Reservoir and Production Engineering Surveillance & Management

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Chris Fair

Chris Fair received his BS in Chemical Engineering (1994) and his MS in Petroleum Engineering (1997) from the University of Houston. During his time in school, he worked in various positions in the chemical industry and oil patch. These included roles in process operations, project/design engineering, PVT and fluid mechanics research, sales engineering, process control and instrumentation, downhole nuclear tool testing (both in the laboratory and in the field), and laboratory instruction in process control, technical writing, and chemical engineering practices (basically, how not to get “blow’d-up” in a chemical plant). In 1997, he joined Data Retrieval Corporation (the SPIDR folks). While there he worked on expanding the range and types of wells that could be effectively tested from the surface, and worked on increasing the company’s markets, both in the US and overseas. In 2005, he started Oilfield Data Services, Inc., a reservoir/production engineering consulting firm that specializes in Automated Reservoir and Production Engineering Surveillance. Outside of his “day-job”, he sings with the Houston Symphony Chorus.

Don Nguyen

Don Nguyen currently serves as the senior reservoir engineer at Esperanza Capital Partners, a firm that focuses on the acquisition of high-quality energy and infrastructure assets located in the U.S Gulf of Mexico. Mr. Nguyen is responsible for the reservoir engineering evaluation of exploration, development, and production activities at the firm. Prior to joining ECP, Mr. Nguyen worked at Oilfield Data Services, Inc. as a senior petroleum engineer. There, he conducted reserve analysis, completion evaluations, well surveillance, production optimization, and field development. Mr. Nguyen has experiences in various regions, including the Gulf of Mexico, the U.S. Gulf Coast, Austral-Asia, the North Sea, and U.S unconventional. Mr. Nguyen also co-authored SPE 202385 – The Propagation of Depletion – The Inclusion of Inertia in the Derivation of the Diffusivity Equation. He received a bachelor's degree in petroleum engineering from the University of Houston and is a member of the Society of Petroleum Engineers.

Venera Zhumagulova

Venera Zhumagulova currently serves as a GOM Surveillance Engineer at OXY. Prior to joining OXY, Ms. Zhumagulova worked at Oilfield Data Services, Inc. as a Senior Reservoir and Production Engineer supporting the GOM and North Sea Region. Ms. Zhumagulova also co-authored SPE 202385 – The Propagation of Depletion – The Inclusion of Inertia in the Derivation of the Diffusivity Equation. She received a bachelor's degree in Petroleum Engineering from the University of Houston in 2015 and an Applied Data Science Degree from Dartmouth College in 2021.

Hieu Le

Hieu Le is a petroleum engineer with Oilfield Data Services. Hieu specializes in Reservoir & Production Engineering for both onshore and offshore wells, including deepwater. Areas of expertise include reserve estimation, production and reservoir surveillance, reservoir boundary identification, and well flowbacks. Hieu holds both a BSc and MSc in Petroleum Engineering from the University of Houston and is a member of SPE as well as Tau Beta Pi and Pi Epsilon Tau, both honorary engineering societies.

Pro-active reservoir/petroleum engineering surveillance is the practice of observing and analyzing historic and real-time pressure, rate and temperature data, understanding the performance of a well/reservoir and how/why it may be changing, then managing the well to maximize the NPV and/or reserves recovery. This training will cover the basic skill sets that are required to be an effective surveillance engineer/manager.

The following topics will be covered:

1. What to measure and how to measure pressure, temperature and rates
2. The physics-based engineering equations to use to calculate:
   - Reservoir volumes (In-place, connected and mobile)
   - Skin, permeability, productivity index
   - Pressure-drop in a pipe or elsewhere in the flow system
3. How to work with automation and when to analyze things manually
4. How to hunt for ways to enhance production

While nothing can match the experience of just looking at lots of data, with these tools and philosophies, an attentive engineer can quickly become effective at pro-active surveillance. The focus of this session will be on high-rate conventional wells. We will also present some material on the surveillance of US shale wells.

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Agenda

8:00 am	–	8:05 am	Speaker's Introduction - Patricia
8:05 am	–	9:00 am	Part 1
9:00 am	–	9:15 am	Break
9:15 am	–	10:00 am	Part 2
10:00 am	–	10:15 am	Break
10:15 am	–	11:00 am	Part 2
11:00 am	–	11:15 am	Break
11:15 am	–	11:45 am	Part 3
11:45 am	–	11:55 am	Q&A
11:55 am	–	12:00 pm	Wrap-up - Patricia

Why Do We Need RE/PE Surveillance?

- Historic Oil & Gas ROI for the last 100 years: 6%
- Historic O&G ROI since the shale revolution: 4.9%

<u>How to lose the Most Money in the O&G Business:</u>

1) Set a billion dollar platform on top of $100 MM of oil
2) Over-Develop: Drill a bunch of wells you don't need
3) Wait until a well/reservoir problem is too bad or too expensive to fix
4) Repeat 2 & 3 until you go broke or find a sucker!

Overall Workshop Outline & Schedule

- **Part 1**
  - What Does Good Surveillance Look Like?
  - Intro to RE/PE Surveillance (Good & Bad)
  - What 'Measurements' are Important
  - Recognizing Bad Data & Odd Behavior
  - How to Play the Surveillance Game
  - Real Life Examples of Surveillance

- **Part 2**
  - **Getting Valid Rates and BHPs!**
    - **What can go wrong with Well Tests (Rates) and Meters?**
    - **Virtual Metering**
    - **DPwb**
  - What are the Parts of the System You Can Evaluate?
    - Reservoir
    - Completion
    - Well Bore
    - Flow Lines
  - What Tools do we have? (P.I., Nodal, MBAL, PTA, Decline Analysis – Not DCA!)
    - P.I. is NOT Enough to Diagnose the problem
    - The Equations behind these tools
    - Automated PTA

- **Part 3**
  - Review of Reservoir Volume Calculations
  - What is Your Job as a Surveillance Engineer?
  - What can go Wrong with Your Well? How Can You Tell?
  - Example: Managing a Trainwreck
  - Tracking KPI's & Presenting Results to Management
  - Examples of Automated Surveillance
  - Concluding Remarks

Part 1

Outline Part 1

- What Does Good Surveillance Look Like?
- Intro to RE/PE Surveillance (Good & Bad)
- What ‘Measurements’ are Important: The ‘Big 4’ (and Rates)
- Recognizing Bad Data & Odd Behavior
- How to Play the Surveillance Game
  - Urgency of Action, Well Performance and/or Reserves Recovery
- Real Life Surveillance Examples
  - Deepwater Oil Well (GOM)
  - Offshore Gas Well (North Sea)
  - Shale Well (West TX)

Reservoir & Production Engineering Surveillance

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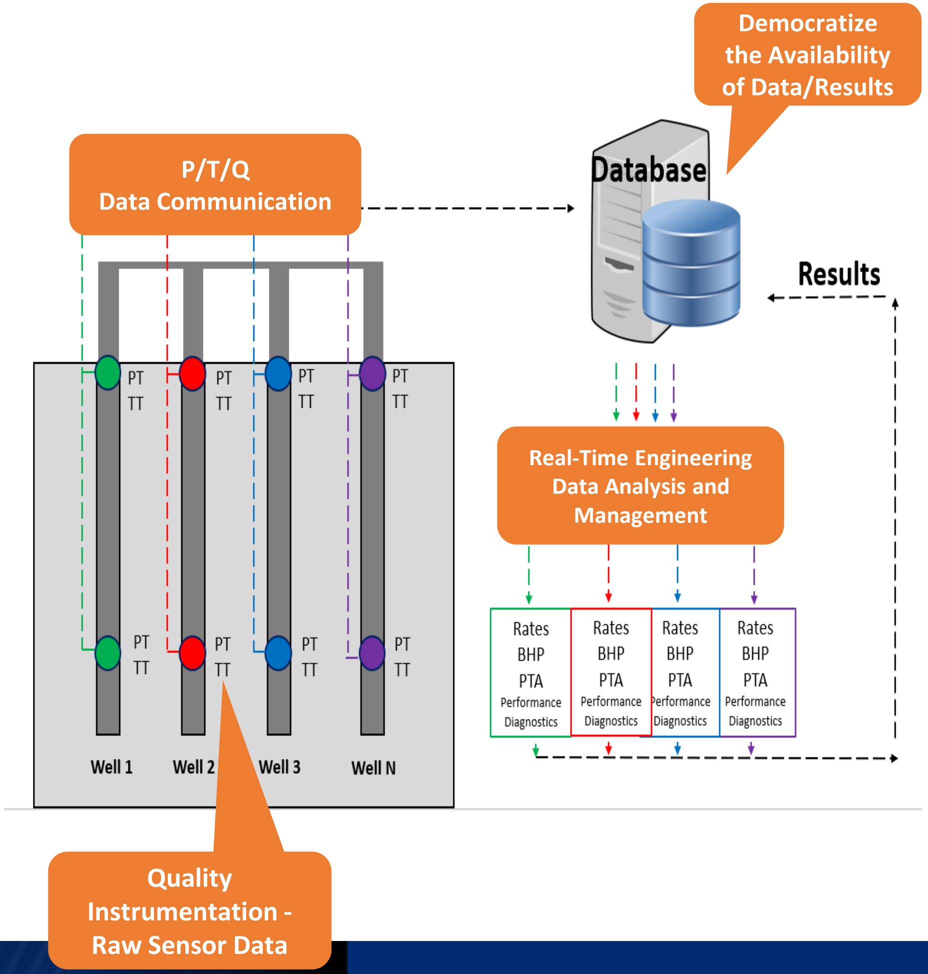
Main Idea

- The Right (Quality) Instrumentation in the Right Place
- A way to get that data somewhere useful, without losing quality
- Easy access for Engineers and Managers
- A way to automate the recognition of important events and present the information to the Engineers/Managers
- Getting past the process and **Silos** to understanding the results (Cultural)
    - Multidisciplinary team meetings optimizes for productive and solutions-based
- Making Decisions in a Non-Biased Way!

Surveillance Data Stream



What is Effective Surveillance?

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Proactive Surveillance

1 Always have a handle on:

- How much oil or gas or water is the well producing?
- How much oil or gas is in the ground?
- How much of it is likely to be recovered?
- What is the current well performance?

2 Is anything changing?

- Are there problems developing in the well bore?
- Are there problems developing in the completion?
- Are there problems developing in the reservoir?

3 If something happens, what is the current NPV of the asset?

- Can anything be done to improve the performance?
- How do we maximize the NPV?

Illustrations

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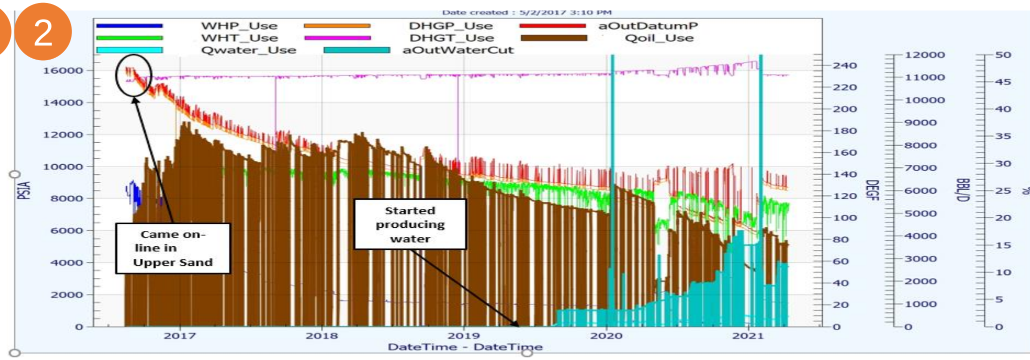

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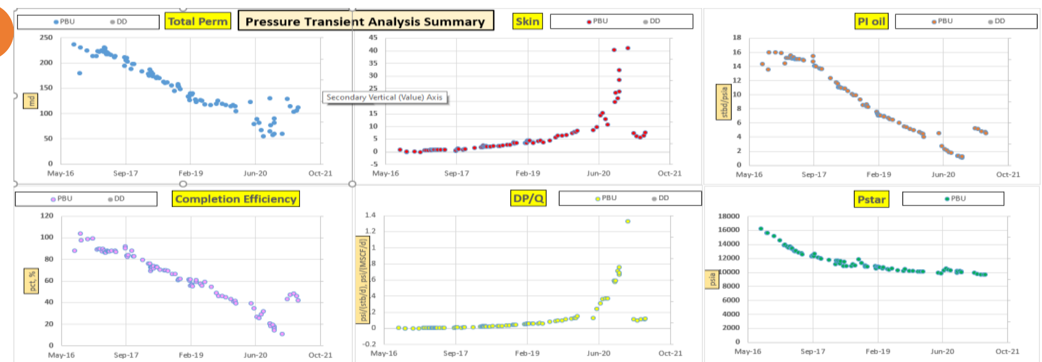

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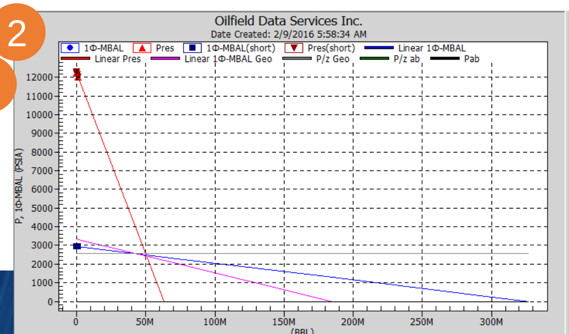

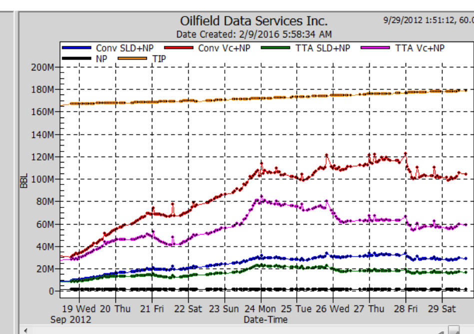

Typical Pitfalls in Surveillance

- Only accept information about the well/reservoir that fits your or the company's beliefs
- Change the "static" or geologic and/or simulation model until you get the answer you want (data is irrelevant)
- Wait until something bad happens:
  - Call it bad luck & move on
  - Say it's too late to fix it & move on
  - Call in a technical expert & move on
  - Use Nodal Analysis or Simulation to muddy the waters

- Be reactive…or just do nothing*

*See: Refusing to Admit You Have a Problem, Blaming Others, Data "Cleaning"; Just Say the Well Watered Out

What is Effective Oilfield Management?

- Maximize NPV
- Maximize Recoverable Reserves/EUR
- Avoid Waste (Time/Money/Resources)
- Mitigate/Minimize Risk (Ops/Reserves/HSE)
- Learn from your Mistakes (and Successes)

- **MAKE BETTER DECISIONS IN A TIMELY FASHION**

Well…We Still Screw It Up!

<u>There are STILL Organizational/Cultural Issues:</u>

- **Give the Boss the Answer He/She Wants!**
- Silos (Unintentional and Intentional)
- Management Directives (See: Deck Chairs/Titanic)
- **<u>Information Hoarding!</u>**
- **<u>NIH Disease</u>**
- Reactive vs. Pro-active
  - Shoot the Messenger!
  - Ass-Covering & Cherry-Picking
- <u>CONFIRMATION BIAS</u>!

Pitfalls in Oilfield Management

- Maximize False Parameters (1st month IP)
- Drill Wells you Don't Need
- Eliminate/Ignore Data That Doesn't Confirm Your Beliefs
- Wait until a Problem is Obvious (and Expensive to Fix)
- Hope No One Notices (Until You've Moved on) – Make sure No One Takes Ownership
- Make the Decision that's Best for <u>You</u>, Not the Company

You’re committed to doing good Surveillance… but you’re drowning in Data?

- Analysts spend 60-80% of their time looking for and manipulating data
- My ROUGH Estimate:
  - 50% time looking for data
  - 50% time stuck in mtgs
  - 50% time preparing reports for non-technical managers

Surveillance: How to Play the Game!

Two Big Ideas to Focus on NPV!

- **Well Performance**: Optimizing well performance and rates while maintaining completion and well integrity
- **Reserves Recovery:** Confidence band in reserves and how it changes over time
  - Maximizing reserves recovery

Initial Surveillance (Evaluation)

- What do I have? (Current well performance conditions and reserves)
- Are there any problems? (Perm, skin, small reserve volumes?)
- If there are currently no problems, am I expecting any near-term and/or long-term problems?

Day-to-Day Surveillance

- What are the current oil/gas/water rates? Are they in line with expectations for this well?
- Is anything changing with the well performance?
- What is changing? Why is it changing?

Long-Term Surveillance

- Is anything changing with reserves? How are they changing? Why are they changing?
- Are there any infill, sidetrack, and development opportunities?
- How historical producers behaved can inform on the type of projects and locations for capturing remaining reserves

Instrumentation and Measurements

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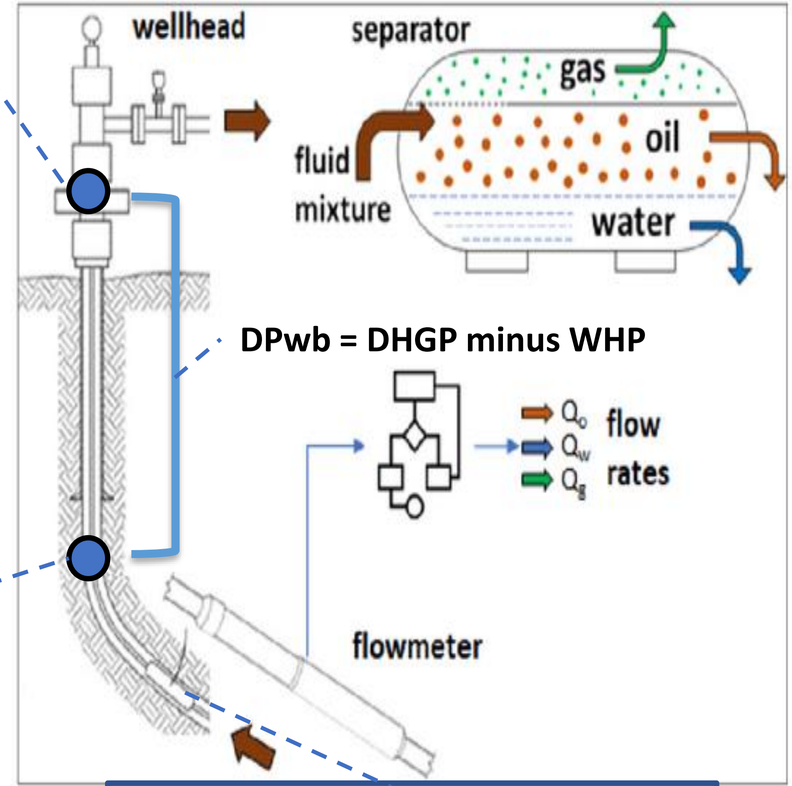
Wellhead Pressure & Temperature

- Gauge should connect directly to the wellhead via a needle valve with proper screening for debris plugging
- Critical for any wellhead gauge to output corresponding temperature reading so that corrections can be made in response to temperature fluctuations



Downhole Pressure & Temperature

- Improvements in cost and quality have made DHGs more prevalent, especially Offshore
- Gauge continuously transmits digitized pressure and temperature data to the surface
- Still room for improvement for consistent gauge life

Other Measurements

- Line P/T, Casing P/T, and Choke settings
- Separator P/T, **"Test Rates"**, Volumes
- Well Status, Valve Status, GLG Rate
- Pump Status Variables
- DTS, DAS

Other Requirements

- Good (or at least adequate) PVT
- E-logs and petrophysical inputs
- Valid Wellbore Schematic
- Deviation Survey
- Geothermal Gradient (at least static BHT)
- Initial Reservoir Pressure
- Completion Reports/Drilling Reports

Multi-phase Flow Meter

- Touted as providing continuous oil, water, and gas measurements
- Requires accurate inputs and calibrations for the measurements to be accurate

D/P or Turbine Flow Meter

- Orifice Meter (Daniels)
- Venturi Meter
- Turbine Meter

Recognizing ‘Bad’ Data & Odd Behavior

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- Dead-banding = Constant value until the data is out of it’s “dead zone”
- Data Gaps = Absence of data between two time periods
- Outliers/Spikes = Abnormal and differs significantly from the observed behavior
- Digit Dropping = Date/Time or Value Truncation due to bad tablature
- Sensor Location and Plugging (SCSSVs) = conditions that will prevent the gauge to capture accurate data
  - Debris plugging the sensors and give false readings
  - Closing the SCSSV, which limits the WHP from capturing pressure for the whole well bore
- Time Offsets = Time difference from the same event in one sensor vs. another sensor (WHP → Rate measurement)
- Pressure and Rate going in the wrong direction
- Rate and Temperature going in the wrong direction
- Noise: Can you get the signal out of the noise?
- Residence Time = Time for fluids to move from one measurement point to another (DHGP → WHP)

Recognizing 'Bad' Data & Odd Behavior

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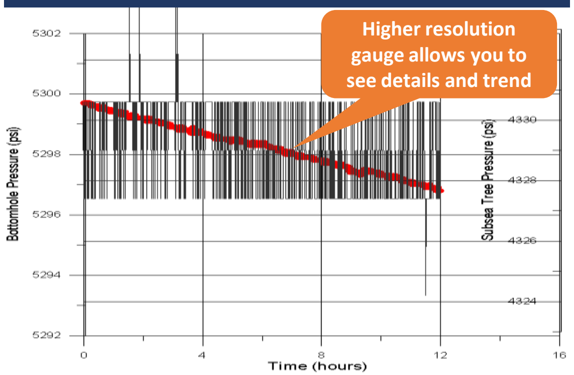
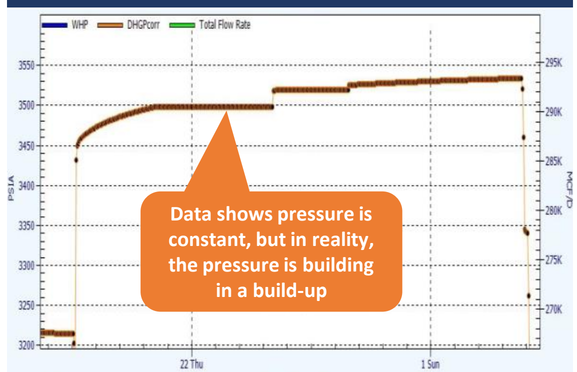
Most Common Data Problems

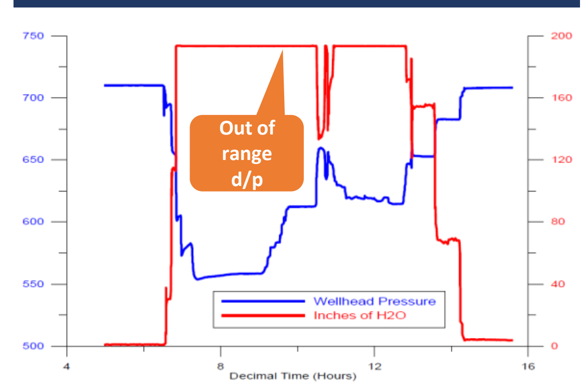
High vs. Low Resolution Gauge



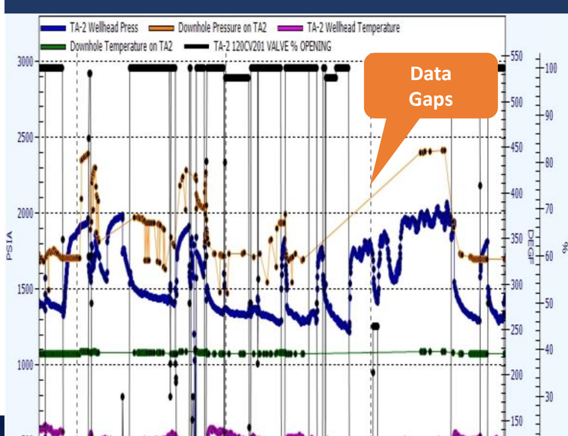
Dead-Banding



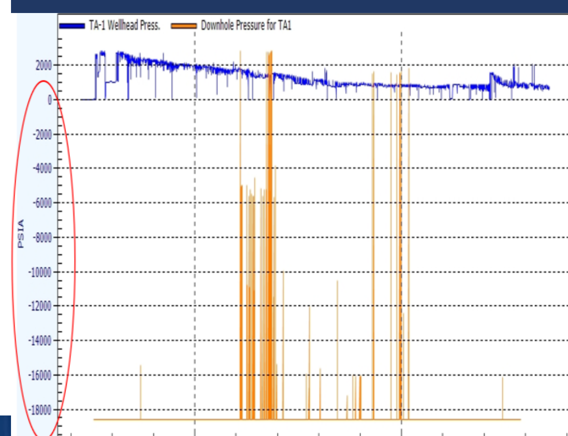
Bad Rates



Data Gaps



Outliers/Spikes

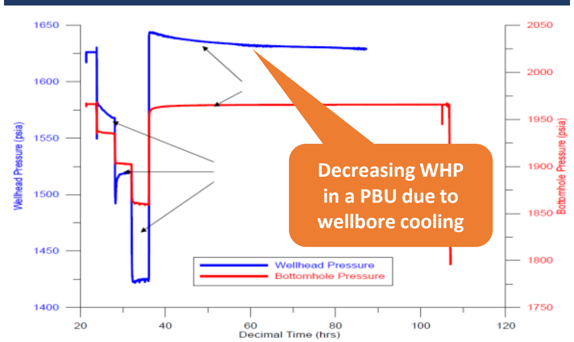


SCSSV-Induced Bad Reading

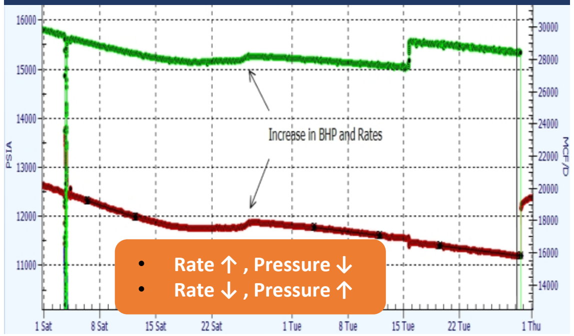
Recognizing 'Bad' Data & Odd Behavior

Most Common Odd Data Behavior

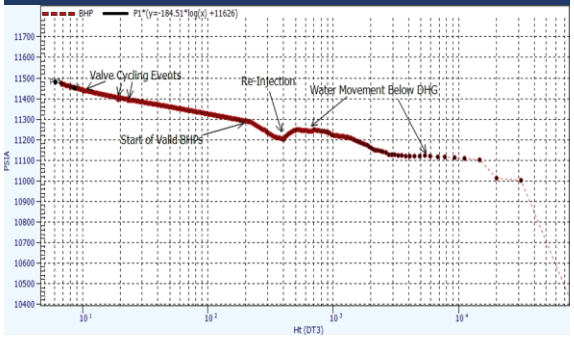
Thermal Transients



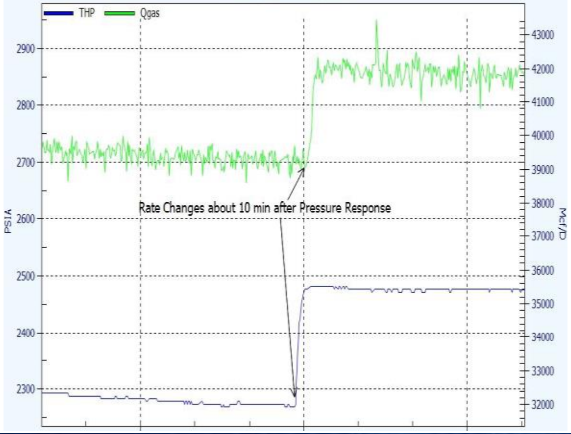
Counter Logic



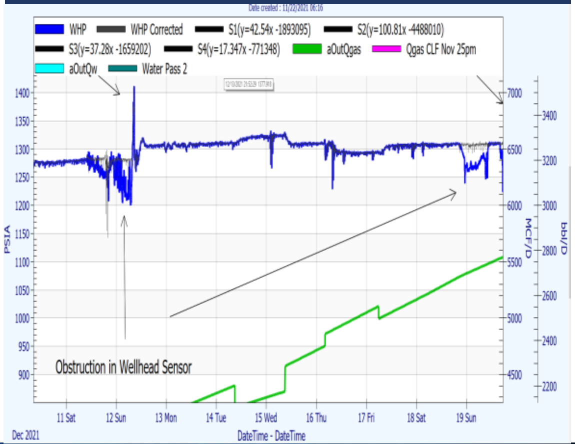
Fluid Movement in the Wellbore



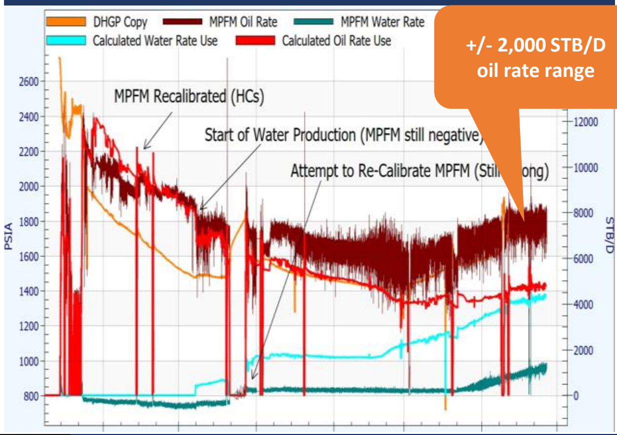
Time Offsets



Sensor Plugging



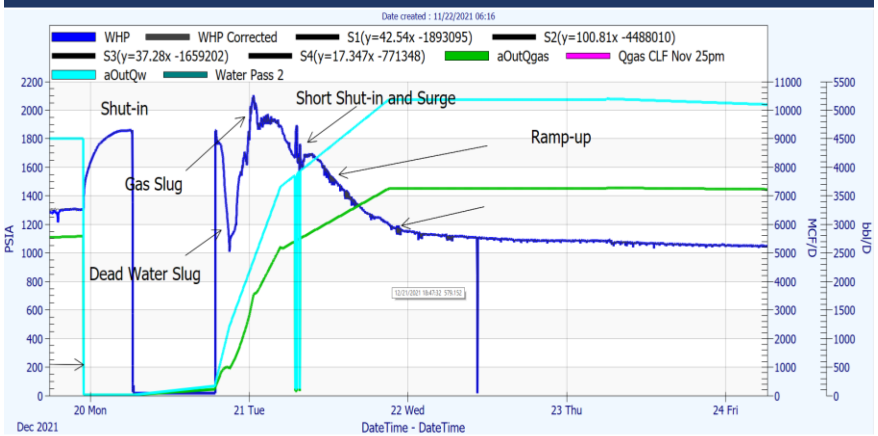
Data Noise



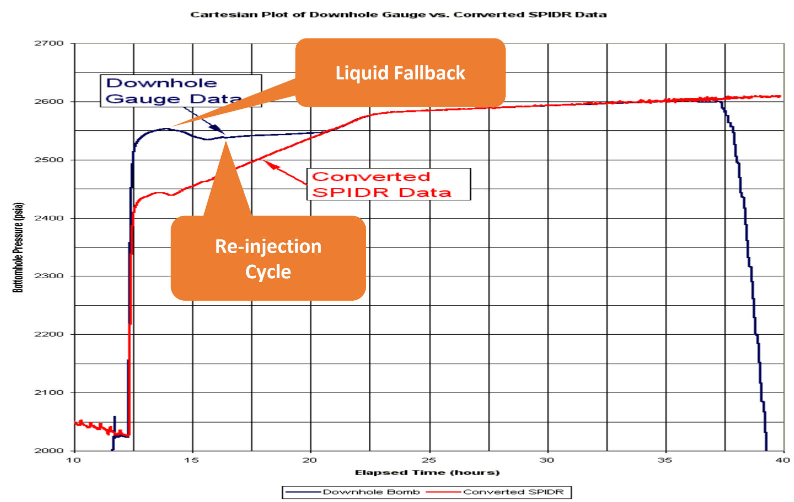
Recognizing ‘Bad’ Data & Odd Behavior

Most Common Odd Data Behavior – Wellbore Surges

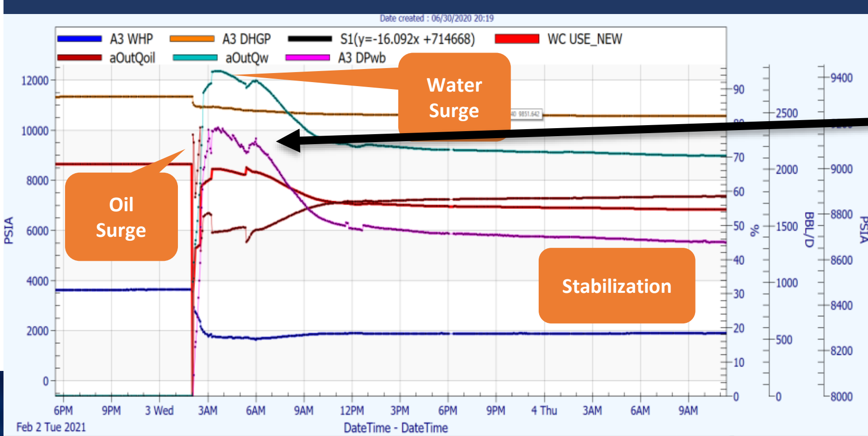
Free Gas, Water Slug, and Gas Slug



Liquid Fallback and Re-injection



Restart Oil Surge, Water Surge, Stabilization



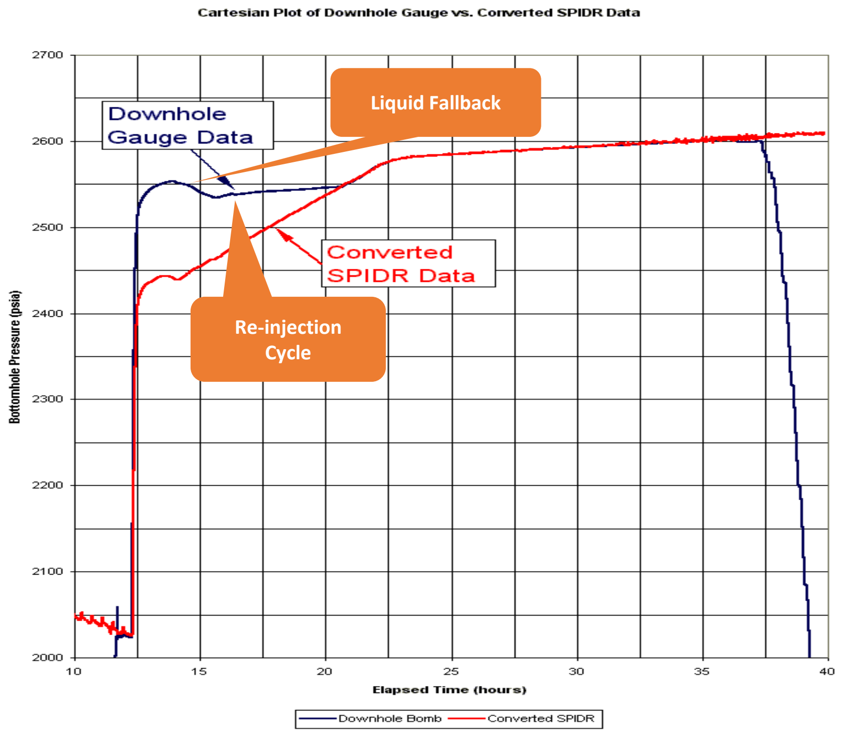
Be Careful! The rates you observe at the meter may not be representative of which fluids are coming out of the reservoir at the sandface!

3-Phase Layer-Cake: Gas-Oil-Water

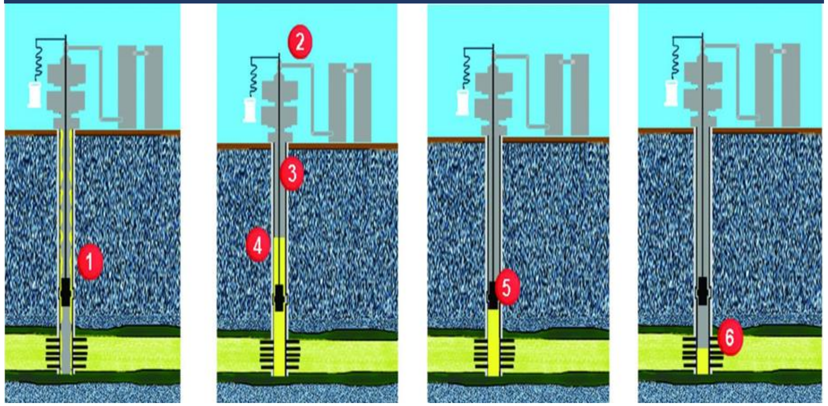
Recognizing ‘Bad’ Data & Odd Behavior

Most Common Odd Data Behavior – Wellbore Surges

Liquid Fallback and Re-injection Pressure Response



Liquid Fallback and Re-injection Process



1. Gas Production Lifts Liquids
2. Well is shut in; rate => 0
3. Liquids that were being lifted by gas fall to the bottom of the well
4. Liquid Column Forms
   - Data collected with a pressure gauge that is above the liquid column will not reflect true reservoir/bottomhole pressure
5. Gas causes liquid to re-inject back into the formation if gas is in the continuous phase
6. Liquid level drops to perforations
   - When the well bore contains single-phase gas from the surface to the perforations
   - Then, pressure acquired from the surface will become valid

Surveillance Case Study 1 – GOM Deepwater Oil Well

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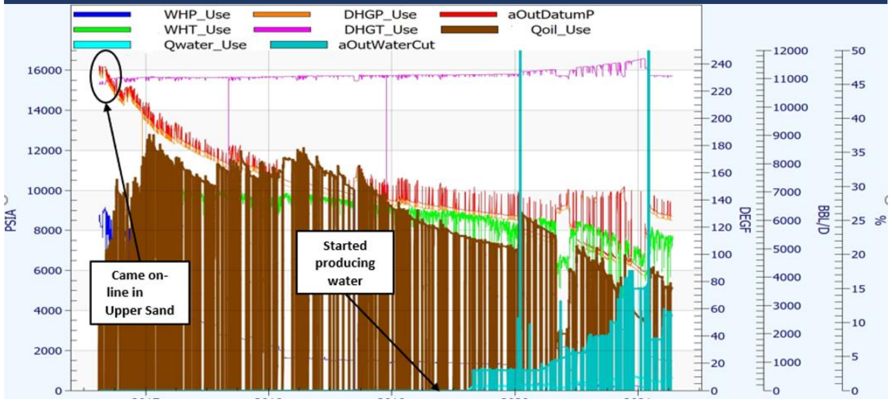
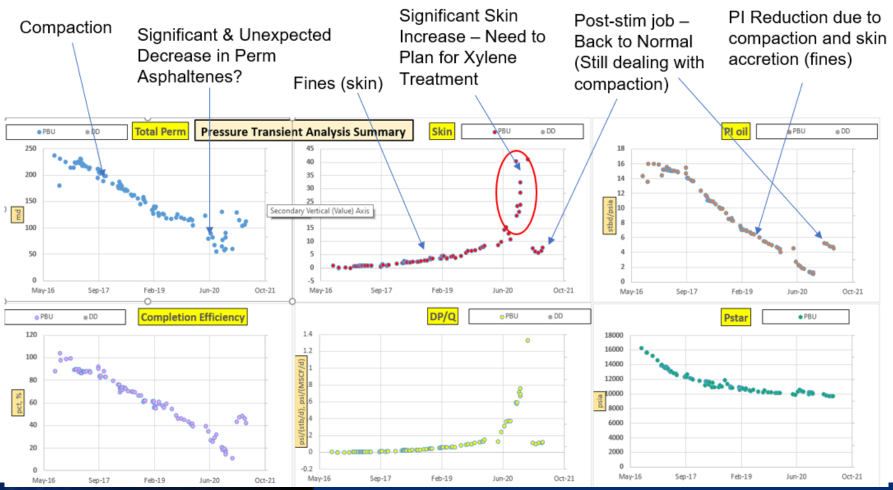
Case Study Description

- **Situation Overview:** Mid-sized GoM Operator with a lean engineering staff needed reservoir and production support for their multi-year drilling and development program for their "crown jewel" asset
- **Instrumentation and Data Acquisition:** WHP/T and DHGP/T data available with a test separator on the platform
  - Spent time working with IT to ensure data quality from the instruments and to establish proper data storing and writing procedures
- **Surveillance Program Thesis:** To monitor and evaluate day to day the reservoir, completion, and wellbore performance, and propose projects to maximize the assets NPV
  - Rate Determination (Spot & Allocation) and BHP calculation
  - Well Performance Evaluation (skin, perm. P.I, etc.)
  - Reservoir Volume Determination
  - Wellbore Lift Efficiency
- **<u>Results</u>: Recognized a sudden decrease in permeability and increase in skin due to asphaltenes and proposed a xylene treatment to restore the well's performance**

Well Production History



Time-Lapse Auto PTA Dashboard



SLB-Private

Surveillance Case Study 2 – Gas Condensate NCS

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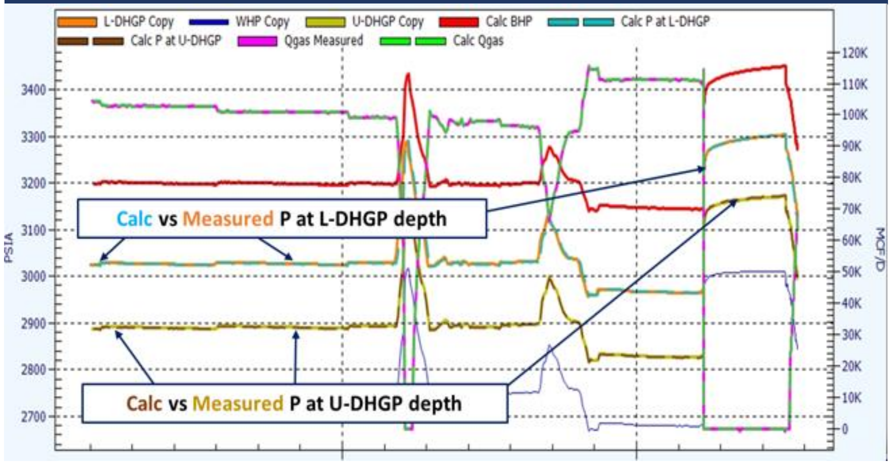
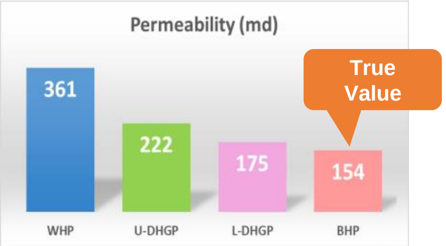
Case Study Description

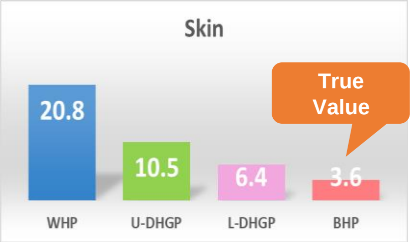
- **Situation Overview:** Major North Sea Operator had all their pressure downhole gauges fail and wanted to determine if this well was a **stimulation candidate using WHP data**
- **Instrumentation and Data Acquisition:** WHP/T and historic 2 DHGP/T data available with a gas meter
- **Surveillance Program Thesis:** To set up a method that would be able to monitor a well's performance accurately without downhole gauges
  - Rate Determination (Spot & Allocation) and BHP calculation
  - Well Performance Evaluation (skin, perm. P.I, etc.)
- <u>**Results:**</u> Failure to perform PTA on the mid-perf BHP leads to overestimation of permeability and skin, and underestimation of P*/Preservoir
  - The well was not a stimulation candidate and an acid treatment would not improve the well's performance

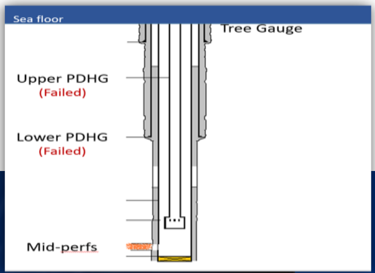
Well Production History

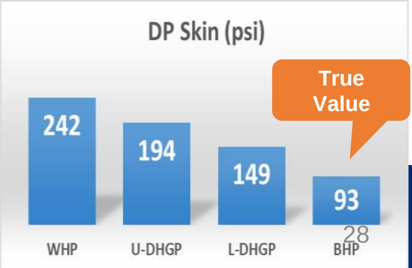


Well Performance Analysis Results









Surveillance Case Study 3 – Shale (West TX)

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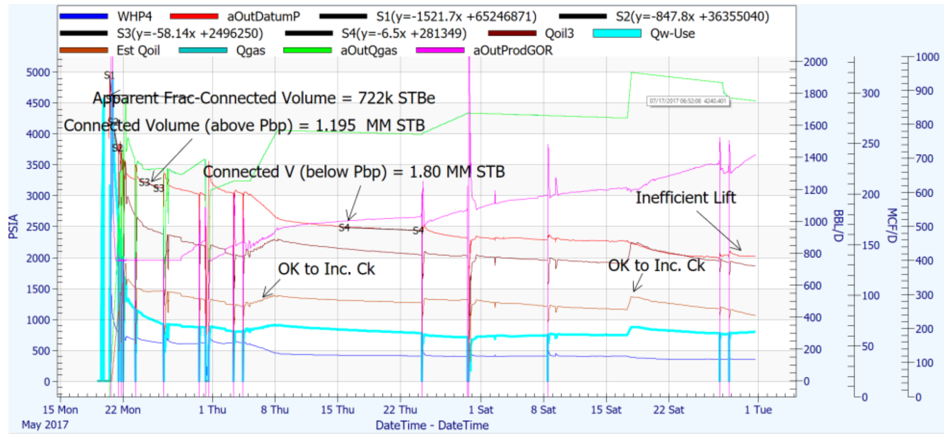
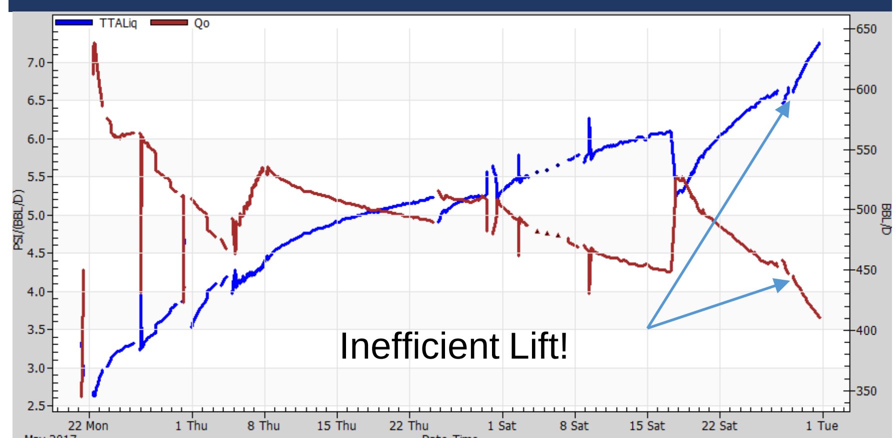
Case Study Description

- **Situation Overview:** Shale well; Independent Operator
- **Instrumentation and Data Acquisition:** WHP/T and Occasional Well Tests (Modeled Rates)
- **Surveillance Program Thesis:** Monitor Frac Performance, especially compaction of the FDV (frac-dominated volume)
  - Develop Optimum Flowback Procedure (on-the-fly)
  - Develop Optimum Restart Procedure after production upsets
  - Recognize when to open choke to maintain free flow
  - Recognize when to run Tubing/Gas Lift
- **Results:** Balanced Value Destruction with desire to maximize oil rate (didn't rip the completion out of the ground for a high 1st month's IP)
  - Opened Choke as needed to maintain lift
  - Recognized Time to Run Tubing/Gas Lift

Well Production History



Well Performance Analysis Results



Break

Part 2

Outline Part 2

- **Getting Valid Rates and BHPs!**
  - **What can go wrong with Well Tests (Rates) and Meters?**
  - **Virtual Metering**
  - **DPwb**
- What are the Parts of the System You Can Evaluate?
  - Reservoir
  - Completion
  - Well Bore
  - Flow Lines
- What Tools do we have? (P.I., Nodal, MBAL, PTA, Decline Analysis – Not DCA!)
  - P.I. is NOT Enough to Diagnose the problem
  - The Equations behind these tools
  - Automated PTA

Most Critical Data for Surveillance: Rates & BHPs

Oil/Gas/Water Rates

- Flow Meters
- Well Tests
- Allocations
- Virtual Metering
  - DPwb
  - DP across choke (very dodgy)
  - Temperature based
  - Choke Setting
  - Glorified Curve Fitting

Valid Bottomhole Pressures

- How do you get valid BHPs?
  - Correlations
  - Mechanistic Models
  - Empirical Models
  - Gradient Models
  - P.I. back-calculation from Allocations

Where did your rate come from?

Note: All Rate 'Measurements' are subject to Error!

- Know how your 'measurements' work; know how they break

Is the error in the flow rate consistent?

- The implications could affect surveillance analyses (skin, perm, P.I., etc.)

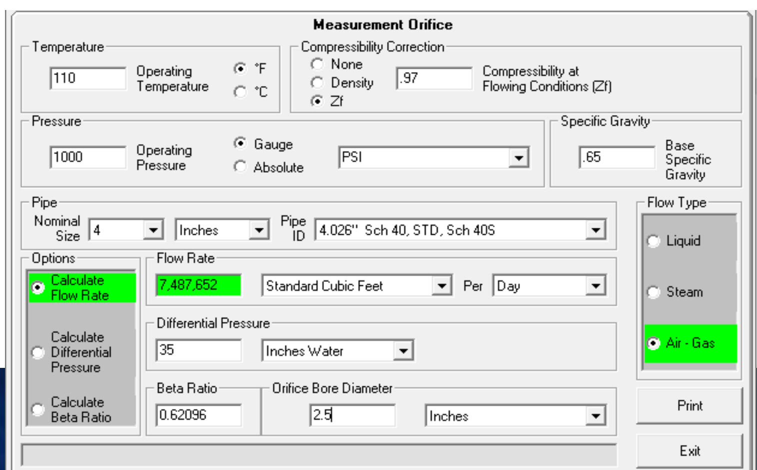
What Can Go wrong w/ Rate Measurements?

Where did your rate come from?

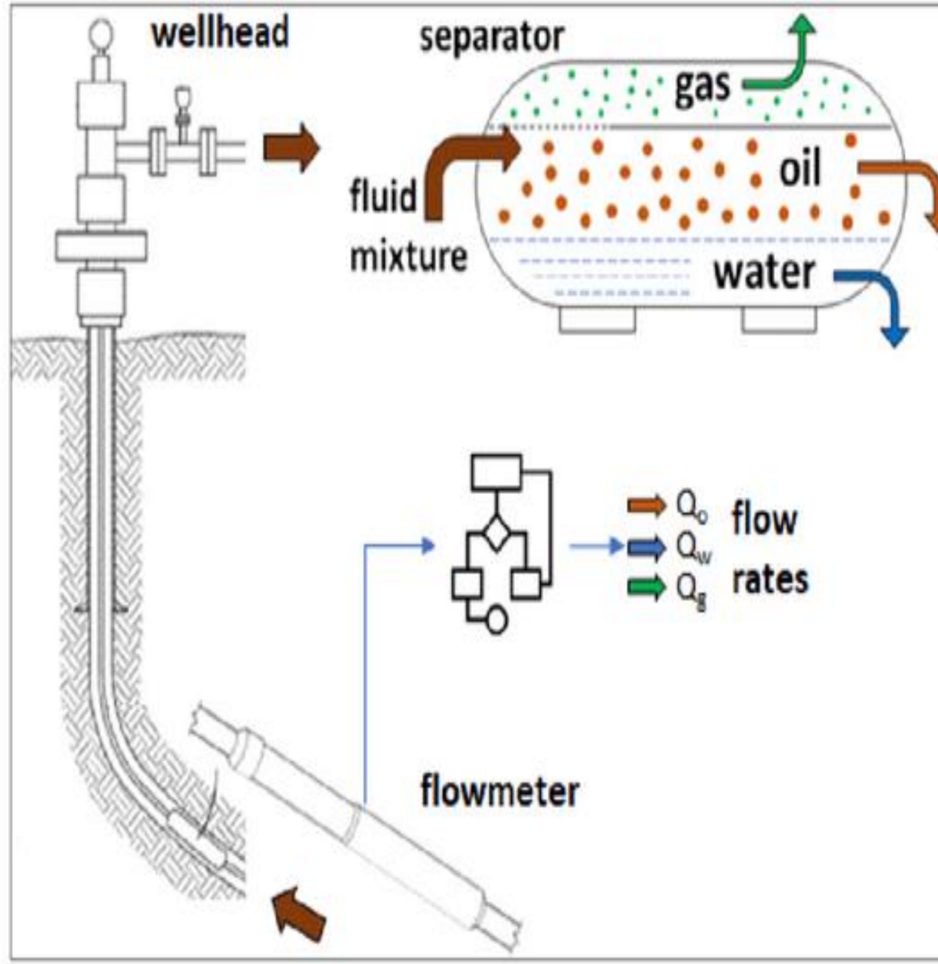
- Dedicated Separator (corrected to STB/s.c.?)
- Meter (right meter for the phases?)
- Virtual Meter
  - DPwb
  - Temperatures
  - Choke Setting
  - Glorified Curve Fitting
- Production Universe-Like System (P.I.)
- Back-Allocation
- SWAG?

Example – How is Rate “Measured”

Dry Gas Daniels Meter Screen – 7 Inputs



Rate measurements along the way



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What Can Go Wrong w/ Rate Measurements?

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Test Separator

- Plugged Sensing Lines
- Wrong Orifice Size (Input for calcs; Outside of Sweet Spot)
- Wrong Turbine Meter Counts
- Dump Valve Blocked
- Previous Well's Fluids still in separator/lines
- Wrong Time Interval
- Wrong Well in Test
- Wrong Shrink Factor
- Boiler plating
- Fat Fingering/Numbers Backward/Human Error in Inputs
- Inefficient Separation (Emulsion, Flooding, Sand in Sep)

D/P Meters

- Scale/Fouling (diameter decrease/friction increase)
- Wrong Orifice Diameter
- Wrong/Changing PVT
- Plugged Lines
- Wrong Inputs for Calculations

Multi-phase Flow Meters

- **Actual Multi-phase Flow (especially free gas)**
- Incorrect/Changing PVT
- Solids
- Scale/Deposition
- Improper Calibration/Re-calibration
- Fixed GOR-based Calculations
- Wrong Conversion to STB/s.c.

Virtual Metering

- What is it really doing?
  - Is PVT included? (Pressure, Temperature?)
  - Just an Analog?
  - Just a Type Curve?
  - Just a Choke Position?
  - Just an Input?
  - Just based on P.I. and your last well test?
  - Just the number your boss wants to see?
- VM Technology has really progressed! Sometimes, it's better than metered rates!

Parts of the System You can Evaluate?

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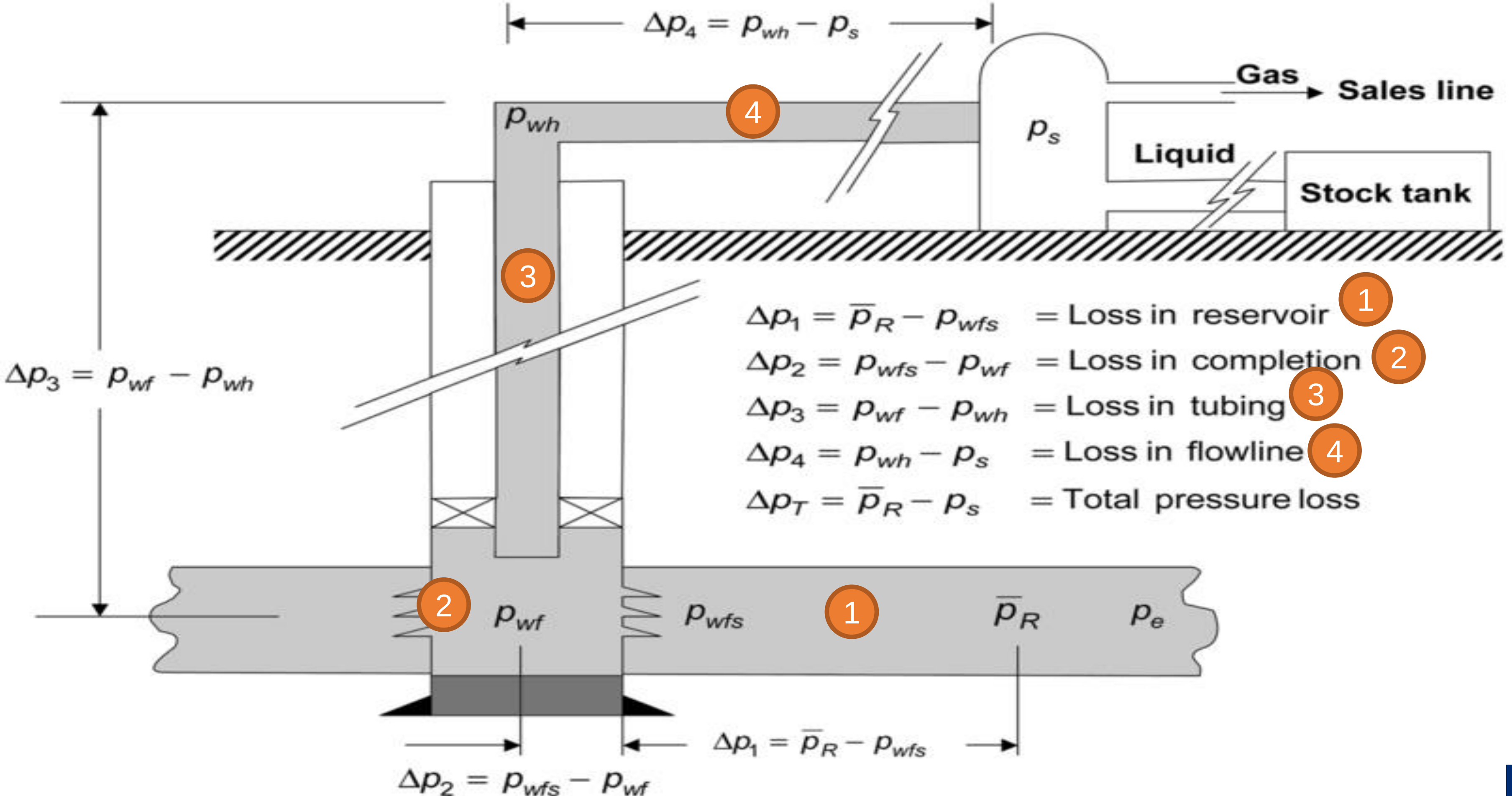
Find the pressure drop that shouldn't be there (and get rid of it)!



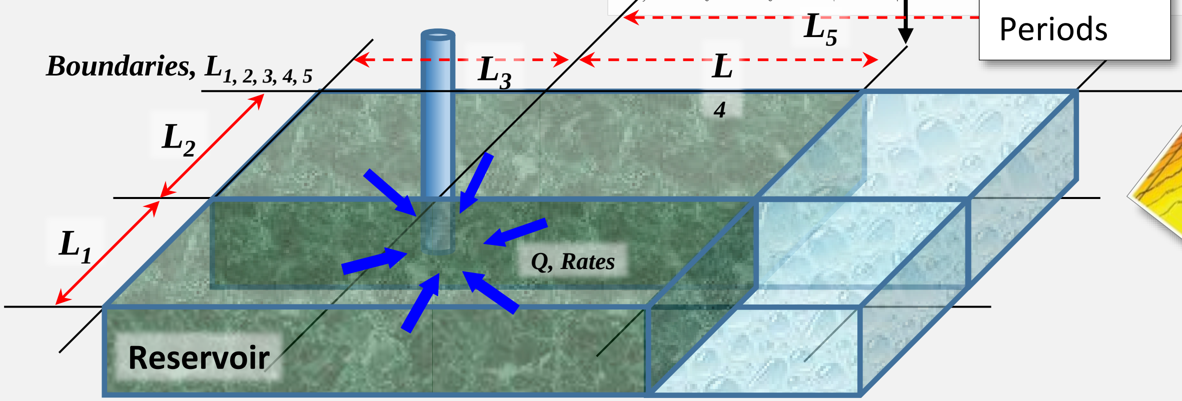
Parts of the System You can Evaluate? 1

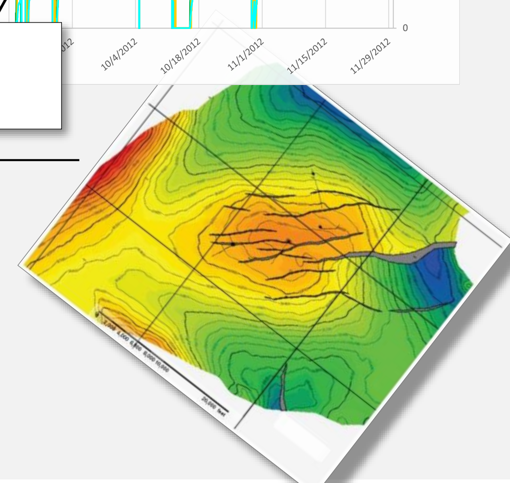
The Reservoir

Determine

- Changes in Drive Mechanisms
- Changes in Permeability
- Changes in Skin Damage
- Changes in Productivity Index
- Changes in Boundary Distances
- Changes in Fluid Contacts
- Changes in Reservoir Pressure
- Changes in PVT

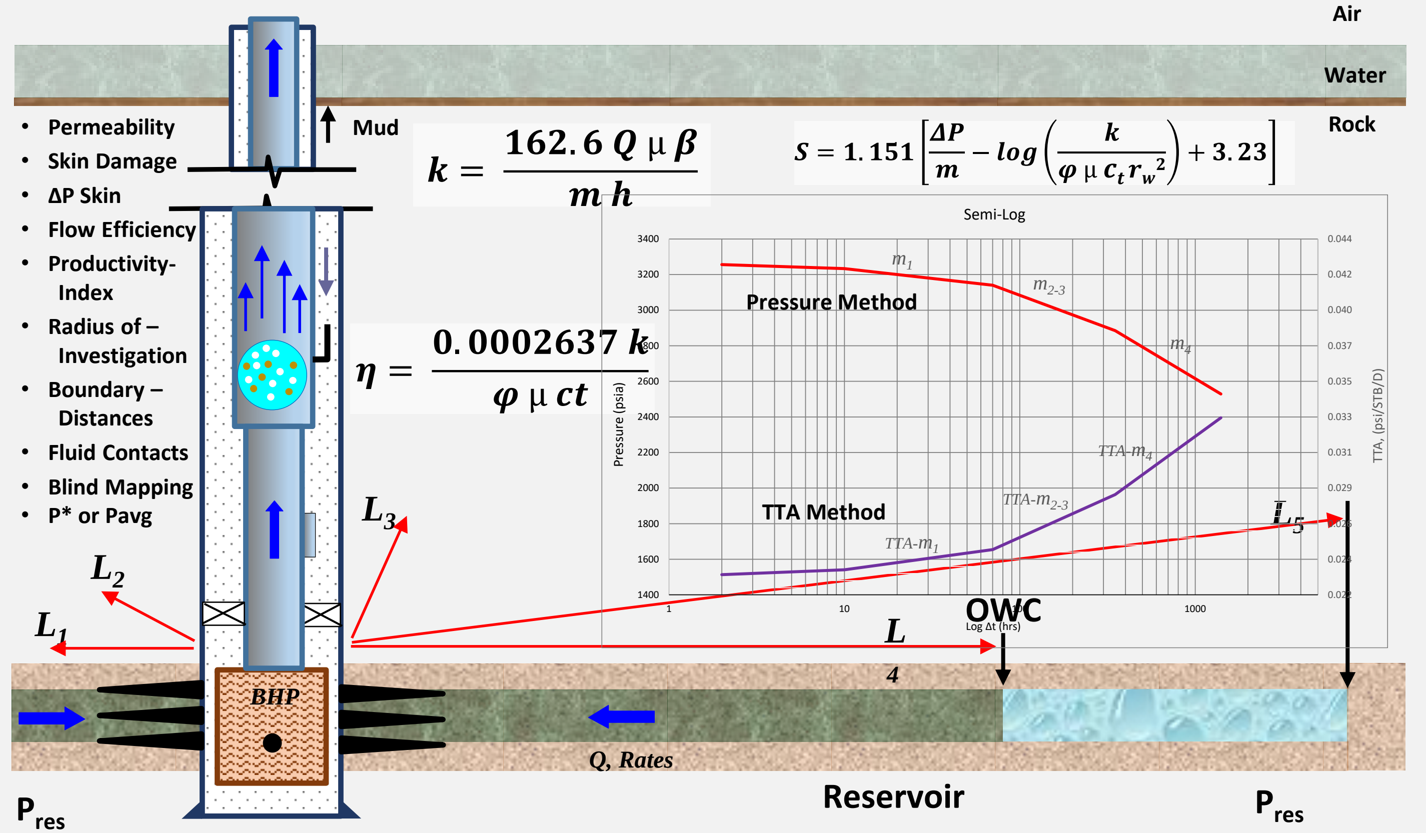
Automatic & Manual Analysis





Parts of the System You can Evaluate? 1 2

Pressure Transient Analysis (TTA Transient)



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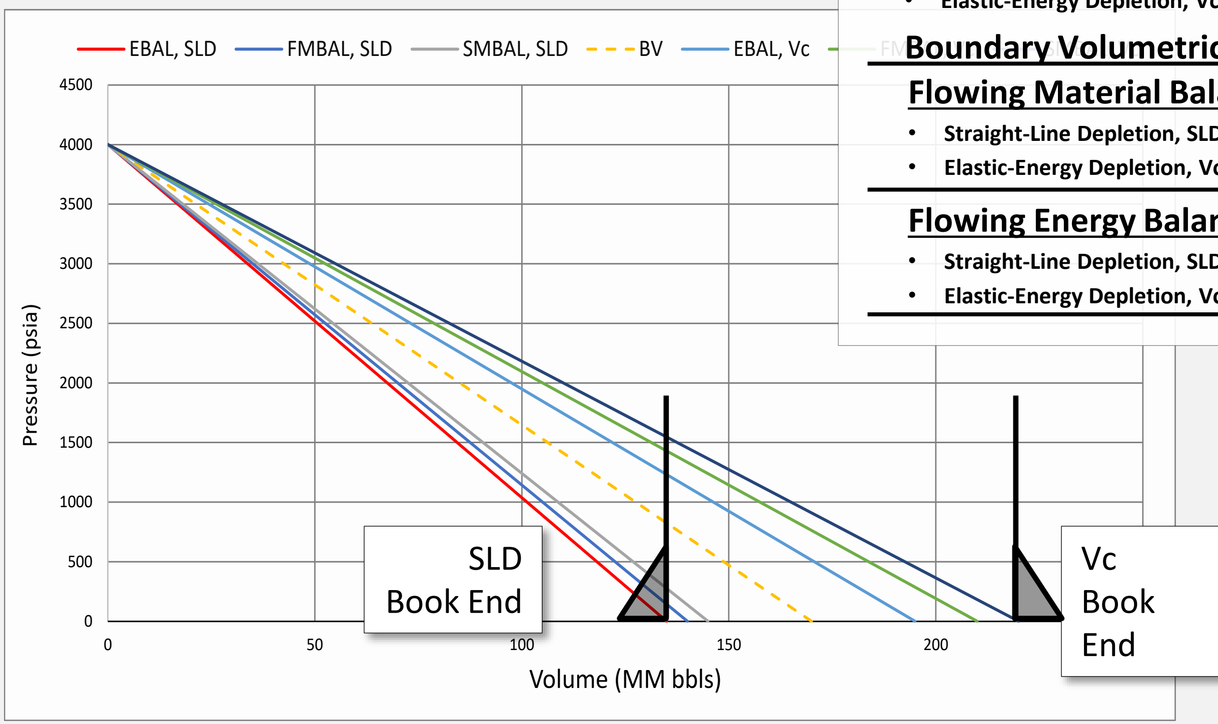
Parts of the System You can Evaluate? 1

Range of Reservoir Solutions – Volumes, NPV!

Calculated Reservoir Volumes



Static Material Balance

- **Straight-Line Depletion, SLD**
- **Elastic-Energy Depletion, Vc**

Boundary Volumetrics [In-Place Volumes]

Flowing Material Balance

- **Straight-Line Depletion, SLD**
- **Elastic-Energy Depletion, Vc**

[Connected Volumes]

Flowing Energy Balance, TTA

- **Straight-Line Depletion, SLD**
- **Elastic-Energy Depletion, Vc**

[Mobile Volumes]

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Parts of the System You can Evaluate?

1 2

Simple P.I. is NOT Enough!!!

Changing P.I. tells you that the performance of the well is changing, but it doesn't tell you WHY it's changing!

$$\text{P.I.} = J = \frac{DP\ term}{Q} \qquad Q = \frac{kh\ (DP\ term)}{141.2\ \mu B[\ln\left(\frac{re}{rw}\right) + S_T - 0.75]}$$

DP Term is some form of: $P^n_{reservoir} - P^n_{wf}$

Parts of the System You can Evaluate? 1 2

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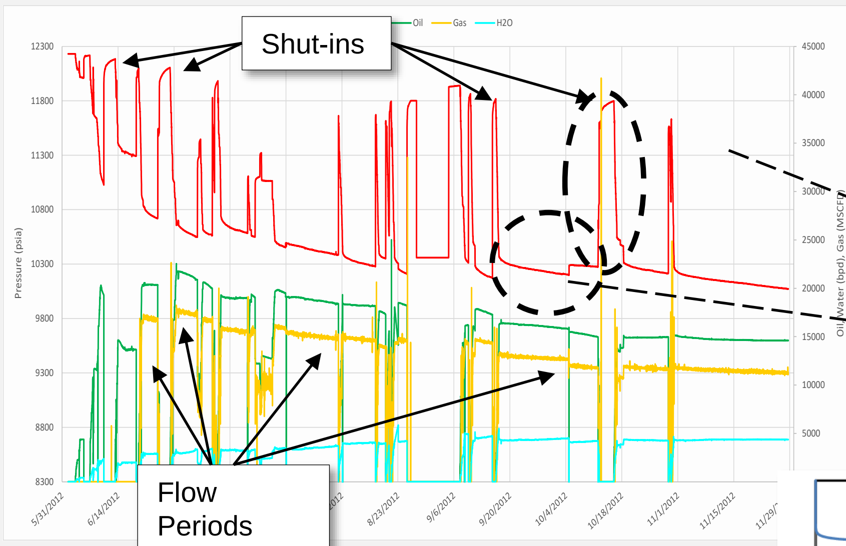
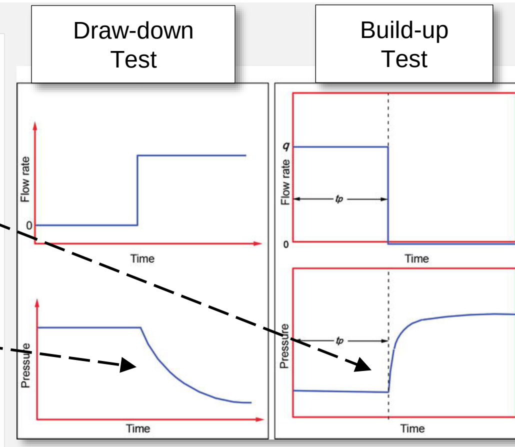
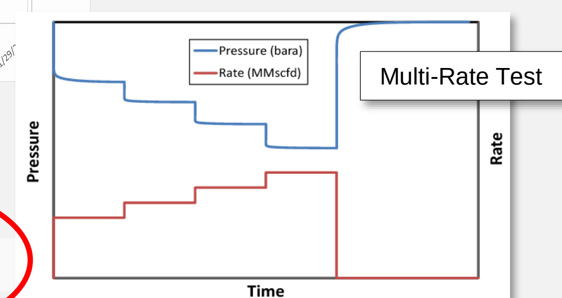
How to break PI into its constituent components







Determine

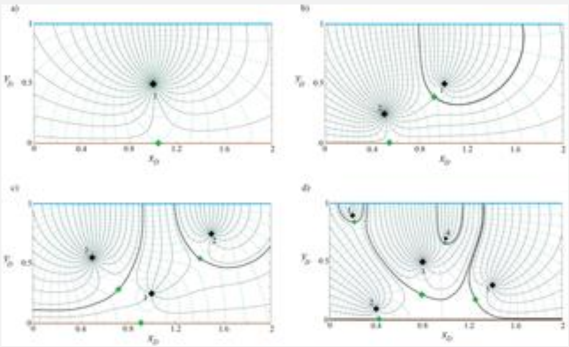
- Changes in Permeability
- Changes in Skin Damage
- Changes in Productivity Index
- Changes in Reservoir Pressure
- Changes in PVT

$$S_T = s + D*q$$

$$\text{P.I.} = J = \frac{Q}{P_r - Pwf}$$

Simple P.I. Equation…
There are more terms that matter!

Well Performance – Transient Nodal

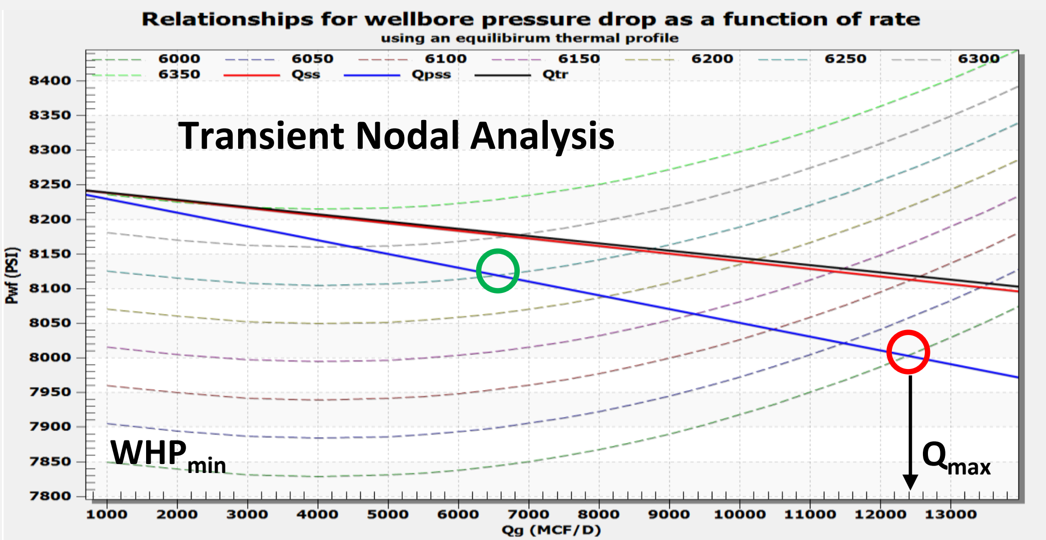


r_e , effective radius can be rate dependent
k, perm can be rate dependent
S_T, Total skin can be rate dependent

IPR Equations

$$q_g = \frac{0.703kh(p_R^2 - p_{wf}^2)}{T\mu_g Z[\ln(r_e/r_w) - 0.75 + s_T]}$$

$$q_o = \frac{kh(p_R - P_{wf})}{141.2\mu_o B_o[\ln(r_e/r_w) - 0.75 + s_T]}$$



Compressibility Volume Equations (Pseudo Steady State Conditions)

$$V_c = \frac{Q_{avg}}{\frac{\Delta P}{\Delta t}Ct}$$ Connected Volume

$$V_c = \frac{1}{\frac{\Delta TTA}{\Delta t}Ct}$$ Mobile Volume

$$^{*}TTA = \frac{(P_{initial} - P_{wf})}{Q_{spot}}$$

Well's Qmax for given minimum WHP pressure

Parts of the System You can Evaluate?

3

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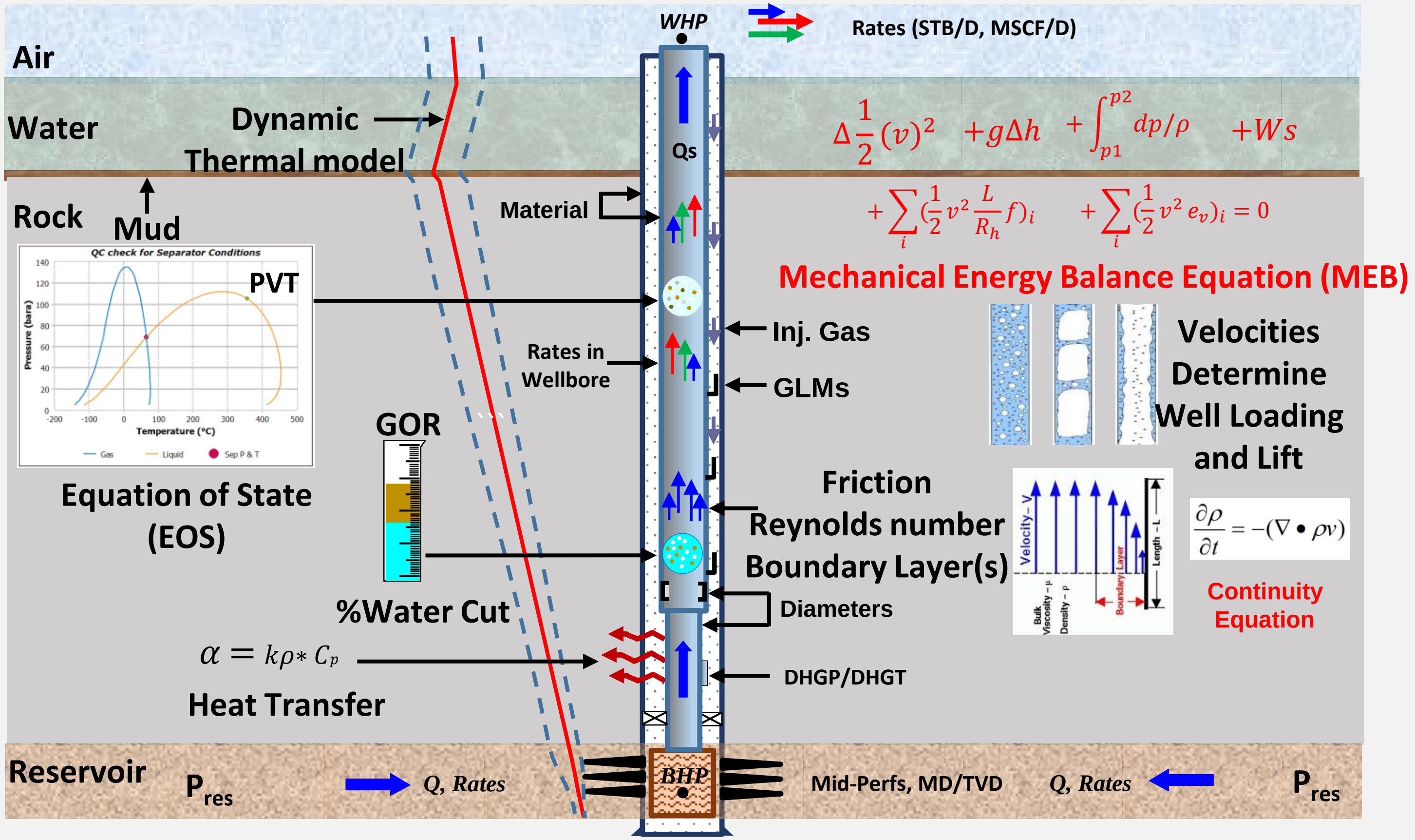
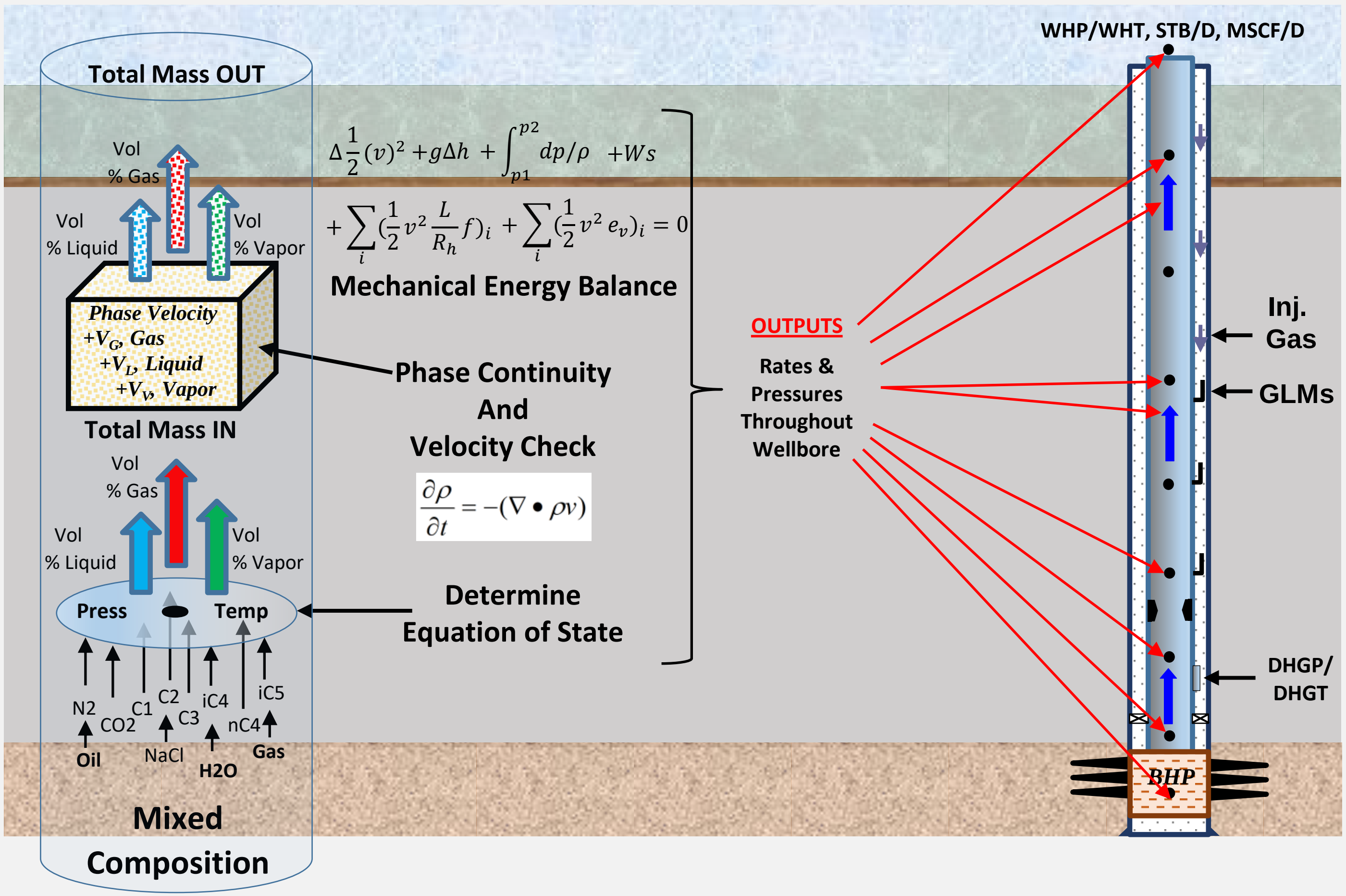
Wellbore Physics



Parts of the System You can Evaluate? 3

Backbone of Wellbore Physics



Parts of the System You can Evaluate? 3

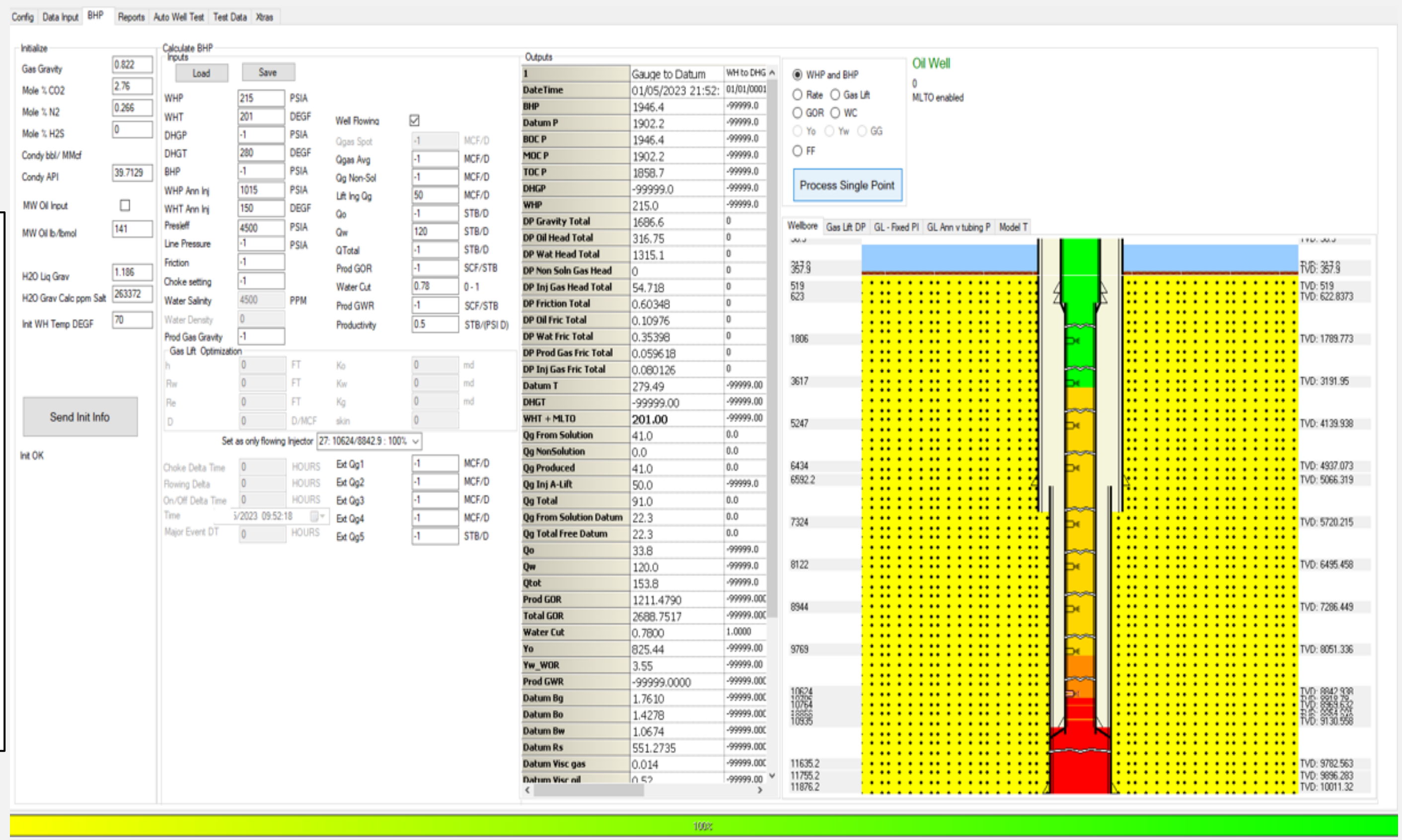
The Wellbore Rainbow – Flow Regimes

Red – Loading

Orange – Slugging

Yellow – Churn Flow

Green – Full Sweep Flow



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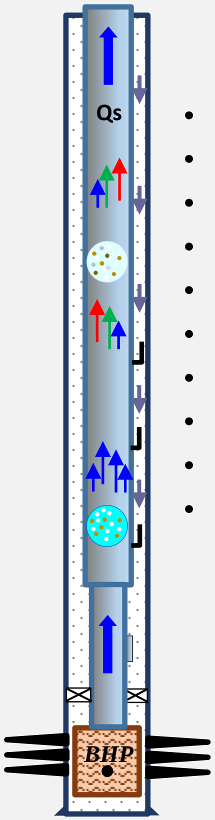
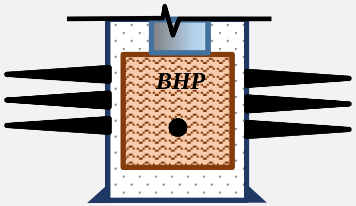
Putting it all together… Well bore – Completion – Reservoir



Wellbore

- Rates
- Pressures
- Water Cut
- GOR
- (In)efficient Lift?
- Loading
- Scaling
- Waxing
- Optimize GL
- Asphaltenes

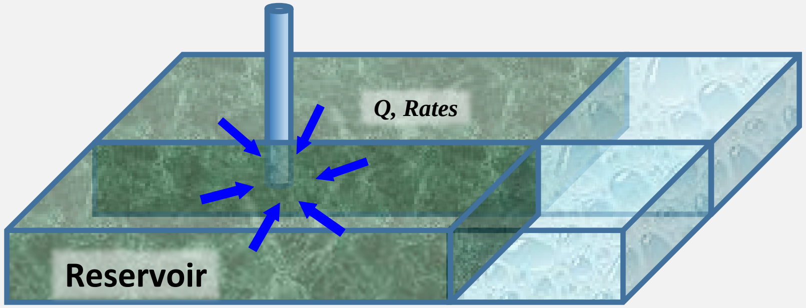


Completion

- Skin Damage
- Screen Plugging
- Shear Failure

Reservoir

- Net Present Value
- Reservoir Management
- Reservoir Depletion
- Formation Compaction
- Water Encroachment
- Water Flood?
- Well Spacing?
- Workover?
- Drill?



What tools do we have?

Wellbore & Surface

- NODAL VLP
- PVT s/w

  PVT Correlations
- DTS & DAS
- Wellbore Flow Regimes
- Surface/Line Network Models
- Gas Lift Curves

Completion

- Pressure Transient Analysis
- Productivity Index
- Rate Transient Analysis (TTA)
- Acoustic Tools to Detect Sand Production
- Production Logging Tools
- Pump Monitoring Technology

Reservoir

- Static MBAL
- Flowing MBALs
- Decline Analysis

  (Not DCA!)
- Boundary Volumetrics
- NODAL IPR
- History Matching Simulation Models

What Engineering Tools do we have?

Gulf Coast Section

Tools Explained in More Detail

- Nodal (VLP & IPR)
- PTA/TTA Well Test Analysis (PBU, DD; 2-Rate Tests)
- AutoPTA
- Static & Flowing MBAL
  - Same Equations…Static uses S/I Pres; Flowing uses Projected Pres
- Boundary Volumetrics
- Conventional Decline
- TTA/RTA Decline
- Well/Reservoir Simulation

NODAL Analysis – IPR + VLP

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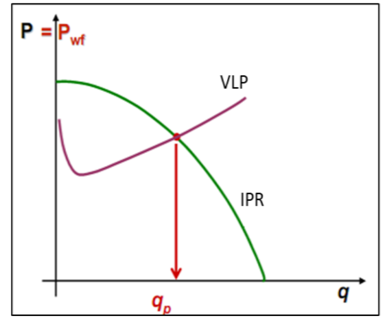
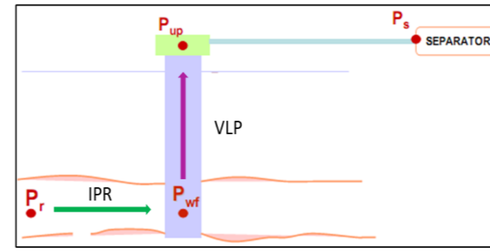
NODAL Description

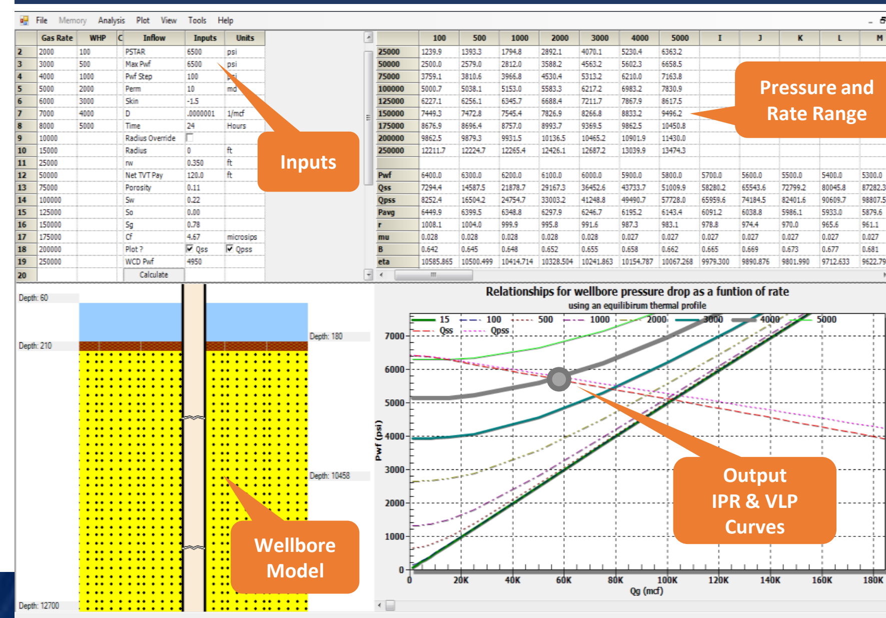
- **NODAL Analysis is a combination of Reservoir deliverability (Inflow Performance Relationship) and Wellbore deliverability (Vertical Lift Performance)**
- **<u>Benefits of NODAL:</u>**
  - Prediction of DP to achieve a Rate (vice versa)
  - Prediction of Liquid Loading Scenarios
  - Optimization of Tubular Design
- **<u>Problems with NODAL:</u>**
  - **Doesn't Decouple Skin & Perm!**
  - **Infinite # of combos of skin and perm to calculate the same rate (can't use NODAL to determine skin or perm)**
  - Reservoir Pressure can change too!!!
  - User has to pick the right inflow model and right VLP/PVT correlations
  - User has to choose the right drive mechanism (Watch Out! It can change!)
  - Doesn't handle transient situations well – may match your well today, but not next month

IPR and VLP Curves





Analysis Inputs and Outputs



Pressure Transient Analysis (PTA)

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PTA Description

- **Pressure Transient Analysis uses changes in pressure to determine reservoir parameters such as productivity, average reservoir pressure, reservoir size, boundary locations, types of boundaries, etc.**
- Build-up: After flowing the well for awhile, shut it in and observe the pressure response
    - If long enough, the build-up can provide valid p*
- Drawdown: After shutting in the well for awhile, flow the well on a constant choke and observe the pressure and rate response
- 2-rate: Change the rate enough to create a new transient; observe the pressure and rate
- Multi-Rate: Change the rates and compare Delta Pressure (DP) vs. Rate
- Communication: Shut-in a well and see if a neighboring well causes the pressure to drop

Permeability Equation

Buildup or Drawdown: Use T_{res} and P_{avg} for fluid property calculations

$$k = \left| \frac{162.6 q \mu B}{mh} \right|$$

k[=] permeability – md
q[=] rate – Bbl/day for oil; Mcf/d for gas
μ[=] viscosity – cp
B[=] formation volume factor – Reservoir bbl/STB for oil; Reservoir bbl/Mcf for gas
m[=] mid-time slope – psi/cycle
h[=] net pay - feet

Build-up Skin Equation

$$s = 1.151\left[\frac{P_{1hr} - P_{wf}}{m} - \log\left(\frac{k}{\phi \mu c_t r_w^2}\right) + 3.23 \right]$$

s[=] skin
P_{1hr}[=] the pressure value where the mid-time slope hits t=1hr – psia
P_{wf}[=] the flowing bottomhole pressure prior to shut-in – psia
m[=] mid-time slope – psi/cycle
k[=] permeability – md
ϕ[=] porosity – fractional
μ[=] viscosity – cp
c_t[=] total compressibility (~gas compressibility for gas wells) – 1/psi
r_w[=] completed wellbore radius – feet

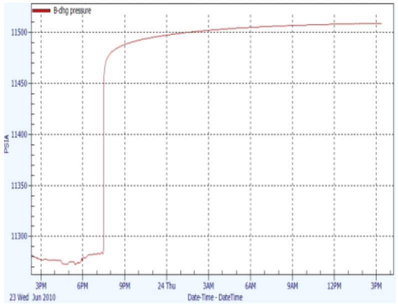
Drawdown Skin Equation

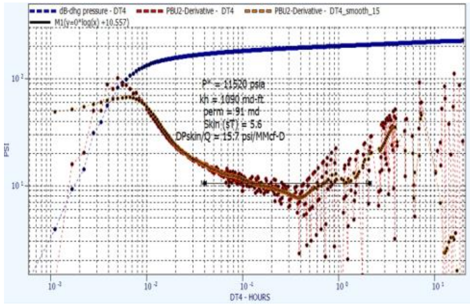
$$s = 1.151\left[\frac{P_i - P_{1hr}}{m} - \log\left(\frac{k}{\phi \mu c_t r_w^2}\right) + 3.23 \right]$$

s[=] skin
P_i[=] the shut-in bottomhole pressure prior to flow– psia
P_{1hr}[=] the pressure value where the mid-time slope hits t=1hr – psia
m[=] mid-time slope – psi/cycle
k[=] permeability – md
ϕ[=] porosity – fractional
μ[=] viscosity – cp
c_t[=] total compressibility (~gas compressibility for gas wells) – 1/psi
r_w[=] completed wellbore radius – feet

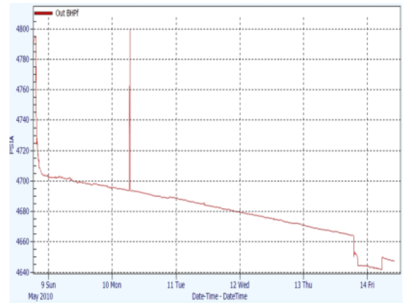
Pressure Transient Analysis (PTA) – Types of Tests

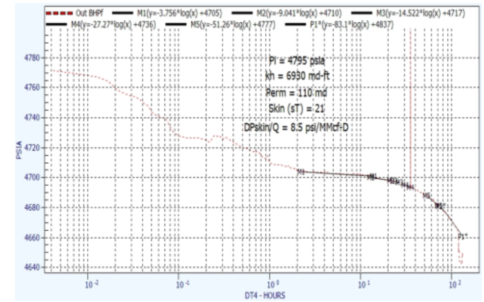
Build-up Analysis



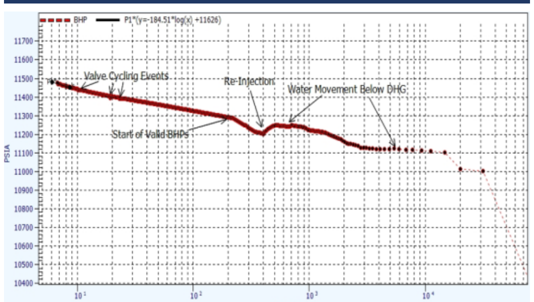


Drawdown Analysis

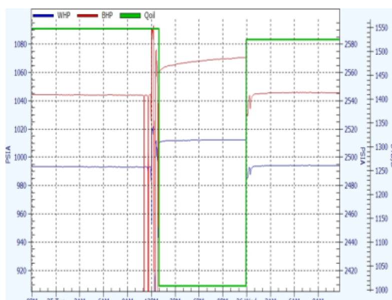


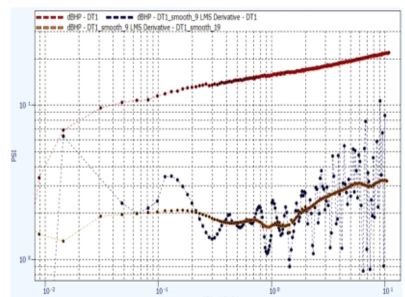


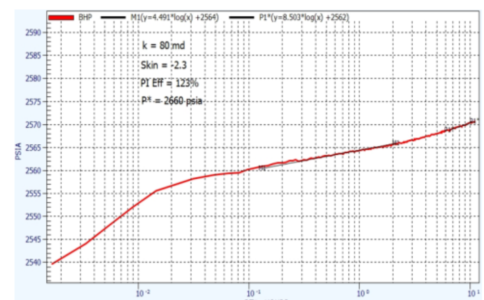
Horner Plot – P* Determination



2-Rate Analysis





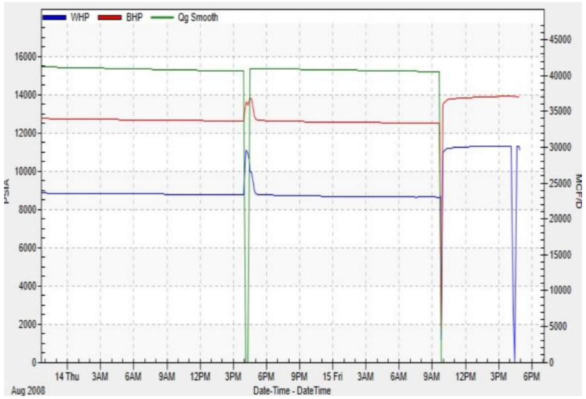


- **Even if you don't pick the right mid-time slope… as long as you pick it after the break-over, you'll be qualitatively correct**
- **Don't get too exercised if the PBU perm is different than the DD perm – this is a common occurrence in unconsolidated sandstones and geo-pressured wells**
- **When you get time, or to validate your initial findings, perform a full pressure transient analysis**
- **Layering/ crossflow/ "squishy" rock**

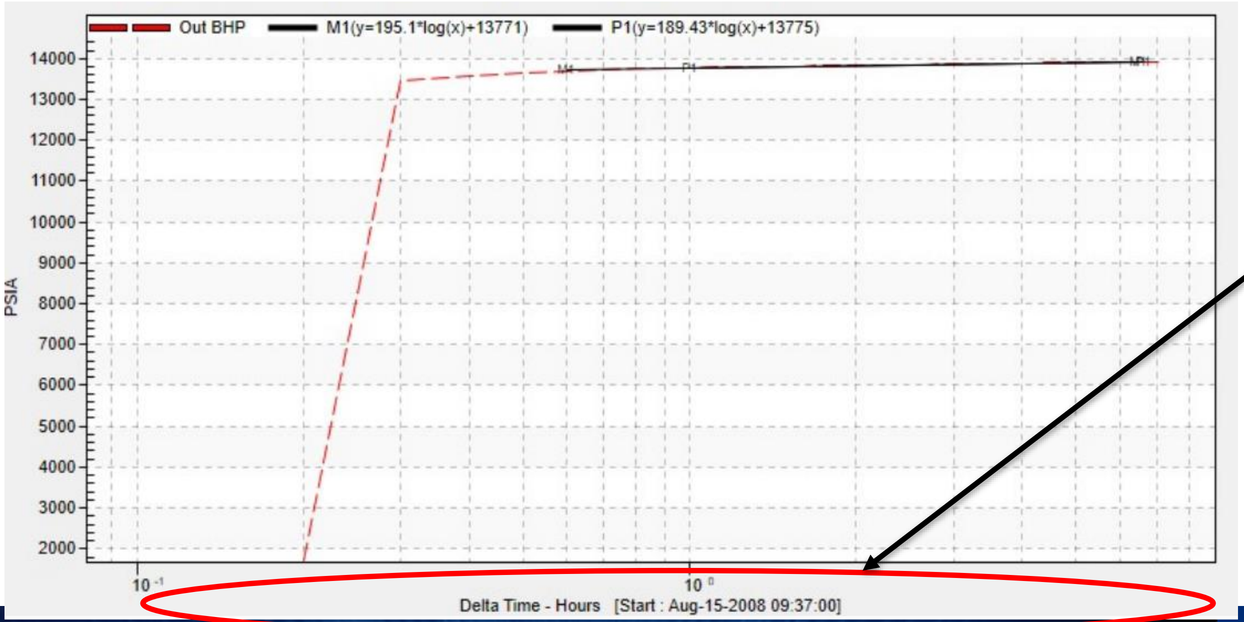
How to Check Auto-PTAs

- Verify start date/time of Delta Time
- Verify Pwf (PBUs) or Pinitial (DDs)
- Derivative plot and Semi-log plot to ensure the MTS slope has been drawn correctly
- Verify that P1hr is correct & verify P* Slope
- Verify the fluid properties used
- For questionable results, verify them by hand (See Skin, Perm, etc. equations)
  - Note: The equations may be different based on the well geometry (vertical, horizontal, Hz-Frac'd)

Verify Start Delta Times

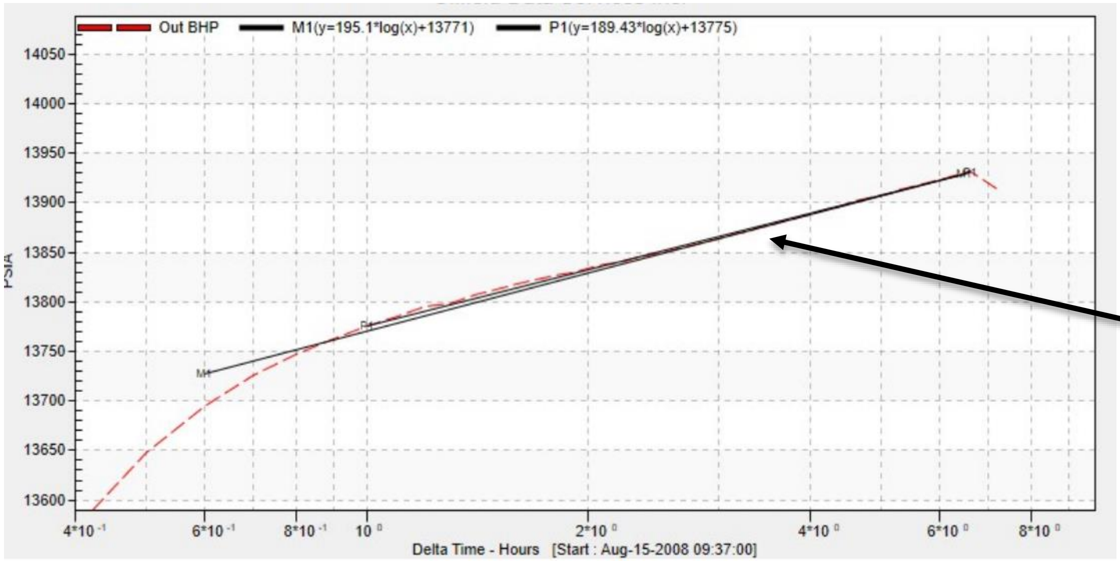


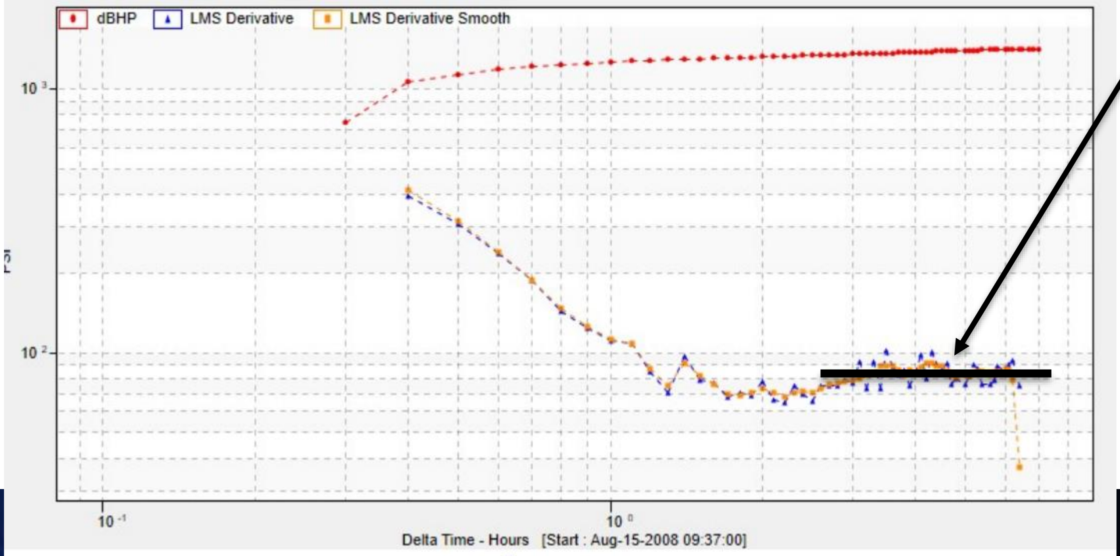
Row	Date Date Time (DateTime)	WHP WHP (psia)	aOutDatumP BHP (PSIA)	WHP Filled WHP (psia)	Yo Yo (BBL/MMCF	Yw Yw (BBL/MMCF	Qgas Qgas (Mcf/D)
3129	08/15/2008 09:13:00	8644.62	12511.7981547781	8644.62	13.710000	2.2000000	40560.878
3130	08/15/2008 09:19:00	8642.56	12509.7030193878	8642.56	13.710000	2.2000000	40558.269
3131	08/15/2008 09:25:00	8642.86	12509.8703438242	8642.86	13.710000	2.2000000	40555.656
3132	08/15/2008 09:31:00	8641.38	12508.363066583	8641.38	13.710000	2.2000000	40553.046
3133	08/15/2008 09:37:00	8639.32	12506.3213130028	8639.32	13.710000	2.2000000	40550.433
3134	08/15/2008 09:43:00	8652.28	12521.256545	8652.28	13.710000	2.2000000	0
3135	08/15/2008 09:49:00	1201.84	1721.40965671748	1201.84	13.710000	2.2000000	0
3136	08/15/2008 09:55:00	10925.92	13448.0400243778	10925.92	13.710000	2.2000000	0
3137	08/15/2008 10:01:00	11037.81	13571.2862965718	11037.81	13.710000	2.2000000	0
3138	08/15/2008 10:07:00	11106.12	13647.0739959785	11106.12	13.710000	2.2000000	0
3139	08/15/2008 10:13:00	11147.93	13694.0104156783	11147.93	13.710000	2.2000000	0
3140	08/15/2008 10:19:00	11176.19	13726.1475591678	11176.19	13.710000	2.2000000	0
3141	08/15/2008 10:25:00	11194.15	13747.0364057297	11194.15	13.710000	2.2000000	0



Correct DT Start
Last Flowing Pwf =
12,506-12,512 psia

Verify Correct Slope Pick





m-slope is selected at the same time as the radial flow period in the derivative plot

VALID SLOPE

Verify Slopes, Pwf, P1hr, P*

ANALYSIS RESULTS

PBU
Aug/15/2008

Calculated Reservoir & Completion Properties

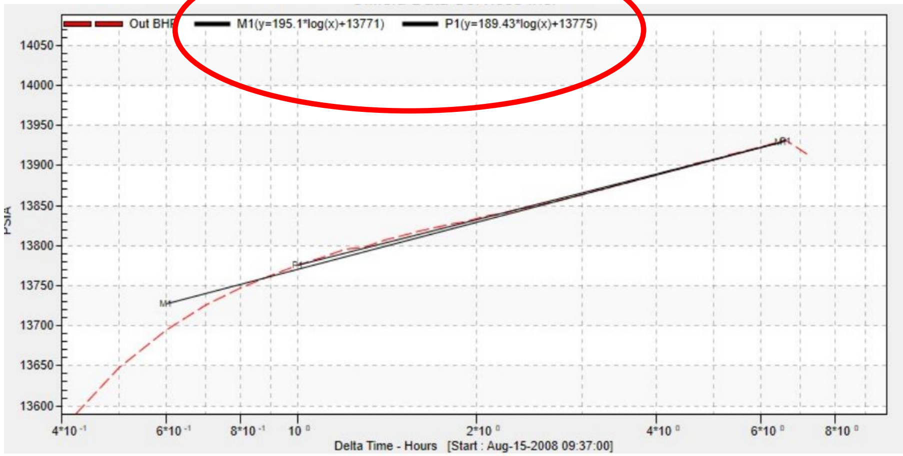
SKIN	1.4	
PRESSURE DROP DUE TO SKIN	233	PSI
COMPLETION EFFICIENCY	82	%
PERMEABILITY	16	md
RADIAL FLOW PI	32.1	MCF/PSI
SKINLESS RADIAL FLOW PI	39.4	MCF/PSI
PERMEABILITY THICKNESS	719	md-ft
MOBILITY THICKNESS	16,271	md-ft/cp

Inputs for Calculated Results

GAS RATE PRIOR TO SHUT-IN	40,557	MCF/D
MID-TIME SLOPE	195.10	PSI/CYCLE
BHPwf	12,508	PSIA
BHP* (est. @T=1000hrs.)	14,343	PSIA
BHP 1hr (Psia)	13,771	PSIA
NET PAY (TVT)	44	FT
POROSITY	20.0	%
WATER SATURATION	35.0	%
WELL BORE RADIUS	0.50	FT

Analysis Fluid Properties @ P=13,770.8 PSIA & T=329 DEGF

GAS FORMATION VOLUME FACTOR (Bg)	0.481	RB/MCF
SYSTEM COMPRESSIBILITY (Ct)	23	µsip
GAS VISCOSITY	0.044	cp
Z-FACTOR (Compressibility Factor)	1.668	



Pwf = 12,506 – 12,512 (12,508) psia
P1hr = 13,771 psia
m-slope = 195.1
P* = 14,343 psia

Verify Fluid Properties

ANALYSIS RESULTS

PBU
Aug/15/2008

Calculated Reservoir & Completion Properties

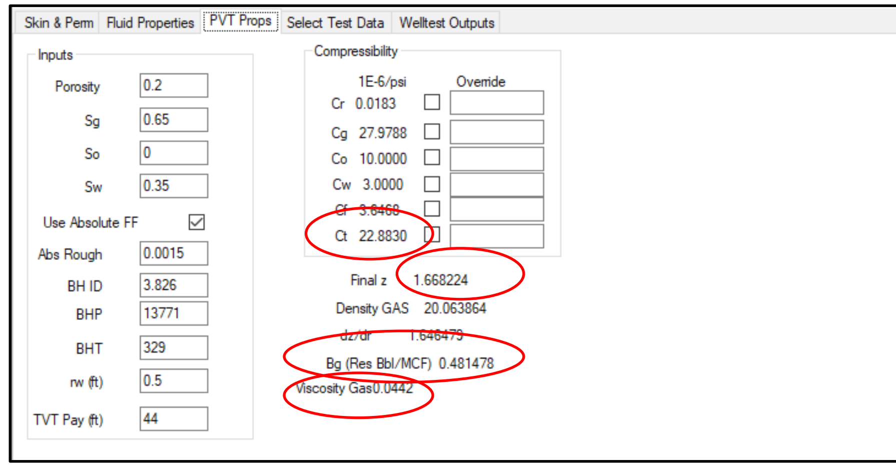
SKIN	1.4	
PRESSURE DROP DUE TO SKIN	233	PSI
COMPLETION EFFICIENCY	82	%
PERMEABILITY	16	md
RADIAL FLOW PI	32.1	MCF/PSI
SKINLESS RADIAL FLOW PI	39.4	MCF/PSI
PERMEABILITY THICKNESS	719	md-ft
MOBILITY THICKNESS	16,271	md-ft/cp

Inputs for Calculated Results

GAS RATE PRIOR TO SHUT-IN	40,557	MCF/D
MID-TIME SLOPE	195.10	PSI/CYCLE
BHPwf	12,508	PSIA
BHP* (est. @T=1000hrs.)	14,343	PSIA
BHP 1hr (Psia)	13,771	PSIA
NET PAY (TVT)	44	FT
POROSITY	20.0	%
WATER SATURATION	35.0	%
WELL BORE RADIUS	0.50	FT

Analysis Fluid Properties @ P=13,770.8 PSIA & T=329 DEGF

GAS FORMATION VOLUME FACTOR (Bg)	0.481	RB/MCF
SYSTEM COMPRESSIBILITY (Ct)	23	μsip
GAS VISCOSITY	0.044	cp
Z-FACTOR (Compressibility Factor)	1.668	



SLB-Private

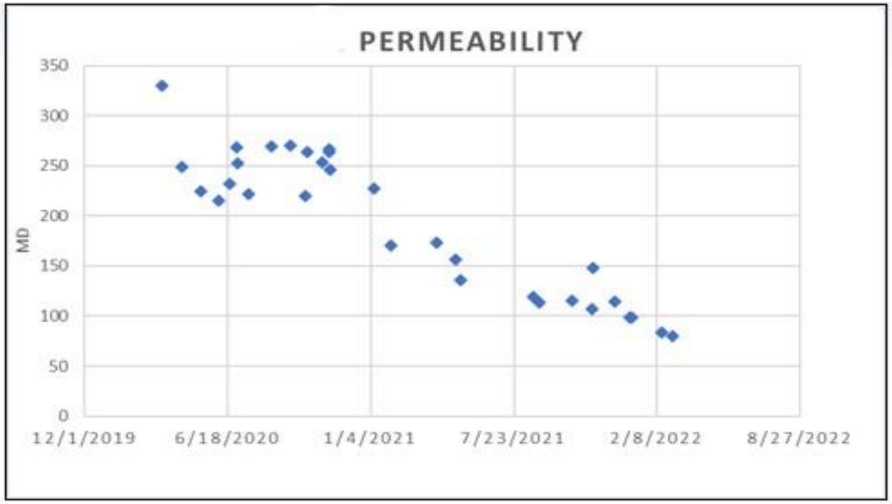
Verify Analysis By Hand (or w/ PTA s/w)

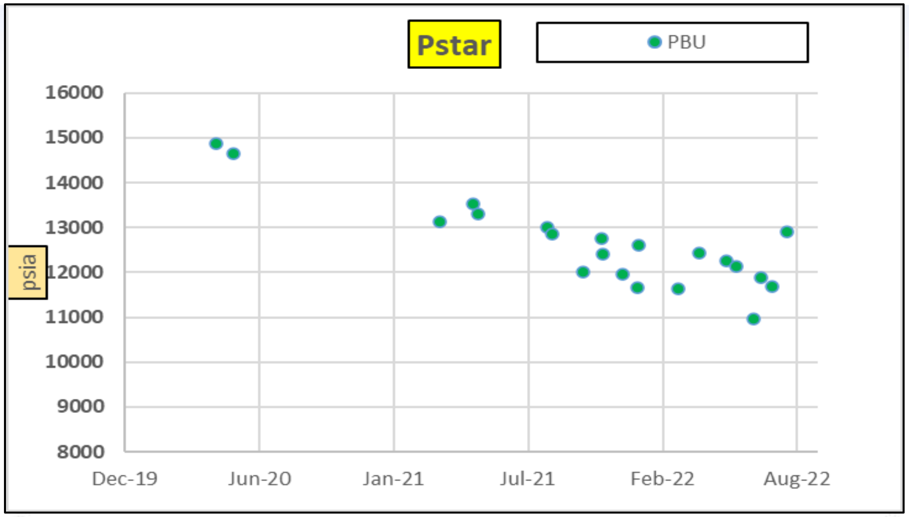
- Perm (k) = 16.3 md vs. 16 md – truncation error?
- Skin (S) = 1.4 (dim'less) vs. 1.4 (dim'less)
- DPskin = 234 psi vs. 233 psi
- Completion Eff. = 82.5% vs. 82.6%

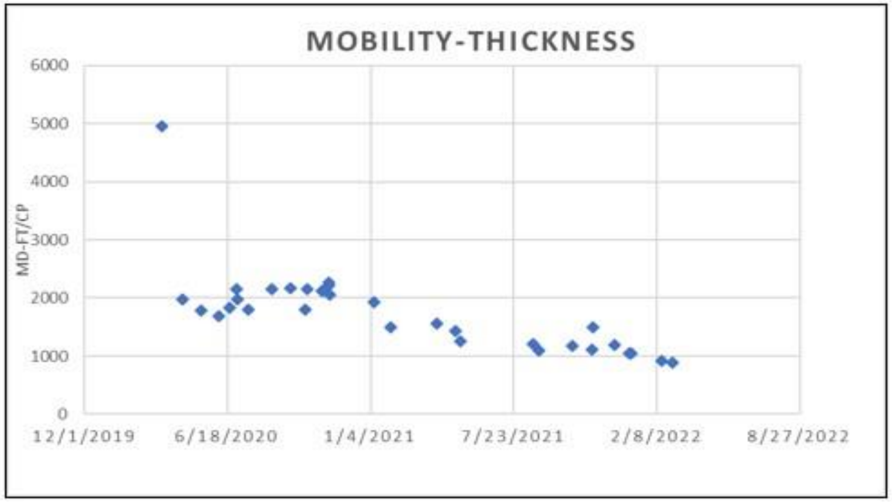
Status = Approved PTA

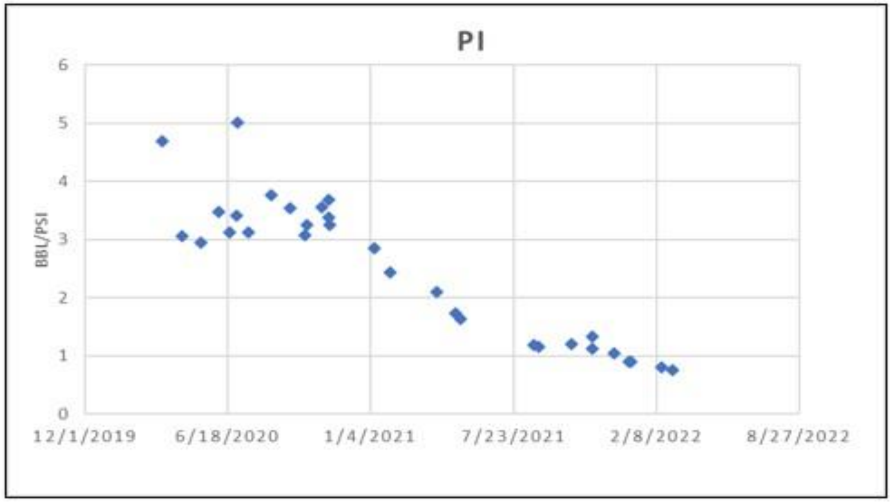
Add to Dashboard

Historic PTA



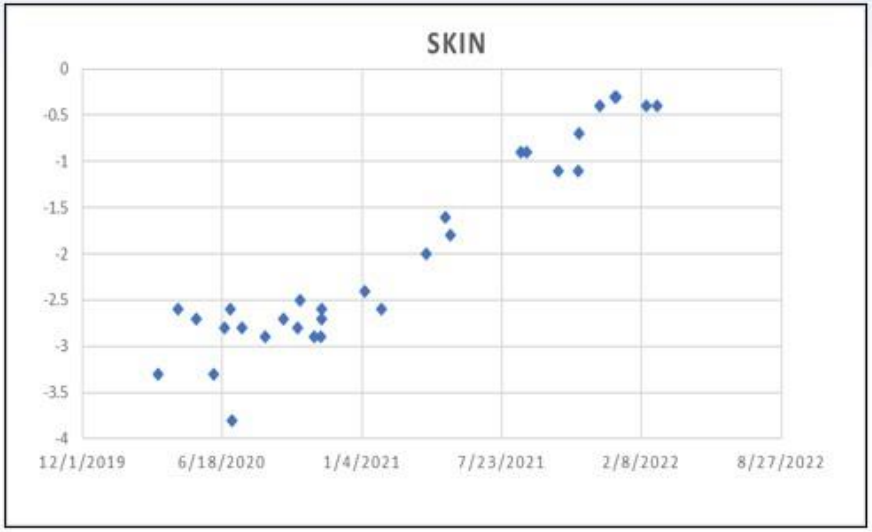


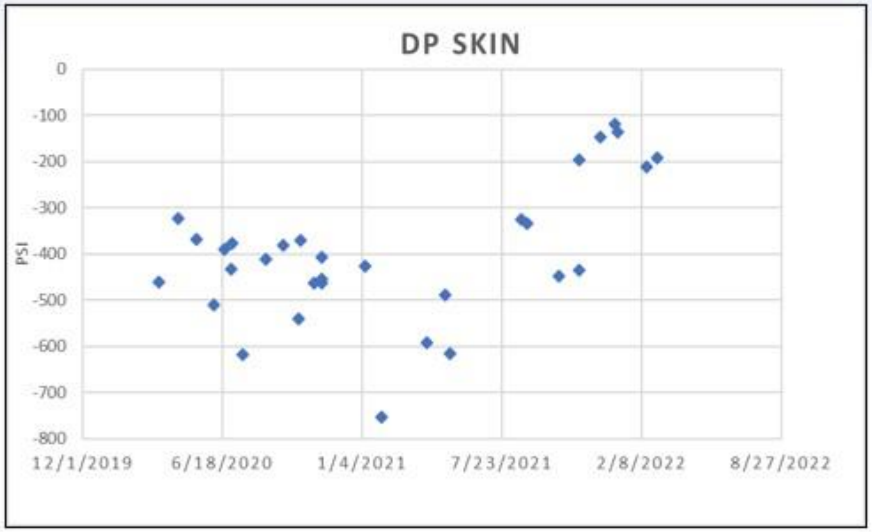


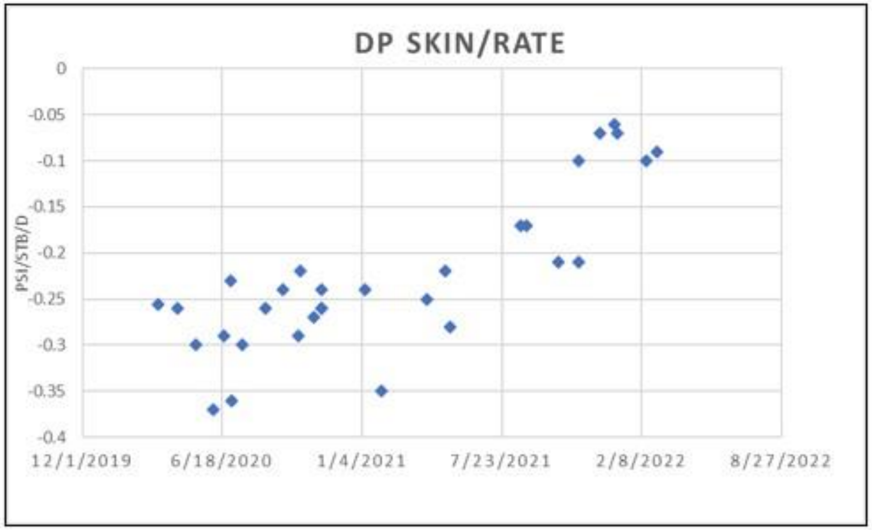


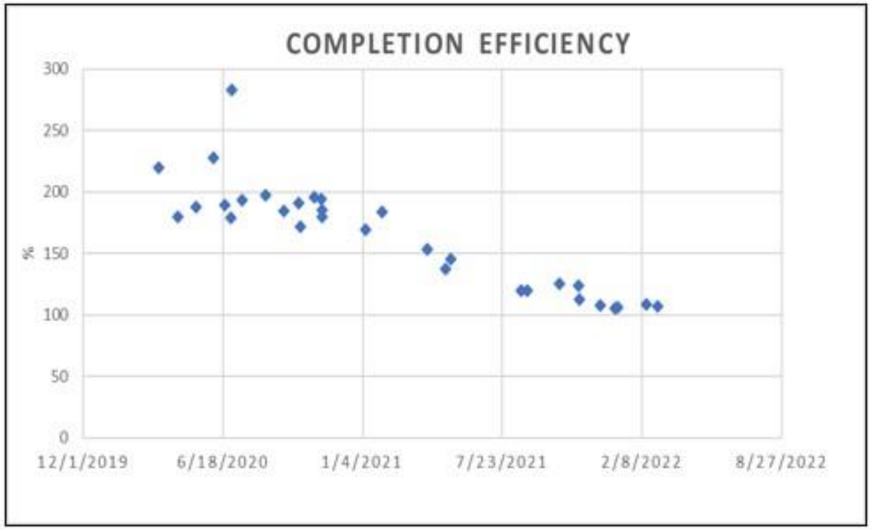
Historic PTA Cont.

Gulf Coast Section









Break

What Engineering Tools do we have?

Tools Explained in More Detail

- ~~Nodal (VLP & IPR)~~
- ~~PTA/TTA Well Test Analysis (PBU, DD; 2-Rate Tests)~~
- ~~AutoPTA~~
- Static & Flowing MBAL
  - Same Equations…Static uses S/I Pres; Flowing uses Projected Pres
- Boundary Volumetrics
- Conventional Decline
- TTA/RTA Decline
- Well/Reservoir Simulation

Static Material Balance (MBAL)

MBAL Description

- **Used to determine original fluids-in-place based on production and static pressure data**
- **MBAL equations considered assume tank-type behavior at any given datum depth – the reservoir is considered to have the same pressure and fluid properties at any location in the reservoir**
- A P/z for gas wells or a Static Material Balance for oil wells provide a means to evaluate the **total elastic energy in a reservoir**
- This volume is then translated into an HC volume to find the in-place volume and with an abandonment pressure to determine the maximum recoverable volume under a likely economic limit
- The biggest challenge with these calculations - they are counting EVERYTHING…gas, oil, water, and elastic energy in the rock, i.e. anything that can move, wiggle or expand
- This is why it is considered bad practice to use a P/z plot on gas wells with known water drive
- By applying another extreme case – that of Straight-Line Depletion (SLD), with hydrocarbons being pushed by an infinite aquifer – a minimum in-place hydrocarbon volume can be obtained
    - Assumption: no hydrocarbon expansion
    - These two cases then provide the bookends to the range of possible hydrocarbon volume in-place

General Equation

$$\underbrace{G_{fgi}E_g}_{\text{free-gas expansion}} + \underbrace{N_{foi}E_o}_{\text{free-oil expansion}} + \underbrace{WE_w}_{\text{free-water expansion}} + \underbrace{V_{pi}E_f}_{\text{pore-volume contraction}} + \underbrace{W_e}_{\text{water influx}}$$

$$= \underbrace{(G_p - G_I)\left(\frac{B_g - B_oR_v}{1 - R_vR_s}\right)}_{\text{net gas withdrawal}} + \underbrace{N_p\left(\frac{B_o - B_gR_s}{1 - R_vR_s}\right)}_{\text{oil withdrawal}} + \underbrace{(W_p - W_I)B_w}_{\text{net water withdrawal}},$$

<u>A P/z for gas wells or a Static Material Balance for oil wells provide a means to evaluate the total elastic energy in a reservoir.</u>

<u>A drawback of the Static MBAL is that the well needs to produce a meaningful amount for the volumes to be valid… But… Why???</u>

Volume – Working Equations

1-phase Oil

<u>Depletion Drive</u>

$$\text{Static MBAL Vc} = \frac{N_p \times Bo}{Bo - Boi}$$

<u>Infinite Water Drive</u>

$$\text{Static MBAL SLD} = N_p \; x \; \frac{P_i}{P_i - P^*}$$

1-phase Gas

<u>Depletion Drive</u>

$$\text{Static MBAL Vc} = \frac{G_p \times Bg}{Bg - Bgi}$$

<u>Infinite Water Drive</u>

$$\text{Static MBAL SLD} = G_p \; x \; \frac{P_i}{P_i - P^*}$$

Correction Factor to account for formation compressibility: Cpp/Ct, where Cpp is the compressibility of the primary phase.

Static Material Balance (MBAL)

MBAL – Estimating P*/Pres

- **There are two ways to estimate P*/Pres**

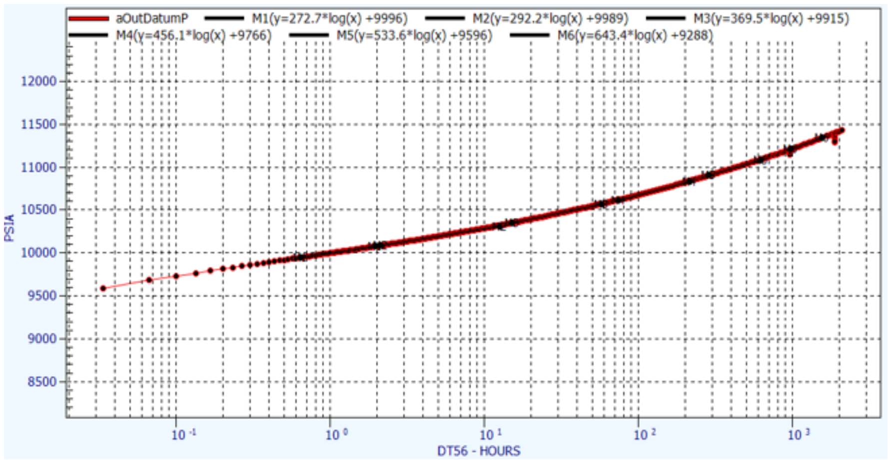
Semi-log (MDH)

- Usually the P* line is extrapolated to 1,000 hours (or DT at the edge of the hydrocarbons); may change based on different well scenarios
- Why extrapolate to 1,000 hours? Because you are likely not going to recover any hydrocarbons beyond that point (DT ~ Distance)

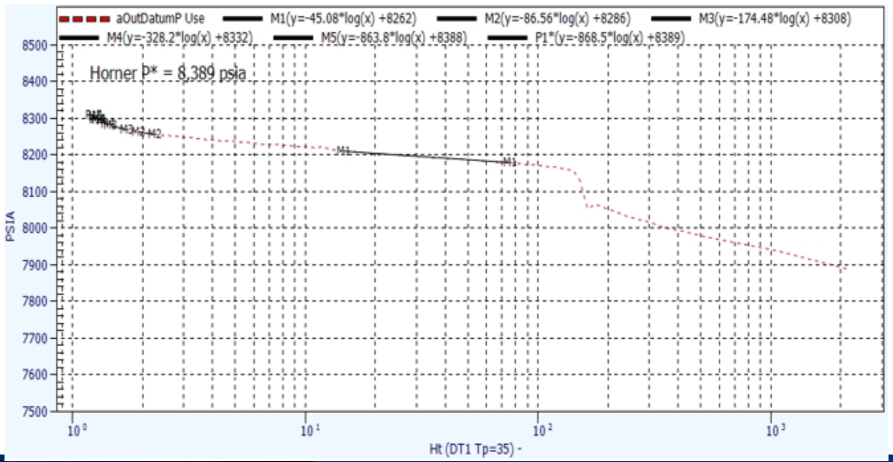
Horner Method

- Used when the well has not been producing for a long time, usually less than 3 to 4 months, or when the build-up is significantly longer than the flow period
- Horner Time Ratio = $\frac{t_p + \Delta t}{\Delta t}$
- Extrapolate P* line to a Horner Time of 1.0 (10^0)

Semi-log MDH Example



Horner Method Example



Boundary Volumetrics (BV)

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BV Description

- Boundary volumetrics is an in-place volume calculation dependent on reservoir properties such as volume, porosity, and fluid saturations
- Preferably, this should be done 'blind', without seeing the reservoir map first
- Should be based solely on fluid & rock properties, as well as pressure & rate data
- Use two bookends to provide a range of volumes:
  - Constant Pay Thickness (h)
  - Pyramid Rule (h/3)
- Better understanding of reservoir when the 'blind' reservoir boundary evaluation is compared to the geological map

Original Oil/Gas In-Place Equations

$$\text{OOIP} = \frac{A\,h\,\emptyset\,S_o}{B_{oi} \times 5.615\,\frac{cu\,ft}{bbl}} \qquad \textit{in STB}$$

$$\text{OGIP} = \frac{A\,h\,\emptyset\,S_g}{B_{gi} \times 5.615\,\frac{cu\,ft}{bbl} \times 1000000} \qquad \textit{in BCF}$$

The Area (A) is determined from the boundaries from PTAs

Working Equations

- To get the area, you'll need to calculate the distance
  - Distance to a boundary = $2\sqrt{\eta * \Delta t}$ *in ft*
- To get the distance, you'll need to calculate the hydraulic diffusivity
  - Hydraulic Diffusivity: $\eta = \frac{0.0002637 * k}{\phi \mu C_t}$ *in ft2/hr*

Boundary Volumetrics (BV)

Identifying Boundary Contact Types

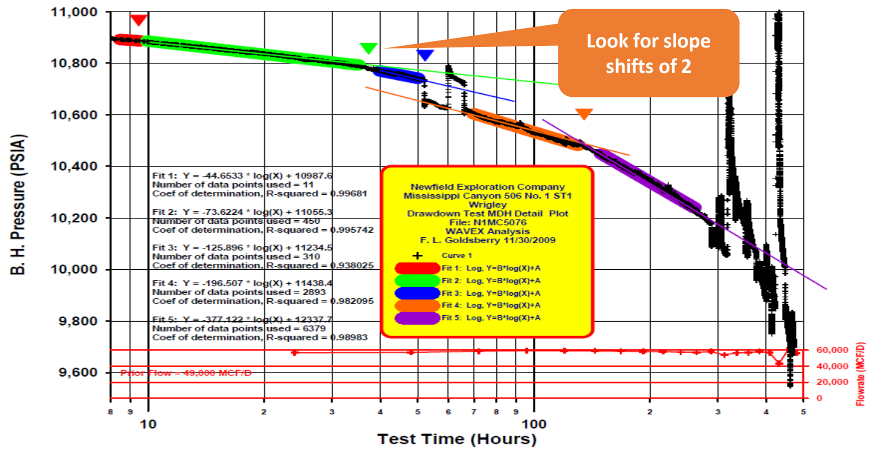
- No Flow Boundary (Stratigraphic or Fault)
  - Slope ratio ~ 2
- Oil/Water Contact
  - Pressure curve flattens provided the oil and water mobility is significantly different
- Gas/Water Contact
  - Pressure curve bounces and exhibits a slope ratio of 1.6

Each of these boundary contacts exhibit a specific pressure response on a Semi-log plot.

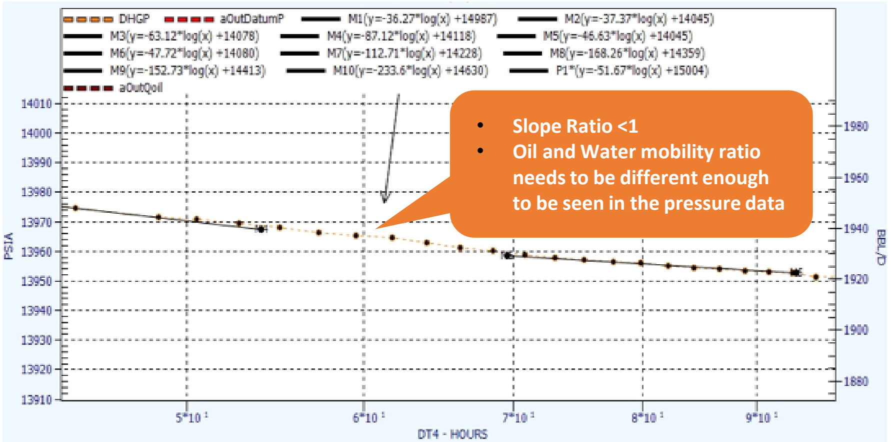
In a high formation compressibility environment, it is highly recommended to use drawdowns to find boundaries – build-ups are suppressed due to rock relaxation

Boundary Volumetrics (BV) – Identifying Boundary Contact Types

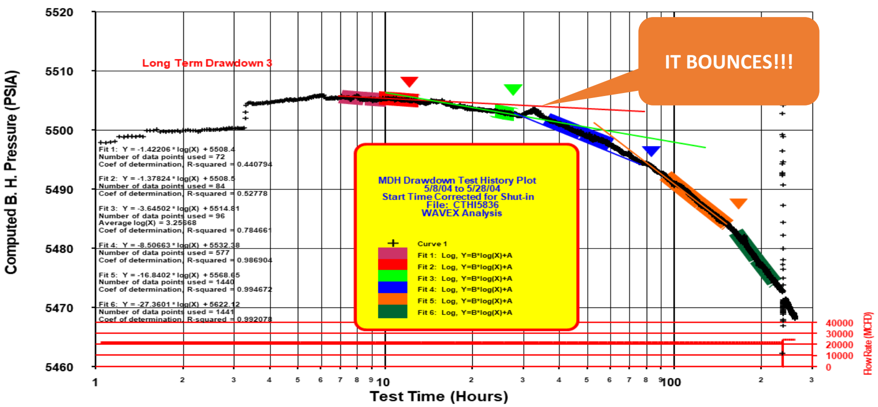
Stratigraphic and Faults



Oil/Water Contacts

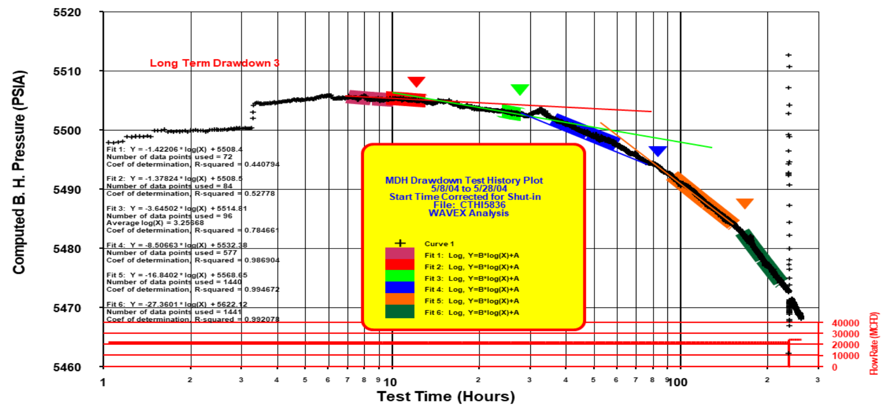


Gas/Water Contact



Plot 16

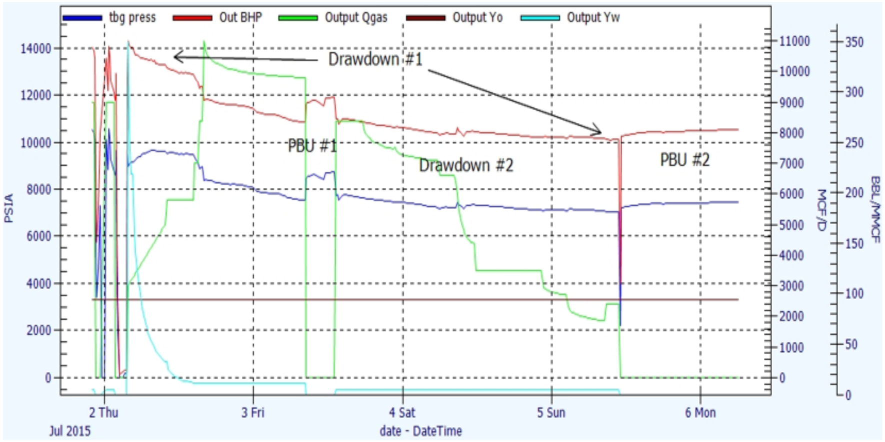
More Complicated Geometries



Plot 16

Boundary Volumetrics (BV)

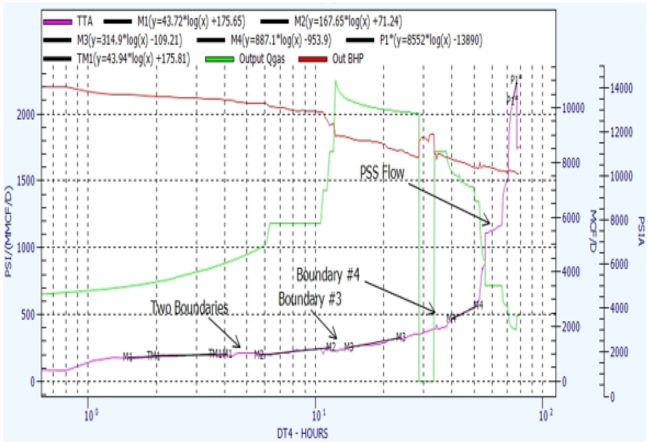
1 Choosing a Delta Time PTA Test



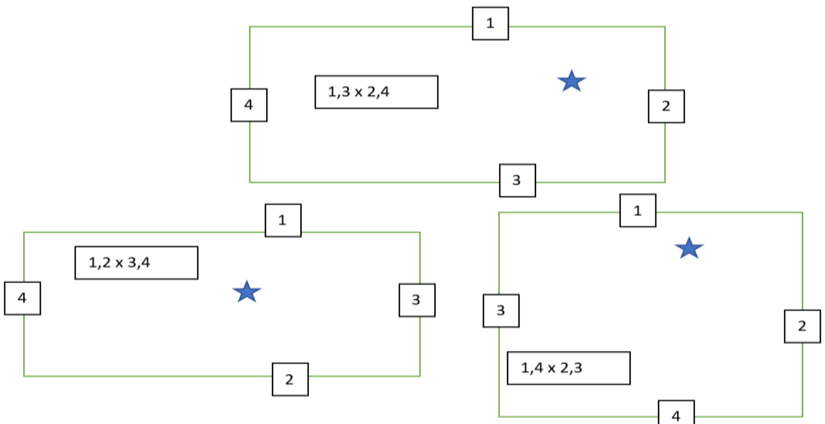
2 Finding Boundaries – Drawdown #1

- **It is possible to hit 2 boundaries at the same time**
- **The slope shifts will tell the story**

Pinitial	14300	psi
porosity	0.29	fraction
Bg	0.5192	RB/Mscf
Sg	0.8	fraction
viscosity	0.0604	cp
Ct	28.06	µsip
Cf	10	µsip
perm	5.0	md
net pay	24	ft



4 Possible Boundary Configurations



3 Distance Calcs – Drawdown #1

- Hydraulic diffusivity η = 2682 ft^2/hr
- Pay count used = 24 ft

- Possible boundary 1 @ 4.5 hours = 220 ft
- Possible boundary 2 @ 4.5 hours = 220 ft
- Possible boundary 3 @ 12.3 hours = 363 ft
- Possible boundary 4 @ 39.2 hours = 649 ft

Boundary Volumetrics (BV)

Step by Step Hydrocarbon In-Place Calculation Example

- Area 1 (1,3 x 2,4) = 506,256 ft^2
- Area 2 (1,2 x 3,4) = 444,698 ft^2
- Area 3 (1,4 x 2,3) = 506, 256 ft^2

Multiply by h (net TST pay) to get Spatial Volume (divide by 5.615 to convert from ft3 to bbl) – Boxcar (constant net pay) & Pyramid (1/3 net pay)

Multiply by porosity to get Pore Volume

Multiply by Sx to get Phase Pore Volume (x = g, o, w)

Divide by Formation Volume Factor to get Stock Tank Volumes

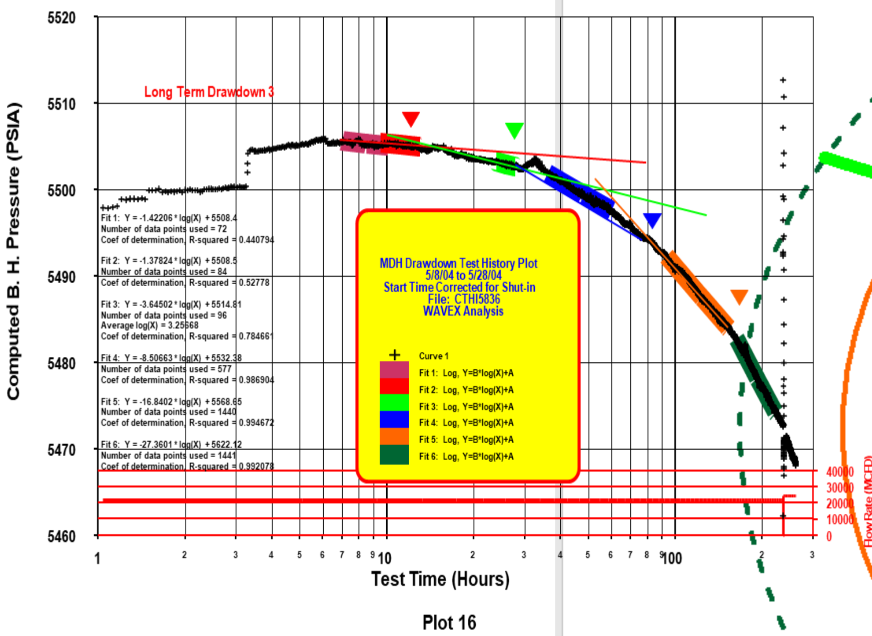
- Volume 1 (1,3 x 2,4) = 0.97 BCF (Boxcar) or 0.32 BCF for Pyramid Dump
- Volume 2 (1,2 x 3,4) = 0.85 BCF (Boxcar) or 0.28 BCF for Pyramid Dump
- Volume 3 (1,4 x 2,3) = 0.97 BCF (Boxcar) or 0.32 BCF for Pyramid Dump

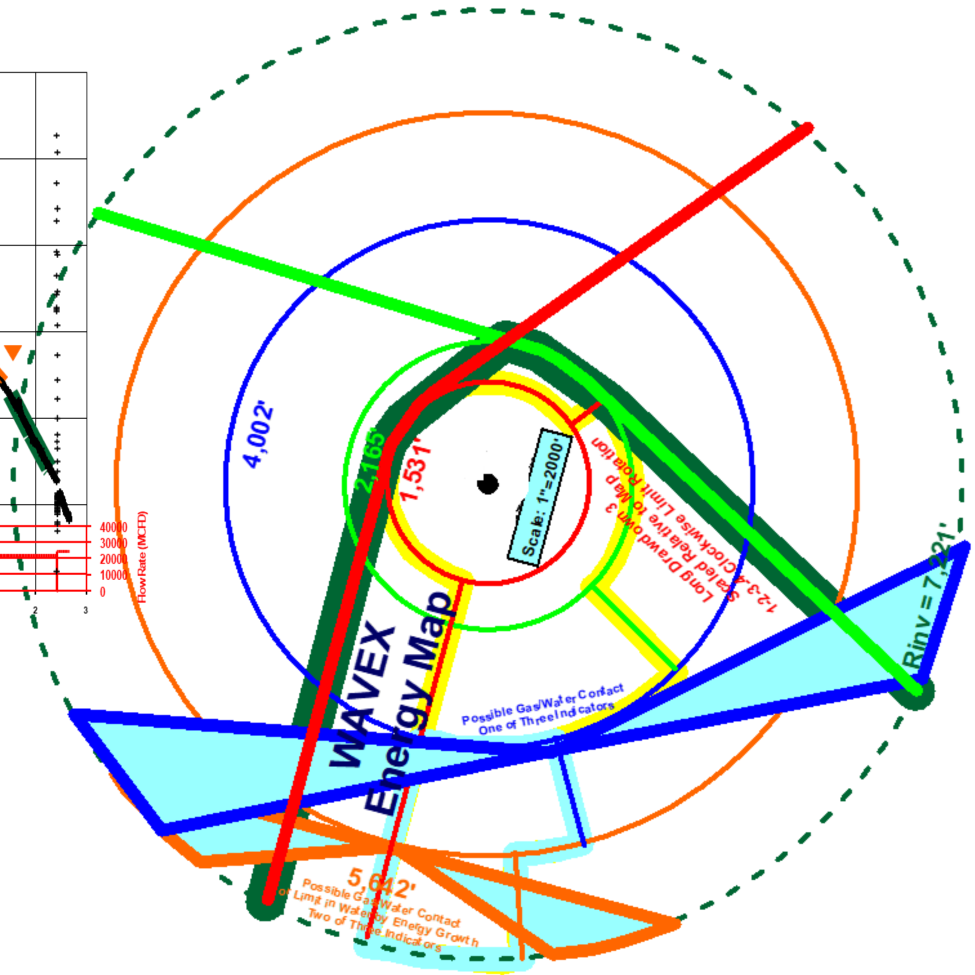
To determine which boundary configuration is correct, we usually consult with the geologist's map

Note: Boundary configuration 2 is a channel. Channel reservoirs exhibit linear flow after the second boundary is encountered.

Boundary Volumetrics (BV) – Blind Mapping

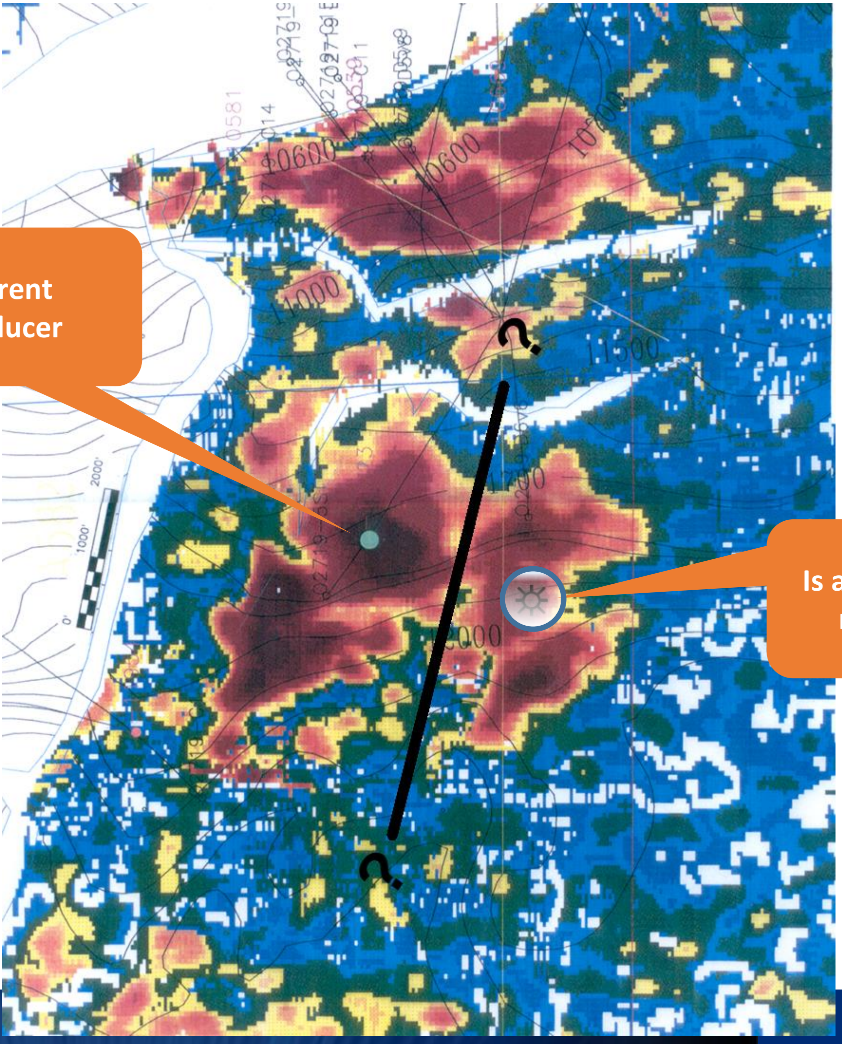
"Blind" Reservoir Image





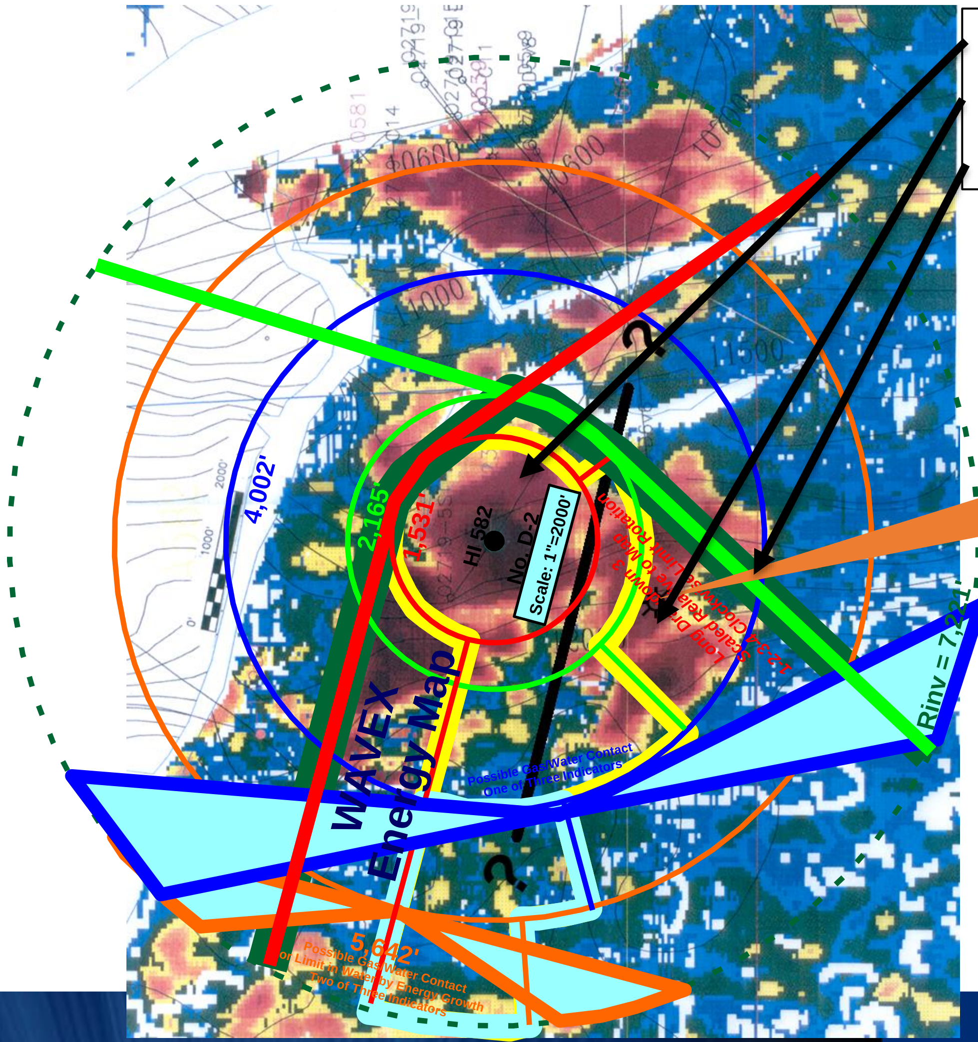
Boundary Volumetrics (BV) – Blind Mapping

Geo-Blob Map



Boundary Volumetrics (BV) – Blind Mapping

Boundary-Geo Overlay and Volume Comparison



Geo-Map Region 1 Volume = 18 BCF

Geo-Map Region 2 Volume = 10 BCF

Boundary Volumetric = 29 BCF

Still need that extra well?

Decline Analysis

Decline Analysis Description

- **Decline Analysis should not be confused with Decline CURVE Analysis**
- **Conventional Decline Analysis = Hydraulically Connected Volumes**
  - The compressibility volume is determined using the rate of decay with pressure per unit time (i.e. PSI/day) on a Cartesian plot
  - If a reservoir is in a closed system and once all of the boundaries of the reservoir are encountered, the well will then transition to some sort of steady-state flow (usually PSS)
- **Thermodynamic Transient Analysis (TTA) = Mobile volumes**
  - Thermodynamic Transient Analysis, TTA refers to any technique of analysis that applies the constant driving force solution of the diffusivity equation.
  - Mobile Volume are hydrocarbons that are not only connected but also currently moving towards the well
- It's easier to think in terms of energy…
- Conventional Decline Analysis is hydraulically connected energy….
- TTA Decline Analysis is mobile energy…
- How do we know what type of energy it is? That's where the engineering comes in!
- One important concept to remember is that the mobile volumes should be equal or less than the connected volumes
  - If the mobile volumes are greater than the connected volumes, then that should be a red flag!!!

Working Equation Matrix

	Connected Volume	Mobile Volume
Depletion via Compressibility	$Conv.\ V_c = \frac{Q_{avg}}{Slope_{DP-DT}} * \frac{1}{C_t}$	$TTA\ V_c = \frac{1}{Slope_{DTTA-DT}} * \frac{1}{C_t}$
Straight Line Depletion via Displacement	$Conv.\ V_{SLD} = \frac{Q_{avg}}{Slope_{DP-DT}} * P_{res.}$	$TTA\ V_{SLD} = \frac{1}{Slope_{DTTA-DT}} * P_{res.}$

Thermodynamic Transient Analysis (TTA)

- TTA is the inverse of relative productivity, so as TTA function increases, productivity decreases and vice versa
  - Units are (PSI/STB/DAY)/DAY
- Pi is initial reservoir pressure - constant
- TTA is a tool used to monitor apparent productivity and how it changes with various reservoir/non-reservoir events
- It is also used to estimate reservoir volumes and for well testing purposes and for modeling rates
- RTA allows Pi to 'float' in order to 'game' reserves

Decline Analysis Definitions

Acronyms

- **Vc** – Compressibility Volume (apparent energy from oil or gas expansion)
- **SLD** – Straight-Line Depletion (apparent energy not related to oil or gas expansion)
- **TTA** – Thermodynamic Transient Analysis (coupled term of rate and pressure drop in reservoir: DPreservoir/Rate)
- **DP/DT** – Change in pressure per unit time (psi/day)
- **DTTA/DT** – Change in the TTA function per unit time (psi/rate per day)

Four Flowing MBAL/EBAL Calcs

- **Two Simple Bookends:**
  - Vc =Expansion Drive Only (Compressibility Volume)
  - Vsld=Infinite Water Drive Only (Pushed Volume)
  - These two bookends are applied for min and max number
  - In reality, the real answer is somewhere in-between, but this a very useful tool when you're trying to make decisions
- **Conventional SLD**: Hydraulically Connected Potential Elastic Energy, assuming infinite water drive
- **Conventional Vc**: Hydraulically Connected Potential Elastic Energy, assuming expansion drive
- **TTA-SLD**: Mobile Connected Apparent HC Volume, assuming infinite water drive
- **TTA-Vc**: Mobile Connected Apparent HC Volume, assuming expansion drive

Decline Analysis – Types of Flow Regimes

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Conventional Wells

- **Transient Flow** — The pressure transient migrates outward from the well without encountering any boundaries
- **Boundary-Dominated Flow** — The pressure transient has reached one or more boundaries (but not all) and the static pressure is not declining uniformly across the reservoir
- **Pseudo-Steady State Flow** — The pressure transient has reached all of the boundaries and the static pressure is declining at the boundary and declining uniformly throughout the reservoir
- **Steady State Flow** — The pressure transient has reached all of the boundaries but the static pressure at the boundary does not decline
- **Linear Flow/Channel Flow** – Cartesian Linear Pressure decline (flow occurs in long, narrow reservoirs) after hitting two parallel boundaries
- **Hybrid Flow Systems**
    - Channel-Levy (Beware of Re-injection)
    - High-Perm Fairway/Blob – Low Perm Feed (HPF-LPF)
    - Weak Water Drive
- **Horizontal Conventional Wells (additional regimes)**
    - 1st Radial
    - Linear Horizontal
    - 2nd Radial

Unconventional Wells

- **Frac** – Flow from just the fracture network itself
- **Linear Frac (FDR)** – Flow within the fracture and from the fracture-affected matrix to the wellbore without much contribution from the unfractured matrix
- **Linear Matrix (Hybrid)** – Flow travels from the formation perpendicular to the length of the wellbore and dominates the fracture response (assumes that the fracture conductivity is high enough that the ROI travels quickly through the fractures)
- **Matrix-Dominated** – The pressure transient has stabilized and behaves as a single equivalent between the fracture and matrix.
- **Quasi-PSS** – When there is significant contribution, the Linear Frac acts as if it is in PSS, while the matrix is in transient flow. This is similar to a HPF-LPF conventional reservoir.

Decline Analysis Workflow

Workflow

- Identify <u>straight-line</u> sections in the DP-DT and the TTA Plots, draw slopes
- Only slopes during PSS/SS or Channel-Linear Flow considered
- Determine Produced Volumes at the point of the slopes
- Calculate Remaining and Total Apparent Volumes for the 4 Decline Analysis Methods

Basic Concepts

Reservoir Behavior

- Transient Flow: Connected and Mobile Volumes are increasing
- PSS: Connected and Mobile Volumes stabilizes to a number

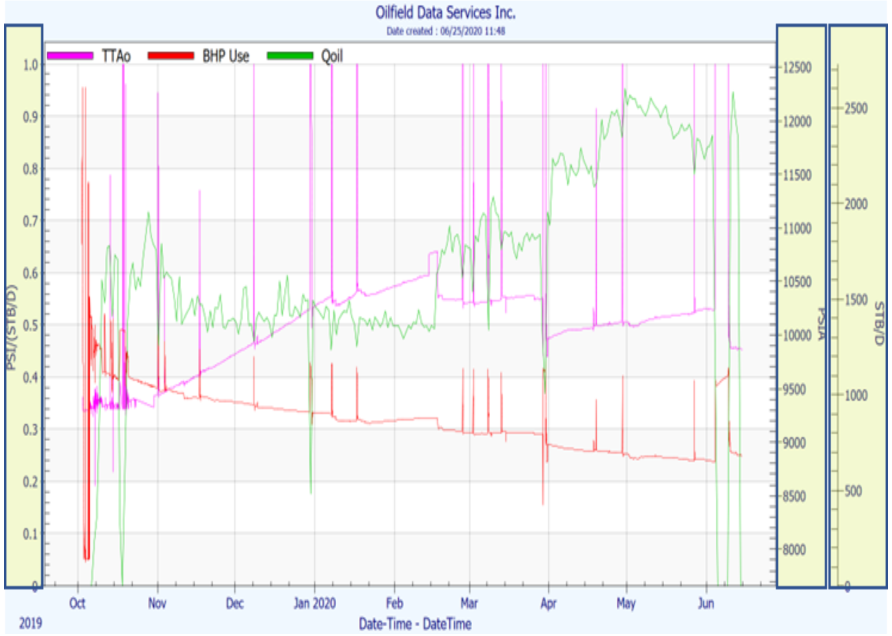
Any increase energy/volume after PSS could be due to:

1. Water: ConVc increases but the TTAVc stay the same
2. Water mobilizes: ConVc trend stays the same but the TTAVc starts the increase.
   - In some cases, TTA Vc > ConVc or ConVc (PSS) = TTASLD or TTA slope of zero (indicating infinite volume)
3. Low perm feed: ConVc gradually increasing with TTAVc staying the same or ConVc and TTAVc gradually increasing…

Decline Analysis Workflow

Hydraulically Connected Volume - Pressure On Left Axis

Mobile HC Volume - TTA on Left Axis



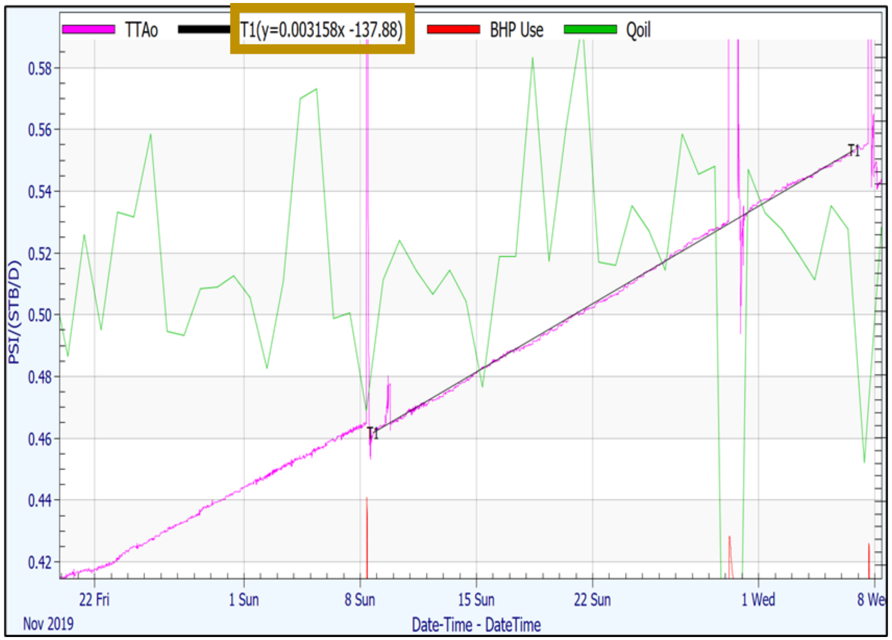
The analysis is used to determine Hydraulically Connected and Mobile HC volumes and how they are changing with time.

Decline Analysis Workflow

Drawing Slopes on Pressure (DP/DT) Cartesian

- Find straight lines on the pressure function, where the period is longer than 1.5 days
- Select the same period as the TTA but on a constant choke (stabilized Qavg rates)
- Qavg = 1,425 STB/d
- Pressure = 9,300 psia
- DP/DT Slope = 2.515 psi/d

Drawing Slopes on TTA Cartesian



- Find straight lines on the TTA function, where the period is longer than 1.5 days
- Once the slope is drawn with the best fit, note the TTA slope and period of time it covered
- TTA Slope = 0.003158 psi/stb/d per day

Decline Analysis Workflow

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Gathering Other Important Parameters

- Total Compressibility (Ct) is based upon the compressibility of the rock/formation (Cf) and compressibility of all the fluids that are in the reservoir such as oil (Co), gas (Cg) and water (Cw)

- The fluid compressibility must also be corrected with saturation values

- Total Compressibility can be calculated using this formula:

$$C_t = (C_o * S_o) + (C_g * S_g) + (C_w * S_w) + C_f$$

- The default value for Cw is 0.000003 Sips or 3 MicroSips (3 e-6 per psi)

Decline Analysis Workflow

Total compressibility (Ct) Calculation Example

- Calculating Ct using the following properties:
  - Oil compressibility of 0.00001 Sips with saturation of 0.8
  - Water Compressibility of 0.000003 Sips
  - No gas
  - Formation Compressibility of 25 microsips

$$C_t = (C_o * S_o) + (C_g * S_g) + (C_w * S_w) + C_f$$

$$C_t = (10 * 0.8) + 0 + (3 * 0.2) + 25$$

$$C_t = 33.6\ microSips\ or\ 33.6x10^{-6}\ per\ psi$$

Decline Analysis Workflow

Decline Analysis Calculation Example

- Based on the previous slides, we have the following parameters:
  - DP-DT Slope = 2.515 PSI/D
  - TTA Slope = 0.003158 PSI/(STB/D)/D
  - Pressure = 9,300 PSIA
  - Qavg = 1,425 STB/D
  - Ct = 33.6 microsips

- We can now Calculate Connected and Mobile Volumes for this specific period

Decline Analysis Workflow

DP/DT Calculation

$$Conv.\ V_c = \frac{Q_{avg}}{Slope_{DP-DT}} * \frac{1}{C_t} = \frac{1425\ \frac{STB}{D}}{2.515\ \frac{PSIA}{D}} * \frac{1}{33.6 * 10^{-6}\ \frac{1}{PSIA}}$$

$$\boxed{= 16.86\ MM\ STB}$$

$$Conv.\ V_{SLD} = \frac{Q_{avg}}{Slope_{DP-DT}} * P = \frac{1425\ \frac{STB}{D}}{2.515\ \frac{PSIA}{D}} * 9300\ PSIA$$

$$\boxed{= 5.27\ MM\ STB}$$

TTA Calculation

$$TTA\ V_c = \frac{1}{Slope_{DTTA-DT}} * \frac{1}{C_t} = \frac{1}{0.003158 \frac{\frac{PSI}{\frac{STB}{D}}}{D}} * \frac{1}{33.6 * 10^{-6}\ \frac{1}{PSI}}$$

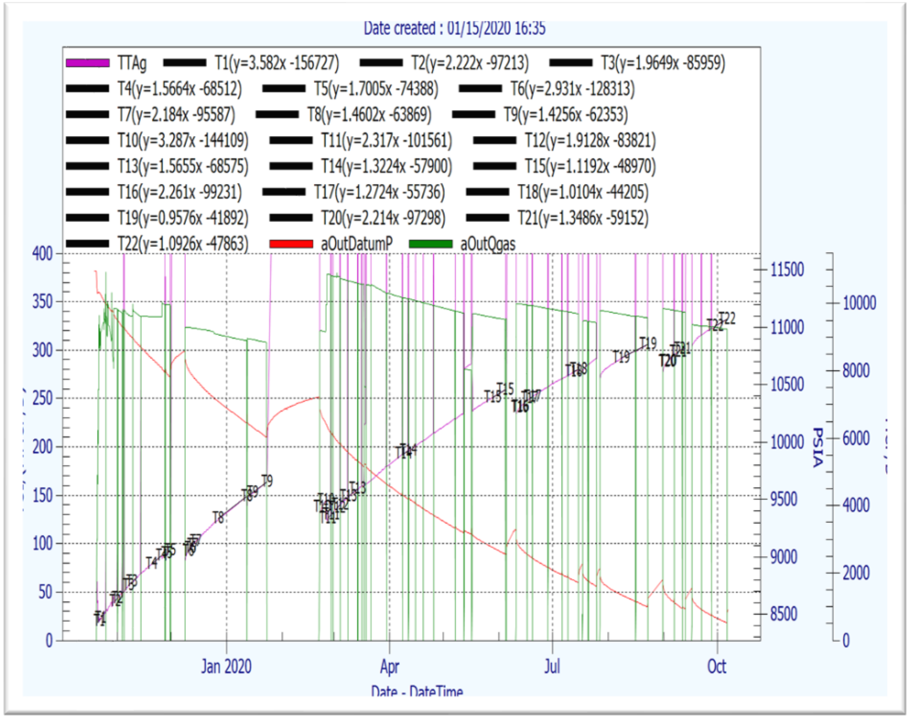
$$\boxed{= 9.43\ MM\ STB}$$

$$TTA\ V_{SLD} = \frac{1}{Slope_{DTTA-DT}} * P = \frac{1}{0.003158 \frac{\frac{PSI}{\frac{STB}{D}}}{D}} * 9300\ PSIA$$

$$\boxed{= 2.95\ MM\ STB}$$

Decline Analysis Workflow

Slopes Drawn Throughout the Prod. History



- Drawn Slopes are tracked throughout the well's production history
  - Done for both the DP/DT and TTA
- Each slope represents the time period with the calculated connected and mobile volumes

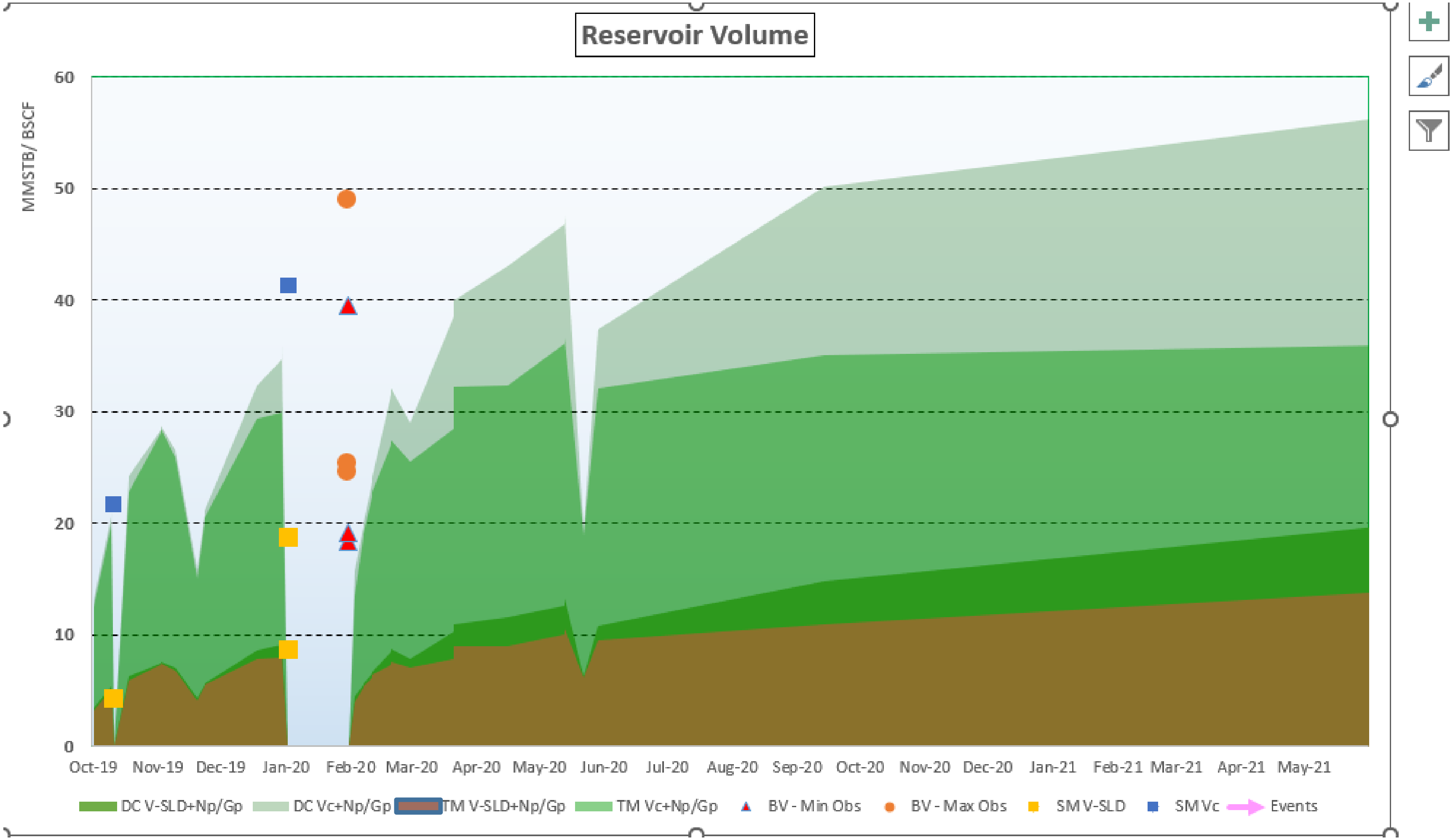
Calculation Table

Conventional Decline/Connected Volumes												
Slope	Date	Pres/Pavg	Bg	DP/DT	Qgas(avg)	Ct	V-SLD	Vc	Incr Gp	Gp	VSLD + Gp	Vc + Gp
#	mm/dd/yyyy	PSIA	BBL/MCF	PSIA/D	MMCF/D	msips	BCF	BCF	BCF	BCF	BCF	BCF
S1	10/22/2019	11473	0.578	30.82	9.131	22.368	3.4	13.2	0.020	0.020	3.42	13.27
S2	10/31/2019	11390	0.579	21.07	9.825	22.469	5.3	20.8	0.086	0.106	5.42	20.86
S3	11/08/2019	11322	0.580	17.758	9.624	22.553	6.1	24.0	0.073	0.179	6.32	24.21
S4	11/23/2019	11222	0.581	14.913	9.605	22.679	7.2	28.4	0.143	0.323	7.55	28.72
Long Shut-in (11/30/2019 - 12/08/219)/Restart												
S9	12/11/19	11086	0.582	25.83	9.283	22.854	4.0	15.7	0.090	0.413	4.40	16.14
S5	12/14/2019	11054	0.583	19.56	9.259	22.897	5.2	20.7	0.030	0.442	5.68	21.12
S7	01/20/2020	10769	0.586	10.89	8.874	23.286	8.8	35.0	0.335	0.777	9.55	35.78
Long Shut-in (01/23/2020 - 02/21/2020)/Restart												
S10	02/24/2020	10480	0.589	28.42	9.168	23.707	3.38	13.61	0.058	0.835	4.22	14.44
S11	02/28/2020	10431	0.589	23.59	10.851	23.782	4.80	19.34	0.033	0.867	5.67	20.21
S12	03/03/2020	10360	0.590	18.40	10.208	23.891	5.75	23.22	0.058	0.926	6.67	24.15
S13	03/12/2020	10243	0.591	14.12	10.626	24.075	7.71	31.26	0.081	1.007	8.72	32.27
S14	04/11/2020	10118	0.593	10.54	10.135	24.278	9.73	39.62	0.302	1.309	11.04	40.93
S15	06/03/2020	9694	0.598	8.12	9.524	25.017	11.37	46.87	0.513	1.821	13.19	48.69
Long Shut-in (06/05/2020 - 06/10/2020)/Restart												
S16	06/12/2020	9617	0.599	20.78	9.983	25.161	4.62	19.09	0.037	1.858	6.48	20.95
S17	06/19/2020	9570	0.600	10.78	9.940	25.249	8.82	36.51	0.059	1.917	10.74	38.43
S19	10/05/2020	8699	0.612	6.72	9.239	27.128	11.96	50.68	0.885	2.803	14.76	53.48

TTA Decline/Mobile Volumes												
Slope	Date	P*/Pavg	Bg	DTTA/DT	Ct	V-SLD	Vc	Incr Gp	cum Gp	TTA VSLD + Gp	TTA Vc + Gp	
#	mm/dd/yyyy	PSIA	BBL/MCF	PSIA/D	MMCF/D	msips	Bcf	Bcf	Bcf	Bcf	Bcf	
T1	10/22/2019	11473	0.578	3.582	22.37	3.2	12.5	0.020	0.020	3.223	12.50	
T2	10/31/2019	11390	0.579	2.222	22.47	5.1	20.0	0.086	0.106	5.232	20.14	
T3	11/08/2019	11322	0.580	1.965	22.55	5.8	22.6	0.073	0.179	5.942	22.75	
T4	11/23/2019	11222	0.581	1.566	22.68	7.2	28.2	0.143	0.323	7.489	28.48	
Long Shut-in (11/30/2019 - 12/08/219)/Restart												
T5	12/11/19	11086	0.582	2.931	22.85	3.8	14.9	0.090	0.413	4.195	15.34	
T6	12/14/2019	11054	0.583	2.184	22.90	5.1	20.0	0.030	0.442	5.504	20.44	
T7	1/20/20	10769	0.586	1.4256	23.29	7.6	30.1	0.335	0.777	8.331	30.90	
Long Shut-in (01/23/2020 - 02/21/2020)/Restart												
T8	02/24/2020	10480	0.589	3.287	23.71	3.2	12.8	0.058	0.835	4.023	13.67	
T9	02/28/2020	10431	0.589	2.317	23.78	4.5	18.1	0.033	0.867	5.369	19.02	
T10	03/03/2020	10360	0.590	1.9128	23.89	5.4	21.9	0.058	0.926	6.342	22.81	
T11	03/12/2020	10243	0.591	1.5655	24.08	6.5	26.5	0.081	1.007	7.550	27.54	
T12	04/11/2020	10118	0.593	1.3224	24.28	7.7	31.1	0.302	1.309	8.960	32.46	
T13	06/03/2020	9694	0.598	1.1192	25.02	8.7	35.7	0.513	1.821	10.483	37.54	
Long Shut-in (06/05/2020 - 06/10/2020)/Restart												
T14	06/12/2020	9617	0.599	2.261	25.16	4.3	17.6	0.037	1.858	6.112	19.44	
T15	06/19/2020	9570	0.600	1.2724	25.25	7.5	31.1	0.059	1.917	9.439	33.04	
T17	10/05/2020	8699	0.612	1.0681	27.13	8.1	34.5	0.885	2.803	10.947	37.32	

- **Tracking the volumes from initial production provides valuable insight to the changes in volumes**
- Observing the trend in the connected volume and mobile volume can help identify
  - Gain or loss in connected energy?
  - Mobilization/movement of any energy?
  - Any changes within the reservoir or fluids?

Tracking the Decline Volume Functions



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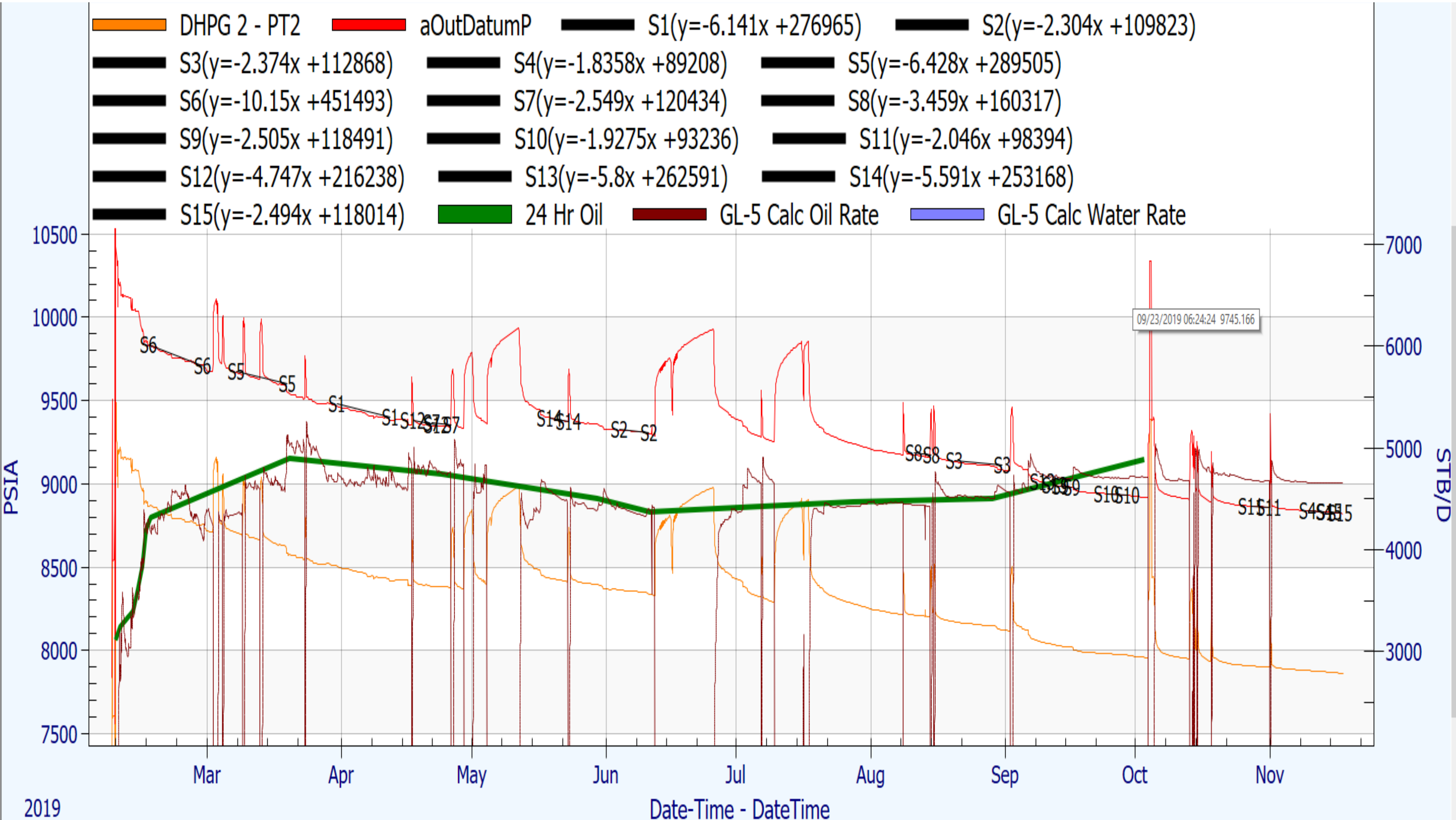
Decline Analysis Workflow

One Last Thing to Remember!

- **Straight-line sections on a Cartesian plot can have more than one potential outcome!**
  - In addition to the well being in PSS or SS, the well could also be in Channel-Linear Flow or Linear (Frac) flow
  - Max In-Place volumes can be evaluated for these particular linear flow regimes…
  - Be mindful of WHAT system you are currently in
- **If Channel-Linear Flow**
  - Max In-Place volume for Channel-Linear flow = ConvVc*4
- **If Linear Flow Frac-only System**
  - Max In-Place volume for a Linear Flow Frac-only system = ConvVc*10
- **Beware!!! Reservoir Flow Regimes Can Change!**

Changing Flow Regimes Example (DP/DT)



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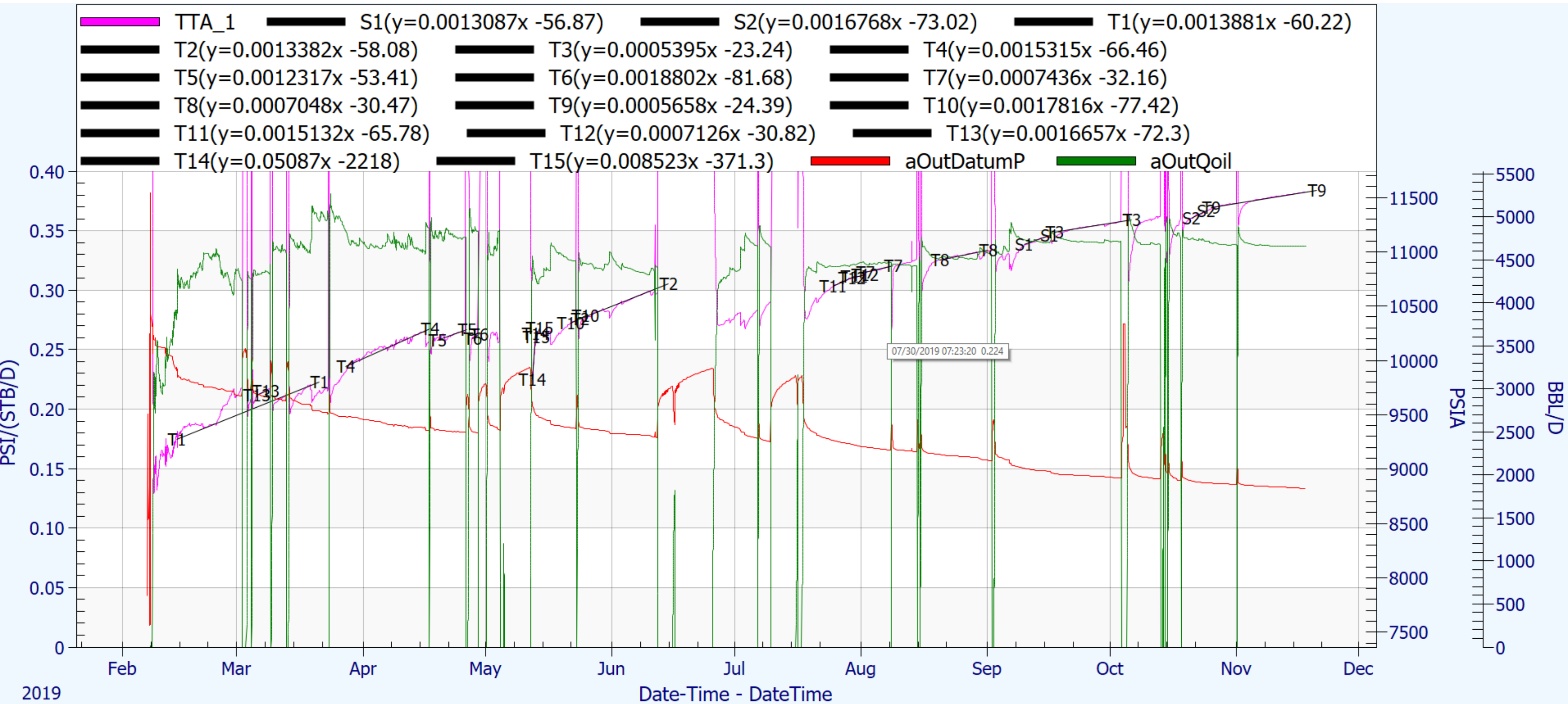
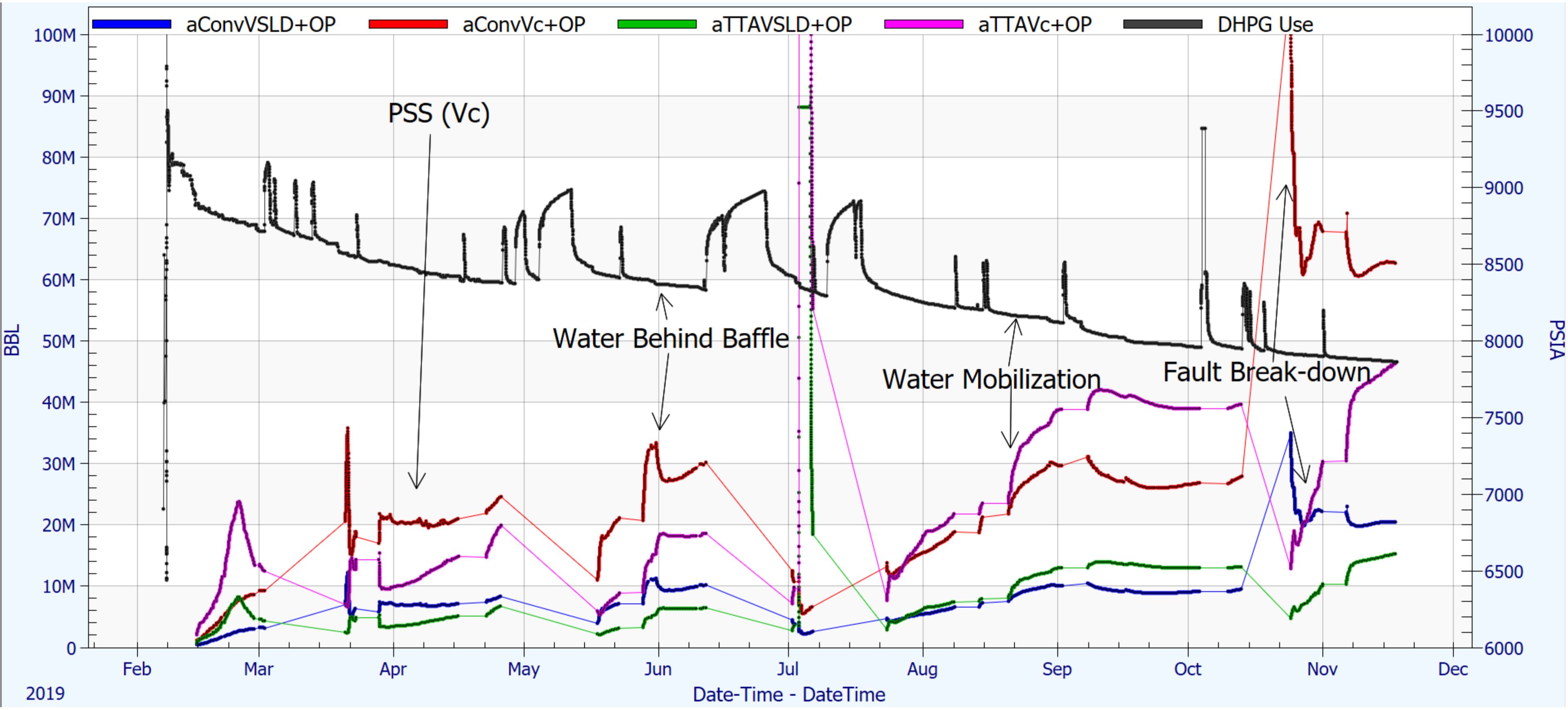
Changing Flow Regimes Example (DTTA/DT)



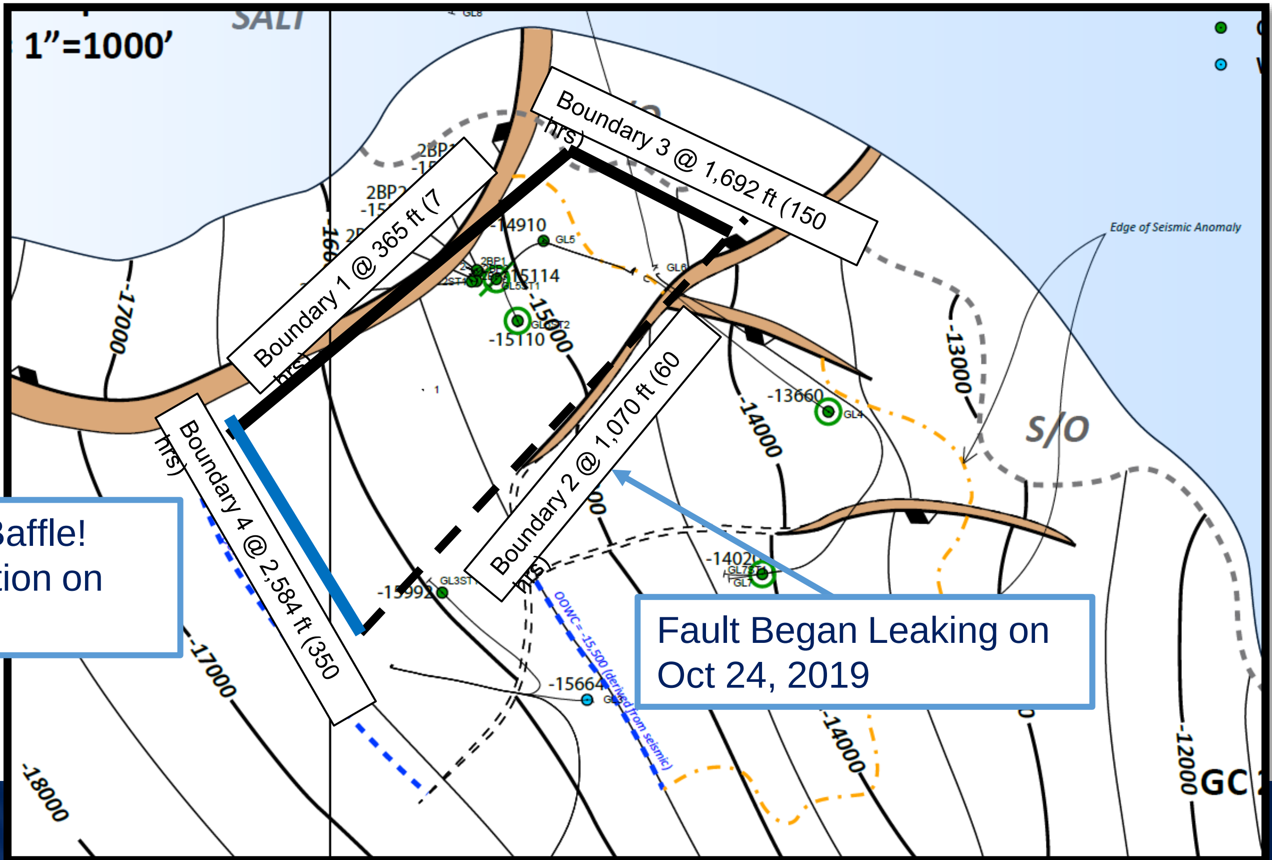
Different Flow Regimes



Geo/Map Comparison – Original Boundaries March 2019 (Main Channel) with Baffles/Leaking Boundaries

Boundary 1 at 365 ft (7 hrs)
Boundary 2 at 1,070 ft (60 hrs)
Boundary 3 at 1,692 ft (150 hrs)
Boundary 4 at 2,584 ft (350 hrs) Baffle/OWC

In-Place HC Volumes			
Volume1	1,3 x 2,4	22.5	MM STB
Volume2	1,2 x 3,4	18.3	MM STB
Volume3	1,4 x 2,3	24.3	MM STB



Water Behind Baffle!
Water Mobilization on Aug 21, 2019

Fault Began Leaking on Oct 24, 2019

Decline Analysis Practice Questions

Question 1

1. Find Conv. And TTA volumes in MM STB for a well:

DP-DT Slope = 11.5 PSI/Day
TTA Slope = 0.0025 PSI/(STBD)/Day
Pressure = 12,000 PSIA
Qavg = 5,000 STB/D
Ct = 0.000015 SIPS

Question 2

2. Based on your volumes, what can you tell about the reservoir?

Question 3

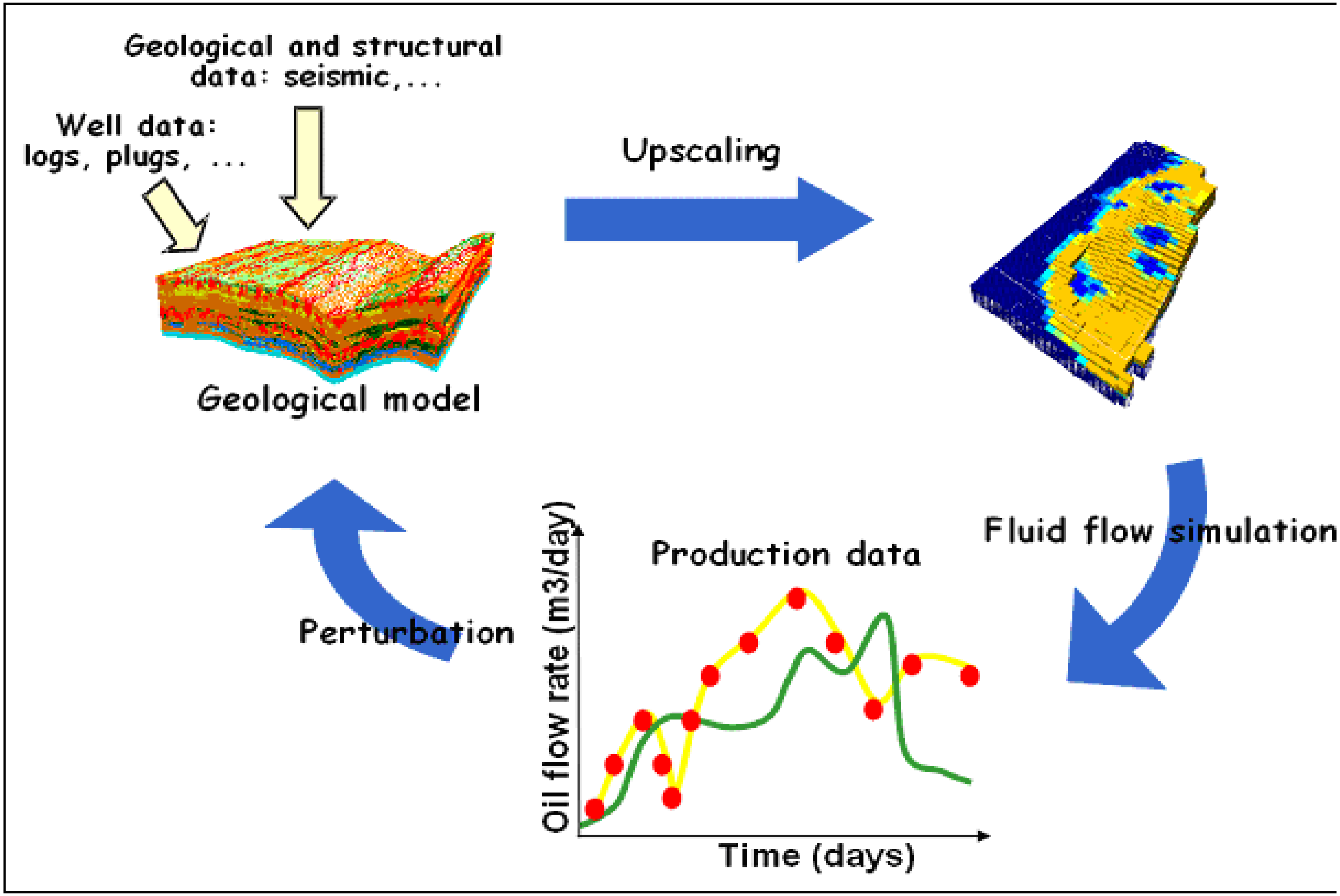
3. For the same well, find the volumes after six months of production:

DP-DT Slope = 9 PSI/Day
TTA Slope = 0.0012 PSI/(STBD)/Day
Pressure = 11,900 PSIA
Qavg = 8,100 STB/D
Ct = 0.000015 SIPS

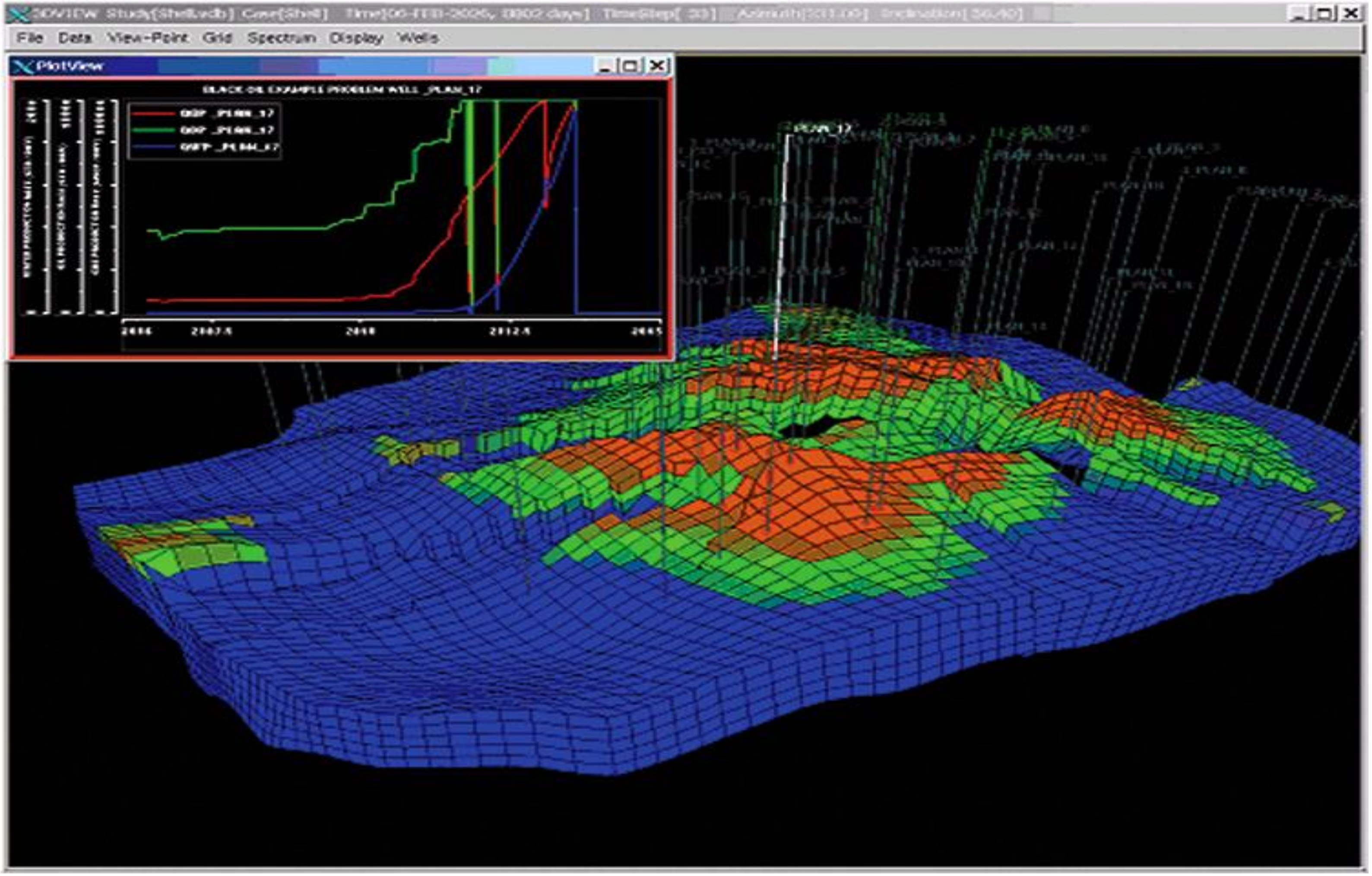
Question 4

4. Based on your decline analysis, please elaborate on the changes in volume and reservoir.

Reservoir Simulation Cycle

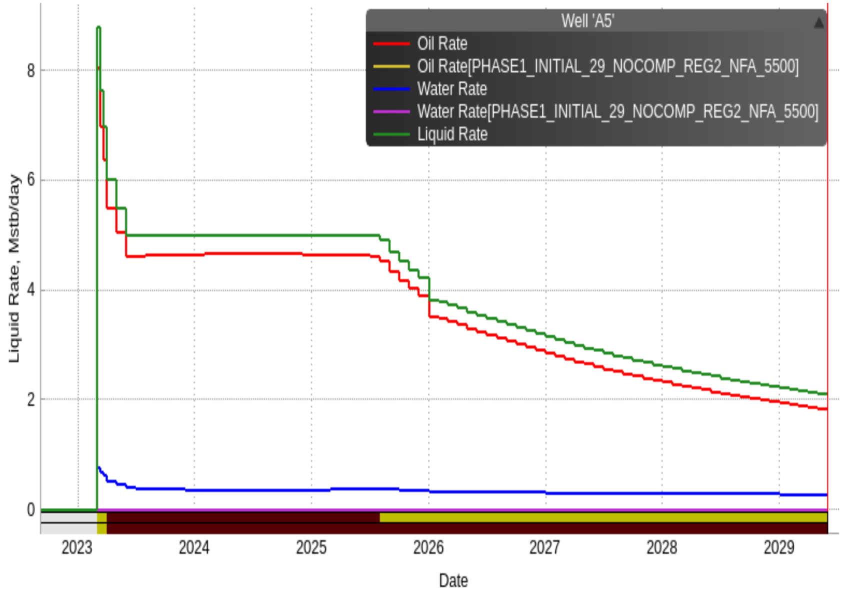


Reservoir Simulation Grid

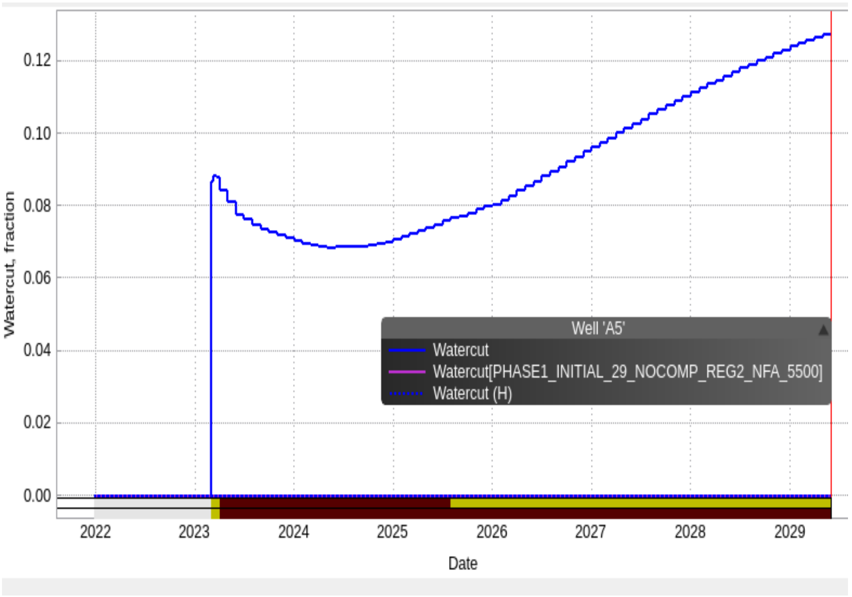


Long-Term Forecast from Res. Sim.

Qoil, Qwater & Qtotal Forecast



Water Cut Forecast



Tools That Have Been Automated

- Pressure Transient Analysis – PBUs, DDs and Multi-Rate Tests
- Wellbore Regime Recognition
- Nodal & Transient Nodal Analysis
- BHP Conversion
- Static & Flowing Material Balance
- Decline Analysis (Conventional & TTA)
- Auto-Feed to Reservoir Simulation Models

Reservoir Volume Calculation Summary

Methods for Calculating Reservoir Volumes

Method	Type of Volume	Comment
Boundary Volumetric	In-Place	Boxcar or Pyramid Rule
Static MBAL	In-Place	SLD & Vc Bookends (no TTA)
Conventional Decline	Connected	Pressure Decay
Flowing MBAL	Connected	SLD & Vc Bookends (no TTA)
TTA Decline	Mobile	TTA (Pi-Pwf/Q) Decay

- Note: Methodology and Equations used to calculate the volume vary based on phase behavior in the reservoir and drive mechanism

Break

Part 3

Outline Part 3

- Review of Reservoir Volume Calculations
- What is Your Job as a Surveillance Engineer?
- What can go Wrong with Your Well? How Can You Tell?
  - Using Mobility-Thickness to Predict Catastrophic Shear Failure Pressure
  - If there's Time: Artificial Lift (Gas Lift, Pumps – ESP, PCP, Sucker Rod – Dynamometer Diagnosis or gauge below standing valve, Jet Pump)
- Example: Managing a Trainwreck
- Tracking KPI's & Presenting Results to Management
  - Oil Well Example and Gas Well Example
  - Dashboards, Spreadsheets, Bubble Maps and Commentary
- Concluding Remarks

Review of Reservoir Volume Calculations

- Static & Flowing MBAL
- Boundary Volumetric (Boxcar and Pyramid)
- Conventional Decline
- TTA Decline

- **Remember the Bookends:**
  - **SLD (Strong Water Drive)**
  - **Vc (Expansion/Depletion/Compaction)**

Review: Static &Flowing MBAL

Review Working Equations

Oil Reservoirs:

Depletion Drive

Static MBAL Vc $= \frac{N_p \times Bo}{Bo - Boi}$

Infinite Water Drive

Static MBAL SLD = $N_p \ x \ \frac{P_i}{P_i - P^*}$

Gas Reservoirs:

Depletion Drive

Static MBAL Vc $= \frac{G_p \times Bg}{Bg - Bgi}$

Infinite Water Drive

Static MBAL SLD = $G_p \ x \ \frac{P_i}{P_i - P^*}$

Correction Factor to account for formation compressibility: Cpp/Ct, where Cpp is the compressibility of the primary phase.

Static MBAL uses Shut-in P*/Preservoir; Flowing MBAL uses Projected P*/Preservoir

Review: Boundary Volumetrics (BV)

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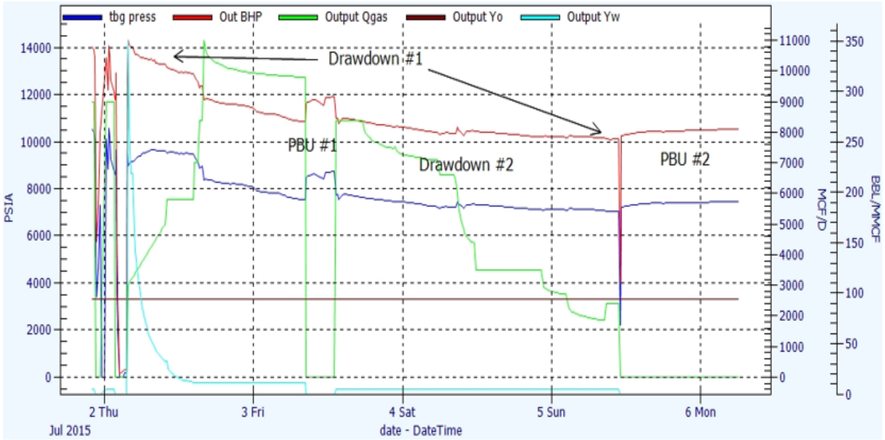
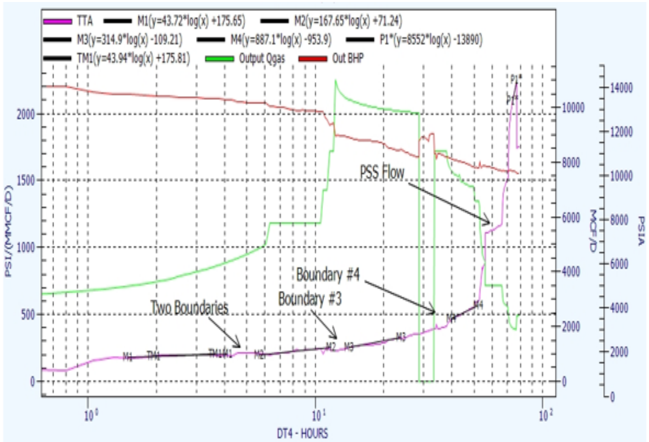
1 Choosing a Delta Time PTA Test



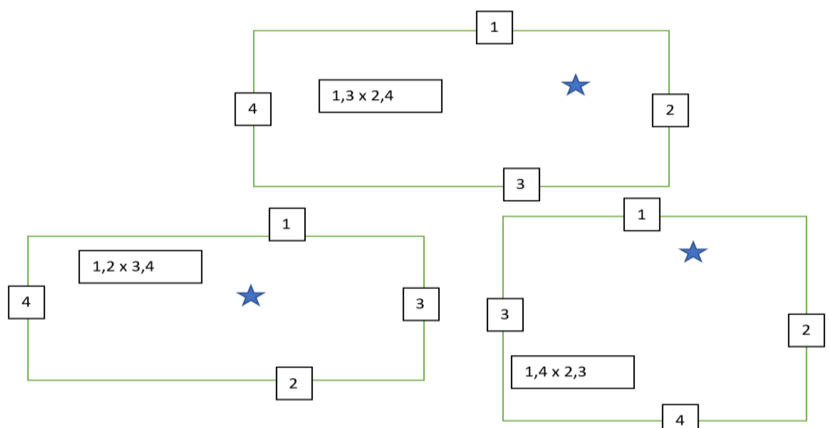
2 Finding Boundaries – Drawdown #1

- **It is possible to hit 2 boundaries at the same time**
- **The slope shifts will tell the story**

Pinitial	14300	psi
porosity	0.29	fraction
Bg	0.5192	RB/Mscf
Sg	0.8	fraction
viscosity	0.0604	cp
Ct	28.06	µsip
Cf	10	µsip
perm	5.0	md
net pay	24	ft



4 Possible Boundary Configurations



3 Distance Calcs – Drawdown #1

- Hydraulic diffusivity η = 2682 ft^2/hr
- Pay count used = 24 ft

- Possible boundary 1 @ 4.5 hours = 220 ft
- Possible boundary 2 @ 4.5 hours = 220 ft
- Possible boundary 3 @ 12.3 hours = 363 ft
- Possible boundary 4 @ 39.2 hours = 649 ft

Review: Boundary Volumetrics (BV)

Step by Step Hydrocarbon In-Place Calculation Example

- Area 1 (1,3 x 2,4) = 506,256 ft^2
- Area 2 (1,2 x 3,4) = 444,698 ft^2
- Area 3 (1,4 x 2,3) = 506, 256 ft^2

Multiply by h (net TST pay) to get Spatial Volume (divide by 5.615 to convert from ft3 to bbl) – Boxcar (constant net pay) & Pyramid (1/3 net pay)

Multiply by porosity to get Pore Volume

Multiply by Sx to get Phase Pore Volume (x = g, o, w)

Divide by Formation Volume Factor to get Stock Tank Volumes

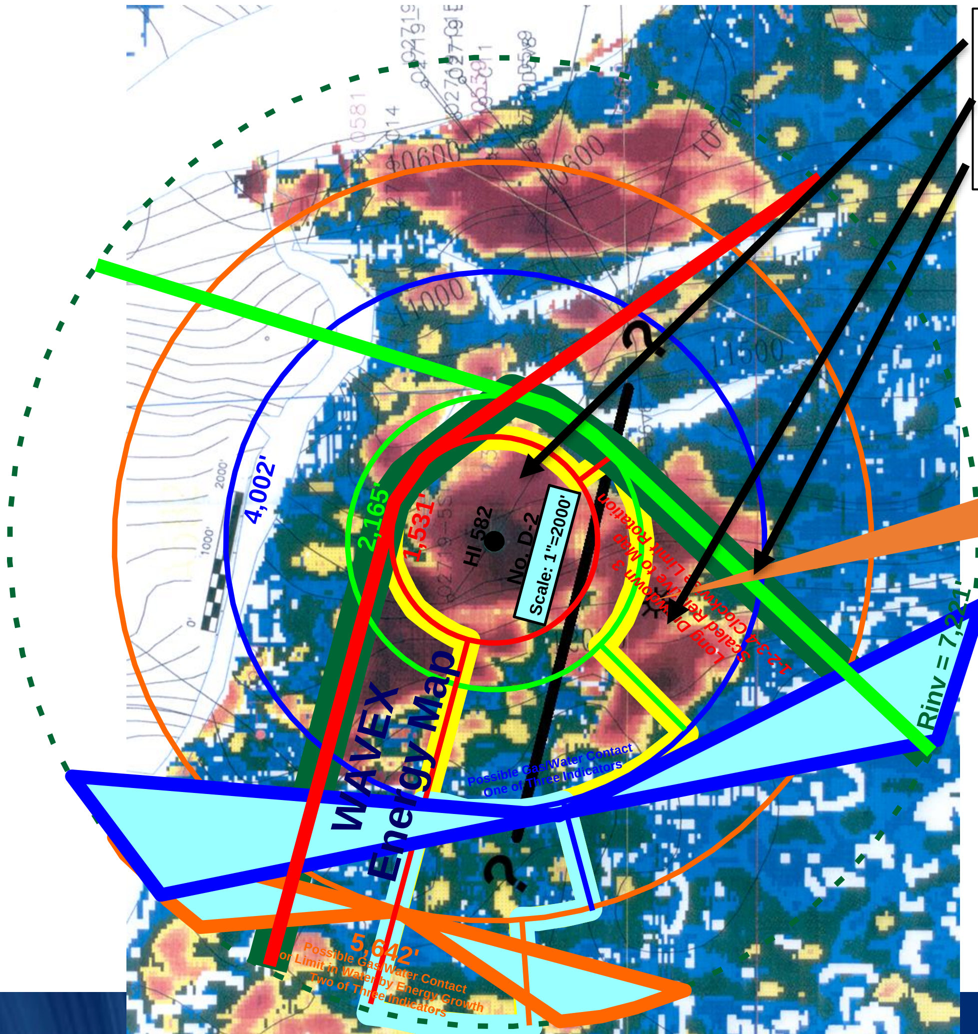
- Volume 1 (1,3 x 2,4) = 0.97 BCF (Boxcar) or 0.32 BCF for Pyramid Dump
- Volume 2 (1,2 x 3,4) = 0.85 BCF (Boxcar) or 0.28 BCF for Pyramid Dump
- Volume 3 (1,4 x 2,3) = 0.97 BCF (Boxcar) or 0.32 BCF for Pyramid Dump

To determine which boundary configuration is correct, we usually consult with the geologist's map

Note: Boundary configuration 2 is a channel. Channel reservoirs exhibit linear flow after the second boundary is encountered.

Review: Boundary Volumetrics (BV) – Blind Mapping

Boundary-Geo Overlay and Volume Comparison



Geo-Map Region 1 Volume = 18 BCF

Geo-Map Region 2 Volume = 10 BCF

Boundary Volumetric = 29 BCF

Still need that extra well?

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Review: Decline Analysis Equations

Working Equation Matrix

	Connected Volume	Mobile Volume
Depletion via Compressibility	$Conv.\ V_c = \frac{Q_{avg}}{Slope_{DP-DT}} * \frac{1}{C_t}$	$TTA\ V_c = \frac{1}{Slope_{DTTA-DT}} * \frac{1}{C_t}$
Straight Line Depletion via Displacement	$Conv.\ V_{SLD} = \frac{Q_{avg}}{Slope_{DP-DT}} * P_{res.}$	$TTA\ V_{SLD} = \frac{1}{Slope_{DTTA-DT}} * P_{res.}$

Review: Decline Analysis Workflow

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Workflow

- Identify straight-line sections in the DP-DT and the TTA Plots, draw slopes
- Only slopes during PSS/SS or Channel-Linear Flow considered
- Determine Produced Volumes at the point of the slopes
- Calculate Remaining and Total Apparent Volumes for the 4 Decline Analysis Methods

Basic Concepts

Reservoir Behavior

- Transient Flow: Connected and Mobile Volumes are increasing
- PSS: Connected and Mobile Volumes stabilizes to a number

Any increase energy/volume after PSS could be due to:

1. Water: ConVc increases but the TTAVc stay the same
2. Water mobilizes: ConVc trend stays the same but the TTAVc starts the increase.
   - In some cases, TTA Vc > ConVc or ConVc (PSS) = TTASLD or TTA slope of zero (indicating infinite volume)
3. Low perm feed: ConvVc gradually increasing with TTAVc staying the same or ConvVc and TTAVc gradually increasing…

Review: Reservoir Volume Calculation Summary

Methods for Calculating Reservoir Volumes

Method	Type of Volume	Comment
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TTA Decline	Mobile	TTA (Pi-Pwf/Q) Decay

- Note: Methodology and Equations used to calculate the volume vary based on phase behavior in the reservoir and drive mechanism

What's Your Job as a Surveillance Engineer?

Gulf Coast Section

Surveillance Engineer Duties

- Everything you've seen has already been (or is in the process of being) automated
- You need to check the automation to make sure it's correct
- You still need to know how to analyze the data manually
- Your Job is to think about what it means…

…and What to do about it!

…and How to Use the Results to Make Your Company More Money!

<u>But…Don't Get Caught Up in Automation Bias!</u>

Well Performance Impairments

What Can Go Wrong With Your Well?

Keep Track of Changes in Well Performance:

a. Skin Increase (or initially higher than you thought it would be)
b. Perm Decrease (or initially lower than you thought it would be)
c. Res. Pressure Decrease (or initially lower than you thought it would be)
d. Lifting/Wellbore issues (Water Head, scale, asphaltenes, wax, obstruction, tubing leak, parted string, bad packer seal)
e. High Flow Line back-pressure (flowline impairment/waxing/obstruction)
f. Flapper partially closed
g. Coning Gas and/or Water (High DD/High Skin)
h. Inefficient GLG/bad GLG design/Multi-porting
i. Non-Optimal Pump Design/Operation
j. Flow behind pipe (esp. water)
k. Choke plugging
l. Choke & Pipe Erosion (Solids)

Reserve Recovery/EUR/NPV Impairments

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What Can Go Wrong With Your Well?

Keep Track of Changes in Reserve Recovery:

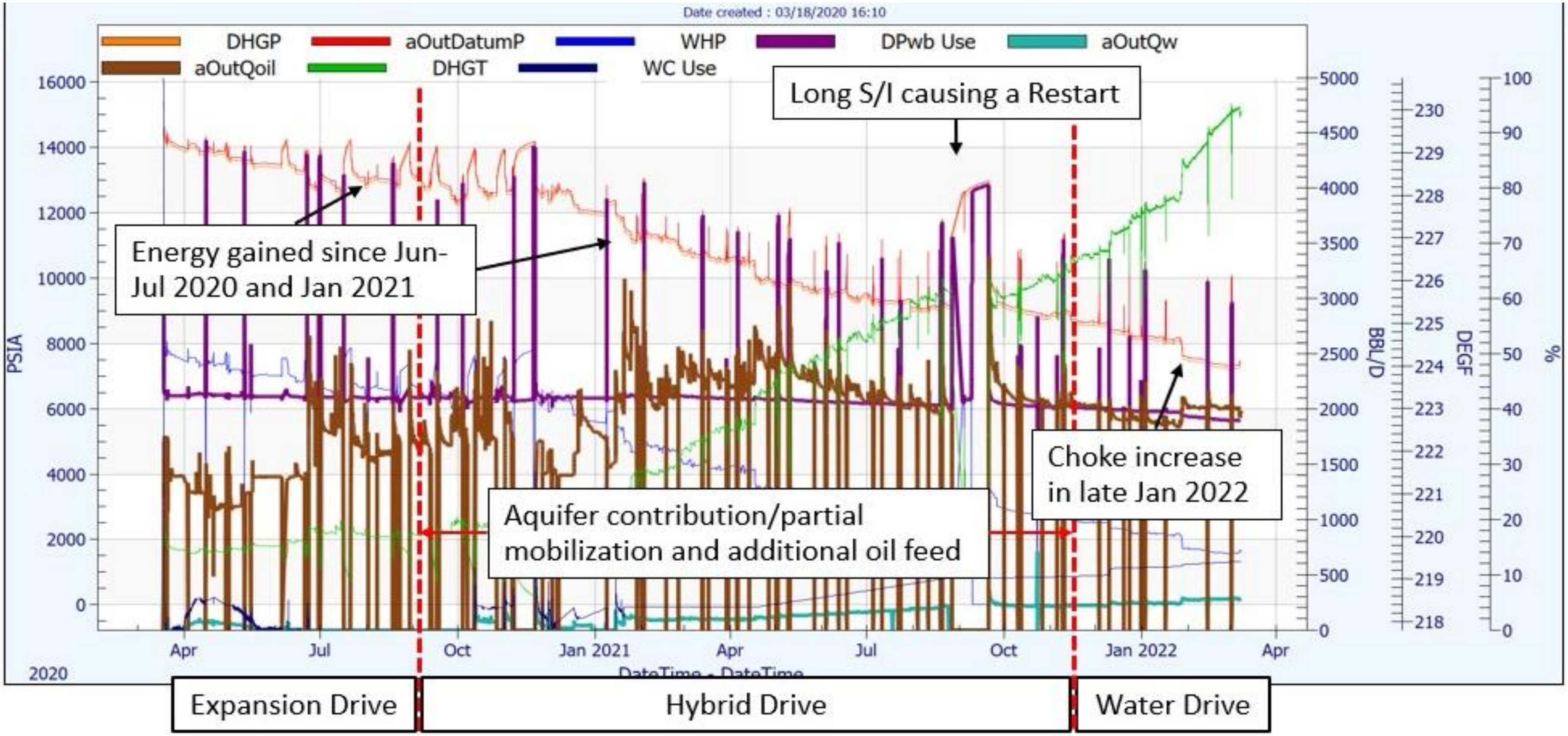
Are You Sure Your Reserves were Right in the first place?

- Will Throwing Money at the Problem Change That?
- Saving Money by Not Spending it on a Dog Well is Really Making Money!

a. Value Destruction Just to Get a High 1st Month's IP
b. Falling in Love with a Rate or Opening the Choke until it sands up (Proppant Fluidization & Catastrophic Shear Failure)
c. Unexpected Change in produced fluids (flow behind pipe, early break-through)
d. Shifting to the wrong ICV/SS position
e. Fault Activation/Baffle Jumping
f. Drilling Development Wells You Don't Really Need
g. Frac Hits
h. Asphaltene Plugging
i. Screen Cutting (Sand + Velocity)

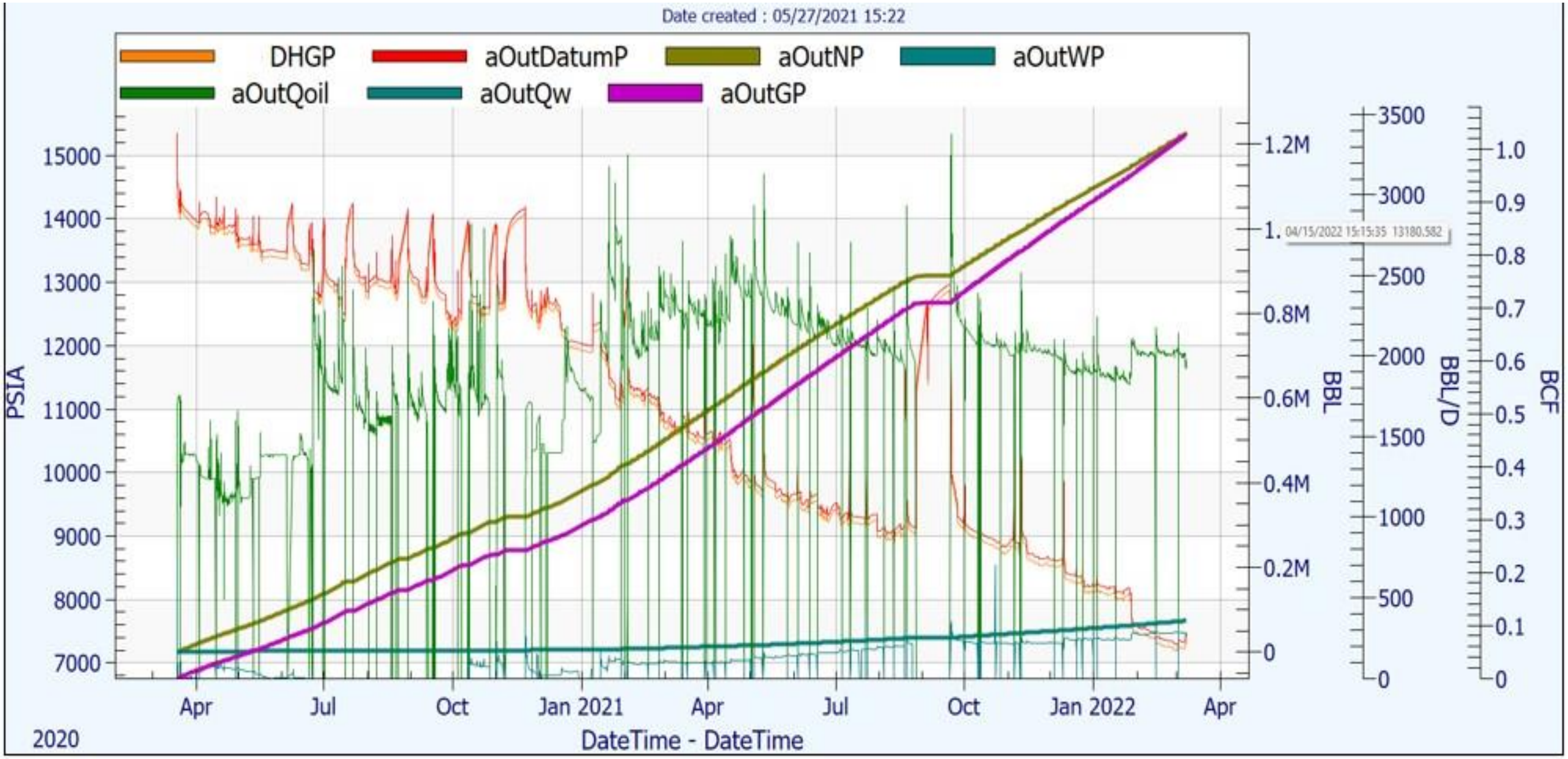
Sand Failure Pressure from Mobility-Thickness Decay

Events Overview



- The energy increases from June-July 2020 and in January 2021 were due to an aquifer/oil feed from vertical baffles/laminations. Aquifer support was more evident based on the Aug-Sep 2020 data. It is possible that the water started contributing sooner
- Noisy pressure data made it challenging to separate the oil and the water volumes

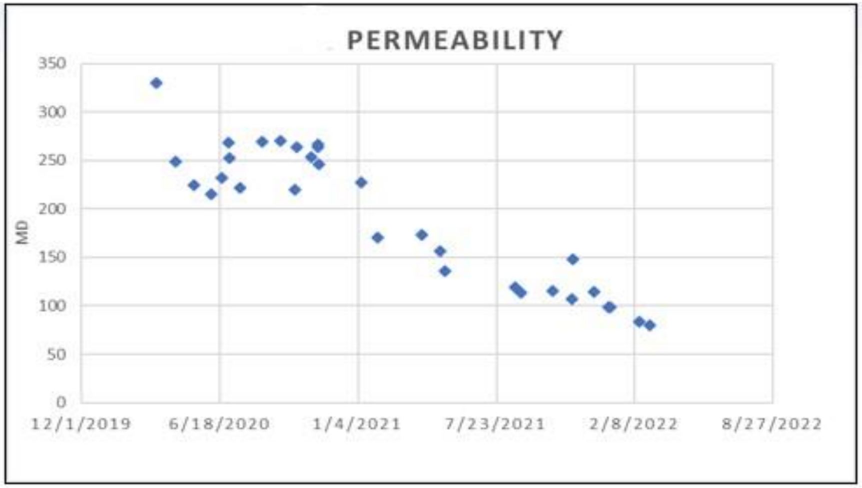
Production History

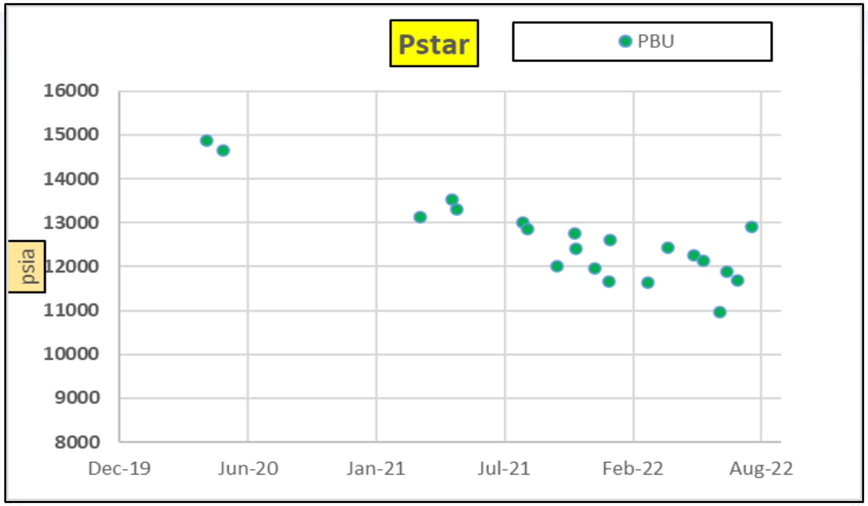


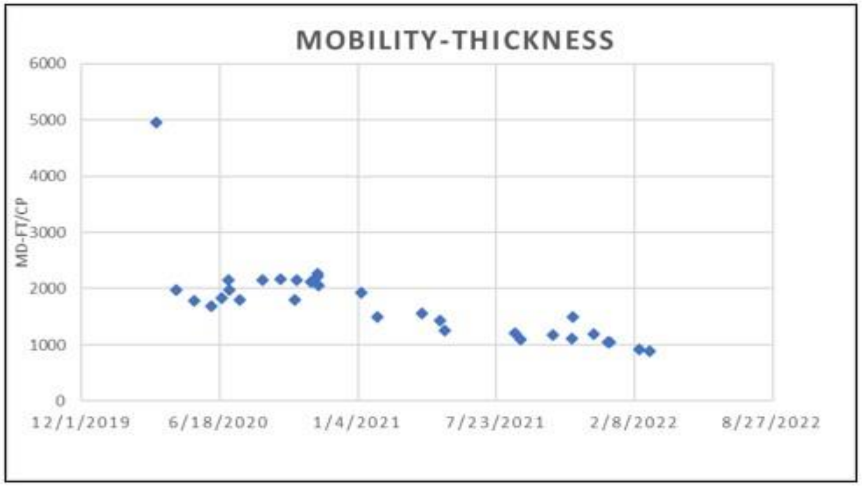
Cumulative Production (as of March 08, 2022):

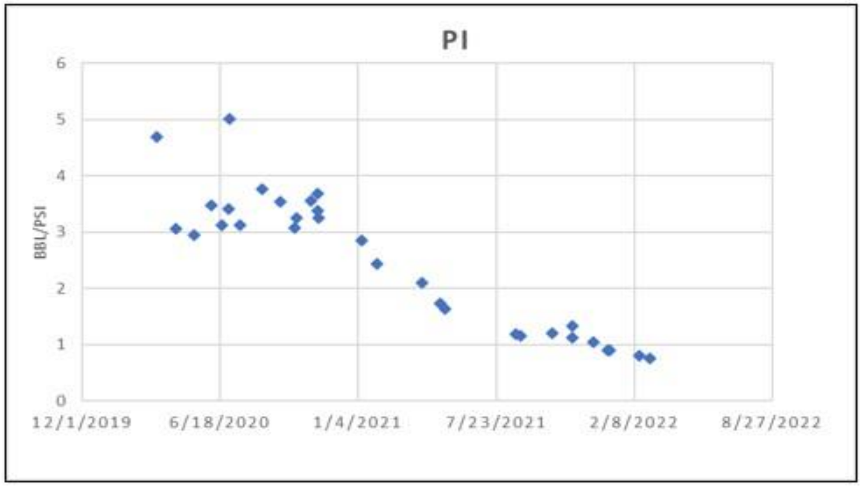
- Np – 1.23 MM STBo
- Gp – 1.03 BCF
- Wp – 0.075 MM STBw

Historic PTA

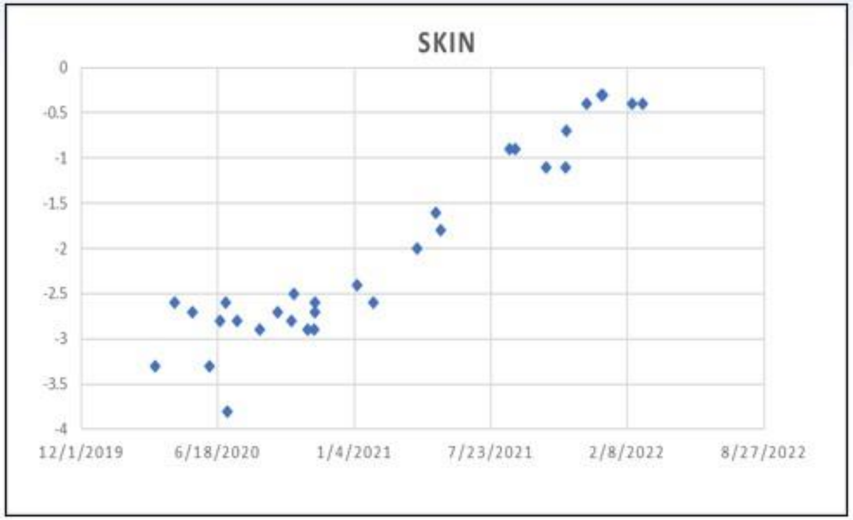


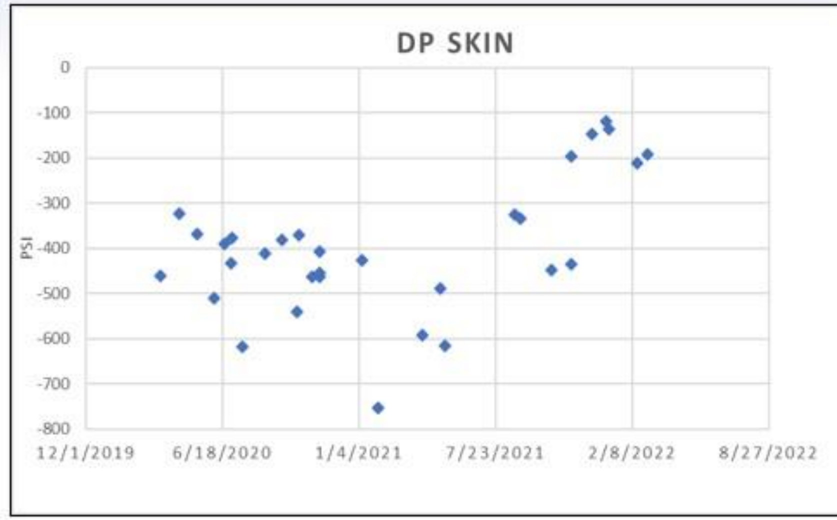


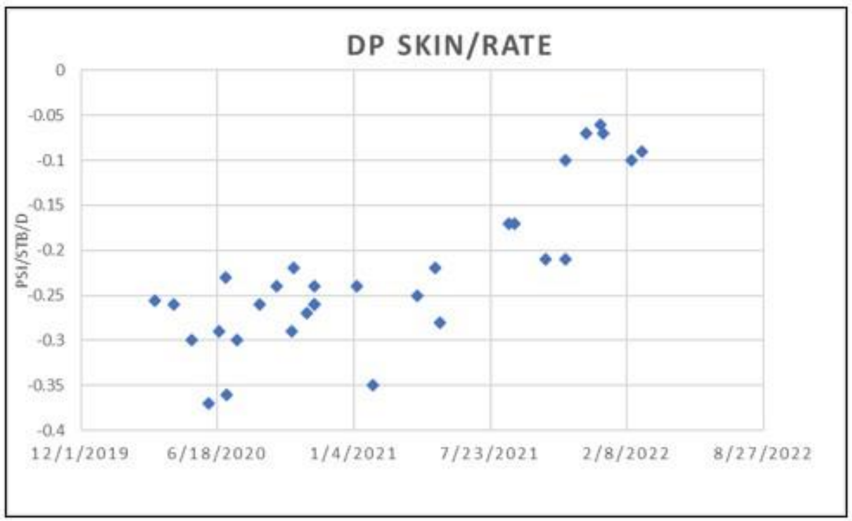


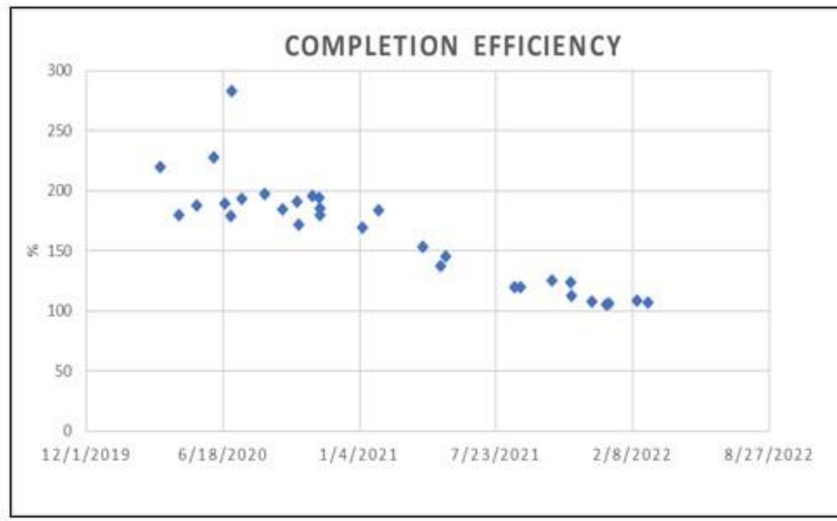


Historic PTA Cont.

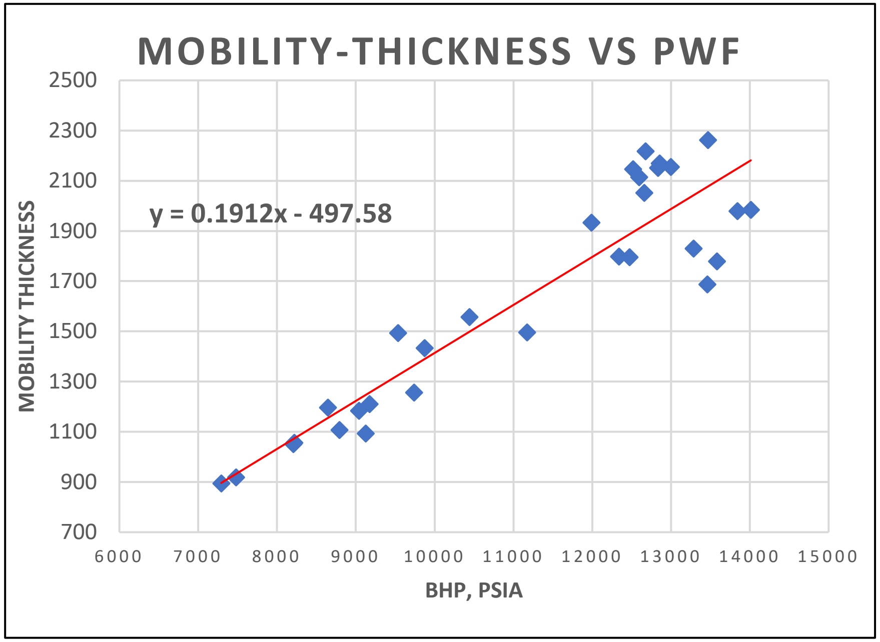


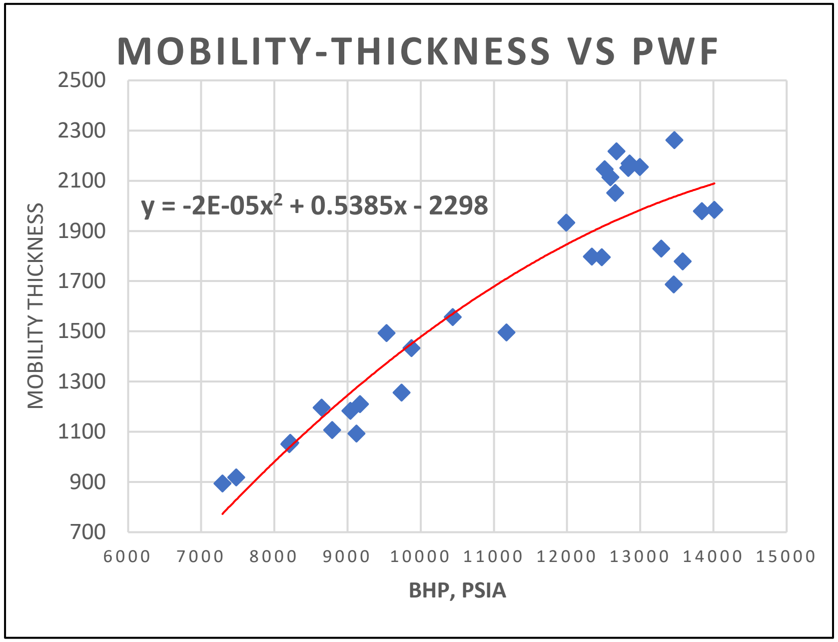






Sand Failure Pressure





- Fitting a linear decline in the trendline and extrapolating it to where the Mobility Thickness equals zero gives us a failure pressure

- The estimated failure pressure for the sand is based on the linear trend is 2,600 psia; however, it is likely to decay in a parabolic fashion. Hence, the failure pressure has been set at 5,500 psia until additional data has been acquired

The Short List of Big Trouble!

Gulf Coast Section

Well Performance/Recovery: Prevent These!

- Ripping the completion out of the ground
- Tearing up your tubing/flow lines/chokes
- Gunking-up your well bore or completion with scale or asphaltenes
- Cutting out your screens
- Coning water and/or gas
- Flowing the Wrong Zone (Check your ICVs!)
- Burning up/Breaking your pump

How Do you Tell?

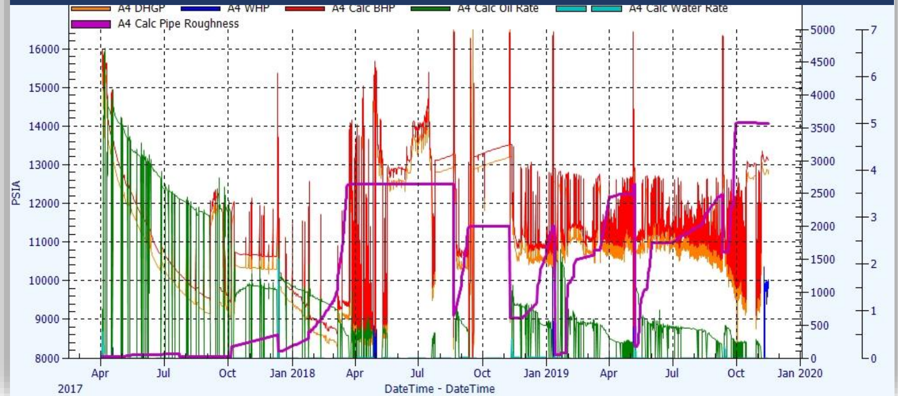
- Figure out what catastrophe looks like
  - Which Failure Modes are Likely/Possible/Unlikely
- Train your system and your engineers to look for it and try to prevent it (without catastrophizing)
- Work Out Decision Trees with Ops/Production/Reservoir/MGMT to know what to do when something bad happens
- Recognize when you have a problem you can’t fix economically
- Look for ways to Make or Save you company More Money!

Example of Recognizing a Problem that Cannot be Fixed

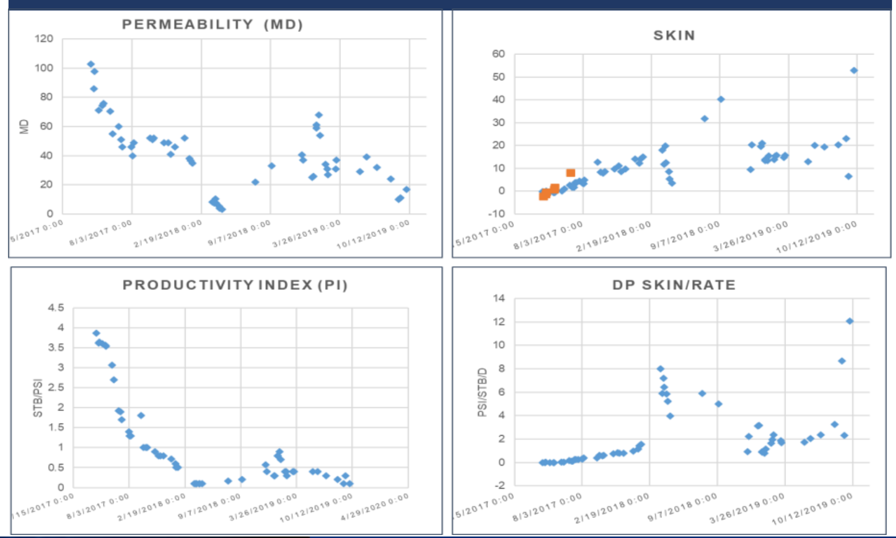
Case Study Description

- **Situation Overview:** Small to mid sized GoM Operator – observed a reduction in well's performance soon after the well came online
- **Instrumentation and Data Acquisition:** WHP/T and DHGP/T data available with a test separator on the platform
- **Surveillance Program Thesis:** To monitor and evaluate day to day the reservoir, completion, and wellbore performance, identify root cause of performance impairment and suggest remedial actions
    - PVT and AOP Modeling
    - Rate Determination (Spot & Allocation) and BHP calculation
    - Well Performance Evaluation (skin, perm. P.I, etc.)
    - Reservoir Volume Determination
    - Wellbore Lift Efficiency
- **Results:** Recognized AOP at the initial reservoir conditions and asphaltene deposition on the screens soon after the startup. Manage the Failure!
- **Is it worth a $5MM stim job to recover $3MM worth of oil?**

Well Production History



Time-Lapse Auto PTA Dashboard



Putting it All Together

- Understand as much as you can about your well/reservoir performance and failure modes
  - Skin, Perm, Completion Efficiency
  - Reservoir Volumes
  - Formation Strength & Stress
  - Sanding Potential
  - Hydraulics (Efficient Lift)
  - Compaction
  - Screen and Wellbore Velocities
- Turn that Knowledge into a Dashboard that Everyone Can Understand (and Can Use to Make More Money!)

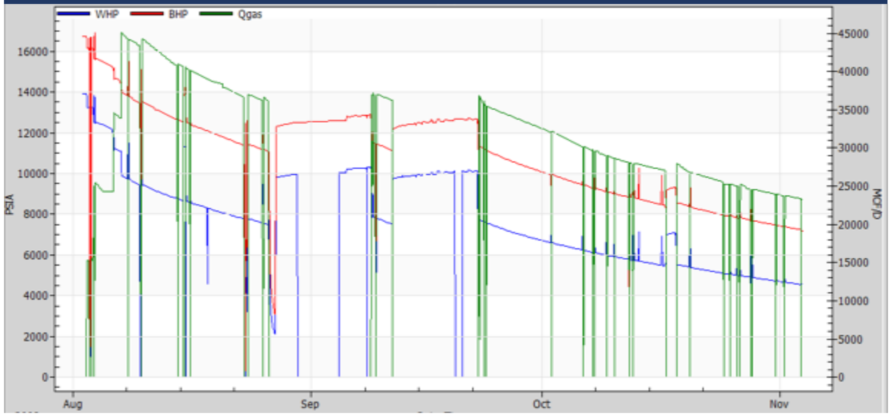
Real-Life Surveillance Example: Gas Well

SPE International
Gulf Coast Section

Case Study Description

- **Situation Overview:** Supermajor GoM Operator wanted support on best reservoir and production practices on one of the early Deep Miocene shelf gas well
- **Instrumentation and Data Acquisition:** WHP/T and data available with a test separator on the platform
- **Fluid Description and Reservoir Strength:**
    - Gas condensate with a yield of 15 BBL/MMcf
    - Strong reservoir rock with a Cf of 8 microsips
- **Surveillance Program Thesis:** To monitor and evaluate the reservoir and completion performance and determine how to maximize NPV against the aquifer front
    - Rate Determination (Spot & Allocation) and BHP calculation
    - Well Performance Evaluation (skin, perm. P.I, etc.)
    - Reservoir Volume Determination
    - Water contact (edge) tagged with PTA/BV
- **Results:** Provided high-frequency BHP conversion based on WHP and gas rates to be able to use the surveillance tools and came up with the production strategy to outrun the water by producing at maximum rates until the water hits, then R/C to next zone up

Well Production History



Reservoir Volume Summary

- **In-Place Gas: 7.5 – 9.5 Bcf**
- **Connected Gas: 7.5 Bcf**
- **Mobile Gas: 5.0 Bcf**
- **Likely EUR: 4.5 Bcf**
- **Water Volume: 6 MM STB**

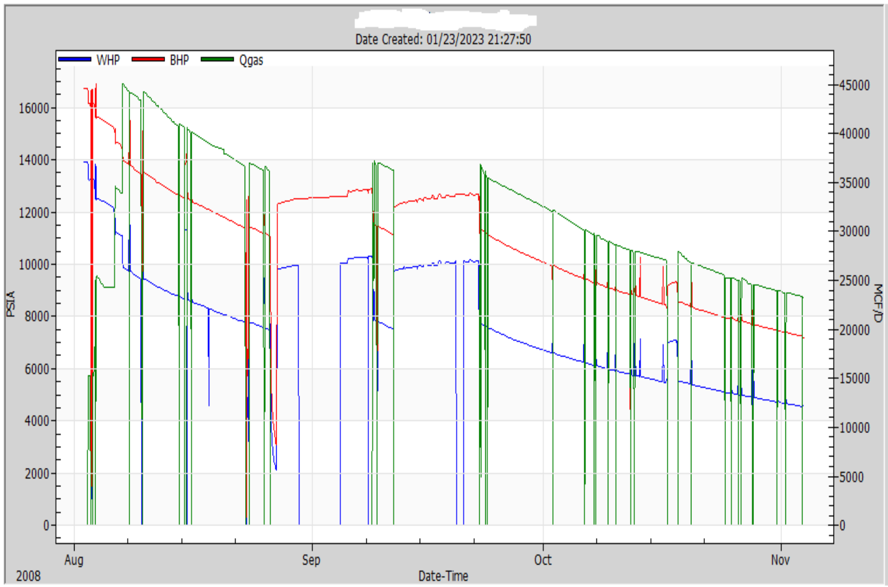
The well will likely make about 4-5 Bcf, then load up and die…

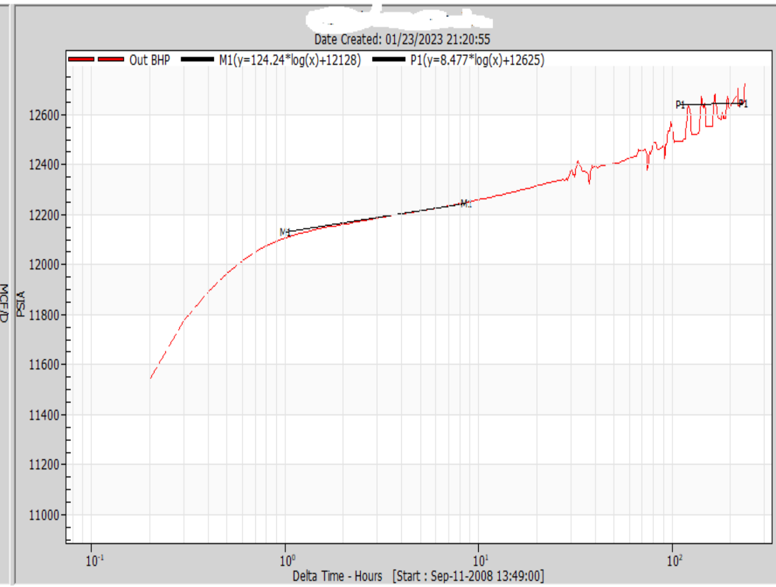
Real-Life Surveillance Example: Gas Well

Auto PTA Checks

Summary | PBU | DD | Derivative | Daily Values | PTA/Productivity | HC Volumes | P/z | Yields | Analysis Events | Analysis

	Start D/T ddMmmyyyy hh:mm:ss	End D/T ddMmmyyyy hh:mm:ss	Test Length Hours	Test Type	WHPi psia	WHPf psia	DHGPi psia	DHGPf psia	BHPi psia	BHPf psia	QGasi Mcf/D	QGas Mcf/D	Perm md	Skin	DPskin psi	PStar psia	PI Eff %	DPs/Q psi/MMcf	kh/mu md-ft/cp	Mid Slope psi/cycle	P* Slope psi/cycle	Report Link
1	15Aug2008 09:37:00	15Aug2008 16:49:00	7.2	PBU	8641	11313	-99999	-99999	12508	13913	40557	40557	16.3	1.4	233	14343	82	5.74	16271	195.1	189.433	ODSIRTRep_2008Aug15_093
2	23Aug2008 09:31:00	23Aug2008 18:19:00	8.8	PBU	7755	9330	-99999	-99999	11372	11770	36506	36506	NaN	NaN	NaN	13021	NaN	NaN	0	0	198.842	ODSIRTRep_2008Aug23_093
3	26Aug2008 13:37:00	08Sep2008 20:01:00	318.4	PBU	7477	10277	-99999	-99999	11070	12852	36012	36012	NaN	NaN	NaN	13324	NaN	NaN	0	0	887.146	ODSIRTRep_2008Aug26_133
4	11Sep2008 13:49:00	22Sep2008 17:01:00	267.2	PBU	7504	10128	-99999	-99999	11110	12691	36205	36205	22.5	3.3	351	12812	66	9.71	24037	124.235	269.841	ODSIRTRep_2008Sep11_134
5	17Oct2008 03:07:00	18Oct2008 12:37:00	33.5	PBU	5448	7046	-99999	-99999	8423	9272	27000	27000	16.2	0.4	47	9692	93	1.75	20429	124.685	227.934	ODSIRTRep_2008Oct17_030



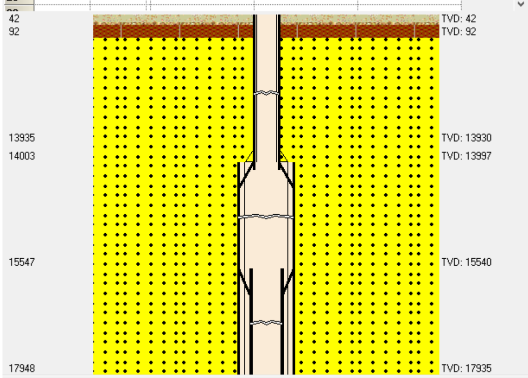


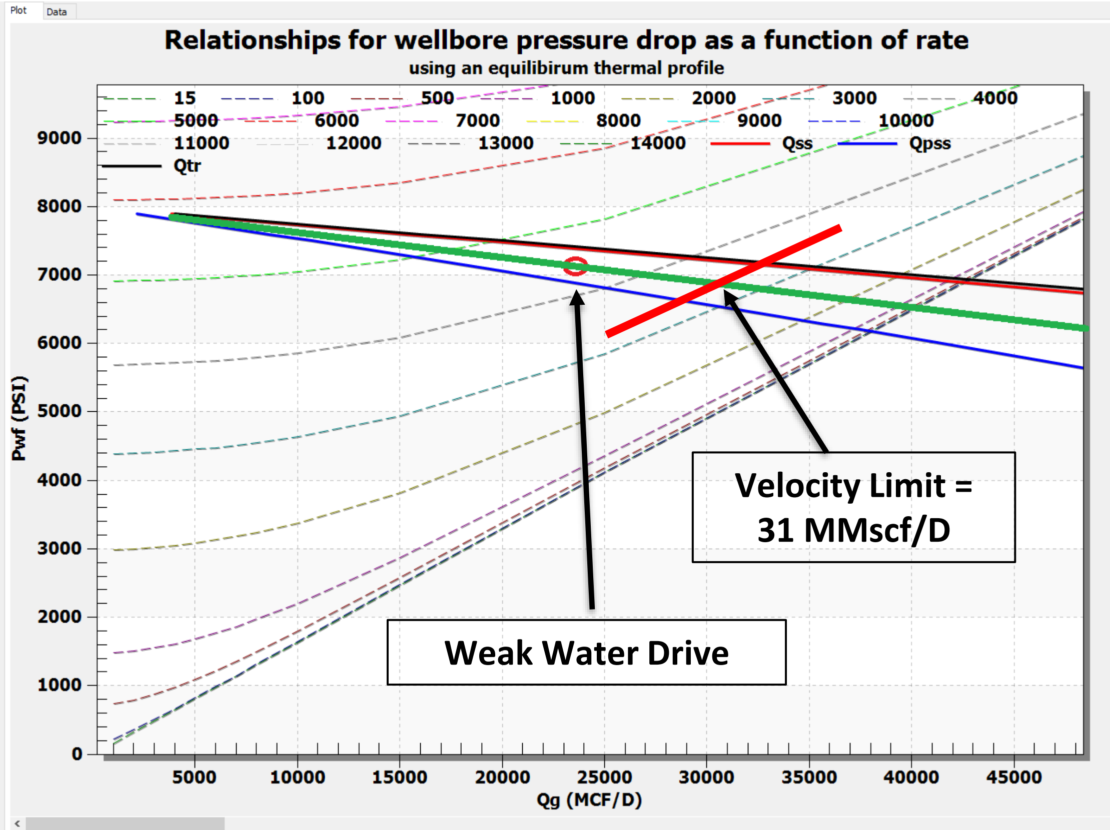
SLB-Private

Real-Life Surveillance Example: Gas Well

Check Match on NODAL – Are We Operating the Well Safely?

	Gas Rate	WHP	Inflow	Inputs	Units
1	1000	15	Pi	8000	psi
2	2000	100	PSTAR	8000	psi
3	3000	500	Max Pwf	8000	psi
4	4000	1000	Pwf Step	100	psi
5	5000	2000	Perm	16.2	md
6	6000	3000	Skin	0.4	
7	7000	4000	D	0.0000001	1/mcf
8	8000	5000	Time	1	Hours
9	10000	6000	Radius Override	☐ ss & pss	
10	15000	7000	Radius	0	ft
11	25000	8000	rw	0.500	ft
12	50000	9000	Net TVT Pay	44.0	ft
13	75000	10000	Porosity	0.20	
14	100000	11000	Sw	0.35	
15	125000	12000	So	0.00	
16	150000	13000	Sg	0.65	
17	175000	14000	Cf	3.65	microsips
18	200000		Plot ?	☑ Qss	☑ Qpss
19	250000		WCD Pwf	15	
20			Yo	15	BBL/MMCF
21			Yw	1.7	BBL/MMCF
22			Plot ?	☑ Qtr	☐ Qfrac
23			Frac Len	0	ft
24			Qg-Inj	-1	mcf/d
25			WCD Q	Qpss	
26			Calc WHT	◉ TFinal	○ From Shut-in
27					
28					



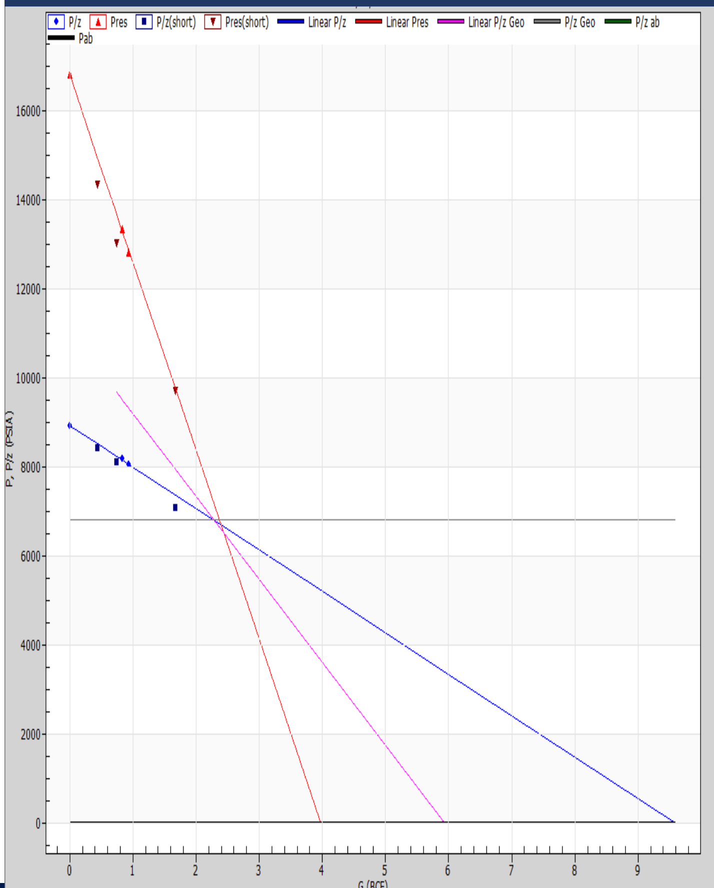


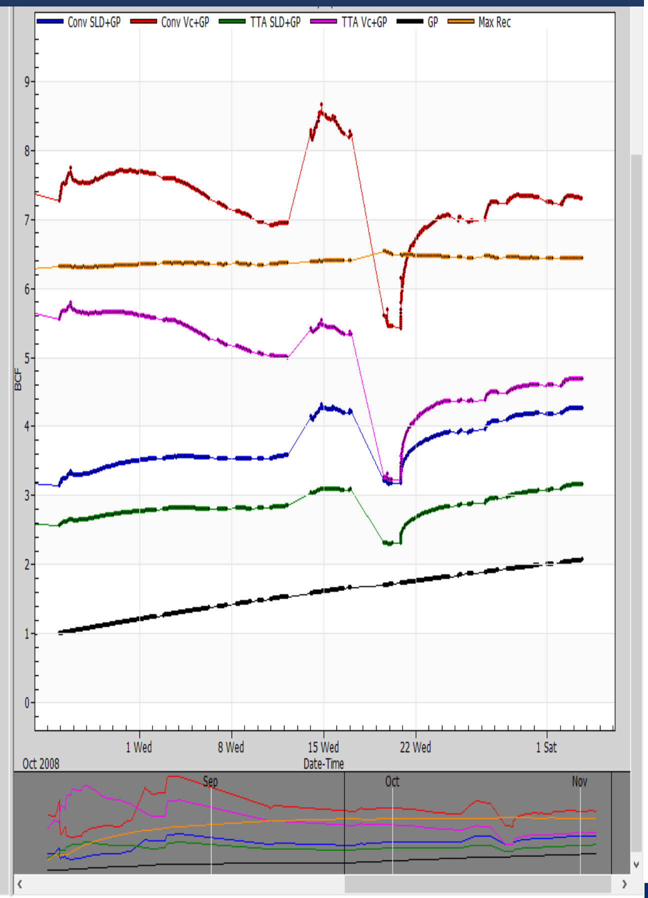
SLB-Private

Real-Life Surveillance Example: Gas Well

Reservoir Volume Determination

Static MBAL (P/z) and Auto-Decline Analysis





Res. Vol. Summary

- In-Place Gas: 7.5 – 9.5 Bcf
- Connected Gas: 7.5 Bcf
- Mobile Gas: 5.0 Bcf
- Likely EUR: 4.5 Bcf
- Water Volume: 6 MM STB

The well will likely make about 4-5 Bcf, then load up and die…

Real-Life Surveillance Example: Gas Well

Gulf Coast Section

Gas Example: Big Problem Checklist

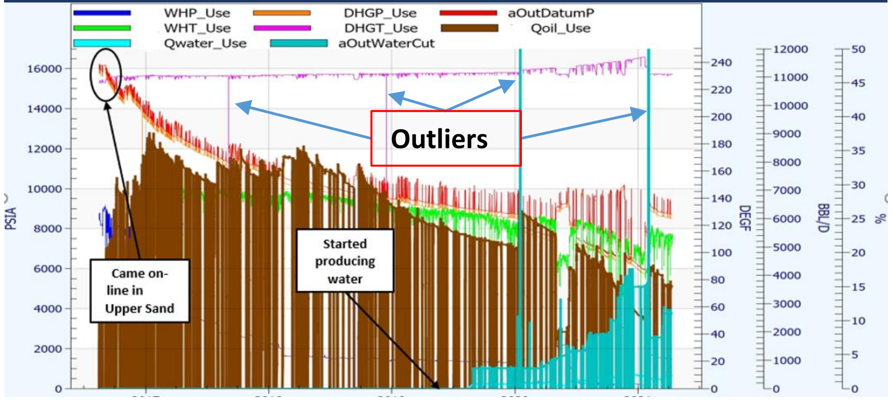
Potential Issue	Good/Bad/Ugly?	Comment
Compaction/Shear	Good	No Issues – Competent Rock…May need to reduce rate once water hits the well and compaction is evident
Completion Velocity	Potential Issues	Velocity issues with free water production, limiting the gas rate to 20 MMcf/D after water breakthrough
Scale	Possible	Unknown until water arrives; reserves likely don't justify a stim job if scale creates skin
Tubing Erosion	Unlikely	Limiting Velocity to avoid this issue
Flow Behind Pipe	Potential Issues	Lots of stacked pays and water sands…reserves don't justify a work-over if it happens

Real-Life Surveillance Example: Oil Well

Case Study Description

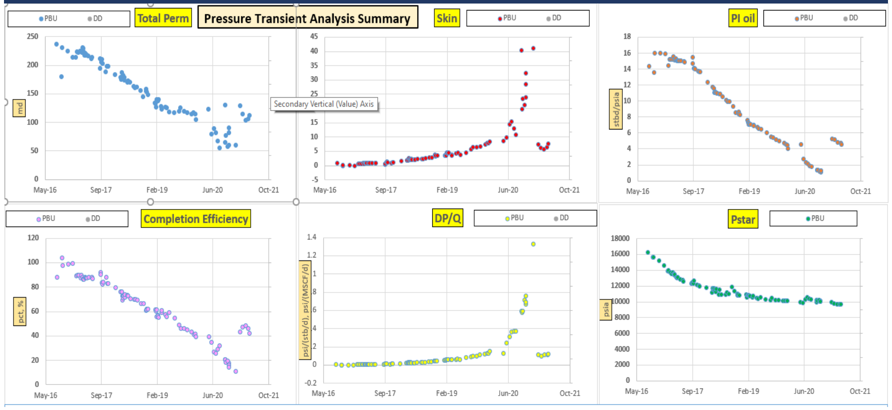
- **Situation Overview:** Mid-sized GoM Operator needed a detailed reservoir description on their first well in a newly discovered Deepwater Mid-Miocene field
- **Instrumentation and Data Acquisition:** WHP/T and DHGP/T data available with a test separator on the platform
- **Fluid Description and Reservoir Strength:**
  - Slightly heavy black oil (25° API) with a GOR of 700 scf/stb
  - Moderately strong reservoir rock with a Cf of 15 microsips
- **Surveillance Program Thesis:** To monitor and evaluate day to day the reservoir, completion, and wellbore performance, and propose projects to maximize the assets NPV
  - Rate Determination (Spot & Allocation) and BHP calculation
  - Well Performance Evaluation (skin, perm. P.I, etc.)
  - Reservoir Volume Determination
  - Water Contact (edge) tagged with PTA/BV
  - Wellbore Lift Efficiency
- **<u>Results</u>: Safely maximized NPV; Recognized a sudden decrease in permeability due to asphaltenes and proposed a xylene treatment to restore the well's performance**

Well Production History



Time-Lapse Auto PTA Dashboard

What can a few simple plots tell you?



Real-Life Surveillance Example: Oil Well

Gulf Coast Section

PTA Dashboard – Accreting Skin Example

Compaction

Significant & Unexpected Decrease in Perm Asphaltenes!!!

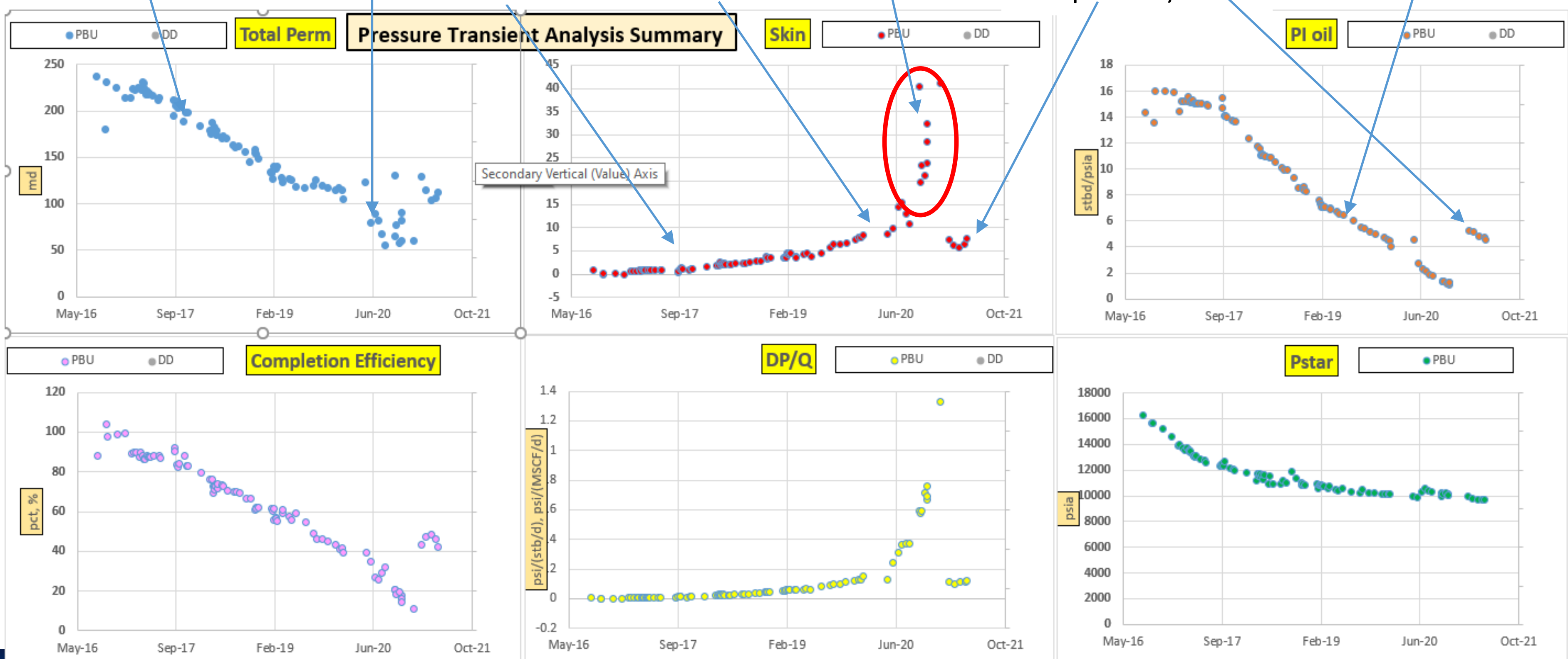
Fines (skin)

Scale & Fines

Oh my!!! Better pump some xylene!

Post-stim job – Back to Normal (Still dealing with compaction)

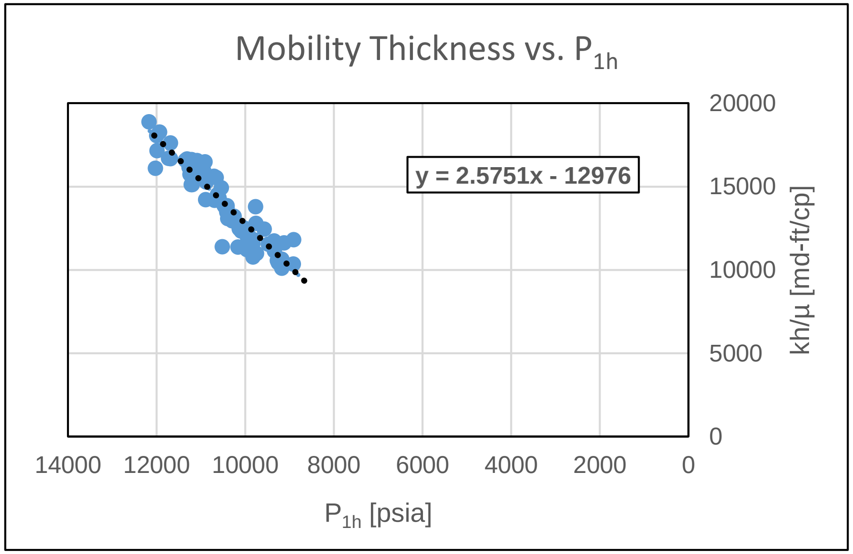
PI Reduction due to compaction and skin accretion (fines)



Real-Life Surveillance Example: Oil Well

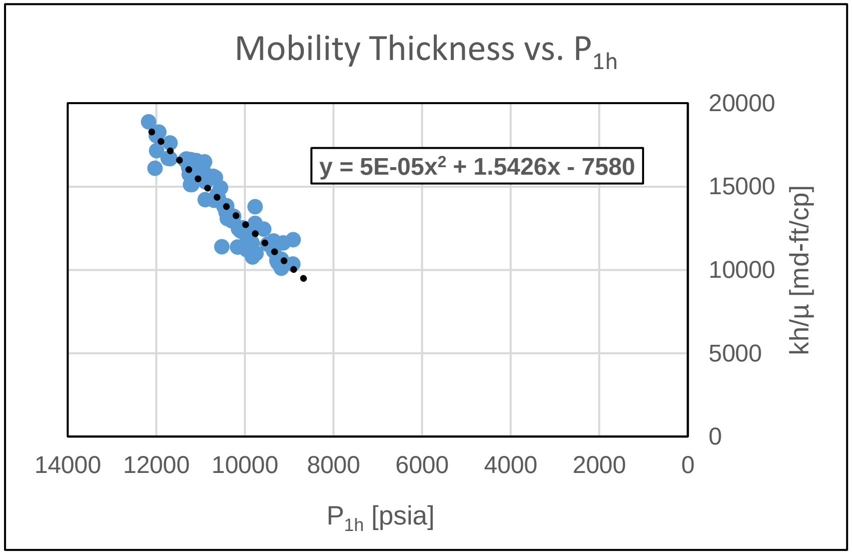
Reservoir Failure Pressure – Estimation

Linear Decline



Following a linear decline from the trendline gives us a failure pressure of ~5040 psia

Quadratic Decline



Following a quadratic decline from the trendline gives us a failure pressure of ~6130 psia

The possible range of failure for the reservoir is 5100-6200 psia
(Likely Pfailure = 5500 psia)

Field Level – Spare Capacity Dashboard

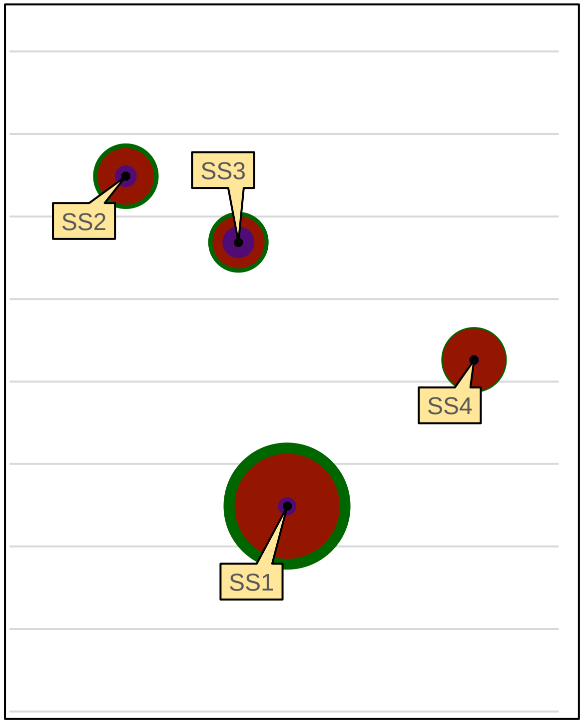
Safely Maximizing Well Performance and Reserve Recovery

Well	ODSI Current Rate (Oil) [stb/d]	Current WC [%]	Operator Current WC (%)	Operator DPR Oil [stb/d]	Operator ΔOil [stb/d]	Excess Capacity (Oil) [stb/d]	FDHGP [psia]	Minimum DHGP [psia]	Min DHGP Rationale	FBHP/Compaction Flag?	Screen Velocity Issues
SS01	10,630	16	15	10,807	-177	2,800	9,953	**8,500**	**Bad Ju-Ju Asphaltenes**	No	No
SS02	2,475	18	26	2,356	119	550	9,500	8,500	Asphaltenes	No	No
SS03	5,194	53	56	4,851	343	0	10,100	8,500	Asphaltenes	No	yes, at higher rates
SS04	5,396	12	14	5,294	102	550	8,650	6,200	Compaction / Sand Failure	Some, not critical yet	No
Sum =	23,695			23,308	387	3,900	**<--Excess Potential Oil Rate**				

Field Level – How Much is Left?

Proactive Surveillance keeps you well informed of your current NPV

GOM Subsea Wells



Well				Remaining EUR, MMSTBo			Comments / Recommendations
	Cum Oil Prod, MMSTB	Cum Gas Prod, BSCF	Cum Water Prod, MMSTB	P90	P50	P10	
SS01	23.5	16.3	1.8	6.80	9.97	14.45	Maintain current Ck setting, plan stim job if skin exceeds 20
SS02	6.2	4.7	0.7	1.60	2.62	3.12	Maintain current Ck setting
SS03	5.3	4.0	1.5	3.00	5.40	6.10	Flow the well as hard as possible for as long as possible to keep water away from the SS1
SS04	6.2	5.8	0.4	0.80	1.60	2.20	Ok to increase choke but monitor closely

Real-Life Surveillance Example: Oil Well

SS01 Oil Example: Big Problem Checklist

Potential Issue	Good/Bad/Ugly?	Comment
Compaction/Shear	Manageable	The well shouldn't get below 5500 psia unless it develops a large skin
Completion Velocity/ Screen Cutting	Possible Issues	Screen Cutting is possible if we try to flow the well at high rates with a high skin
Scale	Treatable	Drop Acetic/HCl if the skin gets above 20
Fines	Manageable	Normal Fines accretion…any stimulation/solvent treatment will push them back
Asphaltenes	**HFS!!!**	**Stay above 8500 psia!!!** **Potential Asphaltene Death Spiral!** 
Flow Behind Pipe	Possible	That Water Sand about 100' up the hole looks ornery…if it breaks through, the reserves justify a R/C Squeeze
Early Water Front Arrival	Possible	Trying to balance withdrawal rate from SS03 and SS01 decay to shape the water front/Maximize EUR & Stay Above AOP

Concluding Remarks

“Surveillance” is Often Used Only to Look Back AFTER a Well Failure to Look for a Scapegoat!

What if We Used the Same Tools to Be Proactive…

…And Make/Save Our Company More Money?

Whose Problem is it?

- Drilling: We got the hole down – it’s not my problem
- Completions: The well flowed – it’s not my problem
- Frac’ing: We pumped all the sand – INMP
- Facilities: I designed it for what you told me the rate was going to be – INMP
- Production: Not a wellbore or skin problem – See my Nodal!
- Reservoir: It’s not a perm/Volume issue – See MY Nodal!!
- Geology/Exp: It HAS to be big! Must be someone else’s **fault**!
- Petro-physics: The interpreted log says it’s HC bearing – the water must be coming from somewhere else

Well…

- Drilling: Fluid Type/Losses can induce damage
- Completions: Fluid Type/Losses, Completion Type and Execution can affect performance
- Frac'ing: If you frac out of zone or the proppant gets crushed, your frac may not be any good
- Facilities: Do the best you can with what you have
- Production/Reservoir: Find the pressure drop that shouldn't be there!
- Geology/Exp: Communicate with RE – How big is it? Do the perms make sense!
- Petro-physics: Try digging up the 'raw" *.las data; don't assume that the service co. "interpreted" it correctly

It’s Everybody’s Problem

- Understand what happened in the Past
- Understand what’s happing Now
- Get an idea of what’s going to happen in the Future

Need a Non-Biased (non-bullying) way to sort things out

Surveillance Timeline

1-2 Months

- Initial Pres, Skin, Perm, Boundaries (Fluid Contacts), BV, Decline Volumes (Conventional & TTA), Initial Drive Mech.

2-6 Months

- Changes in the above, Static MBAL, Flowing MBAL, Changes in Drive Mech.

  (At This Point, You should really know what you've got)

6+ Months

- Keep an eye out for trouble (Changes in the Above)
- Optimize Production and Sales of Spare Capacity
- Watch for Scale, Asphaltenes, Compaction, Changes in Drive and Changes in Fluids

Conclusions

- Democratization of data and results within the organization and asset teams is critical for a proactive and effective surveillance program
  - Encourages a multidisciplinary approach to problem solving
- Automated surveillance and visual dashboards allows engineers to focus on what the results mean to improve production and EUR, which maximizes NPV
  - Analyze ALL of the data, not just the data you have time to look at manually
- Early detection of problems can be bucketed into short- and long-term problems to provide guidance on planning and scheduling
  - Capture opportunistic times for well remediation jobs to prevent prolonged downtime due to scheduling conflicts
  - Get ahead of problems and avoid trainwrecks

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Gulf Coast Section

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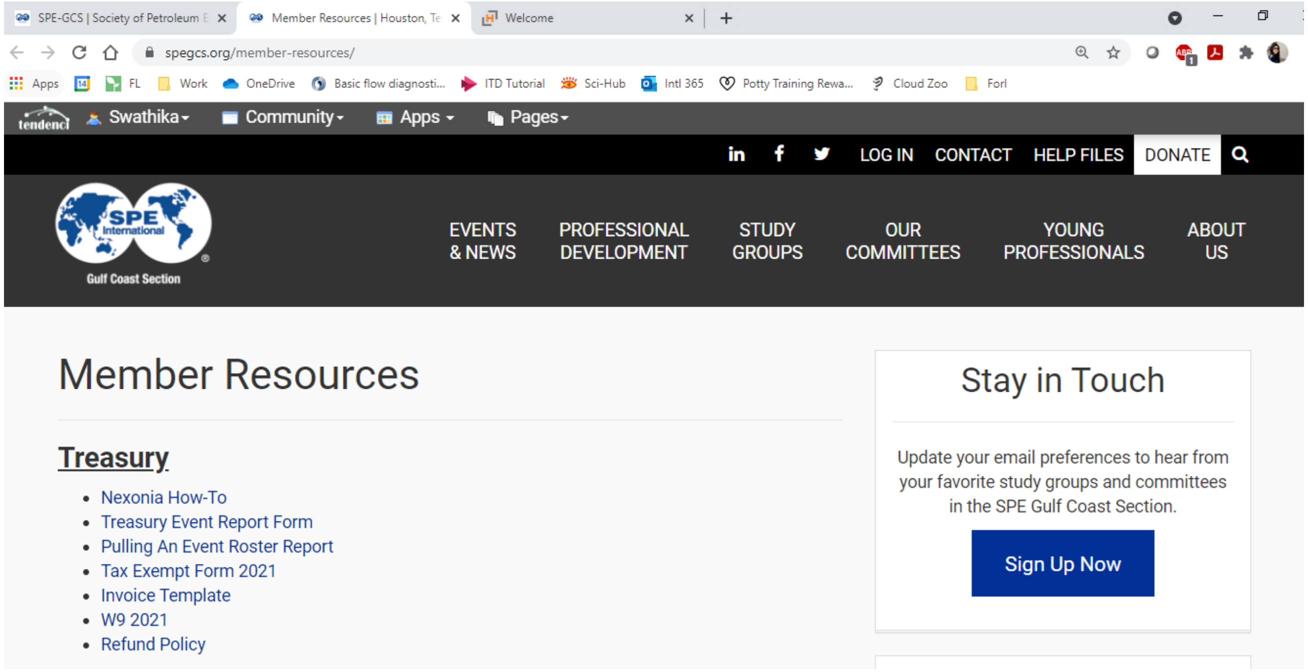

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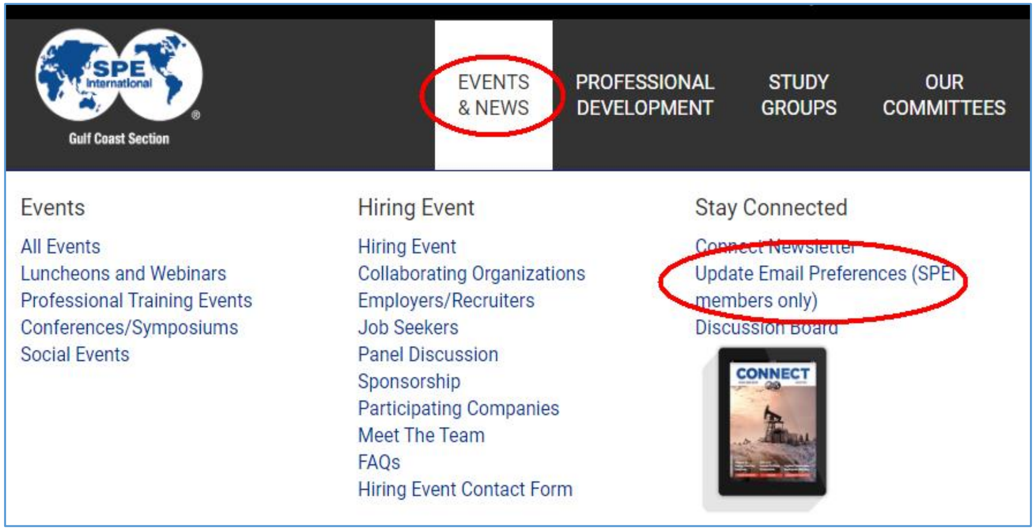

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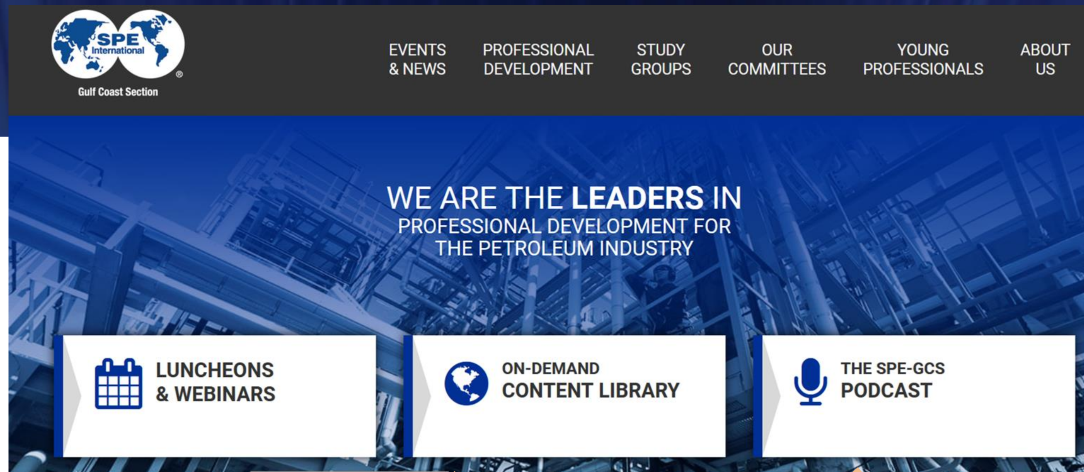

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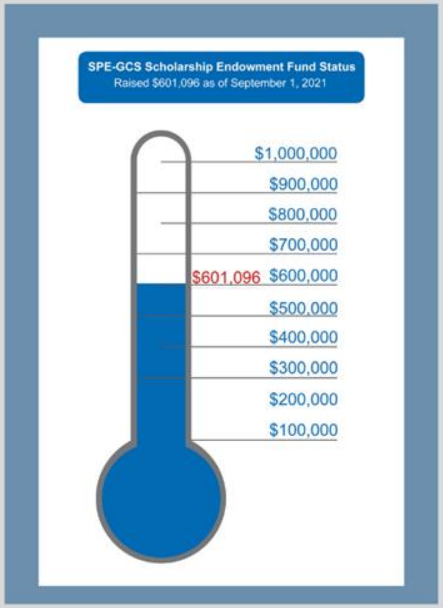

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