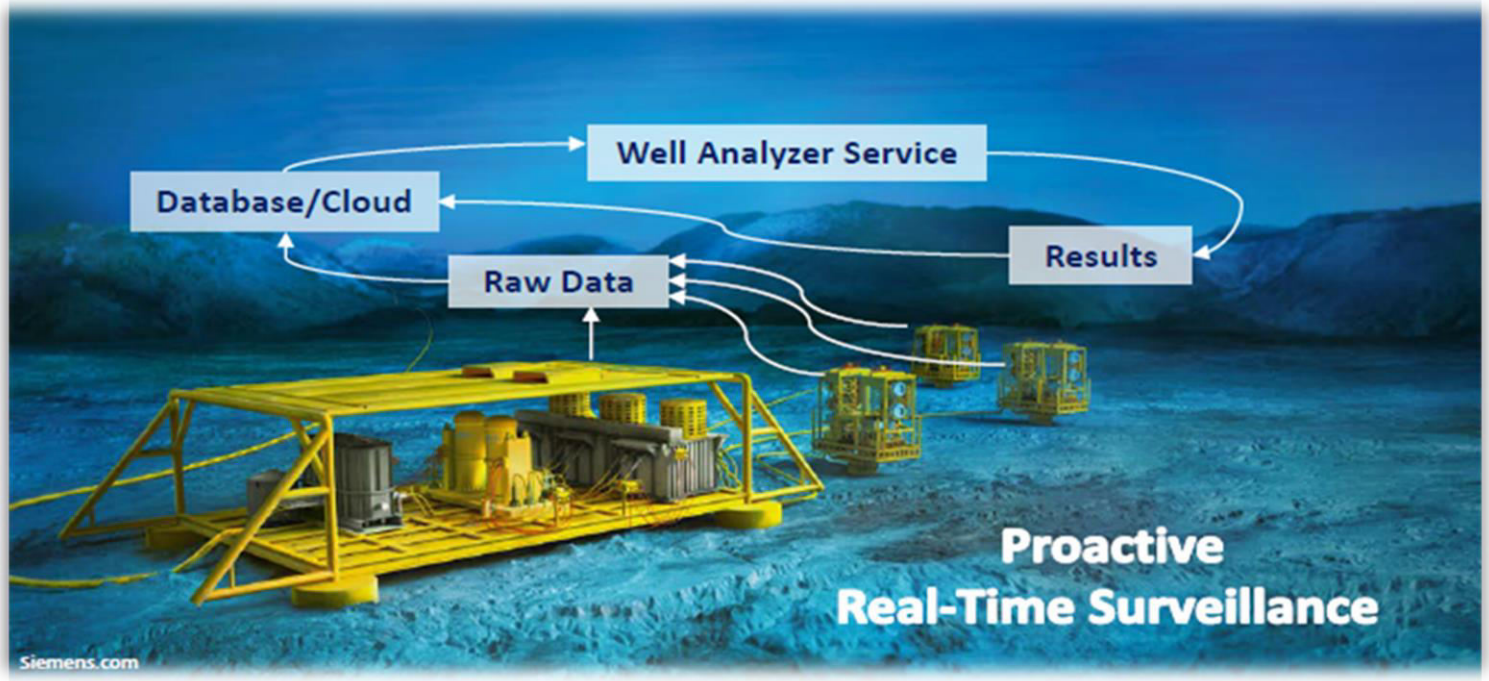
Well Analyzer

Pro-Active

*Automated Real-Time Surveillance **(ARTS)***

Well / Reservoir Evaluation Software Package



Oilfield Data Services, Inc.

- ✓ Oil & Gas Reservoir Testing and Evaluation
- ✓ Real-Time Pressure Transient Analysis
- ✓ Hydrocarbon Volume Determination
- ✓ Well(s) Performance Tracking
- ✓ Multiphase Rate & BHP Calculations
- ✓ Optimize Gas Lift / Oil Production Rates
- ✓ Life Of Well Surveillance/Analysis
- ✓ Automated PVT Calibration

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The Well Analyzer ARTS Concept

Experienced Surveillance Engineers

+

Automation

Spend your time thinking about what the results mean, not just digging for data!

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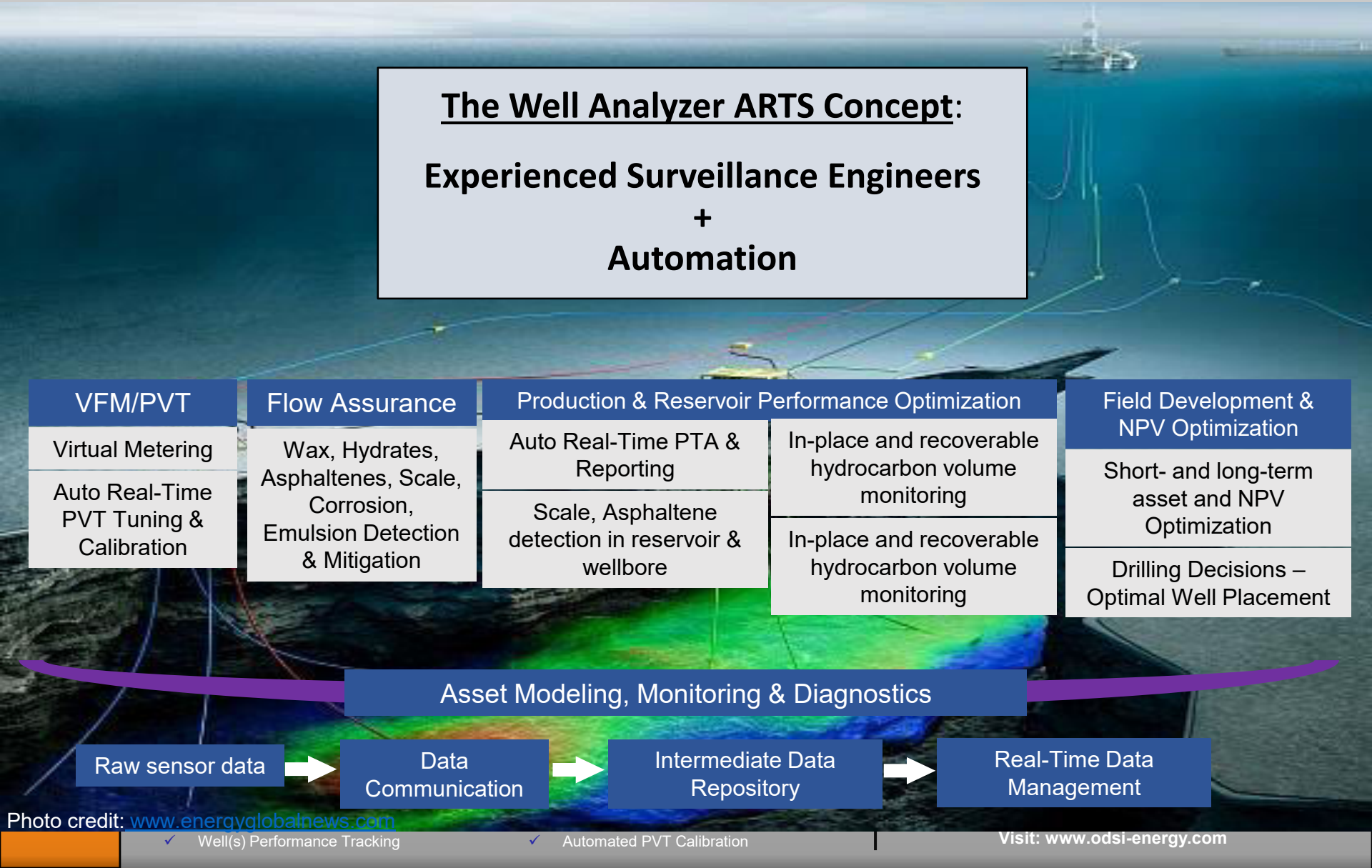
The Well Analyzer ARTS Solution

Presentation Outline

1. Introduction & Setup
2. Features
3. Wellbore Solution
4. ODSI's Well Performance Solution – Basic P.I. is NOT Enough
5. Automatic Time-Lapse PTA Results (Skin, Permeability, etc.)
6. Formation Evaluation 'Sanding Potential'
7. Well Potential Spreadsheet
8. Case Study: Deepwater GOM Oil
9. ODSI's Well Analyzer Benefits Summary

Introduction
Automated Real-Time Service (ARTS)
Real-Time Reporting on Well / Field KPI's



The Well Analyzer ARTS Concept:

Experienced Surveillance Engineers
+
Automation

VFM/PVT	Flow Assurance	Production & Reservoir Performance Optimization		Field Development & NPV Optimization
Virtual Metering	Wax, Hydrates, Asphaltenes, Scale, Corrosion, Emulsion Detection & Mitigation	Auto Real-Time PTA & Reporting	In-place and recoverable hydrocarbon volume monitoring	Short- and long-term asset and NPV Optimization
Auto Real-Time PVT Tuning & Calibration		Scale, Asphaltene detection in reservoir & wellbore	In-place and recoverable hydrocarbon volume monitoring	Drilling Decisions – Optimal Well Placement

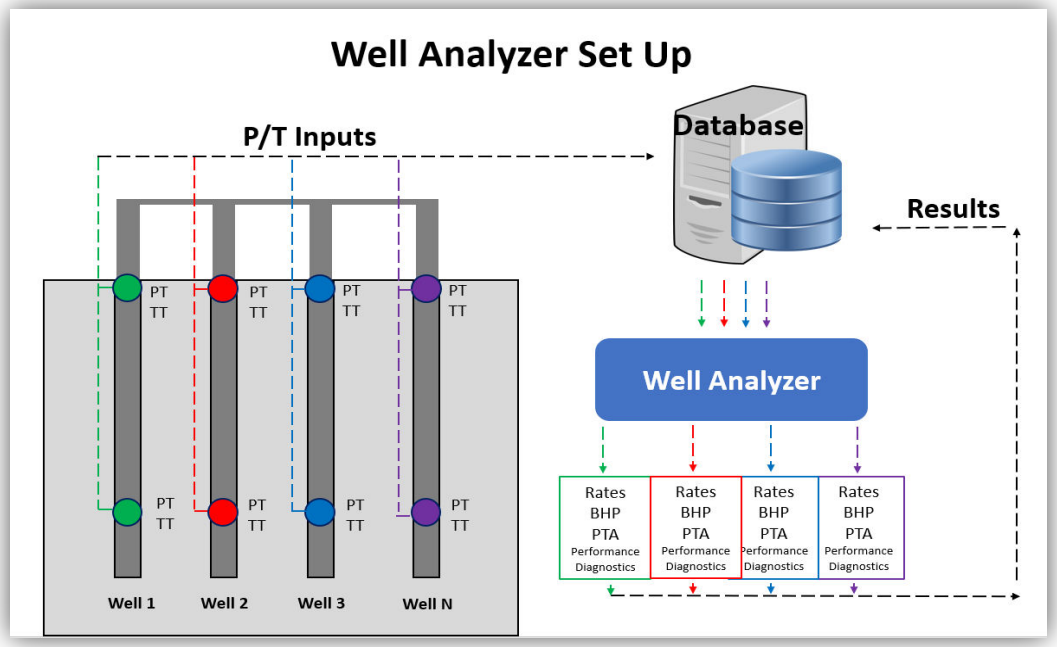
Asset Modeling, Monitoring & Diagnostics

Raw sensor data → Data Communication → Intermediate Data Repository → Real-Time Data Management

Photo credit: www.energyglobalnews.com

Well Analyzer - Real-Time System Set Up

- Setup
  - Dynamic EOS-based phase-thermal and wellbore models setup by ODSI engineers
  - Well Analyzer is installed on client's **existing database**
- Operation - works in **Real-Time** and on **Historic** data
  - Well Analyzer **polls** the required data tags from the database/historian, **performs** the calculations, validates the results and **writes** them **back** to the database
- Maintenance
  - Complementary software and features updates
  - Monthly well performance reviews



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Well Analyzer Real-Time Features

- Automated 3-Phase Rate Calculations and PVT Adjustments
- Conversion to BHP/Datum Depth
- Automated Pressure Transient Interpretation of Build-ups (PBUs) and Drawdowns (DDs), Injection & Fall-off Tests
- Static MBAL
- Flowing MBAL
- Conventional Decline Analysis
- TTA Decline (Thermodynamic Transient Analysis)
- Time-Lapse Skin, Perm, Mobility-Thickness, P* and P.I. or I.I.

Well Analyzer - Wellbore Solution

The only existing software based on a direct numerical solution to the Mechanical Energy Balance (MEB) equation

- Does not rely on vertical lift correlations and, hence, it provides more accurate and reliable results, or flags when the well is slugging or loading

The wellbore model

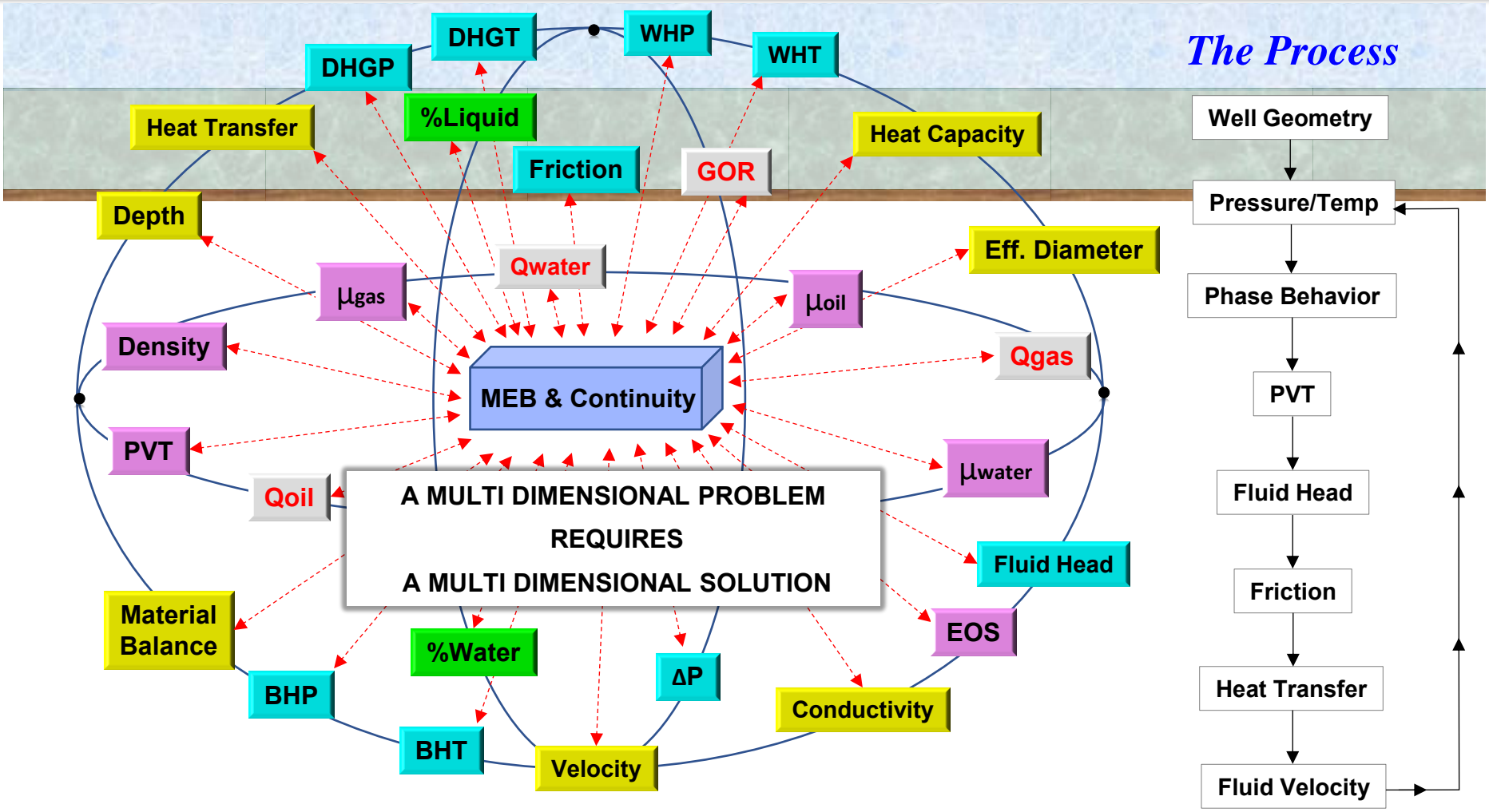
- Accounts for dynamic temperature behavior
- Adjusts the fluid properties/PVT accordingly
- Performs wellbore flash calculations to determine the composition of the fluid in the wellbore

The wellbore flash calculations can be used to determine the water cut or GORs for oil wells and the condensate or water yield for gas wells

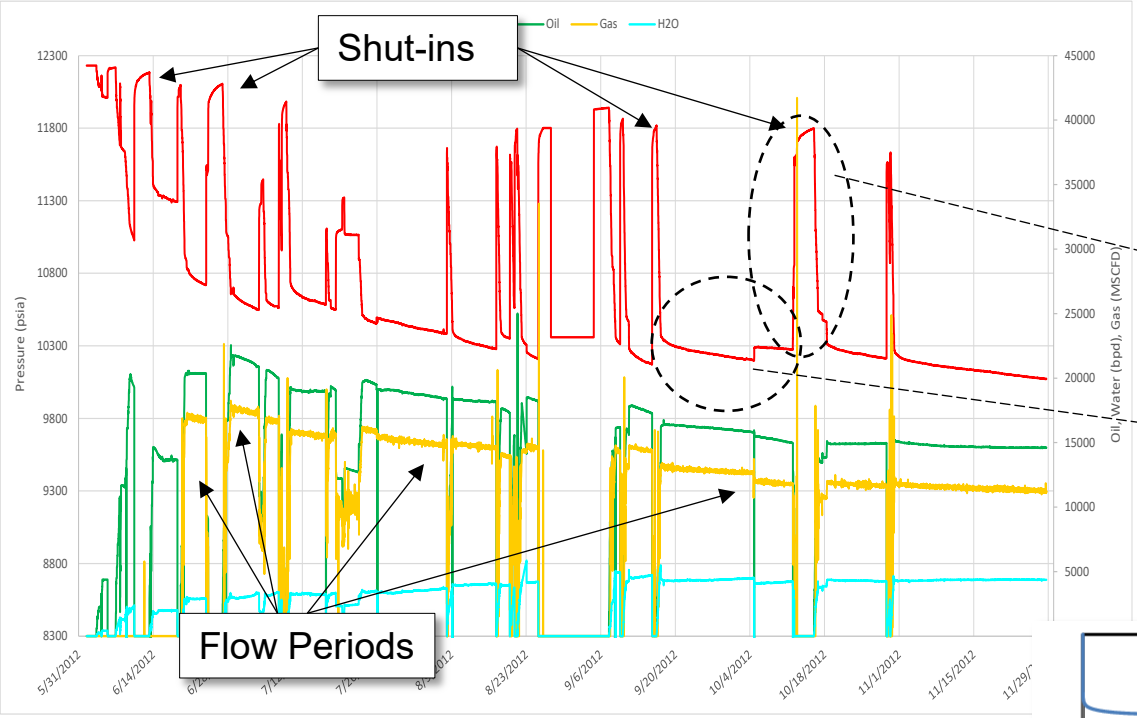
- Within 3 BBL/MMcf for Yield Cals (gas wells) and within 2% (percentage points, not absolute error) for water cuts

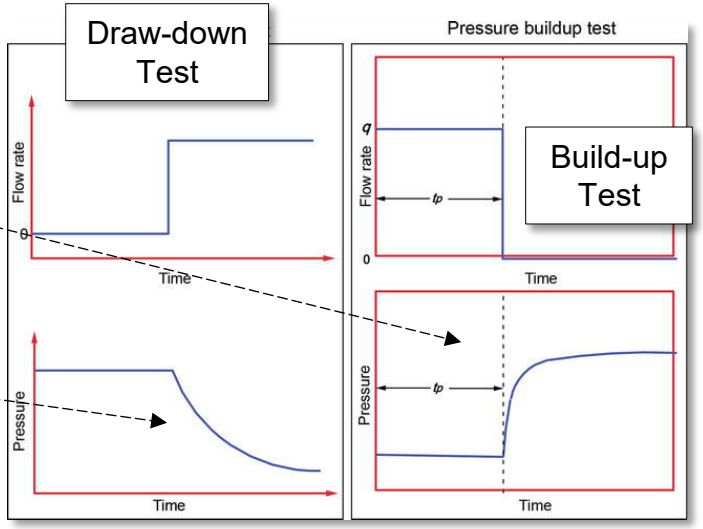
ODSI's Workflow

- Build Well Model (Flow Path, Petrophysics, PVT)
- Tune Well Model with Dynamic Data
- Begin Running Auto-Analysis Features
  - Rate Calcs, BHPs, Auto-PTA, Static MBAL, Decline Analysis, etc.
- Determine Initial Condition of the Well/Reservoir
  - PTA Parameters, KPIs, Well Potential
  - Location (Time & Distance) and Types of Reservoir Boundaries (OWC)
  - Work with Subsurface Team to fine tune reservoir size/drainage volume
- Use Decline Analysis to Determine Drive Mechanism components and how they may be changing with time
- How are things changing? What does it mean?
- Show it in a way that people can understand!



All of these values can change with time. *All of these values interrelate!*



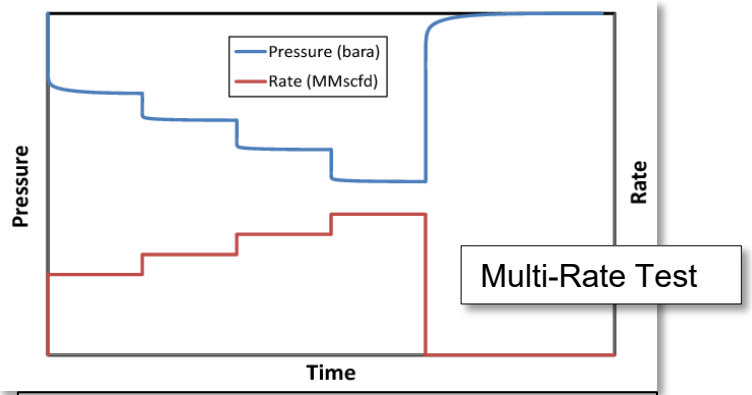


Determine

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

$$S_T = s + D^*q$$

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



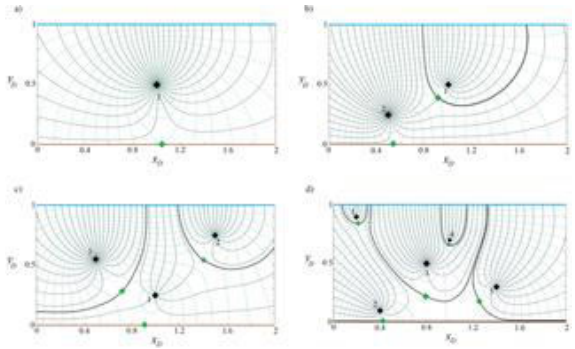
Simple P.I. Equation…
There are more terms that matter!

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

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

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

- Is kh changing?
- Is Reservoir Pressure or P_{wf} changing?
- Are Fluid Properties Changing?
- Is skin (S_T) changing?
- Is r_e changing?
- Is there additional pressure drop in the well bore?

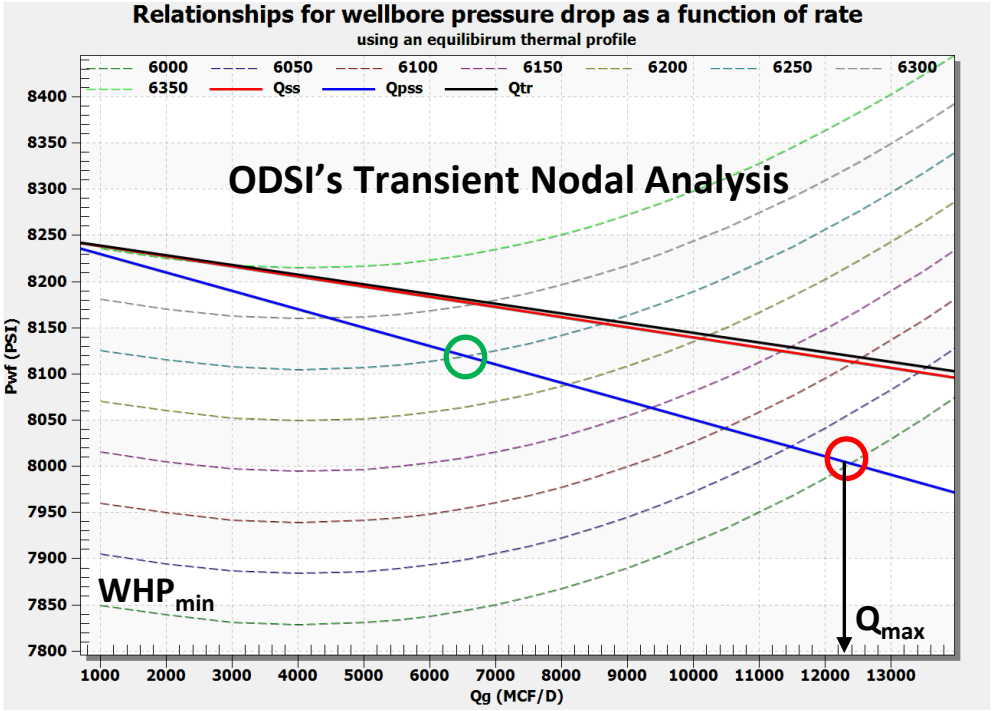


r_e , effective radius can be rate dependent
k, perm can be rate dependent
S_T, Total skin can be rate dependent

IPR Equations

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

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



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**

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

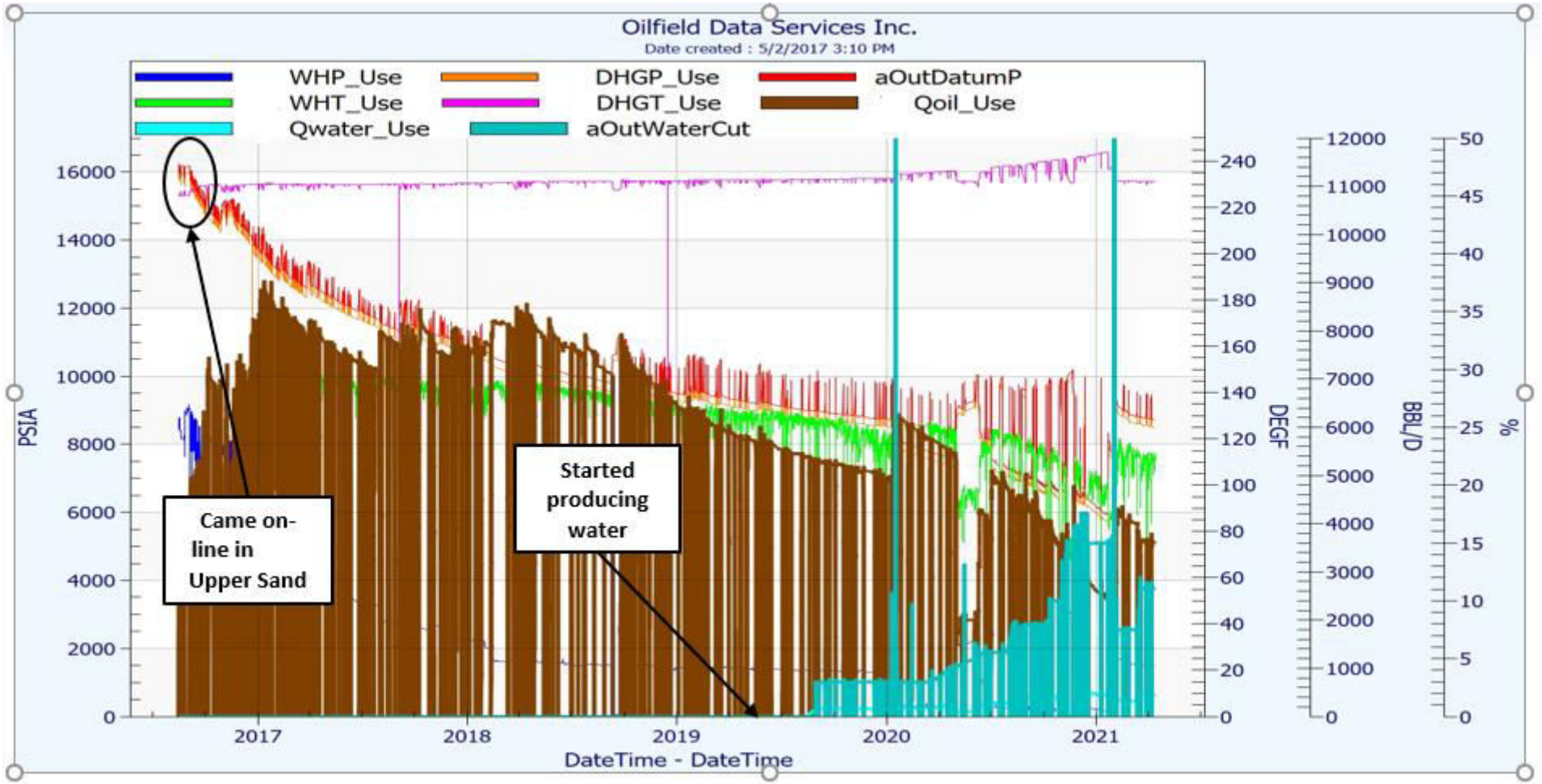
Well's Qmax for given minimum WHP pressure

Time-Lapse Auto-PTA

Time-Lapse Auto PTA

- Automatically analyze every PBU and Drawdown (not just the PBUs that you have time to analyze)
- Get a Baseline Analysis – Teach the computer how to analyze the well
- See how things are changing (and think about the causes…and what you can do to fix it)!

Time-Lapse Auto PTA – Production History



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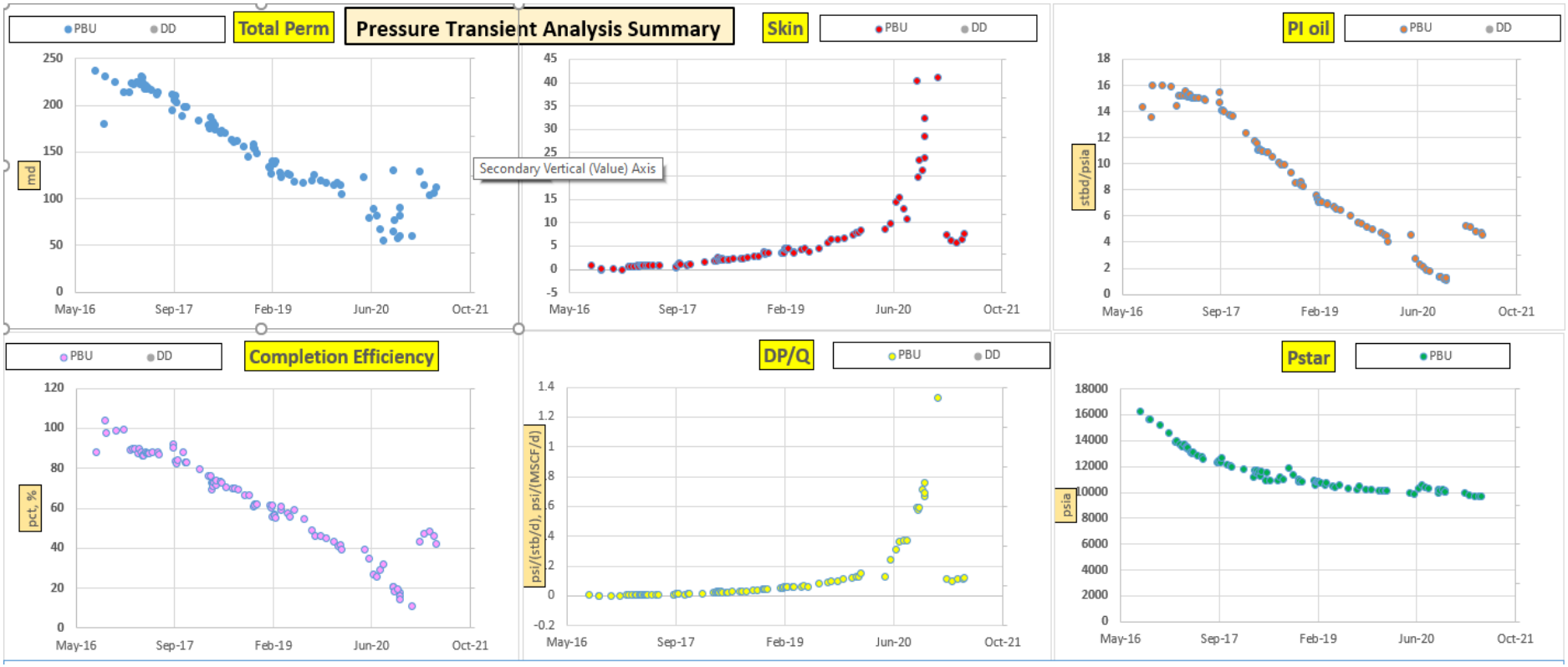
PTA Dashboard – Accreting Skin Example

What can a few simple plots tell you?



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PTA Dashboard – Accreting Skin Example

Compaction

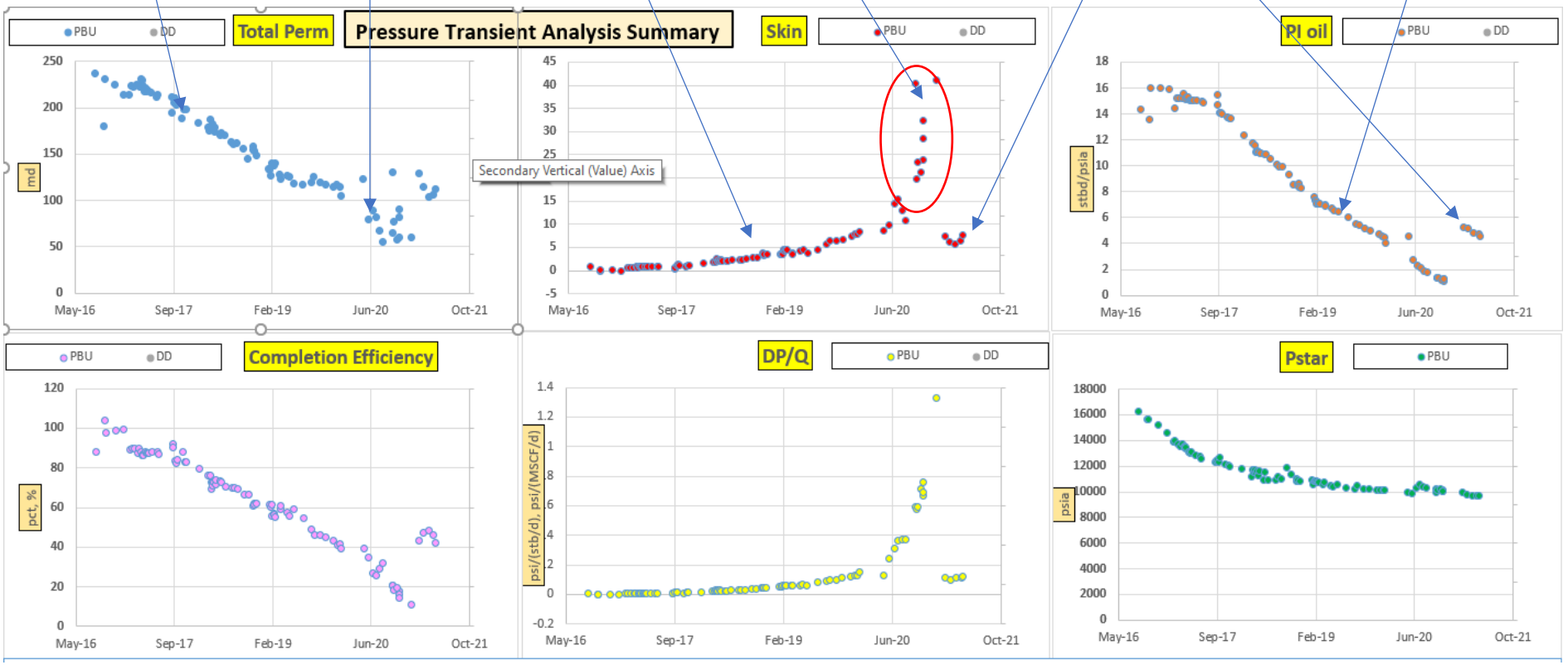
Significant & Unexpected Decrease in Perm Asphaltenes?

Fines (skin)

Significant Skin Increase – Need to Plan for Xylene Treatment

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

PI Reduction due to compaction and skin accretion (fines)



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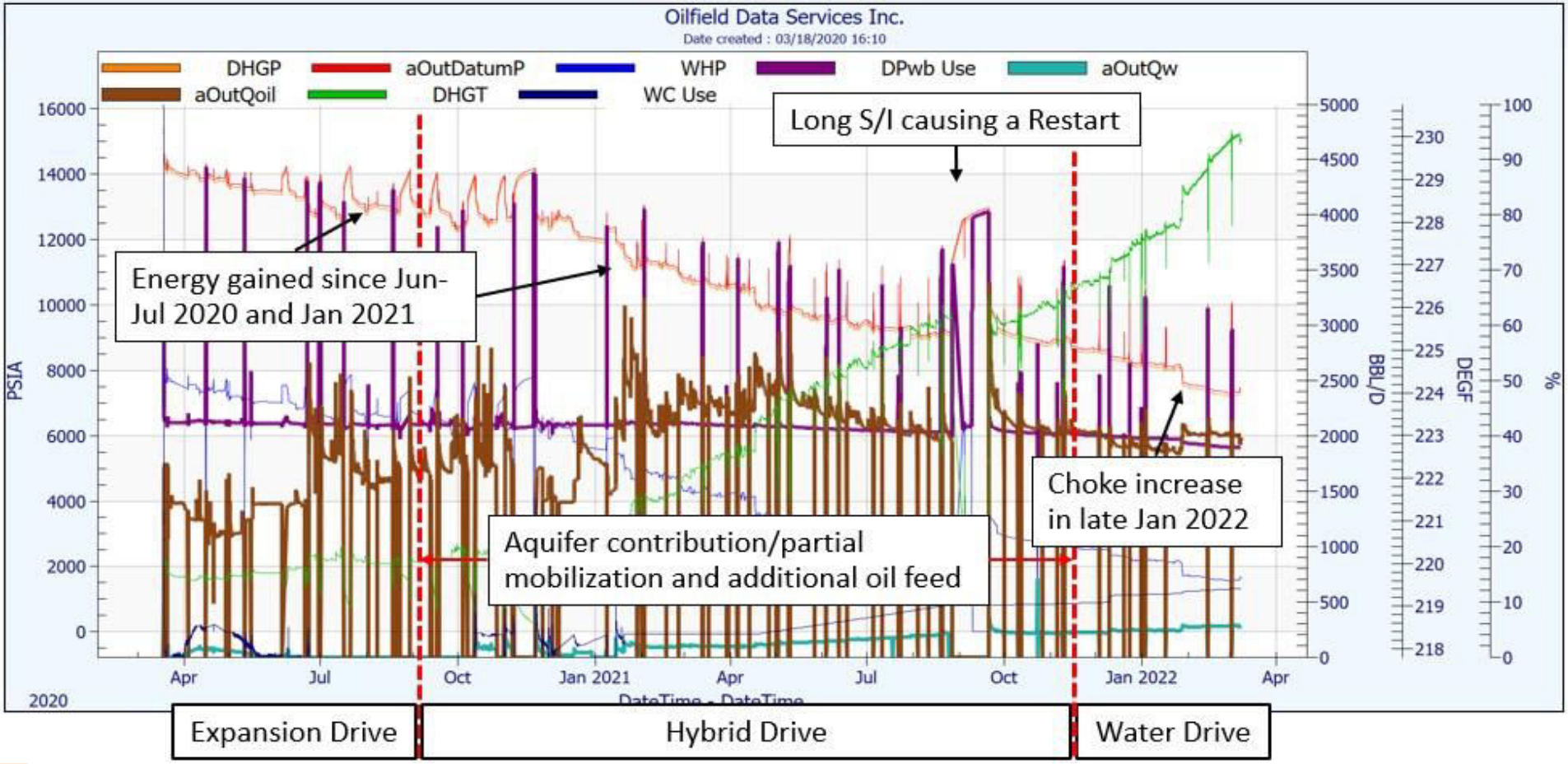
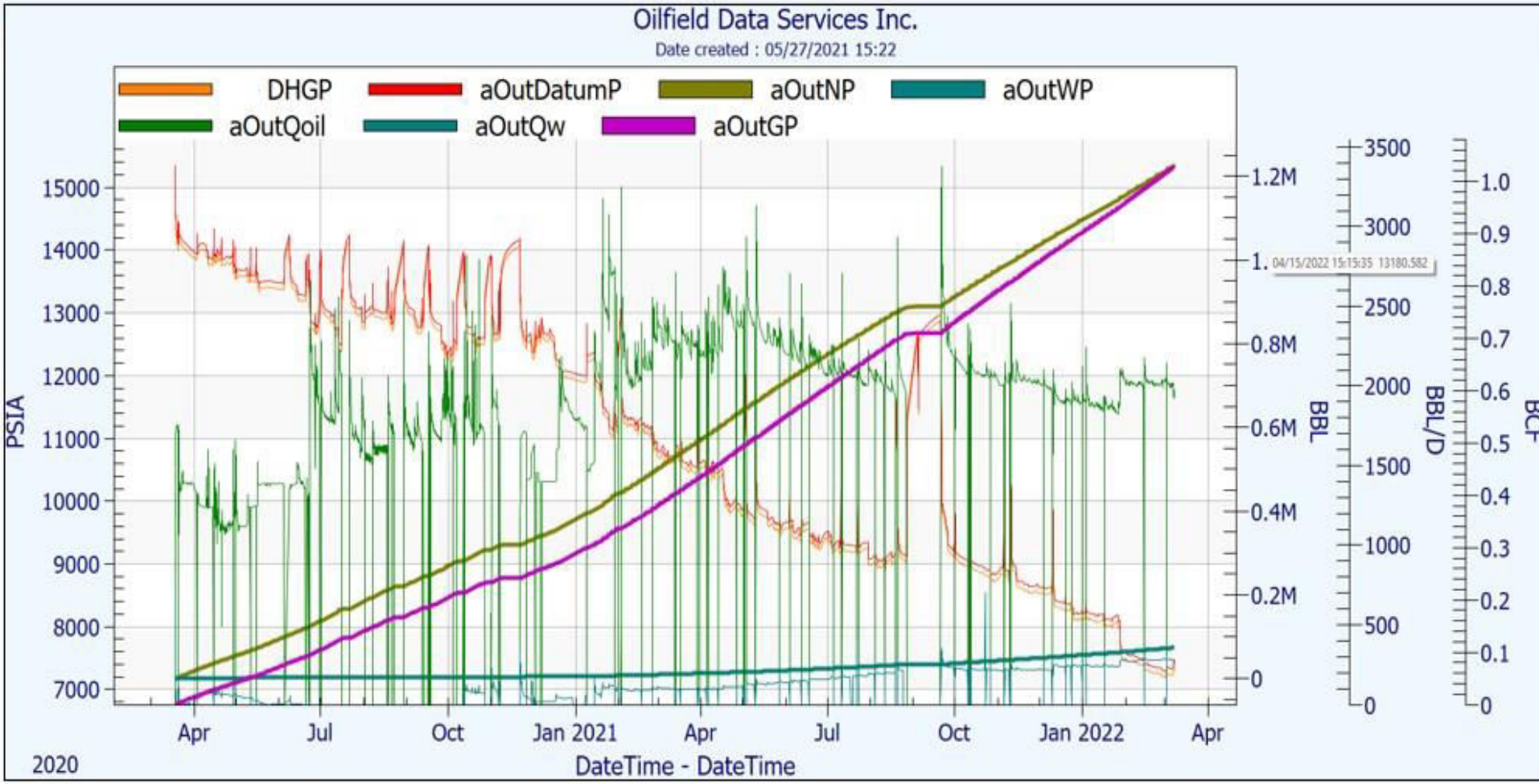
Sand Failure Pressure from Mobility-Thickness Decay

Events Overview



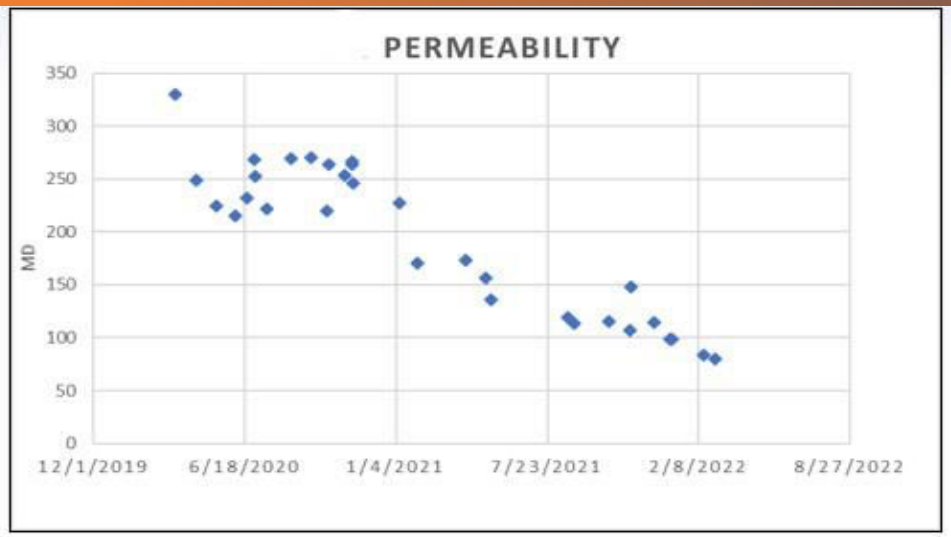
- The energy increases from June-July 2020 and in January 2021 were due to an aquifer/oil feed from vertical baffles/laminations. Aquifer support was more evident based on the Aug-Sep 2020 data. It is possible that the water started contributing sooner
- Noisy pressure data made it challenging to separate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

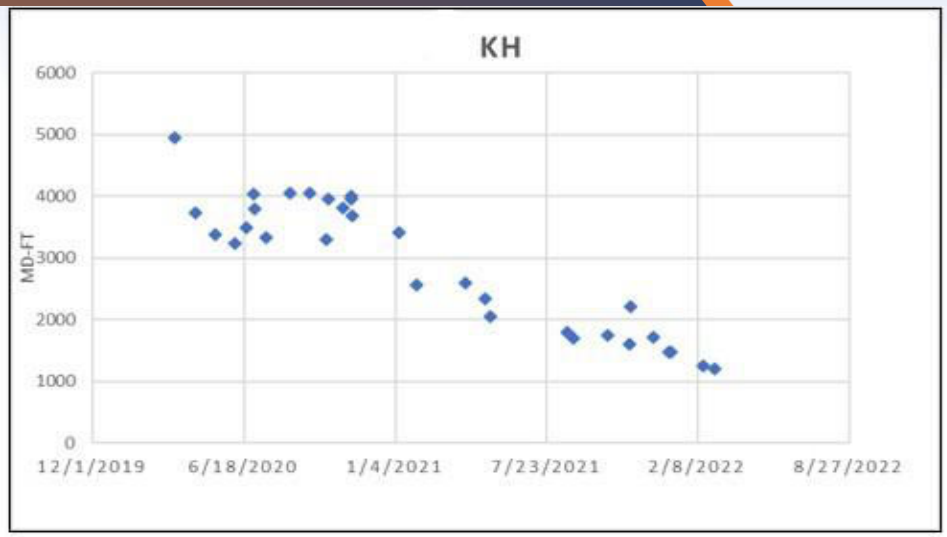
Production History

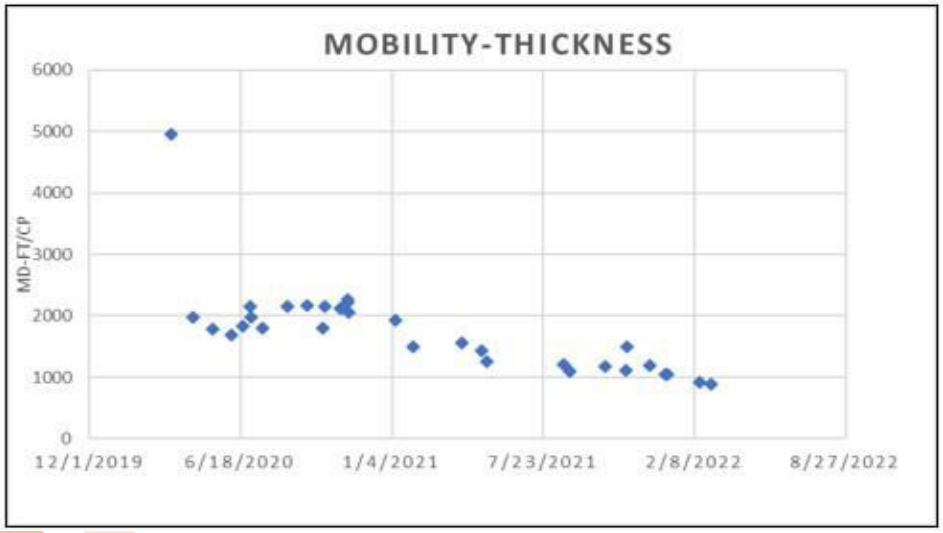


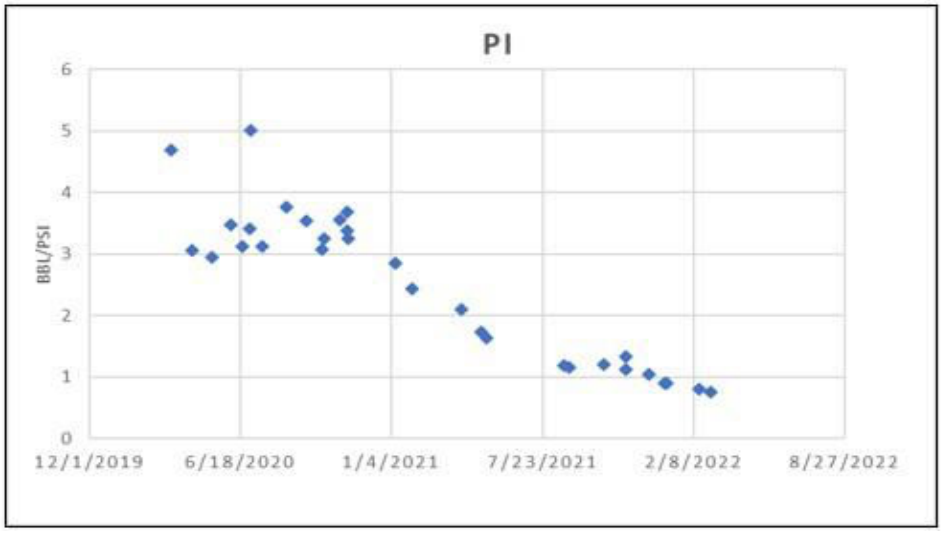
- Np – 1.23 MM STBo
- Gp – 1.03 BCF
- Wp – 0.075 MM STBw

Historic PTA

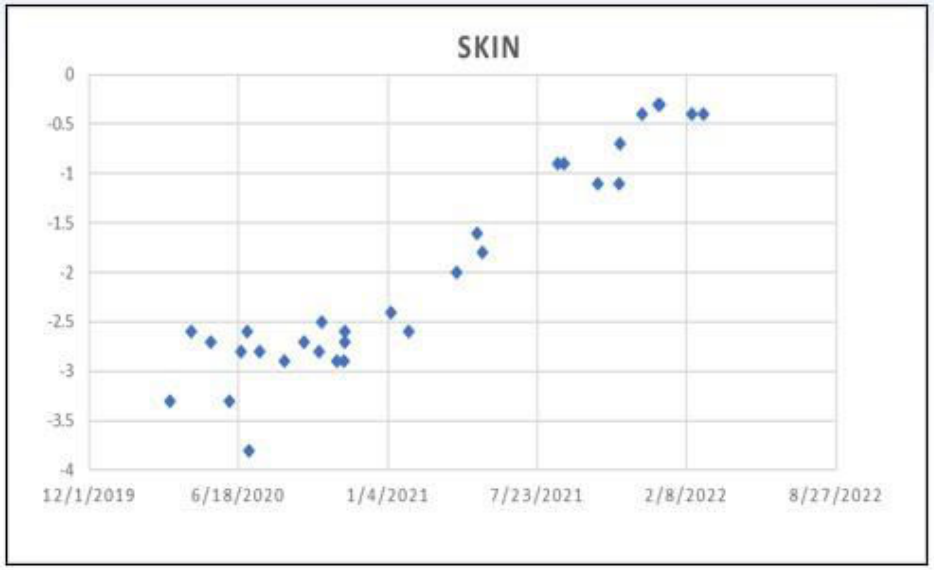


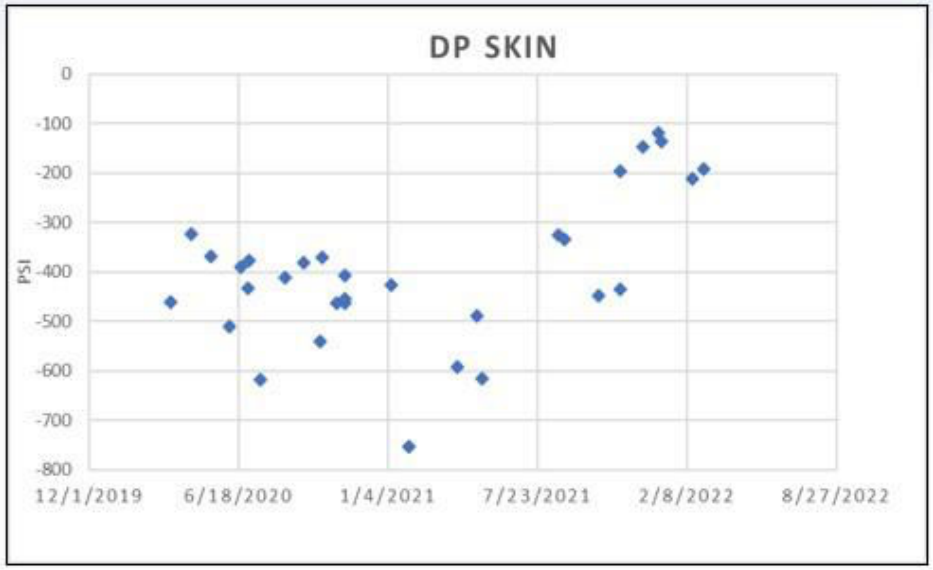


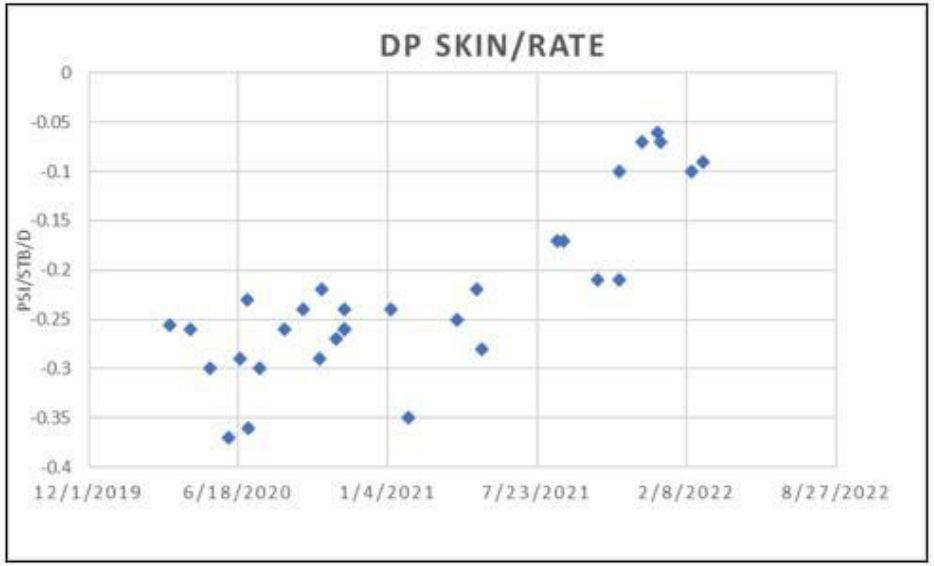




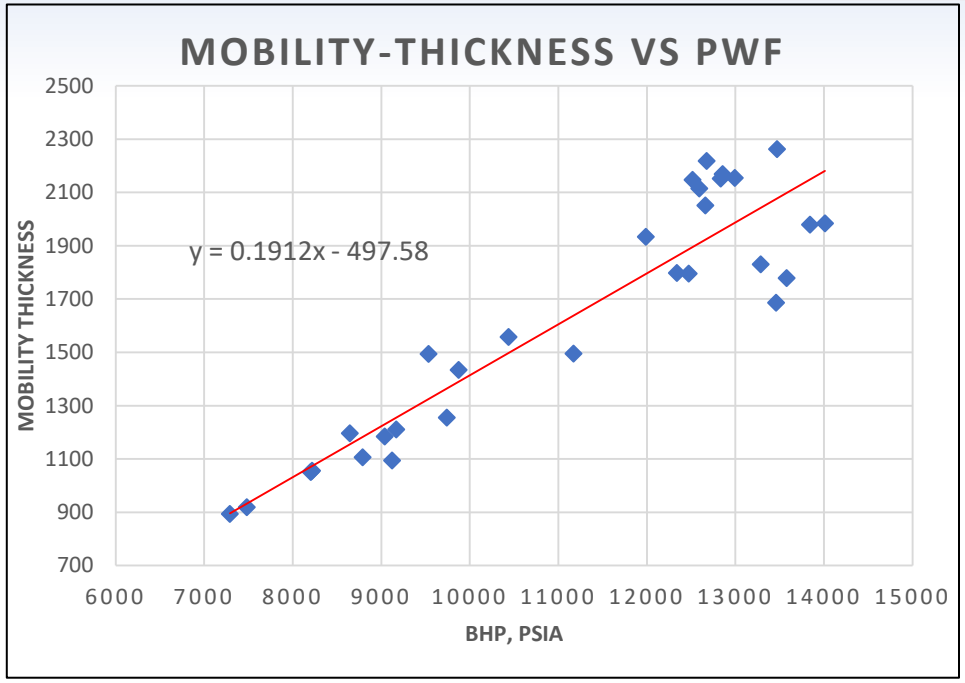
Historic PTA Cont.

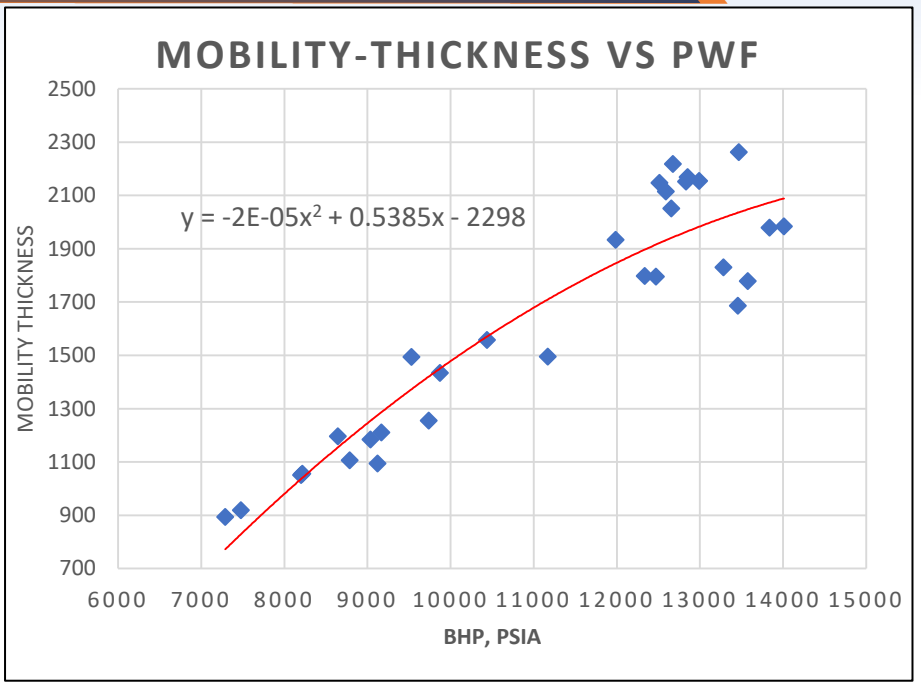






Sand Failure Pressure



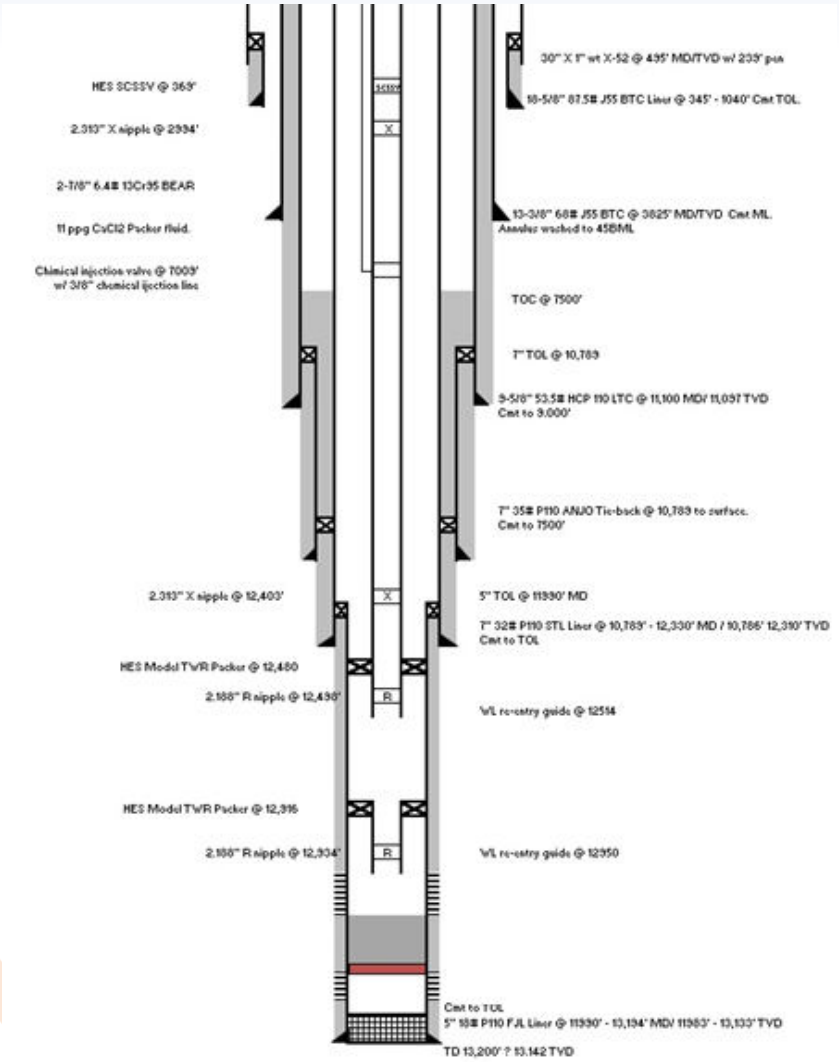


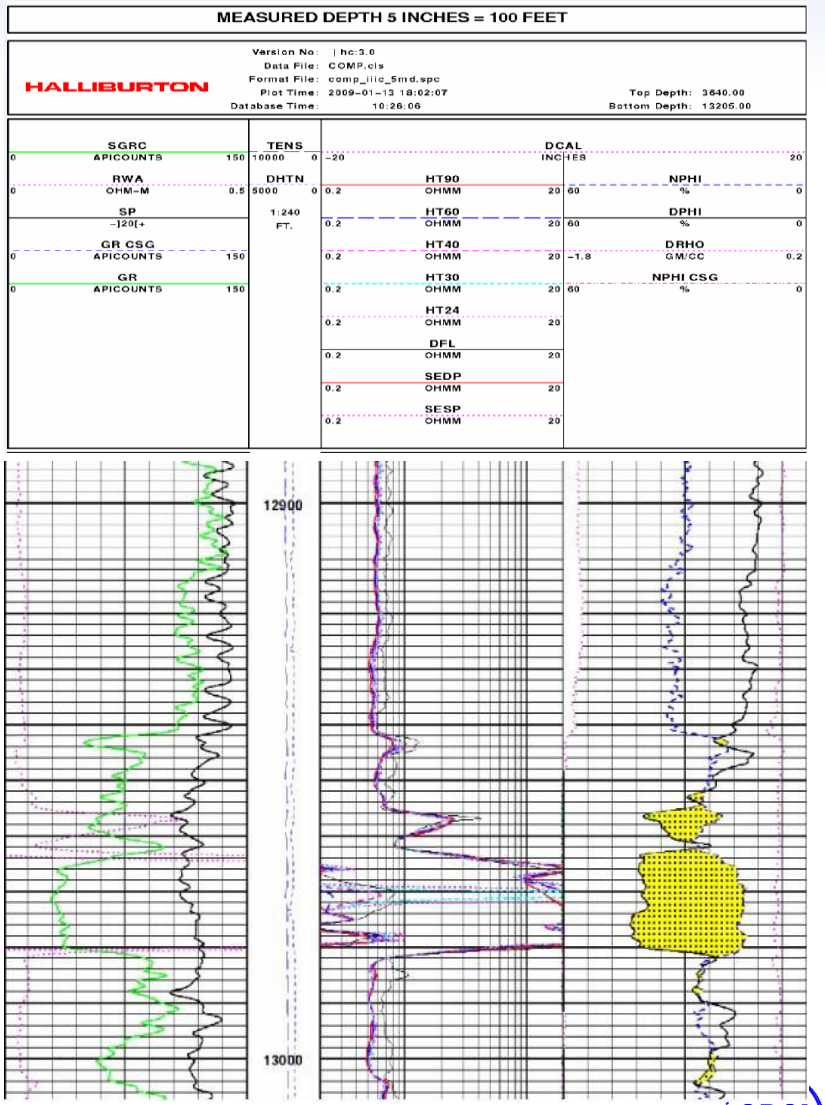
- Fitting a linear decline in the trendline and extrapolating it to where the Mobility Thickness equals zero gives us a failure pressure

- 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

Formation Evaluation
‘Sanding Potential’
(Sonic Logs)

Completion Schematic & Well Logs





Formation Evaluation – (12953' – 12976')

- Since the lower sand (13019' to 13051') started producing sand towards the end of production, the (12953' – 12976') sand was evaluated for formation strength using petrophysical log data

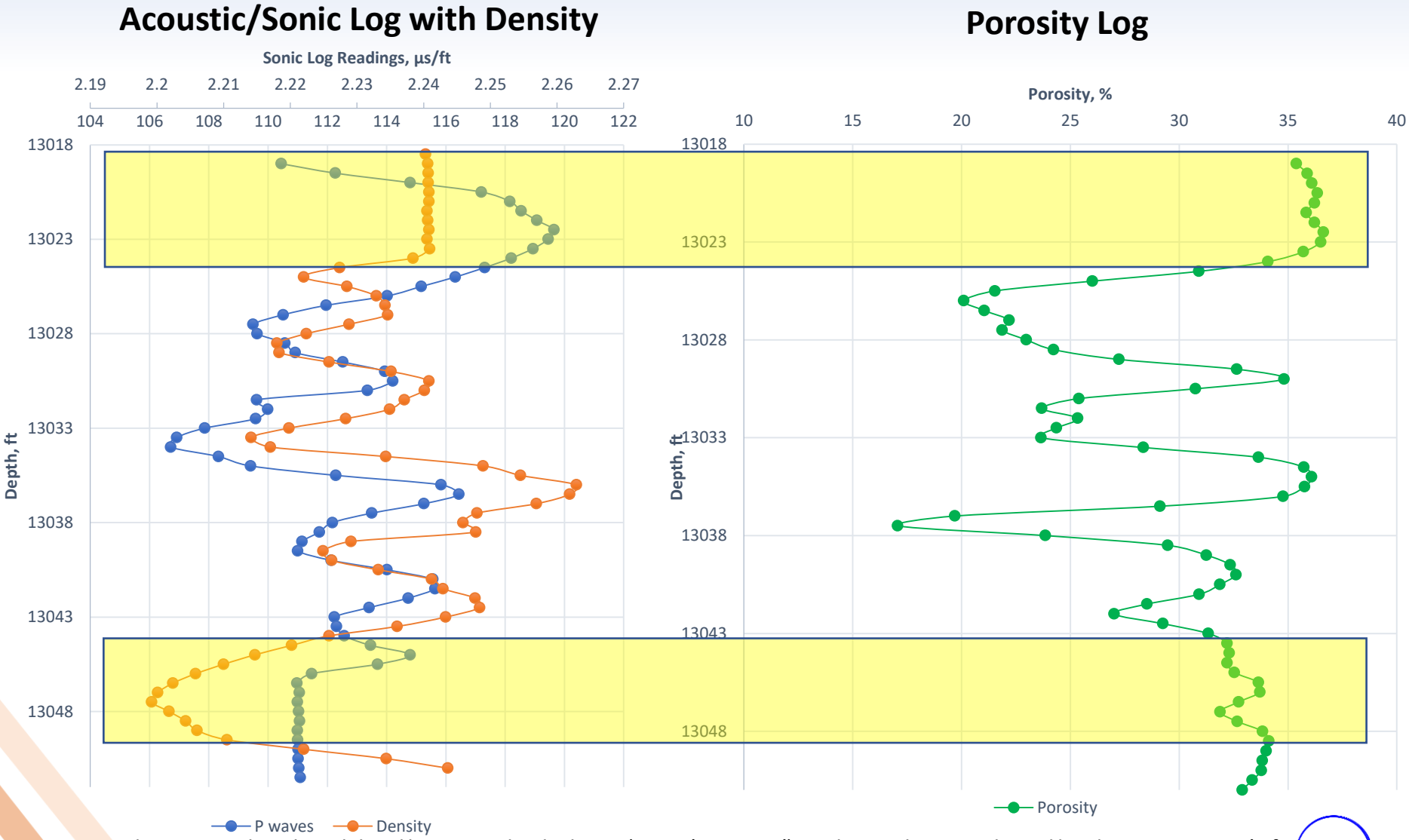
- <u>Underlying Principles of Evaluation:</u>
  - Rule 1: Higher the speed of compressional waves, the less compact the formation is. **Higher speed of compressional waves (P-waves), lower the density (or const.), higher the sanding potential**

$$Pwave \propto \frac{Density}{Strength}$$

  - Rule 2: Increase in the porosity, the more friable the formation is; decrease in the porosity indicates tighter formation likely due to better cementation. **Higher friability indicates a higher sanding potential**

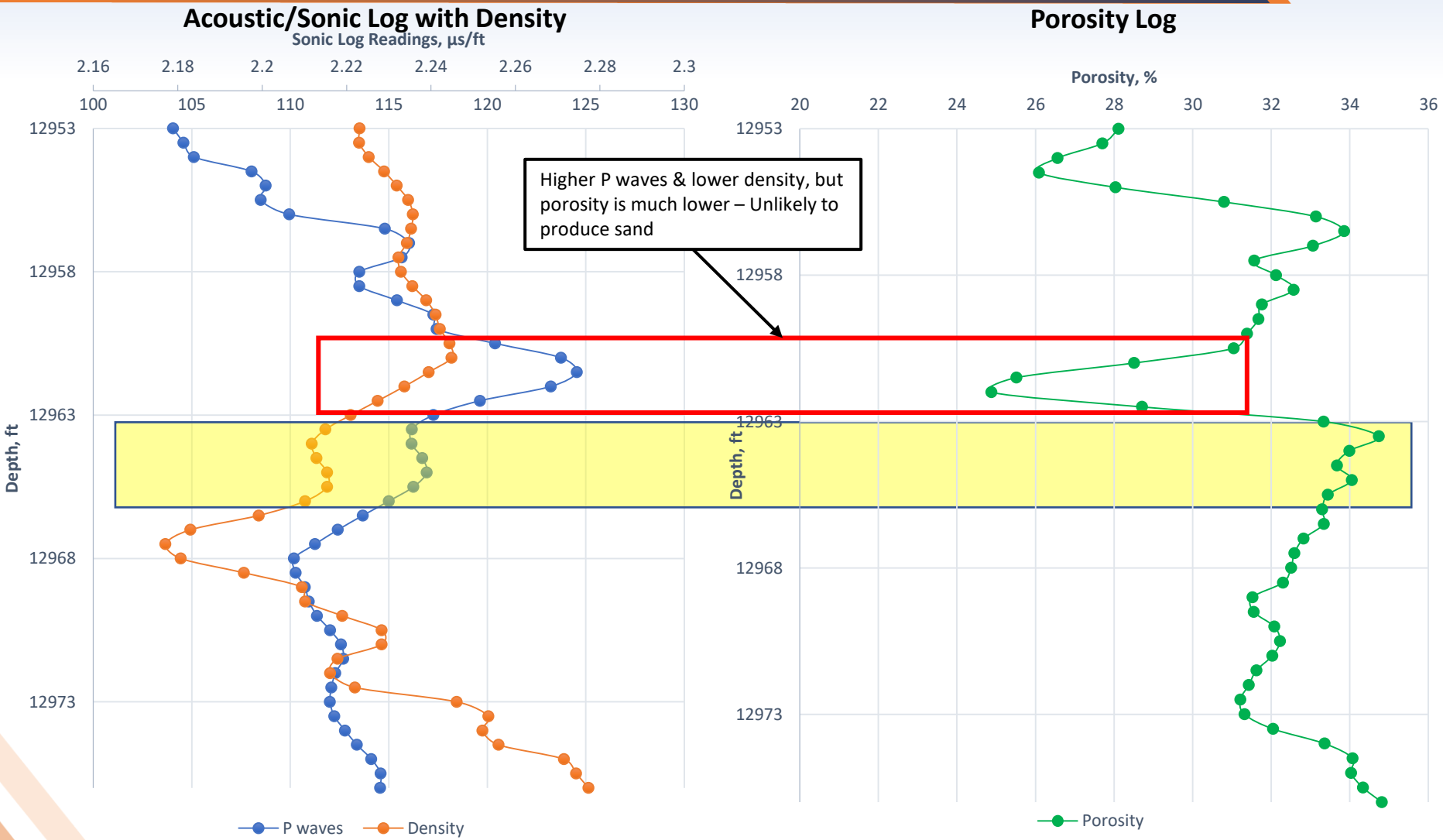
Note: Rule 1 needs to be validated with Rule 2

Formation Evaluation – (13019' to 13051') - Validation



- Sanding potential can be validated by testing the the lower (13019' to 13051') sand using the petrophysical log data – Approx. 10' of the perforated interval (32') had the potential to sand – **Weaker Zones highlighted in 'Yellow'**

Formation Evaluation – (12953' – 12976')



- Sanding potential can be evaluated for the (12953' – 12976') sand using the petrophysical log data – Approx. 3' of the perforated interval (23') have the potential to sand – **Weaker Zones highlighted in 'Yellow'**

Formation Evaluation – Sanding Potential Comments

- On validating the methodology with the lower sand, **the current producing (12953' – 12976') sand was evaluated for sanding potential. Approx. 3' of the 23' (perforated interval)**

- **<u>Mechanisms to monitor:</u>**
  1. Stress dependent permeability – **Current situation**, after increasing the rate from 4.5 to 8 MMSCF/D; Permeability decreased from 123mD to 100mD)
  2. Plastic Hysteresis – Due to the 'squishy' nature of the formation (Cf ~ 13 msips) and stress due to rate changes, formation undergoes compaction can exacerbate sanding potential
  3. Water Production – It is also possible if the eventual water production weakens the remaining cementation of the sand grains. Furthermore, this can possibly increase the skin with scale deposition and exacerbate sanding potential
  4. Sanding potential is also rate/velocity dependent

The Well Potential Spreadsheet/Dashboard

Putting it All Together

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

ODSI

Spare Capacity Spreadsheet

Operator Spare Capacity Table											
Well	ODSI Current Rate (Oil) [stb/d]	ODSI Current WC [%]	Operator Current WC (%)	Operator DPR Oil [stb/d]	ODSI-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**			Date:	5-Jan-2017

Case Study: Deepwater GOM Oil

CASE STUDY

Subsea Deepwater Oil Well

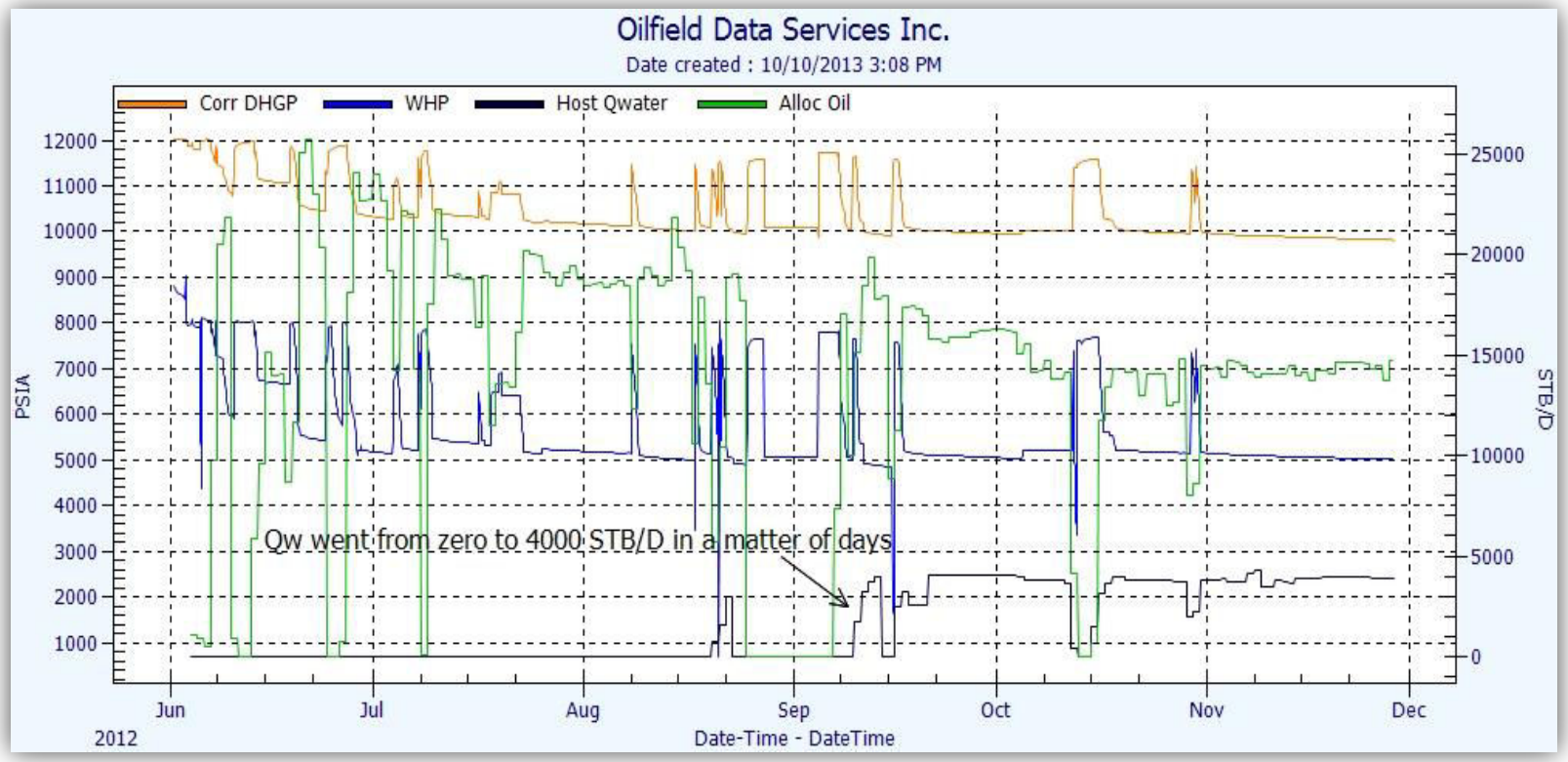
3 Separate Frac Packs

Gulf of Mexico

- 3 Frac Packed Intervals – No Isolation/ICVs
- Well equipped with
  - WHP gauge
  - Downhole gauge
  - Flow meter (MPFM)
- The well suddenly started making 4000 STB/D of water
  - The Operator plans a $130 million intervention program to ‘fix’ the well; the Partner decided to find the origin of water production first
- <u>Objective:</u>
  - Validate metered rates
  - Determine the origins of water production
  - Perform Auto PTA and Decline Analysis

Case Study: Provided Data

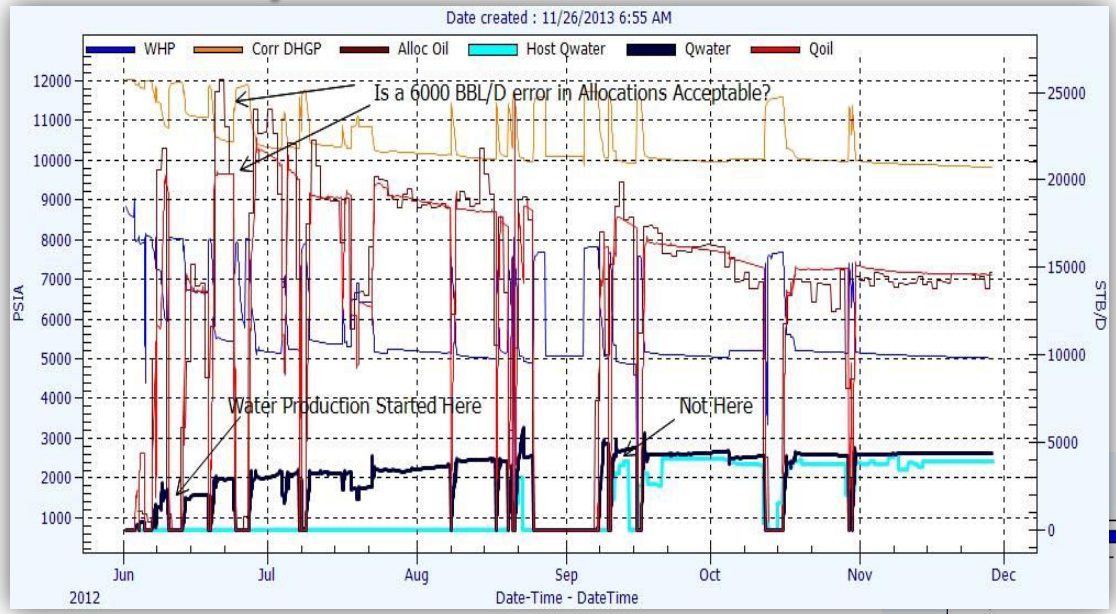
- Water rate went from 0 to 4,000 STB/D in a matter of days; the Operator wanted to perform a $130 MM intervention to ‘fix’ the water problem; the Partner wanted to identify the origin of water production first…Why Spend $130 MM and Shut In a Well Making 15,000 STB/D because it ‘doesn’t match the models’?



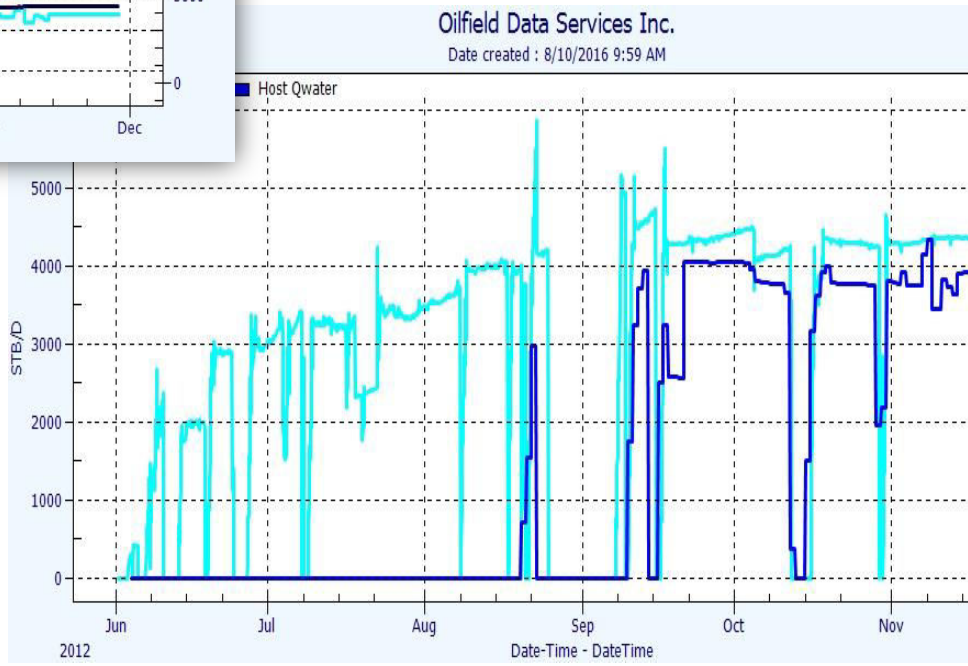
Case Study: Process

- MPFM rates were QC'd
  - Severe Errors in allocations were detected prior to Sept 2012
- Generally, MPFMs for 2-phase liquid flow are accurate on the total liquid rate measurements, but are likely to be off when it comes to individual oil and water rates (even worse if you start making free gas!)
- The total liquid rate was split into oil and water rates using the pressure drop in the wellbore and fluids' PVT properties
- It quickly became obvious that the MPFM was not calibrated when the well came on-line

Case Study: Results



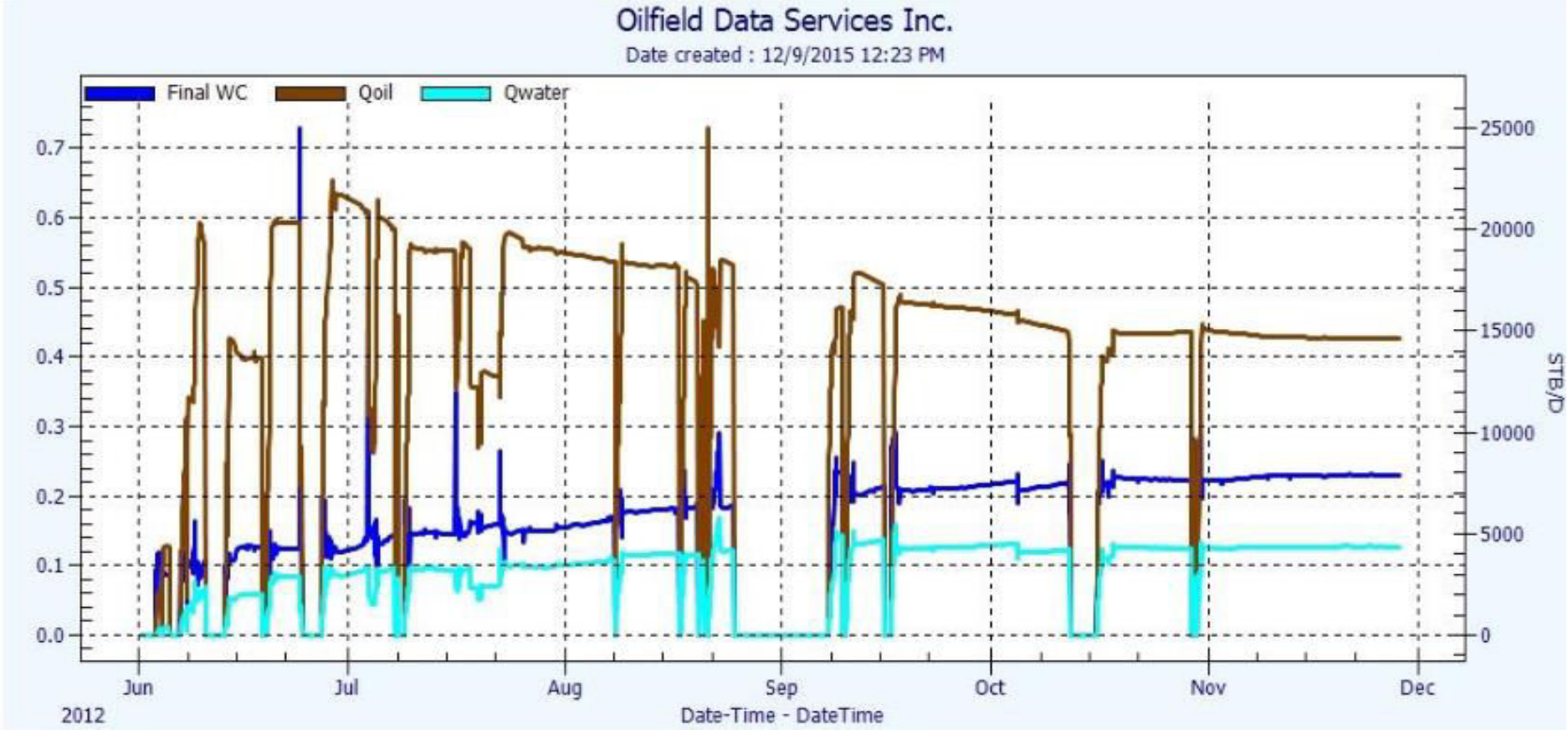
As it turned out, the water production started from the day the well was brought on-line. The operator's allocations were off up to 6,000 BBL/D



- Comparison of the measured (dark blue) vs the calculated (teal) water rates
- The meter was not properly calibrated, and the well was producing water from the day it came online

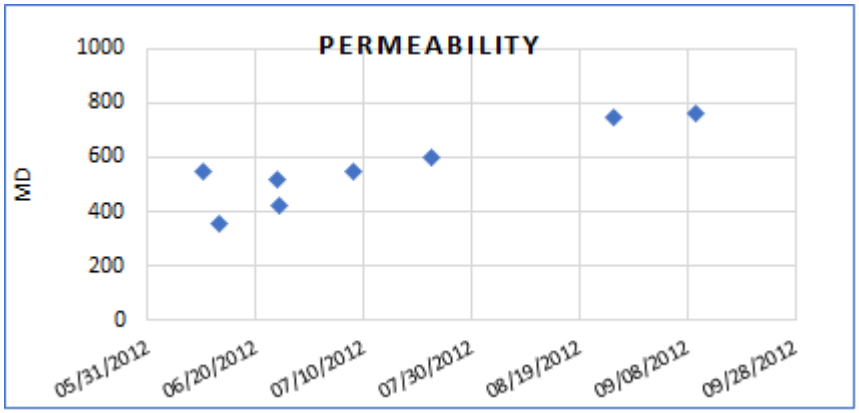
Case Study: Rate Results

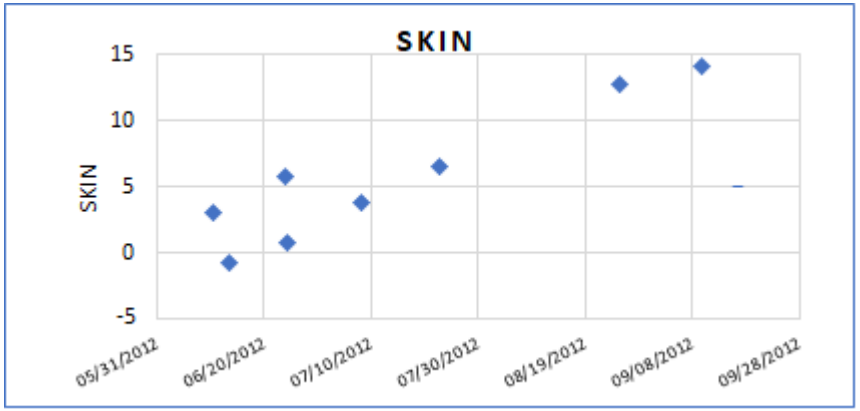
- The Final Calculated Oil and Water rates are presented below
- The water came from a WET 'oil zone' that was added at the last minute

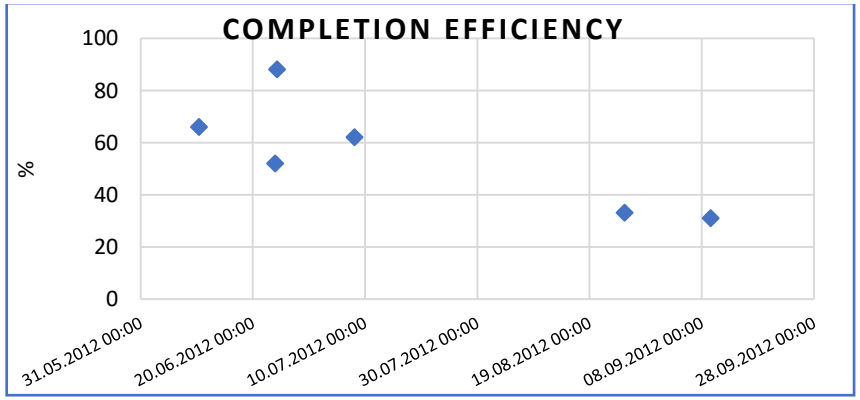


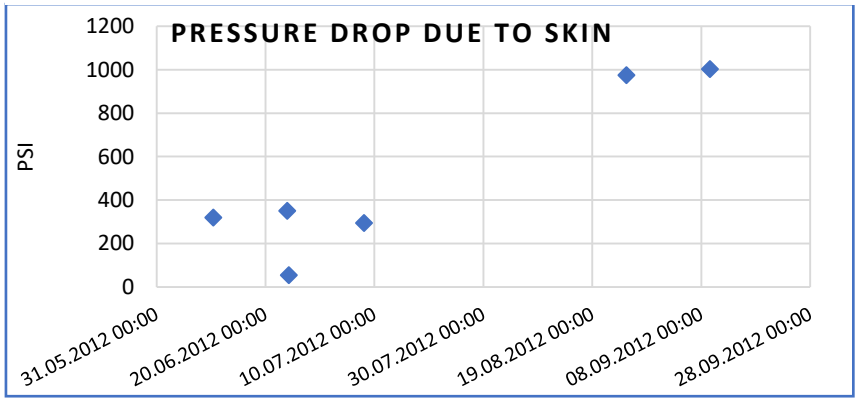
Case Study: Auto-PTA

- High perm ~ 500 md
- Skin was getting worse with time
  - From 0 to 14 (screen plugging w/asphaltenes)
- Productivity was getting worse with time (increasing skin)

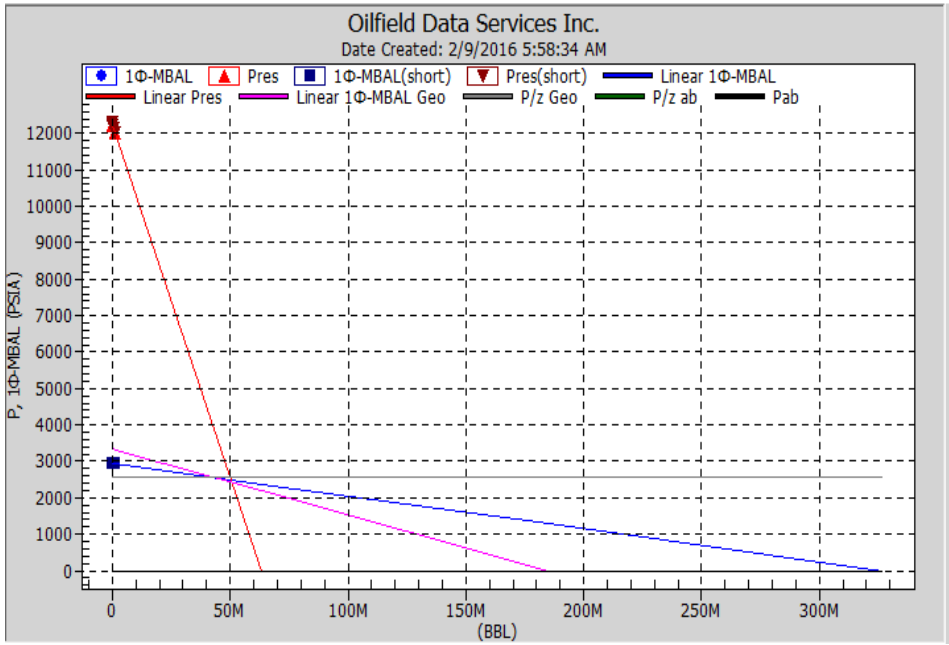


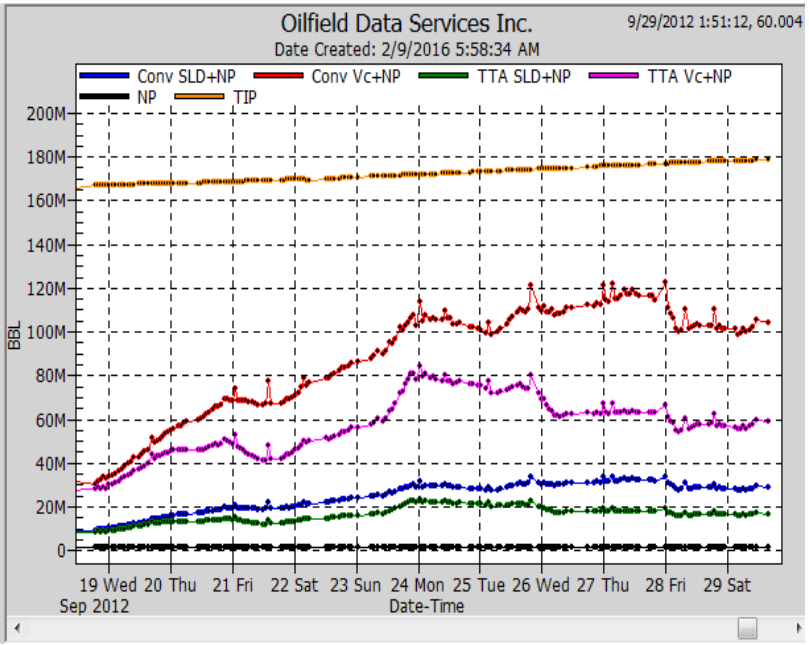






Case Study: HC Volume





The well is likely to have very strong water drive, hence

- Total in-place volume is ~ 65 MM STB
- Hydraulically connected to the well volume ~ 30 MM STB
- Mobile (minimum producible) volume ~ 20 MM STB

- Note: It is important to know how big or small your reservoir can be until you know the drive mechanism. WA ARTS calculates the connected and mobile HC volumes and stores those values on client's database

Case Study: Results

- MPFMs were generally accurate on the total liquid rate, but were off on individual oil and water rates
- Given the pressure drop in the wellbore, the software can split the total liquid rate into its components, providing solutions for:
  - Improperly calibrated flow meters
  - Poor separator testing methods
  - Errors in oil and water allocations
- Once the rate is calculated, WA ARTS can perform auto-PTA and HC volume calculations
- Water production started on Day 1, not in Month 4!
- Use the 'thumbs out' rule to find HC pay!
- Don't spend money on a problem you can't fix!

Case Study 2

Failed Downhole Gauge

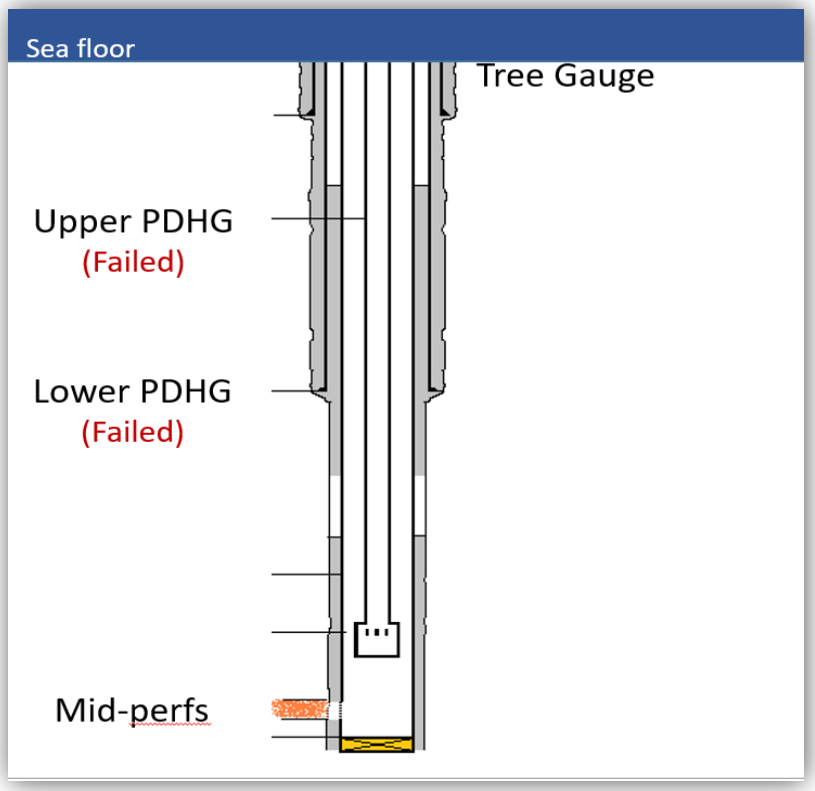
High Skin or Bad BHP?

Case Study 2: Gas Condensate - NCS

Multiple PDHGs and measured gas rate

Objectives:

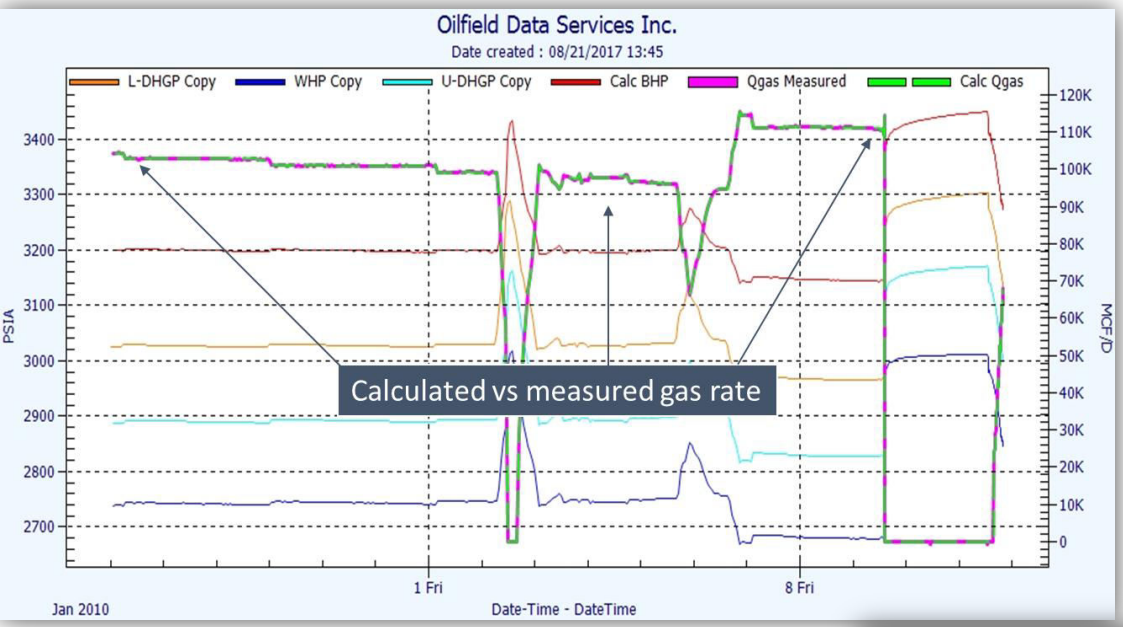
- Calculate and validate the metered gas rate
- Calculate BHP at mid-perf depth
- Perform PTA and determine if the well is a stimulation candidate (?)



Is your well really a stimulation candidate?
High skin or bad BHP conversion?

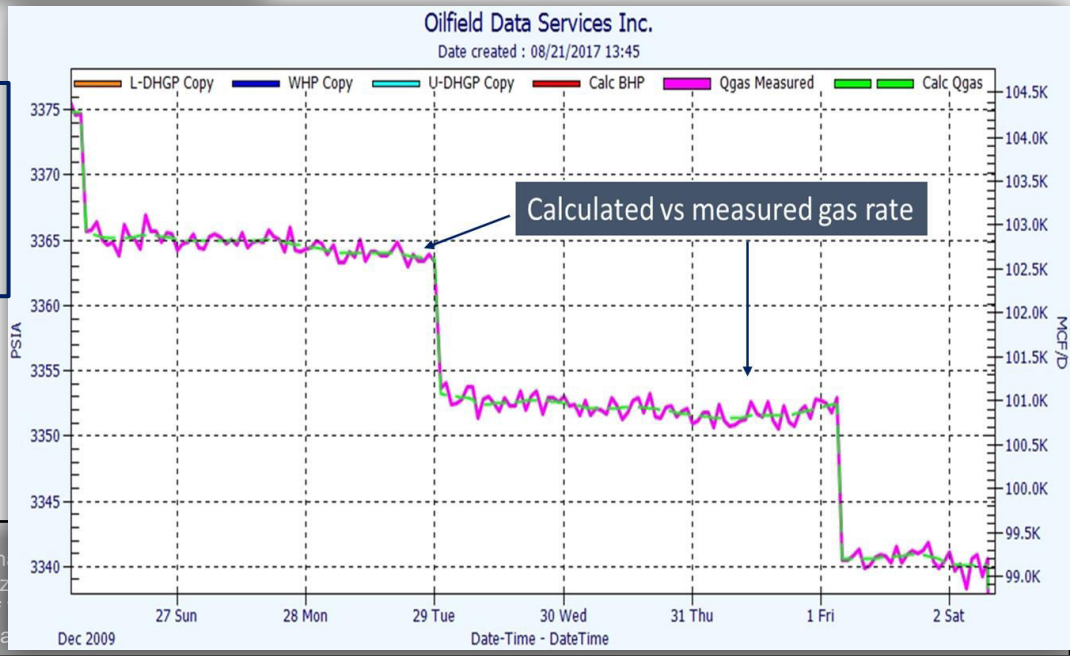
All PDHGs failed. The interpretation was done on the historical data with functional gauges to demonstrate the accuracy of ODSI's BHP conversion and to demonstrate that the well was not a **stimulation candidate**

Case Study 2: Gas Rate Comparison (Proof of Concept)

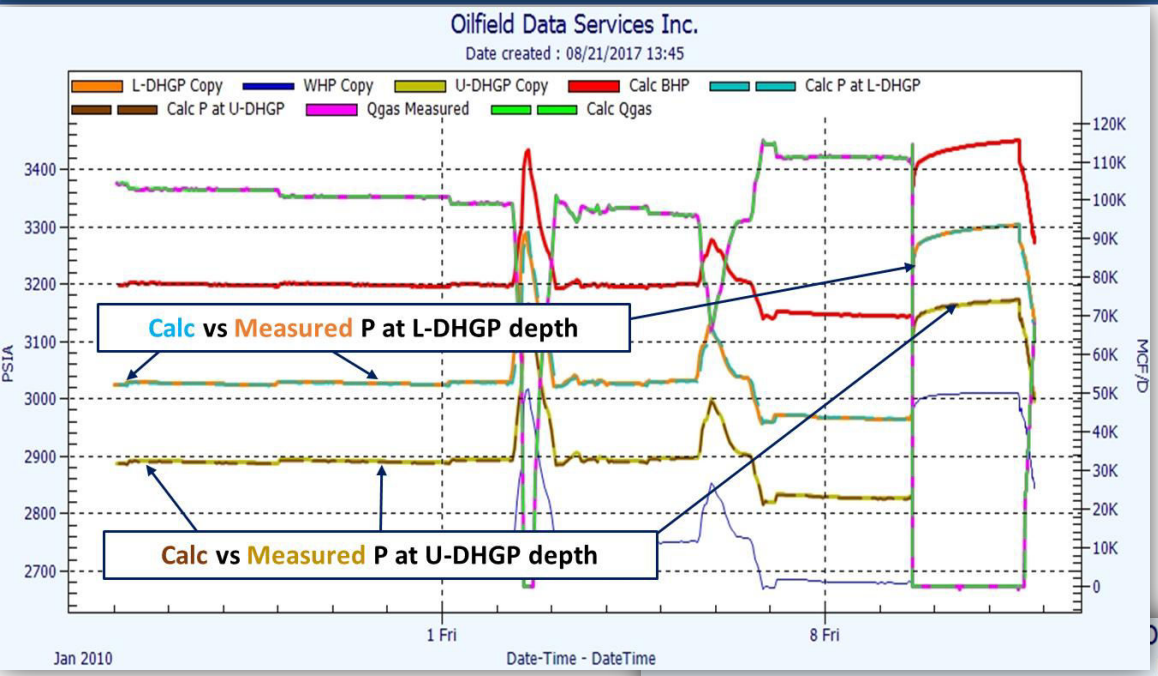


- Gas rate calculated using dP wellbore & compared to the metered gas rate
  - **Less than 1 % error** between the measured and the calculated gas rates

- Independent solution
- Backup if MPFM fails
- Detects errors in allocations

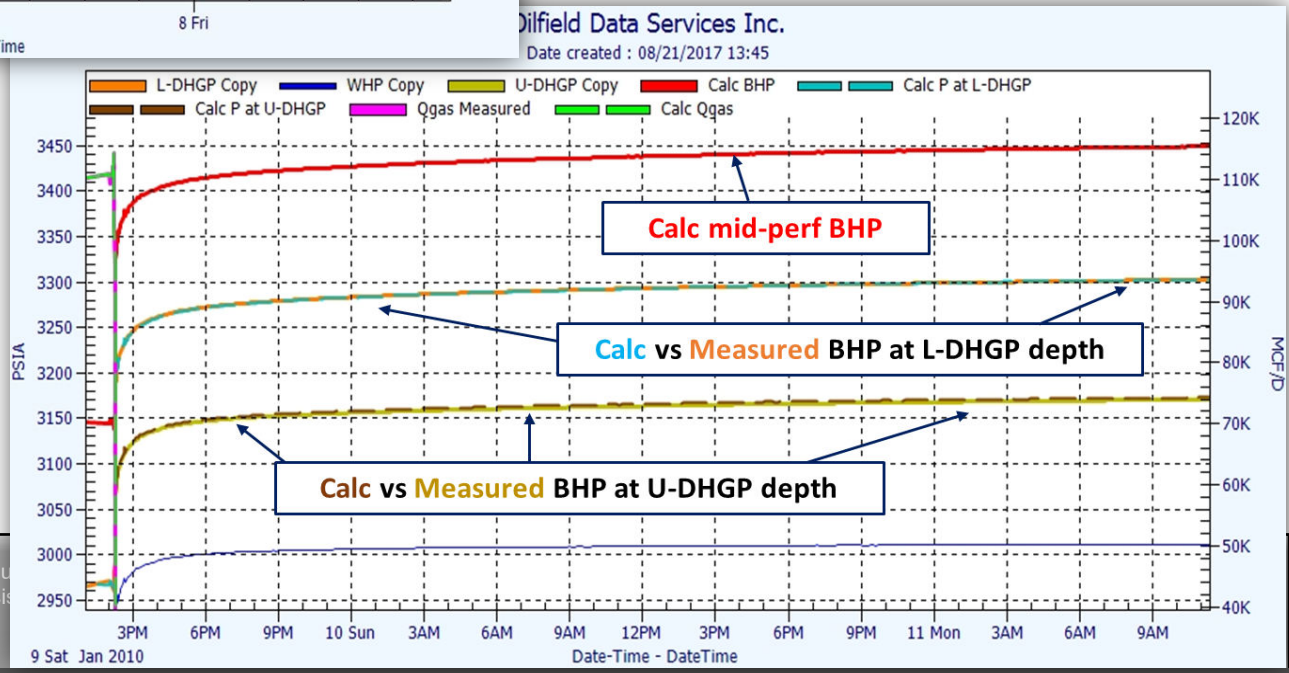


Case Study 2: BHP Comparison (Proof of Concept)



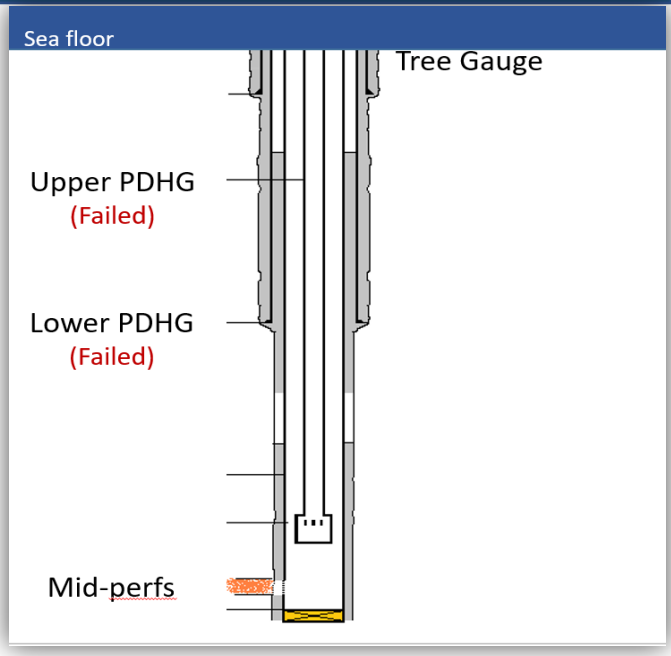
- BHP was calculated at the Upper and Lower DHGP depths using the WHP and the calculated gas rate (proof of concept)
  - **Less than 2 psi error**

- Backup if PDHG fails



Case Study 2: PTA

Importance of VALID mid-perf BHP



Is your well really a stimulation candidate?

High skin or bad BHP conversion?

It is crucial to have a valid mid-perf BHP

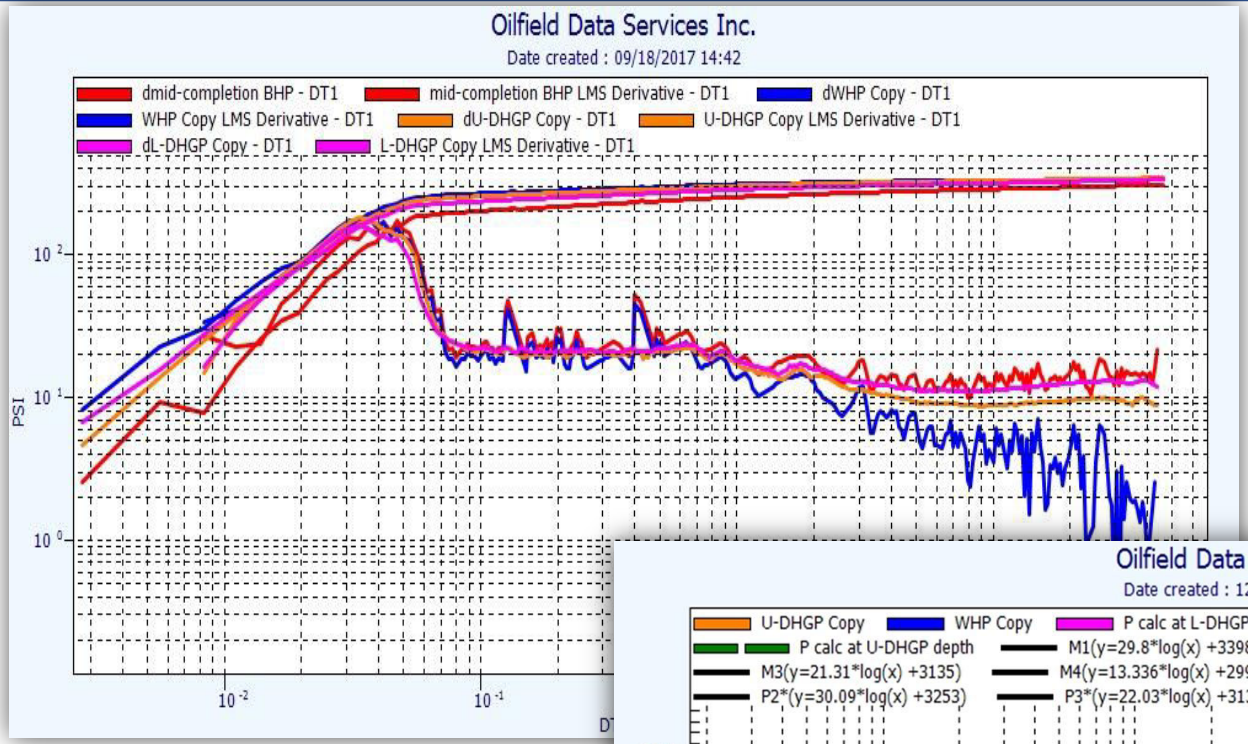
Failure to perform PTA on mid-perf BHP leads to:

- Overestimation of Permeability
- Overestimation of Skin
- Underestimation of P*/Reservoir Pressure

The next slides show how this well could be **incorrectly considered to be a stimulation candidate**

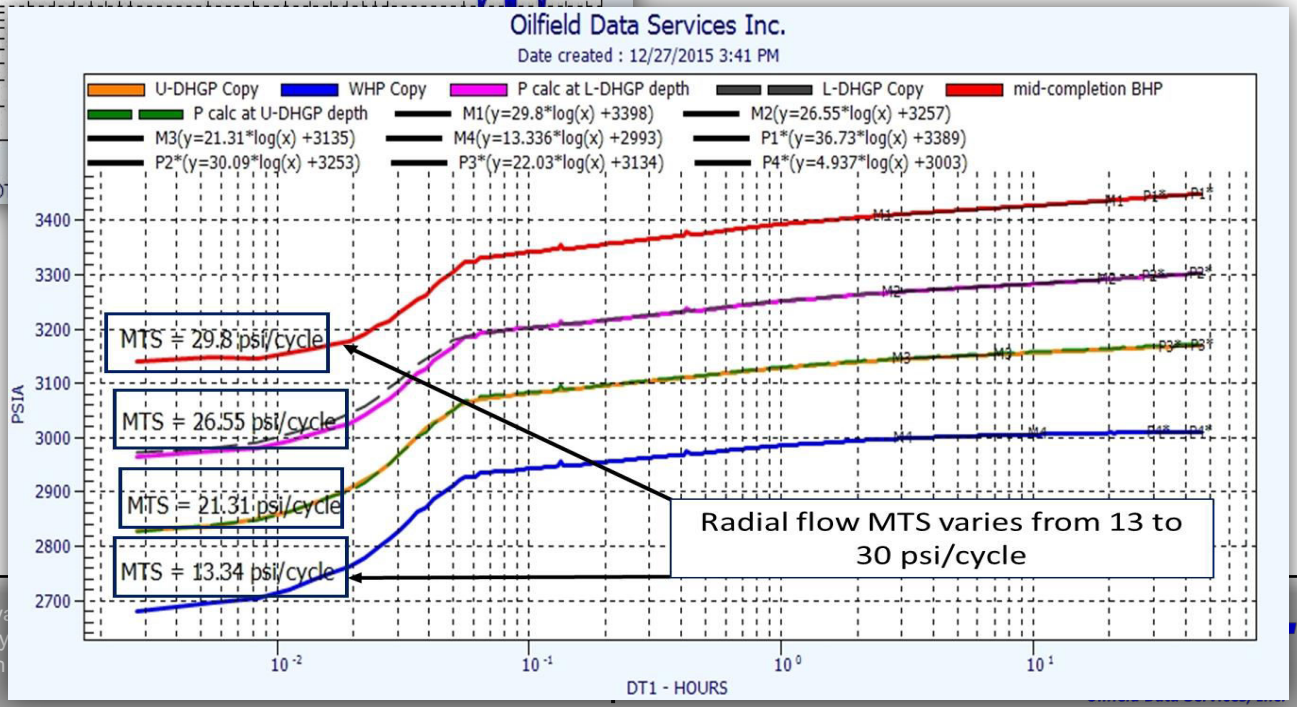
ODSI's solution accounts for rigorous PVT and phase-thermal changes in the wellbore

Case Study 2: Buildup Analysis



Is your well really a stimulation candidate?

High skin or bad BHP conversion?



Calculated mid-perf BHP

Lower PDHG

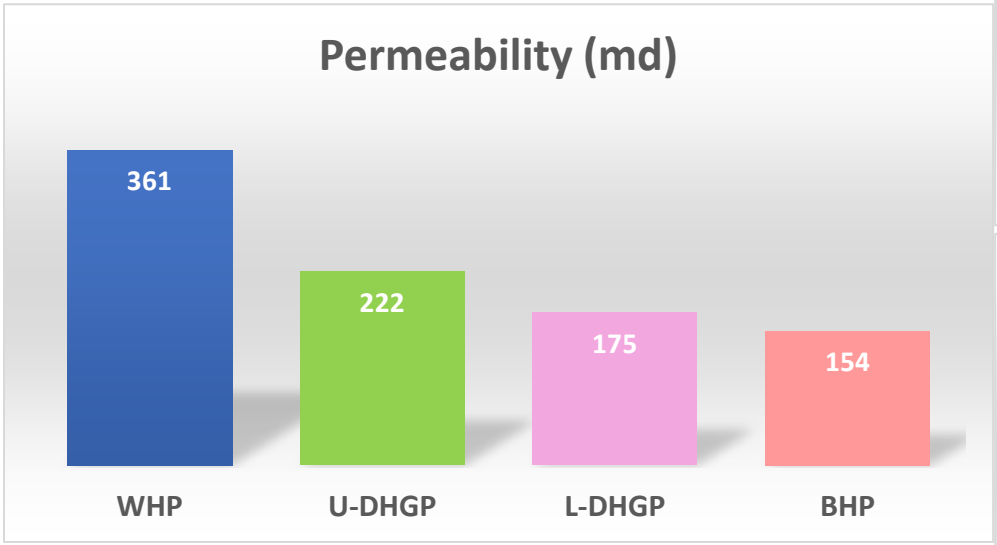
Upper PDHG

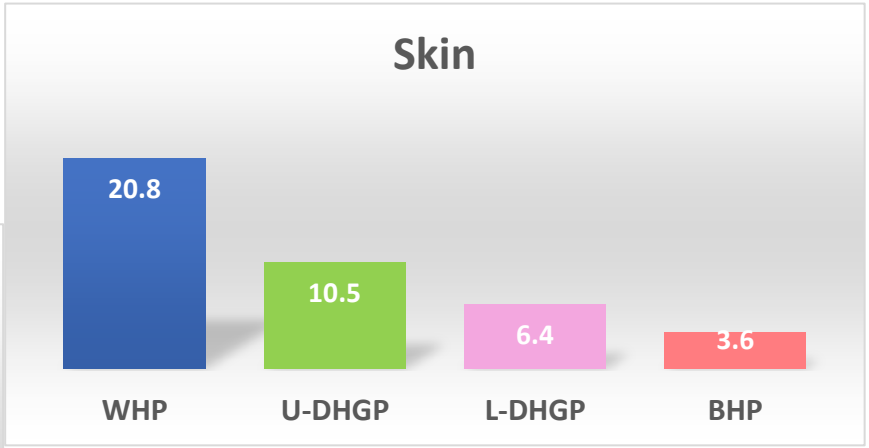
WHP

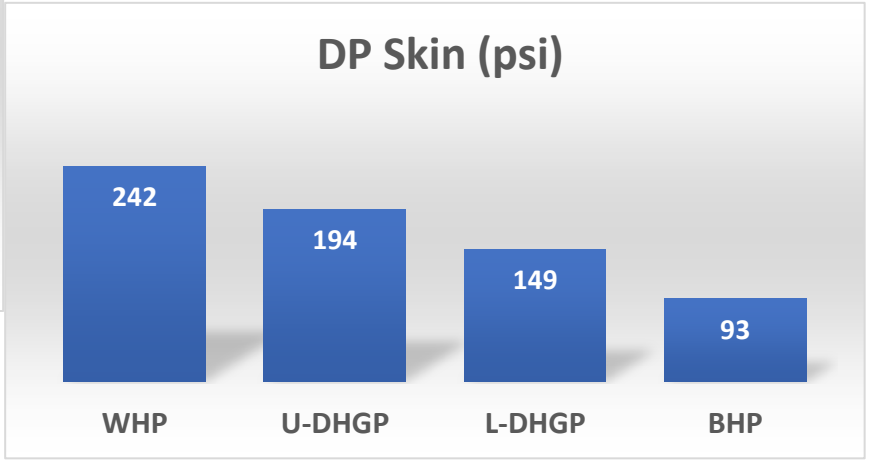
Case Study 2: Buildup Analysis Results

Importance of BHP conversion

- To show the importance of valid mid-perf BHP, the PBU was analyzed using the following:
  - WHP
  - Upper PDHG
  - Lower PDHG
  - Calculated mid-perf BHP







Is the well really a stimulation candidate?

No! It's wellbore cooling

ODSI's solution accounts for rigorous PVT and phase-thermal changes in the wellbore

Case Study 2: Buildup Analysis

Importance of mid-perf BHP

- The difference in the mid-time slope values was caused by wellbore cooling
- **During a shut-in**, the head is **NOT CONSTANT**; wellbore cooling causes fluid density (head) to increase
- **BHP increases** as the reservoir pressure builds up
- However, if the RATE of an increase in the density term is significant, it can result in SLOPE SUPPRESSION on the WHP or even cause DECREASING WHP during a shut-in!

- **Artificially lower MTS would provide artificially higher skin & perm**
  - **ODSI's solution accounts for rigorous phase-thermal fluid behavior at every segment in the wellbore**

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ODSI Oilfield Data Services, Inc.

Case Study 2: Summary

Direct numerical integration to the Mechanical Energy Balance accounting for rigorous PVT, thermal and frictional changes in the wellbore

- Accurate Gas Rate calculation
  - Less than 1 % error between measured and the calculate gas rates
  - Backup if MPFM fails
- Accurate BHP at any point along the wellbore
  - Within 2 psi error margin
  - Backup if PDHG fails

Valid PTA Results

- Failure to perform PTA on valid mid-perf BHP leads to overestimation of skin & permeability
  - Wellbore cooling and additional friction below the gauge

The well was NOT a stimulation candidate

- Treatment would not improve the well's performance

Case Study 3

Gas Condensate Well with changing yield

Offshore Australia

Case Study 3: Gas Condensate - Australia

Gas Condensate well (~ 70 bbl/mmcf) equipped with

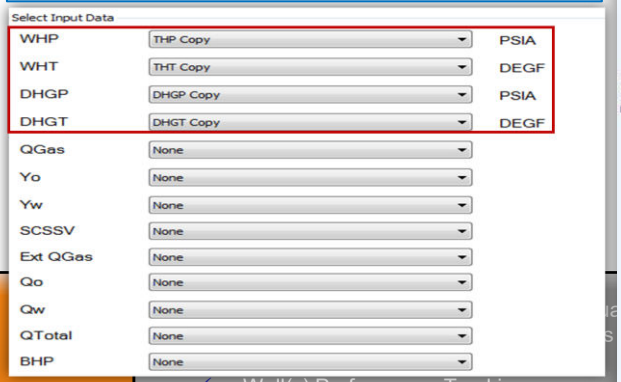
- WHP & Downhole Gauge

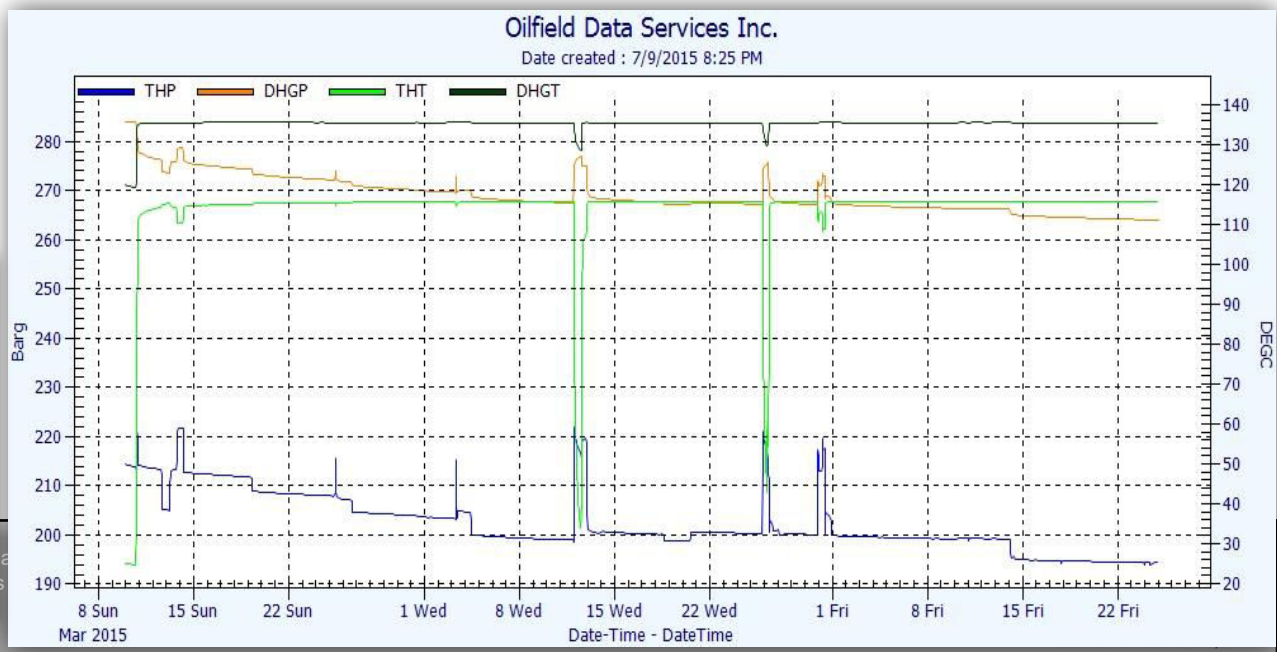
Occasional Gas Rates from test separator

Objectives:

- Calculate gas rate continuously
- Demonstrate automated PVT tuning/liquid yield calibration during S/I
- Calculate mid-perf BHP
- Calculate oil rates (Stock Tank Conditions)
- Demonstrate auto-PTA feature

Input Data: WHP/T & DHGP/T



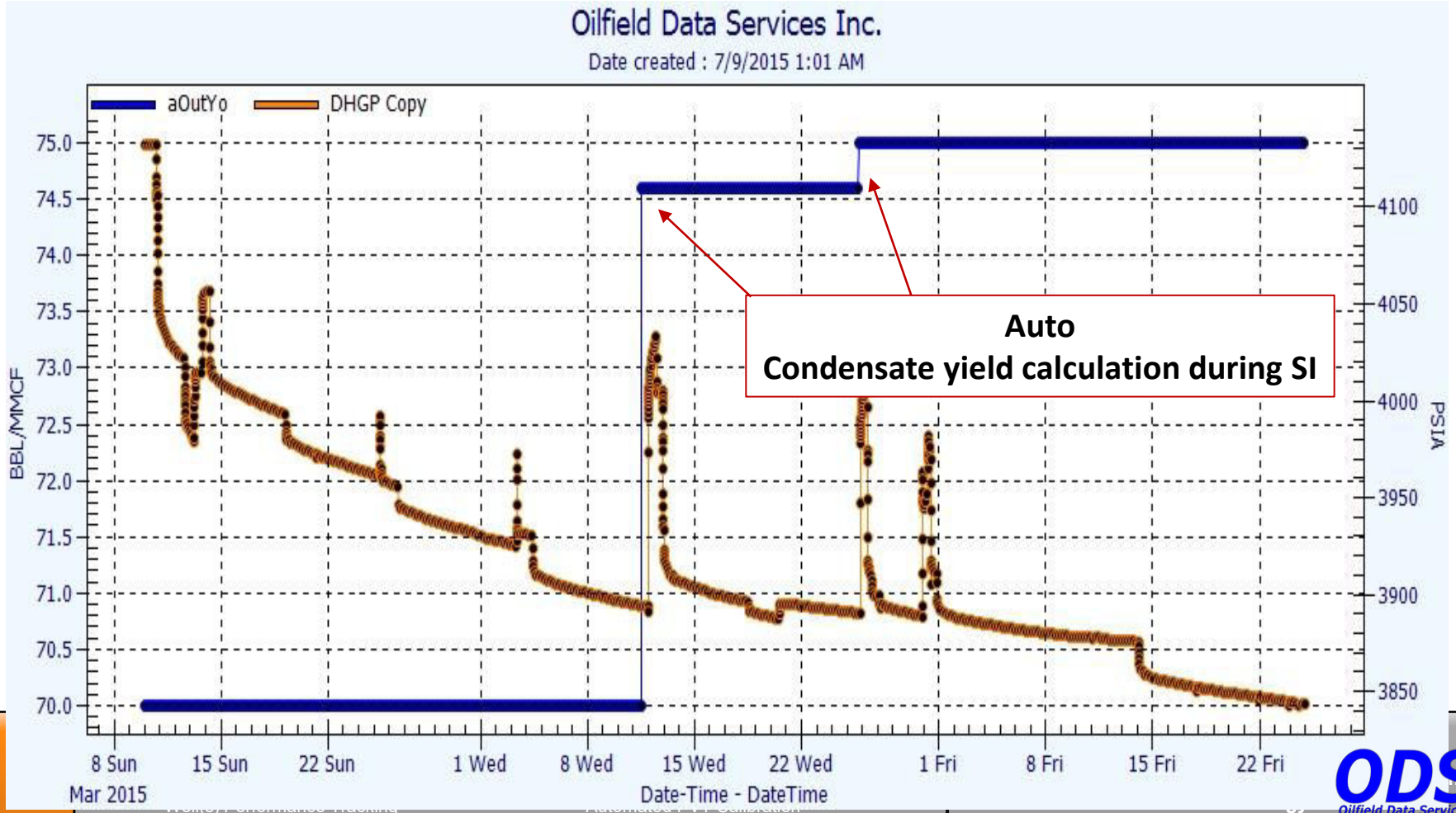


✓ Well(s) Performance Tracking

Case Study 3: PVT Calibration during Shut-ins

At every S/I, gas gravity, condensate yield or water cut are recalibrated automatically & the rates/BHP are adjusted accordingly

- Rigorous PVT and wellbore flash calculations



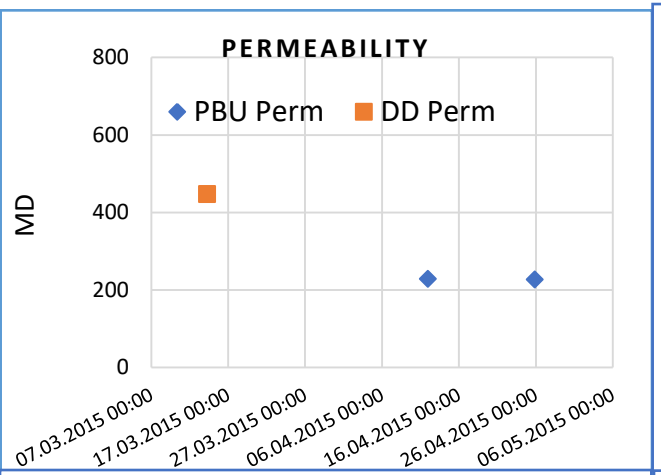
Case Study 3: Rate Calculation

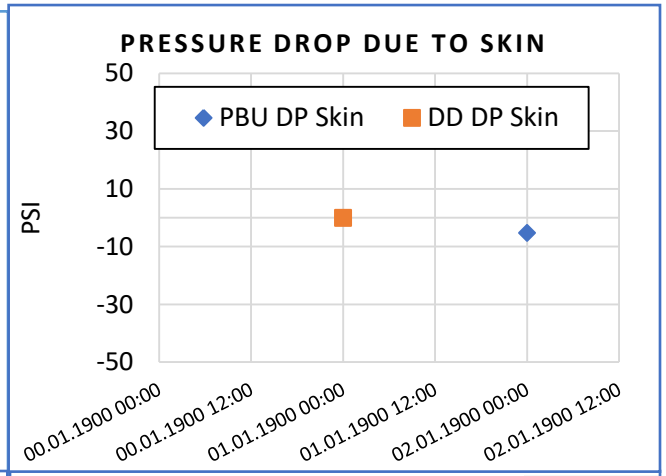
The tool calculates **multiphase rates** using dP in the wellbore using a **direct numerical integration** to the Mechanical Energy Balance and **rigorous PVT**

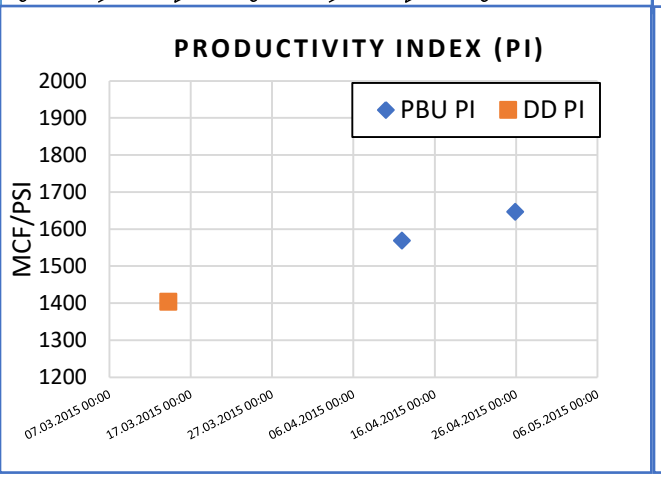
- The calculated rates were compared to the separator test rates
  - The red values in the table below did not match the calculated rates because the rates were changed during the well test

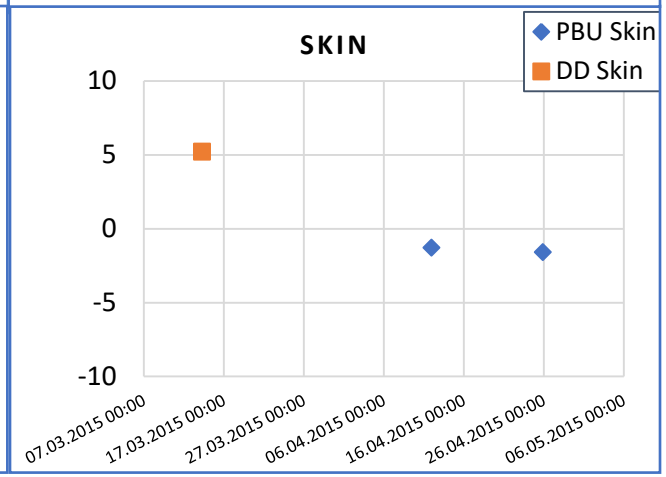
Test Date	Separator Measured Qgas (MMscfd)	Calculated Qgas (MMscf/D)
10-Mar-15	92	92.6
13-Mar-15	115.2	114.3
13-Mar-15	90.4	89.5
14-Mar-15	60.1	54.0
14-Mar-15	93.8	91.5
26-Mar-15	105	107.3
4-Apr-15	107	104.0
30-Apr-15	67.1	64.9
30-Apr-15	99.6	98.6

Case Study 3: Auto-PTA









Each PBU and DD test are analyzed for diagnostic PTA parameters in real-time

A **report** is generated for each test

Historic PTA tables and plots are updated every time there is a new test

'Notification/Alarm' tags are outputted if skin/perm reaches a certain 'reg flag' value (customized per well)

Date-Time	Test Lengh	Test Type	BHPi	BHPf	Qgasi	Qgasf	Perm	Skin	DP Skin	P*	PI	PI Eff
mm/dd/yyyy	hrs		psia	psia	MCF/D	MCF/D	md		psia	psia	MCF/PSI	%
3/14/2015 6:35	482	2-Rate DD	4179	4086	56230	92225	447.1	5.2	27	4043	1402.7	59
4/11/2015 23:15	13.75	PBU	4041	4135	116610	116610	228.9	-1.3	-17	4208	1567.6	123
4/25/2015 21:20	9.08	PBU	4035	4127	111695	111695	226.9	-1.6	-20	4181	1646.3	130

Report Link

Case Study 3: Results & Summary

Gas rate was calculated using dP in the wellbore

- Calculated gas rate matched measured separator test rates
  - The rates that did not match were changing during well tests

Condensate yield was re-calibrated during shut-ins, and oil rates were adjusted accordingly

- WA re-calibrated PVT (density portion of EOS) accounting for changing condensate yield
- The method can be used for gas gravity and water yield re-calibration

BHP was calculated accurately at the mid-completion depth

WA recognized new transients and generated a PTA report for each test

- High perm: 200 md – 450 md
- Low skin: 0 – 5
- High productivity well: 1400 MCF/psi – 1650 MCF/psi

ODSI's Well Analyzer ARTS

Review of Features/Summary

- ✓ Oil & Gas Reservoir Testing and Evaluation
- ✓ Real-Time Pressure Transient Analysis
- ✓ Hydrocarbon Volume Determination
- ✓ Well(s) Performance Tracking
- ✓ Multiphase Rate & BHP Calculations
- ✓ Optimize Gas Lift / Oil Production Rates
- ✓ Life Of Well Surveillance/Analysis
- ✓ Automated PVT Calibration

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Well Analyzer Real-Time Features

- Virtual metering
  - Often more accurate than an MPFM for 3-phase flow
  - Metered rate validation
  - Detects errors in allocation/meter calibration
  - Backup if MPFM fails
- BHP conversion
  - From the surface data
  - Can replace downhole pressure gauge if it fails
- Automated Pressure Transient Interpretation of buildups and drawdowns
  - Skin & Perm
  - Lateral Length Open to Flow
  - Average Pressure/P*
  - Productivity (PI)
- Continuous HC volumes and Mobile HC updates
  - Static and Flowing Material Balance calculations

Well Analyzer Benefits - Summary

- Analyze ALL of the data, not just the data you have time to look at
- Optimize Production at Every Opportunity
- Understand how much Money you have left in the ground
- Train Your Team in Proactive Surveillance
- Spend Your Time Thinking About What You Can Do to Make More Money, Not Just Digging for Data!