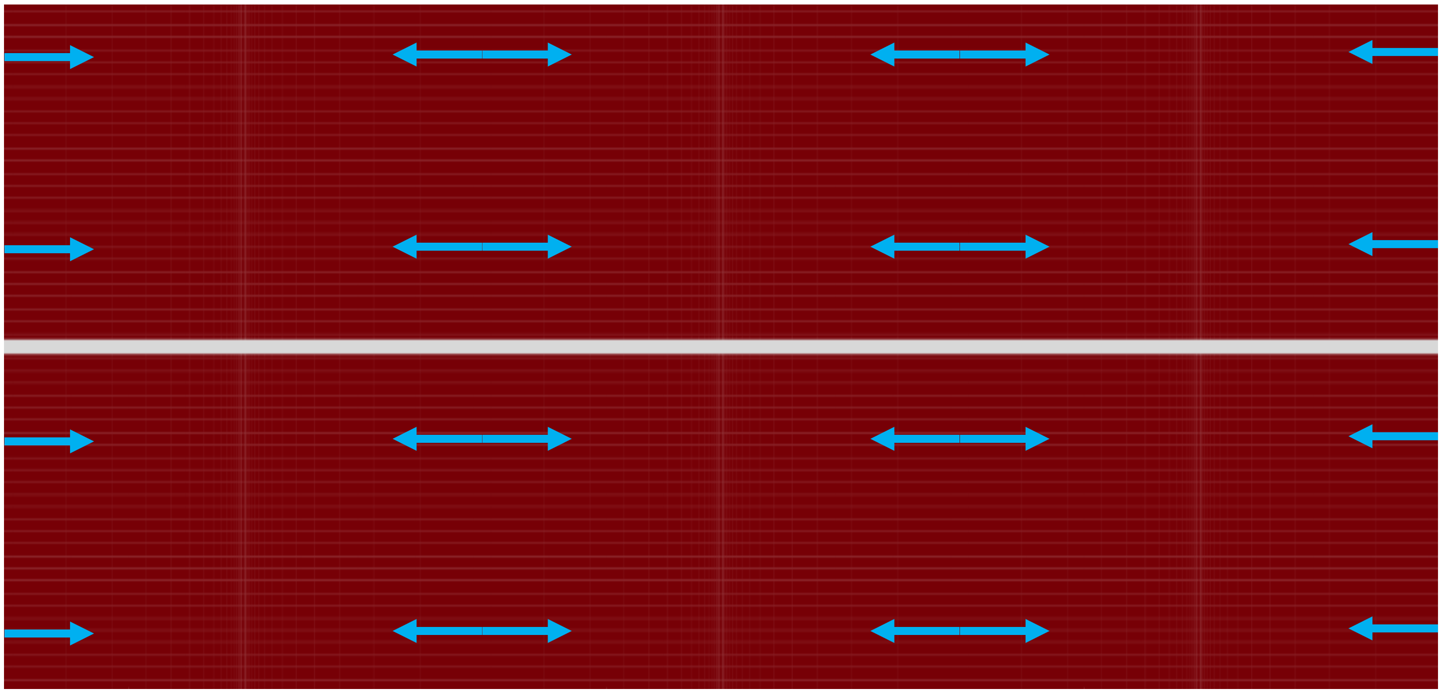


1. Infinite acting (IA)

2. followed by boundary dominated (BDF)

How many boundaries?

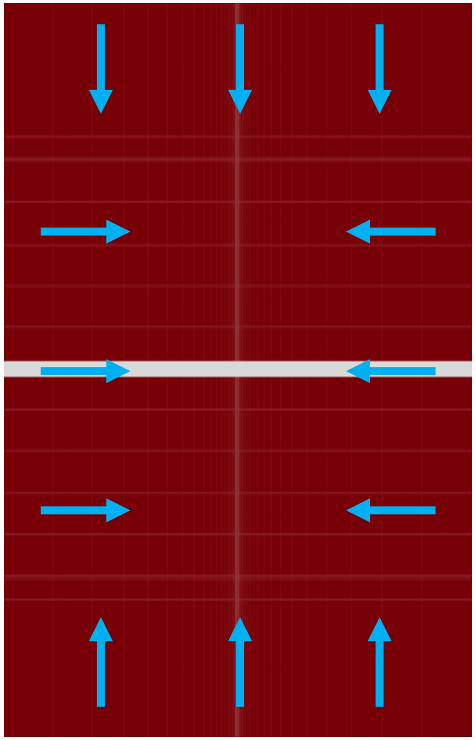
1 boundary



1 dimensional model

How many boundaries?

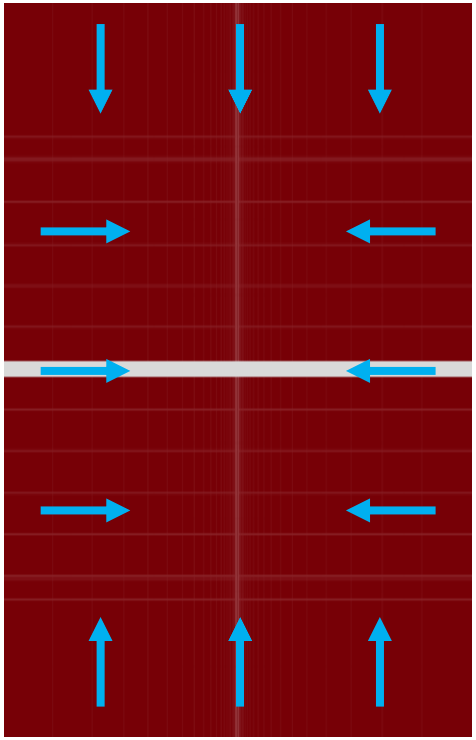
2 boundaries



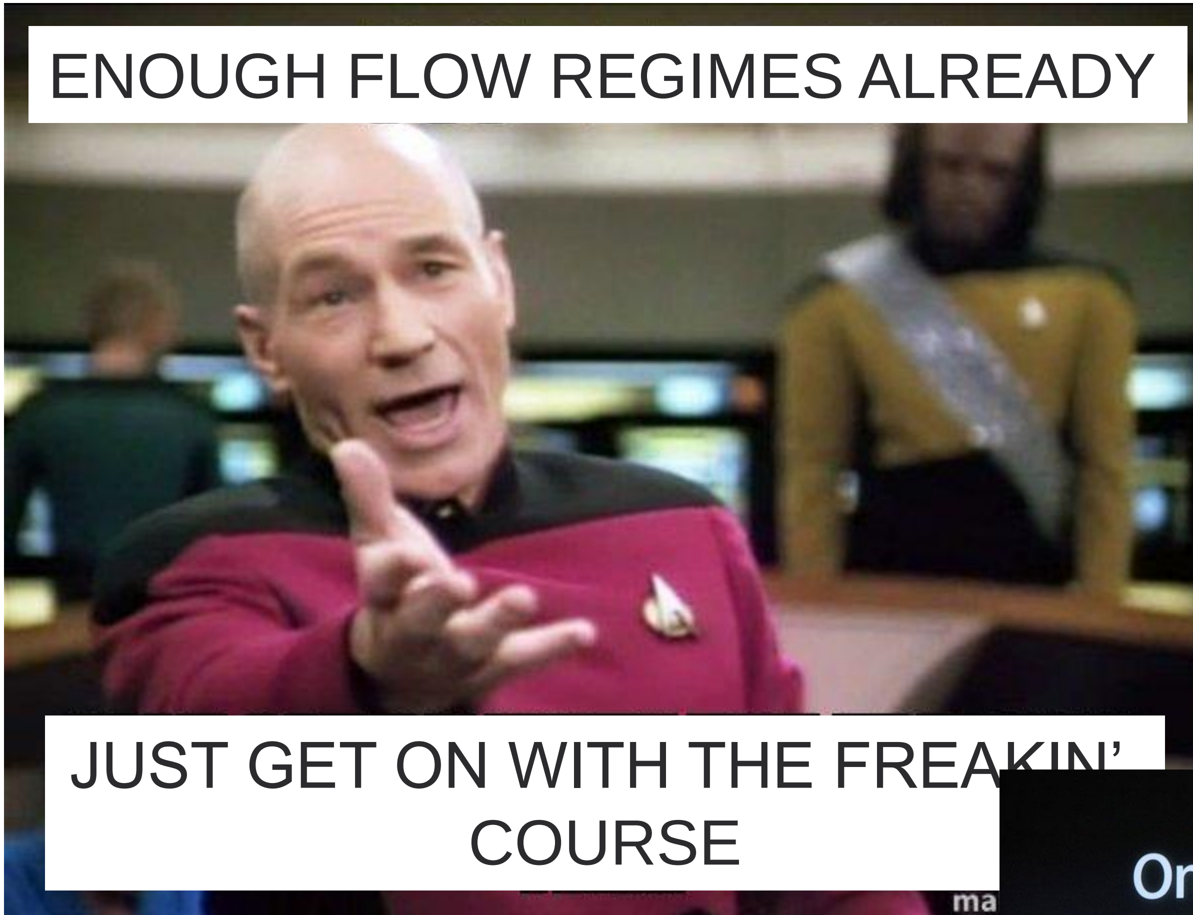
2-dimensional model

How many flow regimes?

3 flow regimes



1. Infinite acting (IA)
2. Transitional Flow
3. Boundary dominated (BDF)


ENOUGH FLOW REGIMES ALREADY
JUST GET ON WITH THE FREA
COURSE

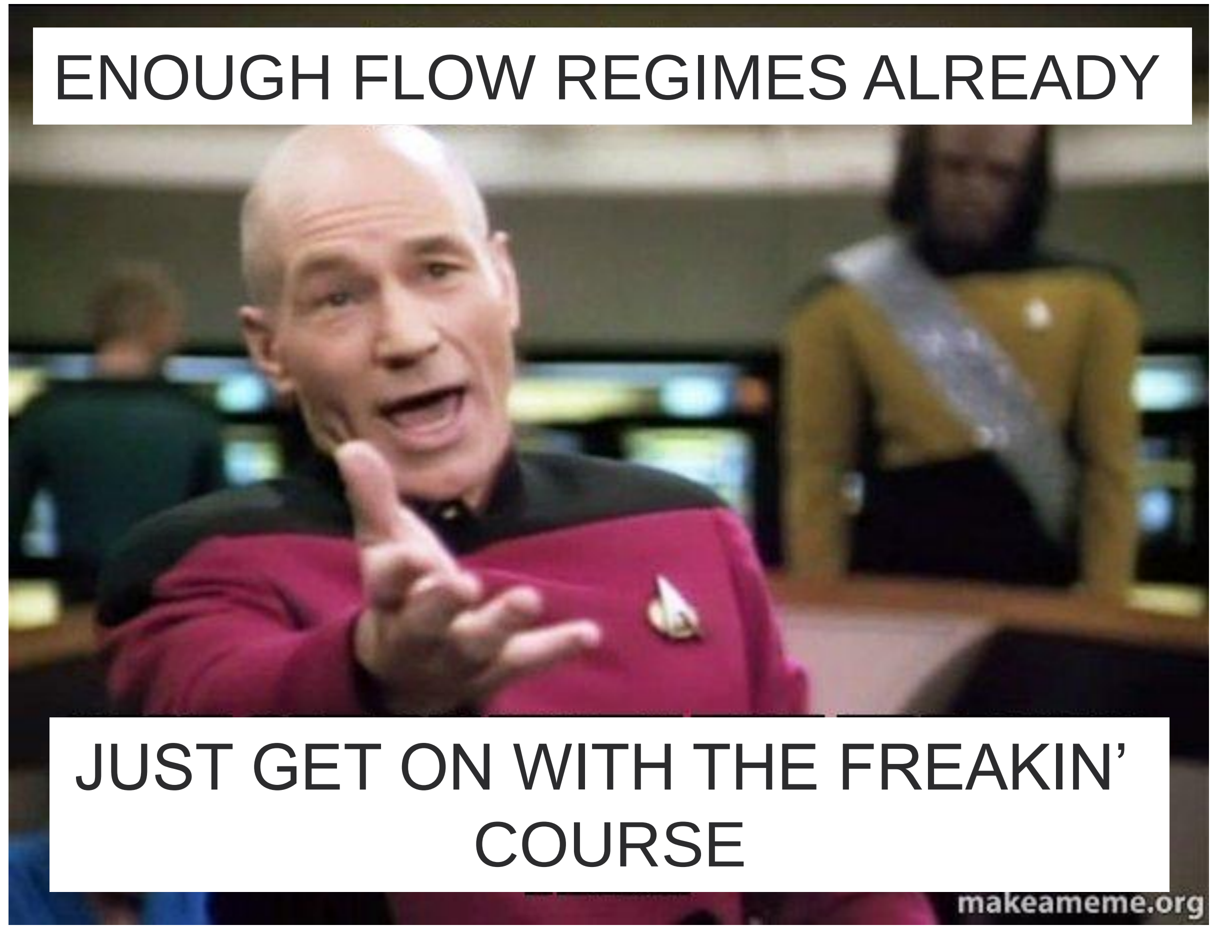

One more thing…

Observed Flow Regimes in Tight Unconventionals

1. *Infinite acting flow* for the entire observed history
2. Initially *infinite acting flow*, followed by *transitional flow* for the rest of the observed history
3. Initially *infinite acting flow*, followed by *transitional flow* and finally boundary dominated flow
4. Initially *infinite acting flow* followed by *boundary dominated flow* for the rest of the observed history
5. *Transitional flow* for the entire observed history
6. Initially *transitional flow* followed by *boundary dominated flow* for the rest of the observed history
7. *Boundary dominated flow* for the entire observed history

Sequence of Flow Regimes in Tight Unconventionals

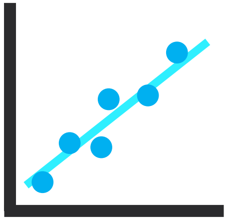
- IA
- IA → TF
- IA → TF → BDF
- IA → BDF
- TF
- TF → BDF
- BDF



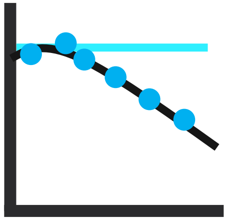
RTA -
In a Nutshell

Different Types of RTA

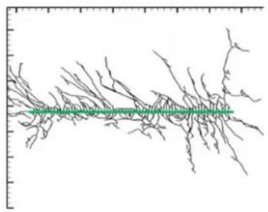
1



2



3



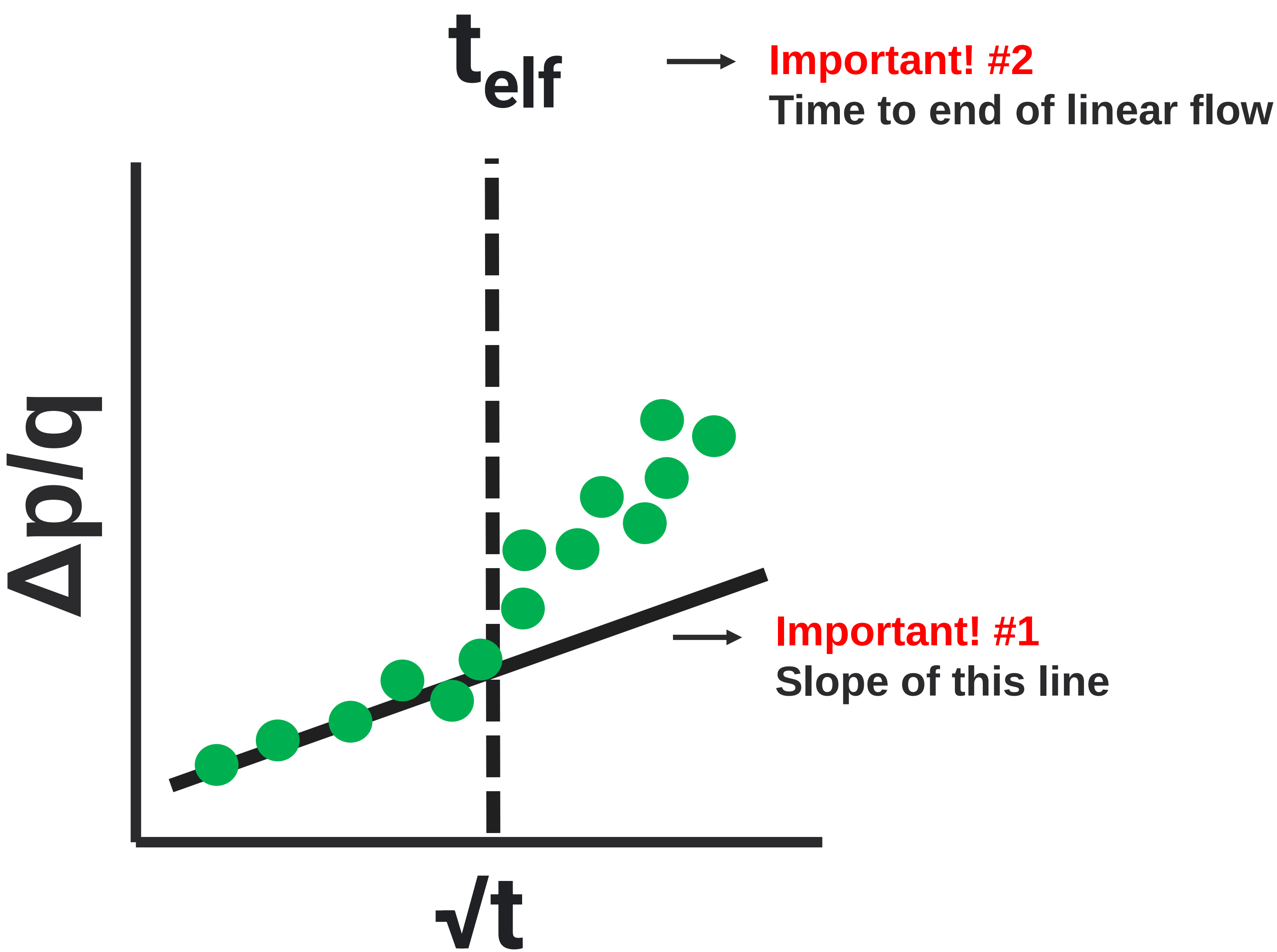
Classical RTA
"Square Root of Time Plot"

Numerical RTA
"Bowie Workflow"

Fractional RTA
"Acuna"

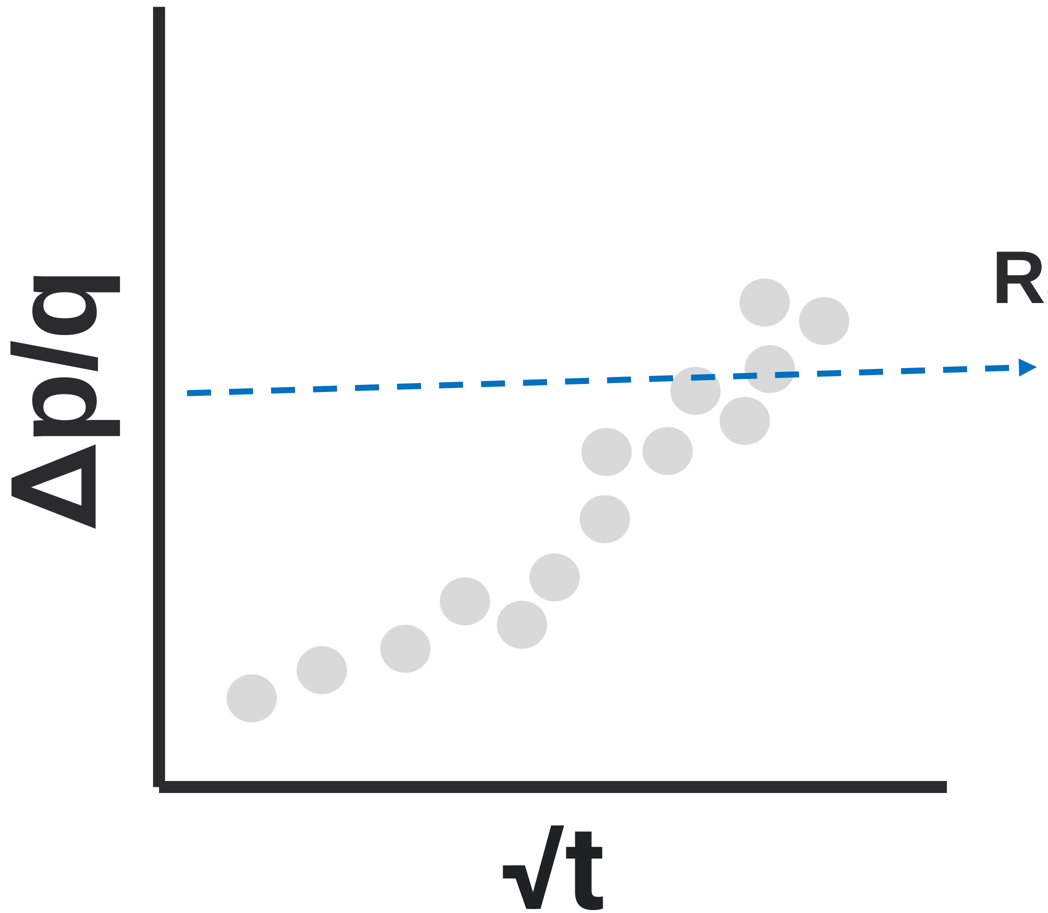
Classical RTA

Square Root of Time Plot



Square Root of Time Plot

1

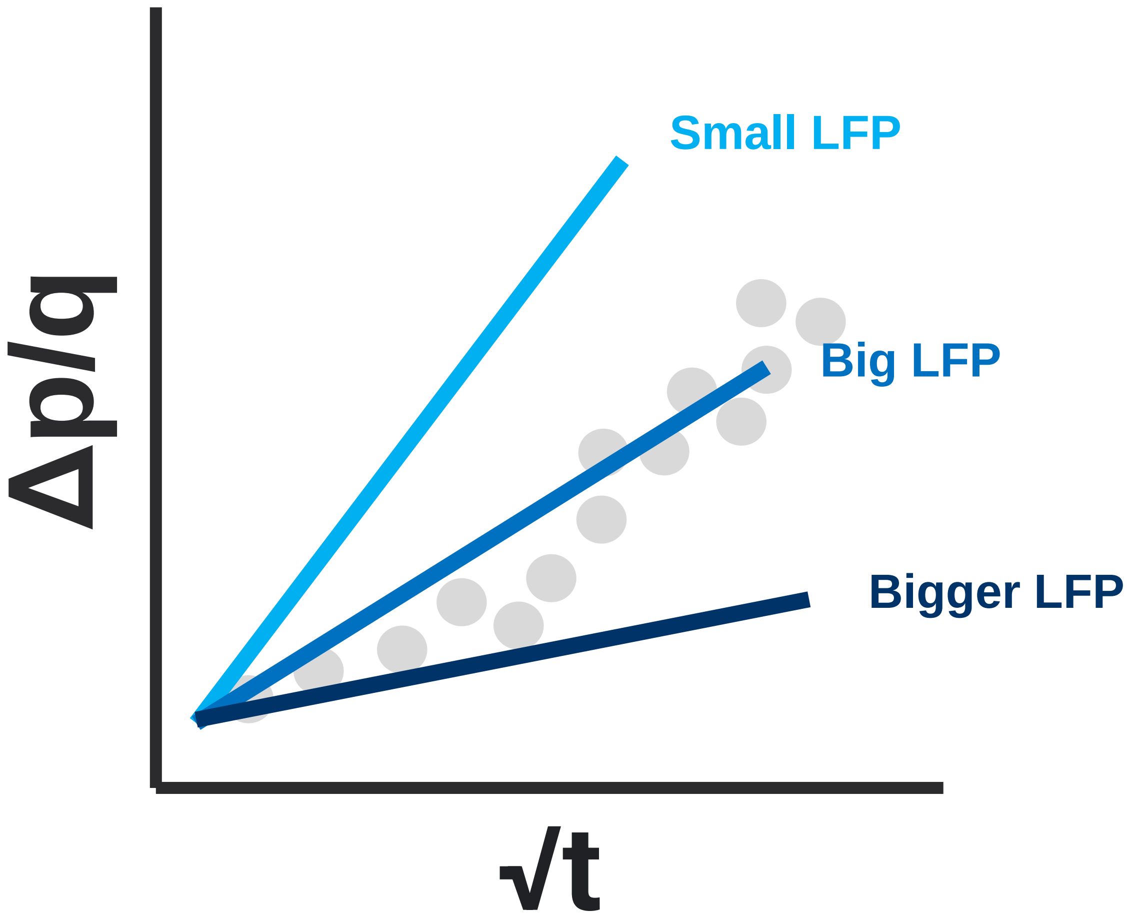


Rate Normalized Pressure (RNP)

$$\Delta p/q = (p_i - p_{wf})/q$$

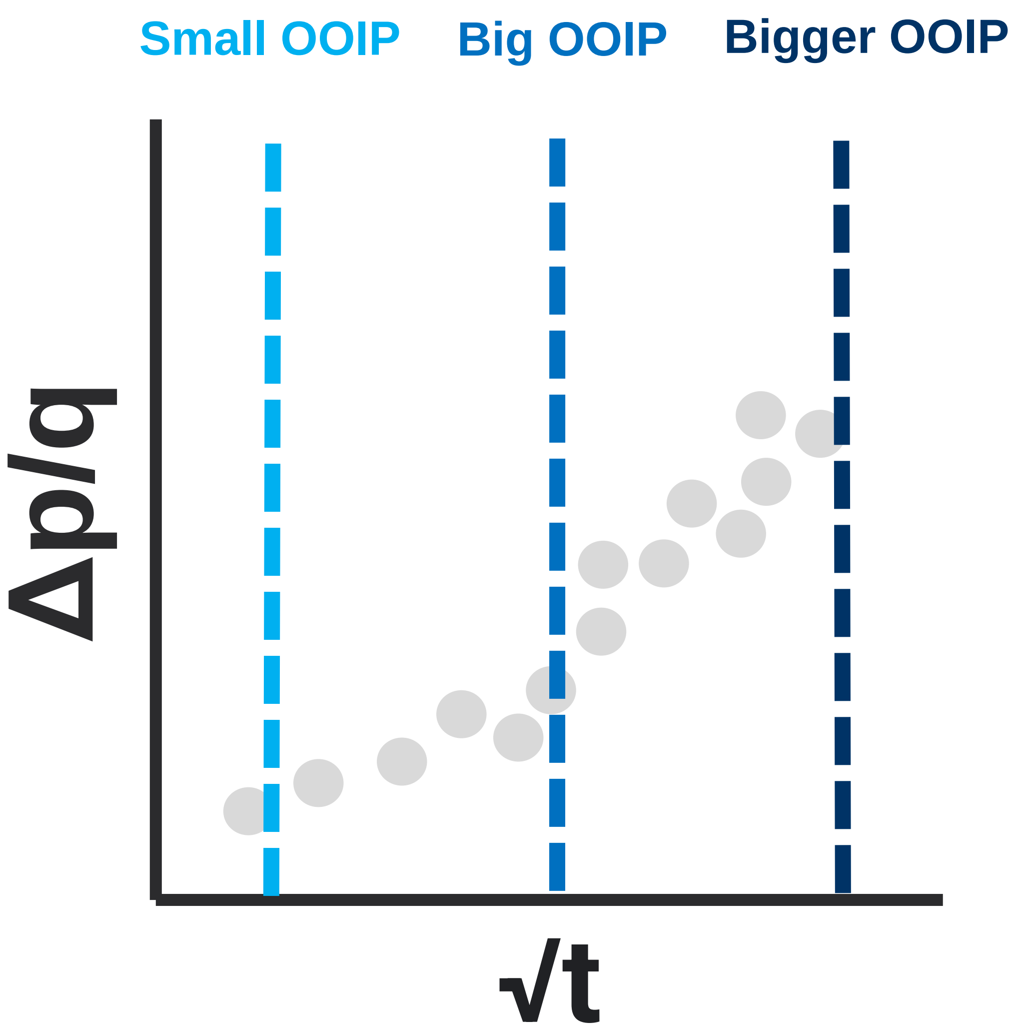
1

Square Root of Time Plot – slope (m)



1

Square Root of Time Plot - t_{elf}



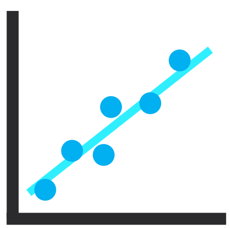
2

Numerical RTA

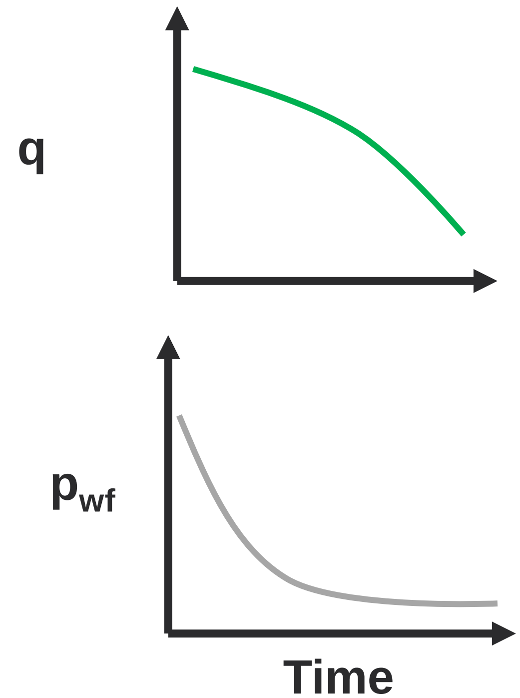
2

Problem

Model



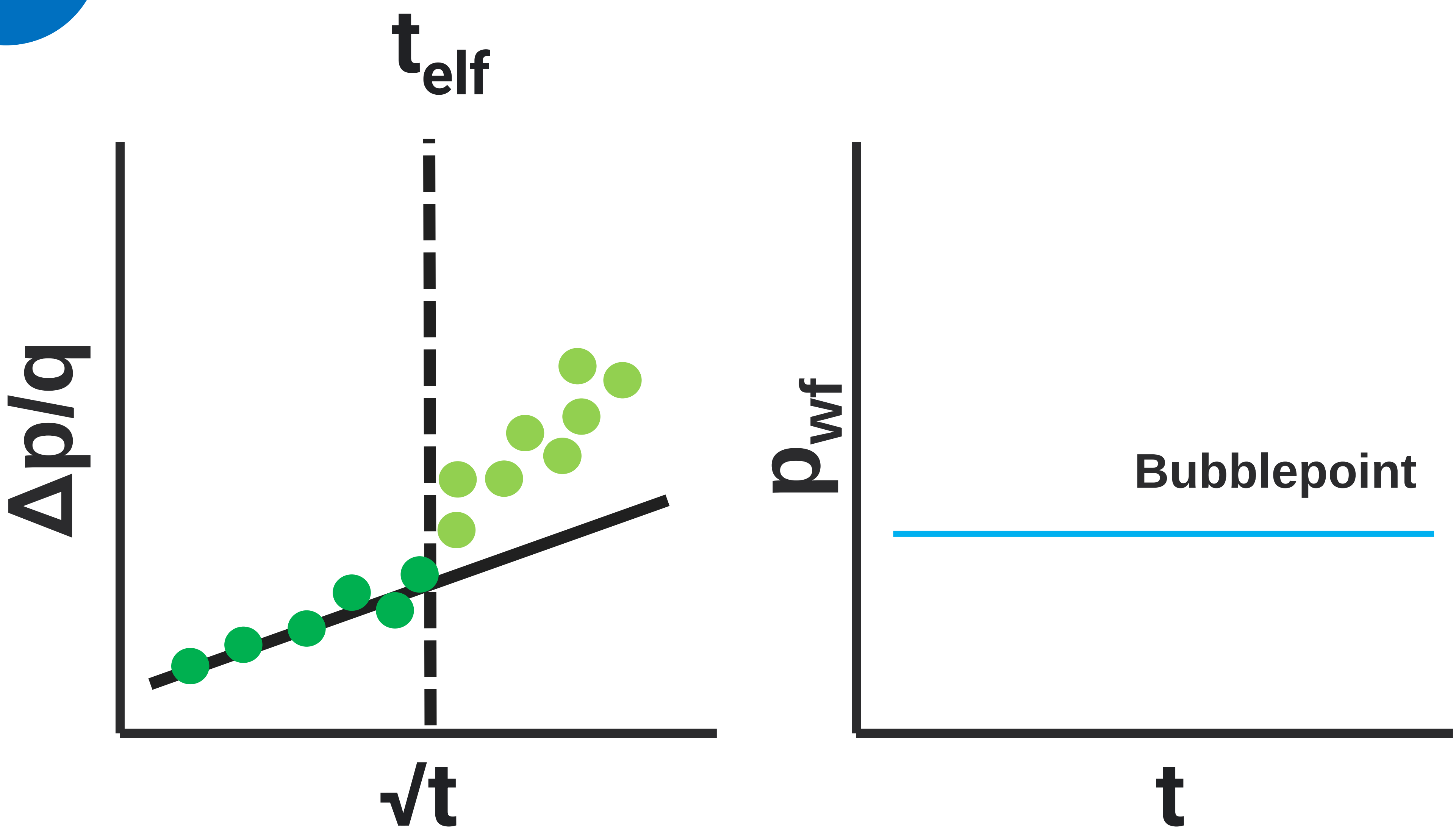
Reality



Assumptions

Single-phase flow and constant rate or pressure

Square Root of Time Plot



2

What does this lead to?

(1) Higher perm

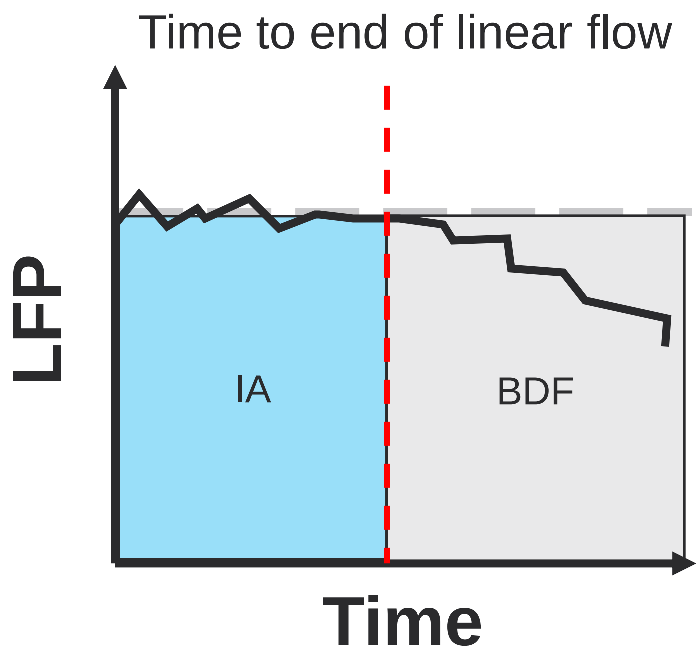
(2) Shorter fracture half length

(3) More wells per section

…

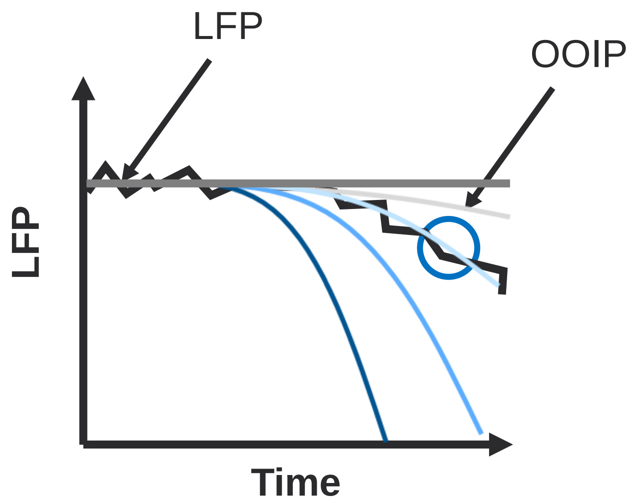
2

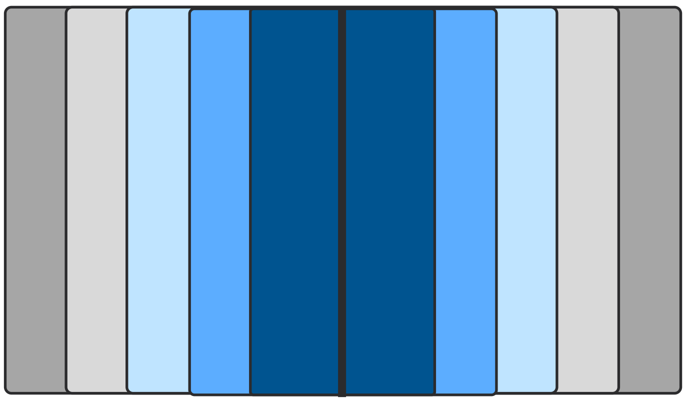
Numerical RTA – Summary



- Horizontal flat line indicates infinite acting, linear flow
- Deviation below this line represents boundary dominated / transitional flow
- The magnitude of the flat line indicates the LFP

Numerical RTA – Summary





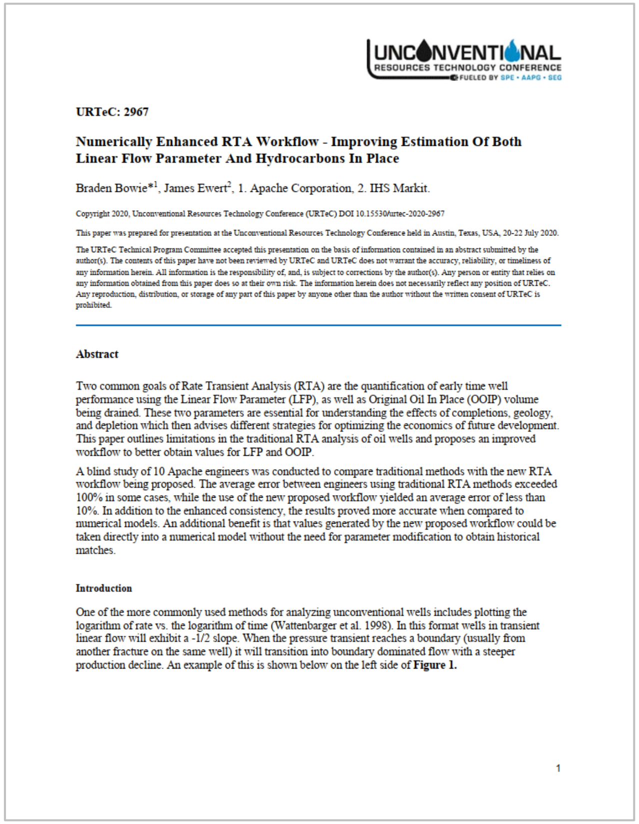
- A set of models are run where the size of the model is the only thing that changes

- Type curve closest to actual data represents contacted pore volume

2

Numerical RTA

URTeC 2967 (2020)



URTeC: 2967

Numerically Enhanced RTA Workflow - Improving Estimation Of Both Linear Flow Parameter And Hydrocarbons In Place

Braden Bowie*[1], James Ewert[2], 1. Apache Corporation, 2. IHS Markit.

This paper was prepared for presentation at the Unconventional Resources Technology Conference held in Austin, Texas, USA, 20-22 July 2020.

Abstract

Two common goals of Rate Transient Analysis (RTA) are the quantification of early time well performance using the Linear Flow Parameter (LFP), as well as Original Oil In Place (OOIP) volume being drained. These two parameters are essential for understanding the effects of completions, geology, and depletion which then advises different strategies for optimizing the economics of future development. This paper outlines limitations in the traditional RTA analysis of oil wells and proposes an improved workflow to better obtain values for LFP and OOIP.

A blind study of 10 Apache engineers was conducted to compare traditional methods with the new RTA workflow being proposed. The average error between engineers using traditional RTA methods exceeded 100% in some cases, while the use of the new proposed workflow yielded an average error of less than 10%. In addition to the enhanced consistency, the results proved more accurate when compared to numerical models. An additional benefit is that values generated by the new proposed workflow could be taken directly into a numerical model without the need for parameter modification to obtain historical matches.

Introduction

One of the more commonly used methods for analyzing unconventional wells includes plotting the logarithm of rate vs. the logarithm of time (Wattenbarger et al. 1998). In this format wells in transient linear flow will exhibit a -1/2 slope. When the pressure transient reaches a boundary (usually from another fracture on the same well) it will transition into boundary dominated flow with a steeper production decline. An example of this is shown below on the left side of **Figure 1.**

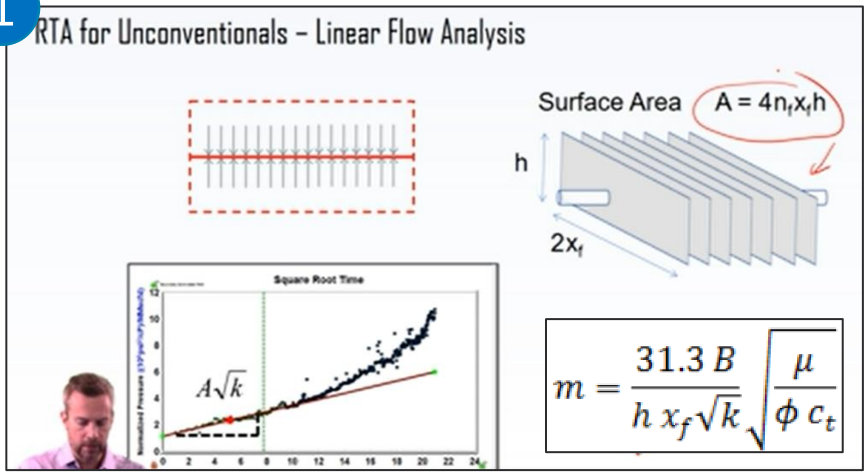
1

Braden Bowie

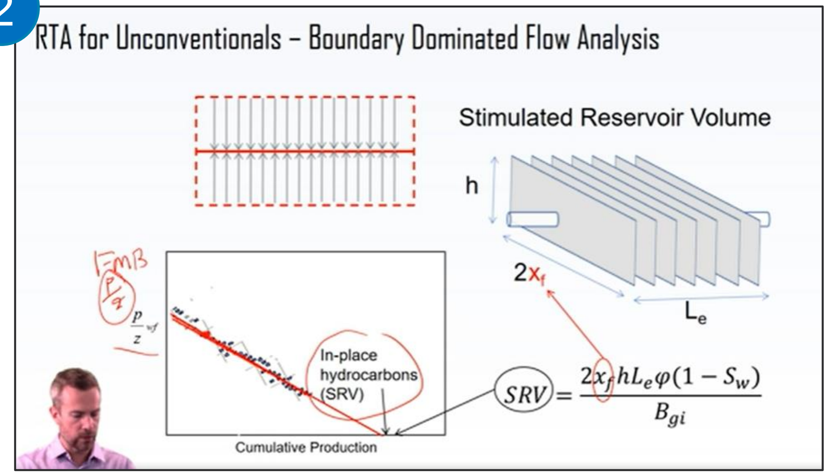
James Ewert

Connecting the Dots …

1



2



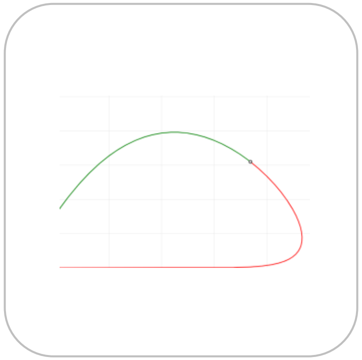
LFP

OOIP

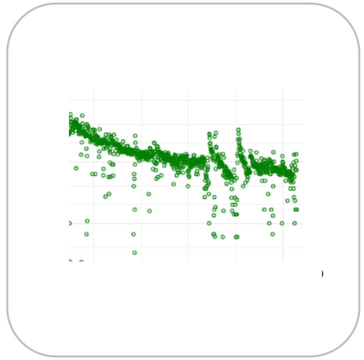
2

Numerical RTA … Inputs

“A problem”



PVT



Prod. Data

Rel. Perm

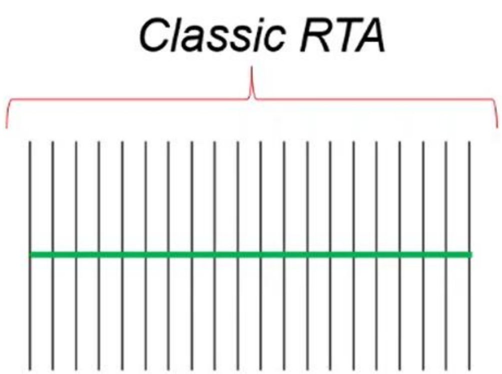
NOT measured or calculated

Fractional RTA

3

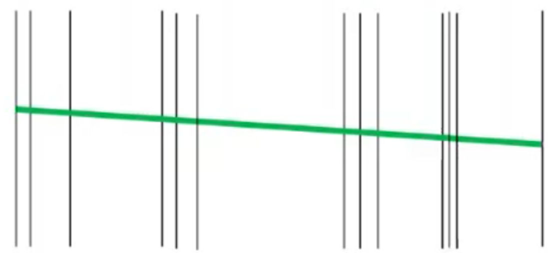
Problem

Model



Equally spaced

Reality



Uneven frac spacing

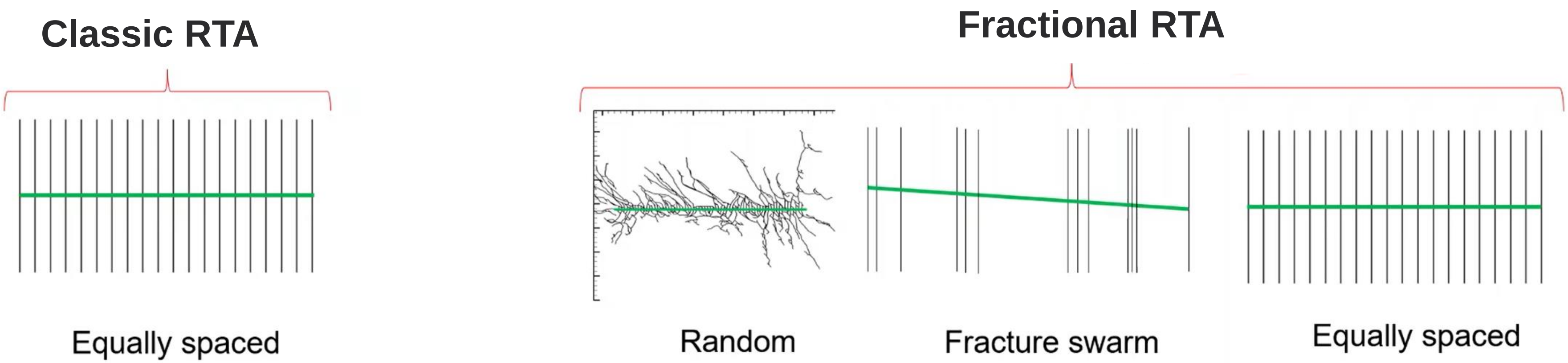
Courtesy: Jorge Acuna

3

Classical RTA vs “Fractional” RTA

Classical RTA: Solves only equally spaced fracture networks (δ = 0.5), gives $A\sqrt{k}$

Fractional RTA: Solves for complex system of fractures (any value of δ), gives Ak^{δ}

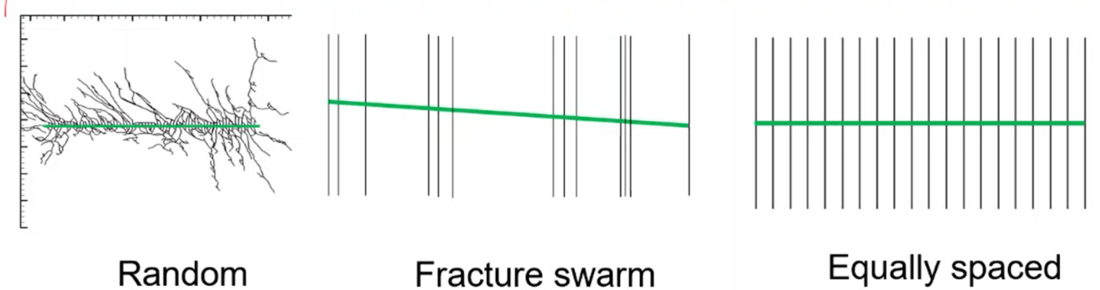


Courtesy: Jorge Acuna

"Generalized" LFP

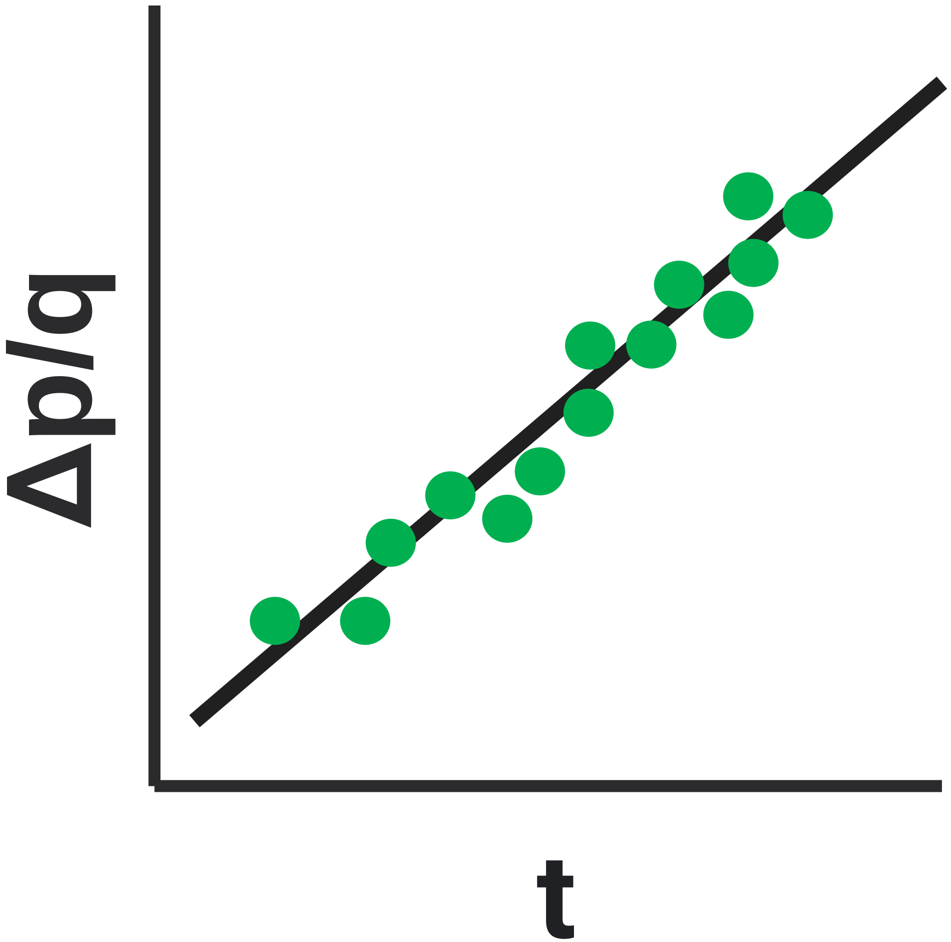
$$LFP = Ak^{\delta}$$

Fractional RTA



3

Rate Normalized Pressure (RNP)



$$\frac{\Delta p}{q} = mt^{1-\partial} + b$$

Physical Significance of Delta (δ)

Infinite acting, linear flow – $\delta = 0.5$

↑ ↑ ↑ ↑ ↑

Transitional flow (period in between) – $0 < \delta < 0.5$

↓ ↓ ↓ ↓ ↓

Boundary dominated flow – $\delta = 0$

**in material balance time*

RTA

RTA

RTA

What can be Derived "Uniquely" from RTA? LFP & OOIP

Correlate with 1 yr cum

LFP

$$= A\sqrt{k}$$

Observed during
infinite-acting, linear flow

Correlate with EURs

OOIP

$$= HCPV/B_o$$

Observed during
boundary dominated flow

whitson

What is A√k aka LFP?

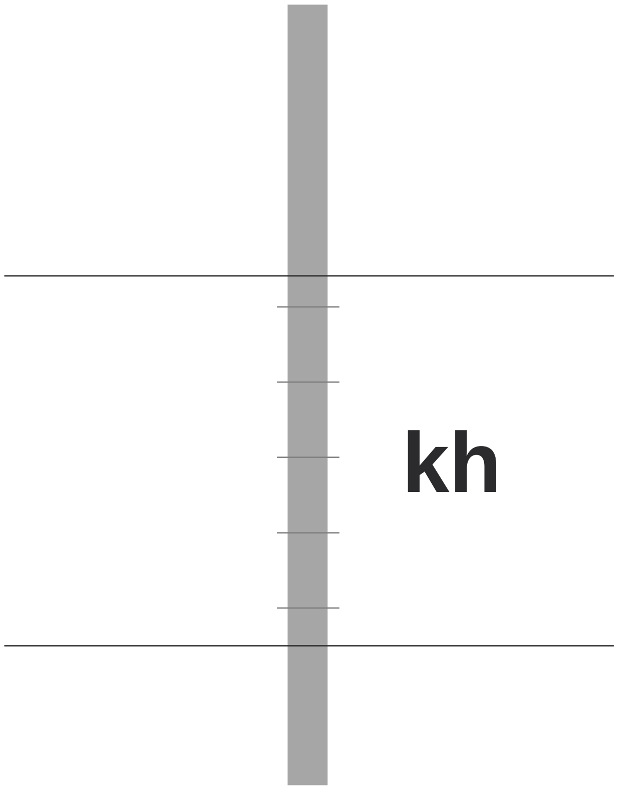
A√k is just the sideways "kh"

Courtesy: Sam Shoun

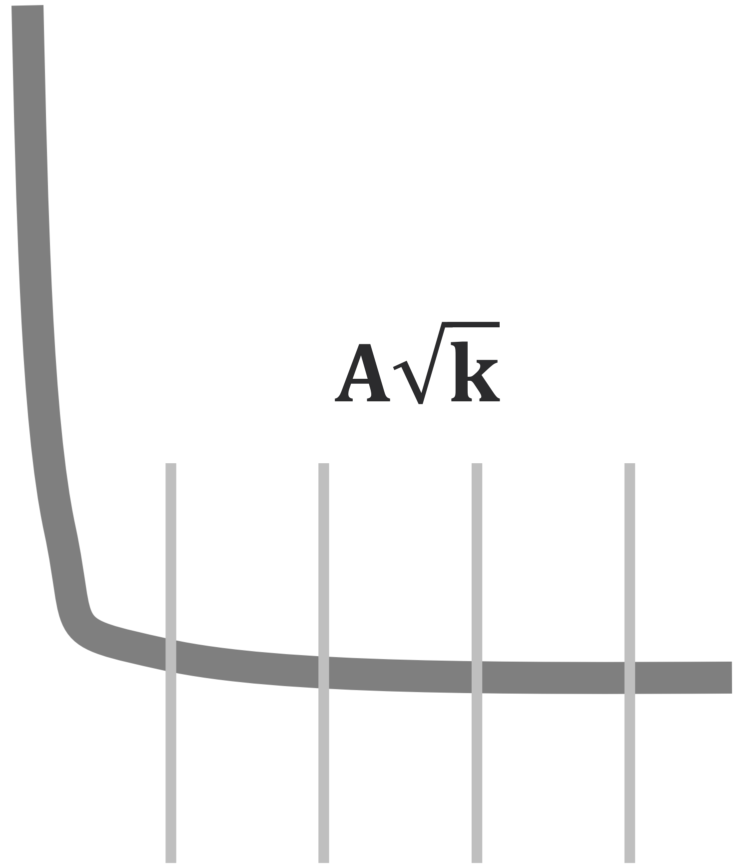
RTA

What are we “hunting” for? $A\sqrt{k}$

Vertical Wells



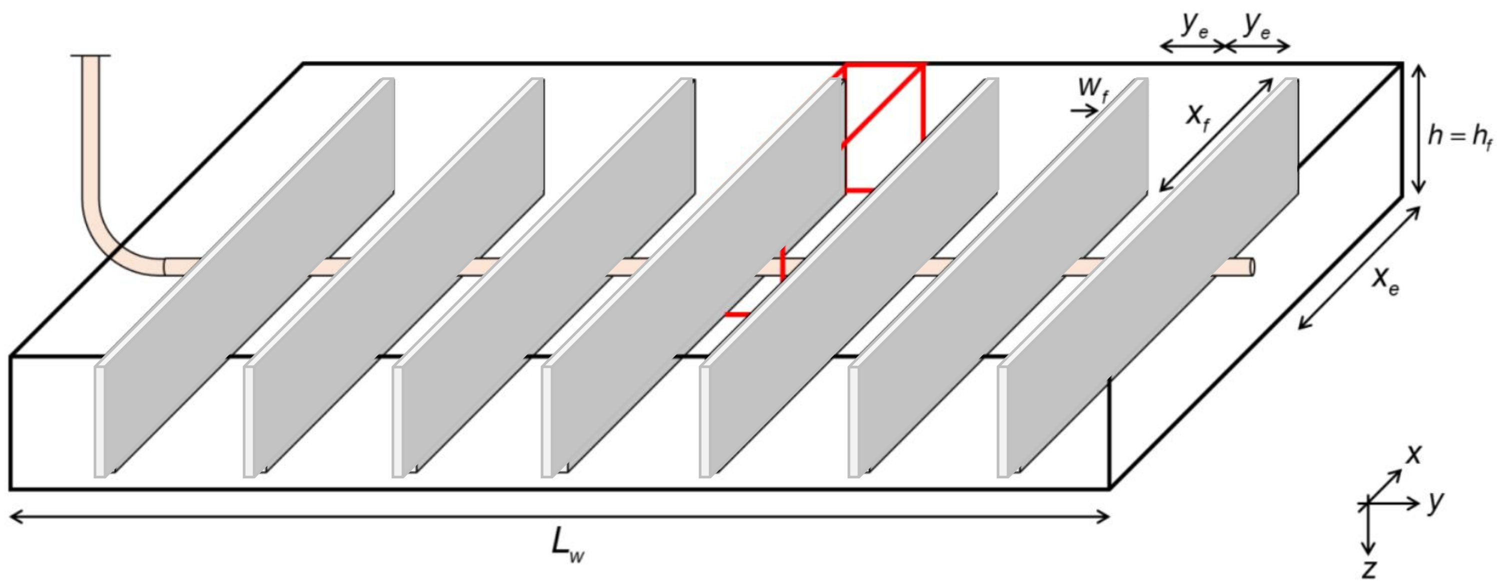
Multi-Frac Horizontal Wells



Courtesy: Sam Shoun

Linear Flow Parameter (LFP)

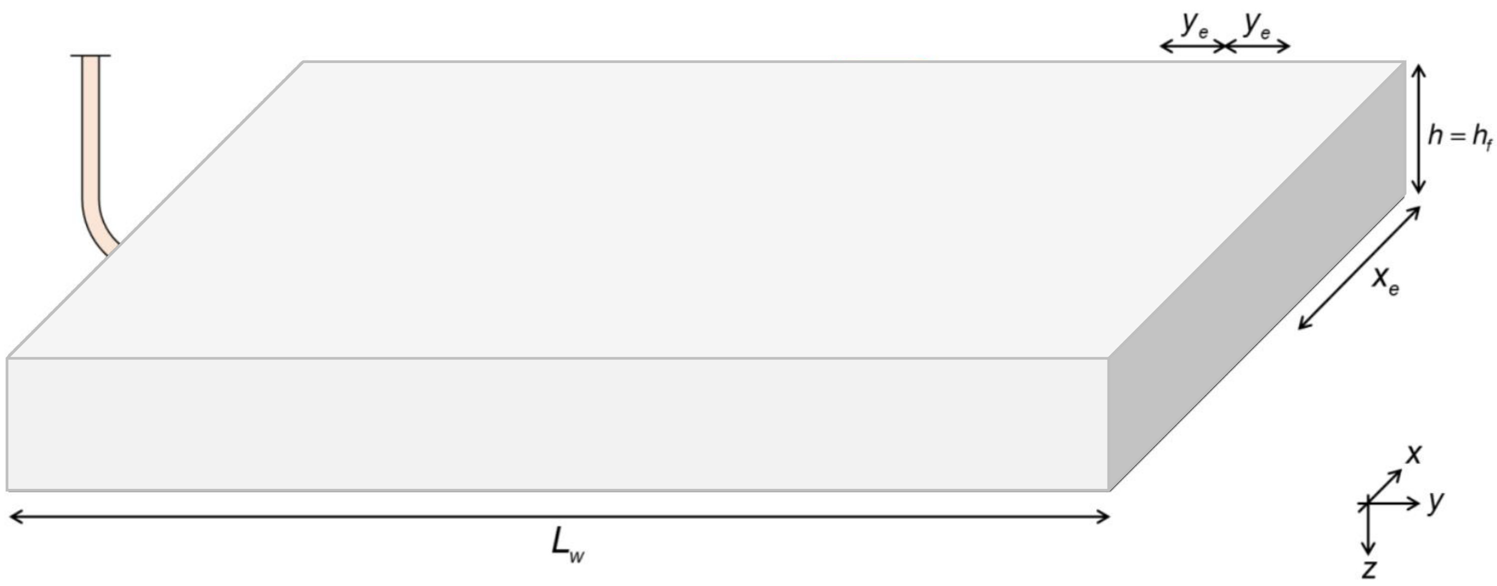
$$LFP = A\sqrt{k} = 4n_f x_f h\sqrt{k}$$



whitson

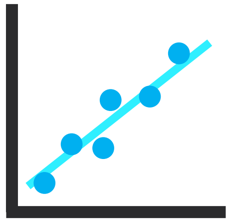
Contacted Pore Volume

$$OOIP = \frac{\text{HCPV}}{B_{ti}} = \frac{2x_f L h \varphi (1 - S_{wi})}{B_{ti}}$$



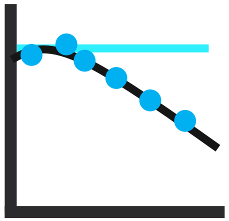
RTA … Different Methods

RTA



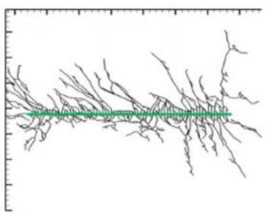
Classical RTA

"Square Root of Time Plot"



Numerical RTA

"Bowie Workflow"



Fractional RTA

"Acuna"

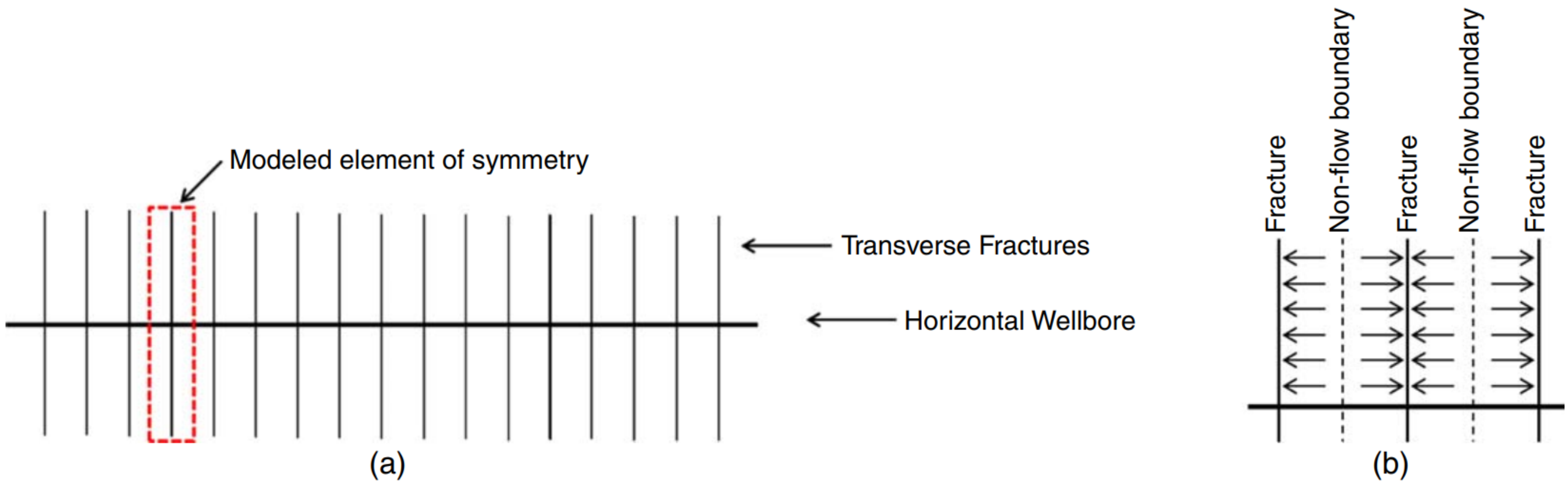
$$LFP_{classical} \neq LFP_{numerical} \neq LFP_{fractional}$$

RTA

Classical RTA

Key Assumption: Symmetry of Element Model

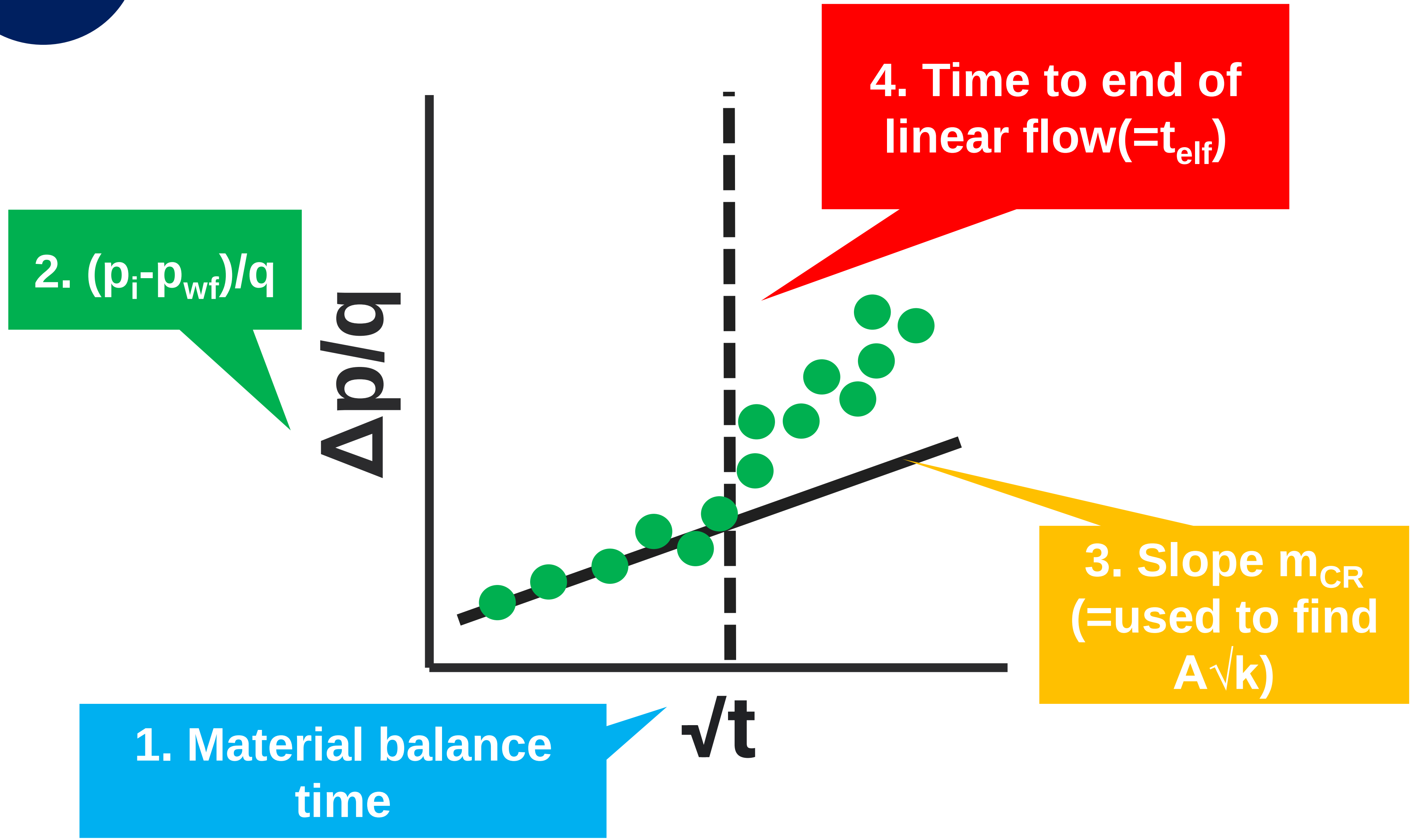
“1-dimensional model” | Only one no-flow boundary



*SPE 184397, Steve Jones

whitson

Classical RTA 1.01



whitson

Material Balance Time

The use of material balance time is common in the rate transient analysis.

Material balance time

- is a **superposition** time function
- converts variable rate data into an equivalent **constant rate solution**
- is rigorous for a **boundary dominated** flow regime
- works well for **infinite acting** data also, but is only an approximation (errors can be up to 20% for linear flow)

Mathematically, material balance time, MBT is expressed in:

$$t_c = \frac{Q(t)}{q(t)}$$

where Q(t) and q(t) are cumulative production and production rate at time t.

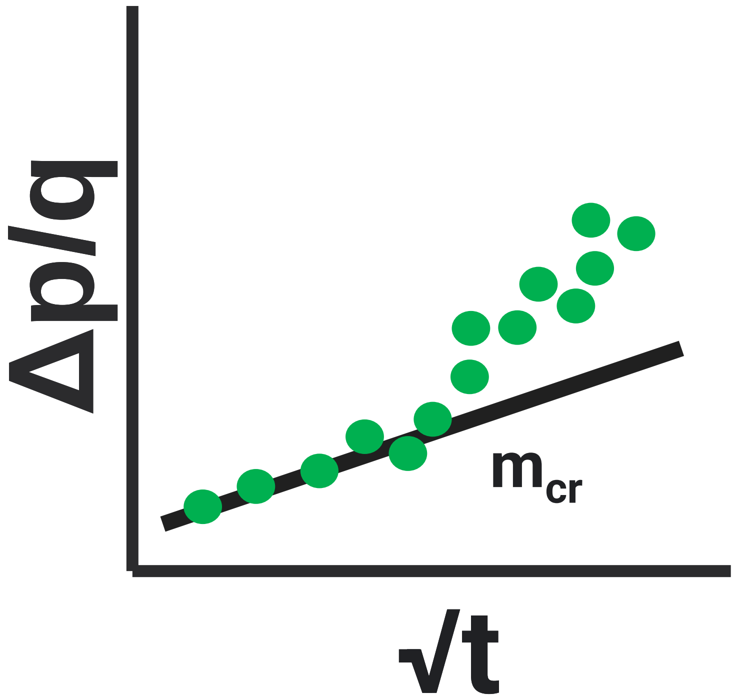
Rate Normalized Pressure: Δp/q

Rate Normalized Pressure (RNP) is very useful for production analysis where flowing pressures and rates change through time.

It is defined as the flowing pressure drop divided by rate.

$$RNP = \frac{\Delta p}{q} = \frac{p_i - p_{wf}}{q}$$

Solution for Linear Flow (constant rate)



Oil

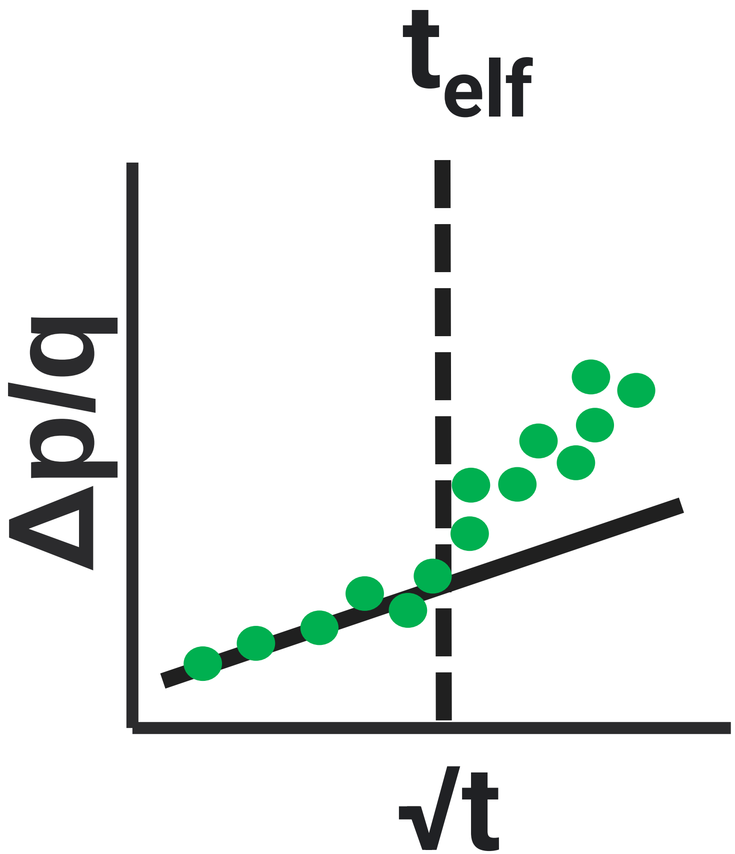
$$\frac{p_i - p_{wf}}{q} = \underbrace{\frac{19.927 B_o}{h x_f \sqrt{k}} \sqrt{\frac{\mu_o}{\phi c_t}}}_{m_{CR}} \sqrt{t} + b'$$

Gas

$$\frac{m(p_i) - m(p_{wf})}{q} = \underbrace{\frac{200.8 T_R}{h x_f \sqrt{k}} \frac{1}{\sqrt{(\phi \mu_g c_t)_i}}}_{m_{CR}} \sqrt{t} + b'$$

Pseudo pressure

Time to end of Linear Flow



$$y_e = 0.113\sqrt{\frac{kt_{elf}}{(\phi\mu c_t)_i}}$$

$$y_e = \frac{L_w}{2 * n_f}$$

Solve for k

Time to end of Linear Flow

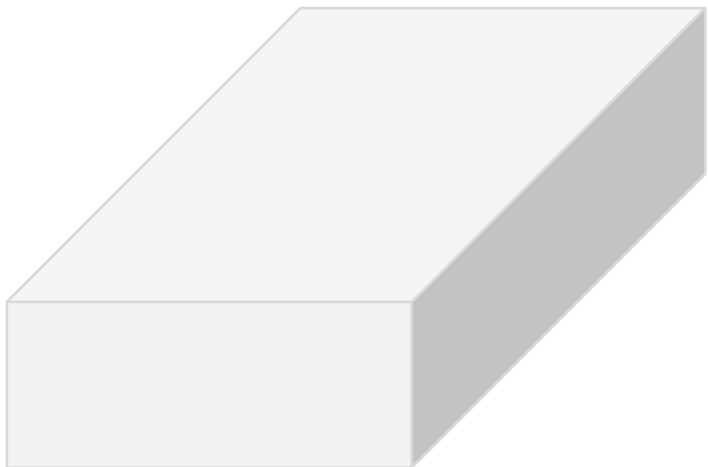
Oil

$$m_{CR} = \frac{19.927 B_o}{h x_f \sqrt{k}} \sqrt{\frac{\mu_o}{\phi c_t}}$$

Gas

$$m_{CR} = \frac{200.8 T_R}{h x_f \sqrt{k}} \frac{1}{\sqrt{(\phi \mu_g c_t)_i}}$$

$V_p = 2 x_f h L_w \varphi$



https://manual.whitson.com/modules/well-performance/analytical_rta/

Pressure Normalized Rate: q/Δp

Pressure normalized rate is the inverse of rate normalized pressure.

Pressure normalized rate is very useful for production analysis where flowing pressures and rates change through time.

It is defined as the rate divided by flowing pressure drop.

$$PNR = \frac{q}{\Delta p} = \frac{q}{p_i - p_{wf}}$$

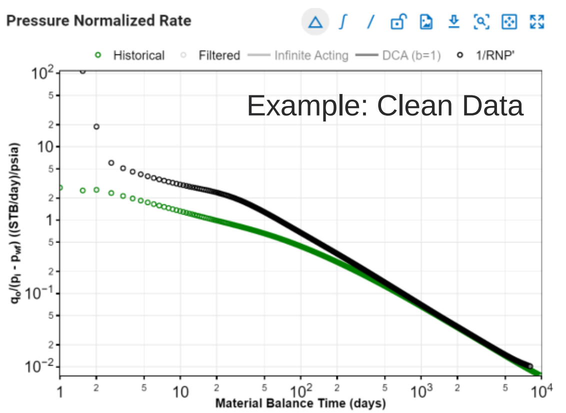
Classical RTA Dashboard

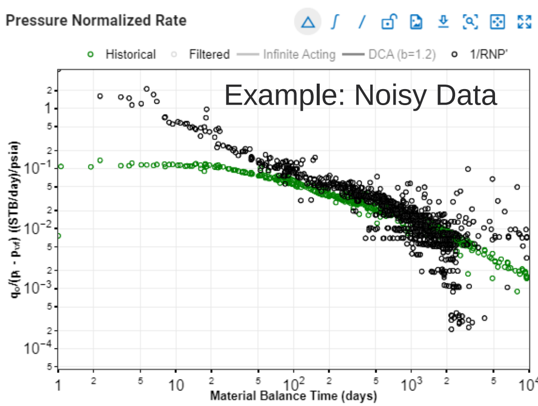
$\Delta p/q$ vs $\sqrt{t}$	q vs t
$q/\Delta p$ vs t	p_{wf} vs t

Derivatives & Integrals

Derivatives

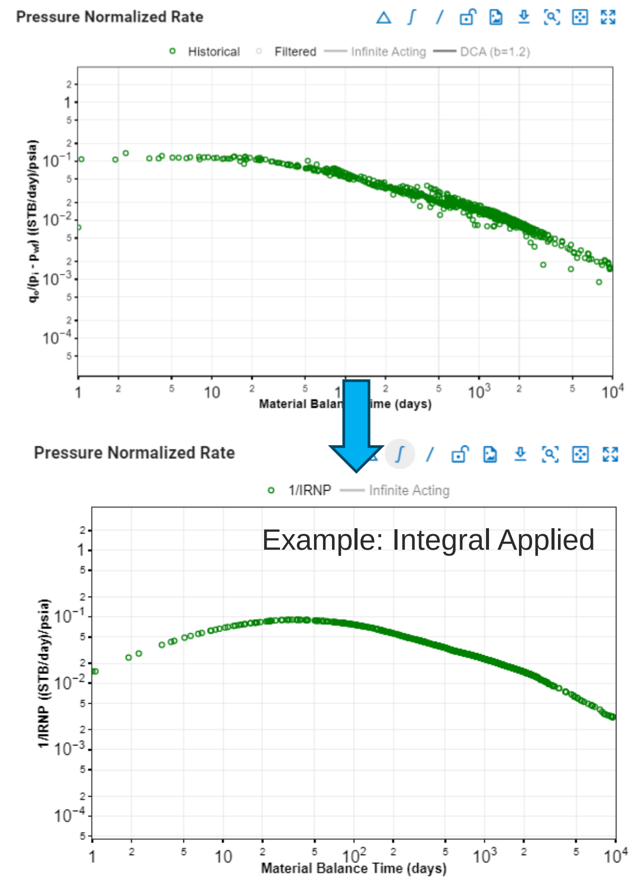
"Derivative analysis amplifies the reservoir signal but also amplifies the noise"





Integrals

"Integral analysis reduces the noise, but also reduces the signal."

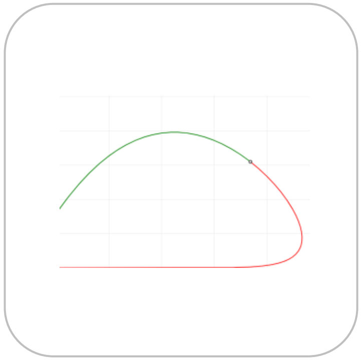


whitson

Numerical RTA

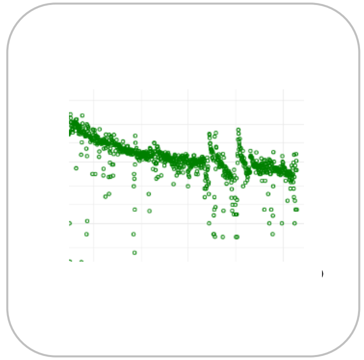
RTA

Numerical RTA … Inputs



PVT

Measured or calculated from readily available data



Prod. Data

Measured or calculated from readily available data

Rel. Perm

<u>NOT</u> measured or calculated from readily available data

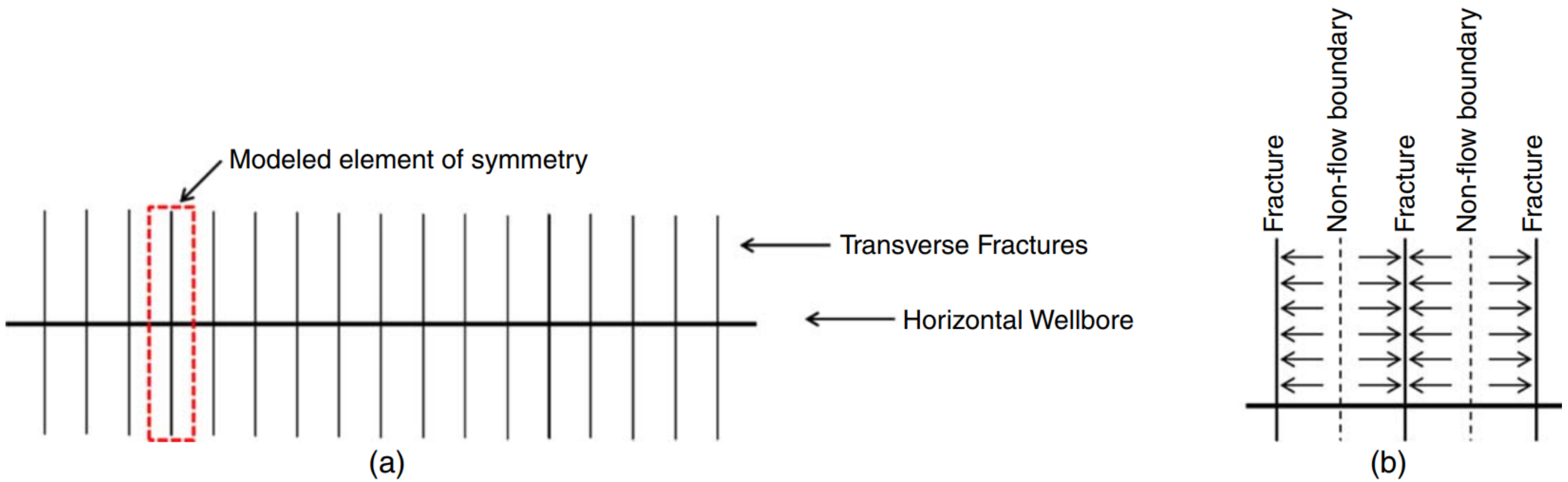
RTA

Numerical RTA

Key Concepts & theory

Key Assumption: Symmetry of Element Model

"1-dimensional model" | Only one no-flow boundary



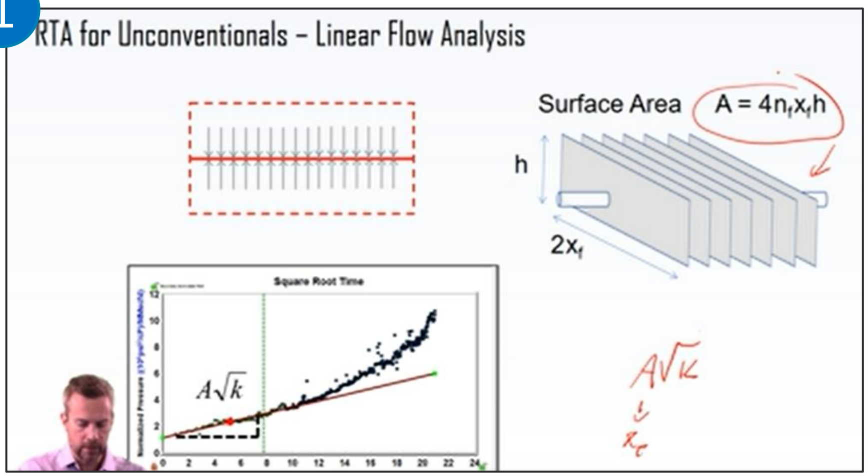
*SPE 184397, Steve Jones

whitson

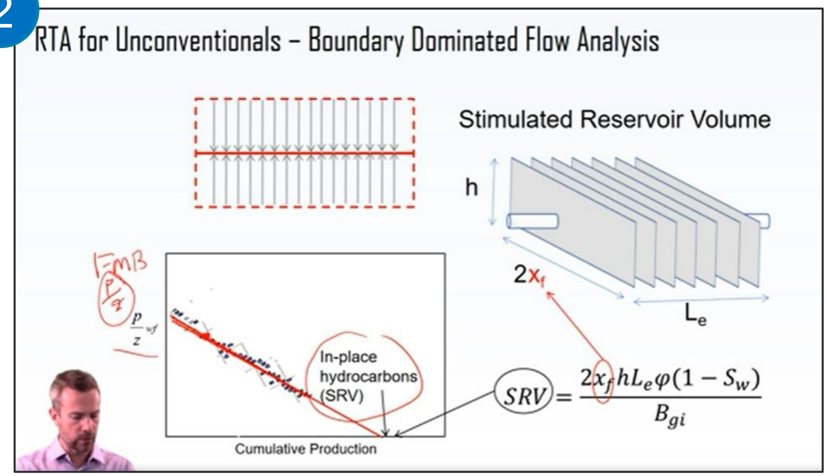
RTA

Industry Standard Workflow

1



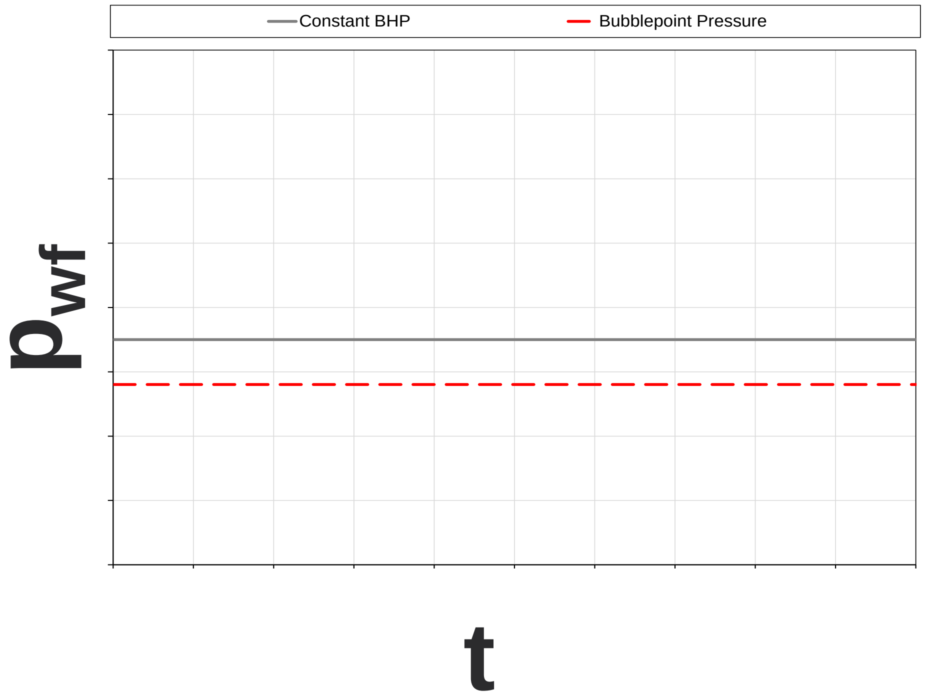
2

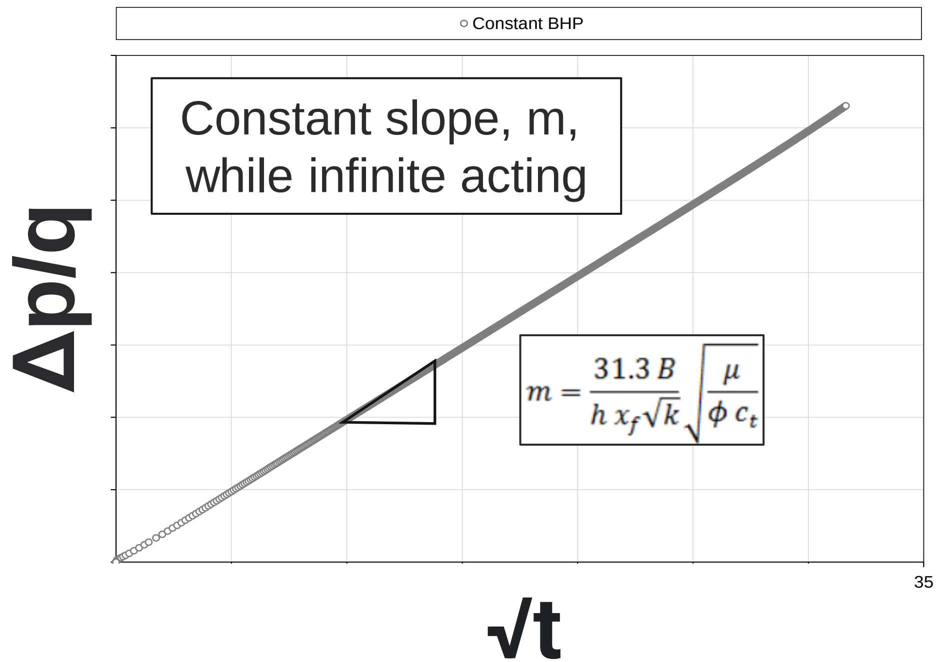


Source: https://www.sagawisdom.com/courses/rate-transient-analysis-rta

Square Root of Time

Single-phase Flow | Constant Bottomhole Pressures

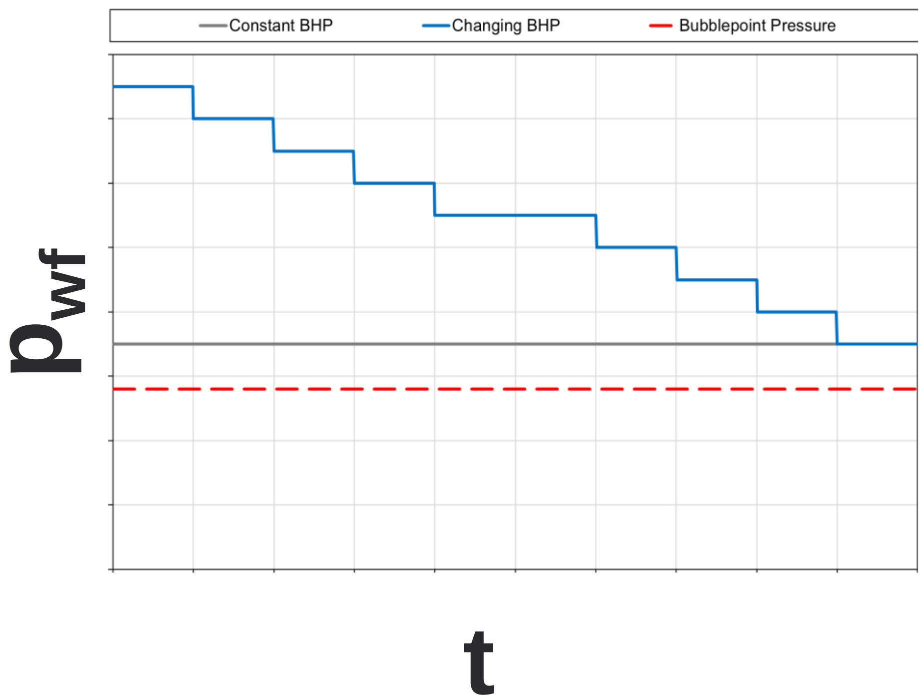




whitson

Superposition Effects

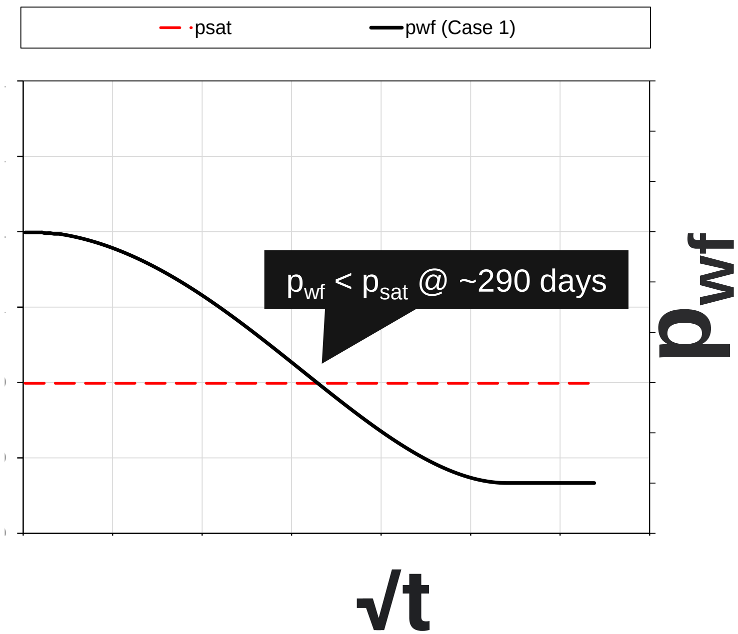
Changing Rates & Pressures

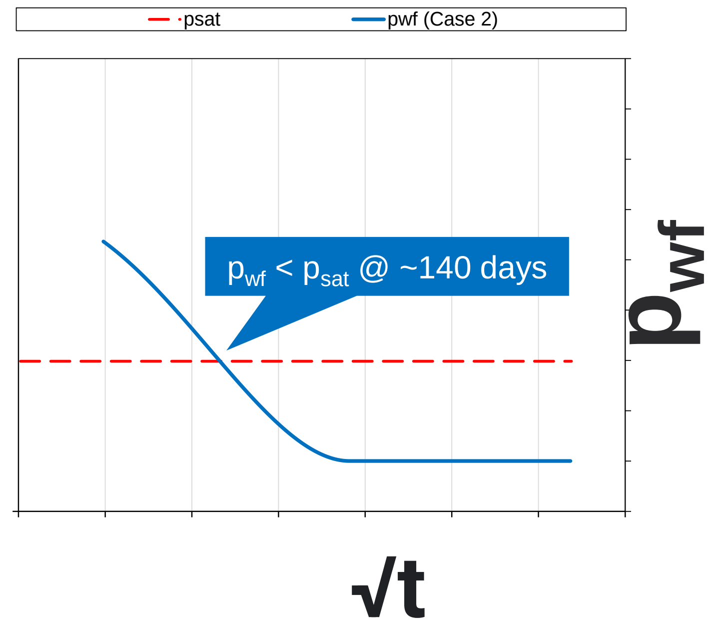


Multi-Phase Flow + Superposition Effects

RTA

Same Infinite Acting Case, different p_{wf} profiles



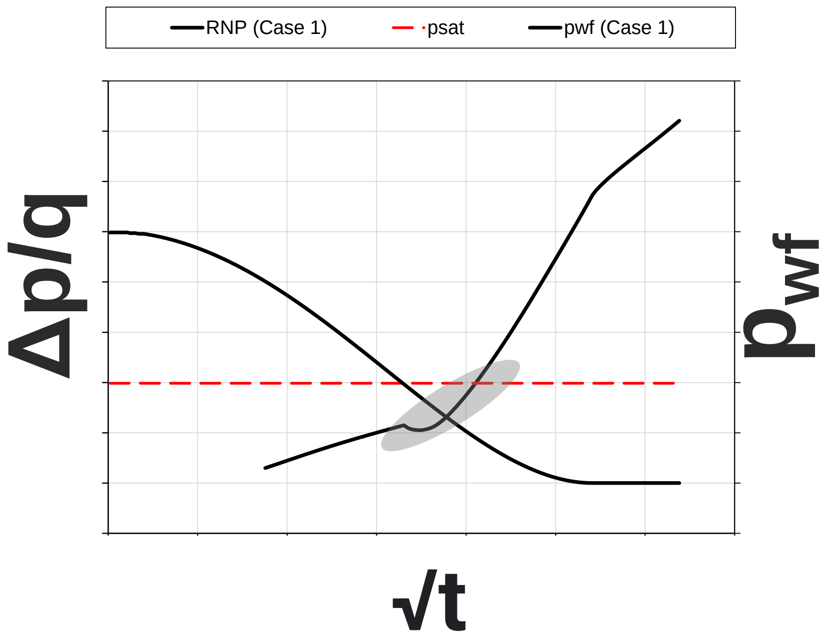


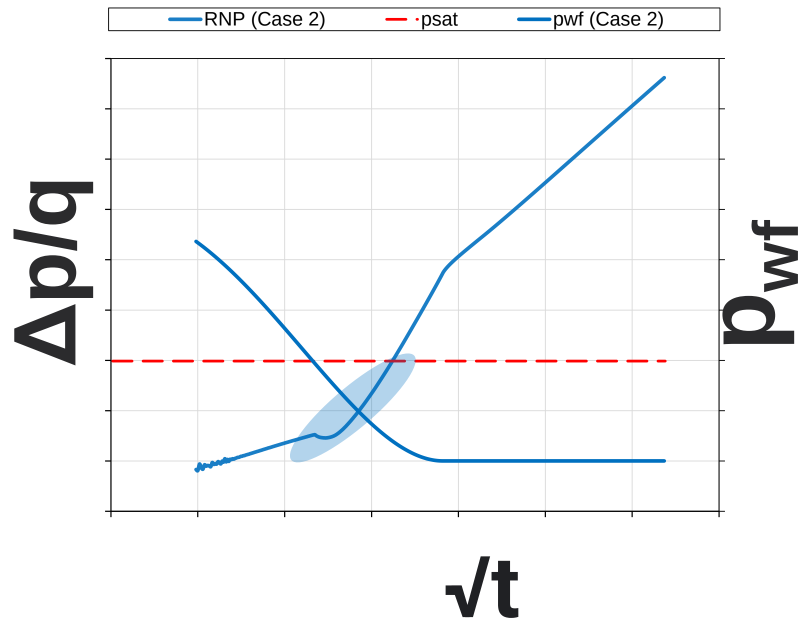
whitson

RTA

Multi-Phase Flow + Superposition Effects

Deviation from straight line introduced when $p_{wf} < p_{sat}$





What does this lead to?

(1) Higher perm

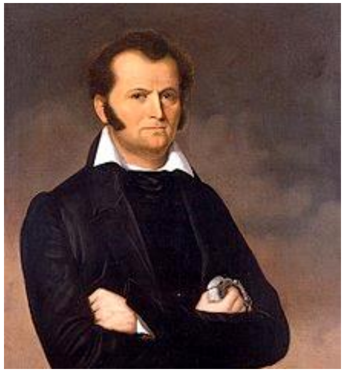
(2) Shorter fracture half length

(3) More wells per section

→ Overcapitalization …

RTA

The "Bowie Workflow"



Nothing to do with
David Bowie, James Bowie or
the Bowie Knife

Braden Bowie
Reservoir Engineering Lead, Apache

https://doi.org/10.15530/urtec-2020-2967

Three Fundamental Relationships

For any two wells*:

(1) with the same value of LFP, rate performance is identical during infinite-acting (IA) behavior

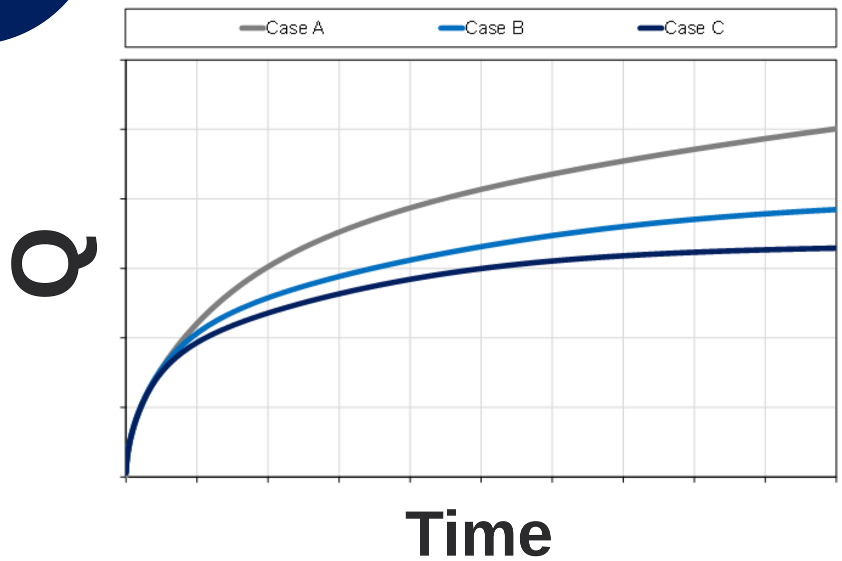
(2) with the same ratio LFP / OOIP, GOR and water cut behavior is identical for all times, IA and boundary dominated (BD)

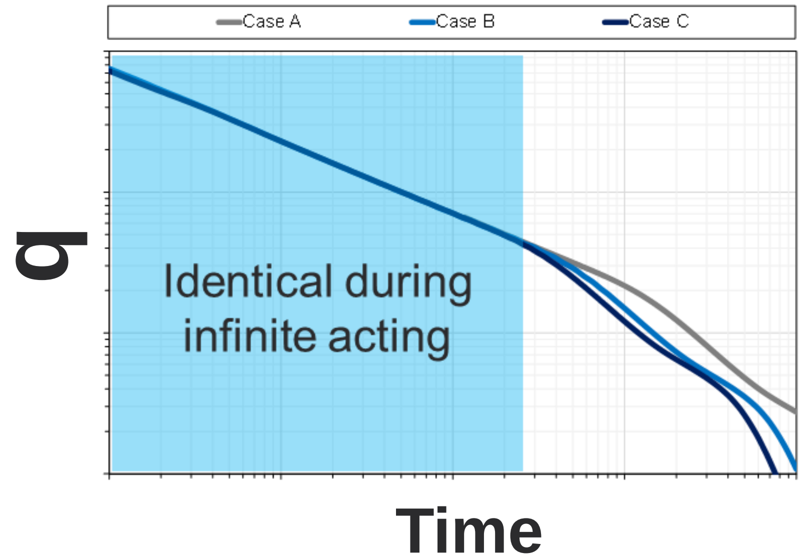
(3) with the same values of LFP and OOIP, rate performance will be identical for all times, IA and BD

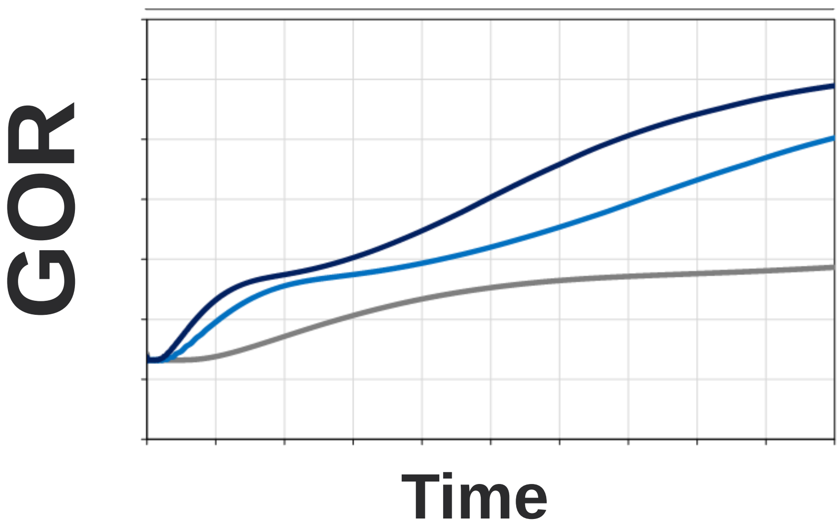
*With the same (a) fluid initialization (GOR_i and S_{wi}) and (b) relative permeability relations, and (c) bottomhole pressure (BHP) time variation (above and below saturation pressure)..

RTA

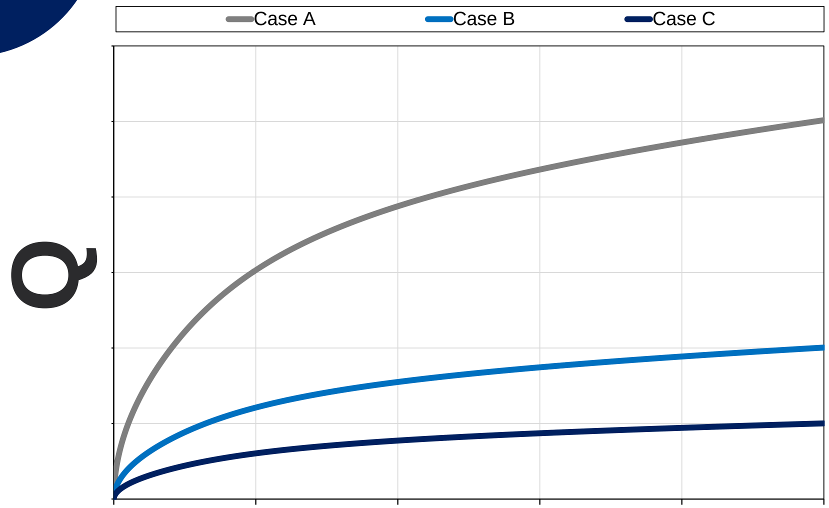
Same LFP, same IA performance

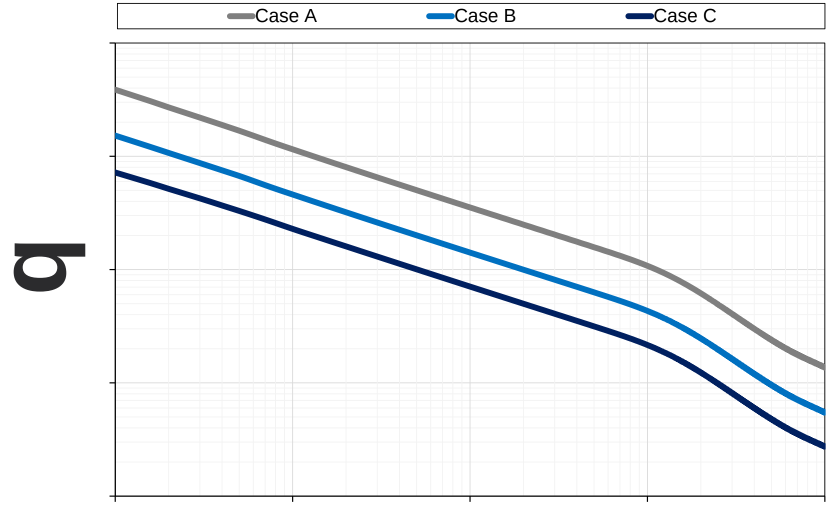


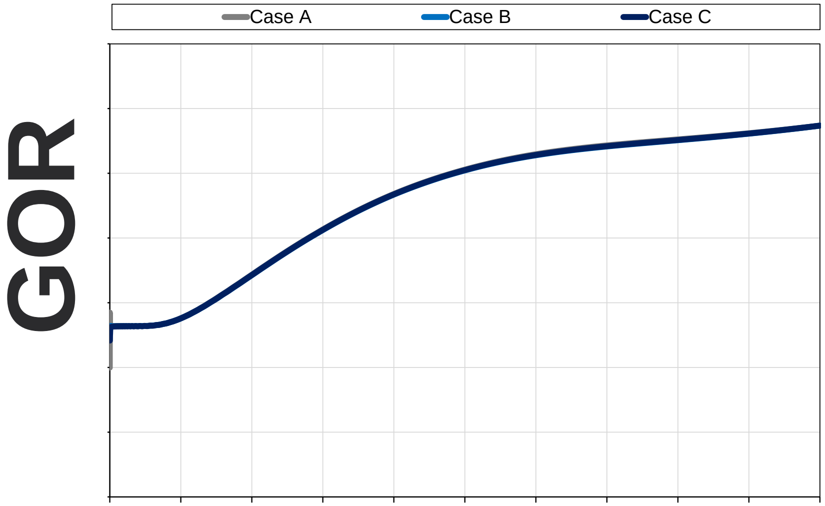




Same LFP / OOIP ratio, same GOR

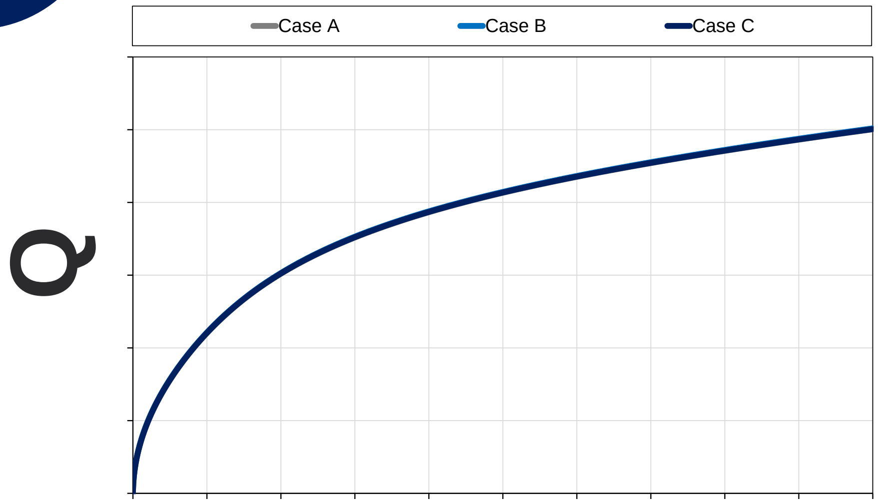


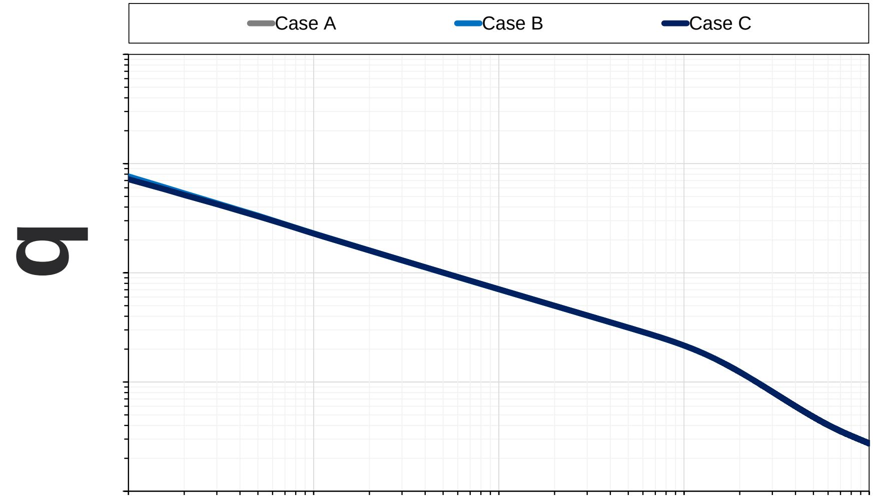


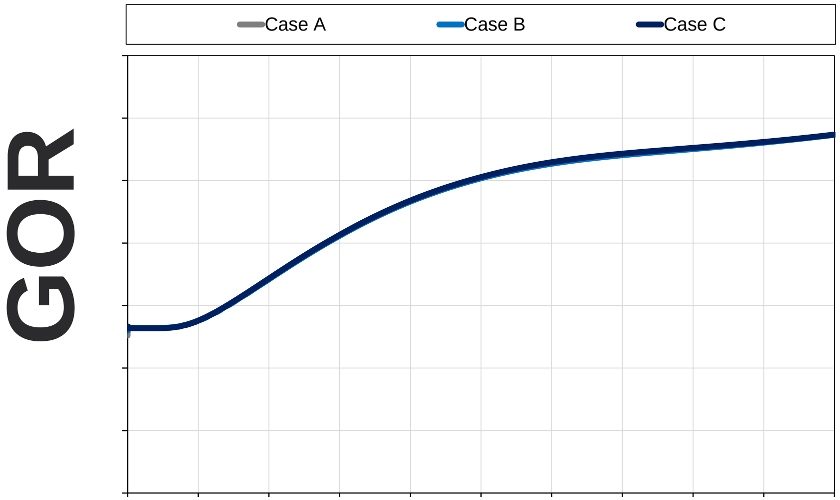


RTA

Same LFP and OOIP, same performance







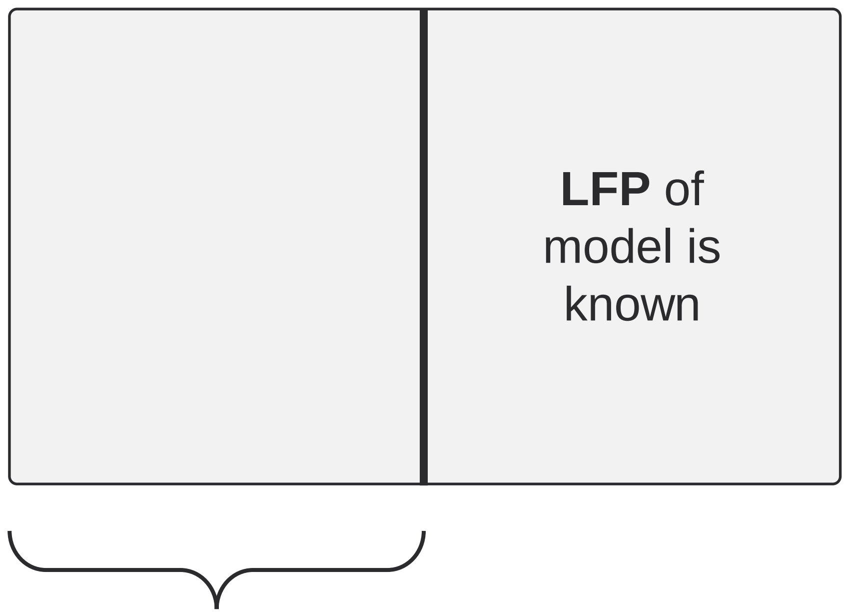
whitson

RTA

The "Bowie Workflow"

1. Create a numerical model that is large enough to behave infinite acting (=large OOIP) for the entirety for the historical time.

Reservoir Model

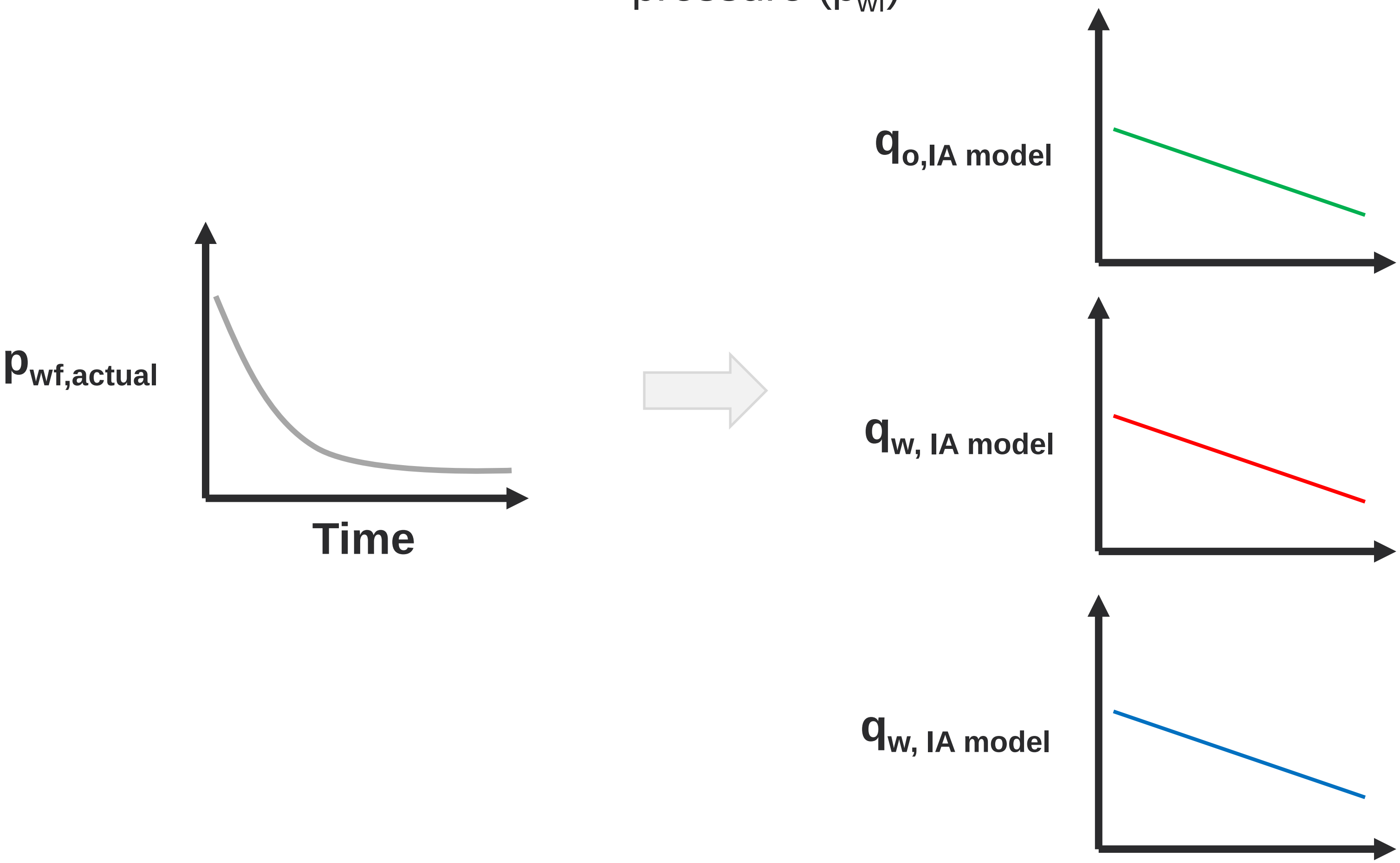


Far to closest boundary

whitson

The "Bowie Workflow"

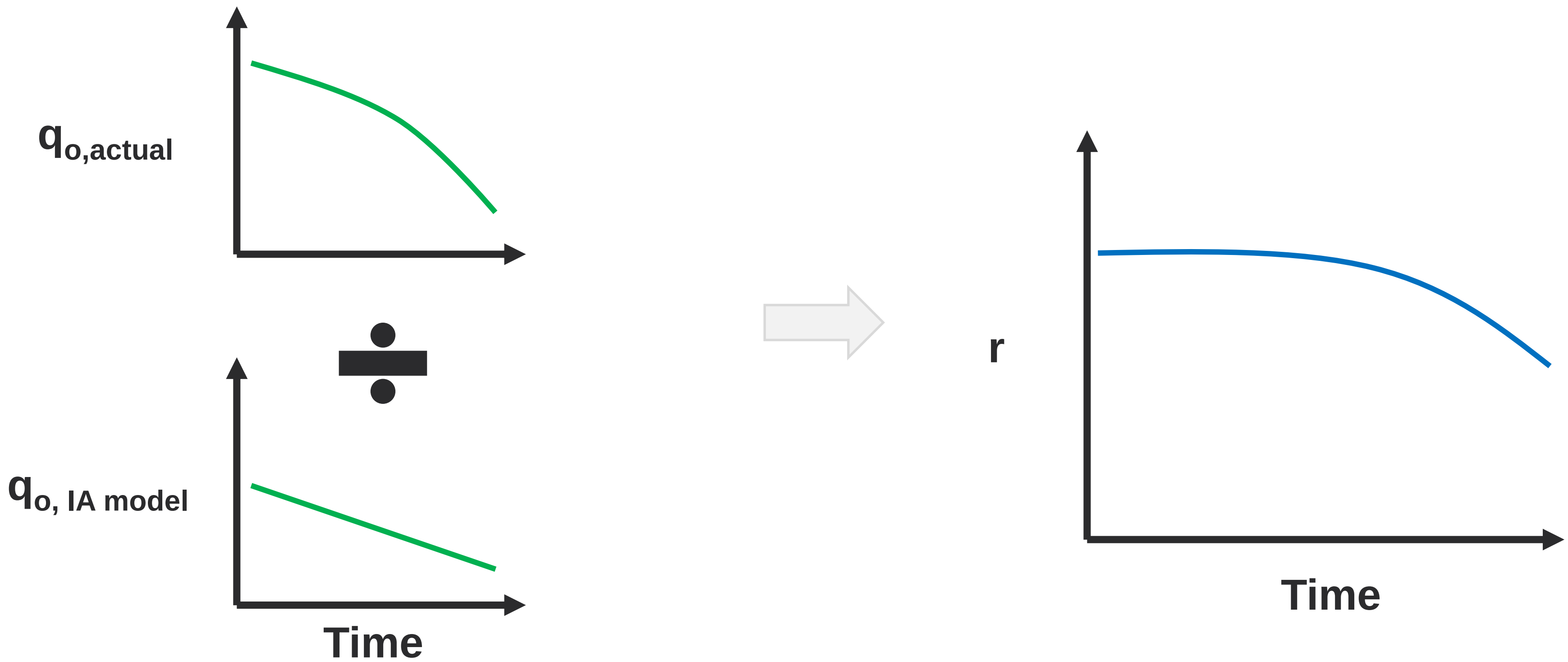
2. Run this "infinite acting model" on the wells actual measured bottomhole pressure (p_{wf})



whitson

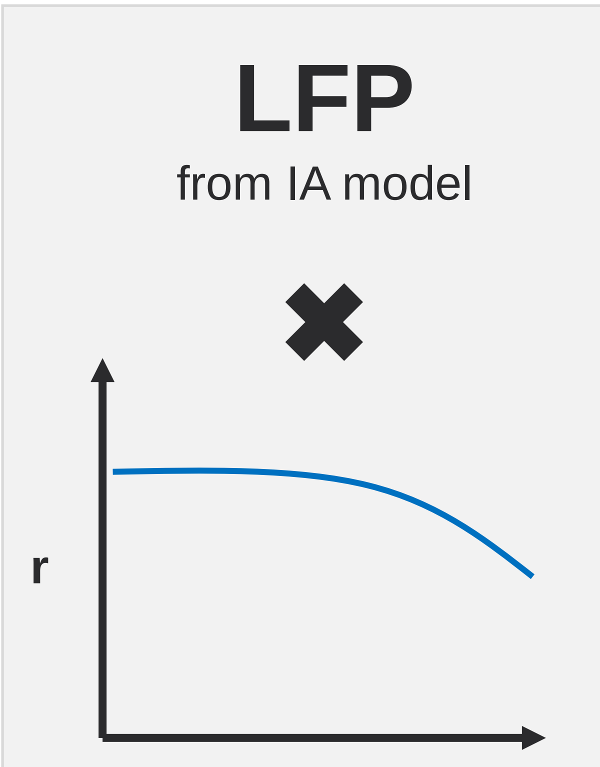
The “Bowie Workflow”

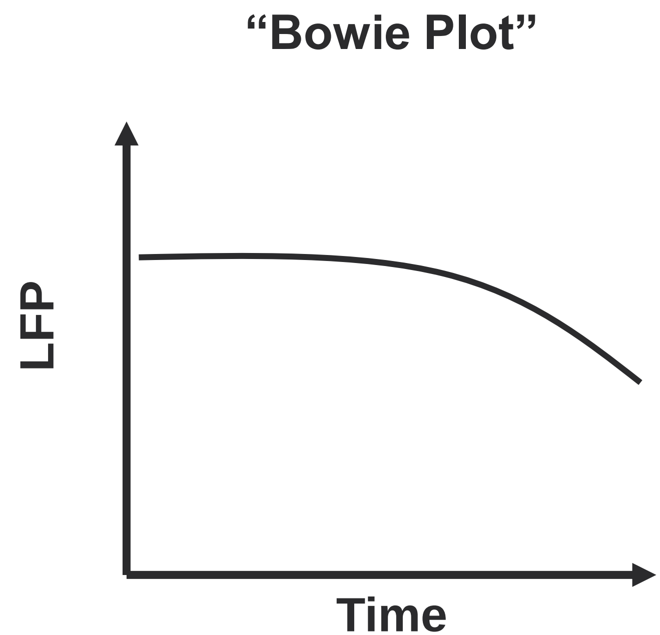
3. Calculate the ratio between the actual measured oil rates and infinite acting model oil rates: $r = q_{o,actual}/q_{o,IA}$ (alternative: $r = Q_{o,actual}/Q_{o,IA}$)



The “Bowie Workflow”

4. Calculate the daily **“LFP”** by multiplying the daily **ratio r** (Step 3) with the **known LFP** of the infinite acting, single fracture model (Step 1)

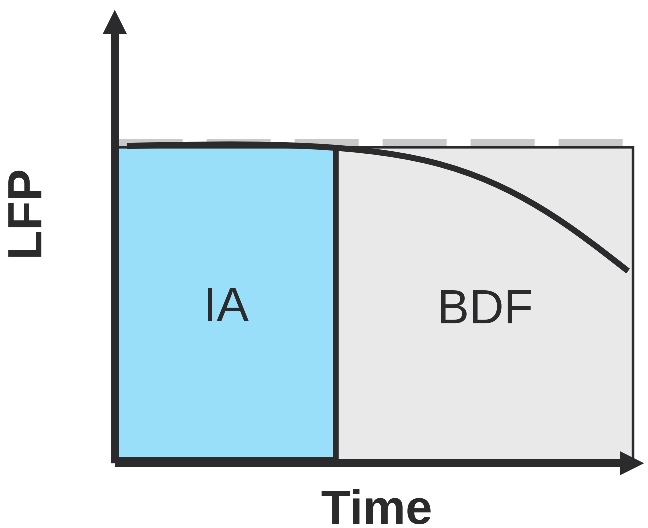




The “Bowie Workflow”

4. Calculate the daily **“LFP”** by multiplying the daily **ratio r** (Step 3) with the **known LFP** of the infinite acting, single fracture model (Step 1)

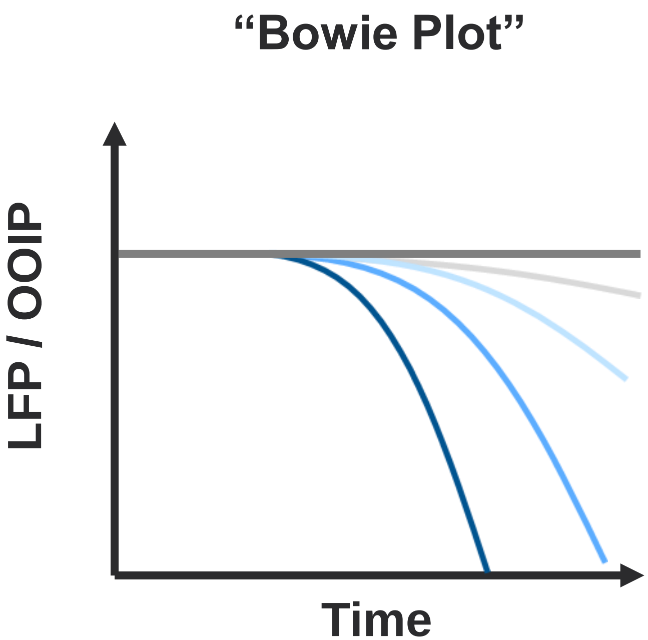
“Bowie Plot”

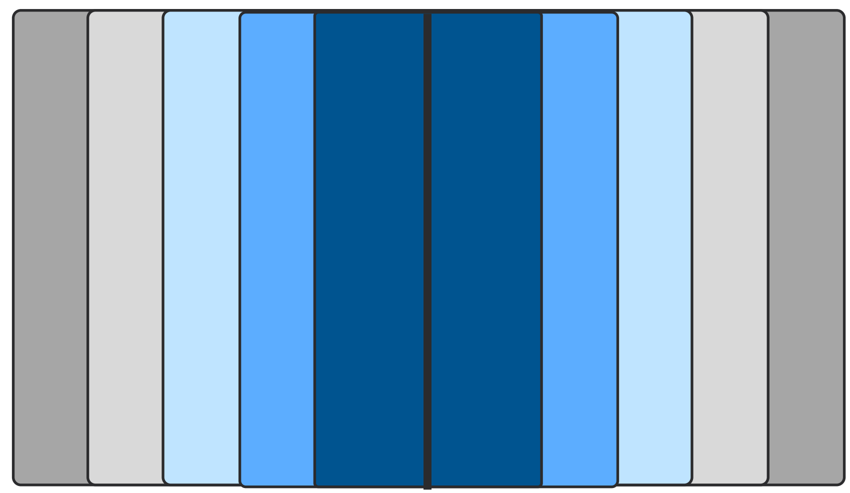


1. A horizontal flat line indicates infinite acting, linear flow
2. Deviation below this line represents boundary dominated / transitional flow
3. The magnitude of the flat line indicates the LFP

The “Bowie Workflow”

5. Repeat Step 1-2 for multiple, smaller OOIP volumes. This results in several “type curves” with each its own LFP / OOIP ratio.

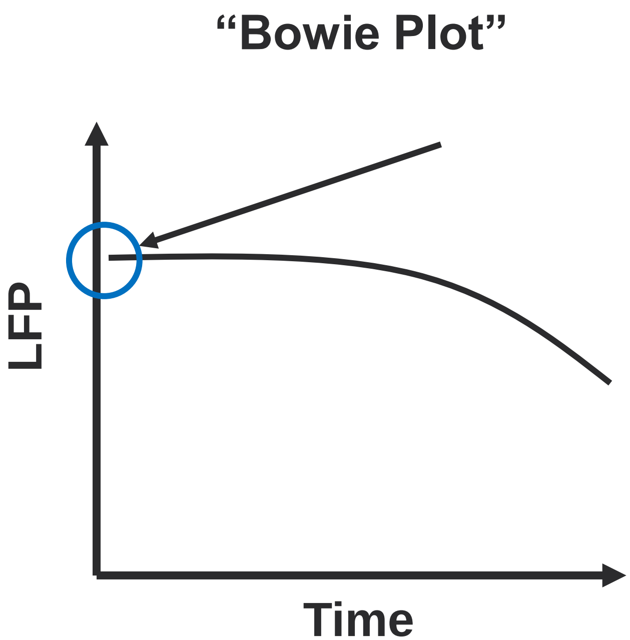




whitson

The “Bowie Workflow”

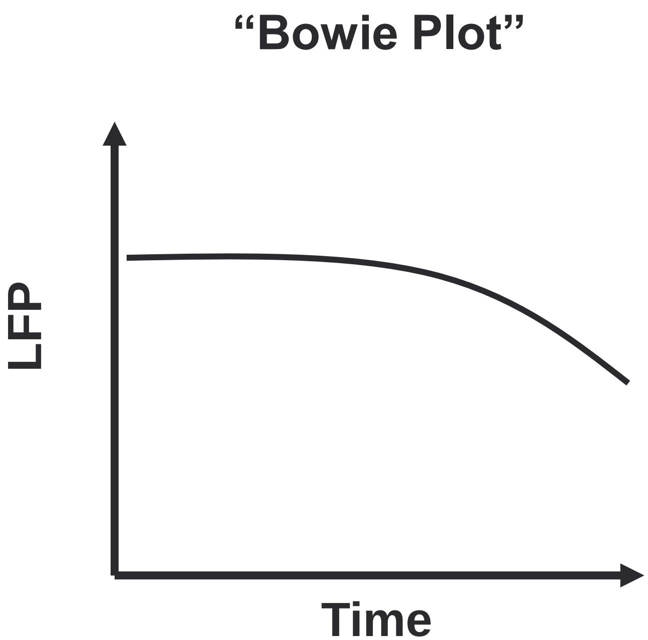
6. Pick a “**Representative LFP**” based on the early time “LFP”. Remember that a flat, horizontal line is expected during infinite acting behavior.

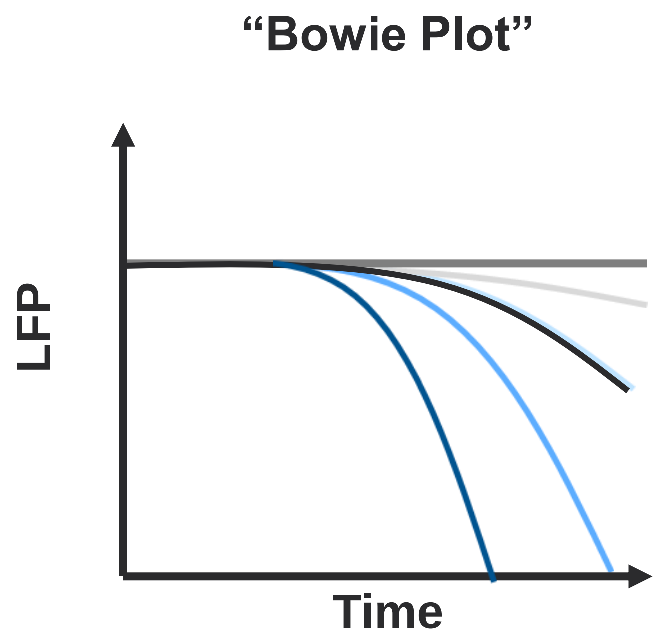


whitson

The "Bowie Workflow"

7. Multiply each the LFP / OOIP ratios simulated in Step 5 by the **"Representative LFP"** picked in Step 6.

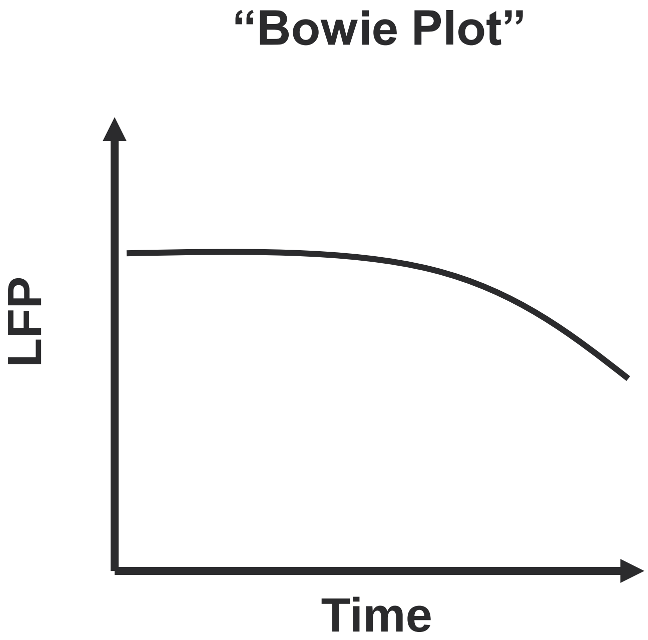


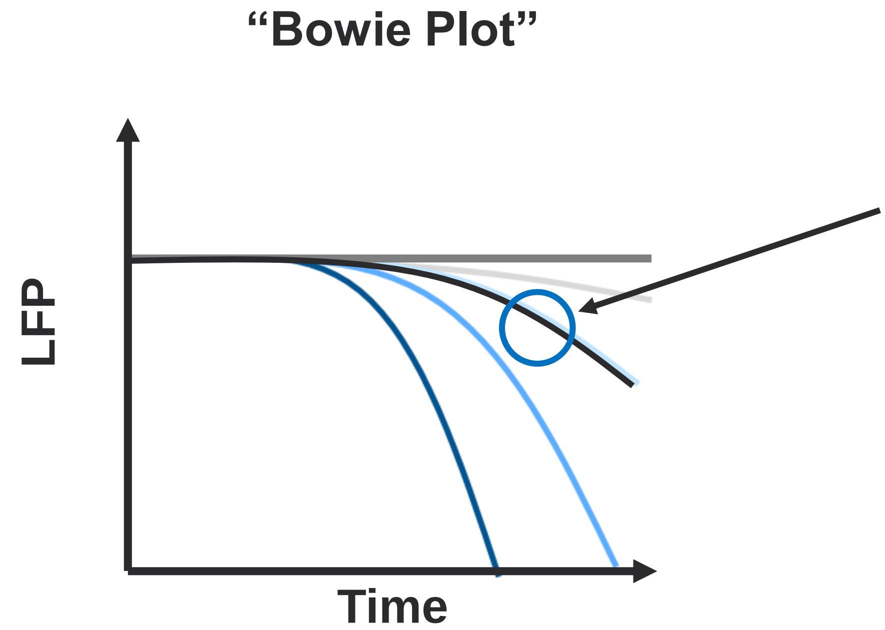


whitson

The “Bowie Workflow”

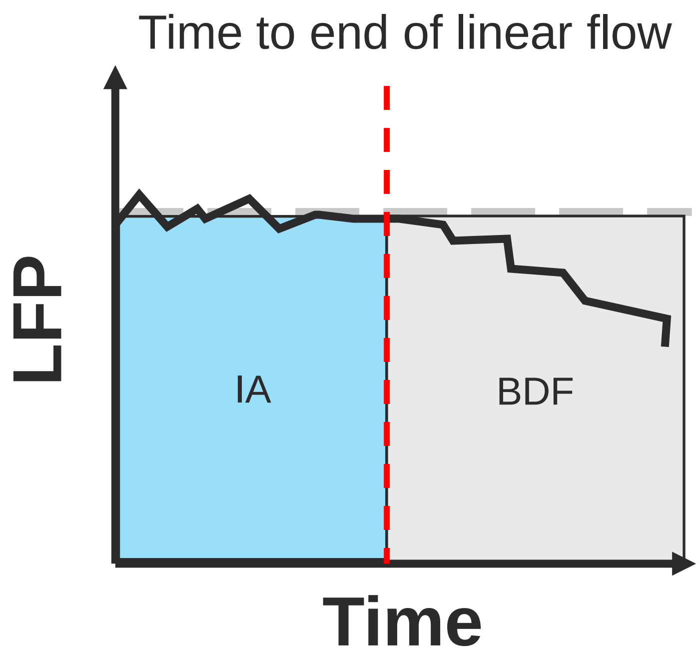
8. Pick the **OOIP** stem that matches the actual production data the best.





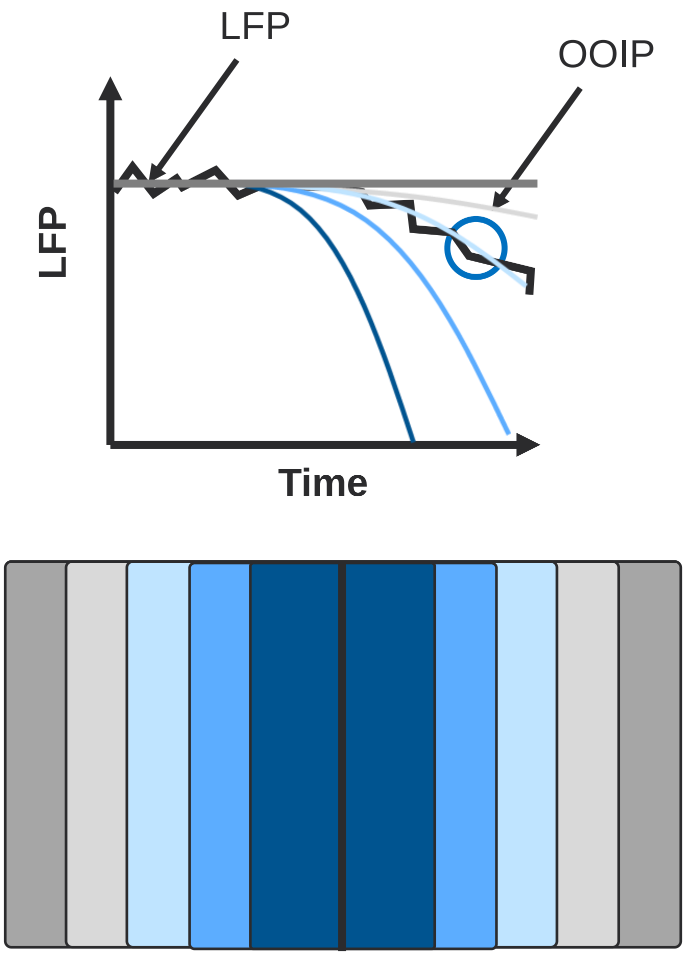
whitson

Numerical RTA – Summary



- A horizontal flat line indicates infinite acting, linear flow
- Deviation below this line represents boundary dominated / transitional flow
- The magnitude of the flat line indicates the LFP

Numerical RTA – Summary



- A set of models are run where the size of the model is the only thing that changes

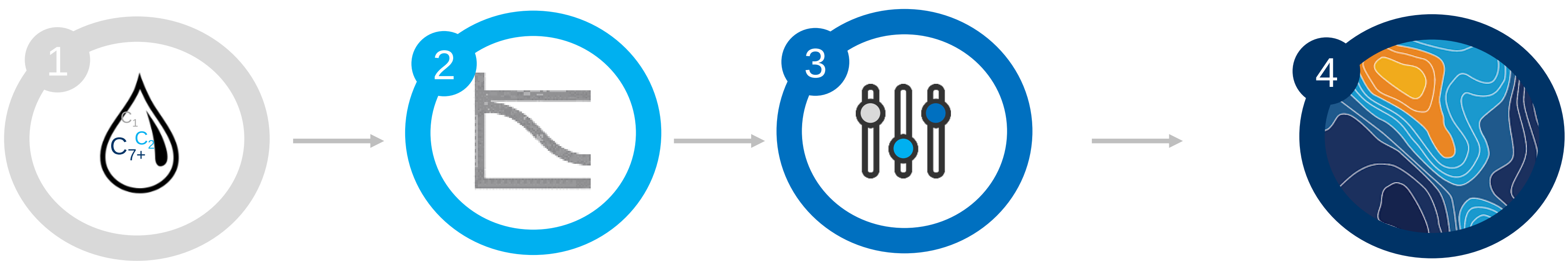
- Type curve closest to actual data represents contacted pore volume

RTA

Unconventional Reservoir Workflow

Numerical RTA
(Bowie Workflow)

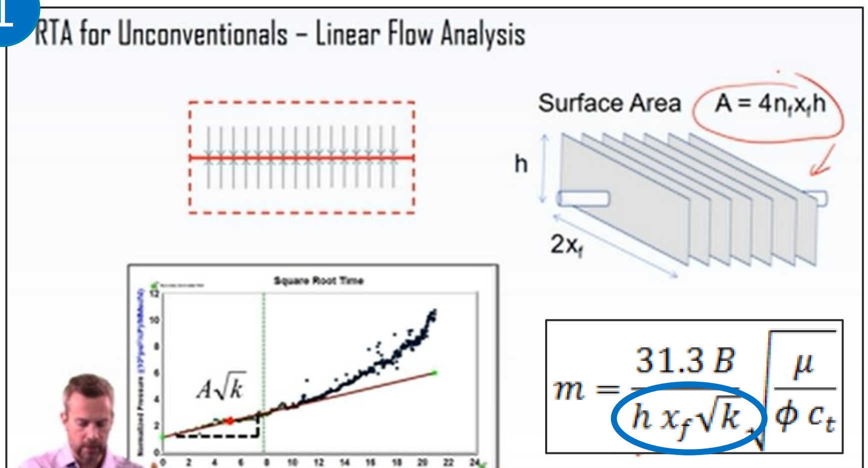
Step 1: PVT & Rel. Perm	Step 2: Interpretation	Step 3: Resolve Parameters	Numerical Reservoir Simulation



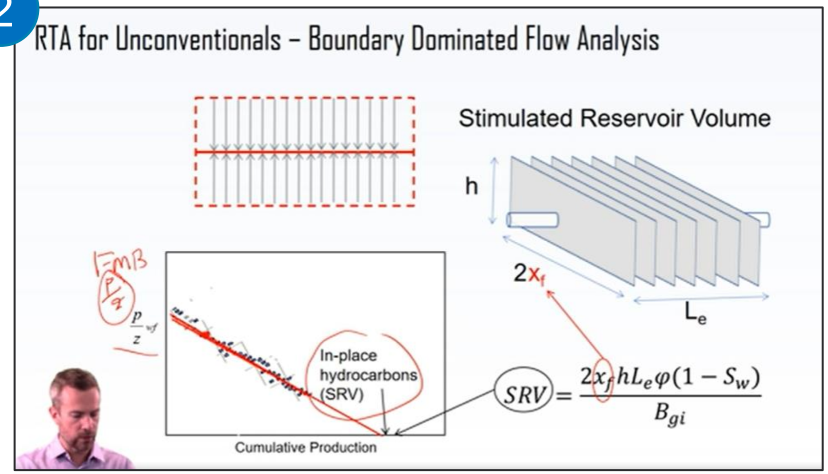
GOR (S_{oi}, S_{gi}), S_{wi}	LFP	x_f
k_r	OOIP	k

Connecting the Dots …

1



2



LFP

OOIP

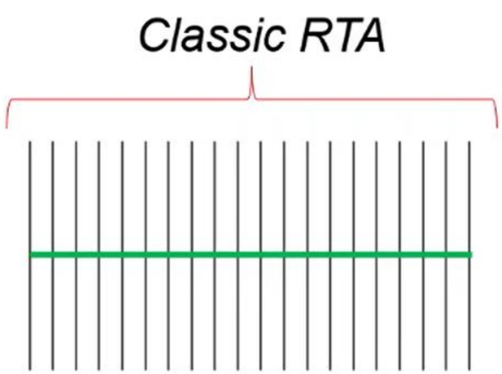
Source: https://www.sagawisdom.com/courses/rate-transient-analysis-rta

whitson

Fractional RTA

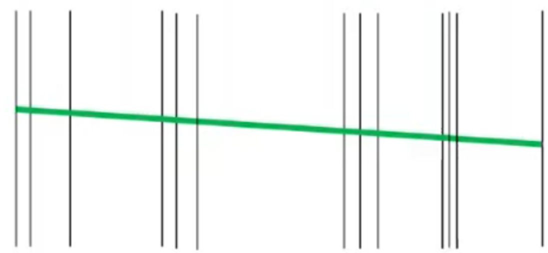
Problem

Model



Equally spaced

Reality



Uneven frac spacing

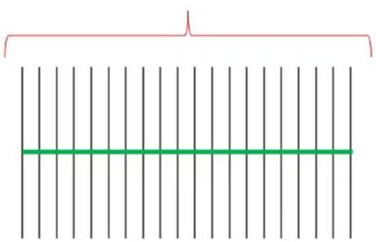
RTA

Classic RTA vs “Fractional” RTA

Classic RTA: Solves only equally spaced fracture networks ($\delta = 0.5$), gives $A\sqrt{k}$

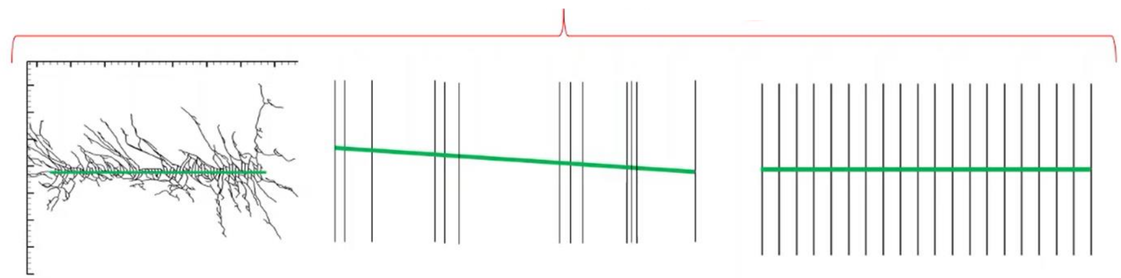
Fractional RTA: Solves for complex system of fractures (any value of δ), gives Ak^{δ}

Classic RTA



Equally spaced

Fractional RTA



Random Fracture swarm Equally spaced

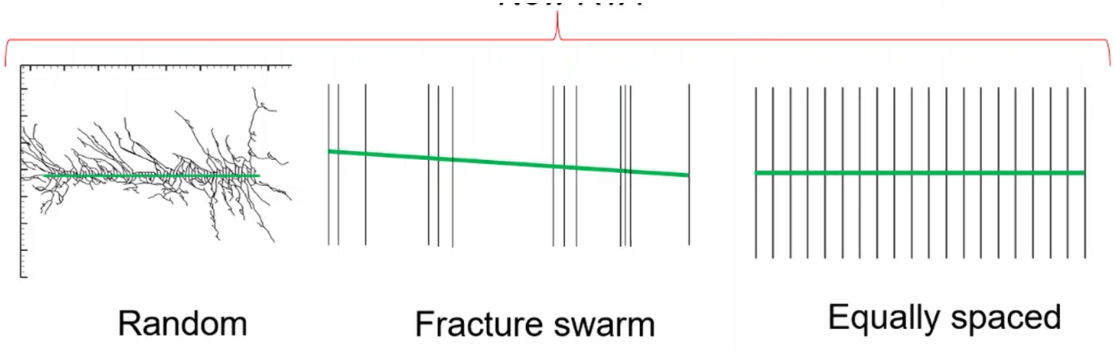
Courtesy: Jorge Acuna

whitson

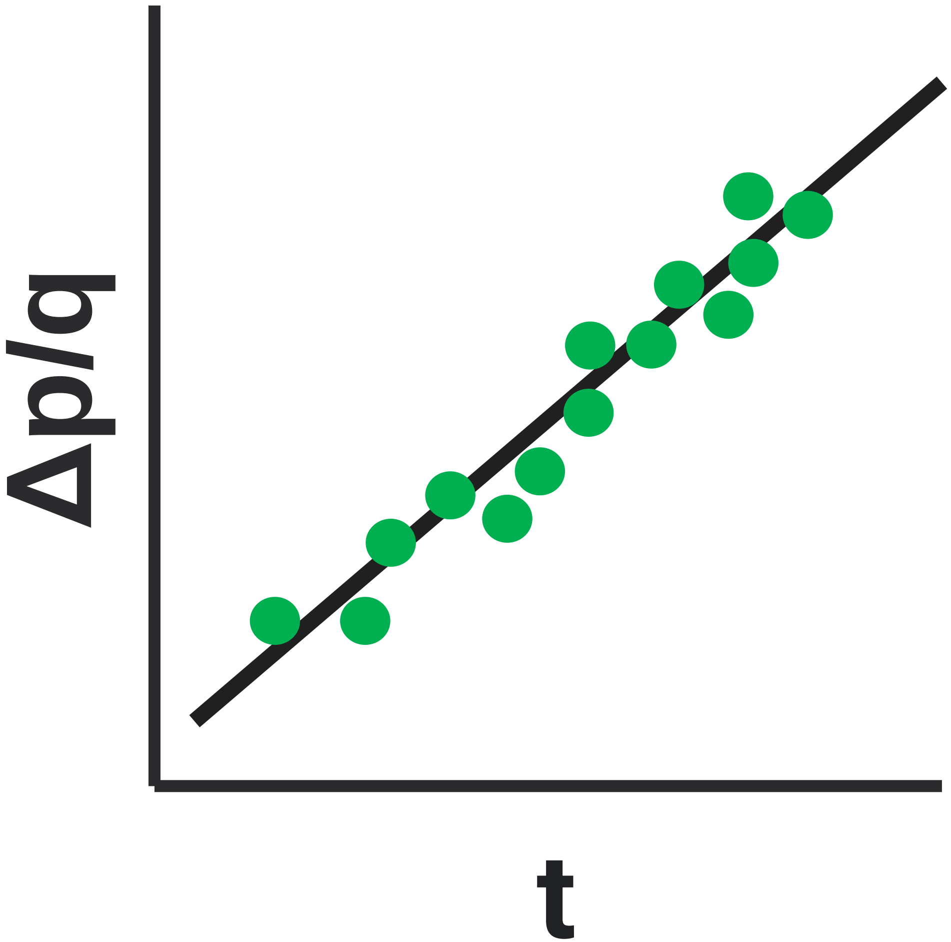
“Generalized” LFP

$$LFP = Ak^{\delta}$$

Fractional RTA

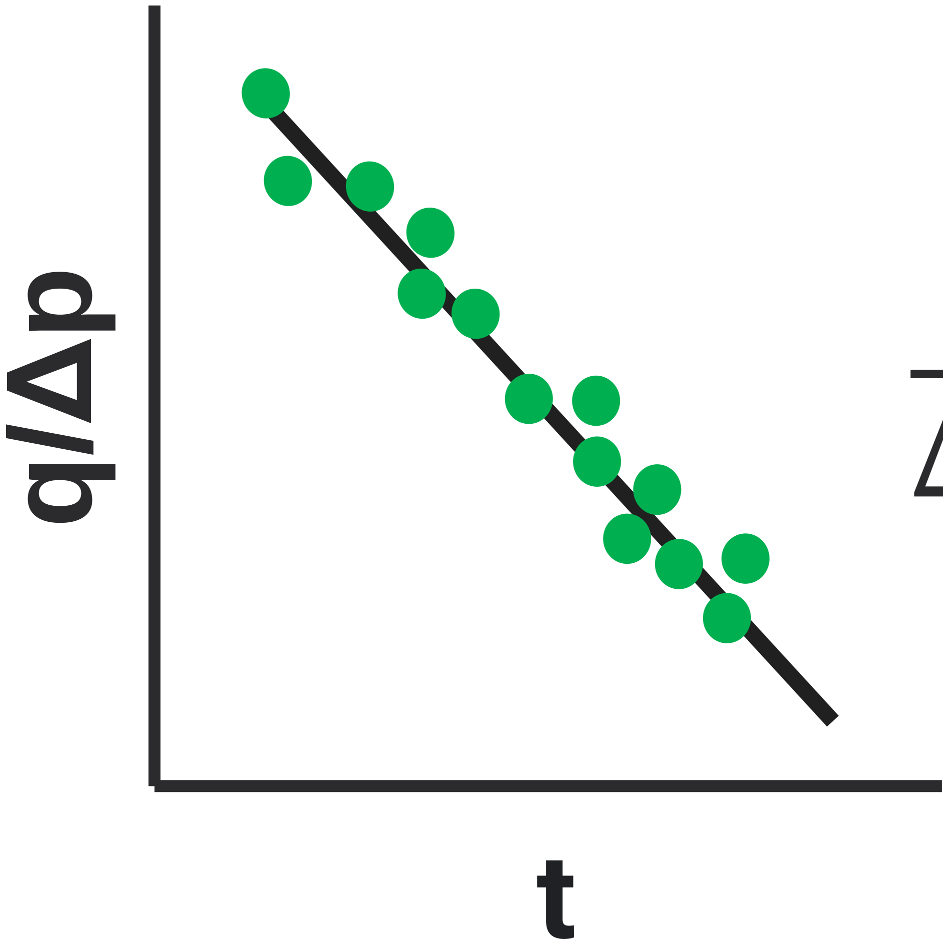


Rate Normalized Pressure (RNP)



$$\frac{\Delta p}{q} = mt^{1-\partial} + b$$

Pressure Normalized Rate (PNR)



$$\frac{q}{\Delta p} = \frac{1}{m t^{1-\partial} + b}$$

RTA

Physical Significance of Delta (δ)

Infinite acting, linear flow – $\delta = 0.5$

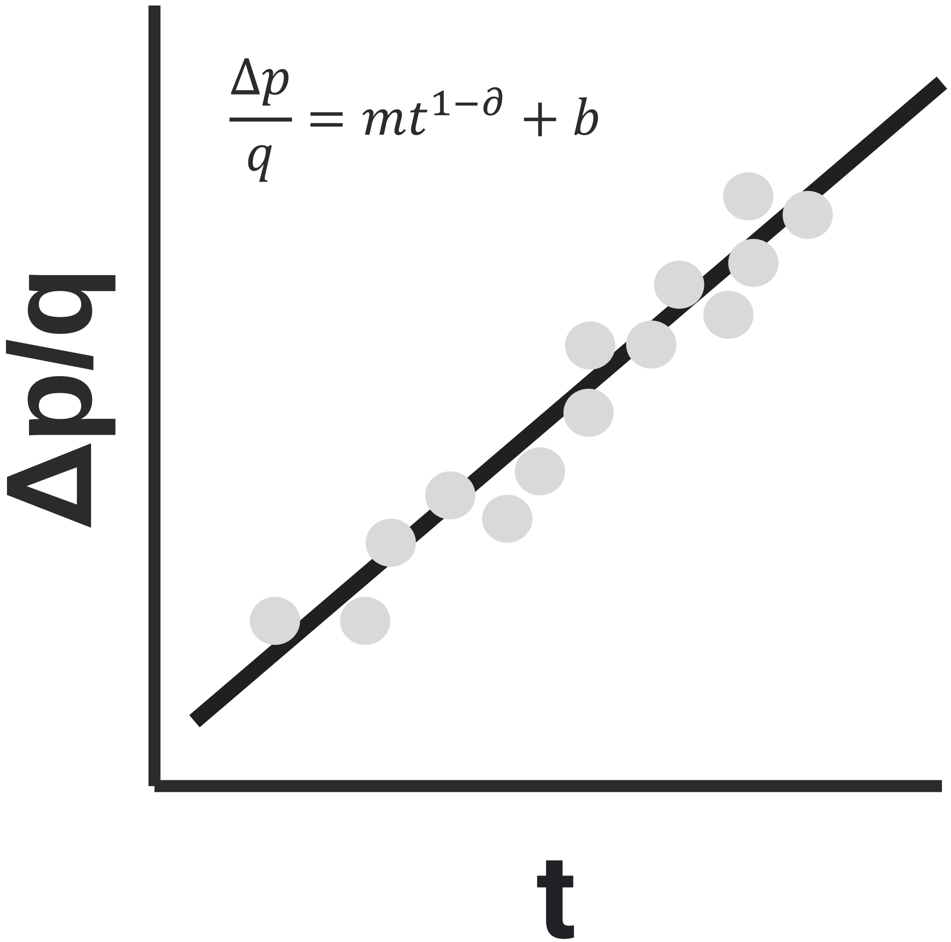
Transitional flow (period in between) – $0 < \delta < 0.5$

Boundary dominated flow – $\delta = 0$

**in material balance time*

Rate Normalized Pressure (RNP)

$$\frac{\Delta p}{q} = mt^{1-\partial} + b$$



Oil

$$m = \frac{0.468}{0.001055^{\delta}} \frac{24^{1-\delta}}{\Gamma(\delta)(1-\delta)} \frac{B_o}{4hx_f k^{\delta}} \frac{\mu_o^{\delta}}{(\varphi c_t)^{1-\delta}}$$

Gas

$$m = \frac{4.716}{0.001055^{\delta}} \frac{24^{1-\delta}}{\Gamma(\delta)(1-\delta)} \frac{T_R}{4hx_f k^{\delta}} \frac{\mu_g^{\delta-1}}{(\varphi c_t)^{1-\delta}}$$

Looks Difficult … Actually Familiar!

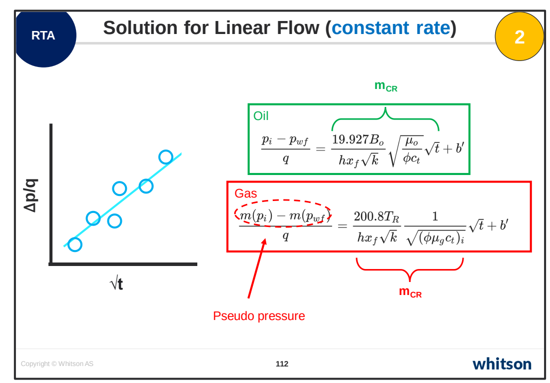
Oil

$$m = \overbrace{\frac{0.468}{0.001055^{\delta}}\,\frac{24^{1-\delta}}{\Gamma(\delta)(1-\delta)}}^{19.927\text{ for }\delta = 0.5}\,\frac{B_o}{4hx_f k^{\delta}}\,\frac{\mu_o^{\delta}}{(\varphi c_t)^{1-\delta}}$$

for δ = 0.5

$$\boxed{\frac{19.927B_o}{hx_f\sqrt{k}}\sqrt{\frac{\mu_o}{\phi c_t}}}$$

Reference



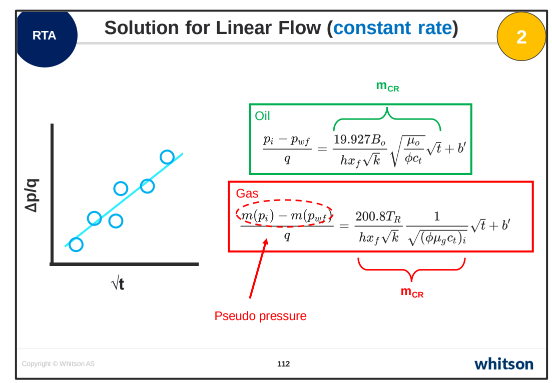
Looks Difficult … Actually Familiar!

Gas

$$m = \underbrace{\overbrace{\frac{4.716}{0.001055^{\delta}}\,\frac{24^{1-\delta}}{\Gamma(\delta)(1-\delta)}}^{200.8 \text{ for } \delta = 0.5}\,\frac{T_R}{4hx_f k^{\delta}}\,\frac{\mu_g^{\delta-1}}{(\varphi c_t)^{1-\delta}}}_{\text{for } \delta = 0.5}$$

$$\boxed{\frac{200.8T_R}{hx_f\sqrt{k}}\,\frac{1}{\sqrt{(\phi\mu_g c_t)_i}}}$$

Reference

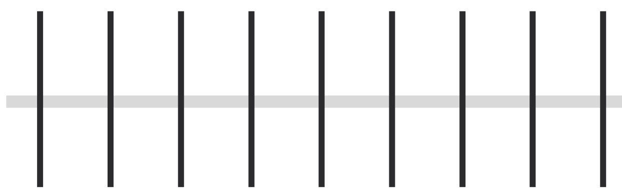


RTA

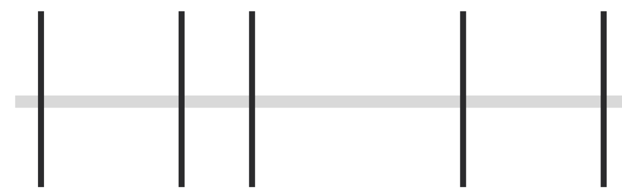
Challenge to the Audience

Correlate δ to completion practices

δ around 0.5 =
high cluster efficiency



δ far from 0.5 =
poor cluster efficiency



whitson

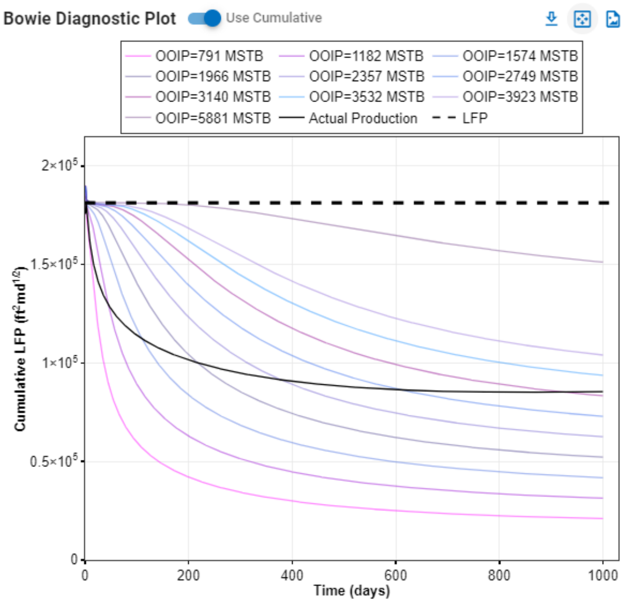
RTA

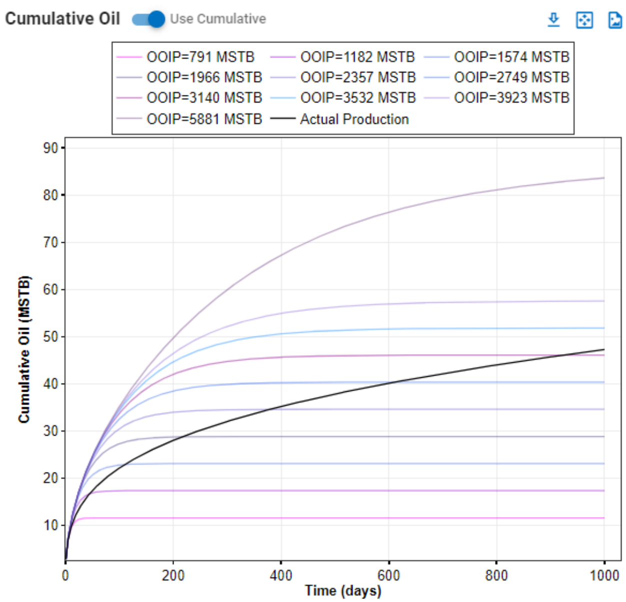
Fractional + Numerical RTA

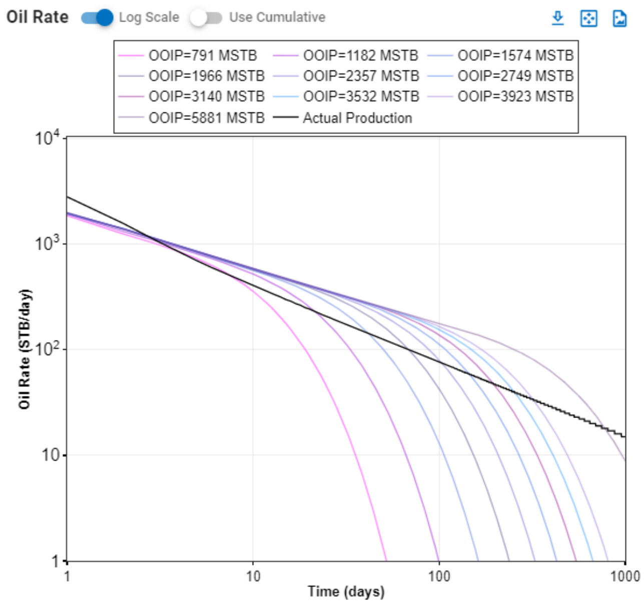
RTA

Well in Transitional Flow for Entire History

Limitations of Classical, Numerical RTA

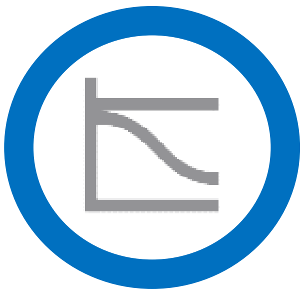




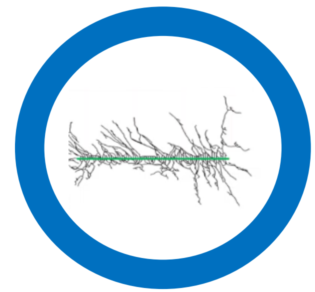


NRTA Extended to Complex Fracture Systems

Numerical RTA



Fractional RTA



Key Definitions

$$LFP = 4n_f x_f h k^{\delta}$$

$$OOIP = \frac{2x_f L h \varphi (1 - S_{wi})}{B_{ti}}$$

RTA

Fundamental Relationship

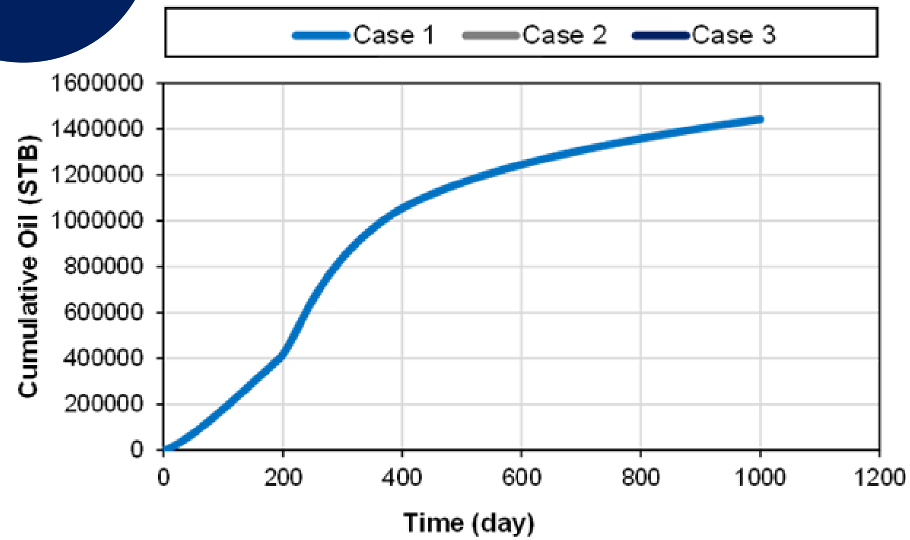
LFP, **OOIP** and δ rate performance will be identical for all times

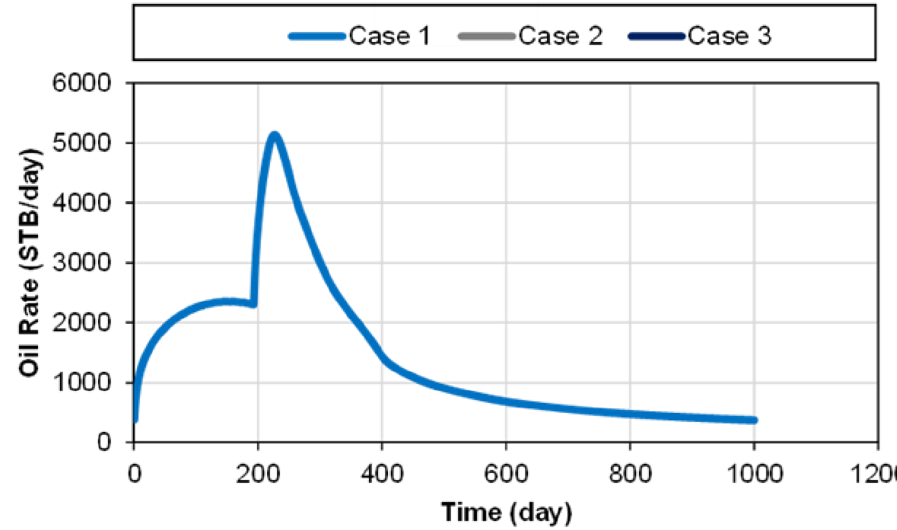
Same production during i) infinite acting (IA), ii) transitional and iii) boundary-dominated flow (BDF)

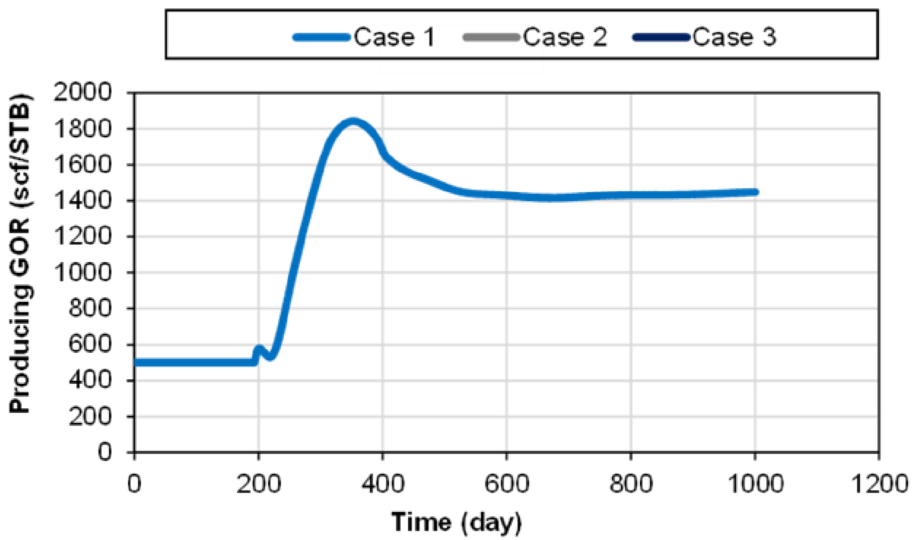
*With the same (a) fluid initialization (GOR_i and S_{wi}) and (b) relative permeability relations, and (c) bottomhole pressure (BHP) time variation (above and below saturation pressure).

RTA

Example





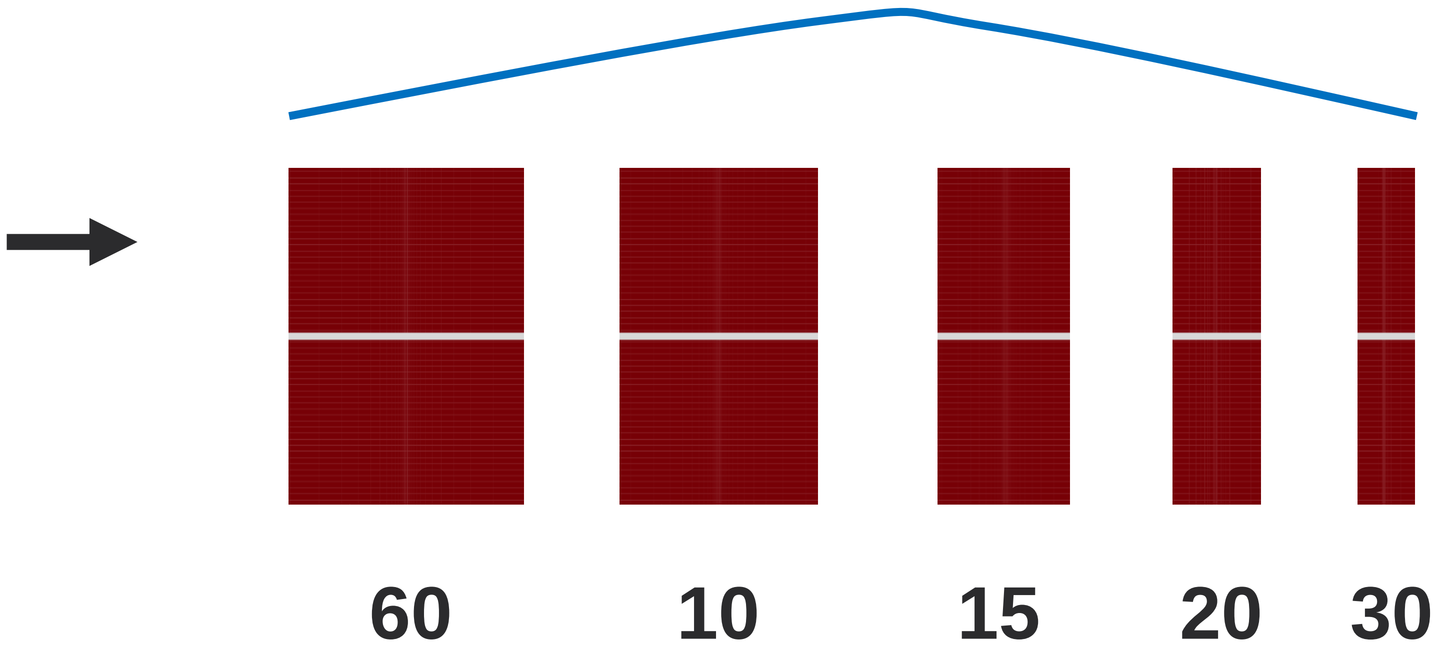


Parameter	Unit	Case 1	Case 2	Case 3
δ	-	0.3	0.3	0.3
V_p	MMRB	14.25	14.25	14.25
OOIP	MMSTB	11.33	11.33	11.33
ϕ	fraction	0.05	0.10	0.20
h	ft	200	100	50
L_w	ft	10000	5000	20000
x_f	ft	400	800	200
B_o	RB/STB	1.26	1.26	1.26
k	md	2.00E-04	1.60E-03	1.28E-02
n_f	#	725	239	631
$LFP' = 4n_f h x_f k^{\delta}\phi^{1-\delta}$	ft md$^{\delta}$	2212809	2212809	2212809

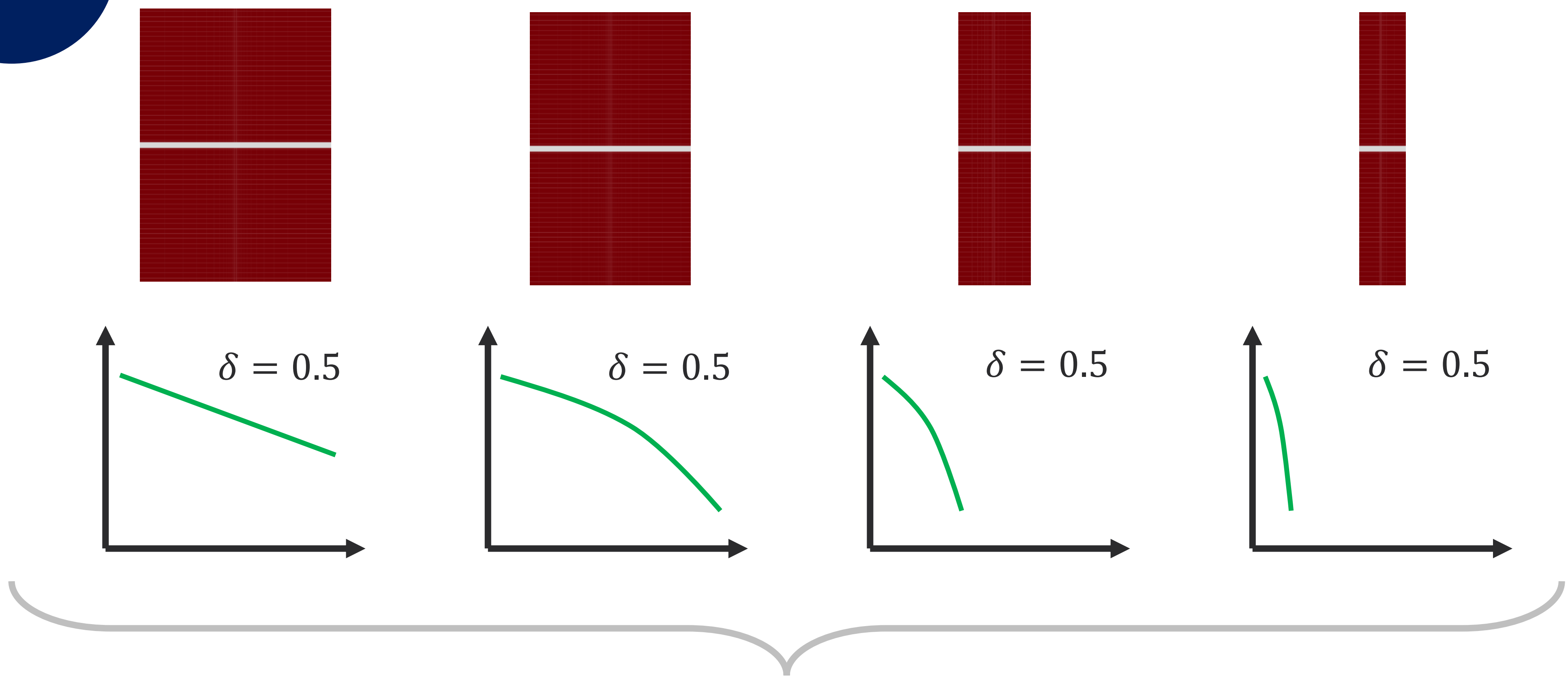
From δ to Numerical Model

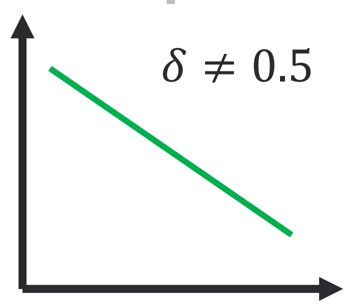
δ

$e.g.\ 0.3$



Relationship between δ to Numerical Model

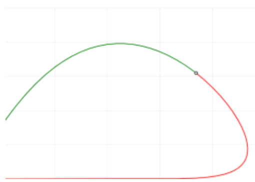




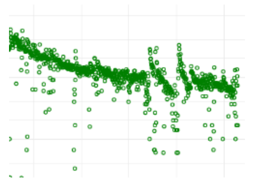
$$q = c' t^{-(1-\delta)}$$

Numerical RTA … Inputs

“Still a problem”



PVT



Prod. Data

δ

Delta

Rel. Perm

NOT measured
or calculated

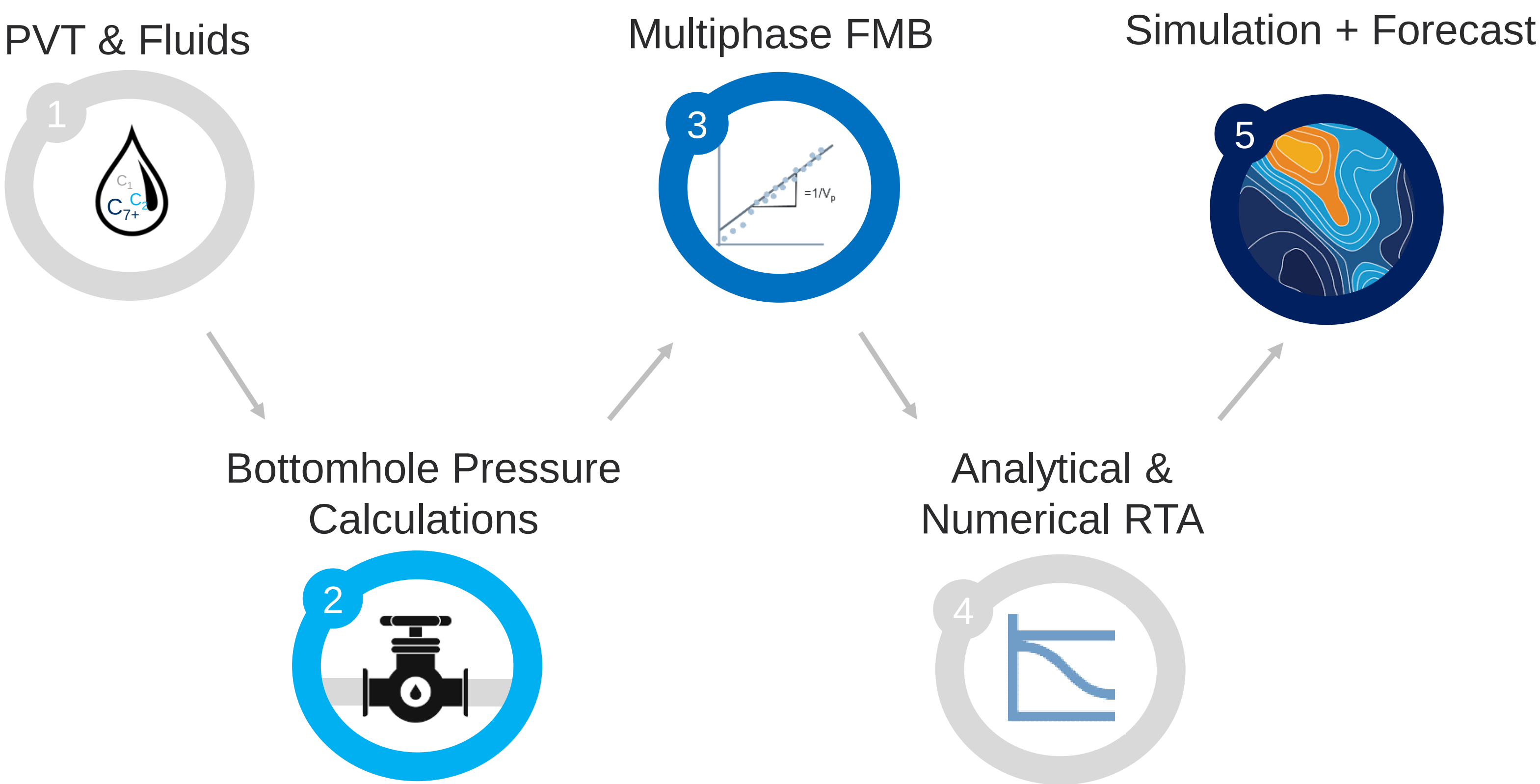
NUM

Numerical Model

Reservoir Simulation & Forecasting

NUM

Unconventional Reservoir Workflow



NUM

Creating a Numerical Model Realization

Numerical RTA Interpretation

Interpretations ?

Linear Flow Parameter, LFP = A√k
306261 $ft^2md^{1/2}$

OOIP		OGIP	
1741	MSTB	958	MMscf

Realization 1

Physical Assumptions ?

Matrix Porosity, φ	0.052	Frac Height	63.37 ft
Well Lateral Length	10950 ft	Number of Fractures	1035
Matrix Permeability	20.86 nd	Fracture Half Length	255.6 ft

Realization 2

Physical Assumptions ?

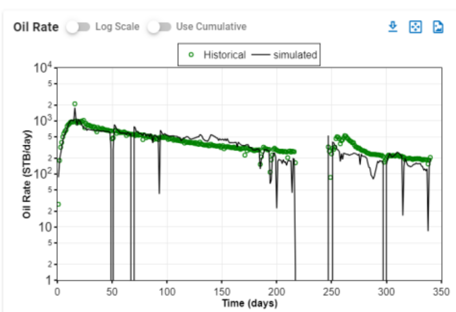
Matrix Porosity, φ	0.052	Frac Height	50 ft
Well Lateral Length	1095 ft	Number of Fractures	103
Matrix Permeability	21.06 nd	Fracture Half Length	3239.5 ft

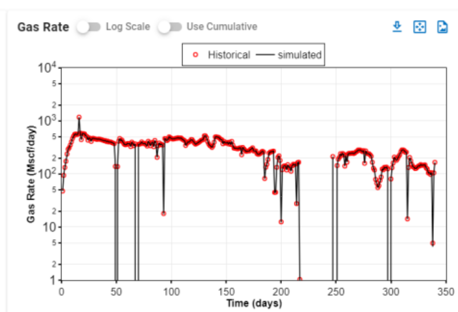
Realization 3

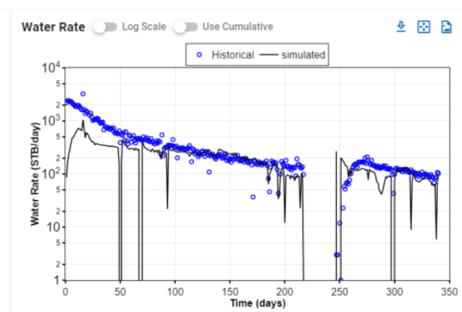
Physical Assumptions ?

Matrix Porosity, φ	0.052	Frac Height	40 ft
Well Lateral Length	5000 ft	Number of Fractures	500
Matrix Permeability	18.64 nd	Fracture Half Length	886.8 ft

Numerical RTA Interpretation







NUM

Numerical Engines

ECL

IMEX

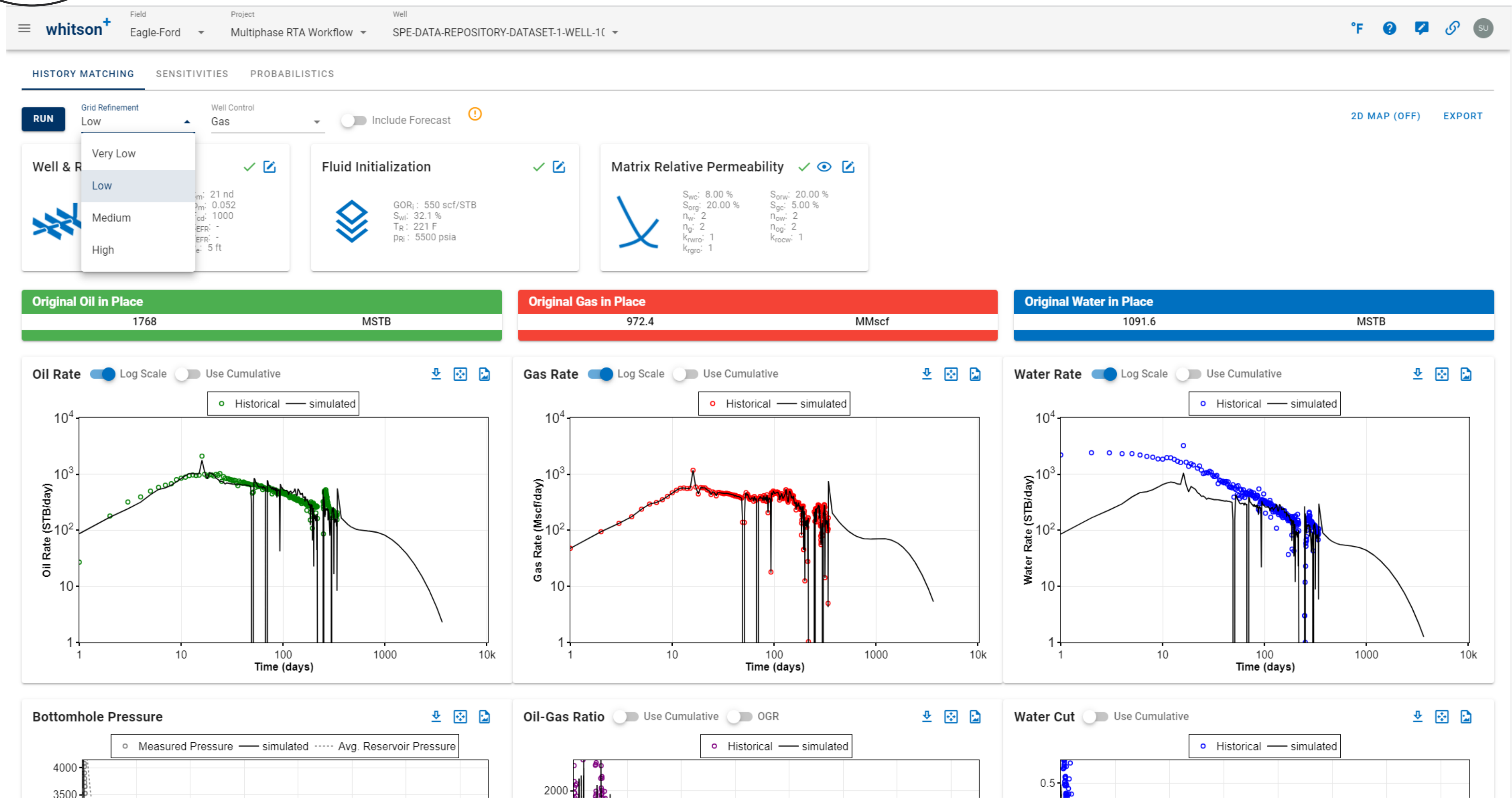
tNavigator®

SENSOR

OPM FLOW

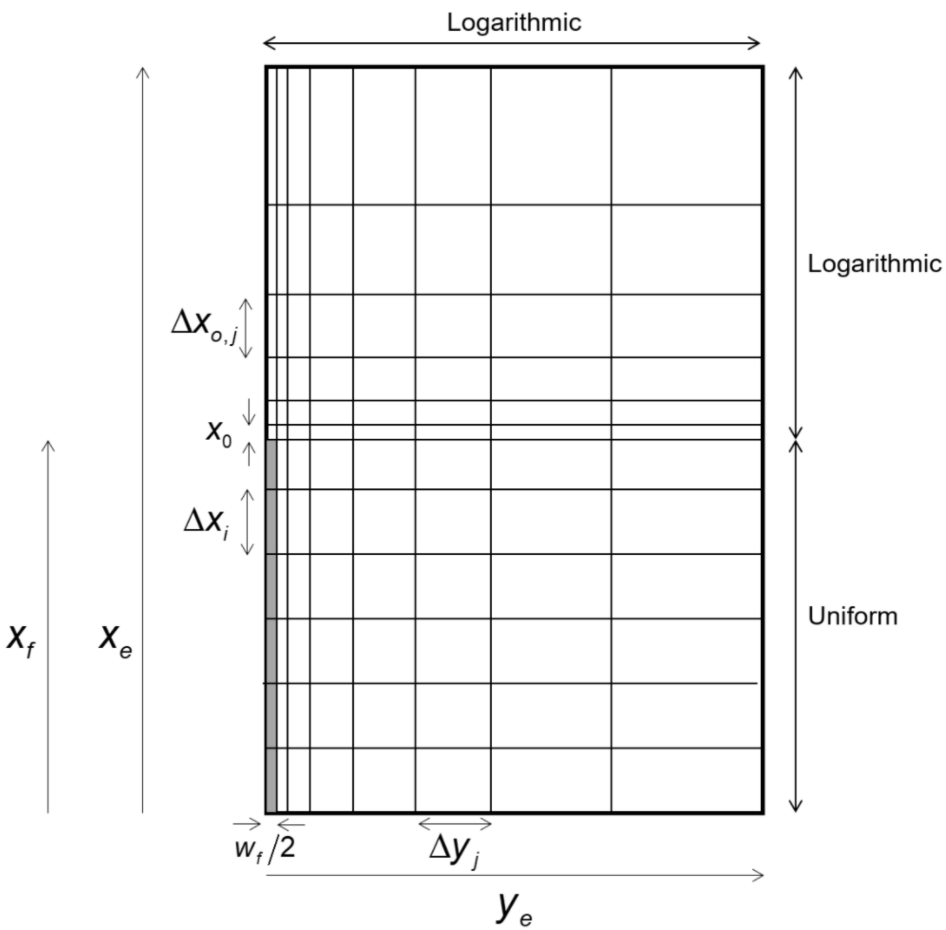
NUM

Grid Refinement



https://manual.whitson.com/modules/well-performance/reservoir-simulation/#21-gridding

Gridding and Numerical Dispersion

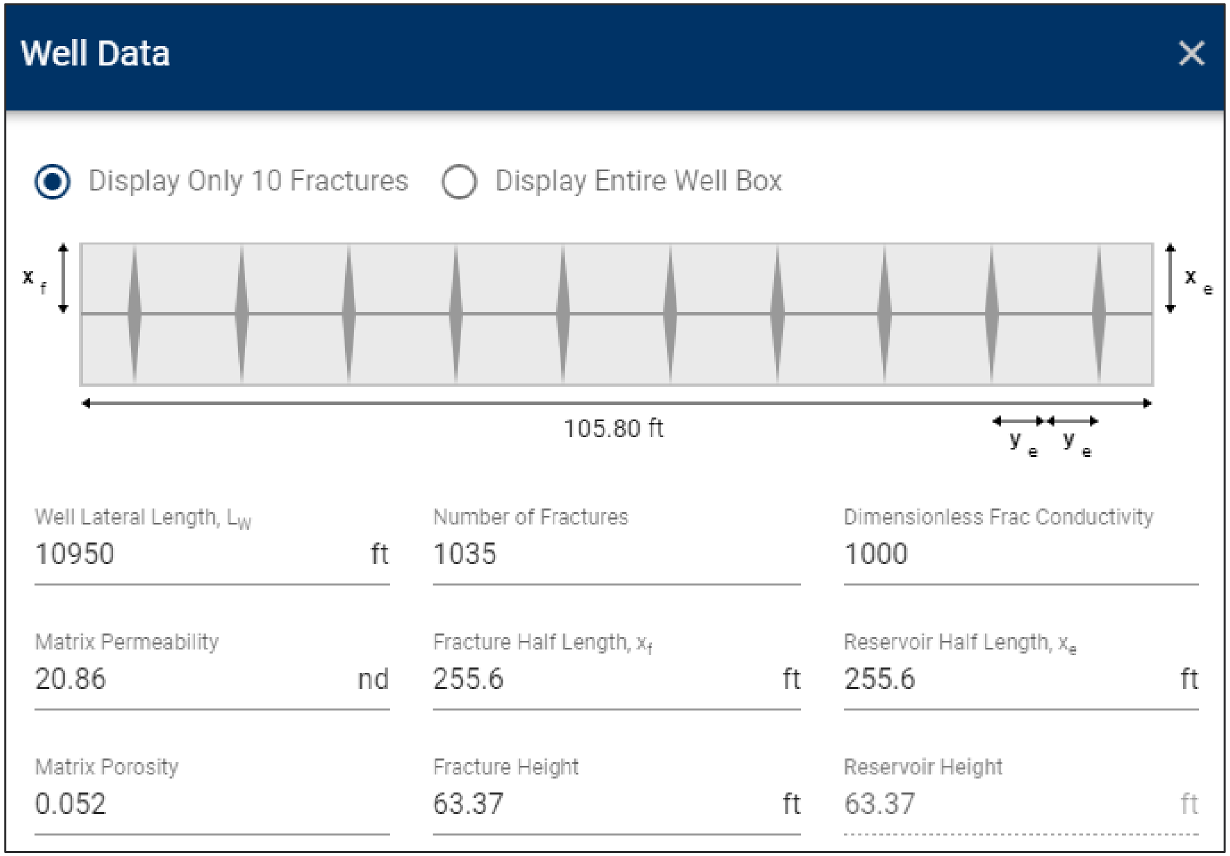


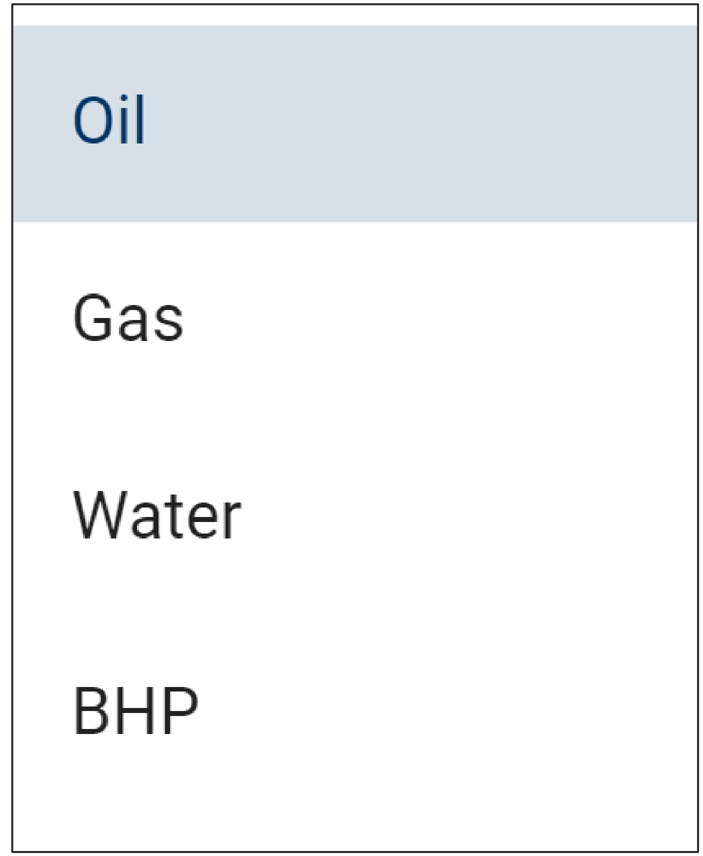
https://manual.whitson.com/modules/well-performance/reservoir-simulation/#21-gridding

- Mix of logarithmic and uniform gridding.
- Numerical dispersion is an inherent reservoir simulation problem that causes computational results to be less accurate.
- When the simulation grids are coarse, numerical dispersion is an undesirable simulation artifact.
- Sufficient gridding is required for accurate results, but also slows down simulation runs. Hence, it’s a fine balance between accuracy and practicality.

NUM

Well Control – What does it mean?





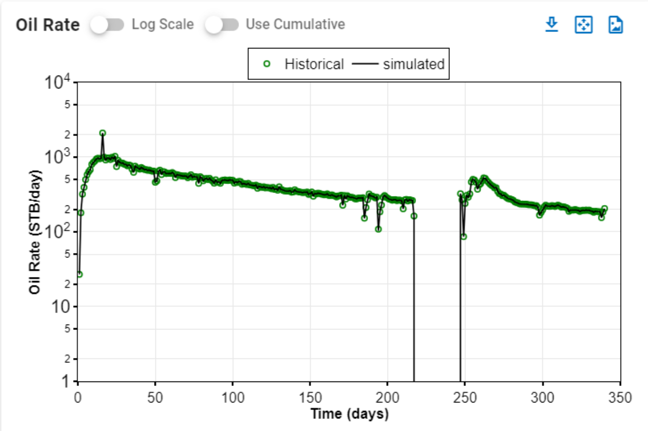
NUM

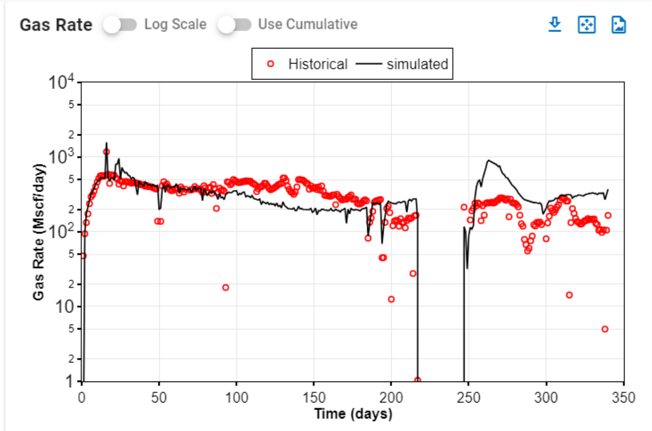
Well Control: Use Oil Rate

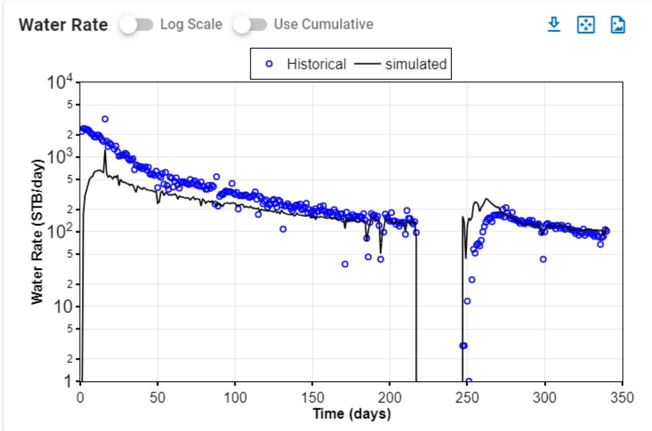
Original Oil in Place	
1768	MSTB

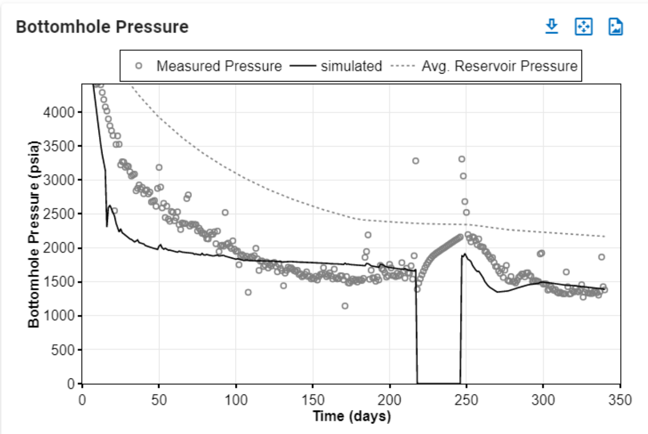
Original Gas in Place	
972.4	MMscf

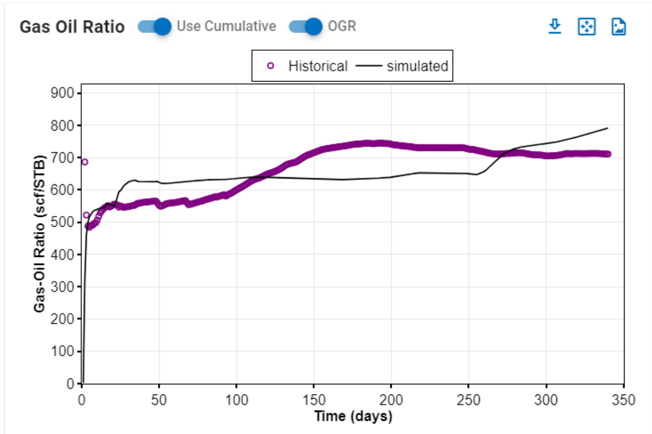
Original Water in Place	
1091.6	MSTB

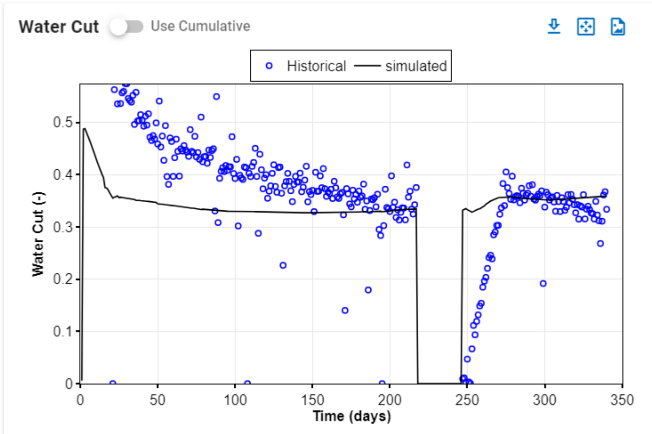








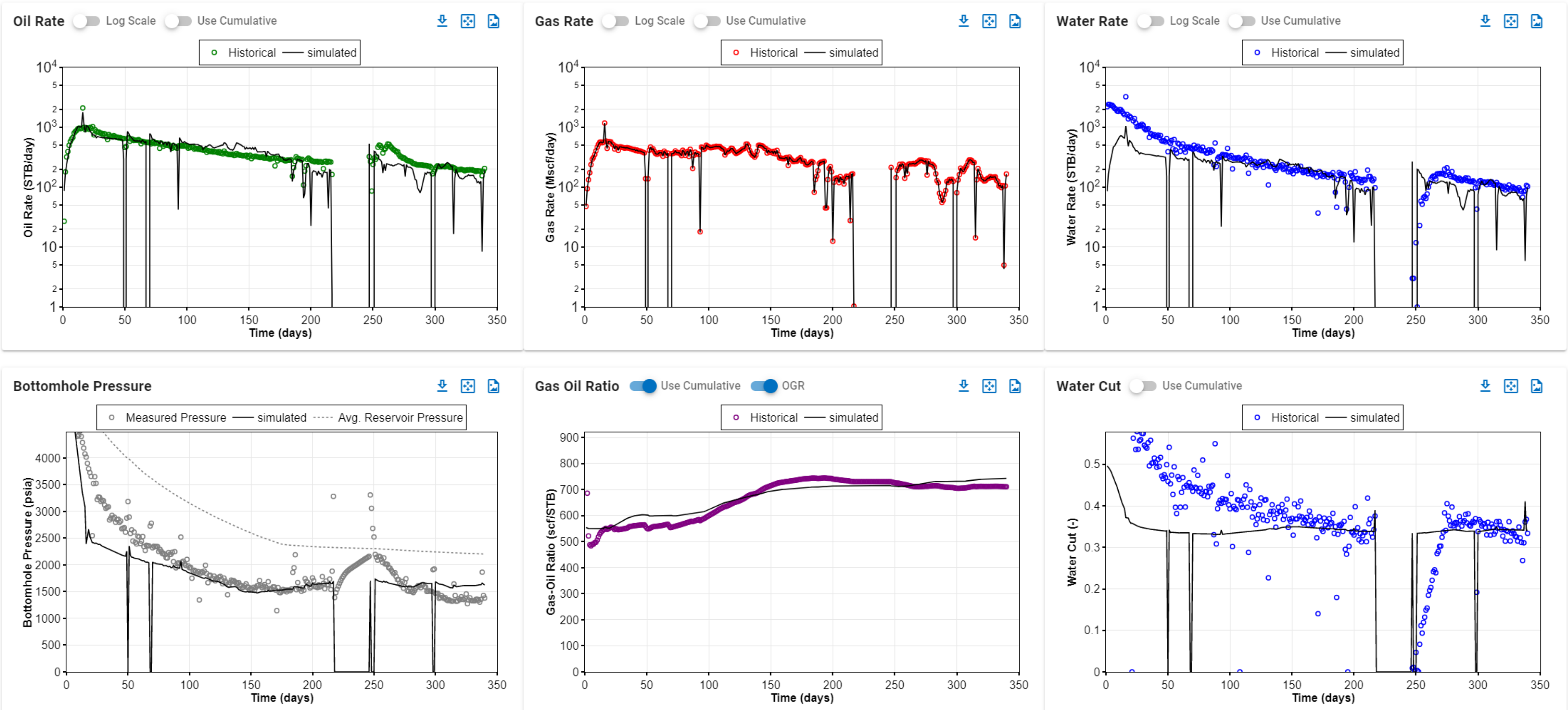




NUM

Well Control: Use Gas Rate

Original Oil in Place		Original Gas in Place		Original Water in Place	
1768	MSTB	972.4	MMscf	1091.6	MSTB



whitson

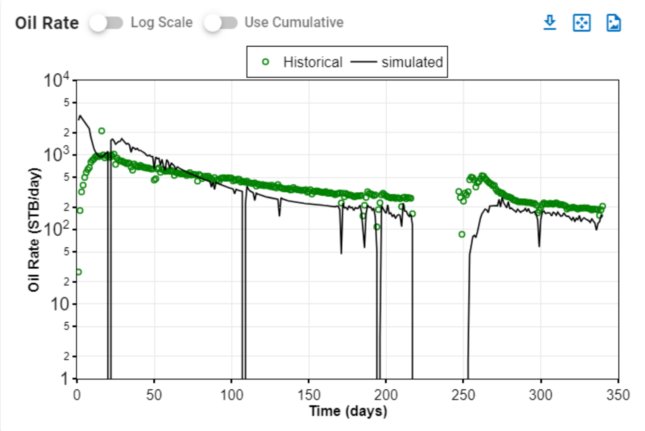
NUM

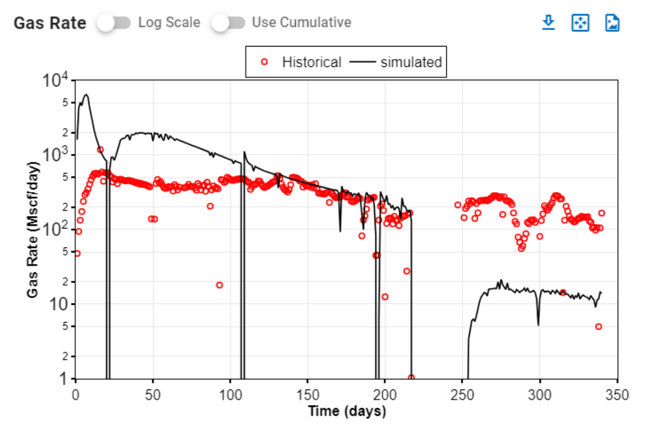
Well Control: Use Water Rate

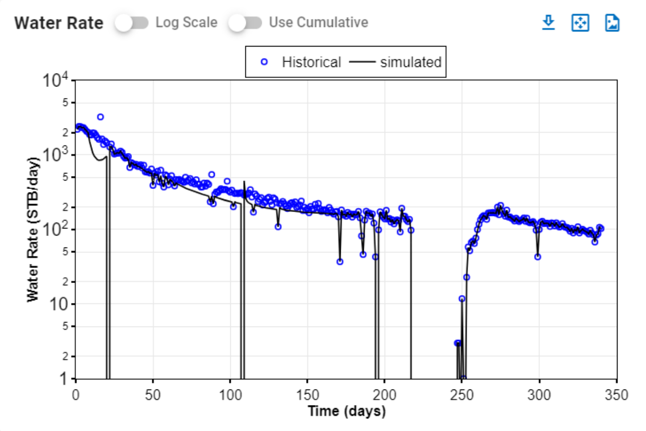
Original Oil in Place	
1768	MSTB

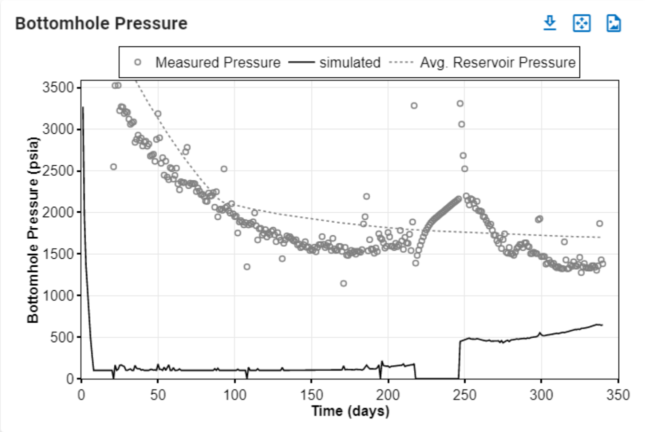
Original Gas in Place	
972.4	MMscf

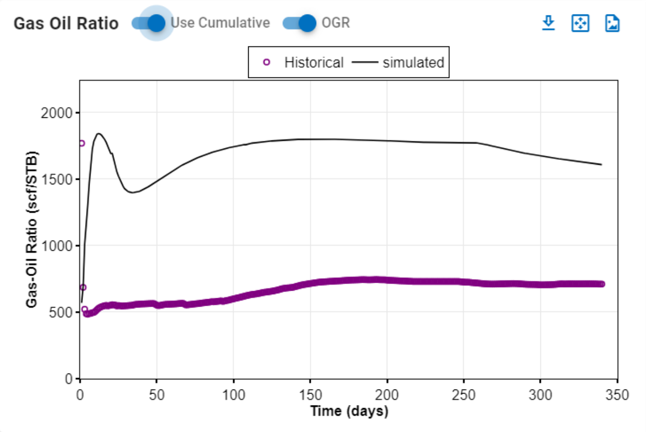
Original Water in Place	
1091.6	MSTB

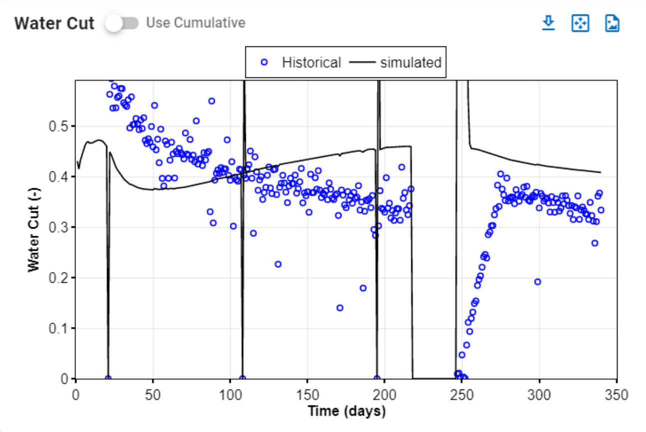












whitson

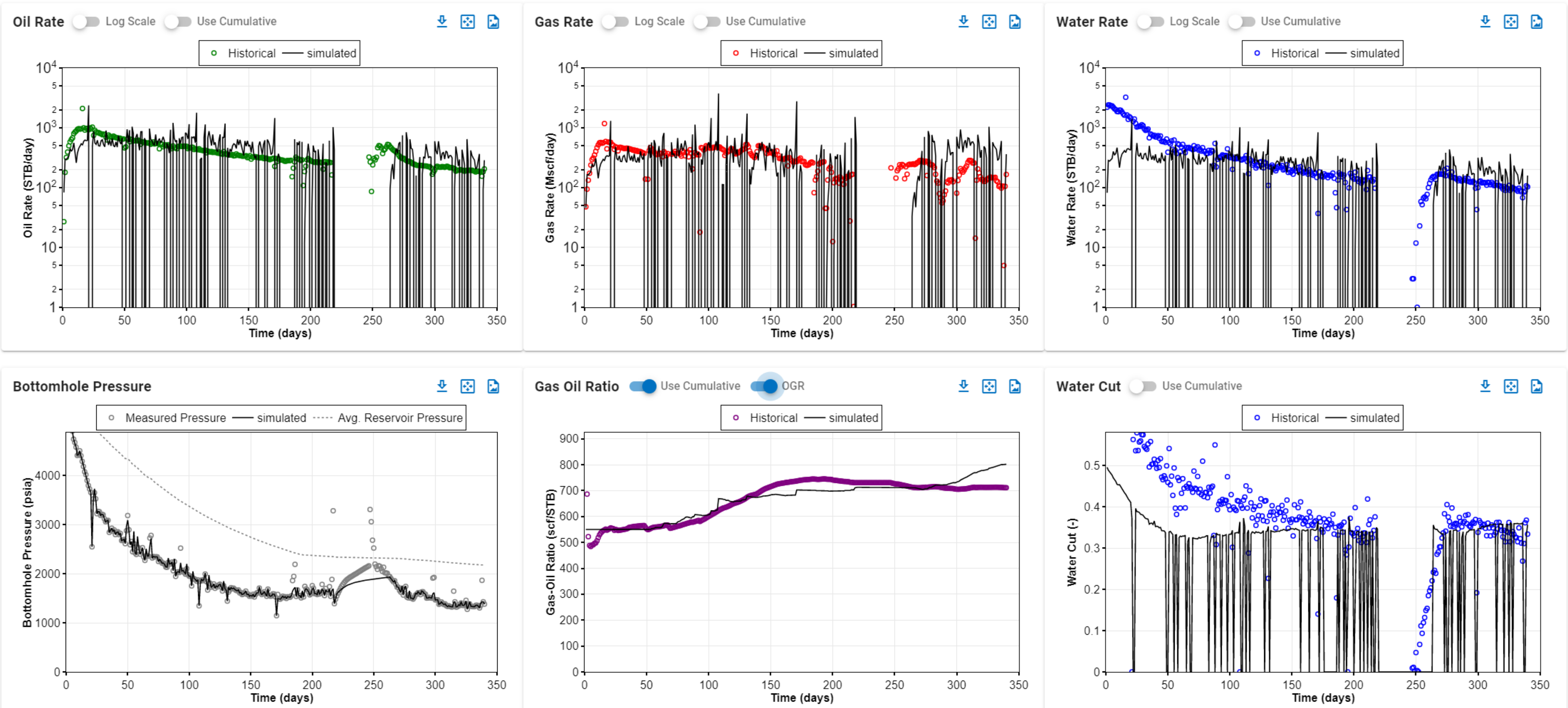
NUM

Well Control: Use Bottomhole Pressure

Original Oil in Place	
1768	MSTB

Original Gas in Place	
972.4	MMscf

Original Water in Place	
1091.6	MSTB



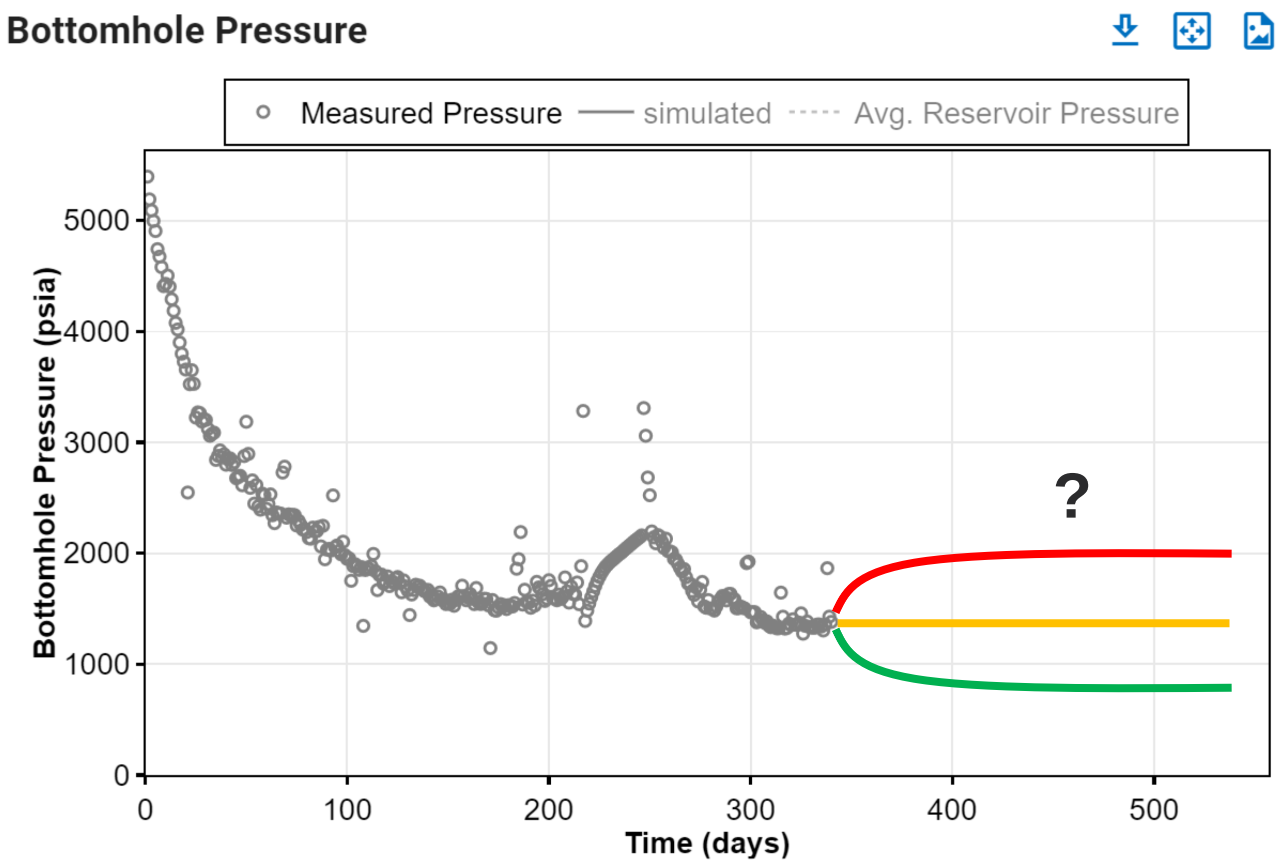
whitson

“There are two kinds of forecasters: those who don’t know, and those who don’t know they don’t know.”

- John Kenneth Galbraith

NUM

Forecast



NUM

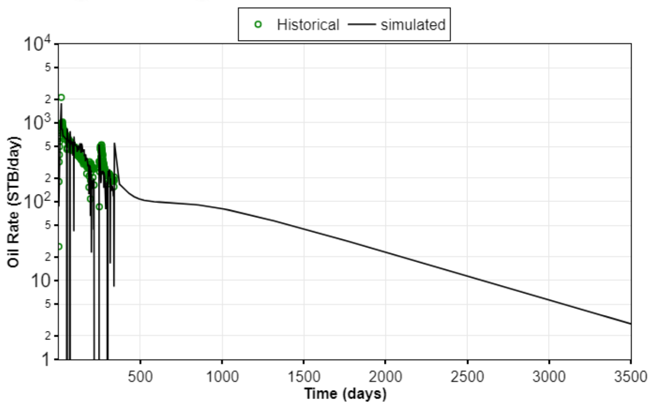
Forecast

Original Oil in Place	
1768	MSTB

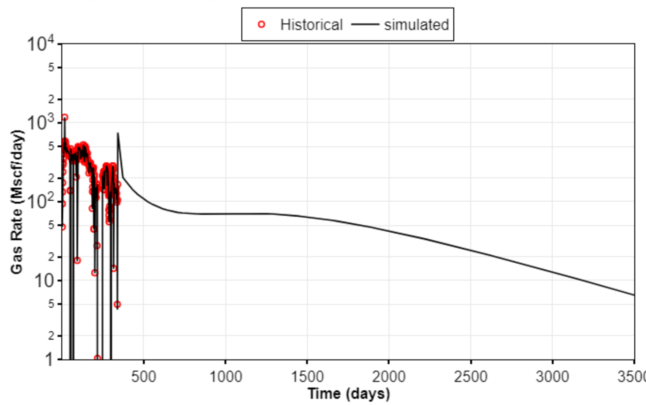
Original Gas in Place	
972.4	MMscf

Original Water in Place	
1091.6	MSTB

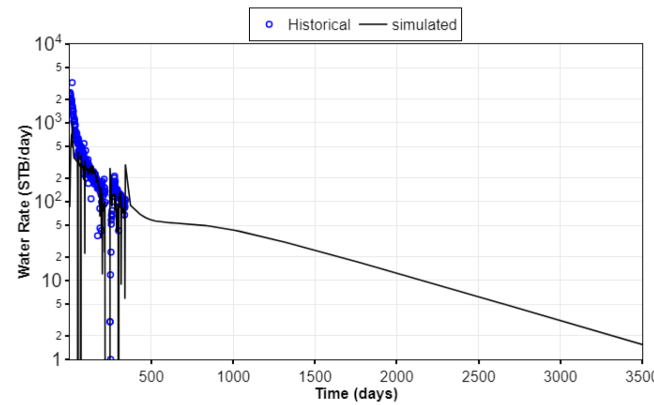
Oil Rate Log Scale Use Cumulative



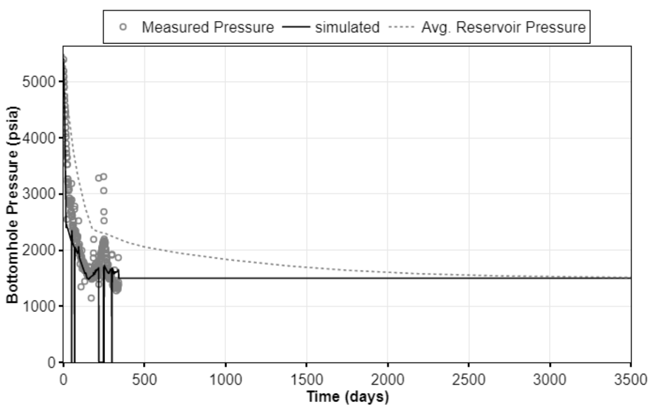
Gas Rate Log Scale Use Cumulative



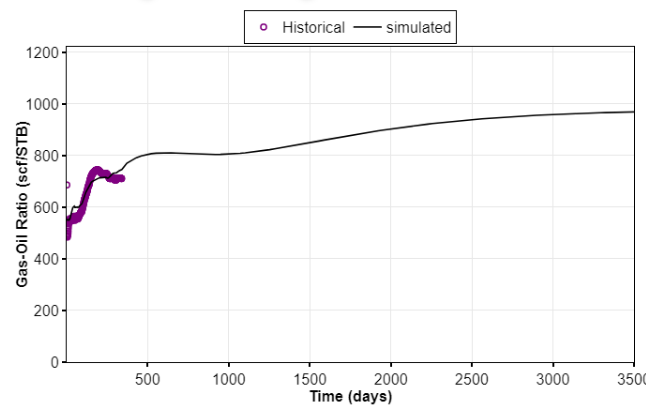
Water Rate Log Scale Use Cumulative



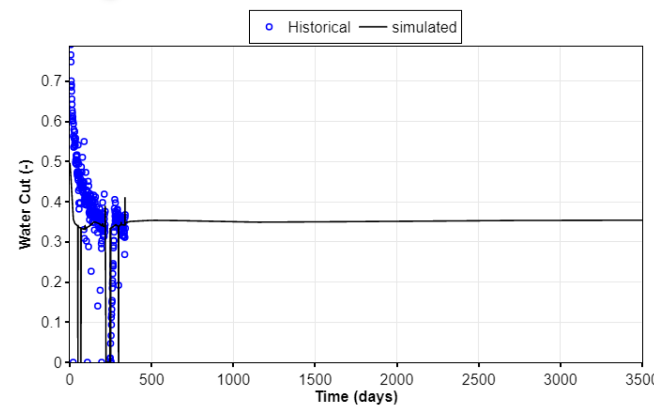
Bottomhole Pressure



Gas Oil Ratio Use Cumulative OGR

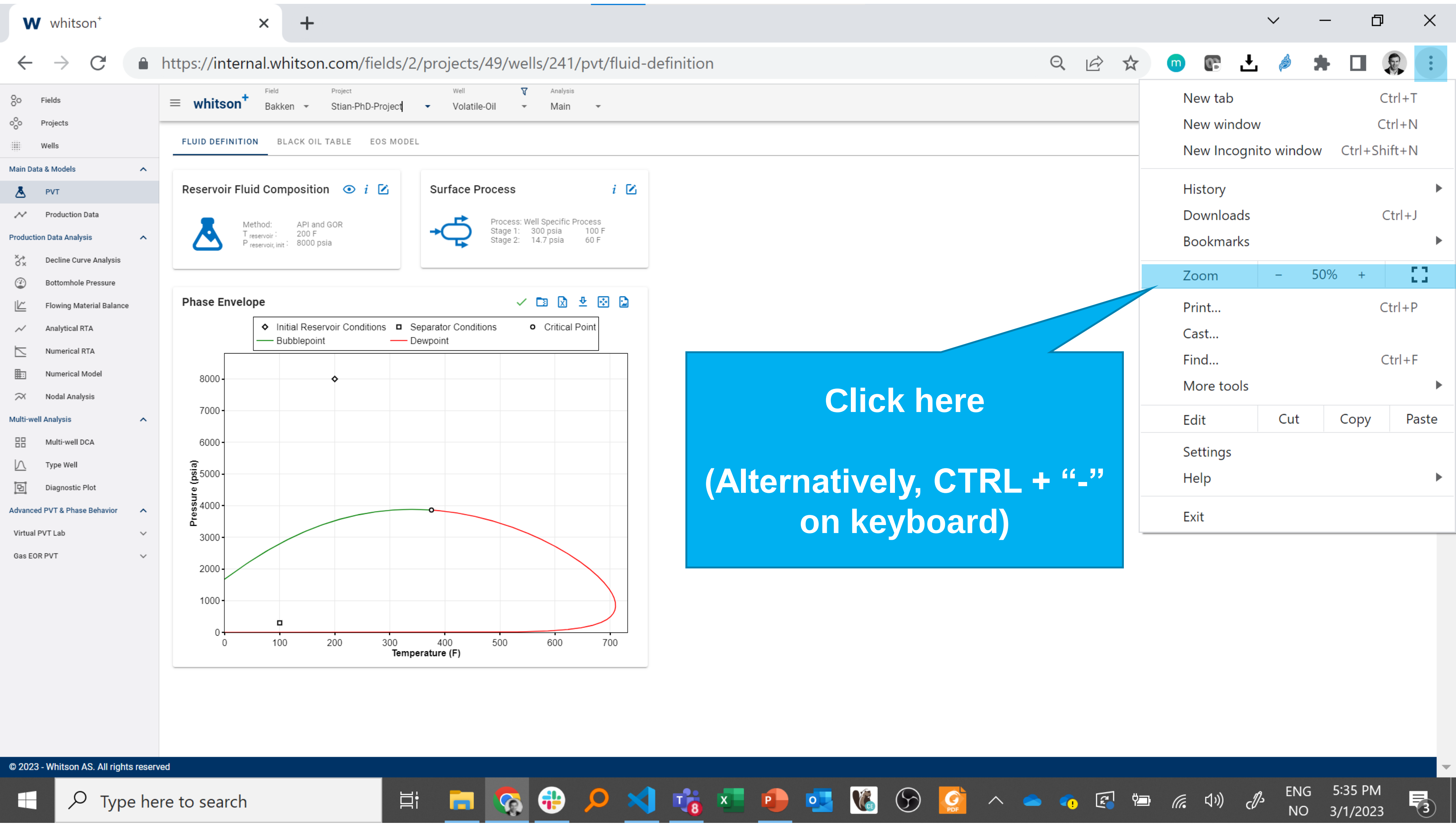


Water Cut Use Cumulative

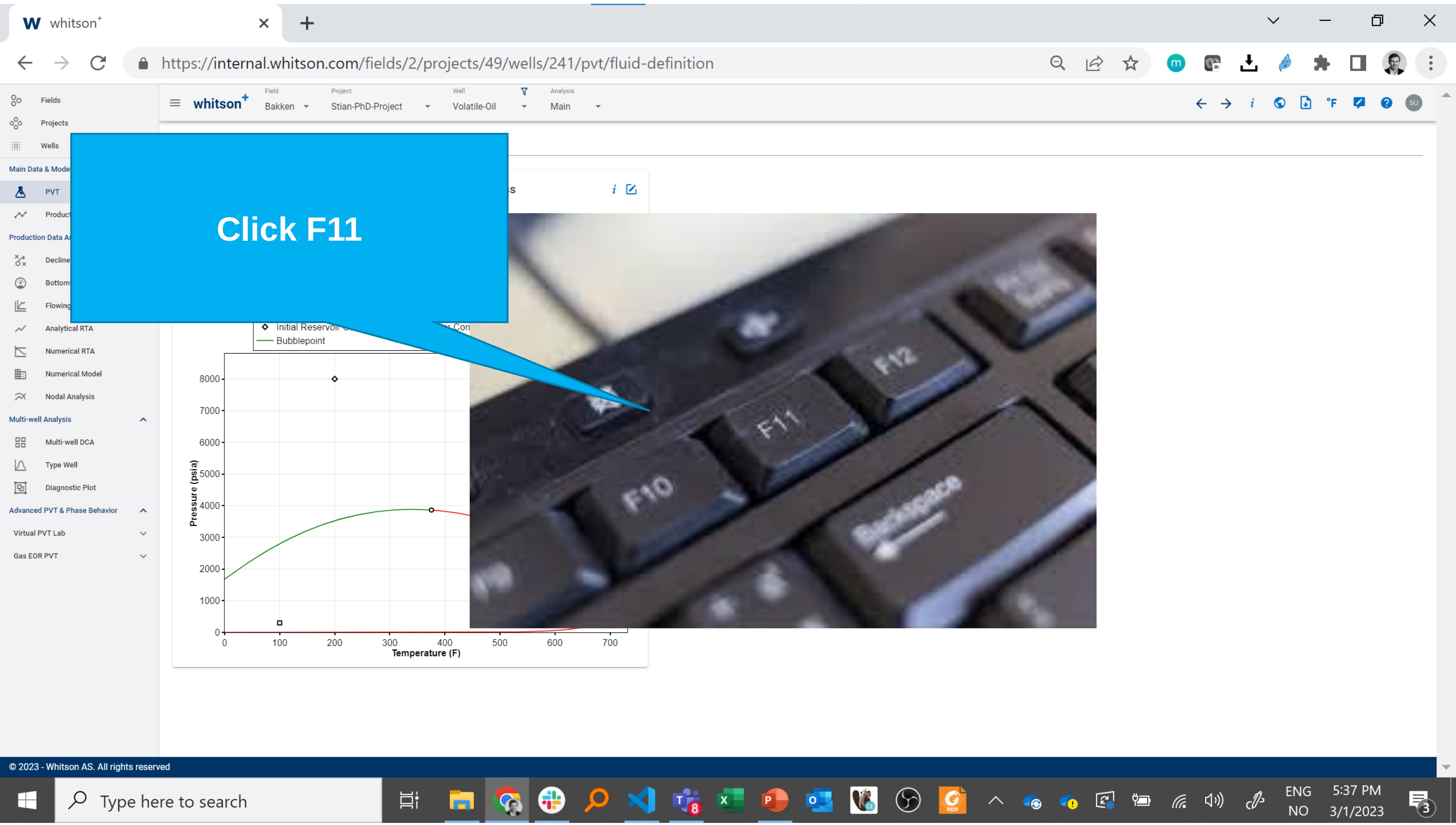


Software Basics

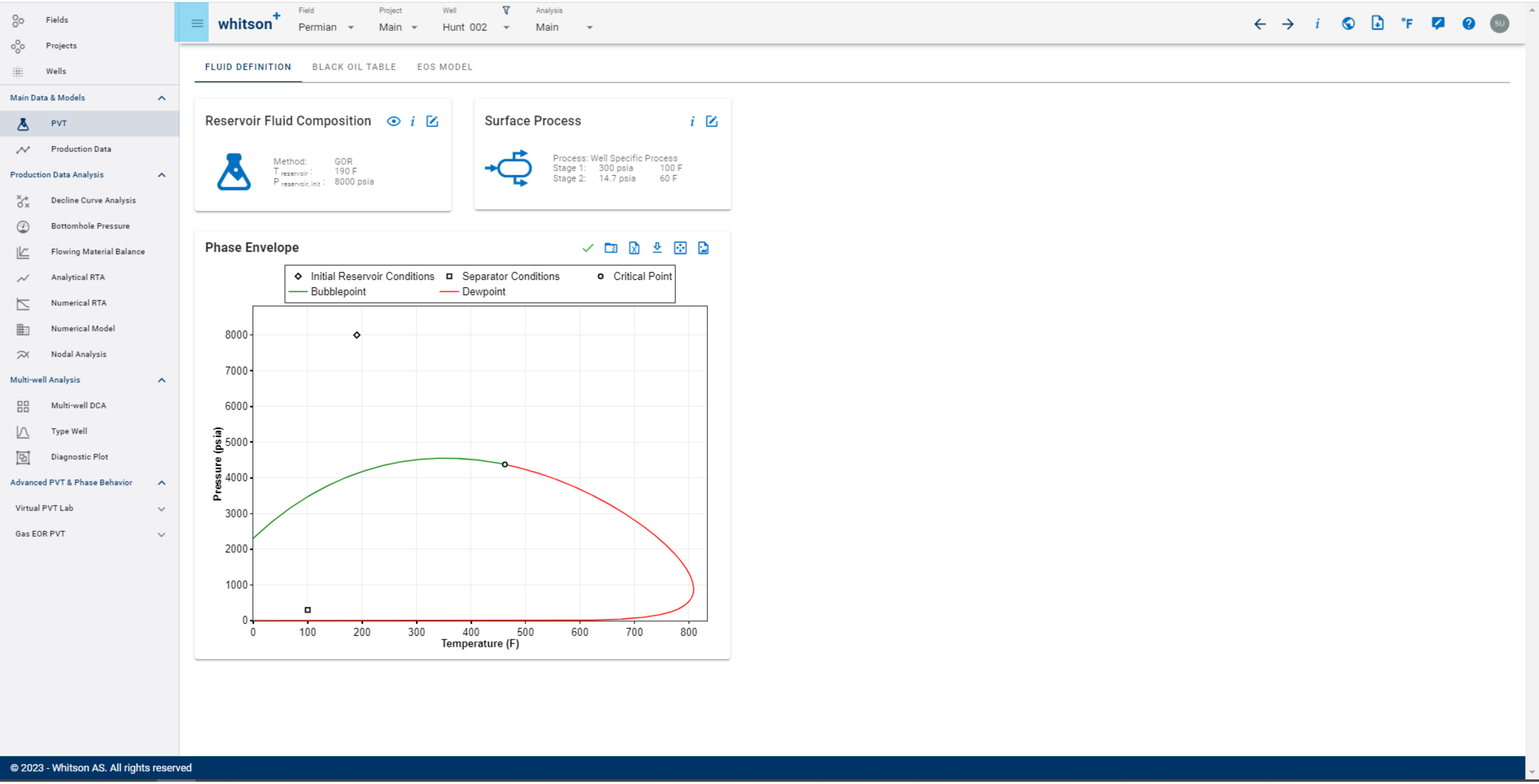
whitson+: Set Zoom to 70-80%



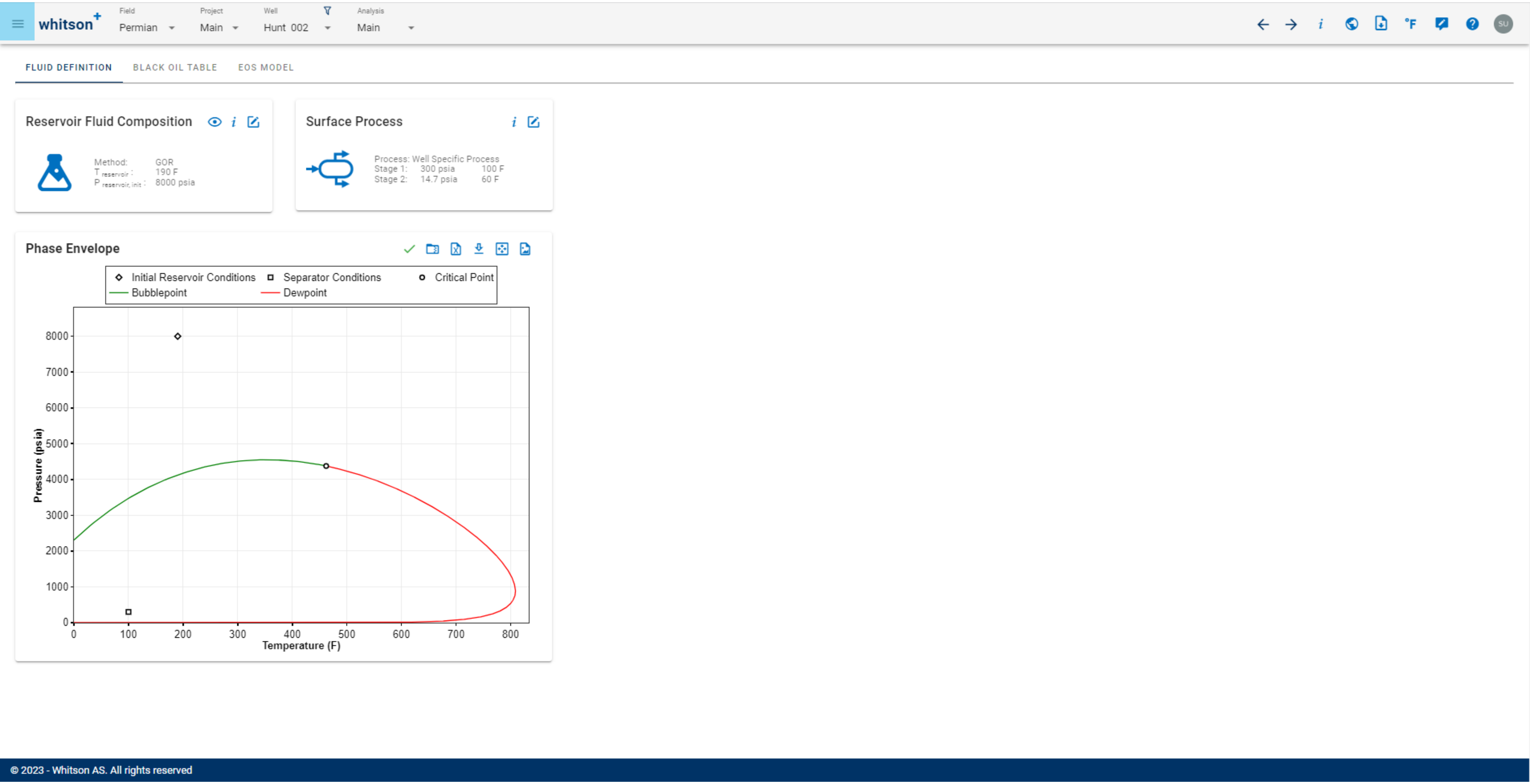
whitson⁺: Maximize Screen by "F11"



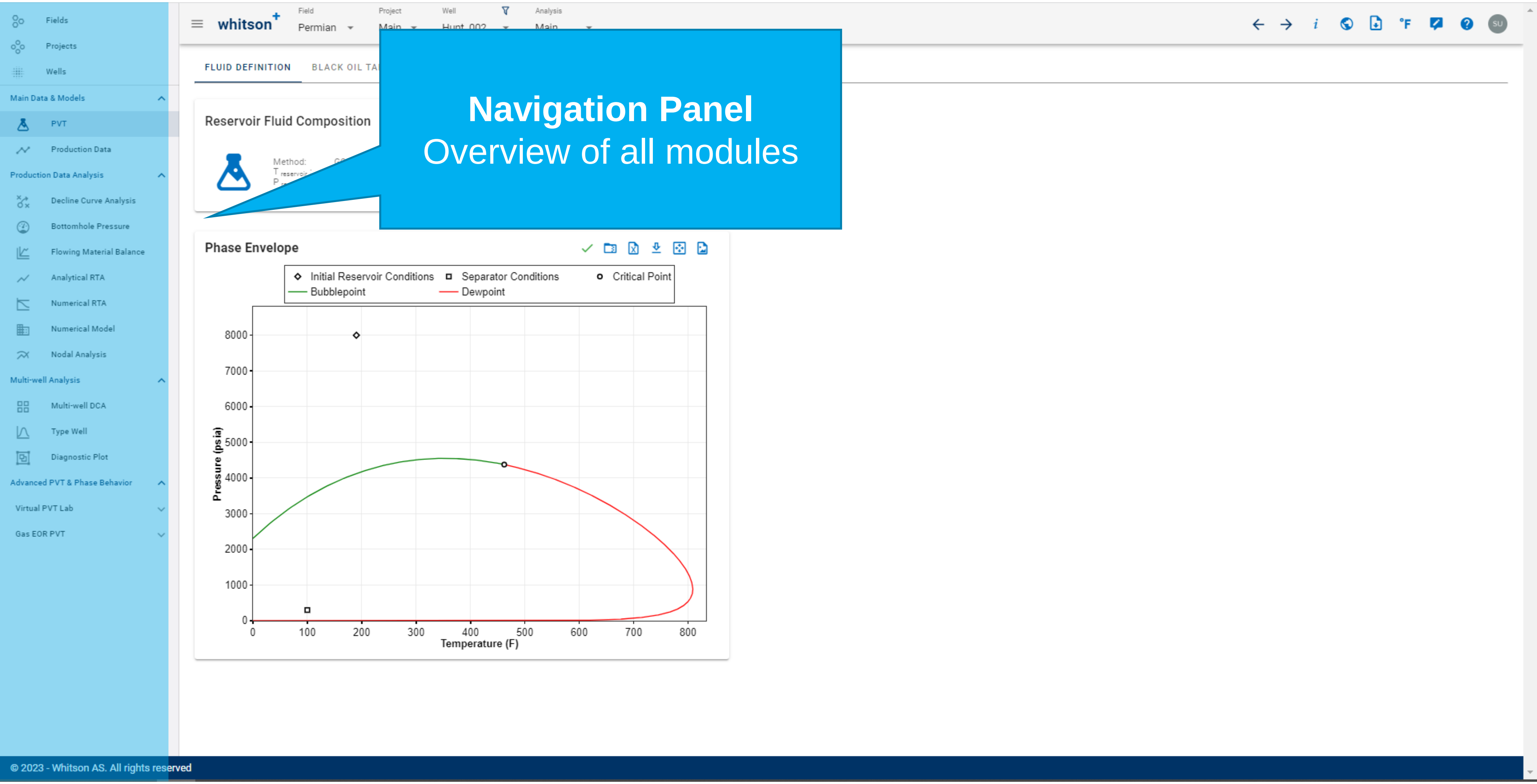
whitson+: More Screen Real Estate



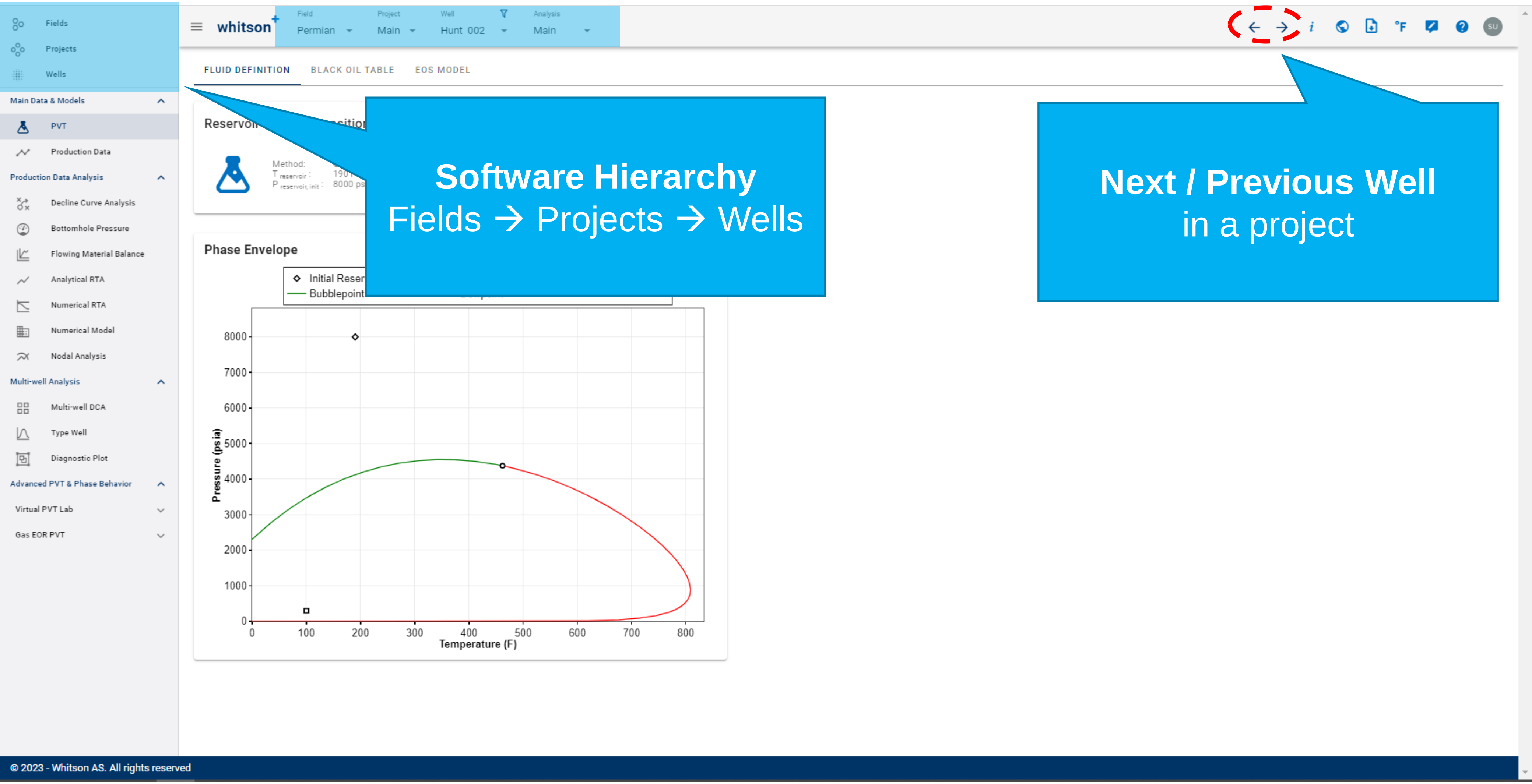
whitson+: More Screen Real Estate



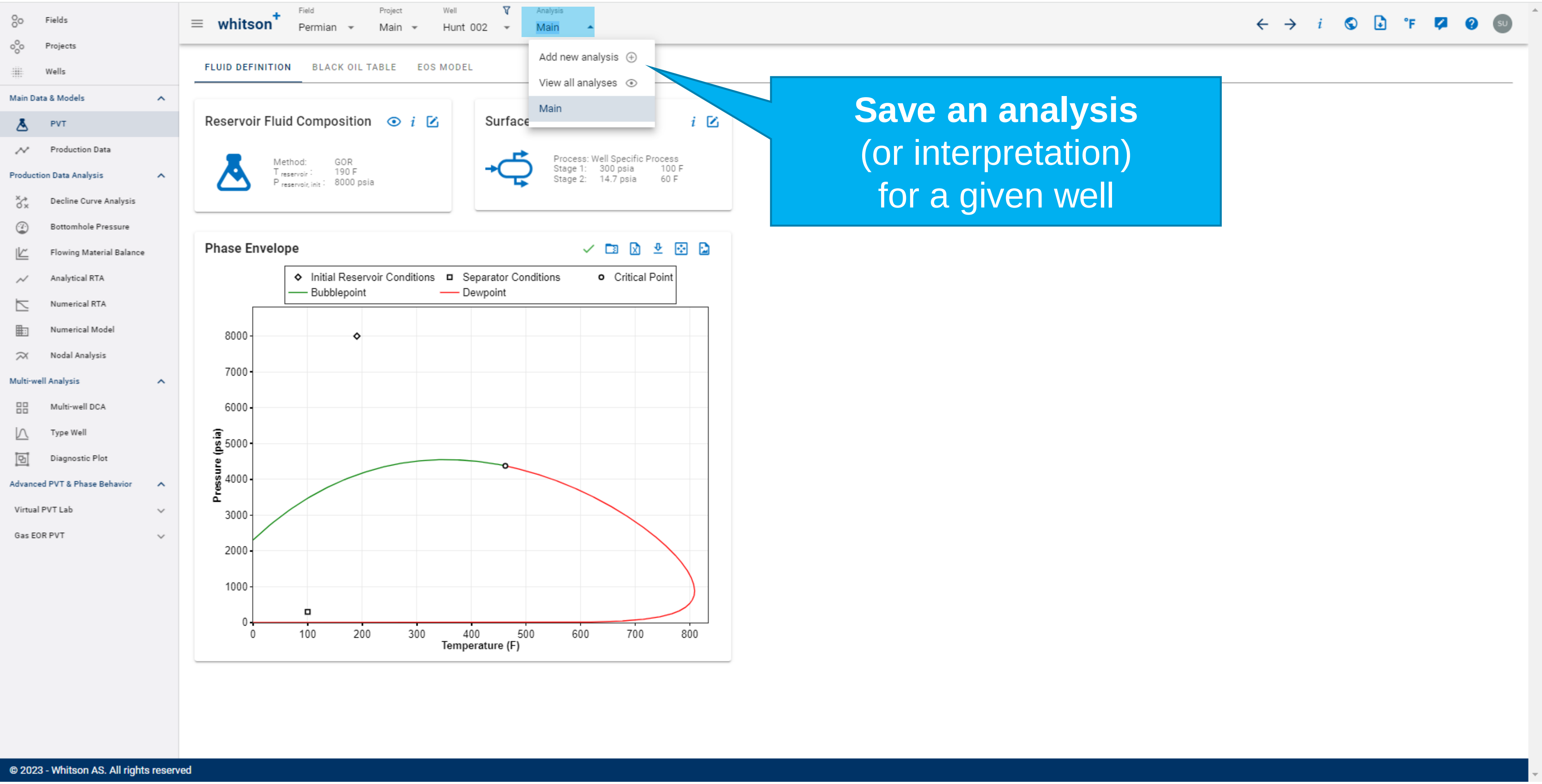
whitson+: Navigation Panel



whitson+: Software Hierarchy

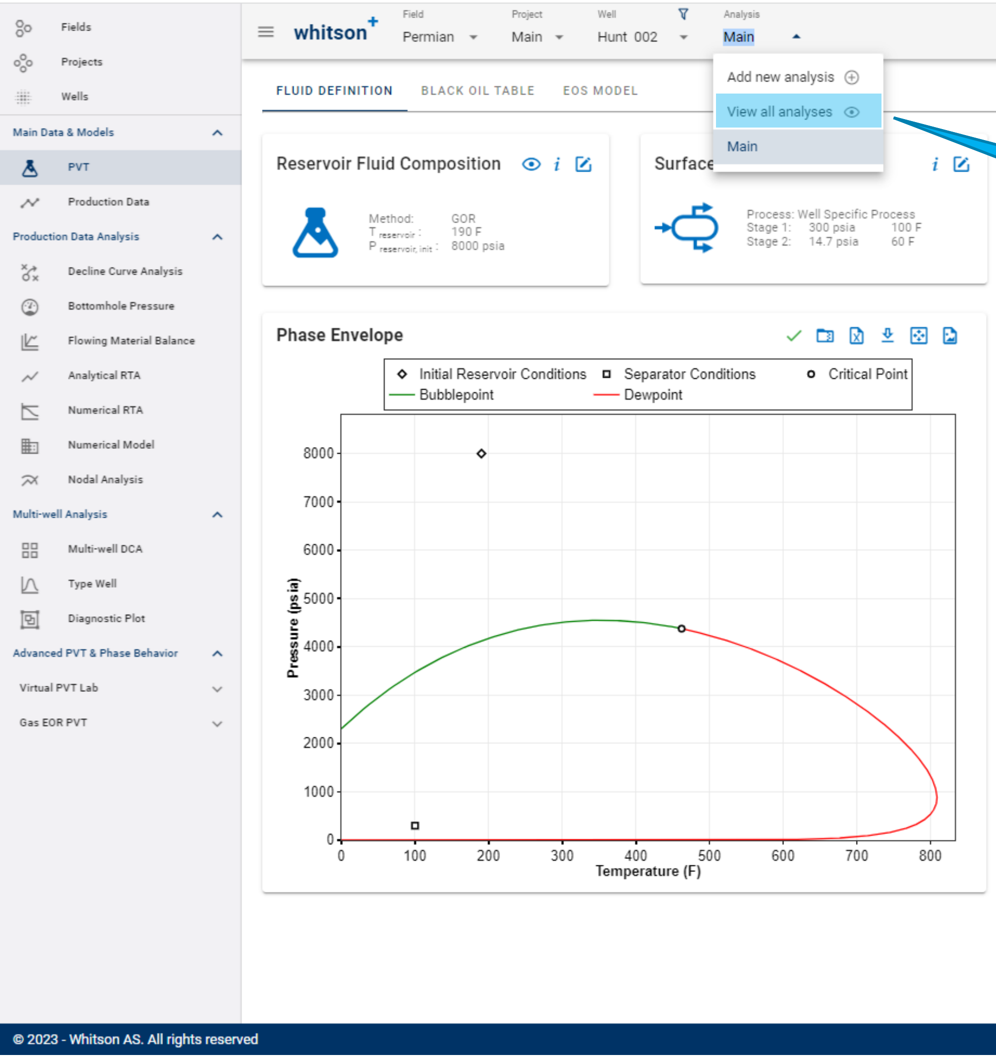


whitson+: Create Multiple Analyses for a Well

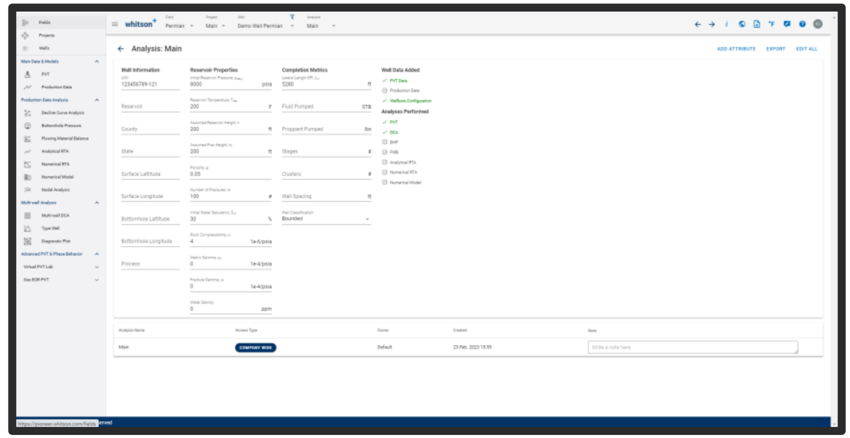


Save an analysis
(or interpretation)
for a given well

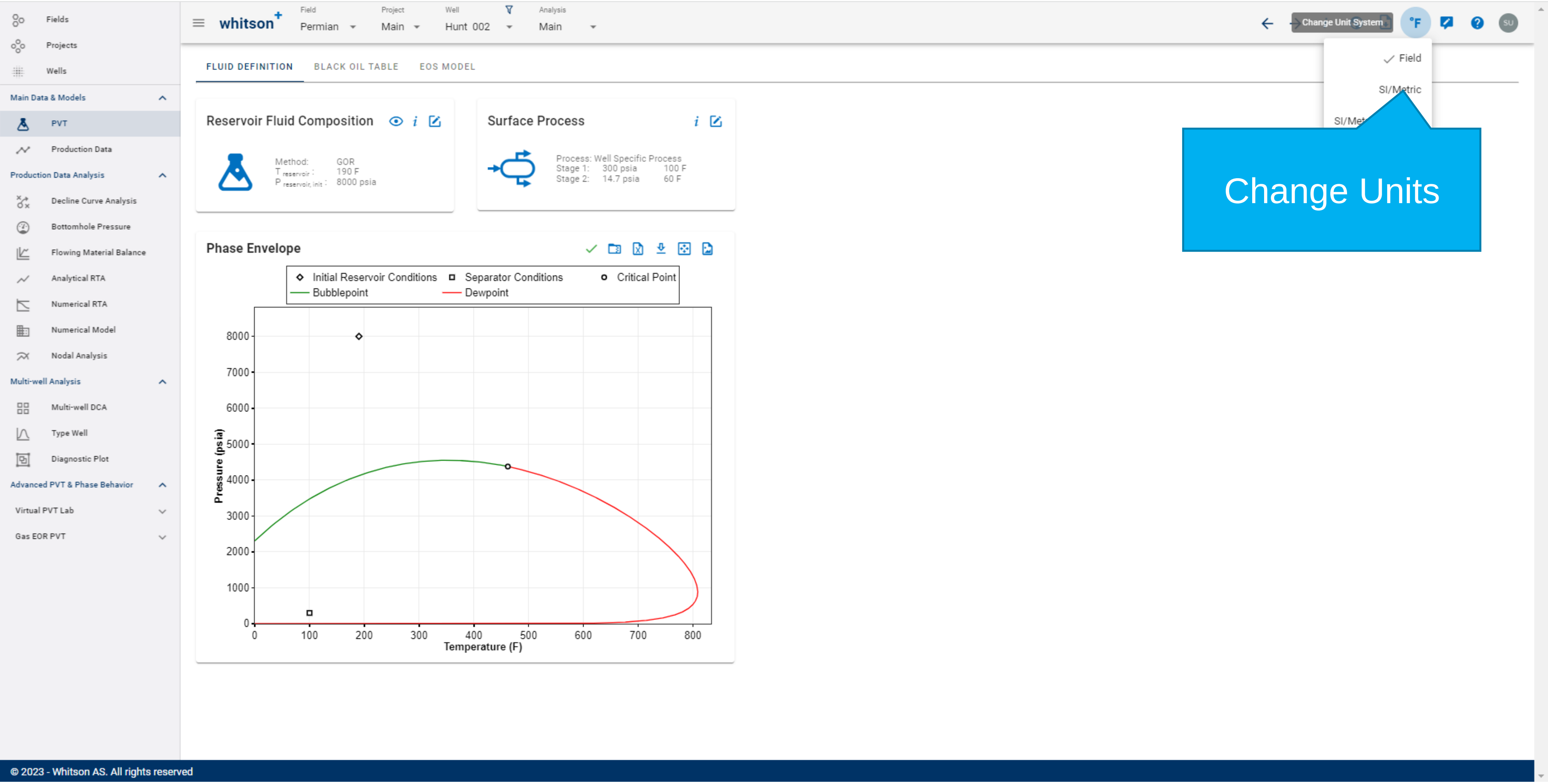
whitson+: Create Multiple Analyses for a Well



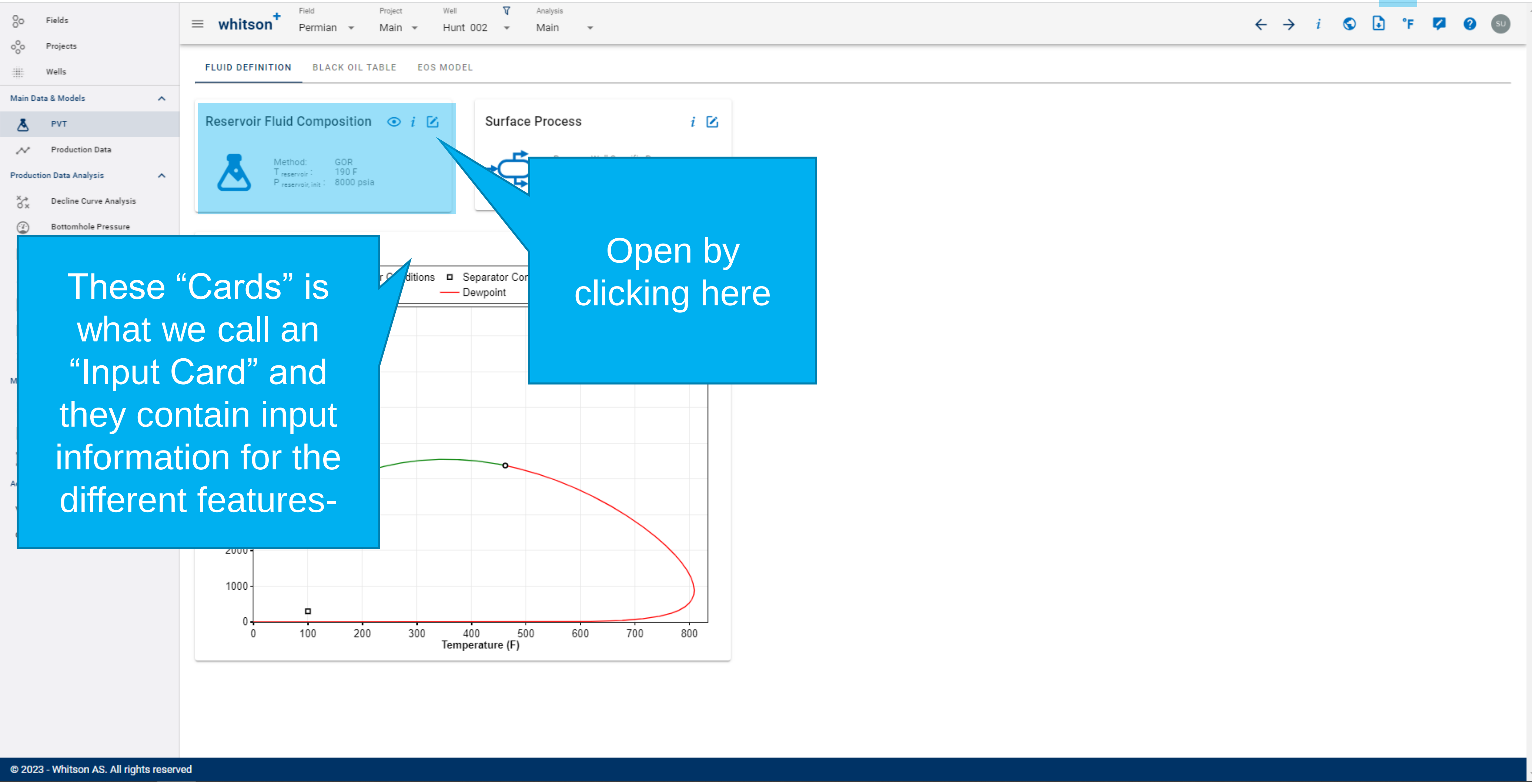
Well Overview page



whitson+: Change Units



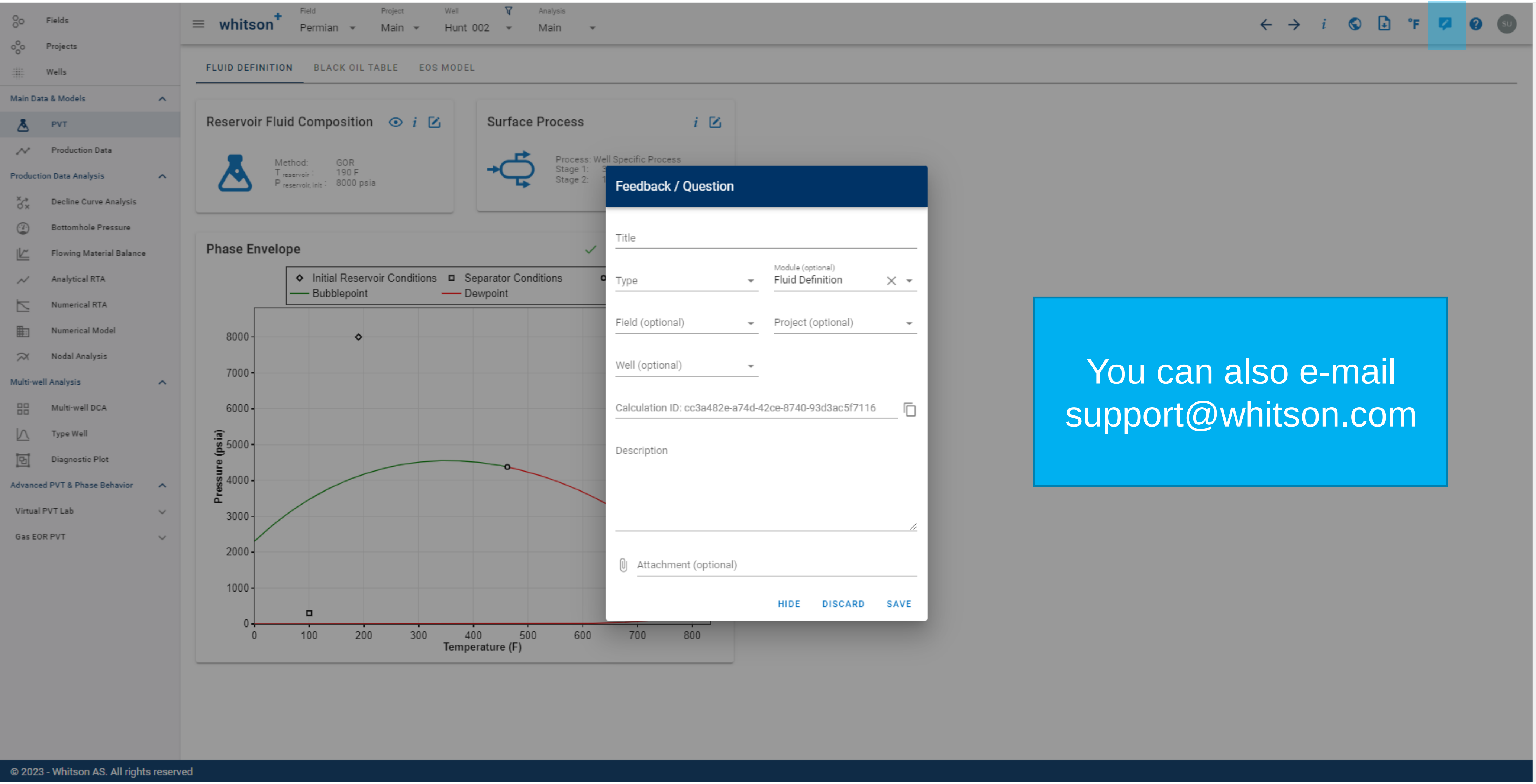
whitson⁺: Input Card



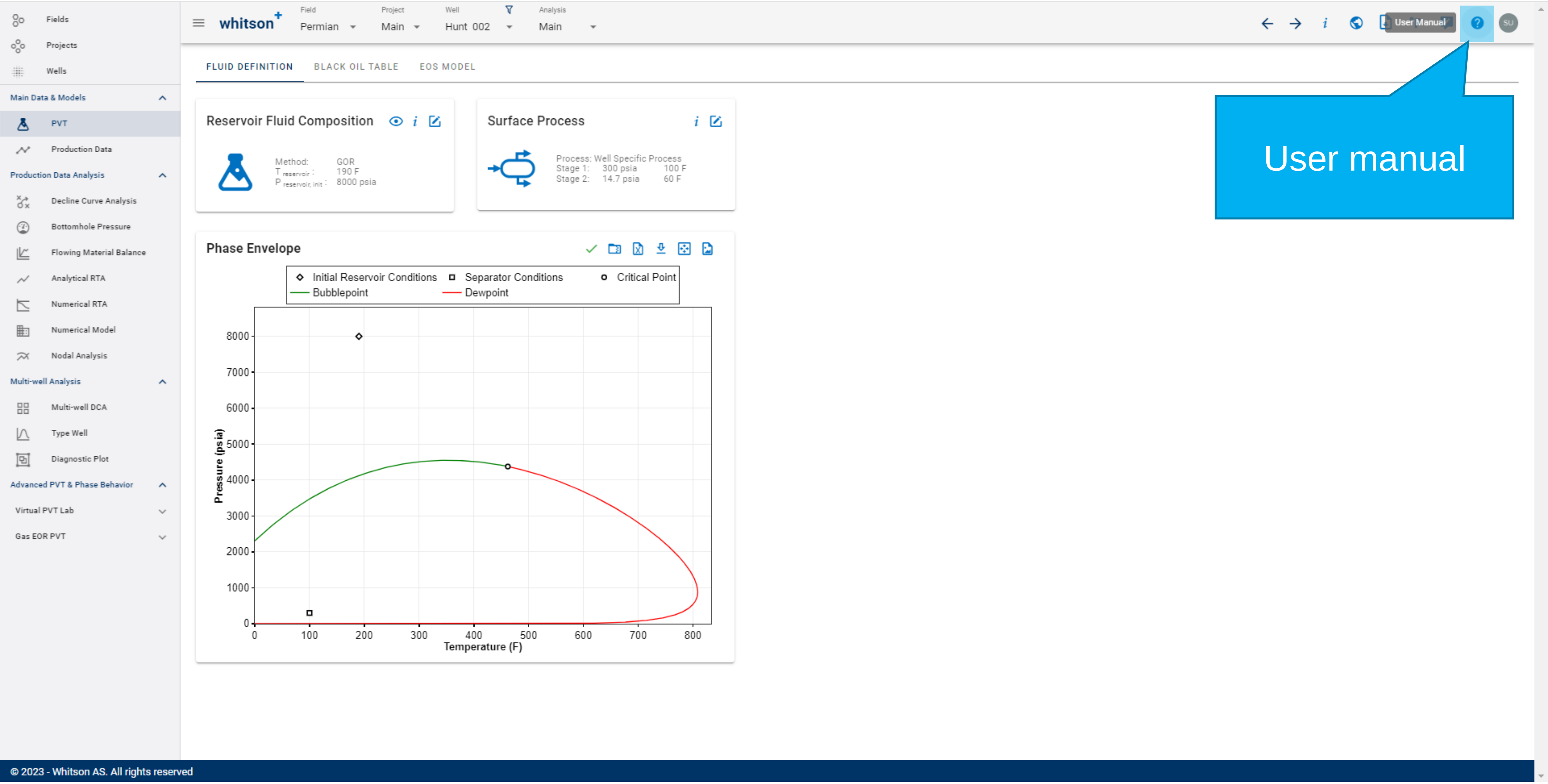
These “Cards” is what we call an “Input Card” and they contain input information for the different features-

Open by clicking here

whitson⁺: Support Ticket



You can also e-mail support@whitson.com


Fields
Projects
Wells
Main Data & Models
PVT
Production Data
Production Data Analysis
Decline Curve Analysis
Bottomhole Pressure
Flowing Material Balance
Analytical RTA
Numerical RTA
Numerical Model
Nodal Analysis
Multi-well Analysis
Multi-well DCA
Type Well
Diagnostic Plot
Advanced PVT & Phase Behavior
Virtual PVT Lab
Gas EOR PVT
whitson+
Field Permian
Project Main
Well Hunt 002
Analysis Main
User Manual
FLUID DEFINITION
BLACK OIL TABLE
EOS MODEL
Reservoir Fluid Composition
Method: GOR
T reservoir: 190 F
P reservoir, init: 8000 psia
Surface Process
Process: Well Specific Process
Stage 1: 300 psia 100 F
Stage 2: 14.7 psia 60 F
Phase Envelope
Initial Reservoir Conditions
Separator Conditions
Critical Point
Bubblepoint
Dewpoint
Pressure (psia)
Temperature (F)
User manual
© 2023 - Whitson AS. All rights reserved

Important Shortcut: Refresh

- Refresh shortcut: “CTRL + R”

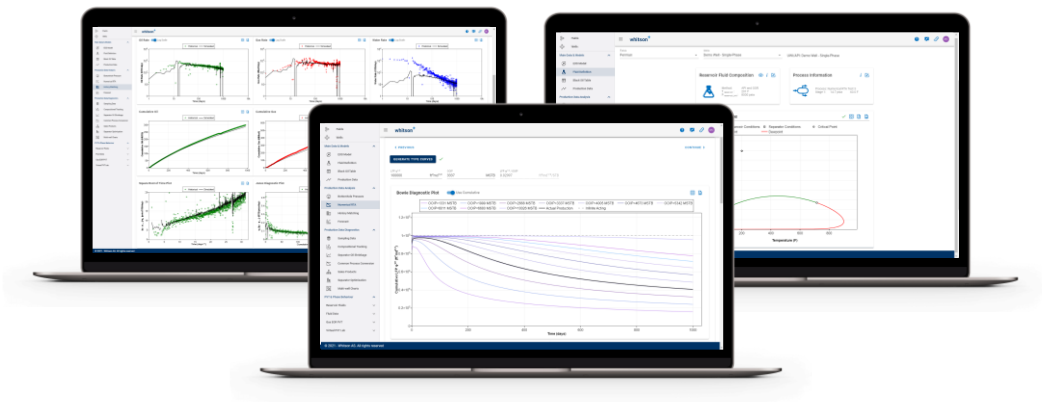
- Use if you experience
  - Bad connection
  - The browser is “stuck”

Eagle Ford Workflow Example

SPE Data Repository Well #4 (Kite)

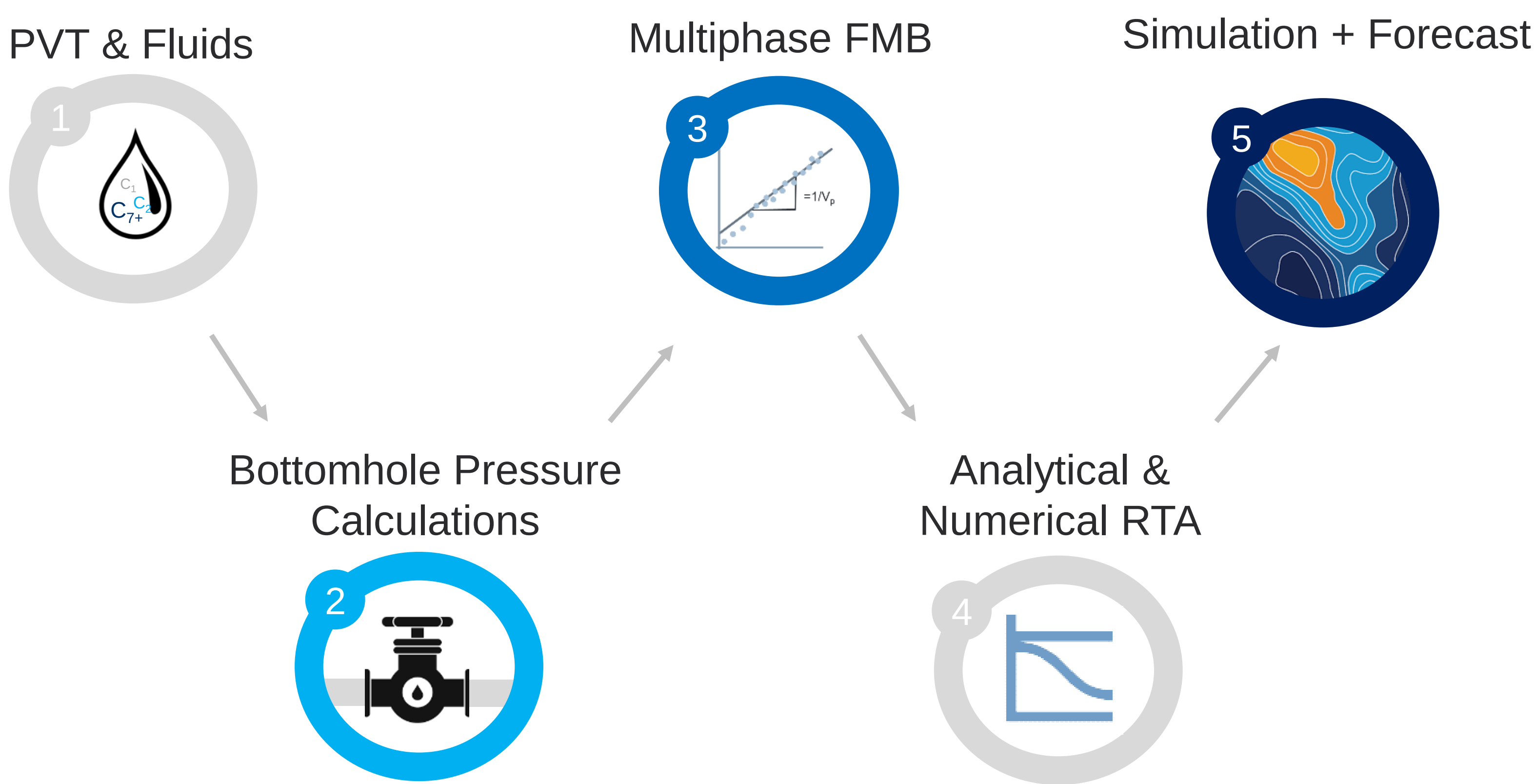
Download associated data here: https://manual.whitson.com/onboarding/mass-upload-examples/

Software – Important Notes



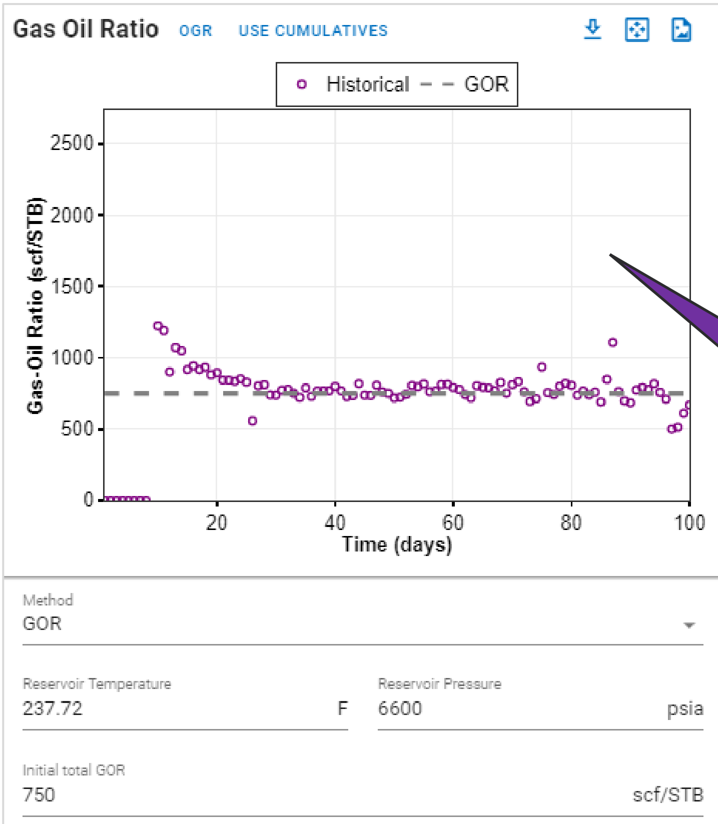
- Set zoom in browser between 60-80%
- Use Google Chrome, Microsoft Edge, or Firefox
- Use F11 to maximize screen
- Click “F5” or “CTRL + R” if you experience issues (hard refresh)

Unconventional Reservoir Workflow



whitson

PVT … Fluid Initialization



Use GOR method in **whitson⁺** to predict fluid composition

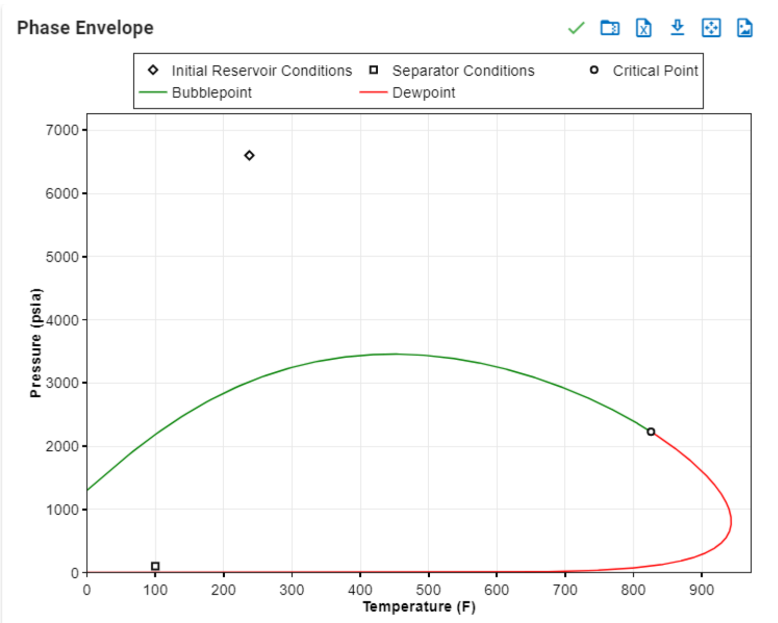
- R_s = 750 scf/STB | B_o = 1.38 RB/STB
- Bubblepoint = 2875 psia
- Undersaturated, black oil

PVT
Assume solution GOR (R_s) = initial producing GOR (R_p) = 750 scf/STB

https://manual.whitson.com/modules/fluid-definition/#initial-gor

1

PVT … Fluid Initialization



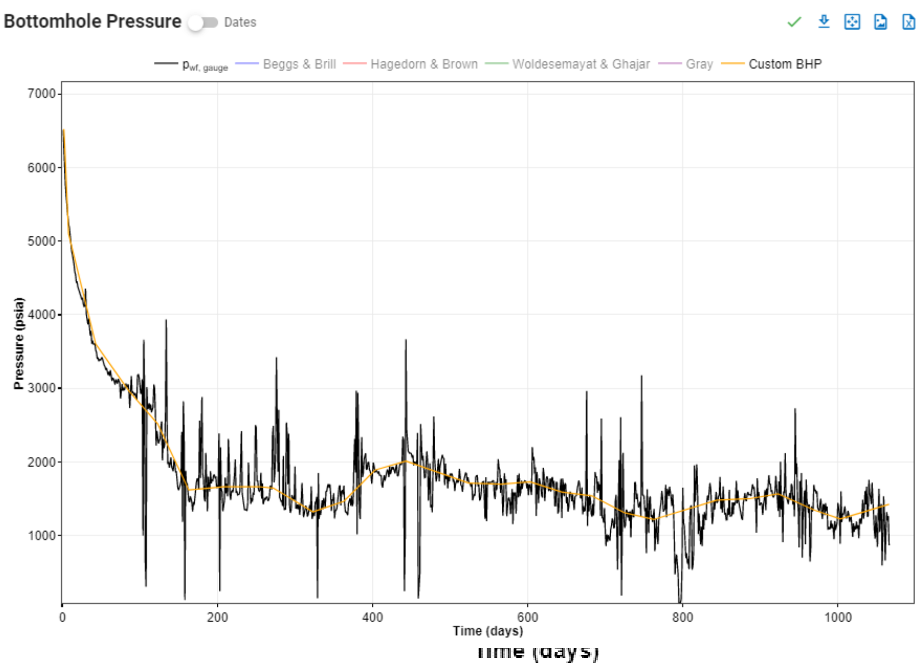
Use GOR method in **whitson$^+$** to predict fluid composition

- R_s = 750 scf/STB | B_o = 1.38 RB/STB
- Bubblepoint = 2875 psia
- Undersaturated, black oil

https://manual.whitson.com/modules/fluid-definition/#initial-gor

2

Flowing Bottomhole pressure (p_{wf})



- Assume bottomhole pressure provided in the SPE data repository dataset is correct

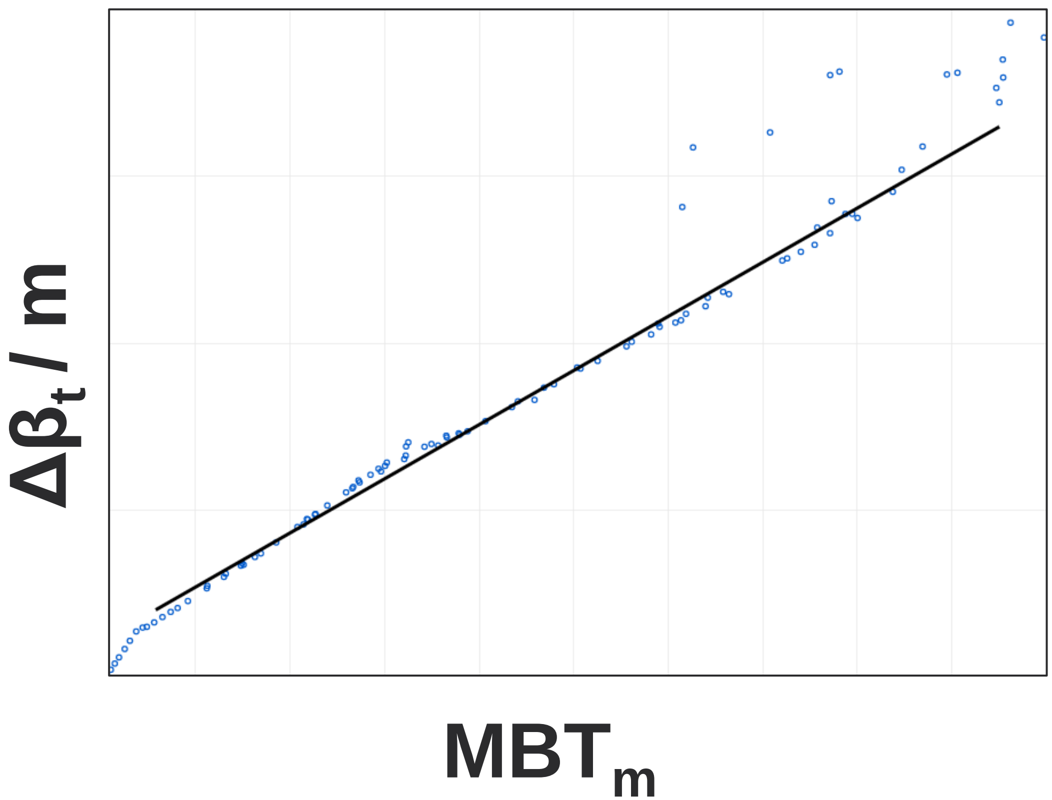
(… even though it's calculated)

- Smooth the pressures graphically in **whitson+**

whitson

3

Multiphase Flowing Material Balance



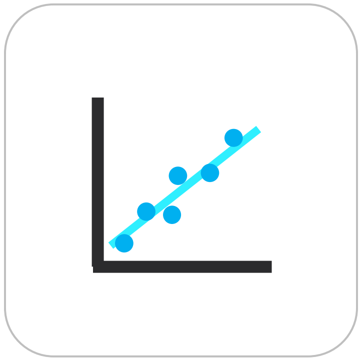
OOIP = 700 MSTB

Source: https://manual.whitson.com/modules/flowing-material-balance/multiphase/

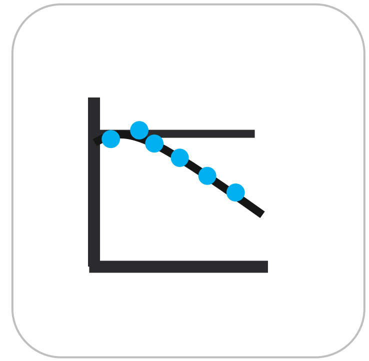
whitson

Analytical vs Numerical RTA

4



Analytical RTA
Single-phase



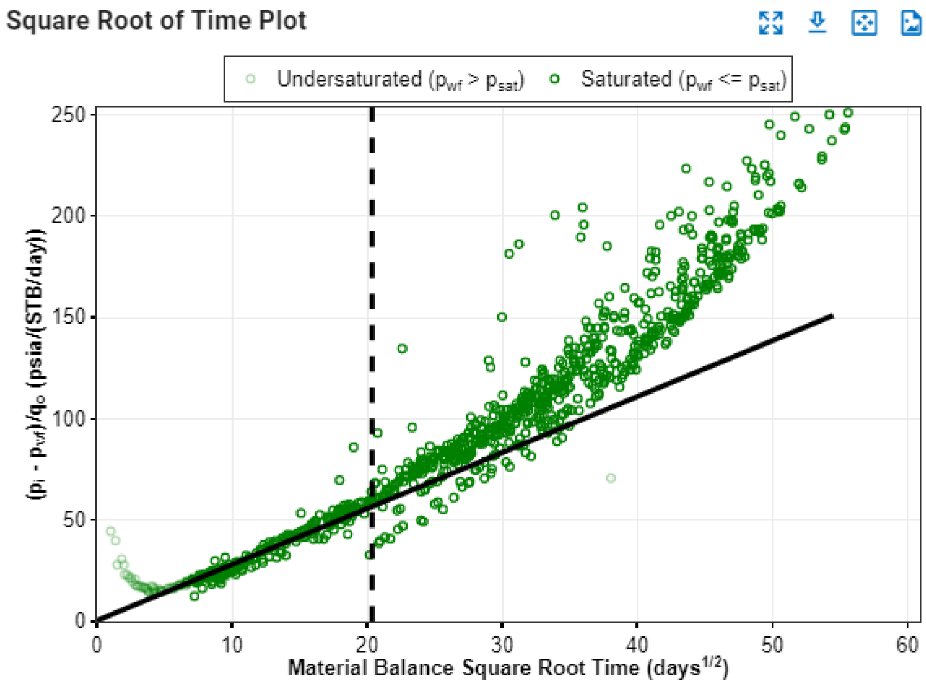
Numerical RTA
Multi-phase

$$\text{LFP}_{\text{analytical}} \leq \text{LFP}_{\text{numerical}}$$

whitson

4

Classical RTA - Pick LFP

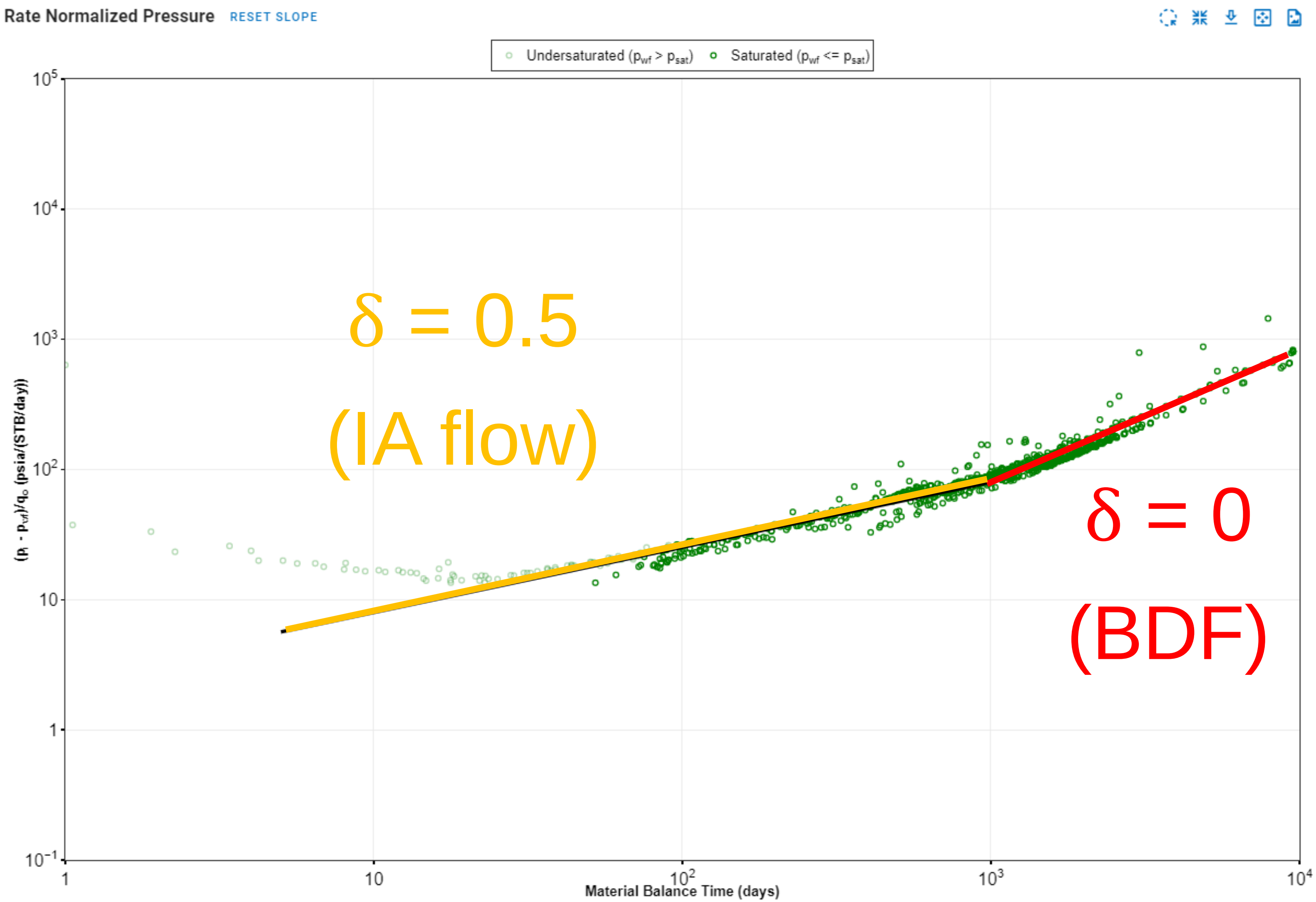


LFP = 24000 $ft^2\ md^{1/2}$

whitson

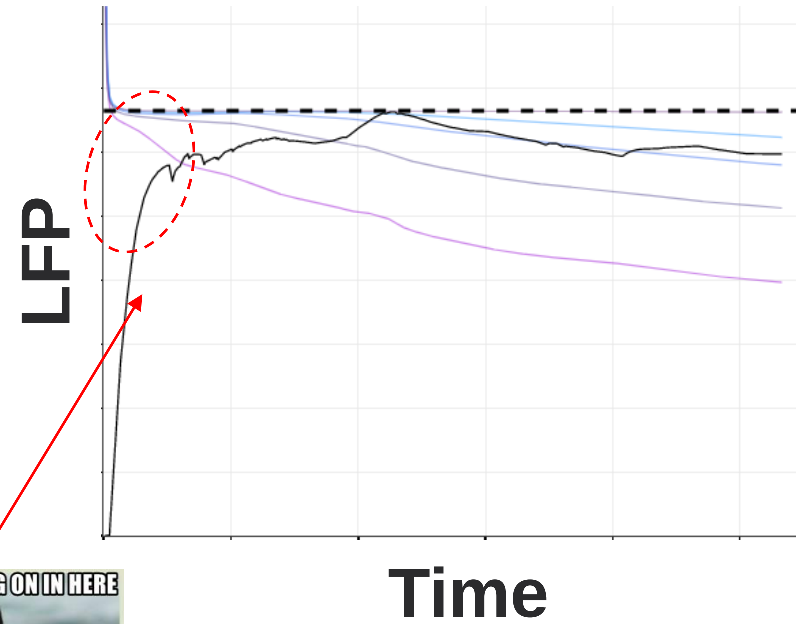
Fractional RTA - δ

4



whitson

4 Numerical RTA – Pick LFP & OOIP



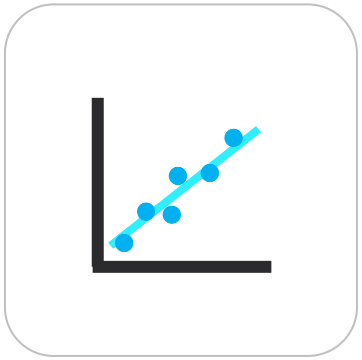
LFP = 50000 $ft^2\ md^{1/2}$

OOIP = 700 MSTB

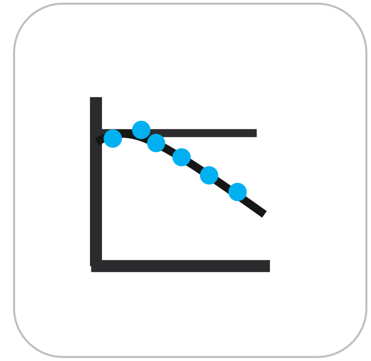
Check out more here: https://youtu.be/i4tS_0kX7qQ?t=13246

4

Analytical vs Numerical RTA



Analytical RTA
Single-phase

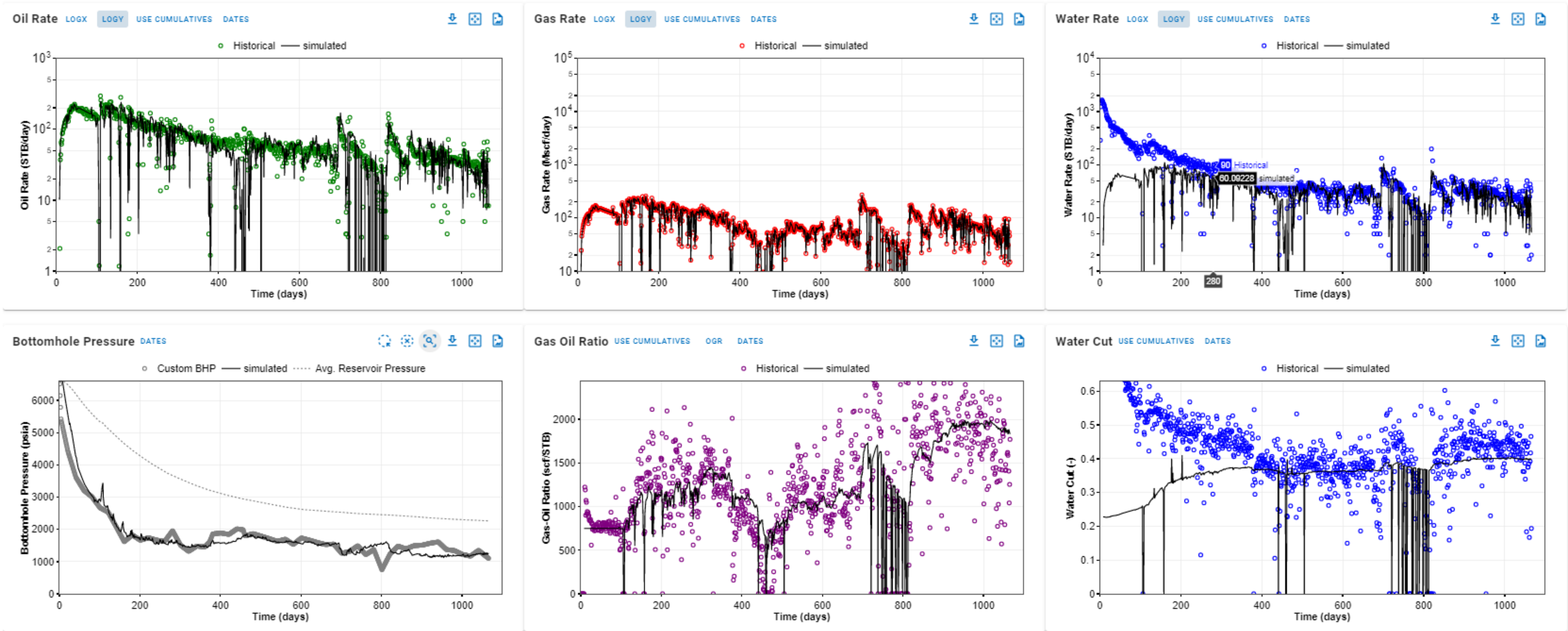


Numerical RTA
Multi-phase

$$LFP_{analytical} = 24{,}000\ ft^2\ md^{1/2} \leq LFP_{numerical} = 50{,}000\ ft^2\ md^{1/2}$$

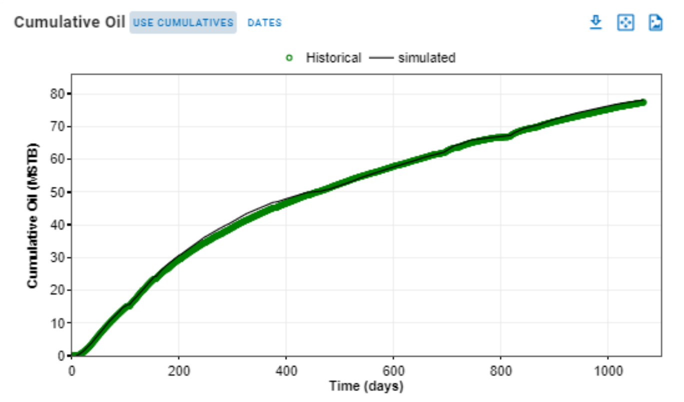
5

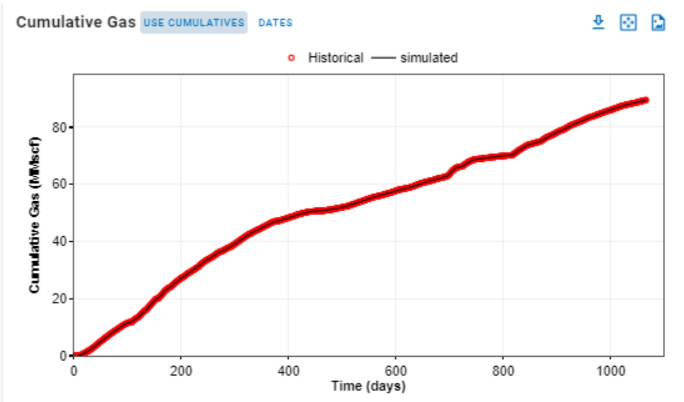
Numerical Model – History Match

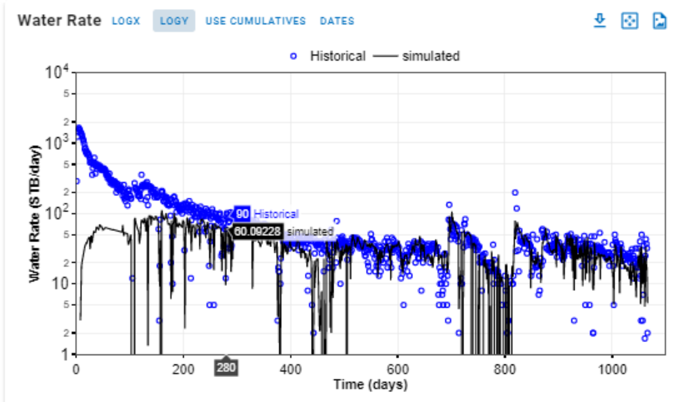


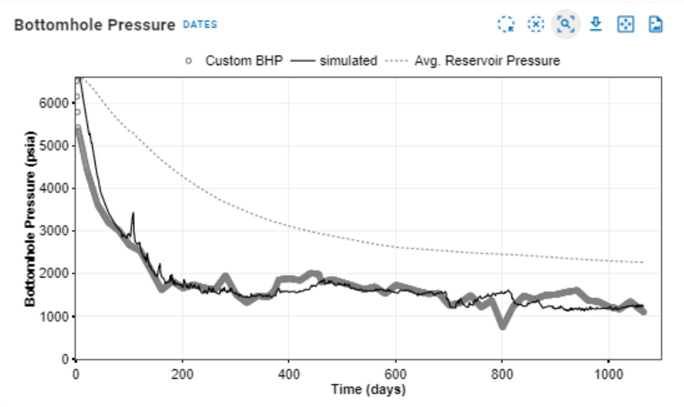
whitson

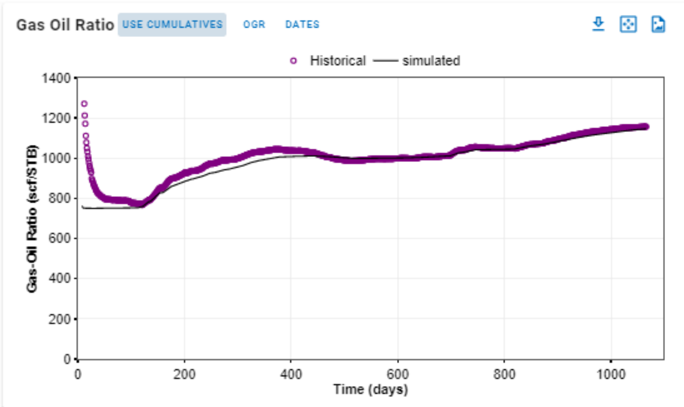
Numerical Model – History Match

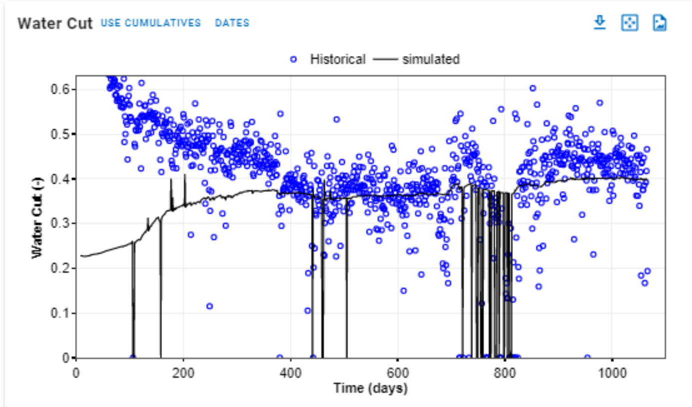






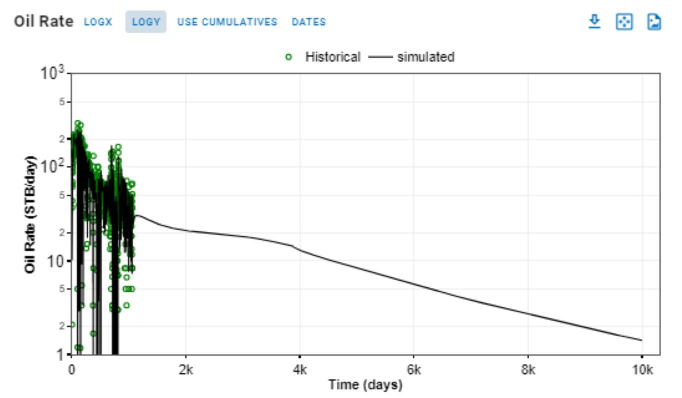


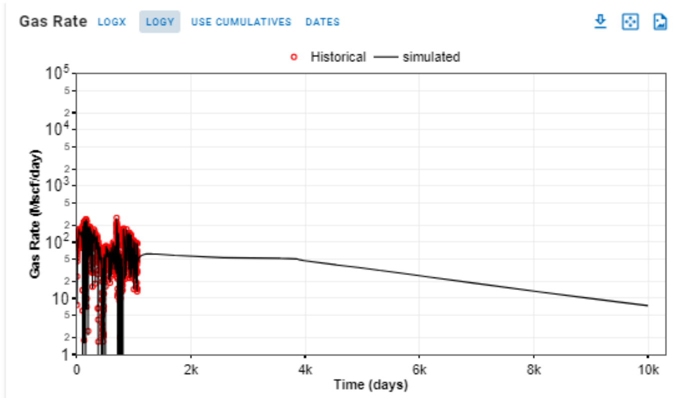


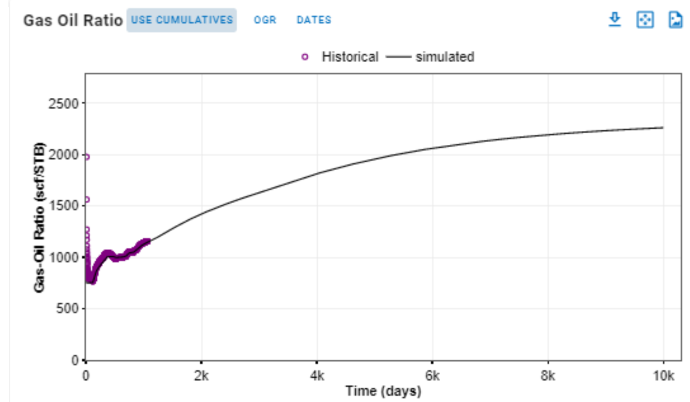


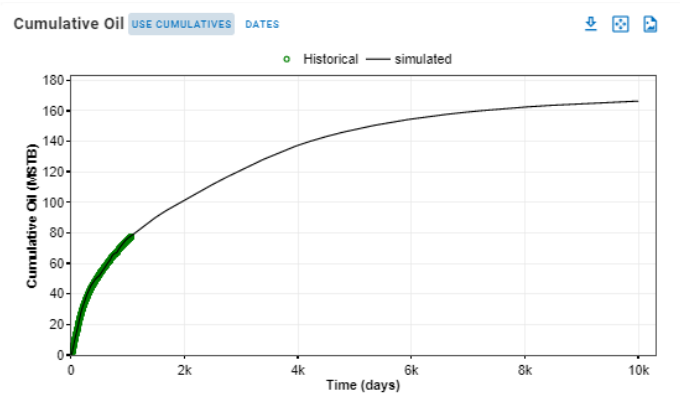
5

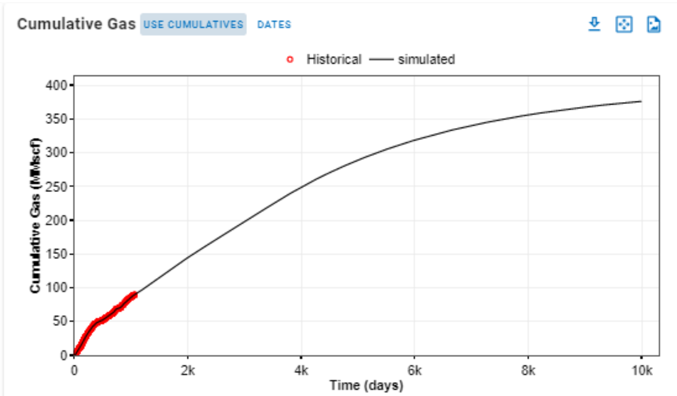
Numerical Model – History Match + Forecast

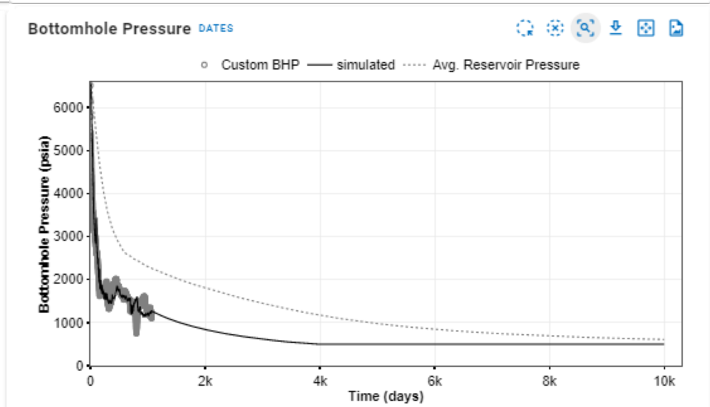












whitson

We support energy companies, oil services companies, investors and government organizations with expertise and expansive analysis within PVT, gas condensate reservoirs and gas-based EOR. Our coverage ranges from R&D based industry studies to detailed due diligence, transaction or court case projects.

We help our clients find best possible answers to complex questions and assist them in the successful decision-making on technical challenges. We do this through a continuous, transparent dialog with our clients - before, during and after our engagement.

The company was founded by Dr. Curtis Hays Whitson in 1988 and is a Norwegian corporation located in Trondheim, Norway, with local presence in USA, Middle East, India and Indonesia.

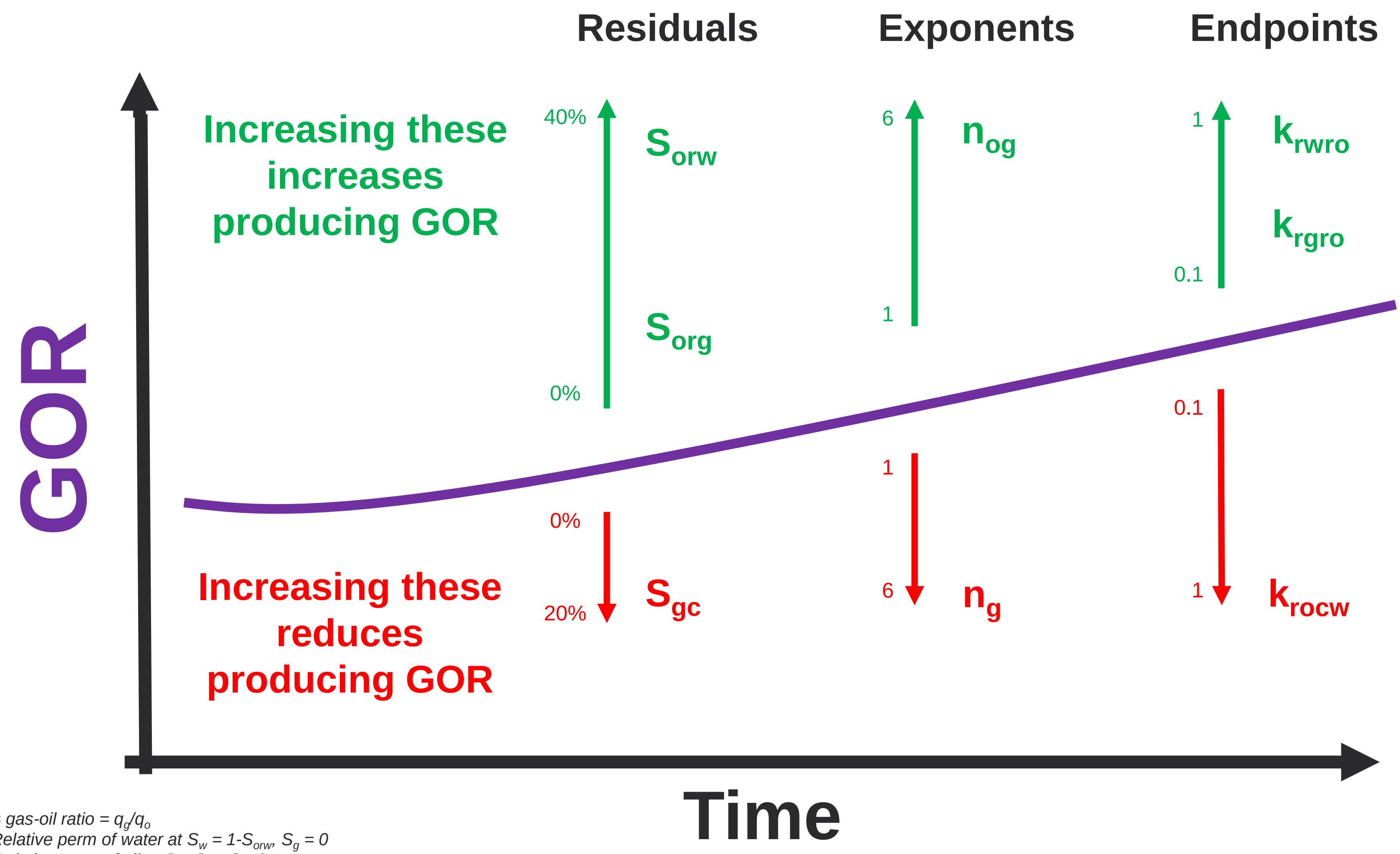
Global	Asia-Pacific	Middle East	Americas
Curtis Hays Whitson, PhD	Kameshwar Singh, PhD	Ahmad Alavian, PhD	Mathias Carlsen, MSc
curtishays@whitson.com	singh@whitson.com	alavian@whitson.com	carlsen@whitson.com

Whitson AS	Whitson USA LLC
Skonnertvegen 7, 7053	3410 W Dallas St.
Trondheim, Norway	Houston, TX 77019, US

www.whitson.com

Rel Perms

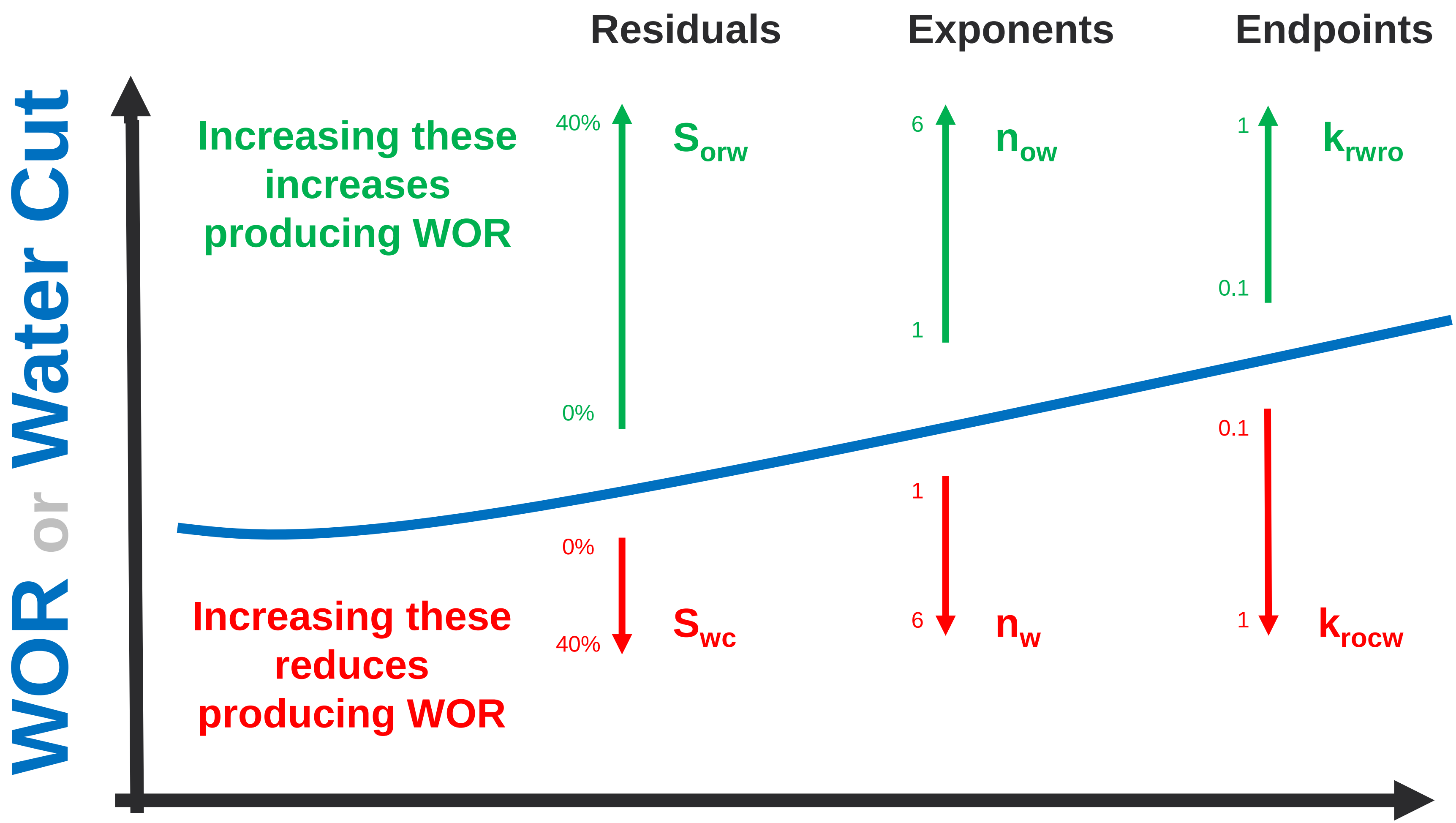
Relative Permeability: Cheat Sheet



[1] GOR = gas-oil ratio = q_g/q_o
[2] k_{rwro}: Relative perm of water at $S_w = 1\text{-}S_{orw}$, $S_g = 0$
[2] k_{rocw}: Relative perm of oil at $S_w=S_{wc}$, $S_g=0$.
[2] k_{rgro}: Relative perm of gas at $S_w=S_{wc}$, $S_o=S_{org}$
[3] Baker is used for three-phase relative perm.
[4] These are rules of thumb and simplifications. Deviations might occur.
[5] Rel. perm parameters such as k_{rgro}, S_{wc}, S_{org}, n_w, n_{ow} doesn't have a big, or simple, relationship with WOR (and water cut) and is excluded from the overview.

whitson

Relative Permeability: Cheat Sheet



[1] WOR = water oil ratio = q_w/q_o | water cut = $q_w/(q_w+q_o)$

[2] k_{rwro}: Relative perm of water at $S_w = 1\text{-}S_{orw}$, $S_g = 0$

[2] k_{rocw}: Relative perm of oil at S_w=S_{wc}, S_g=0.

[2] k_{rgro}: Relative perm of gas at S_w=S_{wc}, S_o=S_{org}

[3] Corey model is assumed here. Baker is used for three-phase relative perm.

[4] These are rules of thumb. Deviations might occur.

[5] Rel. perm parameters such as k_{rgro}, S_{gc}, S_{org}, n_{og}, n_g doesn't have a big, or simple, relationship with WOR (and water cut) and is excluded from the overview.

[6] For reservoir oils, k_{rgro}, S_{gc}, S_{org}, n_{og}, n_g only have an impact on WOR below the bubblepoint, p_b. Hence, if WOR changes are observed below p_b these are helpful.

whitson

Worked Example

Crow Well

Worked Example

Dry Gas Example

Worked Example

Synthetic Well

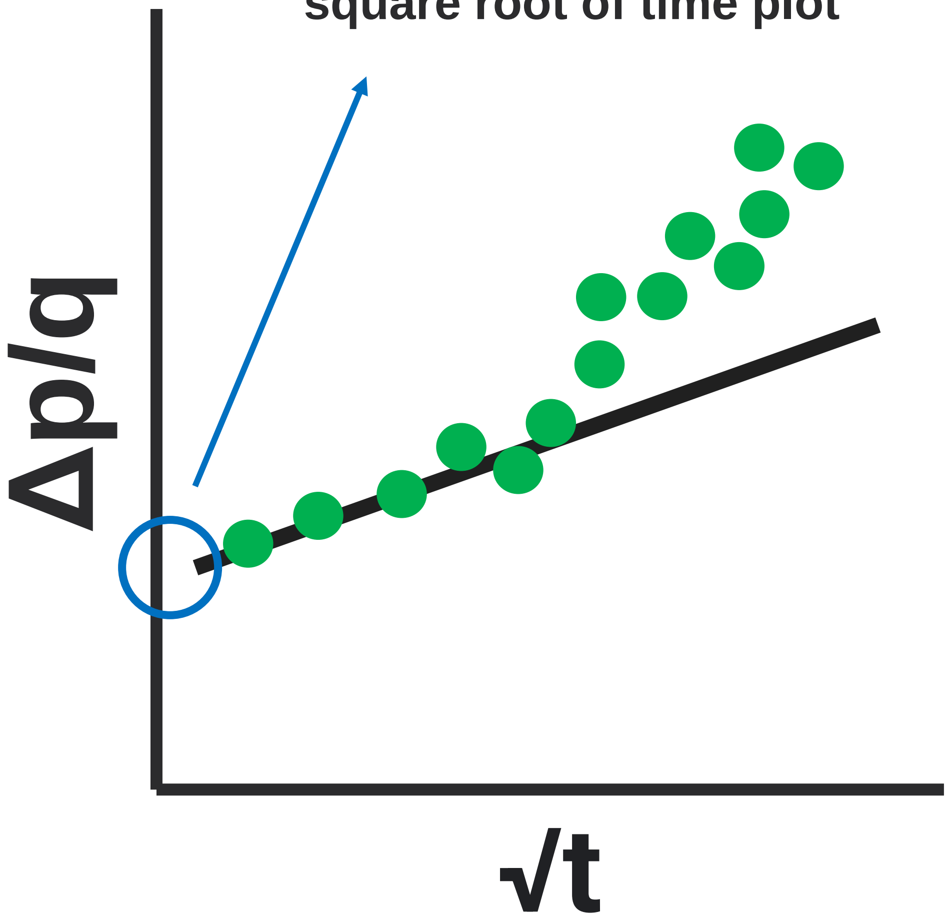
DEMO

AutoRTA

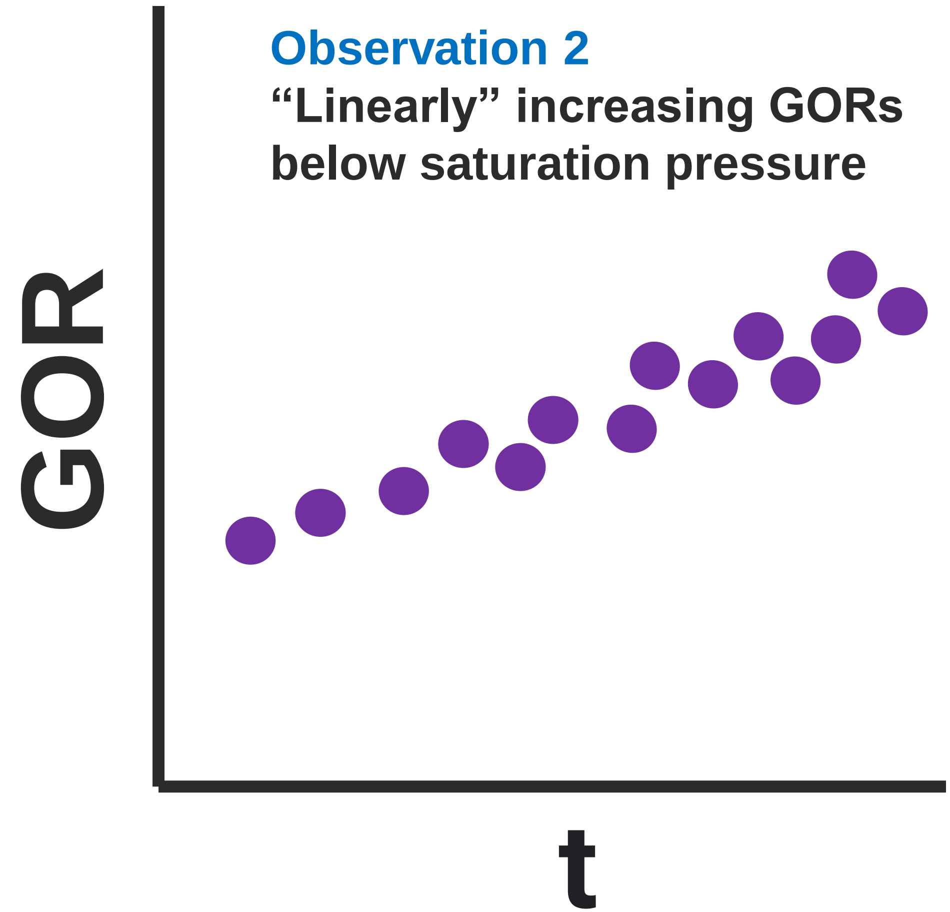
Low F_{cd}

Well Performance Evidence of Low F_{cd}

Observation 1
Positive intercept on square root of time plot

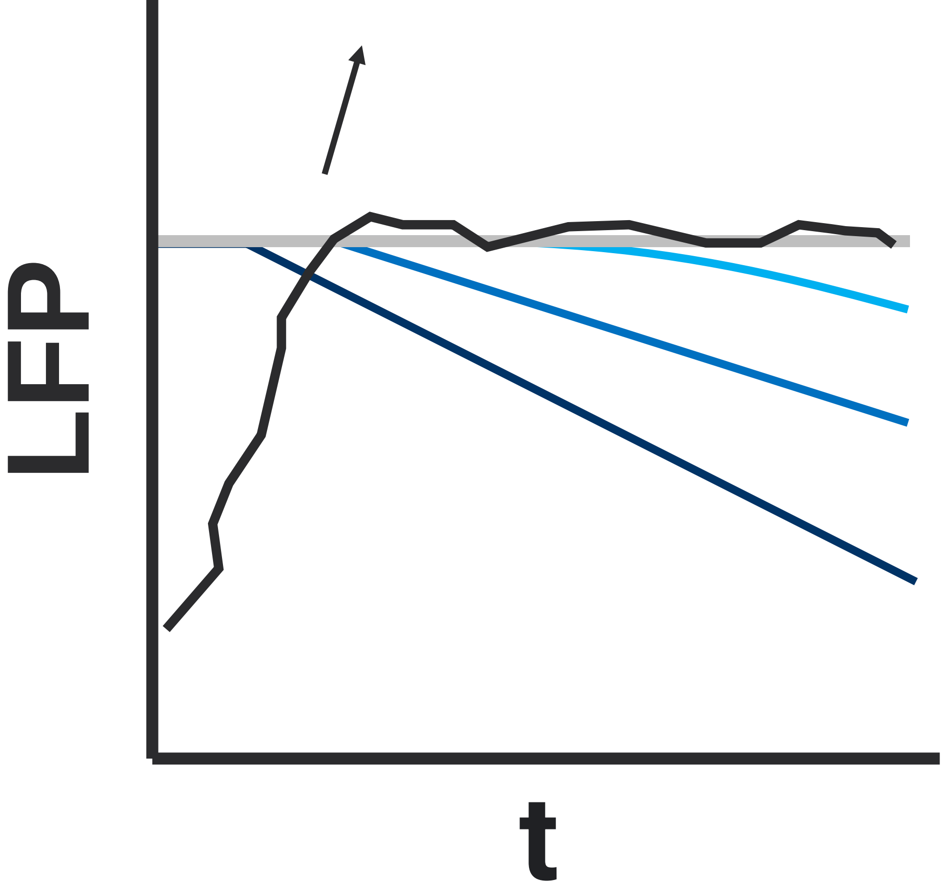


Observation 2
“Linearly” increasing GORs below saturation pressure

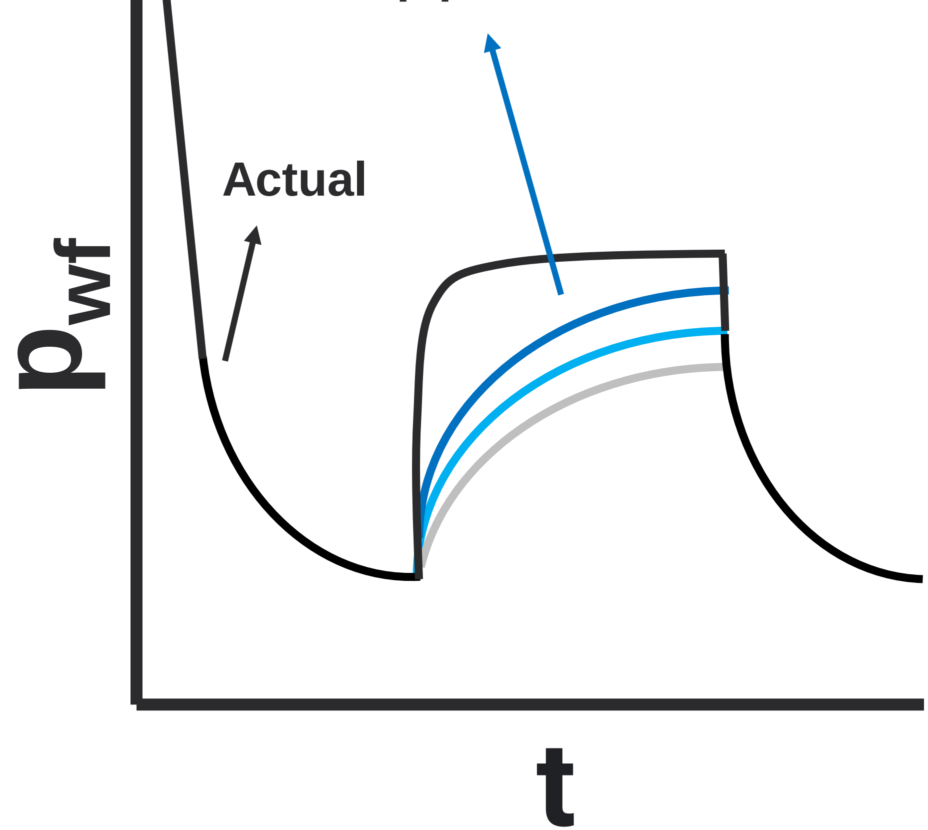


Well Performance Evidence of Low F_{cd}

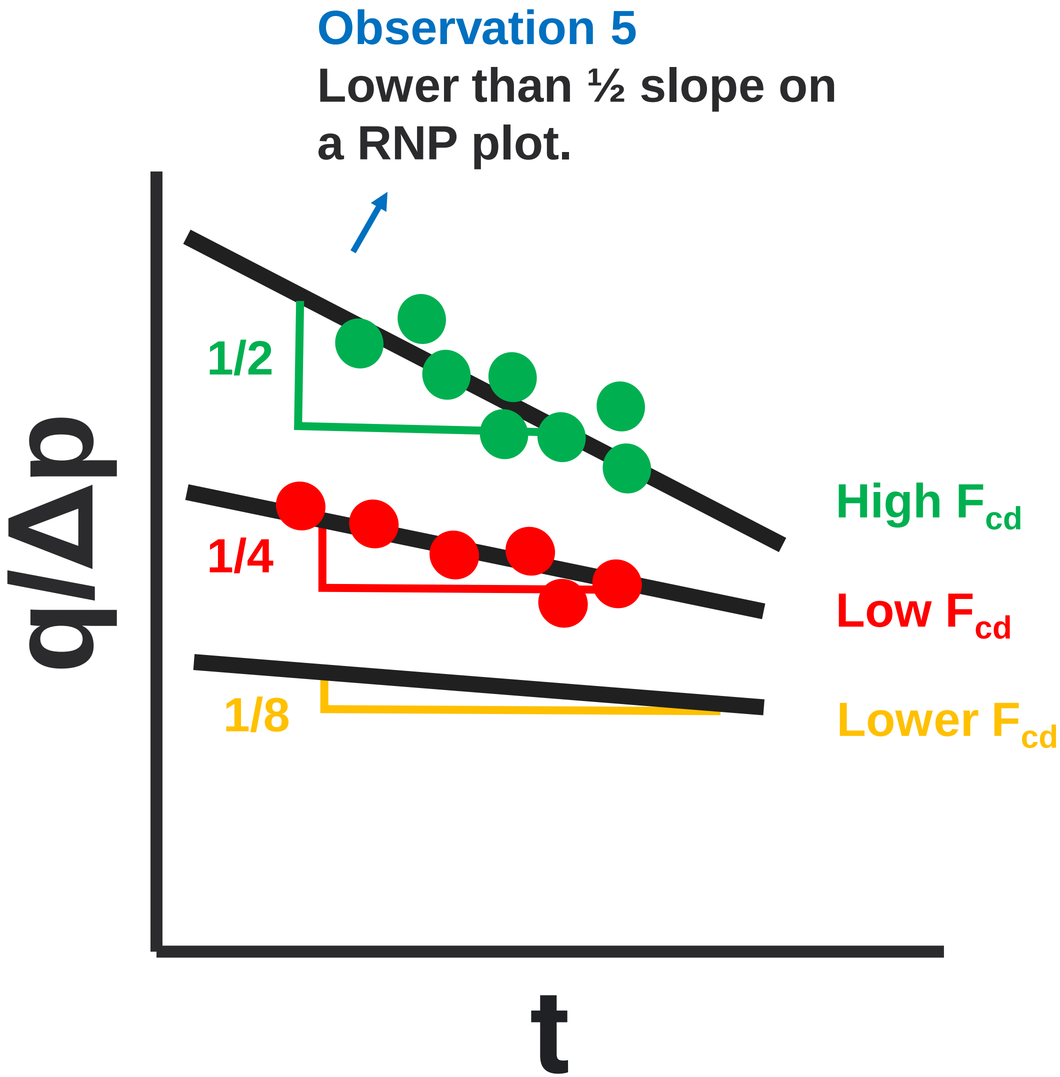
Observation 3
Increasing LFPs in Bowie Diagnostic Plot



Observation 4
Actual build-up pressure higher than modelled build-up pressure



Well Performance Evidence of Low F_{cd}

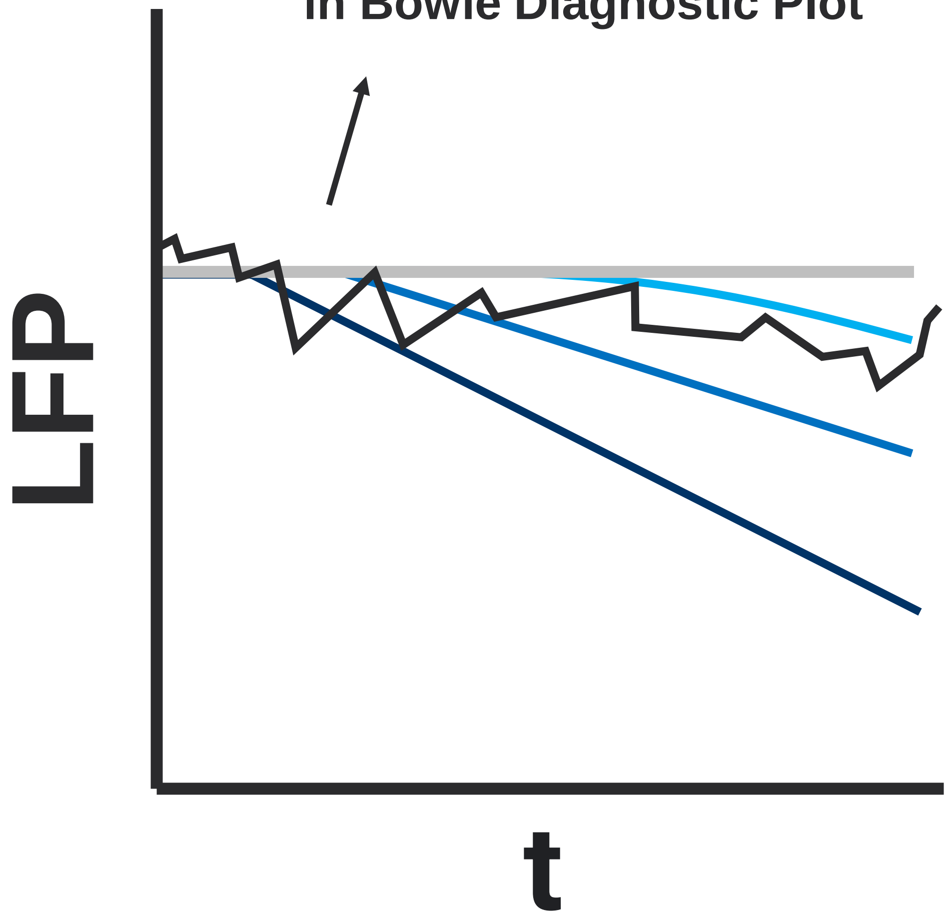


Discussion

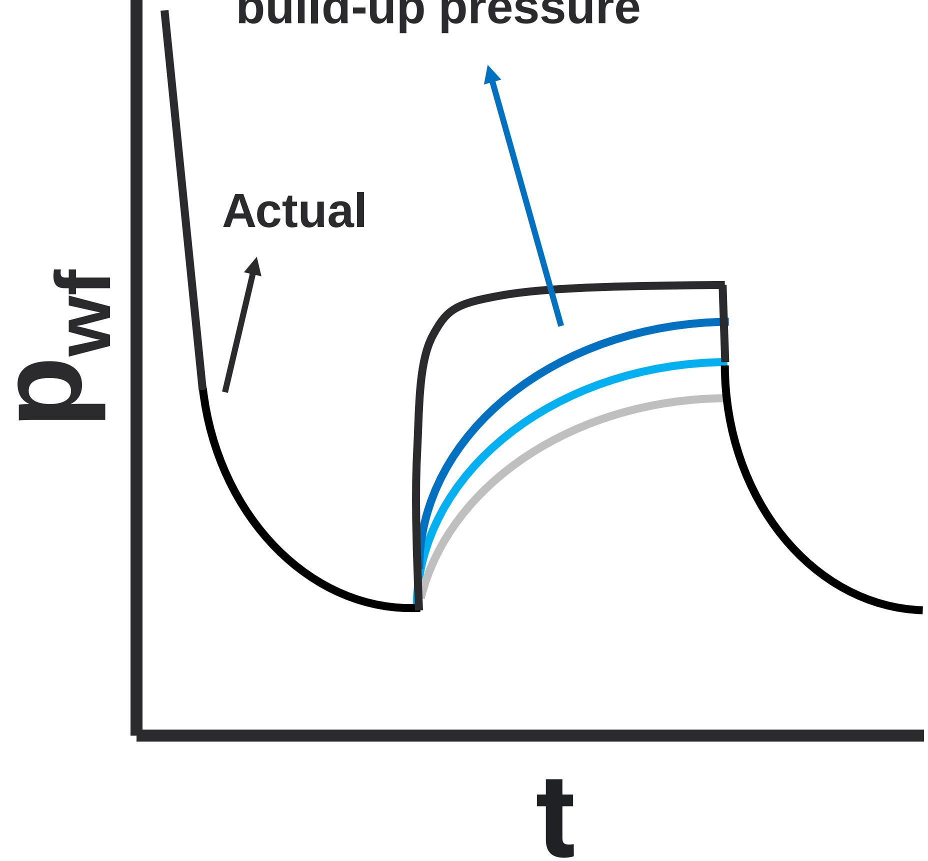
Pressure Dependent Permeability

Well Performance Evidence of Pressure Dep. Perm

Observation 1
LFPs cross through stems in Bowie Diagnostic Plot



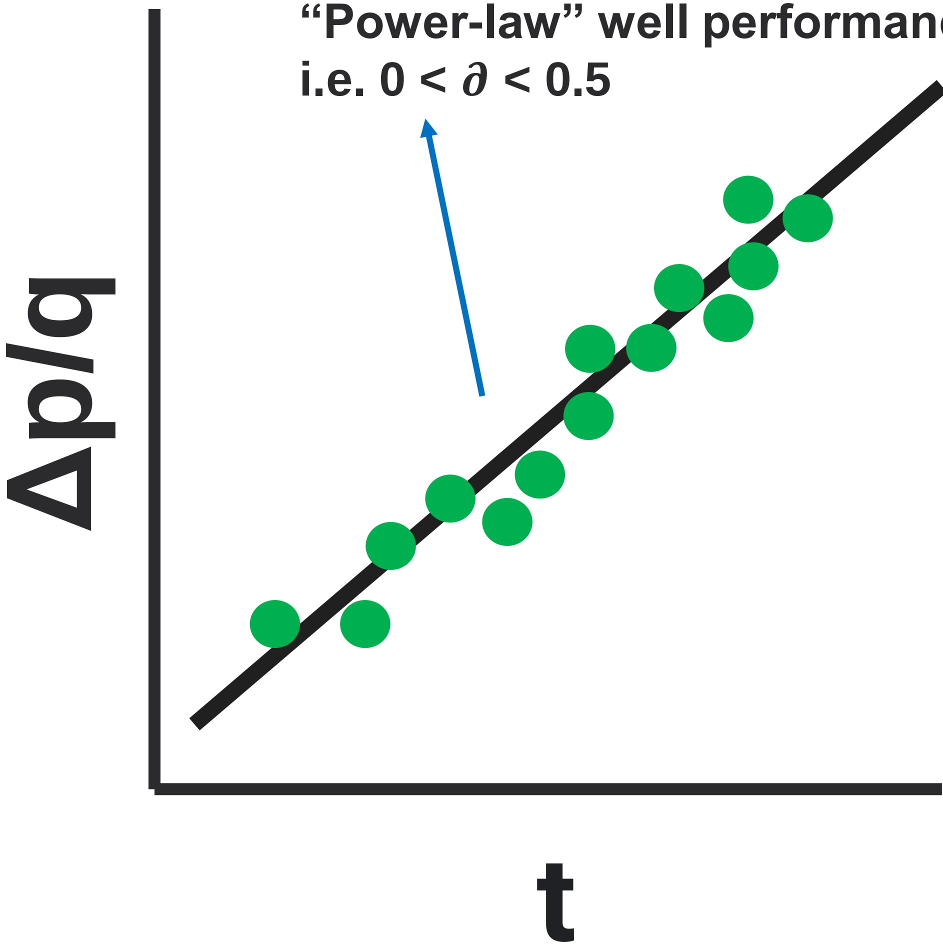
Observation 2
Actual build-up pressure higher than modelled build-up pressure



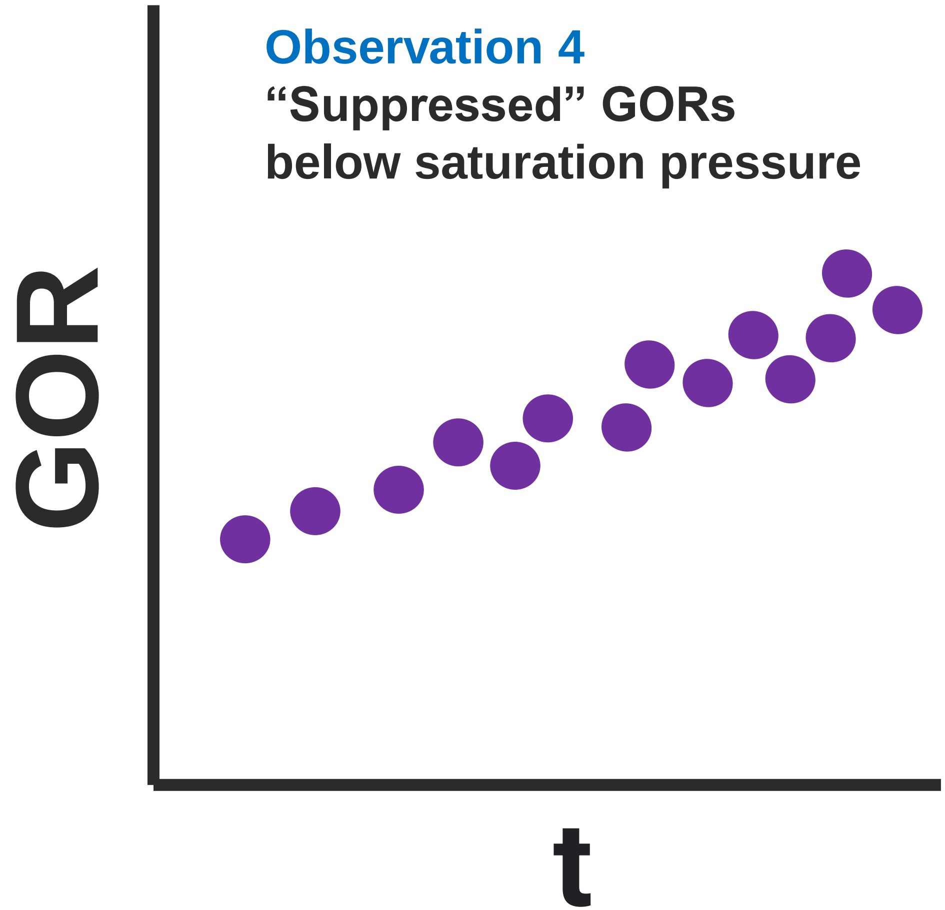
whitson

Well Performance Evidence of Pressure Dep. Perm

Observation 3
"Power-law" well performance
i.e. $0 < \partial < 0.5$



Observation 4
"Suppressed" GORs
below saturation pressure



DEMO

Analytical RTA w/ Total Reservoir Fluids

DEMO

Multi-Layer

DEMO

Derivative Analysis